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Alkaline sodic soils of the Yelarbon area, Australia

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Abstract
Extremely alkaline and extremely sodic soils have been described in the area known as the Yelarbon 'desert', in southern inland Queensland, Australia. The soils are formed on current and relict alluvia at the junction of two rivers, on the eastern edge of the Great Artesian Basin, and have been strongly influenced by the upwelling of $NaHCO_3$ rich ground water. The land degradation observed in the Yelarbon area is in part related to the inherent suite of extreme soil properties, of which sodicity and alkalinity are key factors.

Key Words
Alkalinity, sodicity, salinity, groundwater, degradation, Yelarbon.

Introduction
Lying at the junction of Macintyre Brook and the Dumaresq River, just north of the Queensland-New South Wales border (Figures 1 and 2); the area around Yelarbon consists of landscapes unique in southern Queensland. Because of its barren appearance, the area is referred to as the Yelarbon 'desert'. The slightly to severely degraded landscapes have also been referred to as the Yelarbon 'salinity scald' (Knight *et al*. 1989). Until recently, detailed laboratory analysis existed for only one soil profile in the area of approximately 70 km^2. In the last few years, a number of shallow and deep soil profiles have been described and analysed, and mapping of the land units has been undertaken. The following provides a summary of the findings.

Figure 1. Locality of Yelarbon in Queensland, Australia.

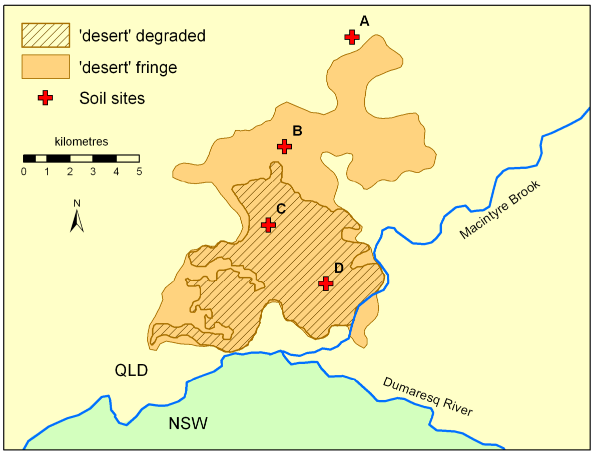

Figure 2. The Yelarbon study area. Results for Sites A, B & C are illustrated in Figures 3 & 5. Site D was described by Thwaites and Macnish (1991).

Soils and geomorphology
The first detailed soil descriptions for the 'desert' area around Yelarbon were provided by Isbell (1957). He drew attention to the very strong alkalinity of the soils and described them as 'solonetz' soils, referring to the presumed leaching of soluble salts through the profile. Thwaites and Macnish (1991) mapped a polygon called 'Desert' and provided analytical data for one soil profile. The profile they described was texture contrast in nature, with a thin silty loam surface over layers of clay. The whole profile was strongly alkaline, (subsoil pH 10-11), but only slightly to moderately saline (maximum EC = 0.81 dS/m at 0.9 m).

The 'desert' is comprised of slightly to severely degraded areas. The claypan-like appearance of much of the area is due to the removal of the surface soil horizons by sheet and wind erosion. In the severely degraded areas there is also rill and gully erosion with gullies reaching depths of up to 3 m. Vegetation is often completely absent in these areas.

Geology mapping (Mond *et al.* 1968) depicts the area as Quaternary cover (sand and soil), overlying Jurassic to Cretaceous sandstones (Kumbarilla Beds), with Quaternary alluvia along the rivers. To the east are outcrops of related sandstone; while to the west are extensive alluvial plains (both current and relict). At the regional scale, Yelarbon lies at the eastern edge of the Great Artesian Basin (GAB), where its sedimentary rocks lap onto metasediments (Texas Beds) of the New England Fold Belt. Various authors (Knight *et al*. 1989; Chen 2003; Biggs *et al*. 2005) have discussed the groundwater hydrology of the area. The general proposition is that over time there has been an upwelling of GAB waters due to a combination of geological faulting and hydraulic pressure. The GAB waters in this region are typically $NaHCO_3$ in nature, with high sodium adsorption ratios (SAR>50).

Vegetation

The Yelarbon 'desert' is mapped as spinifex grassland with scattered low trees and shrubs (DERM 2009), and is home to some locally unique species. It is the most easterly occurrence of the spinifex (*Triodia scariosa*) in southern Queensland, while the tea tree (*Melaleuca densispicata*) is limited to small isolated communities scattered across southern inland Queensland. Bull oak (*Allocasuarina luehmannii*) is also present in the scalded areas. The vegetation of the area is highly disturbed and degraded, with weeds such as mother of millions (*Bryophyllum* spp.) being common. Fensham *et al*. (2007) surveyed the vegetation of the scalded and non-scalded areas and refined the mapping of the 'desert' area (see Figure 2). They found that gradients in floristic patterns were primarily related to local drainage patterns and secondarily to soil pH.

Methods

Recent soil sampling in the area has been opportunistic in nature as part of other projects (e.g. Harms *et al*. 2008), and therefore site selection was not conducted in the manner normally used for a systematic soil survey in Queensland. Soil profiles were sampled with 50mm hydraulic driven soil cores (approx. 1.8 m length) or 43mm split tube percussion cores (Geoprobe) to maximum depths of 6 m. Profiles were described using methods outlined in McDonald *et al*. (1990), and samples (generally from 10 cm sections at 30 cm intervals) analysed at Department of Environment and Resource Management laboratories using standard methods outlined in Rayment and Higginson (1992). Soils were classified using the Australian Soil Classification of Isbell (1996). Mapping of land units has been undertaken using 1:40 000 aerial photographs and various types of satellite imagery (Landsat TM, SPOT).

Results

21 sites were described in the area, covering three main landscape types – degraded ('desert'), slightly degraded ('desert' fringe) and the sloping area outside the 'desert' in a transect running approximately north-south (see Figure 2). Selected soil properties for three sites (A, B and C) representing the three landscape types are illustrated in Figures 3 and 5. The soils outside the 'desert' (on the slope adjacent to the alluvial plain) are very different to the soils of the 'desert', but are typical of soil types in the surrounding area. They are pH inversion Vertosols, and have been included in this paper for the purposes of comparison. The following discussion relates to the 'desert' and 'desert' fringe soils of the alluvial plain.

Profile morphology and classification

Within the 'desert', soils are generally classified as Effervescent or Hypernatric Grey Sodosols. Stratified profiles (arising from alluvial deposition) are common. Silty to sandy textures are typical in the surface soil horizons, which are generally very thin and in many places have been removed completely. The subsoils are light to medium clay with a coarse prismatic to columnar structure. Textures may change to sandy loam in the deep subsoil or buried horizons. The soils of the 'desert' fringe are similar to the 'desert' soils, but are typically not as eroded and have higher clay content. Some are classified as Grey or Black Dermosols that are either Supercalcic or Hypercalcic. Fine-earth effervescence is common throughout the profiles, with the exception of A1 horizons (if they are present). Free carbonate (as soft and hard segregations) is generally prolific, and large patches (>10 cm) are often encountered.

