19th World Congress of Soil Science

Symposium 1.2.2
Soil geography and ecology

Soil Solutions for a Changing World,

Brisbane, Australia

1 – 6 August 2010

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Characterization of four pioneering species from a tropical forest in the Pindorama Biological Reserve, São Paulo State, Brazil based on soil and Phytosociological attibutes

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Abstract
This work had the objective to characterize populations of pioneering tree species of the Biological Reserve of Pindorama, SP, Brazil, based on the physical and chemical attributes of the soil. For this, 65 parcels of 400 m^2 had been demarcated in two toposequences located in remainders of a Seasonal Semi-deciduous Forest. In each parcel the degree of infestation of weed species was evaluated. Inside of each parcel was drafted a subunit of 10 x 10 m (100 m^2), where the physical and chemical attributes of the soil had been evaluated, the altitude, the basal area, the height, the number of individuals of the trees species with diameter at breast height (DAP) equal or superior than 5 cm .The species diversity was calculated with the Index of Shannon (H') and with the Index of Equability of Pielou (J) of the trees species community of each top sequence. It was also calculated the Similarity Index of Jaccard (ISJ) between the two remainders. The characterization was made by sampling parcels considering pioneering species that presented six or more individuals in at least one of the remainders evaluated: *Aloysia virgata* Ruiz & Pav. A. L. Juss., *Acacia polyphylla* DC, *Croton floribundus* Spreng and *Casearia Sylvestris* Sw. The hierarchic grouping analysis by the Ward method made possible a division of the physical and chemical attributes of the ground in five groups of parcels. For each group the average values of each characteristic had been determined, as well as recalculated the index of diversity of species and equability of the tree species that allowed a characterization of the pioneering species for groups. The evaluated species were responsive to different soils and phytosociological attributes. *Croton floribundus* occurred in sandy soil parcels and with lower fertility, *Acacia polyphylla* and *Aloysia virgata* occurred in soils of higher altitudes. The soils with higher clay percentage and of natural good fertility had greater infestation of weeds such as lianas, bamboo and other grassy and lower diversity of tree species. The infestation of the parcels by weeds affected the basal area and height of the evaluated species. In these parcels it was observed that the pioneering species had reduced basal area and height.

Key Words
Top-sequence, phytosociology, soil and vegetation relation, forest fragments

Introduction
The Biological Reserve of Pindorama, SP, located in an agricultural experimental unit called Polo Regional Centro Norte, in the city of Pindorama, SP, Brazil, has an area of 120 ha, distributed in four forest remainders of biome Atlantic Forest, classified as Seasonal Semi deciduous Forest. The majority of the remainders in São Paulo state have small size, due to fragmentation with edge effects (Kronka *et al*., 2006). The structure of these fragments are related with the occurrence of the trees of the different described sucessional groups for Budowski (1965) where pioneer species in bush in a primary sucessional period represent a low density of the tree component, therefore these species tend to occupy areas modified by anthropic actions, areas in the neighborhoods of the edges and bare places in the interior of the remainder (Budowski, 1965). In accordance with Tabanez *et al.* (1997) the edge effect intervenes with the occurrence of pioneering, secondary and climax species in a band that can extend up to 100 meters. In these bands, the occurrence of invading species is favored by the presence of light and ground attributes (Tabarelli and Mantovani, 1999). The opening of bare places can contribute for the diversity of the fragments; therefore some species depend on these occurrences for regeneration, such as the pioneering species (Tabarelli and Mantovani, 1999). The wealth of pioneering species varies with biome, the place and the presence of invading plants. Tabarelli and Mantovani (1999) had determined that the density and diversity of pioneering species had presented negative relations with the height of the adjacent canopy and infestation of bamboo. These factors function as barriers to the arrival of direct light to the surface, the plant cover was related to diverse factors including climate, relief, altitude, physical, chemical characteristics of the soil. The present work had as an objective the characterization of populations of pioneering tree species of the Biological Reserve of Pindorama, SP, on the basis of the physical and chemical attributes of the soil and the phytosociological attributes.

Methods

The parcels were distributed throughout two toposequences 1 and 2, on the basis of Tabanez *et al*. (1997). Each toposequence demarcated into 20 sequential parcels of 20 m x 20 m (400 m^2). In toposequence 1, 43 parcels and, in toposequence 2, 22 parcels were demarcated. In each parcel of 400 m^2 a quadrant of 10 m x 10 m was selected for characterization of arboreous individuals with a diameter at chest height (DAP) ≥ 5 cm, for the phytosociological survey. The phytosociological survey and the collection of material for ground analysis was for the drafted quadrant of each parcel (10 m x 10 m) and for the evaluation of the degree of infestation for invading plants the total parcel was 400 m^2. For soil evaluation, physical and chemical analysis a composite sample of 20 sub samples to a depth of 0-20 cm was used. After air drying, the following analyses were conducted: physical analysis, pH, organic substance, phosphorous, potassium, calcium and magnesium; potential acidity, basis saturation. In the drafted quadrant of 100 m^2, trees with DHC (diameter at chest height 130 cm from the ground) ≥ 5 cm. These individuals were identified with metal plates consisting of the identification number of the parcel and the individual. For each individual the diameter and material collected for botanical identification were written down. The following phytosociological variables: density, dominancy, frequency of the species, value of importance, the basal area of all the individuals of the species and for the analysis of diversity was calculated as the Index of diversity of Shannon (H') and the Index of equability of Pielou (J).To verify the similarity between the areas the Index of Similarity of Jaccard (ISJ) was used. The characterization of the pioneering species was made from pioneering species that presented as six or more individuals in at least one of the studied areas that is: *Aloysia virgata* Ruiz & Pav. A. L. Juss., *Acacia polyphylla* DC, *Croton floribundus* Spreng and *Casearia Sylvestris* Sw. Multivariate analysis of hierarchic grouping was used with the physical and chemical attributes of the ground indicated the division in five groups of parcels were possible. Evaluation of the degree of infestation for invading plants in each parcel of 400 m^2 was evaluated. 10 classes of infestation were created that varied from null (zero) to completely infested (ten) (Valeri *et al*., 2003). Multivariate, exploratory statistical techniques were used to verify similarities between parcels based on physical and chemical attributes of the soil. Analysis of grouping using a hierarchic method used Euclidean distances as a measure of similarity and the method of Ward, as the algorithm linking between groups. After the adoption of five groups of edaphic similarity had been calculated the altitude averages, physical attributes and chemical soil attributes and degree of infestation by invading plants for each group of parcels was determined according to Hair *et al*. (1995). The processing of the grouping analyses was by Statistica software, version 7.0 (Statsoft, 2004) after standardization.

Results

The structure of groups is shown in Figure 1. Division was into 5 groups based on granulometry and attributes of soil fertility was adopted, maximizing the similarity between parcels inside the group and maximizing the dissimilarity between the groups. From the division into five groups the average values of altitude and the physical and chemical attributes of soil for each group were determined (Table 1). Averages were calculated for number of species, number of individuals per hectare, basal area per hectare of all the individuals, value of importance, Index of Shannon (H') and Index of Equabilidade de Pielou arboreous (J) of the community, as well as the degree of infestation by invading plants. The characteristics of occurrence and growth of the pioneering species for groups of parcels of edaphic similarity are presented in Table 2. The characterization of the pioneering species on the basis of the variations of the altitude, of the physical and chemical attributes of soil, and degree of infestation of invading plants for each group of parcels of edaphic similarity are illustrated in Figure 2. The occurrence of the trees and its relation with soil attributes can be seen in the Figure 2.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

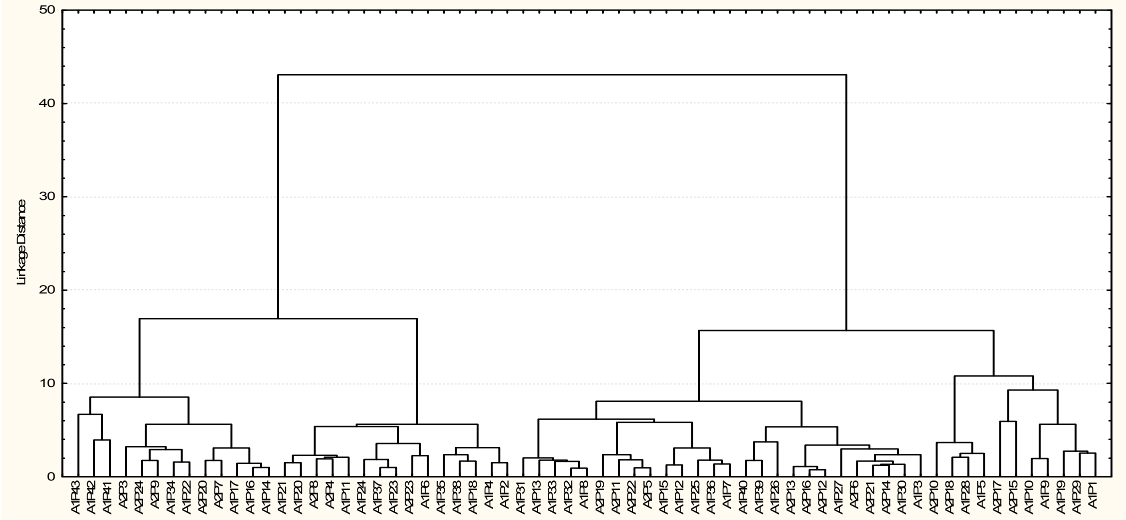

Figure 1. Dendrogram with the structure of the analyzed groups datas based on soil attributes of two top sequences of tropical forest in the biological reserve , pindorama, sp, brazil.

Table 1. Average of physical and chemical attributes of the soil for groups of parcels (g1 to g5).

Groups	Clay	Sand	P	pH	MO	K^+	Ca^{2+}	Mg^{2+}	H + Al	V
	………. g kg^{-1}…...		mg dm^{-3}	Ca Cl_2	g dm^{-3}	……………..mmol$_c$ dm^{-3}			…………..	%
G1	124,07	815,53	4,84	5,60	20,07	1,75	37,15	10,53	17,23	73,67
G2	157,06	752,60	5,06	5,78	24,13	2,06	56,73	12,06	17,40	80,20
G3	142,57	774,21	5,35	6,40	26,35	2,59	63,21	15,07	12,07	86,82
G4	148,00	789,08	5,75	6,11	31,08	2,20	69,75	15,75	14,66	85,62
G5	152,63	736,36	9,54	6,29	29,45	3,23	70,54	15,81	14,27	85,92

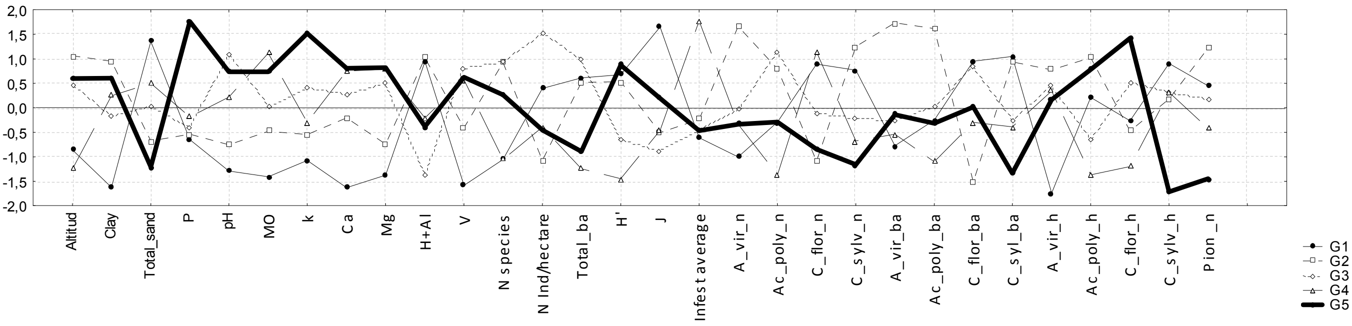

Figure 2. Average for the five groups of altitude, soil attributes, phytosociology attributes and characteristics of the pioneering species. Where A_vir = *Aloysia virgata,* A_poly = *Acacia polyphylla,* C_flor = *Croton floribundus*, C_sylv = *Casearia sylvestris,* n = numbers of individuals, ba = basal area and h = height

Table 2. Number of individuals, basal area and height of the pioneering species.

Groups	*Aloysia virgata*	Pioneering *Acacia polyphylla*	Species *Croton floribundus*	*Casearia sylvestris*
			Number of individual	
G1	0	5	9	4
G2	8	8	1	5
G3	3	9	5	2
G4	2	2	10	1
G5	2	5	2	0
	Basal area (cm^2 ha^{-1})			
G1	0,00000	0,12940	0,15539	0,02977
G2	0,09390	0,38122	0,01031	0,02840
G3	0,01832	0,17005	0,14928	0,01334
G4	0,00882	0,01438	0,08197	0,01179
G5	0,02359	0,12090	0,10028	0,00000
	Height (m)			
G1	0,00	13,60	9,56	7,75
G2	7,25	17,00	9,00	5,60
G3	6,33	10,00	11,60	6,00
G4	6,00	7,00	7,10	6,00
G5	5,50	16,00	14,00	0,00

Conclusion

The distribution and growth of pioneering species varies in accordance with variations of the physical attributes and fertility of soil, relief, and covering of the area with weeds.
The characterization of the population of pioneering trees species and the vegetal covering must be made by unit of area or group of parcels with similar characteristics that represent sampling elements, as species, edaphic characteristic, among others changeable variables.

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Effect of tree belt plantings on nematode communities in pastoral farming systems

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Abstract
By focussing on the central role of the soil –dwelling nematode community in pastoral farming systems of the New England bioregion in Australia, this study aims to discover how restoring native vegetation to farming systems, in the form of diverse, native tree belt plantings, may enhance soil biodiversity and functioning within adjacent pastures. It is hypothesised: 1) that landscape scale patterns of diversity and function of nematode taxa in pastoral farming systems increases as a direct response to native tree-belt plantings, 2) that the local scale distribution of nematode taxa and functional groups are nonlinearly related to distance, as a function of tree heights, from the tree-belt, and 3) that microclimatic conditions and habitat and resource heterogeneity created by tree-belts are major drivers of nematode diversity and function in these systems. Spatial analysis of variables include: nematode abundance, functional groups and genera, plant species diversity and tree belt structure, litter quantity and quality, soil moisture and temperature fluxes, carbon, porosity, ammonium/nitrates, and pH. A spatial sampling method, based on pilot study findings, will be presented, along with results from the first round of sampling conducted in summer of 2009/2010. It is expected the model developed will provide design rules-of-thumbs to land managers.

Key Words
Shelter belts, ecology, holistic, land use, resilience, climate change

Introduction
Conversion of native vegetation for agriculture continues to threaten biodiversity globally. The impact of this on soil biodiversity, however, is largely unexplored or quantified. Yet biodiversity is recognised worldwide as a key driver of adaptive capacity and ecosystem resilience, critical in the face of global climate change. These points raise an important agro-ecological question; by integrating above-ground native vegetation into farm systems to address declining above ground biodiversity, can we enhance soil biodiversity and functioning that underpins farm fertility and productivity?

A method for restoring native vegetation to farming systems is tree belt plantings. In Australia, tree belt aerodynamic properties have been shown to consistently benefit microclimate, soil abiotic properties and productivity despite different regions and management strategies (see McKeon *et al.* 2008). Generally, tree belts have been shown to: provide shade/shelter for animal production (Bird *et al.* 1993); decrease wind erosion, reduce evaporative losses, buffer microclimate extremes, reduce physical damage to plants (Bird *et al.* 2007; Cleugh 2003; McKeon *et al.* 2008); provide habitat for biodiversity (Dengate 1983); control water-logging and dryland salinity (Ellis *et al.* 2006; White *et al.* 2000); increase organic matter and trap sediment and water, including gains on incidental rainfall, within belts (Ellis *et al.* 2006; Leguedois *et al.* 2008; White *et al.* 2000); and increase soil moisture and pasture/crop production in the quiet zone, an area up to six tree heights on the lee side of tree belts (Figure 1) (Bennell and Verbyla 2008). Fencing so that tree/shrub litter can accumulate within the tree belt in the absence of stock, is an important design factor for effective run off capture, moisture rentention, plant biodiversity and habitat creation (McKeon *et al.* 2008)

Tree belts are therefore a valuable tool for mitigating local scale effects of global climate change. For example, in Australia, where it is expected farmers will generally experience reduced rainfall and more extreme temperatures, tree belts provide a tool for buffering climate extremes while increasing water retention in a drying landscape and providing an opportunity for carbon capture in soils and vegetation as a result of the land use change (Ellis *et al.* 2006; McKeon *et al.* 2008).

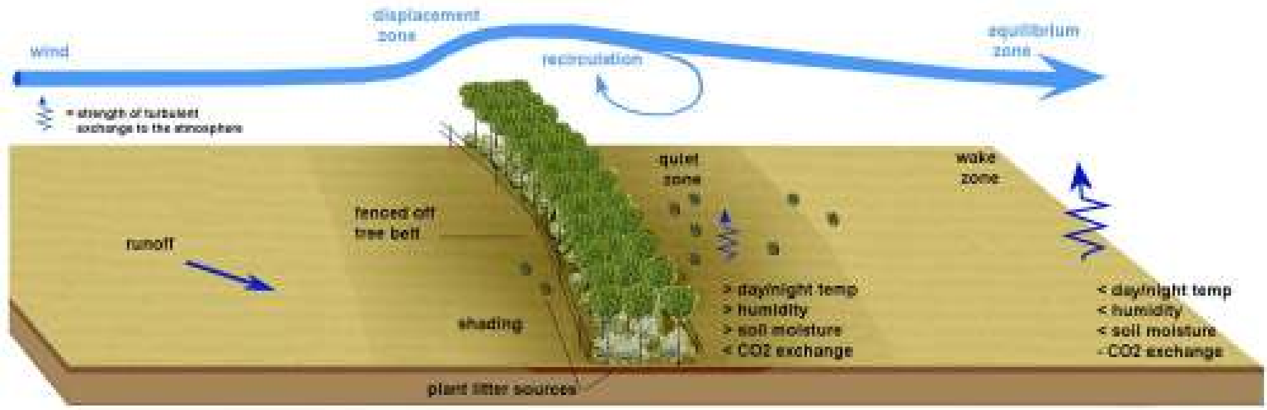

Figure 1. A conceptual model of tree belt effects in agricultural farm systems. Litter accumulates within the tree belts and in areas adjacent. Diverse plantings increase diversity in soil food resources, which may affect soil biodiversity and function. Other factors include changes to soil temperature and moisture, changes to productivity in the quiet zone (reduced wind speeds, shading and reduced turbulent exchange to the atmosphere) compared with the wake zone (where turbulence and wind speed levels return to the same as the wind above), and feedbacks to soil structure and chemical fertility.

What is absent from the general literature is tree belt effects on soil biodiversity and function. Embedded within the aim of this study is to discover if a similar generalisation to those above can be applied. Generally, soil biological function and diversity is influenced by food resource availability and diversity, changes in soil structure, temperature and moisture, as well as the chemical environment (Bardgett 2005). It is plausible therefore that soil biota may respond, within a nominal distance (number of tree heights) of the tree belts, to increased litter inputs, shading, reduced wind speeds and reduced turbulent exchange to the atmosphere (Fyfe *et al.* 2008; Wasilewska 2004).

To gain an accurate snapshot of soil health and biological diversity in tree belt pastoral systems, the central role of soil –dwelling nematodes, as soil function and biodiversity indicator, as well as source of plant pathogens, will be explored through spatially comprehensive, taxonomic analysis of nematode functional groups and genera, following Yeates (2003), Yeates and Bongers (1999) and Yeates and Stirling (2008).
The aim being to discover how these native tree-belt plantings increase nematode diversity and function across multiple scales in Australian grazing landscapes and facilitate soil agro-ecosystem fertility.

It is hypothesised; 1) that landscape scale patterns of diversity and function of nematode taxa in pastoral farming systems increases as a direct response to native tree-belt plantings, 2) that the local scale distribution of nematode taxa and functional groups are nonlinearly related to distance, as a function of tree heights, from the tree-belt, 3) that microclimatic conditions and habitat and resource heterogeneity created by tree-belts are major drivers of nematode diversity and function in these systems.

It is expected that the project will develop design rules-of-thumb for land managers by quantifying native tree-belt effects on the productivity and resilience of pastoral farming systems through stimulation and protection of soil biodiversity, as indicated by nematode community ecology.

Methods and results

Study area

Field sites are located on three properties in NSW, Australia, on the wool/sheep production areas of the New England Tablelands. Three tree belts, each planted between 1994 and 1999 (10-15 years old) have been selected for the project. They predominantly consist of tree, shrub and grass species endemic to the area, are structurally complex (tree and shrub layers) and fenced to exclude stock allowing development of ground covers and a litter layer. Sites will be sampled biannually for two years.

Sampling

The sampling strategy will be based on results from a pilot study conducted late 2009, where spatially intensive sampling for nematode taxa and functional groups within and adjacent to two tree belts at one property has been conducted (Figure 2). The results presented will be for the spatial sampling method developed from this pilot study, and from the first round of sampling conducted in summer of 2009/2010.

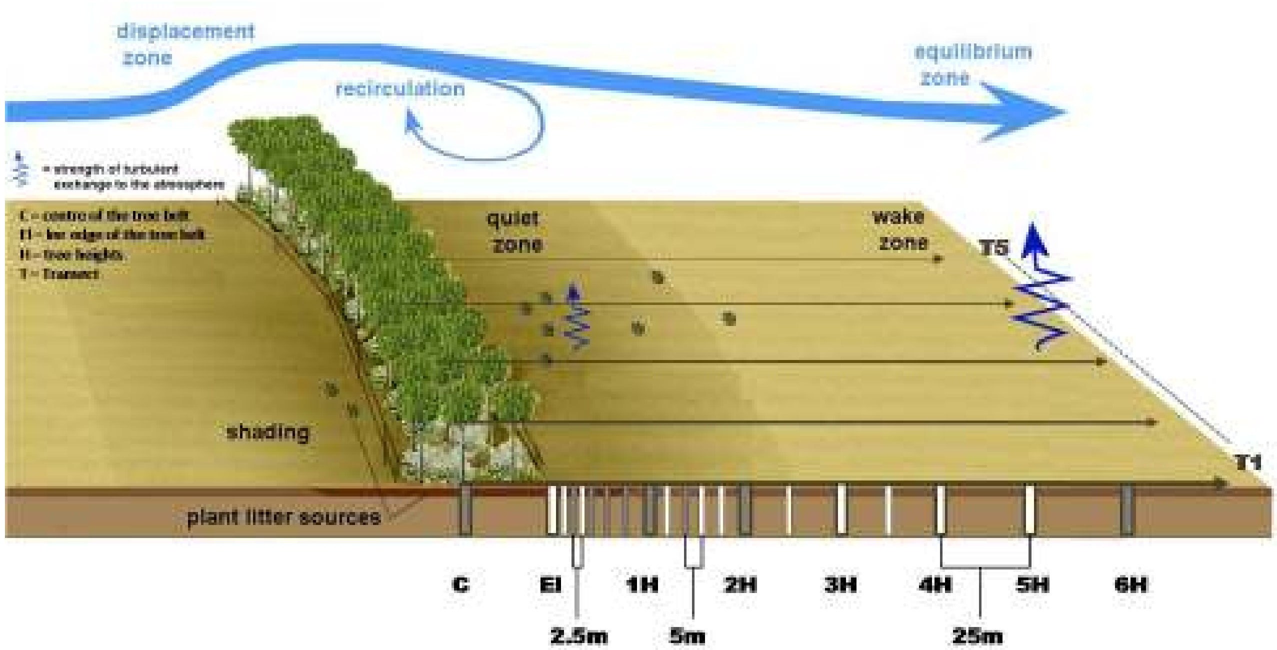

Figure 2. Pilot study sampling strategy conducted at 'Nant Lodge' near Glen Inness, NSW. Spatial variation in nematode abundance, functional groups and genera will inform the sampling strategy for the following two years of biannual sampling. Five transects on the lee side of one tree belt were sampled at all intervals indicated, from the centre of the tree belt (C) out to six tree heights (6H), a distance of 150m. More intensive sampling was conducted within the area more likely to be influenced by tree belt litter. At a second replicate tree belt, three transects where sampled at points indicated by grey shading.

Sampling in 2009/2010 will include soil biological, physical and chemical characteristics, as well as above ground vegetation diversity, quality and structure. At each sampling point, nematode abundance, functional groups and genera will be analysed as the response variables. Explanatory variables include: plant species diversity, function and dominance; tree belt structure (optical porosity, tree height and shrub height) and configuration (width, aspect, on contour, down/across slope); percent ground cover; litter quantity (depth) and quality (C:N); *insitu* logging of soil moisture and temperature to establish daily fluxes; soil carbon (total, organic and labile), soil bulk density and porosity; changes in ammonium/nitrates, and pH. Three further rounds of sampling will be conducted in winter 2010, summer 2011 and winter 2011. Results from the first two rounds of sampling will inform field trials that manipulate certain variables identified by analysis and modelling. Assessing the location of the tree belt root zone may also be considered during this time.

Statistical analysis and modelling

Explanatory variables will be tested for colinearity in the first instance using Spearman's rank correlations and from which explanatory variables for univariate (e.g. ANOVA) and multivariate analysis (e.g. hierarchical partitioning), and mixed effects models (e.g. GLM) will be assembled and analysed using 'R' (R Project for Statistical Computing release 1.9.0 http://www.r-project.org).

This project will develop a predictive model from the study sites within the New England Region to be tested both locally and within different regions, e.g. the higher rainfall Dorrigo plateau to the east, and the lower rainfall Liverpool plains to the west, to ascertain if patterns are spatially consistent for different types of agro-ecosystems.

Conclusion

This study in soil spatial ecology is cross disciplinary, bringing together botany, zoology, geography and spatial ecology, while being rooted in soil science. It examines relationships between above and below ground diversity, what controls biodiversity belowground (at local and landscape scales), and how this affects the function of the system of interest; themes identified by the National Academy of Frontiers in Soil Science (Steering Committee for Frontiers in Soil Science Research and National Research Council 2009).

Tree belts provide a tool for buffering climate extremes while increasing water retention in a drying landscape and providing an opportunity for carbon capture in soils and vegetation as a result of the land use change. This project will address a gap in the literature regarding tree belt effects on soil biodiversity and function and will develop design rules-of-thumb for land managers by quantifying how native tree-belts may stimulate and protect soil biodiversity, as indicated by nematode community ecology.

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Floristic, microclimatic, pedological and geomorphological features of the Balinovac doline on North Velebit (Croatia)

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Abstract
A deep karst area of the Velebit mountain range has abundant in large dolines (sinkholes) – karst depressions with frequent temperature inversions resulting in vertical inversions of the plant cover. Although the initial research dates back to the fifties of the twentieth century (Horvat 1952-1953), the dolines of the Dinaric karst have not undergone a systematic multidisciplinary research until today. It is for this reason that floristic, microclimatic, pedological and geomorphological research of the Balinovac doline on North Velebit was carried out during 2008 and 2009. The research goal was to determine the correlation between the flora, microclimate, soil, geomorphological features of the doline and the selected ecological parameters affecting its floristic composition. Plants along the north-south profile were listed, and five points were determined at which soil pits were analysed for the purpose of determining the soil type and collecting samples for laboratory analyses. The temperature and the relative air humidity were continuously measured for the period of one year. For the purpose of comparison with the results of the laboratory pedological analyses and the field-measured values, the recorded plant species were assigned indicator values of the selected ecological parameters according to Landolt (1977). The research results confirmed the presumed temperature inversion affecting the vertical formation and composition of the flora in the doline.

Key Words
Balinovac doline, flora, microclimate, soil, geomorphology, ecological parameters

Introduction
The Balinovac doline is situated on the territory of the National Park North Velebit. It is located in the south-western part of Modrić-dolac between the peaks of Velika kosa (1622 m), Balinovac (1601 m) and Veliki Zavižan (1676 m), and it is 120 m deep. The vegetation of this area phytogeographically belongs to the lower sub-alpine belt of the Illyric province in the Euro-Siberian – North American region. A botanical station and a part of the Velebit botanical garden are located in its north-eastern part (Bertović 1979). A circular botanical educational trail runs through the doline at the altitude of some 1,470 m, splitting into sections that lead to the surrounding peaks. In the vicinity of the Balinovac doline is a mountain lodge Zavižan and Croatia's highest-placed meteorological station (Bertović 1979). The doline was formed in intensely tectonized, karstified layers of limestone from the upper Jurassic period, while its western part facing Balinovac is composed of Jelar beds (Paleogene/Neogene). In addition to karstification, on the steeper slopes of the doline one can observe intense slope processes, and occasional erosion in places where the parent material is covered in soil. Owing to its altitude, the studied area has a humid boreal climate (Df). The mean annual temperature of the nearby meteorological station Zavižan (1594 m) is 3.5°C (February -4.0°C, July 12.1°C), and the mean annual precipitation is 1 827 mm. The median annual relative humidity is 81% (Perica *et al.* 2002).

Methods
On 23 and 24 July 2008, all of the plants found alongside the north-south profile of the Balinovac doline were listed. Uncertain specimens were collected and photographed for the purpose of subsequent identification, and were stored in the Herbarium of the Croatian Natural History Museum. The plants were identified according to the standard keys and iconography (Domac1994; Javorka and Csapodi 1991; Pignatti 1982; Tutin *et al.*1964-1980, 1993), and the nomenclature was coordinated with the Flora Croatica Database (Nikolić 2010). All of the determined plant taxons were assigned indicator values for humidity, pH value, nutrients, humus, light, temperature, continentality, and life forms were also determined, for the majority of the taxons according to Landolt (1977). An indirect gradient analysis was carried out on the basis of these data. Alongside the profile, altogether five points were determined at the bottom and on the slopes of the northern and southern exposition (Table 1; Figure 1). At these points, soil samples were collected from the soil pits at the depths of up to 20 cm,

and were then analysed for humus content, nutrients (P and K), coarse fragment and pH value. Types of soil were determined on the basis of the results of the analysed parameters and field observations. Thermohygrographs were set up at the same points, for the purpose of continuous measuring of temperature and relative air humidity for the period of one year.

Table 1. Exposition and altitude of measuring points.

Point	Exposure	Altitude (m)
MD-1	S	1513
MD-2	S	1476
MD-3	-*	1434
MD-4	N	1465
MD-5	N	1500

*doline bottom

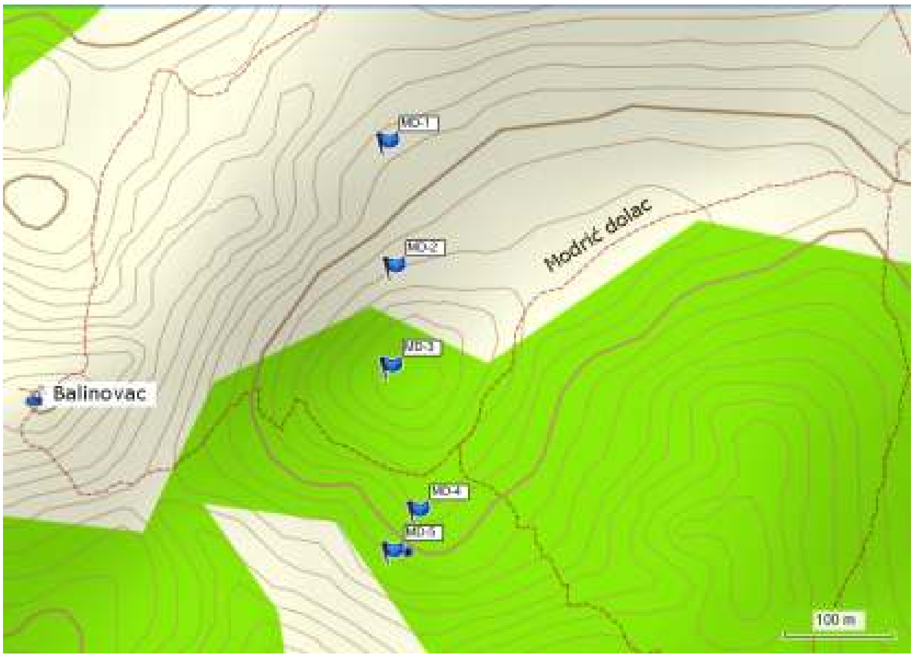

Figure 1. Balinovac doline map with measuring points.

Results

The average values of the air temperature at the measuring points range from 6.06°C at the bottom of the doline (MD-3) to 7.32°C at the top of the southern exposition slope (MD-1). These values are higher than the multi-annual average at the meteorological station Zavižan. The average values of the air temperature in the warmest month – July (13.78 -14.57°C) are also higher compared to the multi-annual average. Nevertheless, an air temperature inversion typical of the mountain dolines was registered, resulting in a vegetation inversion. According to the literary data (Skorup *et al.* 2008), there is a possibility of occurrence of short-term negative air temperature values at the bottom of the doline; however, it was not registered in the vegetation period within this measurement. The relative air humidity is higher on the northern exposition slopes (84-86%), as expected; however, this is insignificant compared to the southern exposition slopes (80-81%).

It has been established that 149 plant taxons grow on the studied part of the Balinovac doline, in three main soil types: haplic Cambisol, colluvic, rhodic; molic, umbric Leptosol, calcaric and leptic, caltic Luvisol, abruptic, skeletic, clayic. The analysis of the life forms of all of the plant taxons identified at the research points shows the prevalence of hemicryptophytes, with their share exceeding 50% and being somewhat higher on the southern exposition slope. Based on the indirect gradient analysis of the ecological parameters, it has been determined that half-shade habitats with arid soils poor in nutrients and humus, in which plants of the mountainous belt mostly grow, dominate the southern exposition slope. Shady habitats prevail on the northern exposition slope, with more humid soils, richer in nutrients and humus, in which plants of the sub-alpine belt mostly grow. According to the indirect gradient analysis, the bottom of the doline is predominated by the habitats with the transitive values of the ecological parameters compared to the southern and northern exposition slopes.

Conclusion

The microclimatic measurement has confirmed the presupposed vertical structure of the values and the temperature inversion typical of mountain dolines. The recorded vertical structure and composition of the flora is also in line with the aforesaid; therefore, the upper, marginal parts of the southern exposition slope are predominated by the warmer and sunlit habitat types, with cooler and more humid ones prevailing at the bottom and on the northern exposition slope, as confirmed by the indirect gradient analysis results.

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How does surface soil geomorphology and land-use influence the soil microbial ecosystems in south eastern Australia? Insights gained from DNA sequencing of the soil metagenome

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Abstract
Soils are a vital resource in Australian agricultural production systems. The sustained health of this resource is dependent on how land-use and management practices impact on the underlying soil microbial community that delivers vital ecosystem goods and services. Collaborative research between Department of Primary Industries Victoria (Melbourne, Australia) and the J.Craig Venter Institute in Rockville (Maryland, USA) research has applied a stepwise DNA-based approached to resolve the influence of contrasting soils (calcarosol and ferrosol) and land-use (managed and remnant vegetation) on the soil bacterial communities. This approach generated small insert clone libraries based on 16S ribosomal RNA (rRNA) sequences for three samples; calcarosol; managed (cropped) and remnant samples and a ferrosol, managed (grazed dairy pasture) sample. A deeper, whole genome shotgun sequencing approach based on Titanium 454 pyro-sequencing technology yielded detailed information on the structural and functional elements of the microbial community in two samples (calcarosol; managed and remnant). All samples yielded unique microbial communities with <1% shared sequences overall. Samples collected from the same regional soils (e.g. highly alkaline calcarosol soil) but with contrasting land-use patterns (e.g. cropped and remnant) were more similar with 13% shared sequences. Samples collected from different regional soils but with similar management shared 4% sequences. The greatest differences in communities were those with contrasting soil, and land-use characteristics with <3% shared sequences. Of the known taxa, Acidobacteria, Cyanobacteria and Planctomycetes were relatively prevalent in the acid soil and Actinobacteria, alpha and delta Proteobacteria prevail in the alkaline, remnant soils. In the alkaline managed soil, Bacteroidetes/chlorobi taxa prevail. We chose the calcarosol samples for additional Sanger and 454 FLX sequencing to evaluate functional genes, with specific emphasis on nutrient cycling and disease suppression pathways. The results provide insight for ecosystem function and management decisions in the context of climate change and resource sustainability.

Key Words
Ecosystem, metagenomics, sequencing, biodiversity, functional genes, 16S rRNA

Introduction
Agricultural production is dependent upon the ecosystem goods and services provided by soil microbial processes (Kibblewhite *et al.,* 2008). An outstanding challenge is to identify the microbial species and functions that underpin these processes so that appropriate and targeted management interventions can be applied. The soil microbial ecosystem presents particular technical challenges because it contains thousands of species of bacteria and fungi per gram that are largely unculturable with only 1-10% of the entire community being identified(Xu, 2006). The emergence of metagenomics, a powerful set of methods that provides a deep assessment of the DNA genetic material contained within microbial communities is offering new opportunities to access the diversity within environmental ecosystems including soils (Handelsman, 2007). Whilst the metagenome of various environmental ecosystems, including soils, have now been partially unravelled (Daniel, 2005; Tringe, 2005; Tyson *et al.,* 2004; Venter *et al.,* 2004), the soil metagenome presents a much more challenging environment due to exceptionally high diversity by most estimates. Because of the technical challenges associated with such a diverse ecosystem, the genetic resource contained within the living component of soils (the microbial community) remains largely untapped (Daniel, 2005).

Methods

Site and sampling description

Sites were selected in Victoria, Australia on two significant soil orders, a calcarosol in north-western Victoria and a ferrosol in the south-east [Figure 1;(Isbell, 2002)]. Three treatments were sampled; one from the ferrosol site under ‘managed’ grazed dairy pasture (FM) and two from the calcarosol site, on contrasting land-uses; a managed-cropped site (CM) and a remnant native vegetation site (CR). Soils were sampled from within a 50m^2 area from six 1m^2 grids. Five soil cores to depth 5cm were collected per grid and composited.

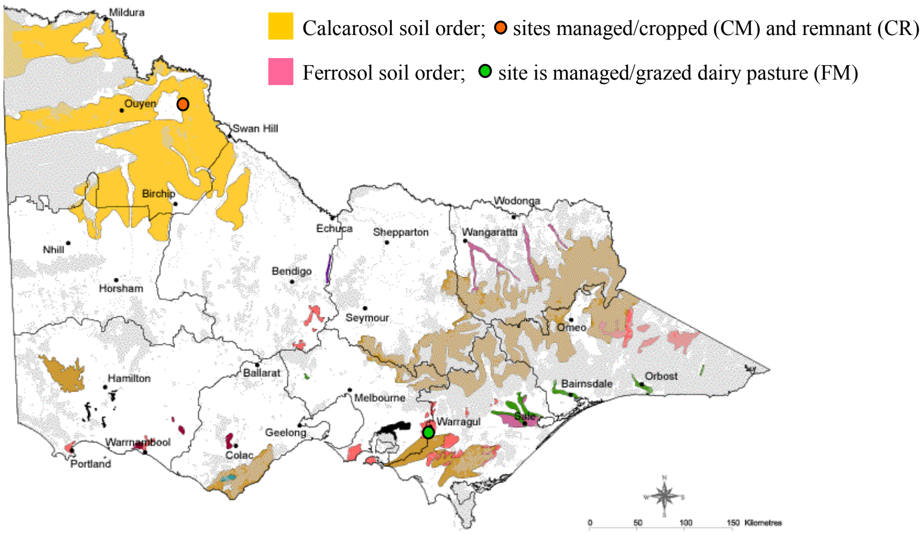

Figure 1. Sample locations in soil geomorphic regions containing the calcarosol and ferrosol soil orders.

The physical and chemical characteristics of each site are described in Table 1. The five cores were then homogenised and frozen immediately for shipping on dry ice to the J.Craig Venter Institute, (MD, USA).

Table 1. Physical and chemical characteristics of soil from each of the three collection sites.

Analyses/soil type & land-use	Calcarosol Managed (cropped) CM	Calcarosol Remnant (native vegetation) CR	Ferrosol Managed (grazed pasture) FM
Particle size			
Clay (<0.002mm)	5.5	16.5	27.5
Coarse Sand (0.2mm - 2.0mm)	47.7	35.4	8.2
Coarse Sand (0.5 - 2.0mm)	40.3	26.8	16
Fine Sand (0.02mm - 0.2mm)	<0.1	5.3	2.2
Silt (0.002mm - 0.02mm)	4.5	7.5	29
pH (H_2O)	6.4	8.1	5.1
pH (Ca)	5.9	7.7	4.5
Electrical conductivity (EC dS/m)	0.07	0.15	0.14
Total soluble salts (%)	0.02	0.05	0.05
Available Nitrogen (mg/kg)			
Ammonium-N mg/kg	0.8	1.3	4
Nitrate-N mg/kg	14	5.4	45
Total N (%)	<0.05	0.14	0.76
Total C (%)	0.62	2.8	9.5
Organic matter (%)	1.1	5.2	18
Oxidisable organic Carbon (mg/kg)			
Organic C	0.73	2.2	9
Organic matter	1.4	4.1	17
Available Phosphorus (mg/kg)	18	5	72
Total cations (mg/kg)			
Calcium	720	19000	2000
Magnesium	920	3800	1100
Phosphorus	160	170	1800
Potassium	2200	5800	2300
Sodium	38	130	150
Sulphur	42	180	920

Soil preparation and DNA extraction
Frozen soils were thawed and the samples from the 1 m^2 grids were combined at each site for the three sites. Soil was then sieved to <3mm, with larger pieces of plant material removed with forceps, on dry ice and 300g subsample was blended at slow speed (Waring blender) in ultra-pure water and then in extraction buffer (10% glycerol, Tween-80). Free DNA was removed using saline phosphate buffer and the ionic strength of the buffer was modified using Chrombach buffer. A Nycodenz gradient was then used to separate cells of specific density which were then isolated and pelleted for storage in buffer. Total nucleic acids were extracted from soils using a MoBio Ultraclean kit according to the manufacturer's instructions.

Library construction and analyses for 16S conserved genes
For library construction, 16S PCR was performed on aliquots of the soil DNA using the prokaryotic 16s primers 27f and 1492r. PCR was performed using pHUSION from Finnzyme. For each sample, three 50 ul reactions were done. Fifteen cycles of PCR were done, the samples were pooled and ethanol precipitated. The PCR products were gel purified. BstXI adaptors were added to the end of the DNA. Excess adaptors were removed by three rounds of gel purification. The PCR product was recovered from the gel and ligated to a vector containing complementary BstXI ends. The resulting ligation was transformed into DH10B competent cells. Clones were sequenced by Sanger sequencing. The 16S rRNA forward and reverse cloned Sanger sequences were concatenated and sequences over 1 kilobases were used as blastn queries against the core set of 16S sequences downloaded from the 'Green Genes' website (http://greengenes.lbl.gov). 16S sequences that produced an HSP of greater than 1kb in this blastn search were trimmed to the segment that produced this match. These trimmed sequences were aligned to the 'core_set_aligned' alignment using the alignment tool in Mothur v 1.4. (www.mothur.org). The resulting alignment was trimmed to: start 400 bp; end 4400bp. These sequences were used to generate Operational Taxonomic Units (OTUs) at 0.03 % divergence and these OTUs were then used as input for phylogenetic analysis of bacterial diversity using the MOTHUR suite of programs (http://schloss.micro.umass.edu/mothur).

Whole shotgun sequencing and analyses using ti454 pyrosequencing
A shotgun library was made for total genomic DNA extracted from CM and CR. DNA was sheared into small fragments, size selected and purified. Standard procedures were followed for ti454 pyrosequencing shotgun library preparation. Adapters were ligated onto purified DNA, which was then prepared by emulsion PCR and titration for addition to the beads. Beads with DNA particles attached were then applied to the glass plates for pyrosequencing. A total of 21.17 million reads of average length of 365 base pairs were generated; 10.6 million for CM and 10.5 million for CR. These sequences were assembled by site and proteins were predicted using Prodigal v1.05. These proteins then used as blastp queries against database of proteins downloaded from completed and partial bacterial genomes from NCBI.

Results
Applying the MOTHUR software (http://schloss.micro.umass.edu/mothur) to the 8,528 OTUs generated from our three treatments (CM, CR and FM) revealed little difference in diversity as determined by the Shannon, Simpson and Chao diversity indices (Table 2).

Table 2. Effect of soil class and land-use on soil microbial diversity using three estimators of diversity, Simpson, Shannon and Chao (http://schloss.micro.umass.edu/mothur).

Diversity indices	CM	CR	FM
Simpson			
$D_{simpson} = \frac{\sum_{i=1}^{S_{obs}} n_i (n_i - 1)}{N(N-1)}$	0.00038	0.00039	0.00040
Shannon			
$\hat{H}_{shannon} = \sum_{i=1}^{S_t} \frac{\hat{C}\pi_i \ln(\hat{C}\pi_i)}{1-(1-\hat{C}\pi_i)^N}$	6.849	6.7259	6.7168
Chao1			
$S_{chao1} = S_{obs} + \frac{n_1(n_1-1)}{2(n_2+1)}$	2846	2322	2986

The microbial community composition however was highly unique between the three sites with < 1% shared sequences overall. Samples collected from the same regional soils (eg highly alkaline soil in very low rainfall site) but with contrasting land-use patterns (eg cropped versus remnant) were more closely related with 13% shared sequences. Samples collected from different regional soils but with agricultural management regimes applied shared 3% sequences. The greatest differences in communities were those with contrasting soil, region and land-use characteristics with <3% shared sequences. Of the known taxa, Acidobacteria, Cyanobacteria and Planctomycetes are relatively prevalent in the acid ferrosol soil (FM) and Actinobacteria, alpha and delta Proteobacteria prevailed in the alkaline calcarosol with remnant vegetation (CR). In the alkaline calcarosol under a cropping management regime (CM), Bacteroidetes/chlorobi taxa prevail.

Whole shotgun sequencing and Ti pyrosequencing of the bacterial metagenomes of two sites, CM and CR revealed the overall dominance of alpha Proteobacteria and Actinobacteria. From alignment with predicted peptides, the dominant taxa in CM compared to CR were the alpha and gamma Proteobacteria. The dominant taxa in CR compared to CM were Actinobacteria, Acidobacteria, Firmicutes, Chloroflexi, delta Proteobacteria and Cyanobacteria. Furthermore in CR, almost 18% of the Actinobacterial peptides were *Rubrobacter* spp, which is highly dominant and contrasts with CM, where Rubrobacter comprised <1% of the Actinobacteria with the strongest representation of Nocardioides at 2%. Alignment with environmental peptides is also likely to reveal significant differences in N, P and C cycles and in disease suppression.

Conclusion

Whilst microbial community diversity measured using several metrics (Simpson's, Shannon's and Chao) were similar at all three sampling locations in south –eastern Australia, the species present at each site were highly unique. Deep sequencing of the metagenome has revealed that the vast majority of species and the functions they perform are not represented by anything presently catalogued in international and publicly accessible sequence databases. Assuming that each taxa provides a vital function, the Ti pyrosequencing approach will resolve the contribution of each grouping of taxa to vital ecosystem services such as N cycling, C fixation and decomposition and disease suppression in these contrasting treatments.

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How soil geographic databases and resources have been used to better understand ecosystem functioning: An example from Australia

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Abstract

Soil resources and land systems inventories are generally presented as maps with an accompanying explanatory report. The maps are often digitized and can be used in a GIS. Here we show that beyond these products, the database of point observations made during the field survey, linked to other environmental data, can be useful for ecological research, thus value-adding to the land resources inventories. An example from Queensland is used to show that co-evolution of plant and insect diversity is associated with the development of salinity during aridification of northern Australian landscapes. The same dataset also suggests that invasion of grassland by the introduced pasture species buffel grass seems restricted to alkaline soils.

Key Words

Digital soil mapping, legacy data, sodium, soil organic C, soil pH, soil survey, soil salinity

Introduction

During the first phase of the National Land and Water Resources Audit (NLWRA) the Australian Soil Resources Information Systems (ASRIS) project in 2001, a relatively large point database of soil properties was created by collating various legacy databases into a single Oracle database (Johnston *et al*., 2003). Using this point database linked to national environmental data for climate (19 continuous variables), geology (23 discrete classes), land use (14 discrete classes), 4 Landsat MSS bands, and topography (14 continuous terrain variables), rule induction using decision trees was used to predict and map soil properties across the intensively used agricultural areas of Australia (Henderson *et al*., 2001). Here an example of using these data linked with vegetation data will be shown to add to our understanding of ecosystem function in two instances. The data are from a soil survey database in Queensland. They show potential for predicting habitats vulnerable to invasion by buffel grass and also suggest co-evolution of plant and insect diversity and landscapes in the Brigalow Belt bioregion.

Data

About 2000 geo-referenced sites from the soil survey of the Dalrymple Shire (Rogers *et al*., 1999) recorded plant species in three vegetation strata at each site, weed species present, and measurements such as electrical conductivity (EC) and pH. The plant strata species in lower, middle, and upper roughly correspond to grasses, shrubs and trees. The three dominant species, identified from a visual estimate in a circle with a ~50 m radius, were recorded in each stratum. Although percentages of each species were estimated, the study by Bui and Henderson (2003) used binary measurements (presence/absence). Thus a maximum of nine species was available for each site; weeds were recorded in a separate field in the database. Total soluble salt (TSS) was estimated as a depth-weighted average percentage from EC measurements on soil horizons (Bui *et al*., 1996) at 1499 sites, which dilutes the salinity of the most saline horizon.

The area intersects three of Australia's bioregions with threatened endemic species (http://www.deh.gov.au/minister/env/2003/mr03oct03a.html), the Einasleigh Uplands, Desert Uplands, and Northern Brigalow Belt (Figure 1). Thus the results are relevant to a very large area of Australia.

Statistical modelling

A correspondence analysis (CA) was performed to investigate vegetation species composition data (Bui and Henderson, 2003). CA extracts the most important environmental gradients from the site by species data matrix and represents that high-dimensional data matrix in a smaller number of dimensions by deriving a set of species (column) scores and a set of site (row) scores that maximally separate the species and sites. The site scores summarize the species profile for each site. Locations with similar site scores thus have similar species present. The species scores provide a summary of the site occurrence profile for each species. Species with similar species scores tend to be present at similar locations. Both sets of scores give an ordering along the environmental gradients identified.

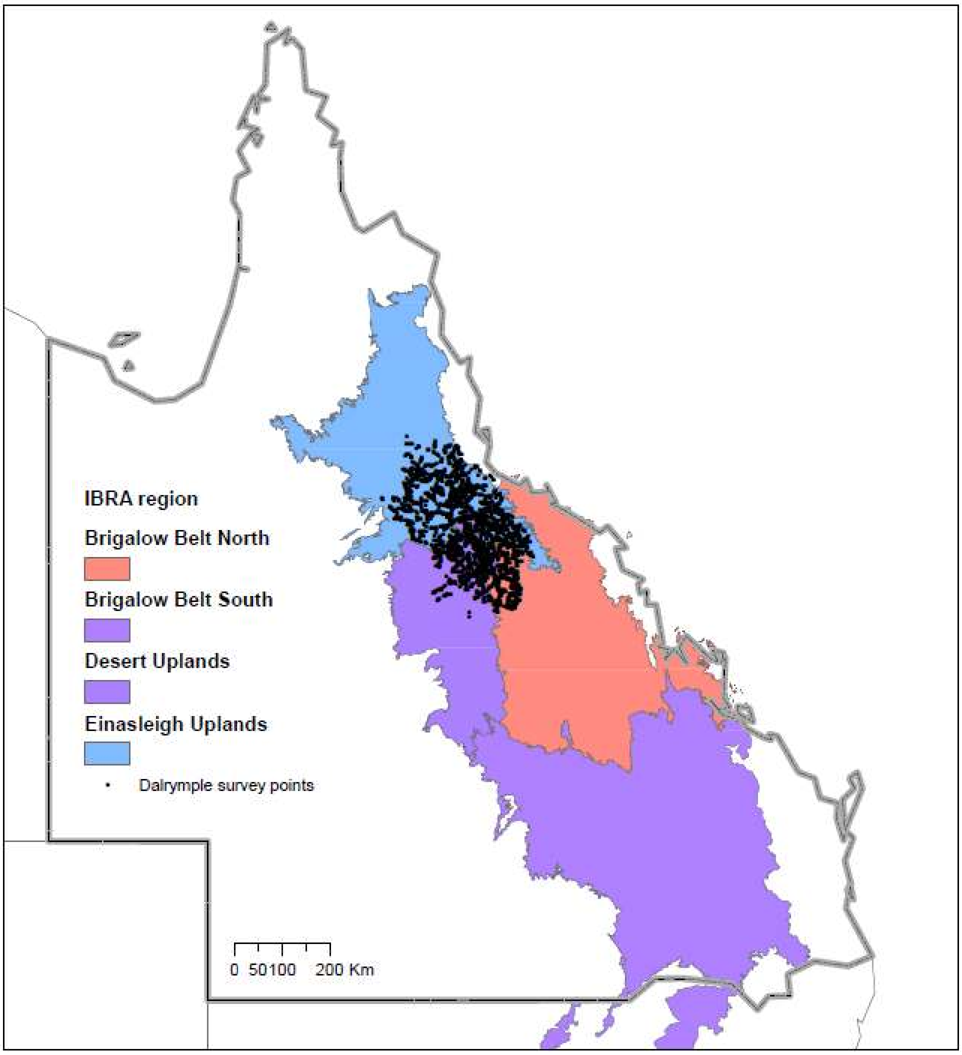

Figure 1. Location of soil survey points with respect to bioregions.

The site by species matrix is shown in Figure 2. Some species are found everywhere but some are restricted in extent (lower right hand corner in Figure 2). These are: *Cenchrus ciliaris* L. (buffel grass) (CECIL), *Lysiphillum carronii* (F. Muell.) Pedley (LYCA1), *Eucalyptus cambageana* Maid. (EUCA1), *Terminalia oblongata* F. Muell. (TEOB1), *Acacia argyrodendron* Domin. (ACAR), *A. harpophylla* F. Muell. (ACHAR), and *A. cambagei* R. T. Bak. (ACCAM).

Species attributes and environmental variables can be investigated to see whether they account for the variation in the species composition as summarized by these species and site scores. An environmental variable that influences species would be expected to show a monotonic relationship with the site scores. A regression model for the site scores with log (TSS) as the sole explanatory variable had an $R2$ of 37% and a mean square error (MSE) of 0.95.

The sites scores were related to other environmental variables in a generalized additive model (GAM): 19 climatic, 10 terrain, two bands of Landsat MSS, soil %clay and thickness, and lithology were investigated. These attributes were sampled from the ASRIS database (Johnston *et al*., 2003) at the sites. Site scores tended to increase with higher elevation, relief, precipitation and moisture index and lower % clay, temperature and radiation. The GAM fitted with the environmental variables had an $R2$ of 41% and a mean squared error (MSE) of 0.89. Adding a smoothing spline for log (TSS) with five degrees of freedom increased the explanatory power of the site scores ($R2$ 57%, MSE 0.65). Soil salinity therefore plays an important role in describing the environmental gradient, even after accounting for the variation explained by other environmental predictors.

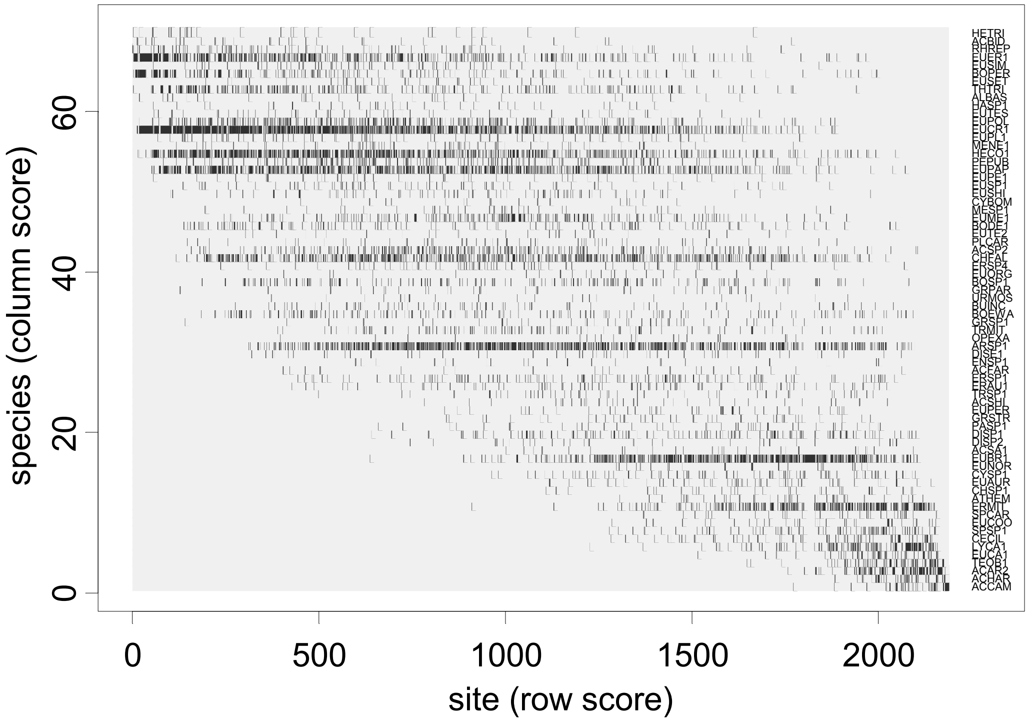

Figure 2. Site by species matrix after correspondence analysis.