Alkalinity

Soil profiles of the 'desert' are strongly to extremely alkaline throughout, with pH ranging from 9 to 9.5 at the surface to 10.5 or more at depths of more than about 20 cm. In the 'desert' fringe area, alkalinity reaches very high to extreme levels at approximately 80 cm; although the surface soil may be neutral or slightly acid (Figure 3a). The very high levels of alkalinity observed here are rare in Queensland and comparable to the most alkaline 'problem' soils reported for other parts of Australia (e.g. Adcock *et al*. 2007). Deeper sampling of the regolith material in the 'desert' fringe area showed that the very high pH levels continue to at least 6 m (see Figure 4).

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Salinity

Salinity levels (as measured by electrical conductivity, EC) in the 'desert' and 'desert' fringe are variable but typically moderate, with maximum values generally attained in the upper B horizons (Figure 3b). In some soil profiles there is a strong correlation between EC and soil chloride (Cl) concentration indicating that the salinity is due largely to chloride salts. However, in other profiles (including those from the more degraded areas) chloride salts are a less significant contributor to conductivity, almost certainly indicating the presence of soluble carbonate salts. Sampling of the deeper regolith materials in the 'desert' fringe area showed no appreciable build up of salinity with depth.

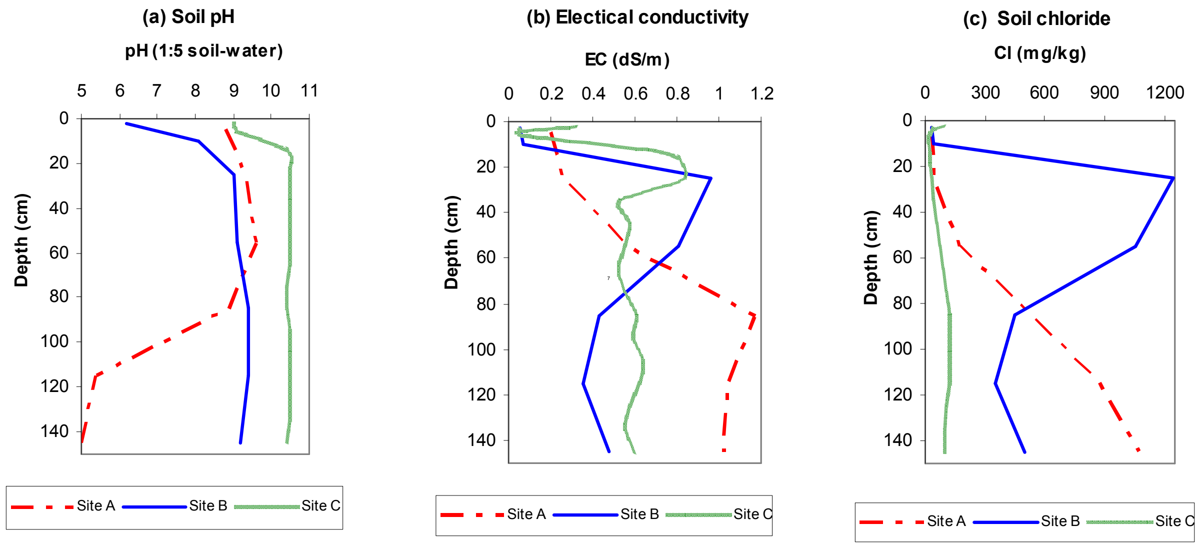

Figure 3. Soil profile properties (pH, EC and Cl) for three sites at Yelarbon. Site A is located outside the 'desert' area, Site B is in the 'desert' fringe, Site C is in the 'desert' degraded area; see Figure 2 for locations.

Cations and sodicity

The clay subsoils generally have a cation exchange capacity of between 20 and 30 meq/100g, and are almost fully base saturated. The exchange complex is dominated by sodium, with ESPs of >80, and in some cases almost 100% (Figure 5a). This obviously implies deficiencies of other cations, especially calcium (Ca) and magnesium (Mg), which are occasionally below detection limits. This is the case for both the 'desert' and 'desert' fringe soils, except that on the fringe, extreme ESPs are generally encountered slightly deeper, at about 50 cm (Figure 5a). Although these soils contain Ca^{2+} in the form of $CaCO_3$, the Ca remains 'unavailable' because at high pH, $CaCO_3$ is insoluble and tends to precipitate out of the soil.

Nutrient deficiencies and toxicities

Surface fertility is very low with deficiencies in all major nutrients. At high pH, deficiencies of phosphorus (P) are expected, as well as for the trace elements (Fe, Zn, Cu and Mn). On the other hand, boron (B) and molybdenum (Mo) are more soluble at high pH, and may be present in toxic amounts. In addition, if the pH is >10, sodium carbonate will almost certainly be present as a precipitate, and this is very toxic even at concentrations of 0.05-0.1% (Scholz and Moore 1998).

Soil physical properties

The clay content of the 'desert' and 'desert' fringe soils fluctuates with depth, which is a function of alluvial deposition. Despite field textures of medium clay being recorded, actual clay content is usually less than 30% (Figure 5b). Silt content is relatively high (>30%) in some profiles. Very high dispersion (R1) ratios (>0.96) were obtained for some soils. This is expected, given the extreme sodicity, and indicates that the clay minerals are almost completely dispersed. Bulk densities were measured for one soil profile on the 'desert' fringe and found to be approximately 1.6 g/cm^3 at 20 cm, increasing to >1.8 g/cm^3 below 1m soil depth. This indicates an excessively compact soil, with a restricted capacity for water movement, and hence root growth. Water infiltration also appears to be greatly restricted – as illustrated by the surface ponding that occurs even after light falls of rain. As a result, leaching fractions are likely to be low.

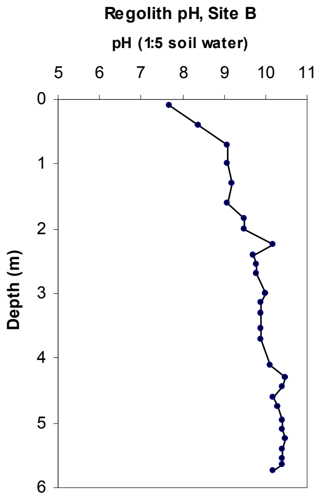

Figure 4. pH of the regolith profile to 6m depth at Site B ('desert' fringe).

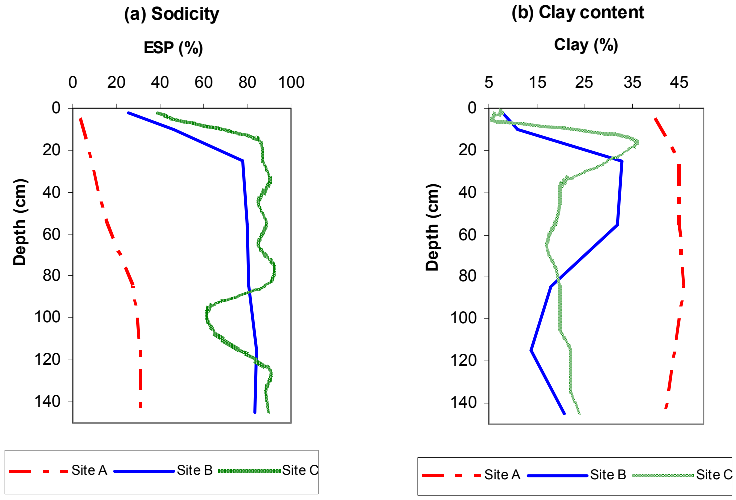

Figure 5. Soil profile properties (sodicity and clay content) for three sites at Yelarbon. Site A is located outside the 'desert' area, Site B is in the 'desert' fringe, Site C is in the 'desert' degraded area; refer to Figure 2.