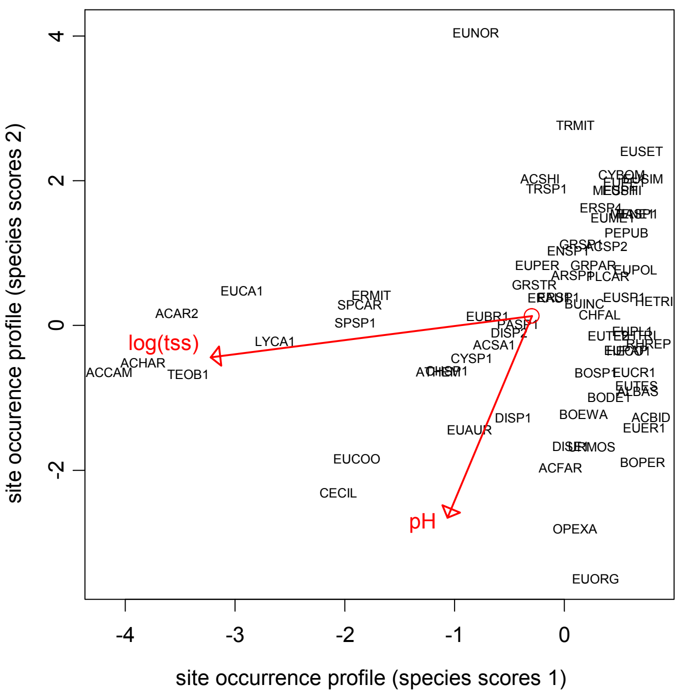

Figure 3. The environmental gradient represented by the first axis of the correspondence analysis is strongly related to log (TSS); the environmental gradient represented by the second axis is strongly related to pH (0-30 cm).

Soil salinity and topsoil pH, respectively, are strongly associated with the first two score axes after correspondence analysis of site by species data (Figure 3). The distribution of individual species, *Eremophila mitchelii* Benth., *Lysiphillum carronii* (F. Muell.) Pedley, *Eucalyptus cambageana* Maid., *Terminalia oblongata* F. Muell., *Acacia argyrodendron* Domin., *A. harpophylla* F. Muell., and *A. cambagei* R. T. Bak., responds strongly to a salinity gradient, starting at low levels of salinity—levels much lower than would typify a saline soil.

Weed invasion
Cenchrus ciliaris L. (buffel grass) (Poaceae) is considered one of Australia's worst environmental weeds and invasion by *C. ciliaris* is seen as a major threat to key habitats in the arid zone (Jackson, 2005). In addition to out-competing native species directly and decreasing herbaceous species richness, *C. ciliaris* invasion may result in major habitat change via its effects on fire regimes because it produces more biomass than native species and this greater biomass, which cures later in the year, leads to hotter late-season fires and an increased incidence of fire (Jackson, 2005). Its occurrence appears to be restricted to soils with alkaline topsoil pH (Figures 2 and 3), thus topsoil pH may be useful to predict its potential to invade new grassland habitats.

Biogeography, biodiversity, and soils are linked over time
Investigations of *Acacia* thrips systematics and their host-plant relationships show that:
- *A. harpophylla* and *A. cambagei* harbor two sister-species pairs of elongate and round gall thrips (*Kladothrips* spp.);
- phyllode-glueing thrips also show host specificity; and
- thrips on *A. harpophylla* and *A. cambagei* display high species richness (Crespi *et al*., 2004).

More recently McLeisch *et al*. (2007) have linked host-driven diversification of gall-inducing *Acacia* thrips and the aridification of Australia in the late Miocene (~6 My).

Taxonomic and recent chloroplast-DNA evidence shows that *Acacia harpophylla, A. cambagei and A. argyrodendron* are closely related species of microneurous *Plurinerves* (Crespi *et al*., 2004). These are the three *Acacia* species that exhibit tolerance of the highest levels of salt (Figure 3). However not all *Plurinerves* are salt-tolerant thus salinity may have played a role in the speciation within this clade. Certainly the brigalow plant communities have adapted to high soil salinity. Thus it seems that co-evolution of acacias related to brigalow and their thrips is linked to development of soil salinity in semi-arid landscapes.

Conclusion
The results have important implications for the conservation of biodiversity under global warming/climate change: they show that climatic variables are not the only important drivers of biogeographic patterns; soil chemistry plays an equally important role. Design of natural reserves for conservation of biodiversity should take both change in climatic pattern and soil geography into account, in particular climate-soil-plant interactions. In many instances soil resources have been neglected in conservation plans, partly because information on soil properties, especially chemical ones, is not extensively available—this example should serve as impetus for soil survey organizations around the world to make more attempts to improve their soil property mapping and to link their data with biological collections.

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Implications of soil resources for vegetable crop options and agronomic practice for sustainable production – a comparison of Eastern Highlands and Central Provinces, Papua New Guinea

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Abstract
Soil resources of the Eastern Highlands Province and Central Province of Papua New Guinea are outlined, with particular emphasis on the implications of their characteristics for agronomic practice and soil management under conditions of increasing demand for food because of population increase. Implications for crop options are also examined. Key areas of irrigation and drainage, acid soil infertility, organic matter based farming and nutrient management, with particular emphasis on nitrogen, phosphorus and potassium supply and availability in soils, are examined in a sustainability context. Cation balance, micronutrient and sulphur supply are also considered. The risk of soil degradation is examined briefly, and the need to select appropriate sites for sustainable intensive production highlighted.

Key Words
Sustainable, vegetables, soil resources, soil management.

Introduction
Soil resources and climatic conditions interact strongly influence crop options and agronomic practices. This interaction is particularly important in developing countries where purchased chemical inputs are usually scarce and expensive, and often inaccessible to local producers because of cost. Value chain analysis provides an holistic framework for guiding the research focus on the bio-physical limitations and variables, for example soil physical characteristics and soil fertility, that will have the optimum socio-economic impact. Soils of the Eastern Highlands and Central Province of Papua New Guinea (PNG) are highly variable, as discussed in Doyle *et al.* (2010) – this paper concentrates on those with the greatest agricultural potential, and examines the implications of soil characteristics and limitations for crop options and agronomic practices, within the constraints of a developing country. Climatic limitations are a relatively minor constraint in the PNG highlands, with adequate rainfall in most months, and moderate maximum and minimum temperatures throughout the year (Table 1). The main climatic constraint is likely to be excessive rainfall causing excess runoff and perched water tables. The coastal lowland areas lie in the seasonally dry tropics, and tend to have excessive rainfall from November to April and dry conditions for the balance of the year, with a tendency for improved distribution towards the east. Temperatures are high throughout the year (Table 1).

Table 1. Mean monthly rainfall (mm) and maximum and minimum temperatures (^oC) at Goroka (Eastern Highlands Province) and Port Moresby (Central Province, coastal lowlands area), Papua New Guinea.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Goroka													
Rain	153.4	214.5	272.2	175.7	151.9	43.8	70.4	49.2	150.1	132.1	145.4	163.8	1722.5
Max	26.7	26.5	26.5	26.9	26.3	26.1	25.6	26	26.2	27.0	27.0	27.5	-
Min	15.5	16.2	16.2	15.7	15.4	15.1	14.9	14.9	15.6	15.4	15.7	16.1	-
Port Moresby													
Rain	192.2	140.6	189.8	105.2	56.2	21.6	13.8	12.0	14.4	15.2	40.0	47.8	848.8
Max	32.1	31.6	31.4	31.3	31.0	30.3	29.9	30.3	31.0	32.0	32.5	32.4	-
Min	23.7	23.5	23.4	23.5	23.5	23.1	22.4	22.6	23.2	23.5	23.6	23.7	-

Source:PNG National Weather Service (2009)

Summary of soil resources characteristics
The Eastern Highland Province (EHP) of PNG is characterised by areas of recent volcanic and associated geomorphic activity, giving rise steep slopes and deep incision of the landscape which often constrains access and increases the risk of land degradation. The most intensively used arable soils are the Andisols which are oxy-hydroxide rich, fine textured soils with variable drainage characteristics formed from volcanic ash.

They have high levels of organic matter, but low chemical fertility and acidic soil reaction trends. The exchange complex is dominated by aluminium with low levels of all exchange cations but with potassium particularly limiting. The soil acidity and high iron oxide levels mean P fixation is an issue (Bleeker 1983, Harding and Hombunaka 1998; Radcliffe and Kanua 1998,). Other nutrient deficiencies include boron, zinc, molybdenum, copper and manganese (Radcliffe and Kanua 1998; Harding and Hombunaka 1998).

In Central Province, the highly dissected Sogeri Plateau forms an elevated area inland from Port Moresby which is accessible by road. Here the dominant soils used for agriculture are well structured, deep Oxisols. However steep slopes in this deeply incised landscape mean a high soil erosion risk exists across much of the area. Hanson *et al.* (2001) indicate high land potential in this area, despite the likelihood of acid soil infertility, strong P fixation and other nutrient deficiencies similar to those in EHP. In the peri-urban areas near Port Moresby, National Capital District (within Central Province), landforms vary from steeply sloping hills and mountains, with shallow soils of low natural fertility derived from siliceous sedimentary rocks to alluvial valleys associated with numerous streams flowing southward from the Owen Stanley Ranges. The alluvial soils are typically deep, dark, and fine textured being derived from mixed felsic and mafic parent materials.

Implications for crop options and agronomic practices

Crop options

Because of limitations of availability and cost of fertilisers, crop selection must consider the adaptation of indigenous and exotic crops to soil fertility limitations. This implies, for example that crops that efficiently extract P from low availability sources in highly P fixing soils, for example sweet potatoes, peanuts and soybeans should be preferred over introduced temperate crops. The low availability of K in many highland soils constrains yield of many crops, particularly the high K requiring crops such as sweet potatoes. However, there are dietary, financial and social factors that impinge on crop selection, sweet potatoes being a staple crop of social significance to PNG peoples, while social change and dietary preference favours temperate vegetables such as Brassicas for urban markets. These latter crops require high levels of fertility, including specific requirements for boron and molybdenum, and therefore require either purchased inputs or new land in which to be grown. The latter option remains available while land supplies are non-limiting, but with increasing population placing pressure on land resources, cannot continue indefinitely. Clearly, areas of production of high nutrient demand crops will need to be carefully selected, but carry the risk of nutrient exploitation, followed by reduced productivity and lack of sustainability of production and the soil resource. Soil nutrient constraints will limit cropping options and require increasingly sophisticated rotations and increased nutrient inputs from local and imported sources. Further, soil limitations will be a major determinant of expansion of crop production to meet the needs of increasing urban populations in Port Moresby and other cities of PNG.

Drainage and irrigation options

In the Eastern Highlands, the topsoils are generally well structured with good drainage. However, some subsoils are more limiting with occurrence of impeding clayey layers, causing permanent and seasonal gleying, perched water tables and formation of iron and manganese segregations, nodules and pans. They indicate that artificial drainage will be necessary for long term production in the lower lying and flatter parts of the high rainfall environments. In the coastal lowland areas, high ground water tables and seasonal flooding will limit crop options and season of production. On the slopes around Port Moresby, irrigation is necessary because of limited soil depth and poor water holding capacity. Currently, migrant highlanders occupy this land without security, and use reticulated (urban) water for irrigation, an unsustainable situation.

Options for managing acid soil infertility

Lack of financial capacity to import ground limestone or dolomite means approaches to soil pH adjustment used in developed countries are not viable. Amelioration of soil pH in the Andisols and Oxisols in the Highlands and Sogeri, utilising limestone in uplift areas of the Owen Stanley Ranges is possible. Local processing to suitable particle size may be viable in the longer term, however, preparation of burnt lime using crop residues as the heat source in small kilns and taking advantage of the cultural importance of fire may offer a way forward (Bailey *et al.* 2008). Though not expected to be a widespread limitation in the alluvial areas, soil acidity is likely to constrain production on the slopes around Port Moresby, and combined with erosion risk on these soils, severely constrain their long term use. Amelioration of soil pH in these sloping areas is unlikely to be considered given the lack of security of tenure of migrant settlers.

Organic matter based farming
The moderate to high levels of organic matter measured in the topsoils of the highlands soils (Bailey *et al.* 2008) suggests nitrogen supply from well managed minearlisation should be sufficient for most crops. However, high C:N ratios may limit N supply, particularly during periods of high crop demand. Also, and the adequacy of N supply and other nutrients partly sourced from organic matter (e.g. sulphur) may not be sustainable as rotations are intensified in response to increased food demand (Bourke 2001). The current practises of burning most crop residues reduces the plant nutrient pool, and leads to degradation of soil structure, adversely affecting crop production and land resource conservation. Further, increasing population pressure is forcing production onto poorer soils with lower organic matter levels and weaker structure, placing these at risk further degradation. These problems are already evident in some of the more intensively farmed areas e.g. Sogeri Plateau and peri urban hillsides near Port Moresby. By contrast, the river valleys of the coastal lowlands are less intensively used for vegetable production, and offer opportunities for increased and sustainable production.

Nutrient management options
Regardless of location in the highlands or coastal lowlands, increased production with shortened rotations will bring new nutrient management challenges and intensify existing limitations. Of the macronutrients, shortened rotations will render nitrogen constraints more widespread and severe, and place increased demands on all other nutrients through crop uptake and removal in harvested product. Consequently, purchased nitrogen, either as fertiliser or imported organic matter (mulch or compost from other cropped or non-cropped areas) or rotations including legumes will be required. Importantly, additional N entering the system is likely to further acidify already acid soils, creating demand for liming materials.

Phosphorus supply represents a major challenge, because of P fixation by several major agricultural soils, inadequate current soil supply, and high cost of P fertilisers. There are also no sources of phosphate rock for fertiliser manufacture (Fixen 2009). Importing plant material from non-crop areas and return of domestic waste, and if available, industrial by-products could assist but are unlikely to meet the needs for soil P especially on highly fixing soils. Thus, in the short term at least, production of P efficient crops e.g. peanuts and perhaps mycorrhizal crops on highly fixing sites and high P demand and P inefficient crops e.g. tomatoes, brassicas on comparatively P fertile sites in lowland alluvial areas emerge as the preferred strategies, provided market conditions allow. In the longer term, though, there appears no alternative to purchased P fertiliser. K supply in many Highland soils is inherently low (Bleeker 1983), and long term production of high K demand crops such as sweet potatoes has exacerbated the situation. Importing organic matter and burning it to release K or using it as mulch (Bailey *et al.* 2008) can provide some K, but simply transfers K from one location to another. Return of domestic and other waste may also provide some K. However, the amounts returned are likely to be small compared to total need and with limited reserves of slowly available K in soils of the highlands, the importation of K fertiliser seems inevitable. Alluvial soils are better supplied, so K application may not be needed for some time.

Calcium and magnesium supplies are low in acidic volcanic soils with low CEC in the Highlands, but be less limiting in alluvial coastal soils. Though not currently recognised as a significant production limitation, intensification and intensification of rotation cycles is likely to result in deficiencies, expressed, for instance as blossom end rot in tomatoes (Ca deficiency). Raising soil pH as outlined earlier would also reduce the risk of metal, especially aluminium, toxicities, while enhancing solubility of micronutrients such as molybdenum. The challenge, in the PNG context, is to provide liming materials at an affordable price.
Inherent sulphur supply in tropical soils depends on the ability of the profile to retain sulphur through adsorption. This in turn depends on parent material. Soils developed on basic parent material will have a greater sulphate adsorption capacity, particularly at depth, than soils developed on acid igneous rocks or sediments (Barrow 1978). This sulphur is much less strongly adsorbed than phosphorus or molybdenum (Barrow 1978), and is therefore relatively available to plants. The capacity of soils to sorb sulphur also increases with annual rainfall because higher rainfall increases weathering and makes soils more acid. As cropping intensifies, depletion of inherent sulphur will occur, and continued supply in the topsoil will depend on inputs of either organic matter or S-containing fertilisers.

Of the micronutrients, boron and molybdenum are most widely recognised as deficient in the highlands of PNG (Bleeker 1983; Bailey *et al.* 2008), but little if any information is available for the coastal lowlands. Raising soil pH can improve molybdenum solubility, otherwise supply of molybdenum as a seed dressing or fertiliser will be required. There is little option but to supply boron as fertiliser to crops that are susceptible to boron deficiency e.g. brassicas, for production to continue in current locations. Alternatively, their production could be increased in more favourable sites in the Highlands or Lowlands, provided market and infrastructure conditions allowed.

Soil degradation and its control

Soil erosion in the regions studied is limited by the small patchwork nature of the production gardens. Even on steep slopes; the cover upslope, well maintained field drains, good soil structure and short slope lengths all combine to limit erosion risk. However the increasing pressure to expand the areas of production, and in particular the drive to grow on poorer more weakly structured soils, notably in the peri urban setting, represents a major soil erosion risk. There is a need to better select intensive production regions to protect the peri urban environment, harness the better regional resources (soil, water, people) and ensure a sustainable and consistent food supply chain.

Conclusion

Suitable soil resources for sustainable vegetable production are available in EHP and CP of PNG. However, limitations of chemical fertility, topographic position and in some locations soil depth will limit crop options and long term sustainability of production. Key areas of irrigation and drainage, acid soil infertility, organic matter based farming and nutrient management, with particular emphasis on nitrogen, phosphorus and potassium supply and availability in soils will require solutions that are affordable for local producers and sustainable. In the longer term, cation balance, micronutrient and sulphur supply are expected to become increasingly limiting and require similar solutions. The risk of soil degradation is a significant production limitation in elevated areas, emphasising the need to select appropriate sites for sustainable intensive production.

Acknowledgement

The authors acknowledge the financial support of the Australian Centre for International Agricultural Research for this work.

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Nestedness analysis of land use change on pedodiversity under the intensive urbanization process

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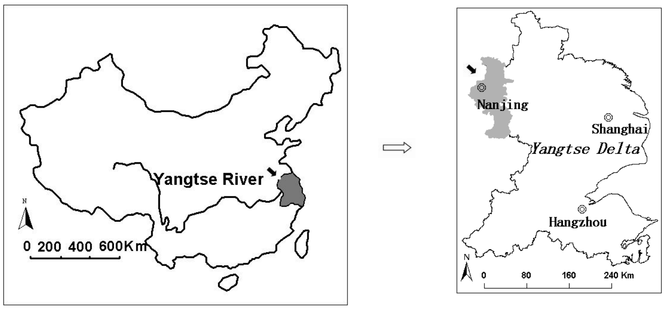
The nestedness analysis method has been used in biological studies for many decades and is thought to have greatly expanded ecologists capacities to deal with complex biotic patterns within archipelagos or "islands" of terrestrial or aquatic habitat. Diverse biotic and abiotic processes are believed to generate nested distributions, including non-random extinction, differential colonization, and nestedness of critical resources. Biodiversity research is the keystone of conservation biology and natural reserves design. One of the most obvious causes of variation in the distribution of plant species and communities is the underlying soil variation. Usually ecologists use soil variables, but do not consider soil types in the same way as they consider bio-species. It was not until the beginning of the 1990s that soil data were analyzed with mathematical tools developed for the study of biodiversity. Only recently, has the extensions of nested subset analysis to other taxa, regions, and spatial scales just begun. Rapid urbanization has caused many social and environmental problems including a clear loss of certain soil types or unique soil units to urbanization. Our recently published research results in Nanjing indicate that 2 soil types, Clay loamy fimic-ferriudic argosol and Loamy car-mottlic-fimic-orthic anthrosol as classified in the Chinese Soil Taxonomy, may be in danger of disappearing under urban/suburban structures because they have been decreased by 41.4% and 62.4%, respectively in the past 20 years. Seven soils decreased by more than 10%, and 8 others decreased by more than 5%. Land use changes, especially resulting from the rapid urbanization process, have often had a great impact on pedodiversity. The loss of soil types may therefore represent loss of whole biological communities unique to those soil types. The conservation of pedodiversity also brings into question the wisdom of converting to agriculture those soils that have not previously been cultivated. This paper tries to share the nestedness analysis method from biological studies to examine the spatial-temporal change of pedological assemblages and pedodiversity characteristics (Nested pattern) due to the influence of the fast urban expansion of Nanjing in the past 20 years.

Study site, data and method

The data used in the study is a set of Landsat satellite TM images overlaid with the digital soil database map (at scale 1:200,000) in which 19 soil mapping unit delineations forming 869 polygons excluding 16 non- soil polygons were linked with their attribute databases of natural conditions and different soil properties of the studied area. Nanjing is located in the Yangtse delta (Jiangsu province, east China, Figure 1), and known as a famous historic city, which was home to a large community of human beings in the late period of the mid-Pleistocene epoch 350,000 years ago and has experienced extensive development in the past 2-3 decades with 9 new economic development zones established around the city.

The methodology consists of analyzing data with a geographic information system (GIS) to combine urban land use maps of different times derived from satellite images with data on soil characteristics contained in the established soil databases before a nested subset analysis is conducted. The integration of satellite remote sensing and GIS technology proved to be an efficient method for mapping and analysis of urban land use change. Some ideas from SOTER methodology were borrowed to build a database for spatial analysis and evaluation. In a perfectly nested matrix, the hypothetical line that separates the occupied area of the matrix from the unoccupied portion is called “boundary line”. Taxa absences above and to the left of the line are defined as unexpected, the same as the taxa presented below and to the right. When randomness is low, unexpected presences and absences cluster near the boundary line. In contrast, when it increases, both unexpected presences and absences move further away from it. The “entropy” of the matrix is a result. The “Temperature Calculator” of Atmar and Patterson used in this paper seems ideally suited to explore various features of nestedness (Figure 2).



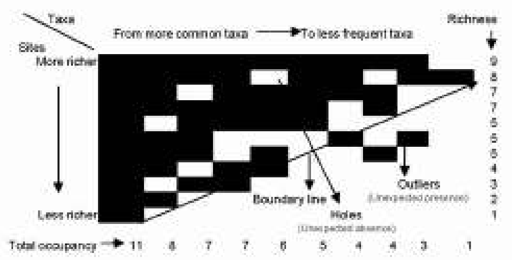


Figure 1. Location of the study area.

Figure 2. Typical realistic nested matrix.

Results and discussion

Land use change under fast urbanization process from 1984 to 2003

The urban sprawl data from 1984 to 2003 was obtained by interpretation of Landsat TM satellite images from different dates (1984, 1995, 2000 and 2003) (Figure 3). The images show Nanjing undergoing rapid urbanization in the past 20 years. The city urban area increased 16,776 ha from its starting area 31,634 ha in 1984 to 48,410 ha in 1995 with a 1525 ha yearly increase (4.8%). During the next two periods, 1995–2000 and 2000–2003, all values were clearly higher than the previous annual increase: 2470 ha y^{-1} or 5.1% during 1995–2000 and an annual increase of 4804 ha y^{-1} or 7.9% during 2000–2003. In the past 20 years, there has been an absolute urban area increase of 43,544 ha in Nanjing area, which is now 2 times larger than before (Table 1). More urban areas including the city, attached county seat and township areas expanded each year at an annual rate of 6.9%. Trends in urbanization of the city show that the city is more urbanized southward than other directions since the city economy was naturally stopped in its growth by the Yangtse River to the northwest. It is considered to be the geographic line dividing north and south China and the mountainous area east of the city. People in this area traditionally preferred to live or do business on the south side of the Yangtse River that played an important role in shaping the city structure in its recent history. The newly established Jiangning economic development zone (Jiangning District) south of the original Nanjing city is another reason for the current city urban/suburban growth pattern. A satellite-based calculation shows that 11.3% of the total land area of Nanjing city is now in urban use (2003) compared with only 4.8% in 1984. It is clear that the best soils are being developed first even though the percentage of urbanized area relative to the city total land surface is not very high. There is evidence, however, that some preservation of the very best soils has been taking place.

Table 1 The extended urban area of Nanjing city from 1984 to 2003 (ha).

Time	1984-1995	1995-2000	2000-2003
Starting area	31634.61	48410.93	60764.49
Extended area	16776.32	12353.56	14414.48
Increased area per year	1525.12	2470.71	4804.83
Yearly increase rate (%)	4.82	5.10	7.91

An increased nestedness of land use pattern under urbanization growth

Ecologists and pedologists are both aware that not all taxa that occur within a region are widespread within that entire region. For a set of sites, one can envisage a presence–absence, or incidence, matrix of resident taxa. Rows represent the sites, and columns represent names of all the taxa. Each site-taxon combination is represented by a one or a zero depending on whether the taxon is present or absent at that site. Summing across rows give the taxa richness recorded in a given site. Summing across columns for a given taxon give the number of locations where its presence has been recorded. These matrices provide a simple graphic illustration of the interrelationships between patterns of taxa and occupancy. The site sample describes the assemblages (pedologic or biologic) of the landscape in a probabilistic manner.

In this case study, all the calculated town level units are respectively defined as ones for "urbanized" or zeros for "not urbanized". Analyzing the expansion of Nanjing in the last 20 years, results (Table 2) show that the fill of urbanized area analyzed by a professional software tool (Nested Temperature Calculator) has been doubled (from 3.5 in 1984 to 7.2 in 2003), and the nested degree has been getting higher and higher (T value at 18.68, 16.96, 16.40 and 15. 17 in the four periods). The pattern of land use is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher; Geographical changes can be found by the distribution of the fill value of different towns. Some towns or districts show very clear increases in fill due to the more rapidly

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

growing urbanization. Jiangning DZ ranks the first since it is completely a new development zone cratered only in the past ten years while the others are less changed.

Table 2. Nestedness analysis of landuse pattern under urbanization from 1984 to 2003.

Year	Matrix results		System temperature(Monte Carlo simulation)		Statistical significance
	T value	Fill value	Average	S.D	
1984	18.68	3.5	14.81	0.53	<0.001
1995	16.96	5.4	24.20	0.66	<0.001
2000	16.14	6.1	27.35	0.67	<0.001
2003	15.17	7.2	32.62	0.73	<0.001

More and more nested soil composition and distribution after land use change

Similarly to the method design above, all the calculated soil mapping units at soil family level are respectively defined as ones for urbanized soil families or zeros for still agriculturally used units. In all 32 soil families, only two were not occupied by the urbanization process in the past 20 years, they were Loamy mollic-car-udic-orthic primosol and clay loamy typic-dark-aqui cambosol. Among all the soil families, Loamy typic-Fe-leachic-stagnic anthrosol, clay loamy fimic-ferri-udic argosol and clay loamy car-typic-hapli-stagnic anthrosol occupied by urban land use were the first largest ones, with occupied areas of 4900 ha, 4660 ha and 3010 ha, respectively. According to the composition of pedotaxa (Figure 4), we recognized classification classes (dominant, normal, rare and endangered) in the Nanjing area, 4 of 32 soil families are classified as dominant (D), 16 as normal ones (N), 10 as rare (R) and 2 as endangered (E) based upon frequencies of both presence and remaining areas. The most frequently appearing soil families are Clay loamy typic-arp-udic argosol, Loamy typic-Fe-leachic-stagnic anthrosol and Clay loamy eutric-arp-udic argosol with their frequencies of presence at 56, 52 and 41, respectively. The least frequent soil families are Clay car-vertic-gleyic-stagnic anthrosol and Clay loamy typic-dark-aqui-cambosol with their frequencies of presence at 2 and 3. The urbanization sprawl already turned 1 soil family from dominant into normal, 2 from normal into rare and 1 from rare into endangered. Running the Nested Calculator program for the data from 1984 to 2003 shows that data sets are nested. The pattern of the composition and distribution of soil is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher. The nested metric T of soil composition is 16.88, 13.91, 13.62, 12.88, respectively (Table 3). Area size and geographical conditions are considered to be the main factors forming the nested pattern in Nanjing area.

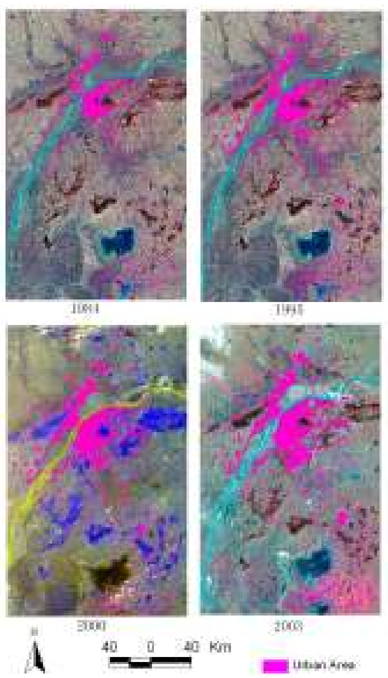


Figure 3. Urban growth pattern.

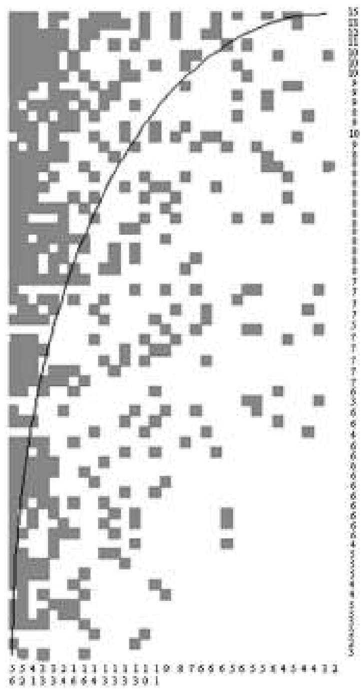


Figure 4. Occurrence of soil family presence.

Table 3. Nestedness analysis of soil spatial pattern in Nanjing from 1984 to 2003.