Conclusion

The Yelarbon 'desert' is an area of extremely alkaline, extremely sodic soils whose nature has been strongly influenced by upwelling of GAB waters rich in $NaHCO_3$. While stratification exists in the current and relict alluvium of the Macintyre Brook and the Dumaresq River, alkalisation of soils is widespread within the degraded and fringing areas. The chemistry of these soils is unique in southern Queensland, and has been a key factor in the land degradation of the area.

References

Adcock D, McNeill AM, McDonald GK, Armstrong RD (2007) Alkaline subsoil constraints in south-eastern Australia. *Australian Journal of Experimental Agriculture* **47**, 1245-1261.

Biggs AJW, Power RE, Silburn DM, Owens JS, Burton DWG, Hebbard CL (2005) Salinity Audit - Border Rivers and Moonie Catchments, Queensland Murray-Darling Basin. Queensland Department of Natural Resources and Mines QNRM05462.

Chen D (2003) Dumaresq River groundwater model: Border Rivers. Model development, calibration and use. Water Assessment Group, Department of Natural Resources and Mines, Queensland. Brisbane.

DERM (2009) Regional ecosystem mapping V5.0. Queensland Herbarium, Department of Environment and Resource Management.

Fensham RJ, Silcock J, Biggs AJW (2007) Vegetation-soil relations in a highly sodic landscape, Yelarbon, southern Queensland. *Cunninghamia* **10**(2), 273-284.

Harms BP, Hughes KE, Payne JE (2008) Detailed soil reference sites for improved land management – report for the Queensland Murray Darling Committee. Department of Natural Resources and Water.

Isbell RF (1957) 'The soils of the Inglewood-Talwood-Tara-Glenmorgan region, Queensland.' Bureau of Investigation, Queensland.

Isbell RF (1996) 'The Australian soil classification.' (CSIRO Publishing: Collingwood).

Knight MJ, Saunders BJ, Williams RM, Hillier J (1989) Geologically induced salinity at Yelarbon, Border Rivers area, New South Wales, Queensland. *Journal of Australian Geology and Geophysics* **11**, 355-361.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) 'Australian Soil and Land Survey Field Handbook.' (Inkata Press: Melbourne).

Rayment GE, Higginson FR (1992) 'Australian laboratory handbook of soil and water chemical methods.' (Inkata Press: Melbourne, Australia).

Thwaites RN, Macnish SE (1991) Land management manual, Waggamba Shire. Queensland Department of Primary Industries, Brisbane. QE90014.

Scholz G, Moore G (1998) Soil alkalinity and soil sodicity. In 'Soil Guide: a handbook for understanding and managing agricultural soils.' (Ed G Moore) pp. 243-250. No. 4343, (Agriculture WA Bulletin)

Assessment of saturated hydraulic conductivity in coastal floodplain acid sulfate soils

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Key Words
Hydraulic conductivity, acid sulfate soil, macropores, floodplain.

Introduction

Coastal acid sulphate soils (CASS) typically contain large stores of soluble acidity and trace metals which can be mobilised and transported to adjacent waterways, causing considerable environmental degradation (Minh *et al*. 1997; Johnston *et al*. 2004a). The main transport pathway of acidic products to drainage systems for soils with macropores in the sulphuric horizon is by saturate flow of groundwater (Bouma *et al.* 1993; Eriksson, 1993; Minh *et al*. 2002; Johnston *et al.* 2004a). Consequently the saturated hydraulic conductivity (K_{sat}) of the sulfuric horizon is an important soil property to evaluate when developing remediation strategies to reduce acid export. CASS typically have distinct soil horizons with large vertical gradients in their physical and geochemical properties due to their unique pedogenesis. Pedogenesis after drainage follows a sequential progression involving physical 'ripening', whereby the drying of gel-like sulfidic material leads to partially irreversible clay shrinkage and increasing development of cracks, plus the production of severe acidity via oxidation of sulfides (Dent 1986). A typical acid sulfate soil profile consists of an oxidised, acidic, sulfuric horizon overlying unoxidised, sulfidic material, with a transition zone of variable thickness in-between. The overlying sulfuric horizon generally has far greater structure development than the underlying sulfidic horizon. This difference in physical structure can result in radically contrasting hydraulic properties between sulfuric and sulfidic soil horizons, whereby the K_{sat} decreases markedly with depth (Thi Minh Hue Le *et al*. 2008). Knowledge of the range and variability of Ksat within sulfuric horizons CASS floodplains and between floodplain catchments is currently very limited. This study explores the variability of sulfuric horizon K_{sat} on seven major CASS floodplains in northern NSW Australia (Figure 1) using a single methodology to provide a statistically robust assessment of the likely range and variability of Ksat occurring within these soils. A major component of the study was the informal, hands-on training opportunity for local council floodplain officers to conduct the simple and semi-quantitative K_{sat} pit test and to analyse and interpret data.

Materials and methods

The methodology for assessing K_{sat} of sulfuric horizons was an *in situ* recovery technique, (Johnston and Slavich 2003; Bower H 1989; Bower *et al.* 1983), conducted in ~0.4–0.65 m deep pits. Duplicate recovery tests were conducted in a total of 148 pits located in 32 separate geomorphic units. An important advantage of the *in situ* techniques is their measure of actual aquifer response and also they avoid potential problems of soil deformation and alteration of pore continuity associated with ex-situ techniques (Bouma 1991). Surveying was conducted on seven Holocene coastal floodplains known to contain acid sulfate soils located in northern NSW, eastern Australia (Figure 1, 28^o 10' to 32^o 40' S, 152^o 12' to 153^o 30' E). Most locations were situated in landscapes assessed and mapped as having a 'high risk' of acid sulfate soils within 1 m of the surface. Pit selection included consultation with local floodplain officers scrutinizing capacity planning and/or implementing site remediation strategies. Field assessment also included groundwater pH and EC measurements, GPS sited, soil profile descriptions, and macropore observations.

Results and Discussion

K_{sat} spanned four orders of magnitude, ranging from <0.5 m day−1 to >500 m day−1. (Assessment of K_{sat} report to councils 2009, Johnston *et al.* 2009). These data indicates that 48% of pits in the range of >15 m day-1 (*High to Extreme*), and 18% of data come from locations with K_{sat} rates >100 m day-1 (*Extreme range*) (Figure 3). The standard deviation analysis (Figure 4) of site means (K_{sat} values from pits per locale), illustrates the inherently high degree of landscape variability in K_{sat} values. It also reflects the resilience of the pit bailing technique in contrasting CASS backswamp environments. An inter-floodplain comparison on range of sulfuric horizon K_{sat} (Figure 2), clearly demonstrates that the occurrence of very high K_{sat} values in sulfuric horizons is not an isolated phenomenon, as it occurs on most of the CASS floodplains examined in our study.