Year	Matrix results T value	System temperature(Monte Carlo simulation) Fill value	Average	Statistical significance
1984	16.88	48.35	7.84	<0.001
1995	13.91	48.57	7.91	<0.001
2000	13.62	46.59	8.08	<0.001
2003	12.88	44.45	7.86	<0.001

Meanwhile there is a good fit between the two factors (taxa-area, Figure 5) for this data set for the Nanjing area (z=0.5023; R^2=0.8162) with the best fit formula:

$S=0.1096A^{0.5023}$ F=126.64, P<0.001, R^2=0.8162

Results of taxa-range size distributions show that the data set of the studied area conforms to a concave curve (Figure 6), as is also the case of most biological and pedological inventories. Furthermore, this distribution conforms to a power law confirming what the ecological literature predicts.

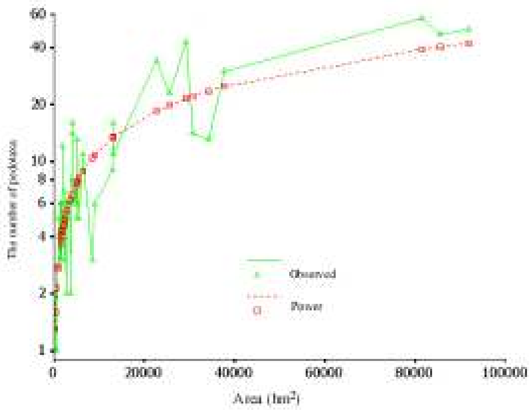


Figure 5. Pedotaxa-area relationship in Nanjing.

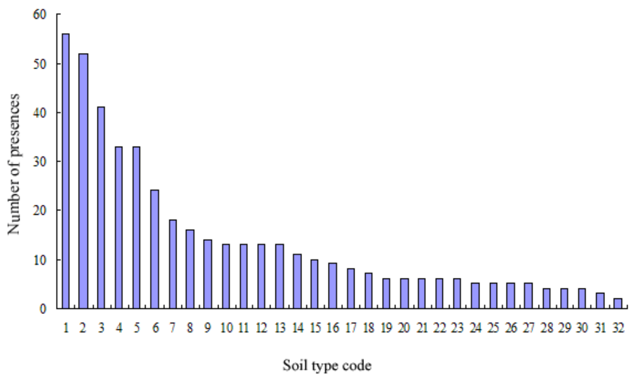


Figure 6. Hollow curve for pedotaxa frequency in Nanjing.

Conclusions

Rapid expansion of urbanization in the Yangtse delta area is still progressing. There has been an absolute increase of 6124 km^2 of urban area in the whole Yangtse delta (from 4873 km^2 in 1984 to 10997 km^2 in 2003) in the past 20 years. Urban area expansion of 322 km^2 each year was at an annual rate of 6.6%. Nanjing city has lost from 4.8 % in 1984 to 11.3 % in 2003 of its surface land to urban use. Results show that the fill of urbanized area calculated by a professional software tool (Nested Temperature Calculator) has been doubly increased (from 3.5 in 1984 to 7.2 in 2003), and the nested degree has been getting higher and higher (T value at 18.68, 16.96, 16.40 and 15. 17 in the four periods). The pattern of the land use is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting higher and higher. Geographical changes can be found by the distribution of the fill value of different towns. Only two among all the 32 soil families were not occupied by the ongoing urbanization process in the past 20 years while the others were more or less affected. Those distinct soil types (at least two soil families), with their unique physical structure and history of formation, may be in danger of elimination, likely resulting in a substantial loss of below ground and above ground biodiversity. A power law fit is satisfactory for a pedotaxa-area relationship in Nanjing. Thus, in Nanjing there exist taxa-area positive correlations. The pattern of the composition and distribution of soil is all nested in 1984, 1995, 2000, 2003, and the nested degree has been getting greater and greater. Area size and geographical conditions are considered to be the main factors forming the nested soils distribution pattern in the Nanjing area. Soil assemblage regularities appeared to be similar to those described in ecological literature. Cumulative pedotaxa distribution curves, rank–abundance curves, richness and diversity indices, and others diversity tools also show patterns similar to diversity in ecological systems.

Acknowledgements

This work was supported by Natural Science Foundation of China (40671012, 40541003, 40171044) and Henan Provincial Commonweal Project (081100911500-1, 081100911600-1).

Net nitrogen mineralization and nitrification at different landscape positions in a lowland subtropical rain forest in Taiwan

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Abstract
Although soil N transformation rate measurements are needed to assess plant availability and N losses in a forest ecosystem, little data is available on lowland subtropical rain forests. The objective of this study is to determine the rates of N mineralization and nitrification in different seasons (January and August in 2006) and at different landscape positions (footslope and summit) in the Nanjenshan forest of southern Taiwan, where the vegetation types and soil properties vary among the different landscape positions. According to our 28-d *in situ* incubation experiments, although there were larger soil C, soil N, and microbial N pools at the summit position, the footslope soils showed higher net N mineralization and nitrification rates, as expressed on a per unit C or N basis. Laboratory incubation results indicated that the N mineralization was more responsive to temperature change than to moisture change in the Nanjenshan forest soils. Our results suggested that the substrate properties at the footslope position contributed to a higher net N mineralization and nitrification rate and that the differences between the N transformation rates at different landscape positions might be related to the types of vegetation.

Key Words
Subtropical rain forest, Net N mineralization and nitrification, Nanjenshan Nature Reserve, Landscape position, Vegetation.

Introduction
Soil N mineralization and nitrification rates often differ with the forest type, elevation, and landscape position (Finzi *et al*. 1998; Knoepp and Swank 1998; Venterea *et al*. 2003). The need to gain a deeper understanding of tropical rain forests is well documented; however, subtropical rain forests have not attracted the same level of attention. The Nanjenshan Nature Reserve in Kenting National Park contains the last native lowland subtropical rain forest in Taiwan. It is worth noting that most of the lowland plant species found in Taiwan are present in the Nanjenshan forest, which also contains numerous rare and locally endemic species of Hengchun flora (Sun *et al*. 1998). Despite the low elevation, it is surprising that temperate-zone tree taxa are also present in the subtropics (Liao 1995; Sun *et al*. 1998). The objective of this study is to examine the rates of soil nitrogen mineralization and nitrification in different seasons (summer and winter) and at different landscape positions (footslope and summit) on Mt. Nanjenshan in southern Taiwan.

Methods
Study site
The study site (22°37’N, 120°10’E) is located in the Nanjenshan Nature Reserve of Kenting National Park on the Hengchun Peninsula at the southern end of Taiwan (Figure 1). The annual precipitation in this area is about 3000 mm, and the mean monthly air temperatures are highest in July (28^{o}C) and lowest in January (18^{o}C). Typhoons are very common during summer; northeastern monsoon winds usually begin to blow in late October and last until late March of the following year. An experimental transect having a length of 450 m and width of 10–40 m was established on the northwestern ridge of Mt. Nanjenshan in 1994 (Figure 1). The vegetation along this 1-ha transect can be divided into three distinct vegetation types, and there is a vegetation compression phenomenon, with great richness in plant species richness within a short elevation range of 200–400 m (Liao 1995). The soils located at the summit position are classified as Typic Paleudults, which have an argillic horizon resulting from strong leaching and illuvial processes. The soils located at the unstable backslope position are associated with steep slopes and those at the footslope position are classified as Typic Dystrudepts, which have a cambic horizon resulting from weak leaching processes.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

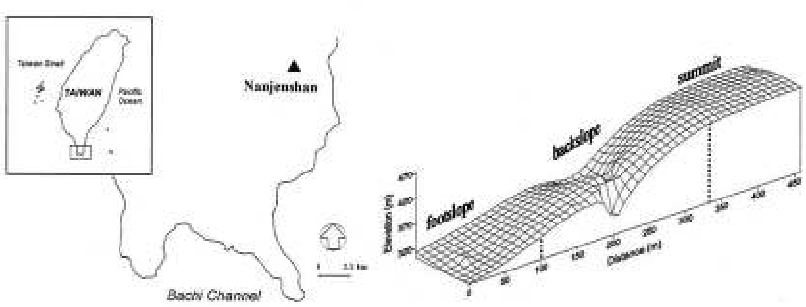

Figure 1. Geographical location of the long-term ecological research site in Nanjenshan Mountain in southern Taiwan.

In-situ incubations
Two sets of three 2 m × 2 m plots were established at the summit and footslope positions in December 2005. All six plots were well covered by a canopy of the dominant tree species. In January and August of 2006, the *in situ* soil net N mineralization and nitrification were measured using 28-d capped cores incubations. Duplicate field-moist soil samples (<5.66 mm) of 20 g were shaken with 100 ml of 2 M KCl for 1-h, filtered, and determined the inorganic N concentrations. The net N mineralization and net nitrification were determined by the differences of ammonium plus nitrate (mineralization) or nitrate-N (nitrification) between the 0-d and 28-d of incubation. The soil microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) were measured using the chloroform-fumigation incubation method (Jenkinson and Powlson 1976). The spare soils were air-dried, ground, sieved to less than 2 mm, and determined the soil N (TN) and the soil organic carbon (OC) by the total Kjeldahl nitrogen procedure and by the modified Walkley-Black method, respectively.

Laboratory incubations
To determine the potential N mineralization and nitrification and to examine the effects of moisture and temperature condition, bulk soil samples at time zero in January and August in 2006 were also collected for laboratory incubation. After transported to the lab and sieved (< 5.66 mm), soil was air-dried at dark room (< 20 ^{o}C) overnight and soil water content (105^{o}C) were determined. Eight soils per plot were weighed to the equivalent of 10 g oven-dry in plastic bottles, rewetted to 20 % or 40 % of gravimetric water contents, and incubated under 15 ^{o}C or 30 ^{o}C in incubators. After 0, 0.5, 1, 2, 3, and 4 mo of incubation, the soils samples were extracted with KCl as described above and the inorganic N concentration determined. We assumed that the net N production rate during the incubation follows first-order kinetics:

$$np = N_0\,(1-e^{-kt}) \qquad (1)$$

where *np* is the amount of inorganic N produced by time *t* (days), N_0 is the potentially mineralizable N, and *k* is the rate constant. Equation (1) was fitted with the Fit Curve procedures of SigmaPlot 5.0 (SPSS Inc., IL).

Results
C and N concentrations of soil and litter, and soil microbial biomass before incubations
Although the litter C and N concentrations did not show any differences between the summit and footslope positions in our collected samples, the concentrations of soil OC and TN at the summit position were significantly higher than those at the footslope position before the incubations (Table 1). The vegetation type and tree species have a considerable effect on the surface soil C and N dynamics (Finzi *et al*. 1998; Hobbie *et al*. 2007). In our study site, the species composition of the summit forest can be distinguished from that of the footslope forest, despite the fact that the elevation difference between the summit and the footslope is small (Liao 1995; Wu *et al*. 2007).We suggest that the leaf litter from the summit tree species is comparably less decomposable than that from the footslope species, and the difference in litter decomposability probably resulted in the higher OC accumulation in the summit soils. The mean values of the microbial biomass C and N concentrations in the footslope soils were lower than those in the summit soils, however, the C_{mic}:N_{mic} and C_{mic}:OC ratios of the footslope soils were significantly higher than those of the summit soils (Table 1). Large C_{mic}:N_{mic} ratios are caused by increased fungal-to-microbial biomass ratios (Joergensen *et al*. 1995), we suggest that there was a larger proportion of fungi distributed in the microbial communities of the footslope soils than those of the summit soils, i.e., the soil microbial populations were different between the landscape positions. Higher C_{mic}:OC ratios in the footslope soils suggests that (a) the C bioavailability of the footslope soils is higher than that of the summit soils and (b) a relatively larger portion of the soil's organic matter is resistant to decomposition at the summit position, as we previously suggested.

Table 1. C and N concentrations of soil and litter, and soil microbial biomass C and N before incubations.

	Soil OC (g /kg)	Soil TN (g /kg)	Soil C:N ratio	Litter C (g /kg)	Litter N (g /kg)	Litter C:N ratio	C_{mic} (mg C /kg)	N_{mic} (mg N /kg)	C_{mic}:N_{mic} ratio	C_{mic}:OC (%)	N_{mic}:TN (%)
January 2006											
Footslope	12.3b	1.11b	10.5b	376a	12.8a	29.3b	863b	32b	29.3a	7.0a	2.9b
Summit	23.4a	1.61a	14.7a	417a	10.7a	39.2a	1158a	102a	11.6a	4.9a	6.3a
August 2006											
Footslope	13.2b	0.95b	13.9a	402a	10.2a	40.1a	962b	71a	13.7a	7.3a	7.5a
Summit	27.1a	1.84a	14.8a	418a	11.0a	38.3a	1259a	140a	9.2b	4.6b	7.6a

Data with different letters between footslope and summit are statistically significant at $P < 0.05$ (Student's t test).

In-situ net N mineralization and nitrification rate

In January 2006, the amount (mg N m^{-2} 28 d^{-1}) of mineralized and nitrified N and the N transformation rate (mg N m^{-2} d^{-1}) of the footslope were similar to those of the summit (Table 2). The net rates and amounts of mineralization and nitrification in August were 1.3- and 2.1-fold higher than those in January on the footslope and 2.29- and 2.46-fold higher on the summit, respectively, both due to significantly higher concentrations in August (data not shown). In addition to the seasonal variation at a given landscape position, the differences in the N transformation rates (mg N m^{-2} d^{-1}) between the footslope and summit positions were greater in August, and the net N mineralization rates and net nitrification rates at the summit position were 1.8- and 1.3-fold higher than those at the footslope position, respectively. In addition to the substrate concentration (soil C and N), the SOM composition also plays a role in regulating N mineralization, and the differences in the N mineralization rates among different ecosystem types reflect the importance of the SOM composition (Booth *et al*. 2005). On a per gram organic carbon basis (mg N g OC^{-1} d^{-1}) and per gram nitrogen basis (mg N g N^{-1} d^{-1}), the net N mineralization and net nitrification rates of the footslope were both higher than those of the summit in January and August (Table 2). It revealed that the differences in the N transformation rates between landscape positions were influenced by the substrate quality, which is directly linked to the vegetation type (Knoepp and Swank 1998) or tree species (Hobbie *et al*. 2007).

Table 2. Net rates and amounts of mineralization and nitrification of the Nanjenshan transect Site.

	January 2006		August 2006	
	Footslope	Summit	Footslope	Summit
Net amount of N mineralization (mg N m^{-2} 28d^{-1})	844	868	1130	1990
Net rate of N mineralization (mg N m^{-2} d^{-1})	30.1	31.0	40.2	71.3
(mg N g C^{-1} d^{-1})	0.018	0.010	0.023	0.019
(mg N g N^{-1} d^{-1})	0.201	0.143	0.313	0.287
Net amount of nitrification (mg N m^{-2} 28d^{-1})	691	737	1440	1810
Net rate of nitrification (mg N m^{-2} d^{-1})	24.7	26.3	51.5	64.6
(mg N g C^{-1} d^{-1})	0.015	0.008	0.029	0.018
(mg N g N^{-1} d^{-1})	0.165	0.121	0.402	0.260

Table 3. Influences of temperature and moisture on the values of potentially mineralizable N (*N_0*) and the mineralization rate constant (*k*) as estimated with non-linear regression of the cumulative net N mineralization during a 4-month incubation of Transect Site soils

Sampling time	Landscape position	Moisture (%, w/w)	Temperature 15℃ N_0 (mg N kg^{-1})	30℃ N_0 (mg N kg^{-1})	15℃ k (day^{-1})	30℃ k (day^{-1})
January 2006	Footslope	20	18.9***	51.7***	0.0187*	0.0240***
		40	25.0***	52.8***	0.0134*	0.0222***
	Summit	20	23.6***	86.2***	0.0150*	0.0192***
		40	29.8***	151.0***	0.0158**	0.0112***
August 2006	Footslope	20	29.4***	86.7***	0.0138***	0.0113**
		40	39.1***	126.4***	0.0116**	0.0059**
	Summit	20	32.4***	140.1***	0.0243***	0.0100***
		40	32.4***	148.7***	0.0295***	0.085**

(*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$)

Moisture and temperature effects on the potentially mineralizable N (N_0)

In our study, the effects of changing soil moisture condition on N_0 varied with different seasons or landscape positions at a given temperature. On the other hand, the N_0 increased by approximately two- to five-fold when the incubation temperature raised from 15℃ to 30℃ at a given moisture condition (Table 3). The N_0 represents not only the quantity, but also the quality of substrates and their interaction with the soil matrix (Wang *et al*. 2003). At the summit position, there were larger soil and microbial N pools than those at the footslope position (Table 1), and they could serve as a nutrient pool that are gradually released under appropriate condition for soil microbes. According to the results of *in situ* and laboratory incubation experiments, it appeared that at a specific landscape position, the seasonal variation in N transformation was mainly affected by the temperature regime, with the soil moisture regime having less effect at the Nanjenshan transect site. This result confirmed the reports of some laboratory incubations that N mineralization was more responsive to temperature change than to moisture change (Knoepp and Swank 2002; Wang *et al*. 2003).

Conclusion

In general, the net N mineralization and nitrification rates at the Nanjenshan transect site varied with the landscape position. Despite the fact that the elevation difference was small, the soil properties and vegetation compositions differed significantly between the summit and footslope positions due to the special geographic location of the Hengchun Peninsula. Although there were larger soil C, soil N, and microbial N pools at the summit position, the footslope soils showed higher net N mineralization and nitrification rates when expressed on a per unit C or per unit N basis. This suggested that the substrate properties at the footslope position contributed to the higher net N mineralization and nitrification rate and that the differences in the N transformation rates between different landscape positions seemed to be related to the vegetation type.

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Preparing a soil organic carbon inventory for the United States using soil surveys and site measurements: Why carbon stocks at depth are important

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Abstract

The Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) states that current rates of change in greenhouse gases (GHGs) in the atmosphere have increased substantially from those of the past, and are directly related to increases in air temperature. Strong scientific evidence indicates recent and rapid rate increases of GHGs in the atmosphere can be attributed to human influence. Various IPCC (IPCC, 2007) modeling scenarios project an average 2°C or greater global air temperature rise in the next century, if GHGs emissions are not curtailed. Agricultural practices are responsible for three primary greenhouse gas emissions: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The agricultural sector has significant opportunities for offsetting GHG emissions: reduction or avoidance of emissions and through carbon sequestration. This project focuses on carbon sequestration efforts. Soil surveys are combined with site measurements to provide the fundamental national inventory needed for assessing the amount of carbon for sequestration. Soil organic carbon is present in significant quantities throughout the soil profile, therefore it is not sufficient to assess only the surface when measuring carbon. Our methods compare surface and near-surface depths distributions of carbon at 5, 20, and 100 centimeters for the United States.

Key Words

United States, soil organic carbon, soil survey, SSURGO, pedon, site measurement

Introduction

There is strong scientific evidence that human-induced climate change is occurring and that these changes will continue. The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) states that most observed increases in global average temperatures since the mid-20th century are likely due to observed increases in anthropogenic greenhouse gas concentrations (IPCC, 2007). Scenario modeling indicates that if left unchecked, increasing greenhouse gas concentrations in the atmosphere could result in a global average temperature rise of 2°C or greater (IPCC, 2009) by the end of this century. Increases in global temperatures can result in significant changes in climate including increased duration and intensity of extreme events, impacting food, fiber, and energy security, natural resources and conservation efforts. As the climate changes, those responsible for managing land and water resources will need new information to assist decision-making. This information needs to be accessible nationally, locally and reliably.

Soil organic carbon sequestered by soils is one of the ways in which greenhouse gas emissions can be offset. Baseline data on carbon stocks both at the surface and at depth are critical to understanding how much soil carbon we have and how much is sequestered or could be sequestered both in natural and managed agricultural systems (Follett *et al*., 2009). This paper uses existing soil survey inventories and site-specific information to develop estimates of soil organic carbon stocks at several depths. This inventory demonstrates a first effort to utilize digital detailed soil survey maps with associated estimated attributes and site specific measurements for the United States, whereas earlier efforts focused on limited extents or used generalized soil geographic databases, such as the State Soil Geographic (STATSGO) Database (Bliss *et al*., 1995; Lacelle *et al*., 2000; Bliss *et al*., 2002; Grossman *et al*., 1992).

Methods

Soil organic carbon content values are calculated for three depths (5cm, 20cm and 100cm) using a December 2008 edition of the Soil Survey Geographic (SSURGO) Database for the United States (USDA, 2008). The December 2008 edition of the National SSURGO collection contained 292,179 map units, 842,390 components, and 2,385,878 horizons expressed as 35,470,421 polygon features. Our method is developed as a MS SQL Server 2005 script and adapted to the SSURGO 2.1 data structure (USDA 2008) from the method by Bliss *et al*., 1995 and Lacelle *et al*., 2000. Water bodies and miscellaneous areas are excluded from the calculation.

Our initial calculations did not use soil map units that contain null value records providing a conservative soil organic carbon content and mass estimate. Our later calculations use expert rules and soil characterization pedon soil organic carbon content values to supplement SSURGO horizon records that contained a null condition. For calculation of total mass, the geometry of the SSURGO map unit polygon vector features in an Albers Equal Area Conic Projection were used to determine area in square meters. These area estimates are compared with map unit areas reported in the SSURGO database for consistency. These methods are similar to those used by Bliss *et al*., 2009 and Bliss and Mausetter, 2010.

The authors wish to acknowledge the contributions of National Soil Survey Center staff members, Darrell Kautz, Bob Dobos, Susan Southard, and Sky Wills to the development and review of this methodology.

Results and Discussion

Preliminary results are summarized for individual states and for the nation by land region (Conterminous U.S., Puerto Rico and the U.S. Virgin Islands; Alaska; and Hawaii with selected Pacific Islands) and are still under review at the time of this publication. However, results for the soil organic carbon content and spatial distribution (5cm and 100cm depths) for the state of Iowa, are offered here as an example of the anticipated national result when using the SSURGO database. Table 1 indicates that soil organic carbon stocks within the 100 cm depth can range from 2,570 to 2,582 Tg, with the digital map feature geometry yielding the higher estimate. These values are similar to those computed for the generalized STATSGO database, with a value of 2,743 Tg (Bliss *et al*., 1995). Average 100 cm depth soil organic carbon contents range from 17.6 kg/m^2 when using reported area to 18.1 kg/m^2 when using map feature geometry.

In Table 2, the upper 5 cm soil organic carbon mass is reported as 214 Tg for the state of Iowa. This near surface estimate represents about 8 percent of the soil organic carbon mass present within the upper meter of soil (2,570 Tg) for the same land area. The average soil organic carbon content based on the upper 5cm soil volume is 1.5 kg/m^2. Based on these values, remotely sensed and other near surface (0 to 5cm) assessments of soil organic carbon, could misrepresent the overall soil organic carbon content and mass of the soil profile. Soil profile depths are generally reported to 100 or 150cm depths for the United States.

Table 1. Soil organic carbon (100cm depth) mass estimates for the state of Iowa based on a 12/2008 snapshot of the Soil Survey Geographic Database (SSURGO).

Source Soil Area	Land Area contributing (km^2)	Average SOC Content (kg/m^2)	SOC Mass Tg (1x10^{12} grams)
Albers Geometry	142,562	18.1	2,582
SSURGO Database	145,864	17.6	2,570
Bliss *et al*., 1995 (STATSGO)	143,801	19.1	2,743

Table 2. Comparison of 5cm and 100 cm depth soil organic carbon mass estimates for the state of Iowa based on a 12/2008 snapshot of the Soil Survey Geographic Database (SSURGO). The 5cm depth mass represents about 8% of the 100cm depth mass for soil organic carbon for the state of Iowa.

Depth Range (cm)	Land Area contributing (km^2)	Average SOC Content (kg/m^2)	SOC Mass Tg (1x10^{12} grams)
0 to 5	145,864	1.5	214
0 to 100	145,864	17.6	2,570

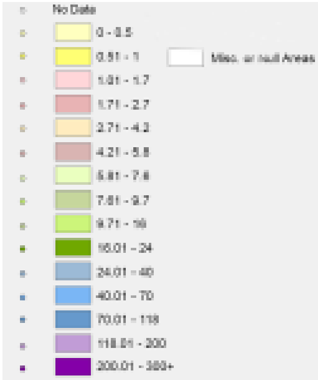

Figure 1. Soil organic carbon content (100cm depth) legend for Figure 2, units are in kg per square meter for both SSURGO grid and pedon site values.

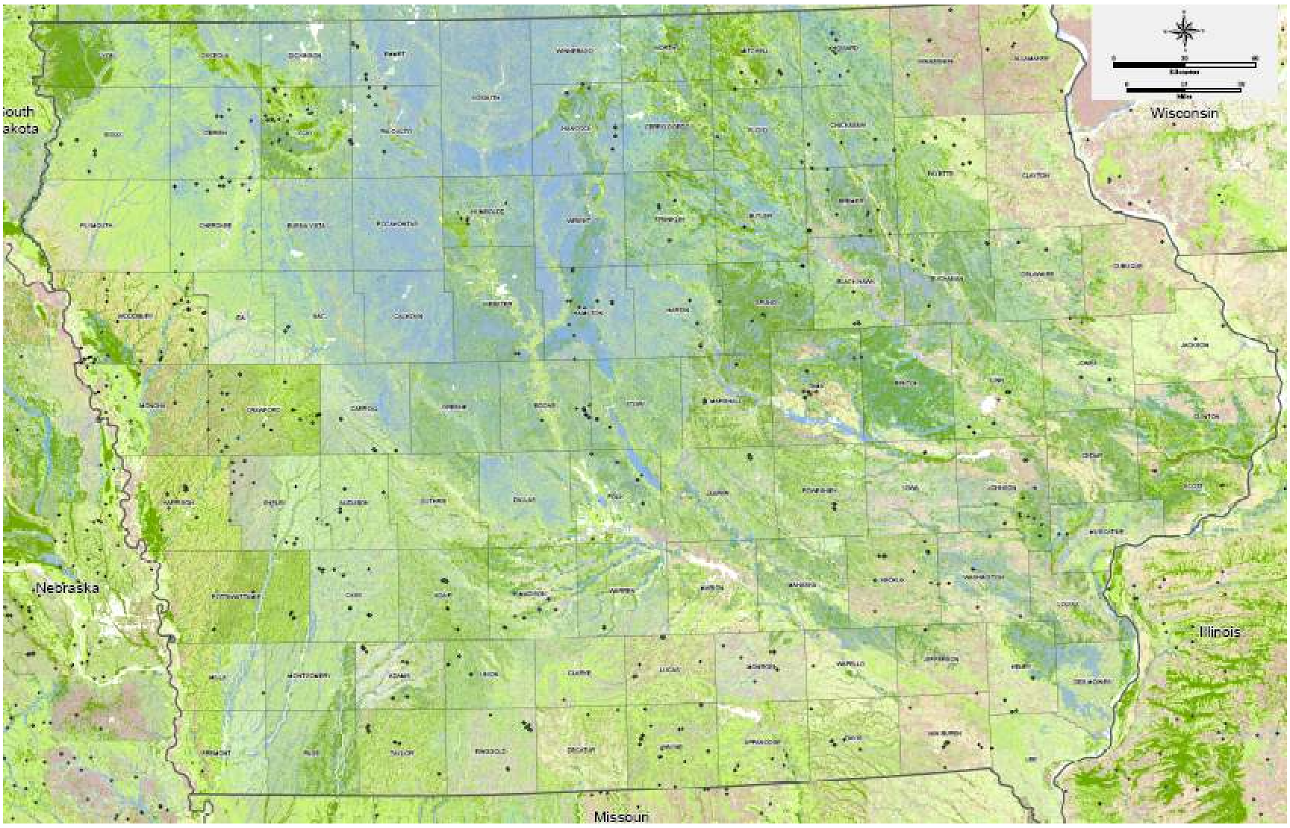

Figure 2. The spatial distribution of soil organic carbon (kg/ m^2) 100 cm depth (SSURGO based) for the State of Iowa with locations of pedon site data.

Figure 1 provides the legend for the 100 cm depth soil organic carbon map of Iowa shown in Figure 2. In Figure 2 the lower value soil organic carbon legend values are shown in pale yellow and tan, moderate values are shown in pale green and blue, and the highest values are shown in pale and deep violet. Water bodies and miscellaneous land areas are shown in white. Locations of pedon sites are also shown in Figure 2.

Conclusion

Soil survey inventories when combined with site measurements can provide the fundamental national inventory needed for assessing baseline soil carbon stocks sequestered. Soil organic carbon is present in significant quantities throughout the soil profile, therefore it is not sufficient to assess only the surface when measuring carbon. Until remotely sensed measurements are calibrated to subsurface information, remotely sensed soil organic carbon inventories should be considered only minimum estimates.

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Soil and environmental education

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Abstract

This project carried out in the APTA Research Unit - Pólo Regional Centro Norte, São Paulo State, Brazil, since 2005 was motivated by the previous environmental program “Environmental Education Program on Water Resource Management” (FEHIDRO project 132/02). Based on the relationship between community, education and research institutions it was financed by a state fund for Water Management (FEHIDRO) and managed by the Turvo and Grande Rivers Drainage Basin Committee (CBHTG). The project offered continuous monitored visits to educators, teachers and students with some practical field activities on soil conservation and water management concepts. At the same time a qualification program focused on educators was carried out to give them enough knowledge and support to work with the technician themes at school with the students before they come on the field monitored visit. The project offered training for 50 educators at a time. The aim of the project was to raise the interest of educators on environmental topics they can experience when visiting the research unit so they could work and develop these concepts with the students A crew of environmental monitors is well prepared and enabled to transfer technician knowledge to students and this way act as multipliers in the local communities. The monitors developed 24 didactic activities based on the science school schedule as well the hydric resource preservation, soil conservation and the drainage basin recognition. The mission of the research unit is to of generate and transfer knowledge in the region and this project has made a great contribution to justify the existence of the Pólo Regional Centro Norte to the community. This project involved 66 municipalities that are part of CBH-TG and 31 linked to the Regional Teaching Directories of São José do Rio Preto, Catanduva, Votuporanga, and José Bonifácio cities of São Paulo state, enabling educational work through drainage basin conceptualization, water resources conservation and soil conservation practices; monitoring learning activities in environmental education program developed in the research unit area and activities.

Key Words

Environmental education, water resources conservation, soil conservation, water source management

Introduction

The environmental subject has always been emphasized in the Pólo Regional Centro Norte, first called *Estação Experimental de Pindorama*. There are monitored visits recorded since the 1940s, with the regional community participation (producers and educational institutions). Four remaining forest fragments with a total area ofA 120 hectares are classified as biological reserves and concentrate an important natural patrimony of the São Paulo State. Actually the Pólo Regional Centro Norte is considered a reference of soil conservationist practice and an educators training center. Working with the CBH-TG and Regional Teaching Offices, the contre has led some projects using fund from the FEHIDRO (Hydric Resources State Foundation) since 2005 where it has transferred knowledge and educator capacity as well as didactic activities within the environmental theme, involving the regional community. The project proposes to develop direct environmental education, using playful and educational activities in monitored visits in the field. In addition, an innovative teaching practice in the region was adopted, using research center facilities to provide natural resources preservation concepts, drainage basin recognition, use and occupation of soil and water concepts through the practical experiments that already happen in the area which are afterwards used in the classroom using interdisciplinary concepts. In addition to these activities it offers to a 50 educator groups a capacity building training which is 96 hours long. The project " *Bacia Hidrográfica: Um Instrumento na Educação* ", FEHIDRO 0039/04, officially started in June 2005 and it has already four years of activity. During this period, 14,500 students visited the project, with 460 educators from 40 cities of the CBH-TG and also other committees. In 2008, the project won the prize of most significant environmental education practice in water resource from the VI Inter Drainage Basin Environmental Education Dialog, event held annually by the DAEE (Department of Water and Energy) in Avaré, SP, Brazil. In 2009 it was again awarded the best poster presented in the VII Interbacias.

Material and methods
The first project work was invitations and folder distribution to 320 elementary schools of Catanduva and São José do Rio Preto Regional cities Education of Offices. They schedule a monitor visit in each 29 cities that belong to these offices. This work includes meetings with the educators, where the monitor present some previous propose of activities already done in the project. This stimulates the monitored visit that can be scheduled in the Unit. In August 2005 the monitored visits started and they ended in December 2005. In this period approximately 190 visits occurred involving 33 students each, totaling 6270 members of public and private schools of 12 cities from the CBH-TG. In the first bimester of 2006 and through 2007 delivered invitations and folders were delivered in the 37 cities of the José Bonifácio and Votuporanga Regional Education Offices In 2008 and 2009, 274 monitored visits and 8200 students with their teachers participated in the Unit activities related to the project. After the monitored visit of the qualification program in the Polo Centro Norte, Pindorama, SP, Brazil, teachers worked on the subject in fields in classrooms, involving the several disciplines of Portuguese, History, Geography, Mathematics, English, Art and Biology. It is important to emphasize that each school's pedagogic coordination has to motivate and coordinate their educators to this interdisciplinary work. Such action requires a constant communication between educators and a prior definition of themes and concepts that will be adopted into the classroom to guide the pedagogic activities related to previous activities experienced in the field by the educators.

Activities with the students
At the end of each visit the environmental monitor asks the respondent for the visit to "return" a report, to evaluate the knowledge and concepts acquired by the students. As a practical result at the end of the work the coordinators of the program have a compilation of work with poetry, drawings, thematic research, and other activities. For the educators, when students experience live situations related to environmental and water studies as a central theme, students are able to cover the subject in all disciplines. So, an environmental education experience in drainage basin recognition supported through induction, perception and conscience is established with 24 didactic and practical activities developed in the field with the students. Students are encouraged to experience the school textbooks programmatic content in a practical way. All activities in the research unit are based on the following themes: preservation of water resources, soil conservation and drainage basin recognition. For each student grade a set of activities was chosen, changeable every six months, according to the following classes lessons: maps observation to recognize water points, forest explanation, seed germination, animal watching in ponds, culture recognition, simulation of the impact of rain on the ground, water in the Globe, Ecologic Kit (ECOKIT) for water analysis, Secchi disk activity, soil profile watching, rational use of irrigation water, recognition of a drainage basin, recognition of a weather station and others.

Capacitating of the educators multipliers
At the same time a student visits, the project offers qualification training to a group of 50 educators, from public and private schools. This activity included the following cities from 2005 to 2007: Ariranha, Catanduva, Cuapiaçu, Itajubi, Novo Horizonte, Pindorama, Santa Adélia, Tabapuã, and Uchoa and in the following years the cities were: Candido Rodrigues, Fernando Prestes, Agulhas, Vista Alegre do Alto, Urupês, Paraiso, Catigua, Cedral, Pirangi, Embauba, Pindorama, and São José do Rio Preto. To promote improvement and extend the environmental thematic knowledge related to water resources, soil conservation and regional reality some seminars were offered as well practical classes by a specialized staff that gave didactic and technical support for the teachers. Afterward they could develop the work with these concepts with a interdisciplinary team and with students. Twelve Educators Trainee meetings occurred in the project from 2005 to 2007 and they were divided into three modules of 32 hours each, totaling 96 hours of activities. Due to the outstanding results presented by the educators, the 2009 phase were done in two monthly meetings, doubling the hours for qualification, changing it from a regular course to a specialization course for multiplier educators. In these meetings the teachers practiced the concepts: the Polo research activities; quality and preservation of water resources, drainage basin characterization constructing models, rationalization of irrigation water use, soil conservation, preservation and riparian forest recovery, among other issues.

Evaluation of the pedagogic process
An important point is that the process of evaluation must be constant within the project development. This can be done internally by members of staff and externally when evaluators that do not belong directly to the institution give their impressions. In this project a work plan is divided into steps and at each step the activities were analyzed and also the progress indicators, verification methods, results, and impacts were verified. An example of applied evaluation was the questionnaires answered by the responsible educators, at the end of the

monitored visit. Another interesting example is the evaluation feedback activities classroom after interdisciplinary classroom practice in the form of reports, writing texts, arts (drawings), mathematics (problems solving) and individual reports of educators about concepts worked during the visit. Those data resulted in a full assessment (criticisms and suggestions) of the work development.

Results and discussions

Due the interest that the project aroused and the number of visits that occurred after the distribution of educational material, we believe that it is necessary to perform some adjustments in the number of schools that should receive this material, because we realized that there is no way to attend all schools as indented previously. This occurred because the project surpassed expectations regarding booked monitored visits by the Unit, attending cities of other committees, a positive point related to dissemination.

We believe that the first objectives were achieved almost totally. This way we highlight that the project activities continued in 2010 which is very important and anticipated by the schools. The dissemination of the obtained results to the regional community was done in December 2007 at the First Environmental Education Meeting of the APTA Pólo Regional Centro Norte in the Rivers Turvo and Grande Bay, which brought together local authorities and an educator audience from all over the region. The event presented its program, educators report about the activities developed in the project and an interdisciplinary exhibition of works developed in classrooms. There were professionals of the Education Secretariat, Agriculture and Supply Secretariat and other institutions. This provided a diffusion of knowledge among participants and opened new regional work perspectives in this area. The activities also promoted the experience exchange among professionals and members of the community, ensuring regional participation and interaction of educators and professionals in the environmental education area. This year we will hold the second environmental education meeting, a conjugate action between Research Institutions, Turvo and Grande Rivers Hydrographic Bay Committee, Schools and Community.

Conclusions

The environmental education work when related to a interdisciplinary concept, and the institutional interchange intensifies the relationship between the educational system, community and research institution, and generate a consistent and interactive partnership. This way this proposal shows that the set of activities, using the drainage basin and soil conservation experiments located in the Apta Pólo Regional Centro Norte, as an education instrument is very interesting. it confirms that the educational process is active, not only by information acquisition, but also by the new meanings added to life through studies, research, and experiments focused on tools and methodologies to incorporate the environmental dimension into different levels and methods of teaching in an interdisciplinary way, supporting the local and regional experiments initiatives. This project opens perspectives to educators and technicians to new practices and possible themes in the education, extension, and research fields, focused on environmental preservation. The lack of information and educational material is perhaps the hardest pointing spreading and consolidating this work.

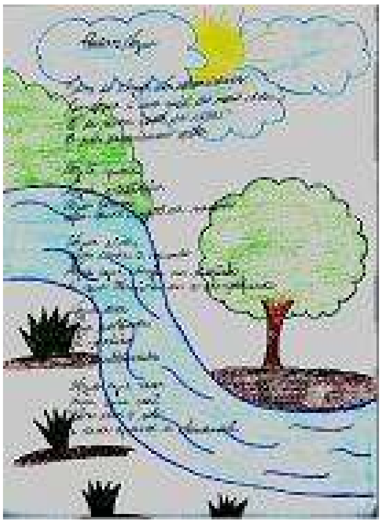

Figure 1. Poetry.

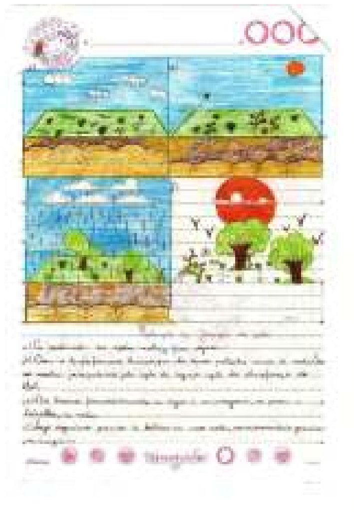

Figure 2. Thematic research.

Figure 3. Mockup.

Figure 4. Explanation forest remainder

Figure 5. Rain simulator.

Figure 6. Qualification on soil.

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Soil moisture enrichment under the desert shrub in the Gurbantungut desert, northwest China

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Abstract
The soil water which is transformed from precipitation is the most important water resource to maintain the growth of vegetation in desert ecosystem. Based on field experiments and observational data, the spatial and temporal distribution pattern and variability of the soil moisture in the root area of desert shrub in the Gurbantunggut Desert are analyzed. The main results are: (1) The 'soil wet island' with higher soil moisture content exists in the root area of desert shrub. The soil moisture enrichment in the dry summer is stronger than wet spring. (2) The soil moisture spatial and temporal variability is strongest in 80-180cm soil layer in the dry July. This layer is also the main root distribution layer of the desert shrub. (3) March and April after the snowmelt is the richest period of the soil water in whole year. This period is also the ephemeral plants season. It is considered that the desert shrub stem flow and high infiltration capacity in the root area are the main reason for the soil moisture enrichment in the desert shrub root area.

Key Words
Gurbantunggut desert, desert shrub, soil moisture, aeolian sandy soil, soil wet island.

Introduction
The Gurbantunggut Desert is located in the hinterland of the Eurasian continent, the central of the Junggar Basin in northwest China, covering an area of 48.8 thousands km^2. The annual precipitation is 70mm to 150 mm. It is the sole desert with a stable snow-covered for 110 to 130 days which depth is commonly between 20 cm to 30 cm in China. The snowmelt water can be storied in the soil profile efficiently and it is difficult to bring surface runoff (Zhou *et al.* 2009; Zhou *et al.* 2009). The groundwater depth is greater than 16m. The soil water which is transformed from precipitation is the most important water source to maintain the growth of vegetation in desert ecosystem. Compared with other deserts which lie in China and the world, the Gurbantunggut Desert have the best of natural vegetation cover, plant diversity and stability (Zhang and Chen 2002), and is also the one among the richest region of the spring ephemeral plants in Central Asia (Mao and Zhang 1994), *Haloxylon ammodendron* is the main species of desert shrub, which sparsely distributed all the desert and the surrounding areas. In this paper, the soil moisture characteristics in root area of desert shrub and its spatial and temporal distribution are discussed. This can help us to identify why the Gurbantunggut Desert has a good natural vegetation cover, plant diversity and stability under the limited precipitation situation.

Materials and methods
Experimental sites
The experimental sites are located in the Beishawo experiment area of National Fukang Desert Ecosystem Station at the southern edge of the Gurbantunggut Desert and the geography coordinate is 44°22′N, 87°55′E. The *Haloxylon ammodendron* is distributed in the top of a semi-fixed exposed sand dune and the inter sand dune which the vegetation and biological soil crust is almost entirely covered. The annual rainfall is 150 mm, which 35.1% of the rainfall water and 81.1% of the rainfall event is less than 5 mm. The average annual temperature is 6.6℃, the maximum is 42.6℃ and minimum is -41.6℃. The desert soil is aeolian sandy soil with 1.57g/cm^3.

Experiment design
(1) Spatial distribution of the soil moisture in desert shrub plot and bare land
For getting the spatial distribution map of the soil water around the desert shrub, the desert shrub *Haloxylon ammodendron* with normal crown shape and growth in the flat topography are selected. The sample plot area is 10m×10m and the desert shrub is in the center. 1m×1m grid cross-point is as the sampling points. For the central 2m×2m range, 0.2m×0.2m grid cross-point is as the sampling points. A total of 246 sampling points with 11 soil

layers for each point from 0 to 300cm profile are chose. The soil layers are 0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm, 100-120cm, 120-140cm, 140-180cm, 180-220cm, 220-260cm, 260-300cm.The soil sampled by soil drill and keep in the aluminum can, and dried the sample for eight hours at 105 by oven. According to the wet and dry weight of the soil sample, the gravimetric soil moisture content can be calculated. We take 2 times in July and October, 2006. As a comparison, the same sampling on the bare land with 5 soil layers from 0 to 1m profile at the same time are also scheduled.

(2) Dynamically monitor of volumetric soil moisture content in root area of desert shrub
Using the TDR-100 with 32 probes which produced by Campbell Ltd. Company, the soil moisture monitor system in the *Haloxylon ammodendron* root area are established. 6 soil profiles are selected and the distance from the main stem of *Haloxylon ammodendron* are 20cm, 50cm, 100cm, 150cm, 200cm and 300cm respectively. There are 9 probes in the 20cm profile from 0 to 300cm depth, 6 probes in the 50cm profile from 0 to 150cm depth, and 3 probes in other four profiles from 0 to 100cm. The volumetric soil moisture content are collected every 30min automatically for all probes.

Results

The intra-annual variability of soil moisture in the root area and bare land
Due to the groundwater depth is very low and no river water into the Gurbantunggut Desert, desert soil water entirely transformed from the rainfall. Figure 1 illustrated the soil moisture variation in a year from August 2007 to July 2008 in root area and bare land, based on the TDR monitoring data. The rainfall of the experimental site is also showed. The curve shows that the spring season, after snow melted, from middle march to middle May is the most abundant soil moisture period in whole year, in general, the volumetric moisture content is up to 15%. This is correspondingly with the spring ephemeral plants growth period. Many studies (Lan and Zhang 2008) demonstrate the ephemeral plants completed their life-cycle rapidly during this period in the Gurbantunggut Desert. The lowest soil moisture throughout the year is from September to the February. The vegetation growing seasons in spring and summer consumed almost all the soil water, and the volumetric moisture content is generally less than 5% in desert region.
Compared with the soil moisture in the bare land and root area, it is found that the soil moisture in bare land is lower than root area of the *Haloxylon ammodendron* except the snowmelt period. In spring, the root area can maintain a long period with high soil moisture content situation. After the May 1, the soil moisture content significantly reduced in bare land. However, in root area, the soil moisture content slowly declined after mid-May. There are better water harvesting and maintaining capacity in the root area compared with the bare land. After the high consumption of the soil water in the spring, the soil moisture content decreased. The actual evapotransration limited by the soil water supply in the summer and autumn. The soil water decrease continuously in addition to after rainfall. In the summer of 2007, the rainfall is obviously high than normal year. This is why the soil moisture maintains a high level in August and September.

The spatial variability of the soil moisture in root area of Haloxylon ammodendron
Using a principal component analysis method, factor analysis method and geostatistical method, the spatial distribution and variability of the soil moisture which is influenced by the vegetation in the Gurbantunggut Desert are studied under different micro space scale. According to the average soil moisture content, the variation coefficient and the conclusions of rotated empirical orthogonal function (REOF), It can be divided into four major layers which are 0-40cm, 40-80cm, 80-180cm and 180-300cm for the whole 0-300cm soil profile. The soil moisture variability is strongest in 80-180cm soil layer during the dry summer. The semi-variogram of soil moisture in each soil layers mainly suit spherical model and exponential model. In July, the variable-range (3.237m) and fractal dimension (1.985) in the third layer are the largest. The variability caused by random factors of the total variability of 0% to 25%. In the central region (plot 2m×2m), the second layer have the largest variable-range (1.000m), the fractal dimension of the third layer is the highest (1.883). There is the similar changing tendency and the variability is lower in October. Comprehensive analyzed the growth conditions of the desert shrub and the water consumption characteristics in different periods, the majority of *Haloxylon ammodendron* and other desert shrub roots distributed in the 60-200cm layer (Xu and Li 2009), which is correspondingly the soil moisture content change rapidly in 80-180cm soil layer. That means the vegetation has a significant impact on soil moisture.

The characteristics of soil moisture enrichment in root area of Haloxylon ammodendron
Measured data shows that the soil moisture content in all soil layers is relatively high in the vicinity of the *Haloxylon ammodendron.* The measurement points which have great contribution for the soil moisture

variability are mostly located near the root area of *Haloxylon ammodendron* by the conclusions of REOF. Figure 2 is vertical variation of average soil moisture content for 3 different plot size around the *Haloxylon ammodendron*. It can be seen the smaller distance from the *Haloxylon ammodendron* roots the higher soil moisture content. Looking the three-dimensional map of soil moisture content, the phenomenon of soil moisture enrichment in the root area of *Haloxylon ammodendron* are better visual displayed (Figure 3), due to its shaped like an island, we can call it "soil wet island" .

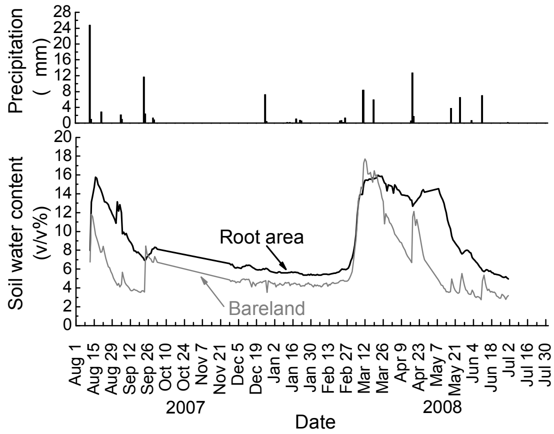


Figure 1. the annual change curve for volumetric soil moisture in the Gurbantunggut desert.

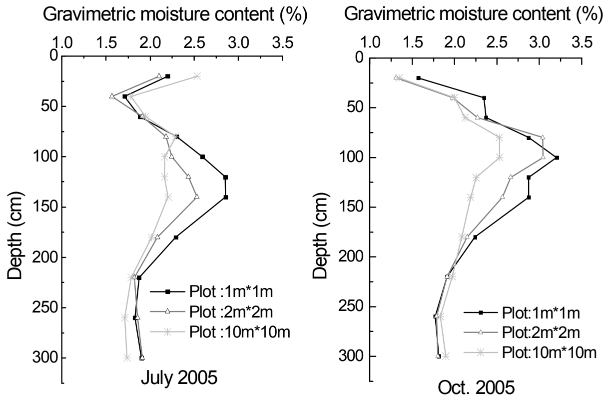
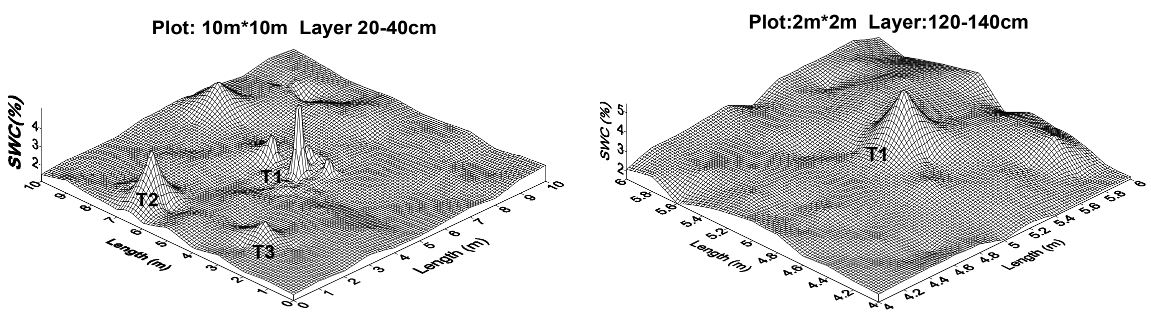


Figure 2. The average moisture content in different layer of soil profile for different root plot size.

The enrichment intensity of soil moisture is different in different seasons. According to the coefficient of variation, the variability of soil water content in July is larger than in October. Otherwise, the increased soil water storage of the 0-300cm soil layer in 0.4m×0.4m plot compared with the 10m×10m plot is more predominance in July. The increased soil water storage is 16% in July and 12.3% in October. In addition, the soil moisture content is almost same between bare land and root area after snow melt completed (Figure 1). It is indicated that the phenomenon of soil moisture enrichment in the root area is not appear in the spring with the most abundant soil water. It is considered that the enrichment of soil moisture in root area is transformed by stem flow infiltration. In the summer, with the strongest evaporation, the soil moisture enrichment in the root area of *Haloxylon ammodendron* has the highest level, but in the spring, with the most abundant soil moisture, the soil moisture enrichment is the least. So, as a result of the interaction between climate and vegetation, *Haloxylon ammodendron* can adapt to the climate change. Before the dry season, the desert shrub can reserved more water in their root area than the surrounding environment. Other parallel experiment results shows that the *Haloxylon ammodendron* is propitious to generating stem flow when an average rainfall more than 0.62mm. In addition, the root area of *Haloxylon ammodendron* have better soil infiltration capacity, the stable infiltration rate declined steeply with the distance increasing from the shrub stem. The radial trend was described by a power-function model. (Tang *et al.* 2009). Changing the crown and stem shape, and the surrounding soil environment, the *Haloxylon ammodendron* can get more water. It is consider that the stem flow and high infiltration capacity of soil in the root area are the main reason of the soil moisture enriched in the root area of *Haloxylon ammodendron.*



SWC - Gravimetric moisture content

T-Haloxylon ammodendron

Figure 3. The moisture content map with different root plot size and soil layer.

Conclusions

(1) In the Gurbantunggut Desert, it is widespread phenomenon that soil moisture enrichment in the root area of *Haloxylon ammodendron*. The enrichment intensity is different in different seasons. In July of the summer with the strongest evaporation force, the soil moisture concentrates at the highest level. In April of the spring with the most abundant soil moisture, the enrichment intensity of the soil moisture is at the lowest level. In October of the autumn, the enrichment degree is between spring and summer. The main reason for rainfall infiltrated and enriched in root area of the *Haloxylon ammodendron* is stem flow and high soil infiltration capacity in the root area.

(2) The spring, from March to May, is the most abundant soil moisture period in the Gurbantunggut Desert. Autumn and winter, from the end of September to the end of February, soil moisture is the minimum throughout the year. Spring and summer, growing season of plants, consumed nearly all the soil moisture transformed by the summer rainfall and the winter snow melt water. From spring to autumn, the soil moisture was continuing downward trend except increase pulse after rainfall. The root area has a better water retention property than the bare soil.

(3)According to the average soil moisture, the variation coefficient and the conclusions of rotated empirical orthogonal function (REOF), the soil moisture has the strongest temporal and spatial variability at 80-180cm layer in dry summer, which is correspondingly the majority of *Haloxylon ammodendron* and other desert shrub roots distributed in the 60-200cm layer. So the vegetation has a significant impact on soil moisture. The semi-variogram of soil moisture in each layers mainly suit spherical model and exponential model.

Acknowledgements

This Research was sponsored by the National Basic Research Program of China (No. 2009CB421301), the National Natural Science Foundation of China (No. 30800144), the National Science and Technology Infrastructure Program of China (No.2007BAC17B02).

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Soil-landscape relationships and soil properties associated with rare plants in the eastern Mojave Desert near Las Vegas, Nevada, USA

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Abstract
The Upper Las Vegas Wash Conservation Transfer Area (ULVWCTA) provides habitat for two of Nevada's special status plant species, *Arctomecon californica* Torrey and Frémont (ARCCAL) and *Eriogonum corymbosum* Bentham var. *nilesii* Reveal (ERICOR). To aid the Bureau of Land Management Las Vegas Field Office in planning, we created a refined soil map focusing on soil-landscape relationships and characterized the soil properties associated with these plants of interest (POIs). We used a Geographic Information System (GIS), original SSURGO polygon lines, high-resolution aerial photography and digital terrain models, and Landsat and ASTER spectral data to refine the soil map. Forty-five soil pedons representing typical soil-landform-vegetation units were described, sampled, and analysed to help develop and document the refined map. We sampled and characterized 658 surface soils (0-8 cm) as part of a vegetation sampling of the ULVWCTA and a POI survey on the basin floor. POIs occur in map units on spring deposits and basin floor sediments that lack a thick gravel veneer: Las Vegas gravely fine sandy loam, 0 -2% slopes; and Badland. These $CaCO_3$-rich soils have petrocalcic horizons or carbonate nodules within 100 cm, and exhibited relict redoximorphic features, indicating they may be exhumed late-Pleistocene paleosols. Pedons in these units had <0.1-5.0% gypsum in the subsoil, but lacked gypsum in surface horizons. The first-to-third quartile ranges of surface pH, estimated clay%, bulk density, and calcified fragments ≥2-mm for POI points were 8.4-8.6, 12-16%, 0.84-1.06 Mg m^{-3}, 96-100%, respectively, and for shrub points were 8.2-8.4, 10-14%, 0.91-1.23 Mg m^{-3}, 0-70%, respectively. These data indicate the relatively narrow distribution of POIs on the basin floor compared to the wide distribution of shrubs on alluvial fans, the basin floor, and in drainage-ways. In the POI survey, surface soil properties differed little between the ARCCAL presence, ERICOR presence, and POI absence points on the basin floor. While it has been suggested that the POIs are gypsophiles, gypsum was rare in all surface soils. Geomorphic surface (e.g., spring deposit, basin floor) and soil map unit are better indicators of POI potential habitat than surface soil chemistry for supporting conservation, restoration, and urban planning efforts.

Key Words
No more than six key word items in order of decreasing relevance

Introduction

The Las Vegas Valley in southern Nevada is one of the fastest growing regions in the USA. The Bureau of Land Management (BLM) has been authorized to dispose of lands consistent with population growth and community land-use plans. The Upper Las Vegas Wash Conservation Transfer Area (ULVWCTA), on the north edge of Las Vegas Valley, provides habitat for two of Nevada's special status plants, *Arctomecon californica* Torrey and Frémont (ARCCAL) and *Eriogonum corymbosum* Bentham var. *nilesii* Reveal (ERICOR). These species are of special interest because they are uncommon and are thought to occur on very specific soil types high in gypsum (e.g., Myers, 1986). Additionally, ARCAL is in a plant family that is noted to have a variety of alkaloids, some of which are likely have medicinal value (Raynie *et al*., 1991).

Our objective was to create a refined soil map focusing on soil-geomorphic relationships and characterize the soils associated with these plants of interest (POIs). Our ultimate goal was to aid the BLM Las Vegas Field Office in conservation-based decision-making, ultimately helping land managers develop for implement plans for urban growth while minimizing impact to critical habitat for these rare, endemic plants.

Methods

Study Area

The Las Vegas Valley is within the Mojave Desert Ecoregion of the Basin and Range physiographic province. This region is characterized by blocks of rock exhibiting high-angle normal faults translating into low angle detachment faults, forming mountain ranges surrounded by extensional basins filled with sediments eroded from the uplifted ranges. In the Upper Las Vegas Wash area, extensional spreading resulted in a northwest to southeast-trending shear zone, known as the Las Vegas Shear Zone (Page *et al*., 2005). Average annual precipitation in North Las Vegas is 12 cm and average annual temperature is 20°C with aridic and thermic soil temperature and moisture regimes, respectively.

During the Pleistocene epoch (about 1.8 mya to 10 kya), atmospheric precipitation was higher and air temperatures were cooler with reduced rates of evapotranspiration. The orographic precipitation produced in the mountains was significantly higher, manifested as groundwater discharge zones on the basin floor, resulting in spring, lake, and marsh deposits. These are rich in Pleistocene megafaunal fossils, including mammoth, camel, horse, bison, and antelope (Page *et al*., 2005).