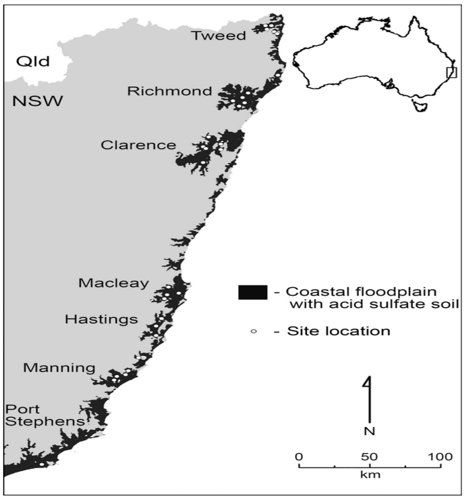

Figure 1. K_{sat} test site locations in relation to coastal floodplains with acid sulfate soils.

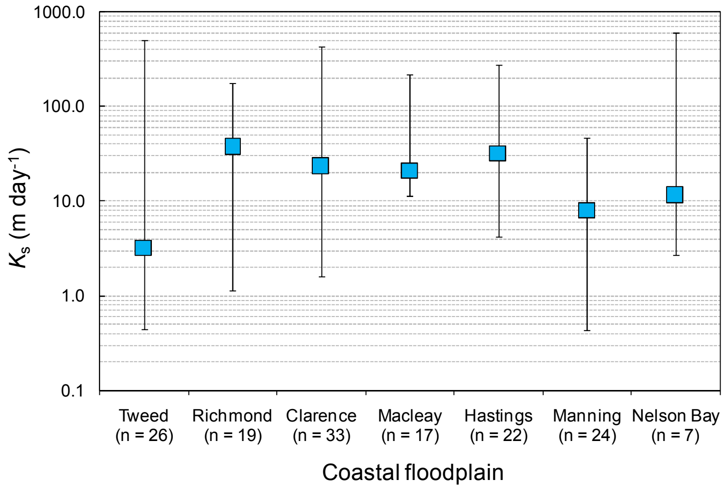

Figure 2. A comparison of the median (box) and range (error bars) of K_{sat} for all floodplains surveyed, where (n) = number of individual K_{sat} pits per floodplain. K_{sat} data calculated using Bouwer and Rice, 1983.

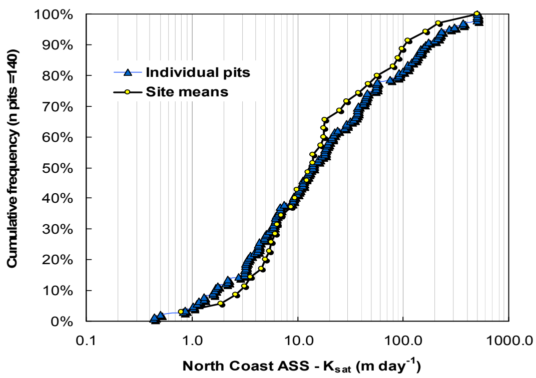

Figure 3. The cumulative frequency of K_{sat} for individual pits and site means (note: log scale x-axis).

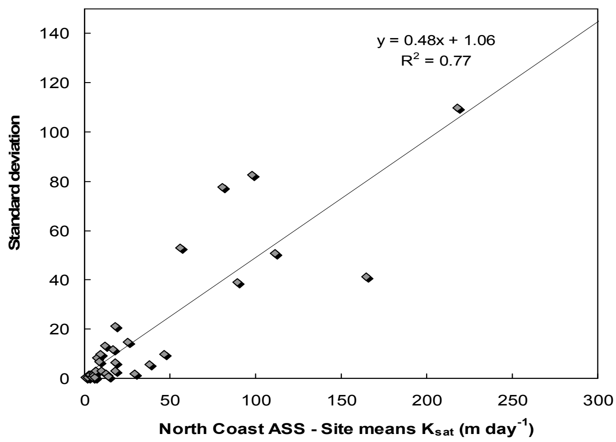

Figure 4: Standard deviation analysis on K_{sat} site means.

Conclusion

The study data on CASS demonstrates that sulfuric horizon K_{sat} is capable of being extraordinarily high, that high K_{sat} is relatively common, and can be extremely variable within individual floodplains. Visual observations confirm that high K_{sat} values were strongly associated with macropore flow, which highlights the need to use techniques for measuring K_{sat} in sulfuric horizons that are both *in situ* and of an appropriate scale: as small volume and ex-situ laboratory based techniques are highly prone to yield unrepresentative results in soils with extensive macropores (Bouma 1991). The results strongly indicate site specific assessments of sulfuric horizon K_{sat} via pit techniques or other similar *in situ* K_{sat} assessment techniques need to be included as a standard part of *risk management analysis* when making changes in backswamp hydrology during acid sulfate soil remediation projects. This is particularly important if strategies include attempts to retain acidic solutes within the landscape or involve floodgate opening and exchange of saline estuarine waters within drains.

References

Bouma J (1991) Influence of soil macroporosity on environmental quality. In: D.L. Sparks (Editor), Advances in agronomy - Volume 46. Academic Press, San Diego, California, pp. 1–37.

Bouwer H (1989) The Bouwer and Rice slug test – and update. *Groundwater* **27**, 304-309.

Bouwer H and Rice RC, (1983). The pit bailing method for hydraulic conductivity measurement of isotropic or anisotropic soil. *American Society of Agricultural Engineering* **26**, 1435-1439.

Dent D (1986) Acid Sulphate Soils: a Baseline for Research and Development. International Institute for Land Reclamation and Improvement Publication No. 39, Wageningen, Netherlands.

Eriksson E (1993) Modelling flow of water and dissolved substances in acid sulphate soils. In 'Selected Papers of the Ho Chi Minh City Symposium on Acid Sulfate Soils, Vietnam'. (Eds D Dent, MEF van Mensvoort) pp. 369–380. (International Institute for Land Reclamation and Improvement, Wageningen, Netherlands).

Johnston and Slavich, (2003a) Hydraulic conductivity – a simple field test for shallow coastal acid sulfate soils. Pp 1-9. (NSW DPI: Wollongbar).http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0009/168408/hc-field-test instructions.pdf.

Johnston SG, Slavich PG, Hirst P (2004a) The acid flux dynamics of two artificial drains in acid sulfate soil backswamps on the Clarence River floodplain, Australia. *Australian Journal of Soil Research* **42**, 623–637.

Johnston SG, Slavich PG, Hirst P (2004b) The effects of a weir on reducing acid flux from a drained coastal acid sulphate soil backswamp. *Australian Journal of Agricultural Water Management* **69** (1), 43–67.

Johnston SG, Hirst P, Slavich PG, Bush RT, Aaso T (2009) Saturated hydraulic conductivity of sulfuric horizons in coastal floodplain acid sulfate soils: Variability and implications. *Geoderma* **151**, 387-394.

Hirst P, Slavich P, Johnston S, Walsh S (2009) Assessment of hydraulic conductivity in coastal floodplain acid sulfate soils on the North Coast of NSW. Report to six north coast councils of NSW and Floodplain Network Consultative group.