The physiography of the ULVWCTA is characterized by broad, coalescing, and gently sloping alluvial fans (bajadas) emanating from mountains that descend to the nearly level basin floor. The basin floor is dissected by the Upper Las Vegas Wash. The parent material on alluvial fans is gravelly to sandy alluvium derived from sedimentary rocks, including limestone, dolostone, and chert. The basin floor comprises finer textured and highly calcareous lacustrine sediments and spring deposits, redistributed in some places by fluvial processes, and covered in some places by a veneer of gravelly to sandy alluvium. The parent material in the relatively active portions of the Upper Las Vegas Wash is gravelly to sandy to loamy recent alluvium.

Soil Map

We created a refined soil map for the ULVWCTA based on the most recently available (2007) SSURGO data for the soil surveys of the Las Vegas Valley Area, Nevada, Part of Clark County, NV 788; and the Clark County Area, Nevada, NV 755. We used Landsat 7 ETM+ (path 039 row 035; acquired June 4, 2000) bands 1-5 and 7, and ASTER (acquired September 19, 2004) bands 4-9 to gain understanding of general landscape patterns and help guide initial sampling. We used a Geographic Information System (GIS) and several digital data layers, including the high-resolution aerial photography (10-cm pixel) acquired September 2006 and the topographic contour map derived from the high-resolution digital terrain model to refine the soil map. We adjusted existing and drew new soil map unit polygon lines by interpreting tonal patterns and landform relief visible in high-resolution photography and topography (Figure 1A), distinguishing soil map units with greater spatial detail in the southeastern part of the ULVWCTA where POIs occurred.

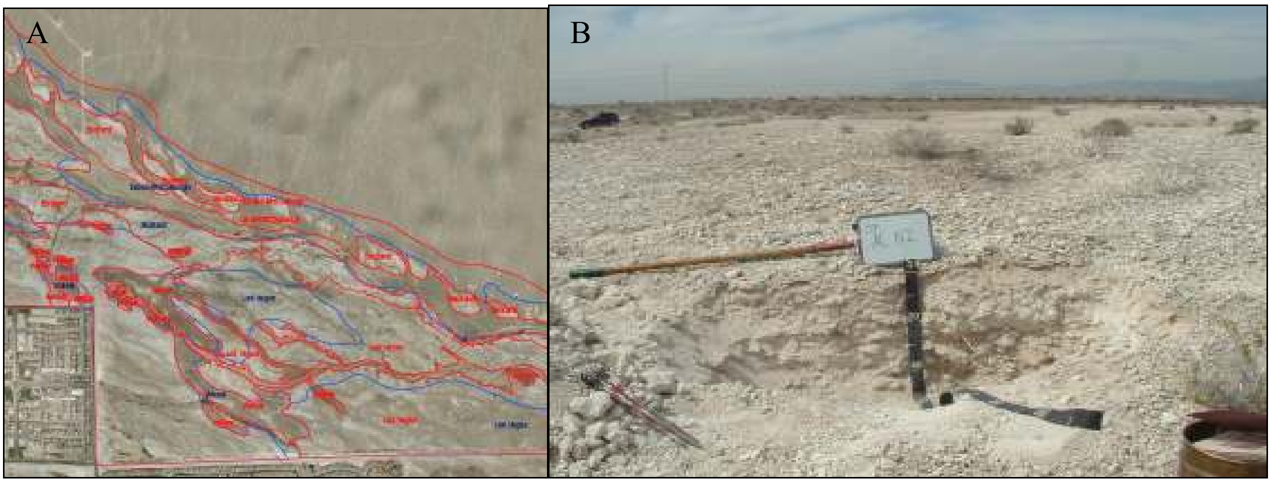

Figure 1. A) Soil map unit polygon lines were refined using high-resolution aerial photography and digital terrain models, after examination of remotely sensed spectral data. B) Typical soil habitat for the POIs.

Forty-five pedons representing typical soil and vegetation units were described, sampled, and analyzed to help develop and document the refined soil map. All pedons were exposed by manual excavation to ≥100-cm depth or to a physical root-restricting layer and described using standard National Cooperative Soil Survey methodology. Pedons were sampled by genetic horizon, and classified to family level using Soil Taxonomy and, where possible, correlated to the closest established soil series. The refined soil map used only existing map units in NV 788 and 755.

Surface soils
We sampled and characterized 658 surface soils (0-8 cm) as part of a general vegetation sampling throughout the study area and a POI survey on the basin floor. At each plot center, the surface soil was sampled under the canopy of the closest shrub (Shrub Presence), and 50-cm away from that shrub in the open (Shrub Absence). If POIs occurred within the 10-m radius plot, the surface soil next to or under the canopy of each plant of interest (ARCCAL or ERICOR Presence) and 50-cm away from that plant in the open (ARCCAL or ERICOR Absence) was also sampled. Surface soil samples from 0-8 cm were collected by pounding steel cylinders of known volume into the soil and excavating the core containing the soil. (If high rock fragment content prohibited us from extracting an intact core, the soil was sampled with a trowel to a depth of 8 cm and "No Data" was recorded for bulk density.) Surface soil samples were collected during the POI survey in the same manner as the vegetation sampling. For presence points we took a soil core sample next to or under the canopy of the plant of interest (ARCCAL or ERICOR Presence). For absence points soil core samples were taken in the open away from the rooting zone of all vegetation.

Laboratory Analysis
Bulk density was determined for soils sampled by intact cores. Soil samples were passed through a 2-mm sieve to separate rock and coarse fragments ≥2-mm. The percentage of calcified fragments in the ≥2-mm fraction was visually estimated. Texture class and clay% were estimated by feel. All subsequent laboratory analysis was performed on the <2-mm fraction: effervescence reaction, soil pH, electrical conductivity (EC) on a 1:2 soil: water suspension. Soil samples with EC >0.50 dS m^{-1} were selected for analysis for gypsum. Gypsum concentration was determined by dissolution in water and precipitation in acetone. Alkaline Earth carbonates (reported at $CaCO_3$) was determined on each genetic horizon for 11 typical pedons via manometric CO_2 evolution with HCl.

Results and Discussion
ARCCAL and ERICOR occur on map units typical of spring deposits and basin floor sediments that lack a thick surface veneer of extremely gravely alluvium, particularly 300-Las Vegas gravely fine sandy loam, 0 to 2 percent slopes (Figure 1B), and 630-Badland. These map units contain soils rich in finely disseminated calcium carbonate that have petrocalcic horizons, many carbonate nodules, and/or intermittent cementation by carbonates within 100 cm of the soil surface. Many of the soils we examined exhibited relict redoximorphic features, indicating they may be exhumed late-Pleistocene paleosols. All pedons sampled in these two map units had small (5%) to trace (<0.1%) amounts of gypsum in the subsoil, but all lacked gypsum in surface horizons. Soil where the POIs did not occur (SHRUB) were deep and gravely (Table1).
Surface soil pH, clay%, EC, bulk density, and percent calcified fragments ≥2-mm were similar between the presence and absence points for ARCCAL, ERICOR, and shrubs in the vegetation sampling (Table 2). However, the pH and percent calcified fragments ≥2-mm were higher and bulk density was lower in ARCCAL and ERICOR presence/absence points compared to shrub presence/absence sites. These data indicate the relatively narrow distribution of ARCCAL and ERICOR on the highly calcareous basin floor compared to the wide range of shrubs on alluvial fans, the basin floor, and drainage ways. There was little difference in the surface soil properties between the ARCCAL and ERICOR presence and absence points in the POI survey. While it had been reported elsewhere that ARCCAL and perhaps ERICOR are gypsophiles, reliably detectable amounts of gypsum were rare in all surface soils.

Conclusions
Previous work on these POIs focused on surface soils and few pedons within a narrow geographic zone (unpublished reports on studies funded by the BLM). Geomorphic surface (e.g., spring deposit, basin floor) and soil map unit may be better indicators of potential habitat to support conservation and restoration efforts than surface soil chemistry at individual sites. Understanding the geography and properties of soils that support these rare, endemic plants will facilitate planning for urban development while minimizing habitat loss and facilitate identification of habitat best suited for restoration efforts.

Table 1. Descriptive statistics of surface soil properties from the vegetation sampling. Only presence data are shown for ARCAL and SHRUB.

	pH	Clay	EC	Gypsum	Bulk Density	Calcified Fragments
		%	dS/m	%	Mg/m^3	%
				ARCCAL Presence		
N	*38*	*38*	*38*	*38*	*38*	*38*
Mean	8.5	15	0.37	0.0	0.96	92
St Dev	0.1	3	0.56	0.0	0.14	20
Median	8.5	15	0.22	0.0	0.95	100
1st Quartile	8.4	13	0.19	0.0	0.89	96
3rd Quartile	8.6	16	0.26	0.0	1.05	100
Minimum	8.1	8	0.15	0.0	0.64	0
Maximum	8.6	27	2.65	0.1	1.27	100
				SHRUB Presence		
N	*225*	*225*	*225*	*225*	*200*	*225*
Mean	8.3	12	0.30	0.0	1.07	27
St Dev	0.2	3	0.23	0.0	0.29	40
Median	8.3	12	0.24	0.0	1.10	0
1st Quartile	8.2	10	0.19	0.0	0.93	0
3rd Quartile	8.4	14	0.33	0.0	1.22	50
Minimum	7.7	5	0.10	0.0	0.44	0
Maximum	8.9	27	2.56	0.0	2.97	100

Table 2. Properties from representative pedons.

Horizon	Depth	pH	Clay	EC	Gypsum	$CaCO_3$
	cm		%	dS/m	%	%
SP-ACN2 (ARCAL and ERICOR present; Las Vegas series)						
A	0-9	8.4	22	0.19	0.00	47
Bkk	9-18	8.6	27	0.23	0.00	67
Bkkm1	18-31	8.5	-	1.29	0.00	67
Bkkm2	31-48	8.3	-	1.68	0.00	69
Bkkm3	48-54	8.5	-	-	-	58
SP-0303 (POI Absent; Weiser series)						
A	0-8	8.4	15	0.22	0.00	40
Bk1	8-17	8.5	14	0.17	0.00	44
Bk2	17-44	8.5	13	0.14	0.00	48
Bkq1	44-71	8.5	12	0.12	0.00	48
Bkq2	71-94	8.6	12	0.12	0.00	52
Bkq3	94-114	8.5	12	0.14	0.00	50

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Soil-vegetation relationships in savanna landscapes of the Serra da Canastra Plateau, Minas Gerais, Brazil

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Abstract
This work aimed to define the relationship between soil distribution and the savanna physiognomies of the "Cerrado" in the Serra da Canastra plateau landscapes. The chemical and physical analysis identified the following soils: Dystric Leptosols, Dystric Cambisols, Dystric Plinthosols, Alumic Gleysols, Rhodic Ferralsols and Xanthic Ferralsols. The endmembers relate to variation between the Photosynthetic Vegetation (PV) and Non Photosynthetic Vegetation (NPV): Hydromorphic Vegetation, Wooded Savanna, Shrub Savanna, Grassland and Rock Outcrops. In the Serra da Canastra Plateau, water-logging in soils, such as Dystric Plinthosols and Alumic Gleysols where Hydromorphic Vegetation develops, were observed. Local well drained soils classified as Rhodic Ferralsols occur on a flat relief where Wooded Savanna is observed. The Dystric Leptosols are on the edge of the plateau, connecting rock outcrops.

Key Words
Soil Classification, Savanna Physiognomies, Cerrado, Serra da Canastra plateau

Introduction
The Brazilian savanna, known as "Cerrado", covers approximately 2,000,000 km² (around 23% of Brazil), with high diversity of species occurring in different types of soils and geologic formation (Eiten 1972; Ribeiro and Walter 1998; Silva *et al*. 2006). Unfortunately, this biome was considered a hotspot of biodiversity due to the high diversity, high species endemism and high threat level caused by the human activities (Myers *et al.* 2000). In the last decades the agriculture expansion intensely exploited this biome and about 40% of the original area has already been converted in unnatural land cover (Sano *et al.* 2001; Ab' Saber 2003).

The diversity of physiognomies has been related to edaphic characteristics, namely the presence of nutrients and the high level of exchanged aluminum in the soil (Haridasan 2000). In addition, the physiognomies have been related to relief, topography variation (Oliveira Filho *et al.* 1989, 1995), water dynamic in the soil (Furley 1996) and geomorphologic aspect (Felfili 1998). The knowledge derived from such studies is essential for the design of conservation strategies.

A sample of this diversity is the Serra da Canastra, located in the Southeast region of Brazil (between 20º00´ and 20º30´ South latitude and 46º15´ W and 47º00´ West longitude). However, there is a lack of detailed spatial information, which is a result of the difficulties and costs involved in mapping the ecological diversity of such heterogeneous region. Remote Sensing and Geographic Information System (GIS) are valuable tools to reach a fast and efficient monitoring phenology and change detection (Yu *et al.* 2003).
This work aimed to define the relationship between soil distribution and the savanna physiognomies of the "Cerrado" in the Serra da Canastra plateau landscapes.

Methods
Soil identification and classification
In this work 250 samples of soil (120 cm depth) were collected in the accessible area of the Serra da Canastra plateau; helicopter flights were taken in order to reach the inaccessible areas and observe the savanna physiognomies and relief changes.

The samples were submitted to chemical and physics analysis to determinate the following parameters: pH in H_2O and in KCl, aluminium (Al), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), hydrogen +aluminium (H+Al), organic matter (OM) and the proportion of sand, clay and silt according Embapa (1997). The Bases and Aluminium saturations, Cation Exchange Capacity (CEC) and ΔpH were obtained from those parameters.

Endmember detection and Spectral Classification

Data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) atmospherically-corrected (Thome *et al*. 1998) were acquired for the spectral classification of the *"*Cerrado*"* physiognomies. The endmembers detection was proposed by Bordman and Kruse (1994) according to the following stages: i) spectral reduction based on the Minimum Noise Fraction (MNF); ii) spatial reduction using Pixel Purity Index (PPI); iii) n-D Visualization and manual identification of endmembers. The Spectral Correlation Mapper (SCM) was applied for the spectral classification based on the endmembers.

Results

According to chemical and physical analysis, five classes of soil were identified in the Serra da Canastra plateau: Ferralsols, Cambisols, Plinthosols, Gleysols and Leptosols (Table 1).

Table 1. Soil classification, chemical and physics analysis. Cation Exchange Capacity (CEC), Organic Matter (OM), Bases Saturation (V) and Aluminium Saturation (M).

Soils	Depth	Sand 2 – 0,2 mm	Sand 0,2 - 0,05 mm	Silt 0,05 – 0,002 mm	Clay <0,002 mm	Silt/Clay	pH		ΔpH	Al	Ca	Mg	K	H+Al	CEC	OM	V	M
							H_2O	KCl		(cmolc dm³)							g.kg^{-1}	
	(cm)	g.kg-1																
FRro	0-30	50	20	150	780	0,19	4,24	4,08	-0,16	0,79	0	1,06	0,11	11,76	12,93	43,4	90,32	403,54
	30-90	40	30	140	790	0,18	4,44	4,47	0,03	0,18	0	0,18	0,03	7,98	8,19	29,3	25,73	460,63
	90-120	40	30	110	820	0,13	4,64	5,12	0,48	0,08	0	0,19	0,01	5,94	6,14	19,4	31,81	290,77
FRxa	0-20	60	390	150	400	0,38	4,78	3,89	-0,89	2,44	0,16	0,23	0,15	6,16	6,70	22,5	80,77	818,44
	20-40	60	370	140	430	0,33	4,92	4,06	-0,86	0,87	0,03	0,21	0,08	4,40	4,72	14,6	68,71	728,27
	40-60	110	350	120	420	0,29	5,38	4,81	-0,57	0,08	0,03	0,32	0,06	1,60	2,01	8,6	202,56	164,47
CMdy	0-20	20	60	140	780	0,18	4,80	4,30	-0,50	0,32	0,26	0,04	0,06	8,08	8,36	28,5	33,97	529,71
	20-40	180	120	180	520	0,35	5,21	5,09	-0,12	0,08	0,24	0,08	0,01	4,76	4,93	18,0	35,03	316,43
LPdy	0-20	180	530	230	60	3,83	4,91	3,96	-0,95	1,31	0,32	0,07	0,08	6,04	6,51	29,0	71,76	737,23
PLdy	0-20	100	50	220	630	0,35	5,26	4,93	-0,33	0,34	0,31	0,14	0,12	8,78	9,35	40,8	61,01	373,42
	20-40	100	50	220	630	0,35	5,55	5,61	0,06	0,05	0,07	0,36	0,06	5,14	5,63	32,6	86,45	93,21
	40-60	160	60	730	50	4,60	5,67	4,12	-1,55	0,00	0,08	0,19	0,03	2,68	2,98	22,3	100,13	0,00
Glau	0-20	80	500	210	210	1,00	4,98	3,97	-1,01	2,54	0,03	0,47	0,09	17,95	17,95	160,4	32,99	810,90
	20-40	120	470	230	180	1,28	5,01	4,16	-0,85	2,13	0,03	0,21	0,04	13,58	13,58	81,1	20,51	884,38

These classes (Table 1) showed relation to four Savanna physiognomies and outcrop rocks, according to endmembers detection (Figure 1). These endmembers express the proportion of chlorophyll and photosynthesis activity of vegetation from Photosynthetically Vegetation (PV) to Non Photosynthetically Vegetation (NPV) and their variations (Figure 1).

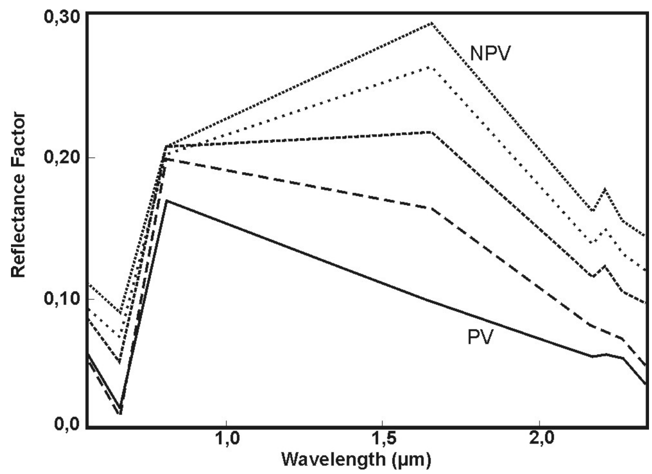

Figure 1. Endmembers detection of the vegetation from ASTER data, where NPV (Non Photosynthetical Vegetation) represents the outcrops and the PV (Photosynthetic Vegetation) represents the Hydromorphic Vegetation; between them, the graphic shows the savanna formations grassland, shrub and wooded savanna, respectively from up to bottom.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

The NPV (Figure 1) represents the outcrops rocks and the PV, the Hydromorphic Vegetation (Gallery Forest and Humid Grassland). Between the NPV and PV, the endmembers detection encompasses the savanna formations encountered in the Serra da Canastra plateau, representing from the dominant herbaceous stratum (Grassland and Shrub Savanna) to the woody dominated stratum (Wooded Savanna).
The Grassland is associated to Dystric Leptosols, Dystric Cambisols, Dystric Plinthosols, Alumic Gleysols.

The Dystric Leptosols are located on the edge of the plateau from wavy to strong-wavy relief, bordering the rock outcrops with sandy texture owing to the presence of quartzite parent material. Dystric Cambisols are enclosed to the rock outcrops and could be associated to Shrub Savanna in a soft-wavy relief (Figure 2).

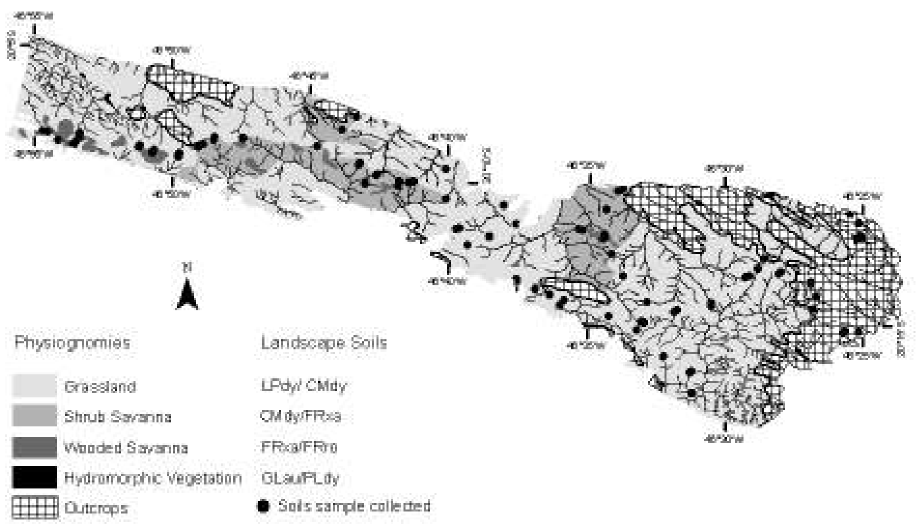

Figure 2. Map of physiognomies related to soil distribution in the Serra da Canastra plateau.

The Serra da Canastra plateau is a synform structure where the origin of soil parent material is heavy clay and likely to be low water permeability. The presence of water-logging soils could be related with this structure control (Valeriano 1995, Liversovskii 1976) which allows the development of Dystric Plinthosols and Alumic Gleysols, in which the occurrence of Hydromorphic Vegetation is observed. Furthermore, the Humid Grassland is associated to Dystric Plinthosols, as well as Gallery Forest to Alumic Gleysols, with high levels of OM and 884,38 g/kg of exchanged aluminum.

On the other hand, the Rhodic Ferralsols are soils of well-drained places on a flat, relief, followed by Xanthic Ferralsols (Macedo 1987). These soils are heavy clay and derived from phyllites, where the occurrence of Wooded Savanna and Shrub Savanna is observed on a flat relief, owing to the soil morphologic structure and depth.

Conclusion

Four physiognomies of “Cerrado” and rock outcrops have been separated by the endmenbers detection and spectral classification. The variation between the Photosynthetic Vegetation (PV) and Non Photosynthetic Vegetation (NPV) corresponded the Hydromorphic Vegetation, Grassland, Shrub Savanna, Wodded Savanna and rock outcrops. In each vegetation environment, the soil classification changed, as well. On the region of rock outcrops, the Dystric Leptosols have been associated with grassland. The water influence is related to Alumic Gleysols and Dystric Plinthosols. These water-logging soils are related to humid grassland and Gallery Forest. Deep weathered soils as Rhodic Ferralsols and Xanthic Ferralsols related to Wooded Savanna and Shrub Savanna were observed. These soils are associated with flat relief and soft-wavy relief. Dystric Cambisols are located in transition areas between grassland and shrub Savanna and between rock outcrops and Shrub Savanna.

Acknowledgements
While conducting this research, the authors were supported by Embrapa Cerrados, where the soils were analysed, by the Ministry of Environment (MMA), which provided financial resources to the expedition. The authors also thank the Serra da Canastra National Park for the hospitality and logistic activities. The lead author thanks CNPq for the Master Degree scholarship, and the Laboratory of Spatial Information System in the University of Brasília.

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.

The ^{15}N signals of different ecosystems in Northeast Brazil

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Abstract
Measuring the ^{15}N abundance in the plants of a site provides information on two of its important ecological aspects: 1) the openness of its N cycle; and 2) the possibility to measure its biological N fixation (BNF). The variation of $\delta^{15}N$ signals in trees of five different ecosystems in Northeast Brazil were measured: 1) a coastal rain forest; 2) a more humid semiarid caatinga; 3) a dry core caatinga; 4) a semideciduous mountain forest within the semiarid region; and 5) one savanna – caatinga transition. The rain forest had a low signal (2.4‰), contrasting with those of the caatinga (6.5 to 10.1‰) and mainly that of the caatinga – cerrado transition (12.6‰). Thus, in these forests, N losses are low, their cycle is relatively close and measuring fixation using the ^{15}N method is not viable. In each of these ecosystems, all the plants of all species had signals varying within a relatively narrow range (±1.6‰), with no significant difference among species, while in the savanna – caatinga transition the differences among species were high (±3.0‰). In the semiarid caatinga and the savanna – caatinga transition the signals are high enough to allow good estimations of N fixation.

Key Words
Semiarid, caatinga, rainforest, N fixation, N-15 abundance.

Introduction
Measuring the ^{15}N abundance in the plants of a site provides information on two of its important ecological aspects: 1) the openness of its N cycle; and 2) the possibility to measure its biological N fixation (BNF). The N inputs from the atmosphere to the large soil pool have $\delta^{15}N$ signals very close to 0; gaseous and diffusion losses are higher for the ^{14}N isotope, thus enriching the soil pool in ^{15}N and shifting its $\delta^{15}N$ signal to positive values (Shearer and Kohl 1986; Handley and Haven 1992; Handley *et al*. 1999). The higher the relative losses, the higher the $\delta\,^{15}N$ signal. If the soil signal is distinctly different from 0 it is possible to separate plants that obtain their N solely from the soil N pool from plants that obtain part of their N through BNF (Shearer and Kohl 1986). Therefore, knowing the ^{15}N abundance in the plants of a site is valuable information. Several places have had their ^{15}N signals measured in the last decades (Handley *et al*. 1999), allowing some generalizations to be made: tropical forests have higher signal values than temperate ones (Martinelli *et al*. 1999) and areas with low mean annual rainfall have higher values than those with abundant rainfall (Austin and Vitousek 1998). Soil type also influences the signals (Roggy *et al*. 1999). However, many exceptions of these general trends have been verified (Swap *et al*. 2004) and there are few systematic studies of variations along soil and climatic gradients within a single region. The Northeast region of Brazil, with its diversity of rainfall and soil conditions, offers a good opportunity for this kind of study. This paper describes the variation of ^{15}N signals in plants of different northeastern places.

Material and methods
The Northeast region of Brazil has an Atlantic coastal line roughly following a north – south direction. Annual rainfall is abundant in the coastal area (>1800 mm) and decreases westward to a semiarid core area, with low and erratic rainfall (about 500 mm). West of this core area, rainfall increases again to 1000 – 1500 mm, more regularly distributed in a 5-6 months rainy season. Interspersed in the semiarid area there are a few mountains (about 1000 m a.s.l.), where rainfall is higher and temperatures are lower. Soils in the coastal zone are deep, low fertility Latosols; in the semiarid zone are shallow, high fertility Luvisols; and in the western portion are similar to those of the coastal zone. The coastal area was covered by tropical rain forest, a few remnants of which still dot the landscape. Half of the semiarid area is covered by a low dense shrub and tree vegetation, locally called caatinga. Very few fragments remain of the semideciduous tall forest that covered the mountain tops in the semi-arid area. The western portion vegetation is a mixture of caatinga and savanna (cerrado) vegetation.
Eight sites were chosen to be sampled, following roughly three parallel east – west transects, along the states of Paraíba, Pernambuco and Alagoas : 1) one in the coastal forest, in Rio Largo municipality , Alagoas; 2) two in the more humid caatinga of the eastern portion, one in Caruaru, Pernambuco and one in Remígio, Paraíba; 3) three in the caatinga core region, in Santa Teresinha, Paraíba, Serra Talhada, Pernambuco and Pão de Açúcar,

Alagoas; 4) one in the mountain forest of Mata Grande, Alagoas; and 5) one in the savanna – caatinga transition at Araripina, Pernambuco. In each site, five to six circular plots of about 20 m radius each and at least 50 m apart were marked in native mature vegetation patches. In each plot, fully expanded healthy leaves of tree species were sampled, excluding species known to obtain part of their N through BNF. The leaves were dried, ground and analyzed for their ^{15}N content, using a mass spectrometer. The results are expressed in $\delta^{15}N$ units, which are calculated as $\delta = (R_{sample}/R_{standard} - 1) \times 1000$, where R_{sample} and $R_{standard}$ are the ratio ^{15}N:^{14}N of the sample and the standard (air), respectively.

Results and discussion

The ecosystems had different $\delta^{15}N$ signals and N concentrations (Table 1). The tropical rain forest of the coastal area had a low signal (2.4‰), contrasting with those of the caatinga (6.5 to 10.1‰) and mainly that of the caatinga – cerrado transition (12.6‰). The signal of the rain forest is one of the lowest found for tropical forests (Martinelli *et al*. 1999). The low value indicates either a continuous significant input of atmospheric N or low losses of N in gaseous or diffusion forms. No estimation of atmospheric N input in these forests have been made but the number of legume trees of fixing species is relatively low, suggesting that the contribution of BNF is also low. Thus, most likely, in these forests N losses are relatively low and they have a close N cycle, as has been shown to occur with the cycling of other nutrients in tropical forests growing in low fertility soils (Stark and Jordan 1978). A consequence of the low $\delta^{15}N$ signals of the non fixing species is that measuring fixation using the ^{15}N method is not viable. The $\delta^{15}N$ signals of the caatinga – cerrado transition is one of the highest already reported for any vegetation in the world (Handley *et al*. 1999). Indeed, it seems to be the highest reported average for a site. It sharply contrasts with values measured in a cerrado of Central Brazil, with $\delta^{15}N$ varying from -2.9 to 6.5 ‰ (Bustamante *et al*. 2004). The two areas have soils of the same order (Latosols), with low pH and low general fertility. Therefore, vegetation and soil types seem to have no direct and definite influence on the ^{15}N – ^{14}N balance. The northeastern area has a lower and more erratic rainfall regime, which could be responsible for higher N losses. The N concentrations in the leaves (22.9 g/kg) were slightly higher than those in the coastal rain forest but not the highest ones.