Minh LQ, Tuong TP, van Mensvoort MEF, Bouma J (1997) Contamination of surface water as affected by land use in acid sulfate soils in the Mekong River Delta, Vietnam. *Agriculture, Ecosystems and Environment* **61**, 19–27.

Thi Minh Hue Le, An Ninh Pham, Richard N, Collins T, Waite D (2008) Impact of soil consolidation and solution composition on the hydraulic properties of coastal acid sulfate soils. *Australian Journal of Soil Research* **46**, 112–121.

Carbon storage in remnant trees and soils of grazing lands in Queensland

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Abstract
A large-scale research project was established in 2001 on a commercial grazing property in Queensland. Various aspects of grazing management at plot/catchment scales were studied for six years. This paper reports on the possible use of remnant trees in grazing lands as a carbon sequestration pathway in comparison to soil carbon. Trees growth was assessed using yearly height/girth measurement of 86 trees (*Eucalyptus dealbata)* in two plots. Some trees were harvested in 2001 and 2005 and the carbon (C) and nitrogen (N) concentrations measured on trunk, leaf and root samples. Total C and N were also measured in surface soil samples in 2001 and 2005. A Linear Mixed Effect model (LME) was developed from the growth data and used in combination with C concentration and tree density to predict C storage per hectare. Though there was no significant change in C storage in surface soil in the treed plots in the measurement period (2001-2005), there was a significant increase in C stored in the trees themselves. Although high tree densities are unrealistic for the entire grazing property, they may be appropriate for the less productive areas of land and could offset C emission from the rest of the grazing paddock.

Key Words
Carbon sequestration, *Eucalyptus dealbata* , trees in grazing lands, soil carbon.

Introduction
There has been much debate in recent years over the merit of keeping remnant trees in the grazing lands of Australia. Authorities have been trying to persuade graziers to keep more native trees on their lands because trees may help reduce compaction, erosion and soil loss while increasing nutrient retention and trees also provide shelter for the grazing animals (Bird *et al.* 1992). However, some graziers note the negative impacts of trees on the productivity of their lands and want to remove them.

In woodlands, the biomass of trees may store significantly more C than herbaceous plants (Young *et al.* 2005). Woodlands may also store more C than pasture and cropping systems, even when soil C values are added to the equation (Young *et al.* 2005). Additionally, C stocks of trees in grazed eucalypt woodlands in Queensland have been shown to increase with time (Burrows *et al.* 2002). This included C stocks in biomass from both live and dead trees, in both long and short-term studies. Increasing C stocks correlate with a reduction in emissions (Moore *et al.* 2001). This study suggested that with an increase in tree basal area in grazed woodlands of southwest Queensland, a decrease in emissions, or alternatively an increase in C storage, could be achieved. Peterson *et al.* (2003) also concluded that in farms which are predominantly used for grazing, the long term growth of tree plantations as C sinks successfully reduced overall on-farm emissions. Different types of grazing affect C storage as well. Grazing which was more productive emitted more greenhouse gases, when compared to less productive grazing under sheep (Moore *et al.* 2001). Some factors may increase the likelihood of tree growth and C storage such as grazing type (Burrows *et al.* 2002) and fire. However, while trees in grazing lands act as C sinks with an obvious environmental benefit, this can often mean that there is less land available for actual grazing and more stress on the remaining land which is grazed (Henry *et al.* 2005). Cook *et al.* (2005) suggested that only around 25% of the C sequestered by living trees is retained, while the remaining C is lost through leaves, twigs and bark to the ground below.

The objectives of this study were therefore to measure C storage within tree plots located within a time-controlled grazing area (TCG) in comparison to surface soils and to assess how this storage would vary with time and rainfall.

Methods
Site details
The land at Currajong Station is used for sheep and cattle grazing, without the use of fertilizers and other inputs. The Station is located in the Inglewood shire in Queensland, Australia (28º 33’ S and 151º 33’ E) at

~675 m above sea level. Currajong has average maximum and minimum temperatures of 24ºC and 10ºC respectively and the average yearly rainfall is 691 mm. A large scale multi-faceted research project was established in 2001 on the Station and run for 6 years (Sanjari, 2009). The project examined the effect of different types of grazing (time controlled and continuous) on vegetation production, soil properties and runoff water quality. Within the TCG catchments, two areas of high tree density were chosen for this study. The tree areas comprised both grazed and non-grazed (fenced-off) areas. The trees were *Eucalyptus dealbata,* which germinated around 1987. Trees were located in plot I which was on sloping land (12%) and 800 m^2 in area (density 0.135 trees/m^2) and in plot II (slope 23%) with an area of 362 m^2 (density 0.221 trees/m^2). Plot I initially contained 112 trees, but 108 trees were counted in 2006, while plot 2 contained 91 trees on first count, but by 2006 this had dropped to 80 trees. Tree density was therefore higher in plot 2. Shrubs were not included in this study, though they were present within these plots.

Geology at the site comprises part of the Warroo land system, generally referred to as Traprock. This is a complex mixture of highly deformed sandstone, mudstone, inter-bedded conglomerate, limestone and volcanic. The soils are shallow to moderately deep with a hard setting brown to dark clay loams.

Tree height/girth measurements
Tree height/girths were measured for 116 trees, in 2001, 2003, 2004 and 2005 in Plot 1. However, there were some missing data, so only trees with a full set of data (86) were used for subsequent statistical analysis. For tree height, tall trees were measured using a clinometers located at 6.0 m from the tree using the following formula: Height of tree = $(\tan \theta \times 6m) + 0.9m$. Shorter trees were simply measured using a rigid tape measure. Tree girths were measured at both 0.5 m and 1.3 m height above ground.

Tree and soil sampling
Trees were harvested from plot 1 for chemical analysis (3 trees in 2001 and in 2005). To avoid decimating tree numbers in plot 1, extra trees were harvested in plot 2 (3 in 2001 and 5 in 2005). The harvested trees spanned a range of heights. Trees were cut up on site before being transported to the laboratory. Samples were subsequently separated into trunk, root and leaf components and were then dried and ground to<0.4 mm. Soil samples (0-10 cm depth) were also collected from treed and non-treed plots within the TCG catchment in 2001 and 2005. The samples from treed plots were taken in both grazed and non-grazed areas.

Chemical analysis
Total carbon (C) and nitrogen (N) contents of the tree and soil samples in 2005, and for the soil samples in 2001, were determined in triplicate for each sample by Dumas combustion using a Leco analyser. However, for the tree samples in 2001, the nitrogen was determined using the Kjedahl method. Data from

Results and discussion
Total carbon in the soil
There were no significant differences in total soil C between 2001 and 2005 and no significant differences between total soil C in treed and non-treed areas or between grazed and ungrazed treed areas (Table 1). Likewise no significant differences were found for total soil N.

Table 1. Amounts of carbon and nitrogen in surface soil samples (0-10 cm) in 2001 and 2005.

	Total C (mg/kg)		Significance	Total N (mg/kg)		Significance
	2001	2005		2001	2005	
Trees present	40637	40350	NS	2778	2609	NS
Trees absent	26540	28763	NS	1875	1988	NS
Significance	NS	NS		NS	NS	
Treed grazed	41225	42982	NS	2849	2663	NS
Treed ungrazed	40050	37718	NS	2708	2554	NS
Significance	NS	NS		NS	NS	

NS = no significant differences between values in the same column or row at P==0.05

The C:N ratios were ~15 throughout. The total C stored in the top 0.1 m of soil in the treed area equates to 48.2 and 47.8 t/ha in 2001 and 2005 respectively using an average bulk density of 1185 kg/m^3 (Sanjari 2009) and a soil volume of 1000 m^3 (0.1 m depth x 10000 m^2 per ha). Sanjari (2009) measured soil organic carbon (SOC) in the surface soil in the open TCG pasture to be ~26 ton/ha in 2001 and ~28 ton/ha in 2006. Herbage contributed another ~1 900 and 2500 ton//ha while litter contributed ~1600 and 2000 ton/ha in 2001 and 2005 respectively.

Total carbon in the trees

Height and girth measurements from the 86 trees were plotted versus the year and growth models were developed using LMEs (Table2).

Table 2. Tree growth models using data from 86 trees.

Tree height = H (m)	H = 2.00 (0.099) + 0.68 (0.028) * years of growth after 2000	(1)
Tree girth at 1.3 m = G (mm)	G = 50.91 (3.18) + 30.81 (193) * years after 2000	(2)

- Figures in brackets represent the std error for the values

Chemical analysis of the tree components (Table 3) indicated the predominance of Total C compared to N. Total C and N were significantly higher (P<0.05) in the leaves compared to stems and roots. There were significant differences in C levels (P<0.01) between 2001 and 2005 for all the tree components.

Table 3. Mean concentrations of carbon and nitrogen in tree samples in 2001 and 2005.

Year	Parameter (mg/kg)	Roots	Trunks	Leaves
2001	Total C	500 167	499 000	543 833
2005		425 114	435 448	484 901
2001	Kjeldhal N	3.314	3.193	12.485
2005	Total N	2.605	2.975	14.895

Using pooled allometric equations from a study in northern NSW by Specht and West (2003), tree measurements (Table 2) were then used to predict biomass of the trees as $W= aD^b$ where W = oven-dry biomass (kg), a = 0.355, D (cm) = diameter at 1.3 m height and b =2.00 (girth was first converted to diameter). Using the calculated biomasses, the C concentrations and tree densities in the two plots, C storage per hectare was then calculated (Table 4) and thus used to predict C stored in the trees over time (Figure 1).

Table 4. Estimated total biomass values and carbon storage of trees with time in two plots.

Year	Average girth at 1.3 m (cm)	Total biomass (kg/tree)	Total Carbon content (kg/tree)[A]	Carbon Plot 1 (t/ha)	Carbon Plot 2 (t/ha)
2000	5.1	0.93	0.45	0.63	1.1
2001	8.2	2.4	1.2	1.7	2.7
2002	11	4.6	2.2	3.0	4.8
2003	14	7.4	3.6	4.8	7.9
2004	17	11	5.3	7.1	12
2005	20	15	6.8	9.1	16
2006	24	20	9.6	13	21

[A]Actual C contents used in 2001 and 2005. For other years, calculation assumes an average C content for all tree parts over both years of 481 411 mg/kg (= 48.14% derived from Table 3).

Figure 1 indicates an exponential increase in C storage in the two tree plots with time. Plot 2 had a greater tree density than plot 1 which gave rise to greater C storage. Some of this C storage would be decreased by leaf/twig fall and root die-back during the year which would in turn be affected by moisture conditions in the area. However, overall carbon storage in the trees did not seem to be affected by variations in annual rainfall (Figure 1) which ranged from ~510 to 760 mm/yr during the years of measurement. This is in contrast to C storage in litter and herbage at Currajong (Sanjari, 2009) which was affected by rainfall, decreasing in dry years. Carbon stored in the top 10 cm of soil exceeded tree C in both years, but tree C would exceed this by 2020 at the current rate of increase or if tree density increased. However, C levels for lower soil horizons were not assessed for this study and these would increase the overall soil C storage. Nevertheless, it is likely that the soil C levels will remain somewhat static compared to tree-stored C, particularly that stored within the trunks and larger branches. Mean values for C density in Victorian forests were found to be between 18.0 and 250.0 t C /ha (Grierson *et al.*1992) while Miehle *et al.* (2006) also predicted C density in a number of *Eucalyptus globulus* plots through use of a model. That study returned predicted values of between 22 and 106 t C / ha for trees aged at 6 years old. Burrows *et al.* (2002) noted that above-ground C stocks in live and standing dead woody plants in eucalypt woodlands gave a mean net above-ground annual C increment for all 57 sites of 0.53 t C /ha. y. The annual C increments are higher for this study (>0.7 t/ha.yr – see Table 4) but they include root material as well.

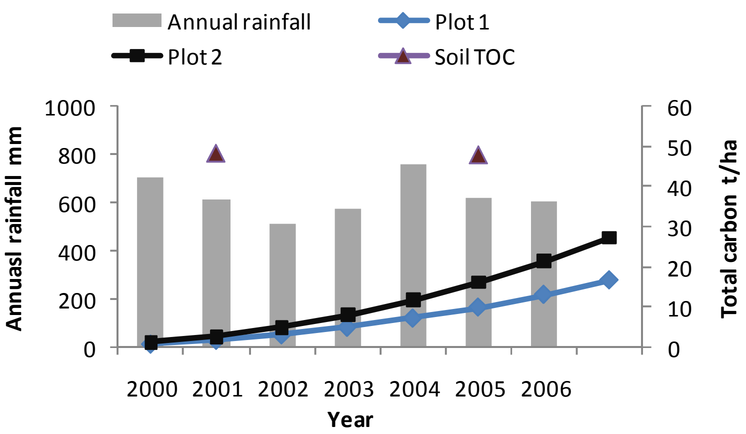

Figure 1. Carbon storage in trees and surface soils as a function of time.

Conclusion

Carbon storage in remnant trees in a TCG zone increased exponentially with time between 2001 and 2005 but remained less than soil surface C which did not change over the same period. Annual rainfall appeared to have little impact on this increase possibly because the trees are conservative in their water use. Further research including measurements of stored soil and root C at depth may help to establish whether graziers can earn ongoing income for sequestering C by returning non-productive parts of their lands to eucalypts.

Acknowledgements

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References

Bird PR, Bicknell D, Bulman PA, Burke SJA, Leys JF, Parker JN, van der Sommen FJ, Voller P (1992) The role of shelter in Australia for protecting soils, plants and livestock. *Agroforestry Systems* **20**, 59-86

Burrows WH, Henry BK, Back PV, Hoffmann MB, Tait L J, Anderson ER, Menke N, Danaher T, Carter JO, McKeon GM (2002) Growth and carbon stock change in eucalypt woodlands in northeast Australia: ecological and greenhouse sink implications. *Global Change Biology* **8,** 769-784.

Cook GD, Liedloff AC, Eager RW, Chen X, Williams RJ, O'Grady AP, Hutley LB (2005) The estimation of carbon budgets of frequently burnt tree stands in savannas of northern Australia, using allometric analysis and isotopic discrimination. *Australian Journal of Botany* **53,** 621-630.