The core and the more humid caatinga sites had $\delta^{15}N$ values intermediate between the rain forest and the caatinga – cerrado transition. The averages of the two types, although not far apart, were significantly different, that of the drier caatinga being lower (7.2‰) than that of the more humid one (9.8‰). This seems to contradict the hypothesis that drier sites have higher $\delta^{15}N$ values, reinforced by the fact that the caatinga – cerrado transition has even higher rainfall and the highest $\delta^{15}N$ values. Therefore, generalizations based on a single environmental variable should be made with caution. Bearing this in mind, it seems that all three semiarid ecosystems have higher values than the coastal rainforest and, therefore, more open N cycles. This could be explained by their lower plant biomass, seasonal leaf fall and plant dormancy coupled with heavy rains in the beginning of the rainy period. Under these conditions, flushes on soil N mineralization would not be followed by high N uptake and mineral N would be more prone to be lost. The N concentrations in the leaves were also different, being higher in the hunid caatinga (26.0 g/kg) than in the core caatinga (19.1 g/kg). In both caatinga types, the signals of non fixing plants are high enough and those of fixing plants sufficiently distinct to allow good measurements of fixation (Freitas *et al*., 2010).

In each of the previous ecosystems, all the plants of all species had signals varying within a relatively narrow range (±1.6‰), with no significant difference among species. They were all trees, which probably had root systems deep enough to absorb N from a considerable soil volume and to integrate the signals of distinct soil layers. Other plant forms, like herbs, epiphytes and vines, may have different signals at the same sites. This relative consistency of signals simplifies the choice of reference species and the sampling scheme when studying fixation of the different tree legumes in a site. Tropical vegetation has a large diversity, with many species represented by only a few individuals in a large area. Sampling in plots, as we did in this study, do not include all legume species in a site, unless the number of plots are impractically high. Pairing a legume and a reference plant is a simpler scheme but it is unlikely that the same reference species is found close to each legume and this scheme only works if several reference species can be interchangeably used.
In the semideciduous forest vegetation of the mountain site, the ^{15}N signals of the different species were less consistent than in the other sites. Some species had signals (3.2‰) as low as those of the coastal forest while some others had signals (9.7‰) as high as those of the humid caatinga, the average (6.6‰) being closer to that of the core caatinga. This vegetation occurs as high forest islands surrounded by caatinga and may include some caatinga species together with some that are typical of the coastal forest. There was a tendency for the signals to follow this origin but it was mixed with a tendency of border plots to have higher signals than those deep within

the forest fragment and the sampling was not large enough to allow a clear pattern to be seen. The available data indicates that measuring fixation in these sites will be difficult. However, it is recommended to sample other mountain forest before arriving at any conclusion regarding this vegetation type. The N concentrations in the leaves were the highest of all ecosystems (29.5 g/kg). Comparing the $\delta^{15}N$ signals and the N contents of all ecosystems, there seems to be no clear trend.

Table 1. N concentrations and $\delta^{15}N$ signals of leaves from non fixing tree species growing in different ecosystems in Northeast Brazil.

Ecosystem	Number of species	N concentration g/kg	$\delta^{15}N$ (‰)		
			average	minimum	maximum
Coastal rain forest	7	18.9	2.36	1.2	4.0
Humid caatinga	9	26.0	9.78	9.4	11.4
Core caatinga	11	19.1	7.22	5.1	8.3
Semideciduous forest	6	29.5	6.56	3.2	9.7
Caatinga – cerrado transition	7	22.9	12.55	11.4	14.2

Conclusion

The $\delta^{15}N$ signals of all sampled tree species within each ecosystem are relatively consistent, except in the mountain semideciduous forest. The semiarid caatinga and the savanna – caatinga transition signals are higher than that of the coastal forest, indicating the openness of their soil – plant systems. In the semiarid caatinga and the savanna – caatinga transition the signals are high enough to allow good estimations of N fixation.

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The biogeochemistry of drought

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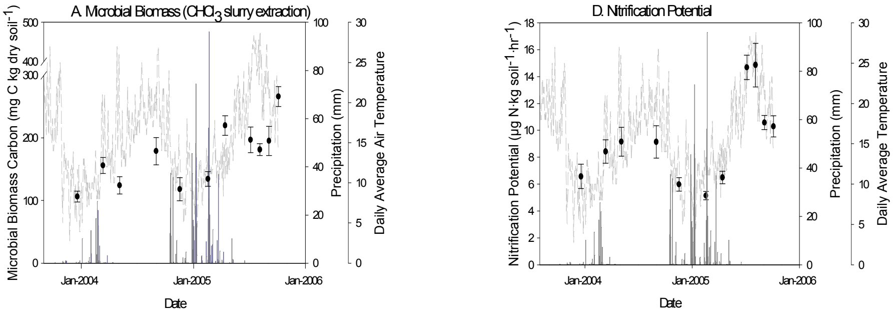
Abstract
At least 1/3 Earth's land experiences regular drought, and climate models suggest this will increase. However, the biological processes occurring during the dry season have only been studied by inference from what happens when the rains return. Important dry soil phenomena remain unexplained, such as the "Birch Effect"--the pulse of respiration on rewetting a dry soil. Important and surprising processes occur during the dry season. For example, during the California summer, in grasslands, soils are dry and plants are dead, but the biomass and population size of several important groups of microorganisms increase, even though their activity is very limited. These changes appear to result from a combination of microbial drought survival physiology and disconnections in soil water films in dry soil and limit substrate diffusion and organismal movement. This talk will discuss the current state of knowledge on microbial drought and dry/wet cycle dynamics.

Key Words
Drought, biogeochemistry, California, grassland

Introduction
The world is a dry place: roughly 1/3 of the terrestrial land surface has arid, semi-arid, or Mediterranean climates that are characterized by long droughts. Climate models also suggest that drought is likely to become more prevalent with climate warming. However, the biogeochemistry of the dry season has usually been studied only implicitly– as "antecedent conditions" that regulate the pulses of biological activity that occur with the early rains or the chemical characteristics of streamflow. However, rarely have the biogeochemical processes that occur during the dry season been studied explicitly to understand what creates the conditions at the beginning of the wet, "growing season."

In California, summer can go 6 months without any rain. During the summer, temperatures can exceed 40° C. It has always been assumed that the "non-growing season" was a period of dormancy and mere survival: native grasses senesce, some native shrubs are partially drought-deciduous, and microbial respiration rates drop to levels of 0.1 to 0.3 g C/m^2/d as soils dry to as low as 5% H_2O (Xu *et al.* 2004).

Surprisingly, however, over the summer, microbial biomass increases (Figure 1a; Parker 2006) as do the potentials for nitrification and denitrification (Figure 1d) and even denitrification potentials more than doubled (Figure 1e). These surprising results beg an explanation. Why, at a time when activities are lowest and conditions appear worst, does it appear that many groups of organisms are doing best?



We hypothesized that these surprising summertime dynamics result from two micro-scale phenomena: a) the physiology of microbial drought survival and b) the hydrological disconnectivity of the "microbial landscape."

As soils dry, microbes experience direct physiological stress, resource limitation from drying, and hydrological disconnections in their environment. On the other hand, microbes may experience reduced predation pressure (Gorres *et al.* 1999) because microbial predators also rely on a connected landscape for foraging.

As water potentials decline, cells must accumulate solutes to reduce their internal water potential to avoid dehydrating and dying. As their primary osmolytes, microorganisms are thought to use simple organics as osmotic agents. In culture, bacteria have been shown to use amino compounds such as proline, glutamine, and glycine betaine (Csonka 1989), while fungi use polyols such as glycerol, erythritol, and mannitol (Witteveen & Visser 1995). Although bacteria are able to accumulate K^+, they only do this after they have exhausted their ability to synthesize or take up preferred compounds (Killham & Firestone 1984).

Accumulating osmolytes however, is energetically expensive. Bacteria can accumulate amino acids to between 7 and 20% of total bacterial C (Killham & Firestone 1984) and between 11 and 30% of bacterial N. In fungi, polyols can account for over 10% of cell mass (Tibbett *et al.* 2002). When extrapolated to an ecosystem scale, the amounts are large. For example, in a grassland soil, osmolyte production to survive a single drought event could conservatively account for 20 g C/m^2, compared to an NPP in the range of 300 - 600 g/cm^2/y. The proportional values for N are larger, 0.75 g N/m^2 or more, equivalent to 10-40% of annual net N mineralization.

If summers are stressful, however, it is thought that the rewetting in the fall could be even more damaging, causing up to 50% mortality (Kieft *et al.* 1987). This is in line with the "Birch Effect," the flush of respiration and mineralization on rewetting a dry soil.

In our research, we have explored the dynamics of dry season biogeochemistry, with specific questions being:
- What are the changes in microbial populations and processes through the dry summer?
- How important are these dynamics in annual C and N cycles?
- What mechanisms are responsible for these changes?
- What happens on rewetting?
- What are the physical and biological mechanisms that regulate drying/rewetting dynamics?

Materials & Methods

Our core research site is at the Sedgwick Reserve in the Santa Ynez Valley of Central California. This is an area with a Mediterranean Climate—cool wet winters and hot dry summers. The soils are Mollisols, typically argixerolls, with pachic argixerolls dominating on valley floors. The vegetation is a mix of open annual grassland, dominated by Mediterranean invasive species dominated by *Bromus diandrus* and *Avena fatua.*

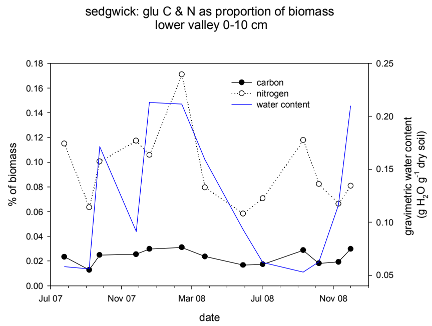
We measured biogeochemical parameters by regular soil sampling throughout several summers. Soil cores were collected to 20 cm depth and returned to the laboratory for analysis. Microbial biomass was measured by a $CHCl_3$ slurry method (Fierer and Schimel 2003). Mineralization potentials were measured by sealing jars and measuring headspace CO_2 accumulation; periodically samples are harvested and analyzed for NH_4^+ and NO_3^-. Nitrification potentials were measured by chlorate slurry (Belser and Mays 1980). Cellular amino acids (osmolytes) were analyzed by HPLC on the $CHCl_3$ extracts. *In situ* fungal growth was measured using minirhizotrons with a microscopic camera and image analysis to evaluate the turnover of individual fungal hyphae. Drying/Rewetting experiments were done in the laboratory with soil samples in canning jars. Soils were allowed to air dry for varying periods of time and then were rapidly rewet.

Results and Discussion

While in situ respiration rates are minimal during the dry summer (data not shown), all indices of microbial biomass and potential are typically highest at the end of the dry season; these include microbial biomass, short-term respiration potential, and nitrification potential. Fungal growth is slow during the summer, averaging < 2 new hyphae /m^2/month. Certain bacterial populations, notably proteobacteria, on the other hand, crash with the onset of summer. Pools of NH_4^+ and extractable organic C (EOC) increase through the summer but crash with the first rains of autumn, the NH_4^+ rapidly being nitrified.

We postulate that NH_4^+ and EOC pools increase because some exo-enzymatic and microbial processes continue in thin water films even in dry soils, but that diffusion is so limited that these materials remain unavailable until soils wet up. What remains unclear is why overall microbial populations increase during the dry summer. We hypothesize that this is because bacteria and fungi that survive the initial dry-down are drought tolerant and so while they maintain low rates of activity and growth, those rates aren't zero. Predation by protozoa and other microfauna, on the other hand, should be even more sensitive to moisture than is microbial growth. Protozoa require water-filled pores to forage. Thus, in a dry soil, death rates may decline even more extremely than do growth rates, allowing populations to increase.

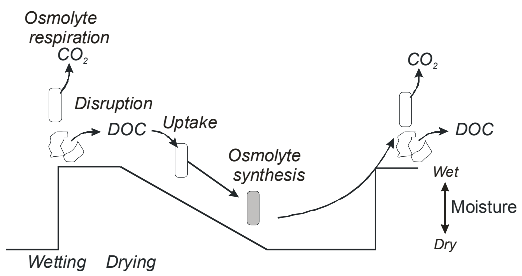
We measured the *in situ* concentrations of cellular amino acids throughout the year, anticipating that concentrations of known amino acid osmolytes (proline and glutamate) would increase over the summer. In fact, proline was never measurable, while glutamate remained a relatively constant proportion of the totat microbial biomass throughout the year, changing little between summer and winter. Thus, amino acids do not appear to be used as osmolytes in this microbial community. We are measuring other possible compounds, but it also remains possible that in a natural soil, where C is a limiting resource, that microbes are forced to rely on inorganic osmolytes or that a large fraction of the community uses glutamate as a constitutive osmolyte.



When dry soils are finally rewet, there is a large flush of respiration. An isotope equilibration experiment, in which ^{14}C-glucose is added to soil and incubated into the microbial biomass prior to dry-down and rewet, indicated that the CO_2 released is dominated by microbial material, although a substantial amount of extractable organic C was also released (Fierer and Schimel 2003). However, in a number of studies, we have found that through multiple dry-wet cycles microbial biomass does not decline, and may actually increase dramatically (Xiang *et al*. 2008). Additionally, through multiple dry-rewet cycles, more CO_2 may be released than was present in the biomass. Thus, while the C released in a single dry-rewet cycle may be dominated by microbial material, over multiple cycles, the C must be released by physical processes, such as aggregate disruption, desorption, and diffusion of otherwise unavailable material to microbes.

Thus, these results raise some conundrums that are difficult to reconcile: the apparent lack of identifiable organic osmolytes, the apparent microbial source for CO_2 respired in the rewetting flush, and the multiple-cycle requirement that it is soil organic matter that fuels successive rewetting pulses. Our current working hypothesis to tie together these different results is that physical and biological processes are closely coupled through multiple dry-rewet cycles.

We hypothesize that during drought, several critical processes occur: 1) microbes accumulate cellular materials that may be respired on rewetting, and 2) desorption, exoenzymes, and microbial turnover produce a pool of easily respired material that accumulates because of diffusion limitation. On rewetting, several processes occur: 1) microbes respire some measure of the cellular material, 2) the accumulated soil material becomes bioavailable and is rapidly metabolized, and 3) mass rewetting redistributes organic materials throughout the soil, overcoming native diffusion limitation, and 4) desorption and aggregate disruption release an additional fraction of otherwise unavailable soil organic matter. The newly-available resources are used by microbes and accumulate as cellular materials as a new drying cycle begins. Thus, while it is physical processes that ultimately drive C from the soil through multiple dry-rewet cycles, these are proximally mediated by microbial processes associated with stress tolerance and the release from stress.



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The Perfect Soil

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Abstract
Soils are products of interacting influences of multiple environmental controls, combining in specific geographical/historical contexts to produce highly improbable (i.e., unlikely to be duplicated) outcomes. Soil systems also have multiple degrees of freedom in responding to environmental influences, thus allowing for many possible soil system states. The "perfect storm" metaphor describing the improbable coincidence of several different factors to produce an unlikely outcome has been applied to geomorphology in the perfect landscape concept. This concept can be further extended to soils. The joint probability of any specific set of global soil-forming factors is low, as the individual probabilities are < 1, and the probability of any set of local, contingent factors is even lower. Thus, the probability of existence of any soil or soil system state is negligibly small: all soils are perfect. Application of the perfect landscape concept to soils is inconsistent with a worldview holding that soils are inevitable outcomes of deterministic laws, such that only one soil is possible for a given set of laws and initial conditions. Rather, a perfect soil/landscape perspective leads toward a worldview that soils are circumstantial, contingent results of deterministic laws operating in specific environmental contexts, such that multiple outcomes are possible.

Key Words
Perfect soil, perfect landscape, contingency, soil geomorphology, soil geography

Introduction
The "perfect storm" has come into wide use as a general metaphor for the improbable covergence or coincidence of several events or factors to produce an unusual outcome since publication of a popular book (Junger, 1997) and subsequent film by that title. Junger (1997) used the term to refer to a rare covergence of synotpic systems to create an extremely unusual meteorological event, and popular use of the metaphor often connotes troublesome of disastrous outcomes. Phillips (2007), however, adapted the metaphor to geomorphological landscapes, arguing that as results of combined, interacting effects of environmental controls that include local historically and geographically contingent factors (as well as universal or general laws or relationships), landscapes are "perfect."

This perspective is perhaps even more readily applied to pedology. The soil-landscape paradigm and the factorial model of soil formation are tracable to the "clorpt" model of Jenny (1941) and the seminal pedological works of Dokuchaev (1883). Soils are seen as the product of the cumulative, interacting influences of climate (*cl*), organisms (*o*), topography or relief (*r*), geology or parent material (*p*), and time, so that the nature of soil (*S*) is a function of these factors: $S = f(cl,o,r,p,t)$ . . . . The "clorpt" factors represent those which are always relevant, and the trailing dots other factors which may be locally important. The geographically-specific, temporally contingent combined impact of multiple controls, and the presence of both global and lcoal controls are explicit in this conceptual framework from its inception. Adaptations and interpretations in recent decades have further recognized the mutual interactions among the soil forming factors and soil themselves, and the fact that any given factor may itself have global and local aspects (see e.g., Phillips, 1989; Johnson and Hole, 1994; Schaetzl and Anderson, 2005).

Few pedologists would claim that any two soils are identical in minute detail. The perfect soil concept goes beyond this axiomatic point to argue that explaining and understanding soils necessitates an integration of local, contingent, historical explanation with deterministic, nomothetic explanation based on universal principles. This paper will argue that, in addition to the multiple environmental controls in geographical and historical context explicit in the factorial model, soils exhibit the other characteristics of perfection in the sense above:

•Multiple degrees of freedom in responses to environmental change.
•Geographical and historical contingency, sometimes exacerbated by dynamical instability.
•Low joint probabilities of any given set of global and/or local controls.

Elements of Perfection

Multiple Degrees of Freedom
Even where soils are influenced by the same set of environmental forcings, multiple degrees of freedom may mean that more than one response is possible (even in the qualitative sense, as opposed to quantitative details). The effects of relative sea level rise on coastal marsh soils, for instance, may trigger responses in mineral accretion, organic accretion, compaction, soil salinity, and surface and fringe erosion, among other things. This in turn leads to a variety of aggregate responses, including landward migration and encroachment on adjacent uplands, drowning or erosion in place, fragmentation, and various combinations of these. Highly localized factors such as surface microtopography, vegetation and litter dynamics, proximity to tidal channels and pools, and topography of adjacent uplands influence the responses, resulting in a variety of idiosyncratic responses, sometimes within a relatively small area (see, e.g., Gardner *et al*., 1992; Phillips, 1992; Reed, 2002).

The response of semiarid soils to overgrazing, for another example, is often dichotomous. Rather than relatively spatially consistent surface changes, divergence occurs into nutrient-rich, vegetated patches with little erosion, and bare, eroded, nutrient poor patches. The local variability of these multiple responses is sometimes exaggerated by dynamical instability and deterministic chaos, such that minor initial variations are increasingly magnified over time (see, e.g., Phillips, 1993; Monger and Bestelmeyer, 2006).

Contingency
Historical contingency in soils is well known in the form of inherited or relic features, and conditionality. The latter occurs when pedogenesis may proceed along two or more different pathways, according to the (non)occurrence of a particular event or phenomenon, such as fires or glaciations. Johnson and Watson-Stegner (1987; see also Schaetzl and Anderson, 2005) give examples of how soils might follow regressive or progressive pedogenetic paths according to whether or not specific events occur. Dynamical instability or chaos may also lead to historical contingency, as persistent effects of small disturbances lead to soil memory (e.g., Phillips and Marion, 2004).

Joint Probabilities
Any given soil is influenced by *n* general state factors *G* reflecting universally or at least very widely applicable influences associated with a particular climate setting, lithology, etc., whenever and wherever it might occur. The soil is also affected by *m* contingent state factors *L* reflecting local particularities. The same state factor might have both *G* and *L* aspects. For instance, limestone parent material will result in some aspects of soil which are common to all limestone-derived soils, and some which are particular to the geochemistry, mineralogy, and structure of, e.g., the Lexington Limestone formation. The probability of occurrence on any given specific soil is a function of the joint probabilities of the *G* and *L* factors:

$$p(S) = \prod^{n} p(G_i) \prod^{m} p(L_j), \quad p(G_i), p(L_j) < 1, \qquad (1)$$

The probability of any given $G_i < 1$, and by their very nature, $p(L_j) << 0$. Thus $p(S) << 1$.

Implications
The basic components of the perfect soil concept are that (1) soils are strongly influenced by laws, principles, and relationships that are independent of location and time, and that apply within their domains everywhere and always (*G* factors); (2) soils are strongly influenced by geographically and historically contingent factors particular to place and time and thus idiosyncratic *(L* factors); and (3) the probability of a specific set of *G* and *L* factors at a given place and time is extremely low; thus soils have elements of uniqueness. While some particular problems in pedology can be solved based entirely on *G*-factors, in general the significance of *L*-factors is irreducible. That is, no amount of data, detail, or model refinement can eliminate the role of geography and history. In fact, eq. (1) indicates that inclusion of more details—adding *G* or *L* variables—must decrease the generality of results.

Divergent Evolution
The importance of local contingencies and the role of dynamical instabilities suggests that in many cases soil landscapes may undergo divergent evolution, whereby the soil cover becomes increasingly differentiated. This is in contrast to classical notions of convergent evolution toward mature, zonal soils characteristic of regional climatic zones.
A simple example is given by soil thickness in the Ouachita Mountains, Arkansas. *G*-factors associated with the "clorpt" factors at a regional scale determine the broad population of soils found in the region, and *G*-factors

associated with topographic relationships, microclimate (i.e., slope aspect), and parent material create some systematic variations in thickness at a more local scale. Nonetheless, major variations in thickness exist within small plots unrelated to topography and lithology. These are instead associated with effects of individual trees, such that vegetation history is an important explanatory variable at the hillslope scale, and self-reinforcing pedologic influences of trees create divergent evolution at the patch scale (Phillips and Marion, 2004; 2005; Phillips *et al*., 2005).

Concluding Remarks

The perfect soil concept leads to a worldview based on the notion that soils are circumstantial and contingent results of general laws and principles operating in specific environmental and historical contexts. A given soil is only one possible outcome of a given set of processes, initial, and boundary conditions, which is partly determined by a particular, irreproducible set of contingencies. However, the pedological outcomes are strongly constrained by the applicable general rules and relationships. While it is often legitimate and useful to conduct soil research based on either global, general *G*-factors or local, idiosyncratic *L*-factors, the ultimate goal of explaining pedogenesis and soil variability requires the integration of these approaches.

A perfect soil worldview stands in contrast to traditional soil science reductionism, and to equilibrium as a normative (rather than a possible or reference) state, though it does attempt to integrate deterministic, nomothetic, process-based pedology with historical and interpretive pedology. The notion of irreducible contingency may be bothersome to some soil scientists—most of us were trained to strive towards explanation based entirely on general principles, with recourse to local particularities only as a last resort. However, soil perfection also implies numerous opportunities and possibilities for unravelling the stories the soil can tell.

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The role of ants in forming biomantles

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Abstract
Soil biomantles, not uncommonly sandy ones – called "sand plains" by some, are notable components of many midlatitude, subtropical, and tropical soilscapes. The role of ants in producing them has historically elicited genetic interest, and some controversy. Interest began in 1881 with the appearance of Darwin's book on soil formation by worm bioturbation, in which ants are mentioned. Subsequent attention to the theme involved leading scientists during the 19th-20th century transition period. Beyond touching on several post-Darwin highlights of ant bioturbation, this study reports on soil bioturbation volumes produced by *Lasius neoniger* and *Tetramorium caespitum* during one activity season in Illinois, USA. Extrapolating these data with time suggests that the two species play key bioturbative roles in producing comparatively thin (~30-60 cm) sandy and or silty biomantles in the upper Mississippi Valley region. Conversely, our recent work in Texas and Louisiana suggests that *Atta texana*, the leaf-cutter (parasol) ant -- a prodigious and legendary soil bioturbator and mound maker -- plays a key and probably dominant role in producing comparatively much thicker (~0.6-2+ m) sandy biomantles found in the southern Mississippi Valley and Texas-Louisiana Gulf Coastal plain.

Key Words
biotransfers, bioturbation, biosorting, turnover, Geoarchaeology, topsoil

Introduction
The year before he died, Darwin (1881) produced a soil process book that focused on animal bioturbations. In the book he showed how bioturbation by animals – mainly worms in his case (though he implicated other animals, including ants), promotes textural differentiation in soils, which leads to the formation of a surface layer of soil, first identified in 1975 as a soil biomantle (Soil Survey Staff 1975, p. 19; cf., Johnson 1989, 1990; Johnson *et al*., 1987, 2005). The biomantle is an approximate equivalent to what in Darwin's time was called 'mould,' or 'vegetable mould,' mainly topsoil. An important sub-theme of Darwin's book was how animal bioturbation leads to burial of surface-deposited objects (artifacts), in his case Roman coins dropped two millenia earlier on the English landscape, and how they gradually sink downward to subsoil levels. Darwin presciently noted "Archaeologists ought to be grateful to worms, as they protect and preserve for an infinitely long period every object, not liable to decay, which is dropped on the surface of the land, by burying it beneath their castings" (p. 308).

Because Darwin's book encouraged new questions, a flood of papers on animal bioturbations began appearing (e.g., Von Ihering, 1882; Gounelle, 1896; Drummond, 1885; 1988; Keilhack, 1899; Seton, 1904). Some authors emphasized the predominant role of ants in producing surface horizons (e.g., Von Ihering, 1882; Drummond,1888; Gounelle, 1996; Branner, 1900, 1910; Passarge, 1904), especially in the lower latitudes where, with bioturbation being year-round and involving more species, biomantles are comparatively thicker – in some cases significantly thicker, than those Darwin described in seasonal and comparatively ant-sparse England. Shaler (1888; 1891), likewise influenced by Darwin, was particularly impressed with the role of ants over other bioturbators in producing surface mantles in various fields of northeastern USA. Similarly, Passarge (1904) concluded that the collective bioturbations of African ants and termites play preeminently co-dominant roles in producing, and constantly replenishing, the latitudinally extensive Kalahari Sands, one of Earth's largest sand plains. Likewise, Branner (1900; 1910) extolled the preeminent mantle-producing roles of ants across Brazil, most notably the supremely bioturbating *Atta* (leaf cutter, parasol, town) ants that, along with termites, produce monster mounds that spread out over time to form thick biomantles (2-8 m) in the New World tropics. Such biomantles also occur in Central America and Cuba, and, while thinner (≤1-2+ m), also occur across much of the southern USA. The large-mound-builder *Atta texana*, however, occurs only west of the Mississippi River, in Louisiana and Texas, and south into Mexico. The thick sandy biomantles of Louisiana and Texas are notable among archaeologists for containing prehistoric artifacts, not infrequently scattered vertically (pocket gophers, *Geomys bursarius*, however, also are firmly bioturbationally implicated here). Two *Atta* mounds that we recently directly measured, with aboveground volumes calculated (not including either the huge belowground nest-chamber volumes, or the distal satellite heaps that erupt far beyond the mound perimeters), were: 24 m diameter x 50 cm high (452 m^2 area, 226 m^3 volume) on Davis Hill, Liberty County TX; and 18 m diameter x 48 cm high (254 m^2 area, 122 m^3 volume) in Natchitoches Parish LA (satellite heaps extend centripetally outward >95 m from the center of this mound!). Notably, mature *Atta* mounds in these southern USA states, and in the Neotropics generally, can have considerably greater areas and volumes than those we measured and calculated (pers. com. John Moser [USFS, LA], and Ulrich Mueller [U. TX, Austin], 2009; cf., Hölldobler and Wilson 2009, p. 457-463).

Soil biomantles of the loess belt of the upper Midwest of North America, as in Illinois, are considerably thinner (0.3-0.6 m) than those in the south, owed partly to erosional removals being greater than bioturbational renewals reflecting intensive agriculture during and since the 1800s. The role of ants and worms in producing such mantles was brought home to us – quite literally, in spring of 1971 soon after moving to a house at 308 Hessel Boulevard, Champaign IL (built in 1948, owned and managed then by University of Illinois Housing). During backyard gardening we discovered a buried, un-grouted 13.8 m^2 brick patio buried under ~ 7-10 cm of grassed sod, where the bricks, apparently, originally had been assembled on the lawn surface by a previous renter. After clearing the bricks of sod and soil, pleased with gaining a new patio – and perplexed why anyone would bury it (with absolutely no thought that it might have been buried naturally and biogenically), we left in early May for 3 months' out-of-state research. Returning in early August we discovered, to our astonishment, that our new patio was undergoing – again, burial, almost entirely by spoil heaps of ants and earthworms, formed above gaps between the ungrouted bricks, and which had spilled over onto them. Essentially the entire patio was being rapidly biogenically buried by ant-worm turnover, which mirrored Darwin's 19th century observations!