Grierson, PF, Adams MA, Attiwill PM (1992) Estimates of Carbon Storage in the Above-ground Biomass of Victoria's Forests. *Australian Journal of Botany,* **40,** 631-640.

Henry B, Mitchell C, Cowie A, Woldring O, Carter J (2005) A regional interpretation of rules and good practice for greenhouse accounting: Australian savanna systems. *Australian J. of Botany* **53,** 589-605.

Miehle P, Livesly SJ, Feikema PM., Li C, Arndt SK (2006) Assessing productivity and carbon sequestration capacity of *Eucalyptus globulus* plantations using the process model Forest-DNDC: Calibration and validation. *Ecological Modelling* **192**, 83-94.

Moore JL, Howden SM, McKeon GM, Carter JO, Scanlan JC (2001) The dynamics of grazed woodlands in southwest Queensland, Australia and their effect on greenhouse gas emissions. *Env. Inter.* **27**, 147-153.

Sanjari G (2009) Evaluating the Impacts of Time Controlled and Continuous Grazing Systems on Soil Properties, Surface Hydrology and Pasture Production in South-East Queensland. PhD Thesis, Griffith School of Environment, Griffith University.

Specht,A, West PW (2003) Estimation of biomass and sequestered carbon on farm forest plantations in northern New South Wales, Australia. *Biomass and Bioenergy* **25**, 363-379.

Young R, Wilson BR, McLeod M, Alston C (2005) Carbon storage in the soils and vegetation of contrasting land uses in northern New South Wales, Australia. *Australian Journal of Soil Research* **43**, 21-31.

Economic value of the beneficial function of organic paddy farming in Korea

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Abstract
In order to evaluate the beneficial functions for organic farming, we have divided beneficial functions as 9 sub-functions such as flooding control, fostering water resources, purifying the air, mitigating summer climate, purifying water quality, decreasing soil erosion, accumulating soil carbon, conserving biodiversity, and preventing accidents from pesticides. They were quantified by searching related reports and statistics, and surveying fields. Organic farming, especially organic paddy farming, showed that some functions like fostering water resources, accumulating soil carbon, conserving biodiversity, and preventing accidents from pesticides were higher than conventional paddy farming, while for the others were similar. The fostering water resources function was evaluated as 4,297 ton/ha.year an increase of about 3.6% compare with that of conventional farming. A New function for accumulating soil carbon at organic paddy fields has been assessed by 4.67 ton/ha in terms of long periods over 10 years. Considering the area of organic paddy farming in Korea and value of carbon price, it the monetary value is 22.4 to 84.1 billion won using the new method. It could be also evaluated that flooding control, fostering water resources, purifying the air, mitigating summer climate, purifying water quality, decreasing soil erosion, and preventing accidents from pesticides were value at 2,980, 123.4, 482.6, 87.5, 0.9, 55.6, and 284.1 billion won, respectively. Conserving biodiversity function would be a very big benefit of organic farming though it couldn't be evaluated as monetary value.

Key Words
Multifunctionality, beneficial function, organic paddy farming.

Introduction
Modern agriculture made it possible to grow more food per unit area by using of modified seeds and chemical input like pesticides and chemical fertilizers. Because agro-ecosystem has been threatened by over application of pesticides and fertilizers, the current challenges is to meet the food demands of a growing population by maintaining and enhancing the productivity of agricultural system without further damaging their beneficial functions, so called multifunctionality. Especially, organic paddy farming will be predicted to have higher values of beneficial function than conventional paddy farming. But most people do not know how much beneficial values has been embedded, even though they have recognized there is a beneficial side in paddy farming including organic farming. The role of environmental service for organic farming needs to be propagated to public citizens. Objectives of this study were to assess the beneficial functions of organic paddy farming on the basis of research reports, national statistics, and fields survey, and evaluate then as monetary values.

Materials and methods
Categories
There would be many beneficial functions according to researchers or other peoples because of differences on standpoints. According to previous reports(Seo *et al.* 2001), it could be categorized 6 sub functions for conventional paddy farming such as flooding control, fostering water resources, purifying the air, mitigating summer climate, purifying water quality, decreasing soil erosion. In addition to these sub functions, sub functions of organic paddy farming such as accumulating soil carbon, conserving biodiversity, and preventing accidents from pesticides also exist.

Assessment
The amount of each function was quantified against 9 categories. flooding control, fostering water resources, purifying the air, mitigating summer climate, purifying water quality, decreasing soil erosion were followed by previous research's method, which were established estimated models. Especially, the depth of water level at organic paddy fields was measured with near conventional paddy fields for estimating the function of fostering water resources. The function of accumulating soil carbon was analyzed by establishing a model using data from long-term rice cultivating fields and analyzing soil carbon in organic paddy fields. The

function of preventing accidents from pesticides uses stastical data about pesticide poisoning deaths. rates were evaluated using a first-order kinetic models.

Economic value
After assessment of on beneficial functions about organic paddy farming, we made an attempt to give each function a monetary value by means of a replacing method. The amount of carbon accumulated in soil in organic paddy fields should be replaced by the price in carbon exchange markets which is related to climate changes.

Results and discussion
As results of surveying the level of flooded water at organic snail paddy fields with near conventional paddy fields, it was showed water level at organic snail practice filed were deeper as almost two times than near conventional practice. Comparing soil organic matter for organic and conventional paddy fields, organic matter was higher than conventional, being 30.1 and 23.5 g/kg, respectively. On the basis of soil carbon in the view of long term practices, the function of accumulating soil carbon could be estimated as 4.69 ton/ha for organic paddy farming. Organic farming could prevent poisoning by pesticides accidents. The amount of each sub function was estimated by unit area as shown as Table 1 except for conserving biodiversity.

Table 1. The amount of beneficial function for organic paddy farming dividing as 8 categories.

Sub functions	Amount of sub function	Monetary value (billion won)	Comparing with conventional farming
flooding control	2.94 ton/ha.year	2,980	Same
fostering water resources	4.3 ton/ha.year	123.4	Increase 3.6%
purifying the air	CO_2: 21.9 ton/ha.year	76.2	Same
	O_2: 15.9 ton/ha.year	406.4	Same
mitigating summer climate	3,049 ton/ha in summer	87.5	Same
purifying water quality	20.7 N kg	0.9	Same
decreasing soil erosion	110.8	55.6	Same
accumulating soil carbon	4.69 C	22.4-84.1	New
preventing accidents from pesticides	984 person	284.1	Average in 2003-2005

Table 1 also shows their monetary values for sub functions for organic paddy farming while the function of preventing accidents from pesticides was for the whole of organic farming. But It the function of conserving biodiversity cannot be quantified even though there were many examples related during the research for example finding rare animals in organic paddy fields.

Conclusion
The beneficial function of organic paddy farming was investigated by analyzing reports, statistics and fields data. In the view of the environmental conservation function, most subfunctions were very similar to those for conventional farming except fostering water resources, which is increased by 3.6%. From the view of alleviating green house gases, a new beneficial function was revealed to make a role of accumulating soil carbon in long term a continuing practice. Generally organic farming does not use dangerous chemicals. It means that organic farming has the potential for preventing accidents from pesticides which bring about social problems.