Apart from occasionally much larger, though spatially far fewer, harvester ant mounds in the Midwest, most ant contributions to upper Midwestern biomantles appear to be by *Lasius neoniger* (Emori) and *Tetramorium caespitum* (Linnaeus). This statement is based on their innumerable spoil heaps that form, then wash away after rains, and reform again. Such never-ending processes are observed in fields, gardens, forests, patio cracks, sidewalks, and driveways in many Midwest communities, including, of course, Champaign-Urbana. It was observed, for example, during April of 1978 soon after moving to our current residence that our gently sloping (< 1 %) brick walkway, linking the city sidewalk to our front porch, regularly sprouted ant heaps through cracks, particularly after rainstorms, especially during spring and summer months. The walkway was constructed in 1968, inadequately, such that by 1987 about 15 percent had cracked, particularly where cement grout had separated from the bricks. Ant spoil (heaps) regularly appeared above the cracks, and during periods between rainstorms, especially after them, such that spoil became notably conspicuous. The walkway was also observed to be generally lower than the surrounding lawn, and one badly cracked section had broken up, was uneven, and had noticeably sunk. This section, Area A, allowed (and of this writing still allows) more opportunities for ant burrowing and surface heaping, and clearly had (and has) experienced the greatest undermining and sinking.

Study area and methods

The study area is a 12.14 m^2 grouted, but somewhat cracked (~ 15 %) brick walkway at the authors' current residence, 713 South Lynn Street, Champaign, Illinois. The walkway proved useful for a study of ant turnover (i.e., soil biotransferred from depth to the surface), because most cracks were narrow enough (≤ 1 mm) to exclude earthworms and other mesofauna, but large enough to admit the two ant species indicated. The study began informally following a rain shower on 27 April, 1987, when ant spoil was observed to gradually grow over burrows along the cracks, reaching sizeable volumes. On 10 May, 12 days later, that accumulated spoil was collected by cordless vacuum, placed in a labeled dated container, oven dried, weighed, and recorded (displayed as the first column of fig. 1, which covers 2 weeks' time). For the rest of May, spoil was irregularly vacuumed as it accumulated, processed as above, with weights summed weekly (fig. 1).

Beginning 1 June, the procedure was refined, with spoil from each ant heap daily vacuumed, processed as before, but with identifying burrow numbers painted on bricks, matched to numbers on the collection canisters. A scaled map was made on which every brick and ant burrow was located. As new burrows appeared, ants were aspirated from them to match species with their burrow numbers, and their relative turnover volumes (ants identified by W. LaBerge, Illinois Natural History Survey, Urbana). Ant turnover ceased on 9 November with the onset of notably cold temperatures.

Results

A total of 2.08 kg of ant turnover spoil was produced jointly by *L. neoniger* and *T. caespitum* over an estimated 15% of the 12.14 m^2 walkway (the cracked portion) during the 196-day activity period (27 April-9 November) of 1987. During the last 163 days of this period (1 June-9 November), a total of 87 burrow openings were mapped, numbered, and matched with the respective volumes that the 2 species produced. Of the 87 burrows, 80 were by *L. neoniger*, which accounted for 88 percent of soil turnover by weight during this period, and 7 were by *T. caespitum*, accounting for 12 percent. The data were assembled in tables from which Figure 1 is derived. Assuming a topsoil bulk density of $1.3 g/cm^3$, the 2.08 kg of combined ant spoil equates to a soil layer 0.09 cm thick in one year, or 9 cm/100 years, 90 cm/1000 years, 4.5 m/5,000 years, and a 9 m thick biomantle in 10,000 years -- 88 percent of which would be produced by one small, insignificant-appearing ant: *Lasius neoniger*.

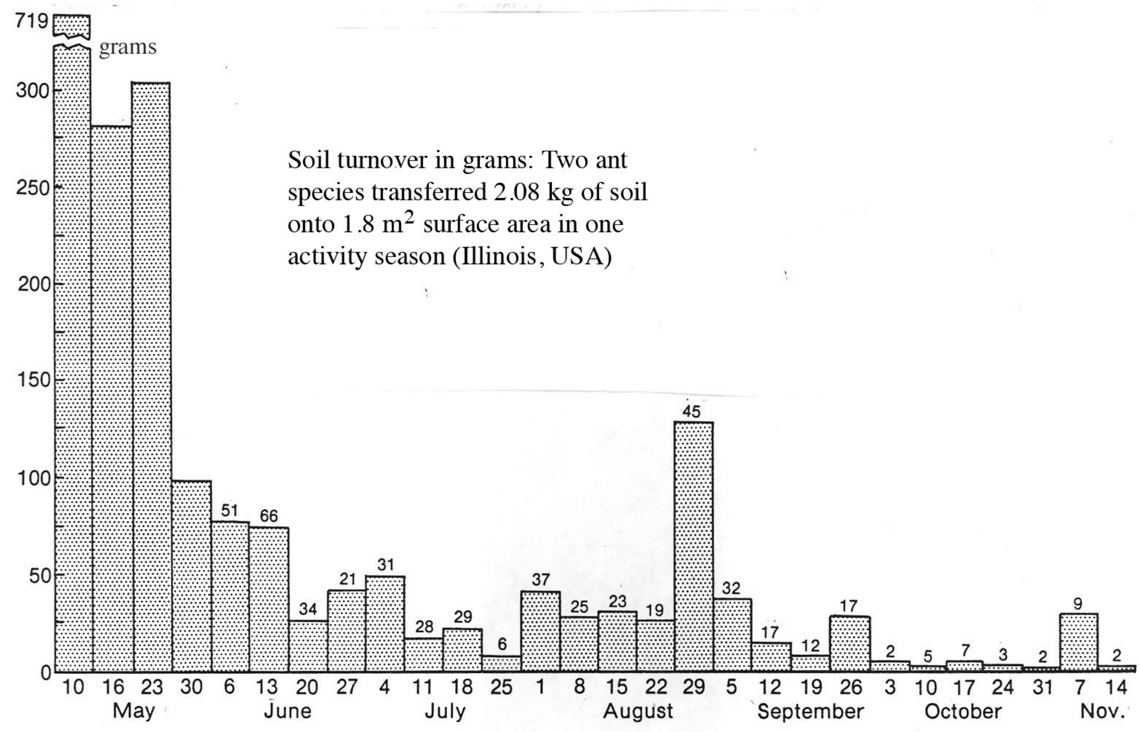

Figure 1. Total turnover of ant surface spoil, 2.08 kg, produced jointly by 2 ants, *L. neoniger* and *T. caespitum*, during a 196-day ant activity season in Illinois, 1987 (April-November). First column (10 May) represents 2 weeks' turnover (27 April-10 May). All other columns, except last, represent weekly summed turnovers. Last column (14 November) represents several days' turnover, to November 9. Numbers at column tops (June-November) represent numbers of ant burrows (both species) that produced turnover during that week.

Caveats

One assumes that the walkway was intact when constructed in 1968. Grout failure, cracking, and subsequent bioturbation began afterward, being underway upon our arrival in 1977, continuing until the study began in 1987. Cracking and breakup processes are still occurring, as of this writing, with about 85% of the walkway still intact (un-cracked). A point we stress is that if the entire walkway had been un-grouted, like the backyard patio at 308 Hessel Boulevard described earlier, then eminently more bioturbation involving the full retinue of invertebrate bioturbators – with consequent far greater walkway undermining, sinking, and expected soil-sediment turnover -- would have occurred. Our numbers, therefore, are preeminently more conservative than had that been the case! Furthermore, an unknown but sizeable quantity of ant spoil was lost to rainstorms before it could be collected, rendering our numbers even more conservative.

Conclusions

Our conclusions and projections for biomantle formation, based on the above data and caveats, are as follows. We estimate, very conservatively, that two common ant species *L. neoniger* and *T. caespitum* alone contribute significantly to Midwestern soil biomantles in amounts of at least 90 cm/1000 years, 4.5 m/5000 years, and 9 m/10,000 years. These estimates assume that such turnover volumes are neither offset by erosional removals, nor augmented by either other soil infaunal turnover, or by eolian infall. Turnover by the two ant species --

increasingly augmented since 1987, in Area A especially, by other mesofauna (earthworms, sphecoid wasps, killer wasps, etc.) -- still occurs on our walkway, every spring, summer, and fall, usually beginning in mid-April, and usually ending in late October-early November. The entire walkway, again especially Area A, is still slowly sinking!

Regarding the comparatively thicker sandy biomantles of Texas and Louisiana, unlike ants in the upper Midwest, *Atta* ant turnover in this more southerly region -- except during occasional winter cold snaps -- is largely year-round, and augmented by many other ant species in these lower latitudes. One must, in fact, take time to travel widely in the region in order to bear witness to and fully appreciate the size and density (in places), and extent of *Atta texana* mounds, and project back to pre-plow times. Only then can one begin to comprehend the key role these ants play, and have played, in the origin of soils and landscapes of this large area. Their volume contributions to the comparatively thicker biomantles in the region, though unquantified, are unquestionably very great -- and very greatly deserving of thesis attention.

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Tree nitrogen fixation in a tropical dry vegetation in Northeast Brazil

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Abstract
Quantification of symbiotic nitrogen fixation is scarce, especially in tropical dry forests. We estimated the amounts of N fixed annually, measuring the proportions of fixed N (%Ndda) and the amounts of N in the leaf biomass of tree legumes in one area of mature caatinga in Northeast Brazil. The %Ndda was calculated comparing ^{15}N concentrations of legume and reference species. Leaf biomass was estimated using allometric equations based on the stem diameters at breast height. *Mimosa tenuiflora*, *Piptadenia stipulacea* and *Anadenanthera colubrina* had large proportions of their N derived from atmospheric N_2. The average sizes of the plants of the fixing species were not very large and the leaf biomasses corresponded to 5 to 10% of the total aboveground biomasses. The N content in the leaves was higher in legumes than in the non legume species. The low plant density and the low leaf biomasses of the fixing species contributed the most to the relatively low amounts of fixed N in the leaves (10.6 to 15.1 kg ha^{-1}). Although low, they are almost twice the amounts estimated for tropical rain forest and a nearby caatinga. Their accumulated inputs, along the years, are crucial to the nutrient balance of the systems.

Key Words
Biological nitrogen fixation, *Mimosa tenuiflora*, *Piptadenia stipulacea*, *Anadenanthera colubrina*, 15-N, caatinga

Introduction
Symbiotic nitrogen fixation is the main process of N entry in natural ecosystems and one of the most significant ecological processes (Cleveland *et al*., 1999). In spite of this importance, data on its quantification is rather scarce, especially in tropical vegetations. A suitable method to determine fixation in trees is the major limitation. The most reliable method, based on ^{15}N abundance, requires a significant difference between signals of legume and reference plants (Boddey *et al*., 200;, Högberg, 1997). This condition is not found in many vegetation systems (Roggy *et al*., 1999; Gehring and Vlek, 2004; Handley *et al*., 1994) but it is found in Brazilian tropical dry forests (caatinga) (Freitas *et al*., 2010), which covers about one million square kilometers in Northeast Brazil (Sampaio, 1995).

Based on the ^{15} N abundance method, the proportions of symbiotically fixed nitrogen to the total plant N have been determined for several tropical dry forest species, under different environmental conditions, in Africa (Sclulze *et al*., 1991; Ndiaye and Ganry, 1997) and America (Shearer *et al*., 1983). To estimate the amounts of N fixed in the plants, these proportions must be coupled with determinations of their amounts of produced N. This poses some difficult in evergreen forests but it is easier on deciduous mature forests, where leaves are renewed every year and compose most of the produced biomass (Machado *et al*., 1997). To estimate the N amounts fixed in a certain area, the quantities of N in all fixing legume trees in this area must be determined. This is also easier in dry forests than in humid ones because they tend to have fewer species. These integrated measurements have seldom been done and only a few papers have been published with estimates of fixation in native tropical vegetation (Roggy *et al*., 1999; Sylla *et al*., 2002). In spite of being easier to obtain, very few published data were found for tropical dry forests. Considering this lack of information, we estimated the amounts of N fixed annually by the leaves of trees and shrubs in one area of caatinga, in Northeast Brazil.

Material and methods
The study was conducted at Fazenda Tamanduá, Santa Teresinha municipality, Paraíba state, Brazil, around the coordinates 07º00’14" latitude South and 37º20’38" longitude West. Average annual rainfall is 600 mm, with large year to year variation and concentrated in three months, usually March to May. Average annual temperature is 26^{o}C, with little seasonal and daily fluctuations. Soils are Neossolos Litólicos (Leptosols), relatively shallow and of low fertility.

Three areas were chosen in the property, all covered by mature caatinga not disturbed for over 50 years In each area, one 50 x 20 m plot was established. Within each plot, all plants with stem diameter equal to or above 2 cm were marked, located, identified and had their stem diameter measured at breast height (DBH). The total and the leaf biomasses of each plant were estimated using allometric equations developed in a previous study (Sampaio and Silva, 2005). Since all legume species are deciduous, the estimated leaf biomasses were considered equal to the annual leaf biomass productions.

Mature, fully developed leaves of the fixing legume species were collected in each plot, together with leaves of a non-fixing legume (*Caesalpinia pyramidalis* Tul.) and leaves of a non-legume species (*Aspidosperma pyrifolium* Mart.), to be used as reference plants. A maximum of five plants of each species were selected in each plot. A random selection of the five sampled plants was made when more than five of a species occurred in one plot. The leaves were oven dried, ground and analyzed for their N and ^{15}N contents (by mass spectrometry).

The proportion of fixed N in each plant was calculated using the formula (Shearer and Kohl, 1986):

$$\%Ndfa = (\delta^{15}N_{(reference)} - \delta^{15}N_{(diazotrophic)}/\ \delta^{15}N_{(reference)} - B) \times 100$$

Where $\delta^{15}N_{(reference)}$ is the mean value of the $\delta^{15}N$ of the reference species of each site, $\delta^{15}{}_{(diazotrophic)}$ is the mean $\delta^{15}N$ value for the plants of each specie identified as diazotrophic and B is the $\delta^{15}N$ value for fixing plants cultivated in the absence of a mineral N supply. Due to the high $\delta^{15}N$ values found for non fixing plants of the caatinga and methodological complications for estimating this value in arboreal species (Högberg, 1997; Boddey *et al*., 2000), the B values in this work were not estimated. However, according to the suggestion by Högberg (1997), the importance of using extreme B values in the %Ndfa calculations was tested. With the absence of data for the studied species, values of 0‰ and -2‰ were used which are commonly found in studies of tree legumes (Schulze *et al*., 1991; Raddad *et al*., 2005; Roggy *et al*., 1999).

The quantity of fixed N in the leaves was estimated multiplying the leaf biomass of each plant in one plot by the average of the proportion of fixation of the species in the plot.

Results and discussion

The % $\delta^{15}N$ in the leaves were significantly different between the fixing (averages from 1.02 to 1.74%) and reference plants (4.48 and 4.70%) (Table 1). All fixing species had large proportions of their N derived from atmospheric N_2. The high capacity of fixation of *Mimosa tenuiflora* (Willd.) Poir. and *Piptadenia stipulacea* (Benth.) Ducke had already been reported, in a nearby site (Freitas *et al*., 2009) but *Anadenanthera colubrina* (Vell.) Brenan plants had shown no fixation in this same nearby site. The proportions of fixation by these species are among the highest already reported for native legume trees in natural vegetation (Schulze *et al*., 1991; Ndiaye and Ganry, 1997; Roggy *et al*., 1999; Sylla *et al*., 2002; Gehring *et al*., 2005).

The average sizes of the plants of the fixing species were not very large (Table 1) but followed the usual pattern of the vegetation in the site, limited by water availability during five to seven months every year. The leaf biomasses corresponded to 5 to 10% of the total aboveground biomasses, within the range already reported for caatinga plants (Silva and Sampaio, 2008).

The N content in the leaves was higher in legumes than in the non legume species (Table 1). The amounts of fixed N in the leaves of *A. colubrina, M. tenuiflora* and *P. stipulacea* reached 12.8 or 18.3 kg ha^{-1}, according to the B value adopted. Among the variables that compose the calculation of fixation of on a plant basis - leaf biomass, N content and proportion of fixed N – only the leaf biomass has low values in relation to other vegetation types. On an area basis, the low plant density and the low leaf biomasses of the fixing species contributed the most to this low amounts of fixed N (Table 1). These amounts are lower than those reported for cultivated legumes (*Mucuna pruriens*), which may reach 87 to 177 kg/ha (Hauser and Nolte, 2001), but almost two times the values estimated by Roggy *et al*. (1999), in a tropical rain forest in Guyana, and by Freitas *et al*. (2009), in a nearby caatinga. Although low, their accumulated inputs, along the years, are crucial to the nutrient balance of the systems.

Table 1, Leaf biomass, leaf N content, N amount, foliarδ^{15}N, nitrogen derived from atmosphere and fixed N in tree species of one area of dry forest (caatinga) in Northeast Brazil.

Species	Leaf biomass	Leaf N content	N amount	δ^{15}N	Ndfa		Fixed N	
					B=0	B=-2	B=0	B=-2
	kg ha^{-1}	%	kg ha^{-1}	‰	%		kg ha^{-1}	
Fixing legumes	738		20.2				15.1	10.6
Anadenanthera colubrina	106	2.72	2.9	1.84	60.4	42.3	1.7	1.2
Mimosa tenuiflora	141	3.24	4.6	1.02	78.0	54.6	3.6	2.5
Piptadenia stipulacea	491	2.70	12.7	1.05	77.5	54.2	9.8	6.9
Non-fixing legumes	1931	2.77	53.5	4.79	0	0	0	0
Other species	2773	2.04	56.7	4.48	0	0	0	0

Conclusion

Mimosa tenuiflora, *Piptadenia stipulacea* and *Anadenanthera colubrina* fixed large proportions of their nitrogen, but their low plant density and their low leaf biomasses contributed to the relatively low amounts of fixed N in the leaves (10.6 to 15.1 kg ha^{-1}). Although low, their accumulated inputs, along the years, are crucial to the nutrient balance of the systems.

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Using a national digital soil database to predict roe deer antler quality in Hungary

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Abstract
Roe deer *Capreolus capreolus* (Linnaeus 1758) play a key role in the life of rural hunting enterprises. There are numerous factors affecting antler quality and they can be examined from different scientific approaches. In the present work we searched for relation among a nationwide digital soil database and a digital nationwide antler database. Researches in this field are concentrating on quantitative measures of soil fertility, on general differences among regional soil conditions. The results were obtained by completing a spatial analysis of the national digital soil map (Agrotopography Map of Hungary, mapping scale of 1:100,000) and roe deer antler weight information maps covering the whole area of Hungary. Based on our results we can state that it was possible to show the effects of soil physical parameters on antler weights. As the result of using the General Linear Model soil physical parameters are explaining 42.5% of the variance of antler weight ($F_{68,1133} = 12.316$, $p < 0.001$, $R^2 = 0.425$).

Key Words
Physical soil parameters, antler weight, *Capreolus capreolus*.

Introduction
The roe deer (*Capreolus capreolus* Linnaeus 1758) is native in Hungary (Sempéré *et al.* 1996). Sexual dimorphism of the roe deer is not as significant, concerning their size (bucks weight 20-30kg vs. does 15-25 kg) (Andersen 1998), as in case of other species. The most significant difference between the 'bucks' and 'does' is that bucks grow antler. In the normal case this antler is upstanding, 15-25cm long, with two or three short tines. Compared to other deer species (Cervidae), compared to their body size their antler is smaller both in ratio and tine number (Lister *et al.* 1998). Antlers are the bony appendages that are cast and fully regenerate every year and grow from two attachment points on the skull called a pedicle (Goss 1983).
The development, size and quality of antlers are influenced by numerous factors. It is not fully known what effects are more important but environmental effects and furthermore feeding condition are considered as among them (Bailey 1984; Goss 1983; Azorit *et al.* 2002) unlike hereditary characteristics (Hartl *et al.* 1995; Harmel 1982). The quality of the food has good relation with the soil, its physical and chemical characteristics.

Bailey (1984) emphasizes the importance of soil among the habitat components effecting the antler development of the roe deer. He summarizes the relationship of soil and game population and calls attention to the influence of soil in game management. Jacobson (1982) found positive connection between the soil element content and deer weight and reproductive capacity. Higher soil fertility resulted bigger antler size (Dunkeson and Murphy 1953; Sweet *et al.* 1952). Researches with *Odocoileus virginiaus* proved that for using antler-based, selective-harvest criteria for reaching maximum antler size it worth considering the soil characteristics of the given area, too (Strickland *et al.* 2001; Strickland and Demarais 2000).

The purpose of the present research is to prove differences in antler characteristics of the roe deer with different soil physical parameters. We fulfill this task with spatial analyses of the digital soil type and antler characteristic map covering the whole area of Hungary.

Methods

Trophy measurement data
In Hungary it is obligatory to show the antler of the shot roe deer bucks to the trophy scoring committee. The data of the evaluated trophies is collected and stored by the National Game Management Database of Hungary (Ministry of Agriculture and Szent István University).

The National Game Management Database of Hungary handles the borderlines (as spatial information) of the game management units (GMUs) and their changes, thus the spatial connection of the trophy data is solved.
To describe a game management unit, we used the average of the left and right beam length (cm) and weight (g) data from the database, using the CIC (International Council for Game and Wildlife Conservation) trophy scoring formula (Whitehead 1981). In the research we used the data of the 4 to 6 years old bucks (n=117426), shot in the period between 1997 and 2006. We used the average of the 10 year data because this sorted out the differences caused by changing weather and wild management (Azorit *et al*. 2002).
1202 game management units cover the area of Hungary. These units have data for beam length (cm) and weight (g).

Soil data

For spatial analyses, we used the only nationwide available digital soil information map (Agropotpography Map), prepared by the Hungarian Academy of Sciences, Research Institute of Soil Science and Agricultural Chemistry (HAS-RISSAC). The database of the map is prepared at the scale of 1:100 000 (Várallyay 1985). In the present study we only used physical data (parent material, soil hydrology and texture).

Spatial analyses

We used ESRI software (ArcInfo, ArcView) for spatial analyses. To analyze soil data on the area of the game management units we used the union command of the software (Zeiler 1997) that computes the geometric intersection of two polygon coverage. Finally we have received the 1202 dataset for the 1202 game management units for statistical analyses. The database contains the proportion of the main soil types and the trophy data for each given game management units.

Statistical analyses

The null hypothesis of the applied statistical analysis is that connection between the two parameter group can be proven. We used cluster analyses to prepared clusters of the independent variable (parent material, texture and soil water management) for the examined cases (in this case for the 1202 game management units) and analyzed the differences of the dependent variables (antlers weight) for these clusters. First the number of the groups was determined with Ward's hierarchical cluster method. The suitable group was manually chosen based on the dendrograms and icicle plots, on the number of elements in the groups and on the distance of the groups. After the determination of the necessary number of groups, K-means (quick) cluster analyses method was chosen to classify the 1202 units into one of the formerly determined clusters. Finally differences between antler weights among the soil determined clusters were examined with analyses of variance (ANOVA). For comparison of the clusters in pairs Duncan's multiple comparison procedure, Duncan post hoc test was used.

Results

The prepared clusters based on parent material

Analyses of parent material resulted in five clusters. Cluster 1 is dominated by loess deposits (84.7%); Cluster 2 dominated is by clay (62.2%); Cluster 3 dominated is by Tertiary and older sediments (73.8); Cluster 4 is influenced by glacial and alluvial sediments (85.4%) and Cluster 5 by limestone and dolomite (33.2%), loess sediment (17.1%) and andezite, basalt and riolite (16.9%).

Analyses of soil texture resulted six clusters. Cluster 1 is dominated by loamy sand (37%), loam (24.9%) and not or partially weathered (84.7%); Cluster 2 by clayey loam (74.5%); Cluster 3 by high (20-40%) organic matter content (56.8%); Cluster 4 by loam (83.4%); Cluster 5 by sand (71.9%) and loamy sand (17%) and Cluster 6 by clay (64%) and clayey loam (20.8%) texture.

Analyses of hydrophysical properties resulted eight clusters. Cluster 1 is dominated by medium infiltration rate and hydraulic conductivity, big water holding and good water retention capacity (69.6%); Cluster 2 is dominated by weak infiltration, very weak hydraulic conductivity, strong water retention capacity, soils with very unfavourable, extreme water regime (64.2%); Cluster 3 is dominated by very big infiltration rate and conductivity, weak water storage and very weak water retention capacity soils (68.1%); Cluster 4 is dominated by big infiltration capacity and conductivity, medium water retention capacity, weak water holding soils

(67.8%); Cluster 5 is dominated by medium infiltration capacity and weak conductivity, big water storage and strong water retention capacity soils (65.5%); Cluster 6 has good infiltration capacity and conductivity, very large water storage capacity and water retention capacity (60.6%); Cluster 7 is represented by shallow soils with extreme water regime (64.4%) and Cluster 8 is characterized by good infiltration and conductivity capacity, good water storage capacity and good water retention capacity soils (75.6%).
The cluster center values in the table representing the percentage of each cluster composing variable in the GMUs.

Analyses of the clusters based on parent materials, soil texture and soil water management properties show significant differences among clusters concerning antler weights (Table 1.).

Table 1. Significant differences among the clusters concerning antler weight

Clusters	Weight	SD	CV (%)	SSD	Weight	SD	CV (%)	SSD	Weight	SD	CV (%)	SSD
	Clusters based on parent material				Clusters based on soil texture				Clusters based on soil water management properties			
Cluster 1	305,1	26.71	8.8	d	282.4	29.69	10.5	a	282.6	28.28	10.0	b
Cluster 2	286,3	27.02	9.4	b	294.3	34.53	11.7	b	308.7	26.09	8.4	e
Cluster 3	262,9	26.62	10.1	a	288.4	29.19	10.1	a b	294.4	28.50	9.7	c d
Cluster 4	296,6	27.31	9.2	c	294.5	29.51	10.0	b	300.2	27.19	9.1	d e
Cluster 5	258,2	24.77	9.6	a	296.4	28.94	9.8	b	291.8	35.01	12.0	b c d
Cluster 6					315.5	22.261	7.1	c	22.3	31.08	10.8	b c
Cluster 7									264.5	24.91	9.4	a
Cluster 8									307.9	25.04	8.1	e

SD = Standard deviation, CV = Coefficient of variation, SSD = sign of significant difference
*(different letters mean significant difference, Duncan post hoc-teszt, $p<0.05$).

Effects of different parent materials on antler weight
Antler weights are the smallest in Cluster 5 (average 258.18g) and in Cluster 3 (average 262,86). These are significantly different from all other clusters. Cluster 2 is characterized by an average 286.31g antler weight is significantly different from other clusters. Cluster 2 has the second highest antler weight values (average 296.63g) and it is significantly different from other clusters. Cluster 1 has the biggest antler weight values (average 305.09 g) and it is significantly different from other clusters.

Effects of different soil textures on antler weight
Antler weights are the smallest in Cluster 1 with the smallest average value (282.38g). Values of Cluster 1 are significantly smaller than the values in other clusters (except Cluster 3). Cluster 3 with an average of 288.43g antler weight is significantly differs only from Cluster 6. Average values of Cluster 2 (294.27g), Cluster 4 (294.47) and Cluster 5 (296.37g) are statistically higher than Cluster 1 and smaller than Cluster 6. The average values of Cluster 6 (315.54g) is significantly higher than all other clusters.

Effects of different soil water regime characteristics on antler weight
Cluster 7 is characterized by the significantly smallest average antler weight (264.47g). Average antler weight in Cluster 1 (282.61g) is significantly different from other clusters. Cluster 6 with an average of 287.83g antler weight is significantly higher than values of Cluster 7, smaller than values of Cluster 4, 8 and 2 but do not differ from Cluster 1,5, and 3. Average antler weight in Cluster 5 (291.82g) is statistically different from Cluster 7, 8, and 2. Average antler weight in Cluster 3 (294.35g) is significantly different from Cluster 7,1,8, and 2. Average antler weight in Cluster 4 (300.21g) is significantly higher than values of Cluster 7,1, and 6. Average antler weights in Cluster 8 (307.92g) and Cluster 2 (308.70g) are statistically higher than all other clusters except Cluster 4.

Conclusion
The biggest antler weights were found on soils formed on loess, glacial or alluvial sediments. Regarding antler weights worst soils for antler weight gain are Tertiary and older sediment, limestone and dolomite.
Analyses of soil texture proved clay and loamy clay to have the best affects on antler weights growing. No differences could be proved among other texture types. Examination of water regime types resulted contradiction. Based on the analyses of water regime we can state that the biggest antler weights were found on soils with big infiltration and conductivity, medium water holding and weak water storage capacity. Water regime type of the clay texture (resulted the biggest antler weights during the analyses of soil texture) resulted

small antler weights. The effects of water regime are greatly affected by the amount of precipitation and its spatial and monthly distribution. From this point of view the results with clayey soils are not contradictory because where there are clayey soils in Hungary, there are the biggest precipitations or those soils are water affected, geographically low laying soils.

It was possible to show the effects of soil physical parameters on antler weights. As the result of using the GLM soil physical parameters are explaining 42.5% of the variance of antler weight ($F_{68,1133}$ = 12.316, p # 0.001, R^2 = 0.425).

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