References

Harpinder S, Sandhu Stephen D, Ross C, Brad C (2008) The future of farming: the value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecological Economics* **64**, 835-848.

Seo MC *et al.* (2001) Assessment of positive Function of Paddy Farming According to Agricultural Production Conditions. Report on Research of Agricultural Environment, NIAST, Official No. 11-1390093-000064-10. pp. 355-377.

Jeong MH, Kim JH, Park KH, Lee HD, You AS, Kim BS, Choi JH, Kwon OK (2008) Examination of pesticide poisoning death statistics in Korea and precautionary measures against pestiside-poisoning, *The Korean J. of Pesticied Science* **12**, 134-140.

Effects of landuse types at different slopes on soil erodibility factor (A case study from Amol area, north of Iran)

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Abstract
The soil erodibility factor (K) represents the combined effects of susceptibility of soil to detachment and transportability of the sediment, and the amount and rate of runoff given a particular rainfall erosivity. This study investigated the Effects of land use and slope on soil erodibility factor in four adjacent land use in northern Iran. Land uses were forest, pasture, irrigated farming, and dry farming that were located in three sites with different slopes of 3-8, 8-18, and 18-40 percent. Three replicated soil samples were collected from each land use at each site. Some chemical and physical properties of soil samples were determined. K values were estimated by using the nomograph method (k equation). Data analysis showed that there are significant differences between different slopes and land uses. K value increased with slope for most land uses due to changing erodibility components such as SOM, texture, structure, and permeability. Pasture land with slope of 8-18% had minimum value of erodibility (0.023). The maximum K value was for irrigated farming with 8-18% slope (0.078). In addition, forest has the second highest value; however dry farming has much more erosivity than forest.

Key Words
Erodibility factor, Soil erosion, Soil erodibility nomograph, USLE, Iran.

Introduction
Soil erosion is one of the most important factors involved in destroying many fertile agricultural soils around the world. Hence , predicting the erosion factor can be of great help in solving the problem. USLE is among the equations which may enable us to estimate soil erosion. Definition of K factor is:

$$K = \frac{A}{R} = \frac{A}{E \times I30} = \frac{M/L^2}{(FL/L^2)(L/T)} = \frac{MTL^2}{L\ LFL^2} = [(Mg/ha)\ (ha\ .h/MJ.mm)]$$

The concept of soil erodibility was introduced as the K factor, which was defined as the average rate of soil loss per unit of rainfall erosion index from a cultivated continuous fallow plot, on a 9% slope 22.1m long. Thus, the K factor for a specific soil can only be determined from long-term observations of rainfall erosivity and soil loss from a unit plot. To allow estimation of soil erodibility from measurable soil properties, the soil erodibility nomograph was published in the early 1970s (Wischmeier *et al.* 1971). Factors which affect soil erodibility are generally categorized into two groups. One relates to the physical characteristics of soil which are easier dealt with compared to the second one which is related to farming management or conservative actions.

There are different direct and indirect methods to evaluate soil permeability. To evaluate through direct methods, using some especial tools, the permeability is evaluated directly, while to evaluate permeability through indirect methods, some parameters are measured and mathematical relations are used. Lufran experiment, falling head, constant head, Porche method, using particle size distribution and double ring are some methods of estimating permeability. Landuse change from non-agricultural to agricultural has led to decrease of soil organic matter which cause adverse effects on the soil structure. Riezebos and Lorts (1998) have found a correlation between soil quality and land use. When a forest changes to cultivated farming, soil organic matter decreases significantly. Soil legislation is of great importance around the globe to limit the amount of soil loss. As the country of Iran is located in a mountainous land, there is a high level of erosion. The aim of the present study is to determine effects of landuse types on different slopes on the soil erodibility factor.

Material and methods

The studied area is located on latitudes between 36.25and 36.50 and longitudes 52.25 and 52.50 in Amol area northern Iran. Sampling positions were determined according to the map resulting from intersecting between landuse and slope maps in Arc-GIS environment. Four different landuses including forest, range, irrigated farming and dry farming and three slope categories in each landuse including A- 3-8% B- 8-18% C-18-40% were selected. Using the aforementioned data the exact sampling positions were determined (Figure 1). The four land uses were chosen with the nearest possible distances from each other in order to prevent changing parent material (Figure 2).

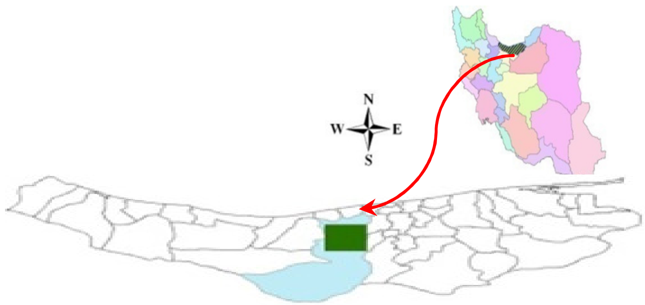

Figure 1. The studied area located in Amol county northern Iran, with the scale of 1:25000.

Figure 2. The four land uses were chosen with the nearest possible distances from each other in order to prevent differences in parent material.

Using GPS the selected positions were found and disturbed samples were collected with three replications for physicochemical analyses and undestroyed samples were collected in 5 replications for determination of bulk density and Ks (Wischmeier *et al.* 1971). Permeability was measured in two replications at different landuse and slope classes using double rings. Organic matter was determined using Walkli and Black (1954) method. Particle size distribution was determined by hydrometer. Erodibility was estimated using nomograph method and the results were analyzed using SAS statistical software. Soil structure codes and profile permeability classes were obtained from National Soils Handbook No. 430 (USDA 1983) and shown in Table 1. There was no dry farming with slope 18-40% in the study area.

Table 1. Average laboratory analyses of soil samples.

Land use	% OM	% Clay	% Silt	% sand	VFS	structure code	Permability code
Pasture 3-8%	1.76	44.44	24.96	30.60	28.52	3	1
Pasture 8-18%	1.69	38.49	50.88	10.63	1.12	3	2
Pasture 18-40%	1.72	14.68	54.71	30.61	22.99	3	3
Forest 3-8%	6.26	22.09	52.51	25.41	15.77	4	4
Forest 8-18%	6.55	20.21	55.21	24.58	20.56	4	4
Forest 18-40%	6.09	19.89	10.87	69.25	59.58	4	4
Irrigated farming 3-8%	2.21	20.88	52.62	26.50	18.68	4	3
Irrigated farming 8-18%	2.64	14.60	52.43	32.97	31.94	4	5
Irrigated farming 18-40%	0.80	3.60	30.76	65.63	17.97	4	4
Dry farming 3-8%	2.87	21.53	52.47	25.99	16.70	3	1
Dry farming 8-18%	1.84	17.42	48.86	33.72	21.55	4	2

Table 2. Analysis of variance for erodibility for different land uses.

Source	DF	Mean Square
Model	3	0.00123695**
Error	29	0.00498827
Corrected Total	32	0.00869912

Table 3. Analysis of variance for erodibility for different land uses and slope.

Source	DF	Mean Square
Model	10	0.00085161 **
Error	22	0.00000832
Corrected Total	32	0.00869912

Significant at 5% and 1%, respectively **: and*

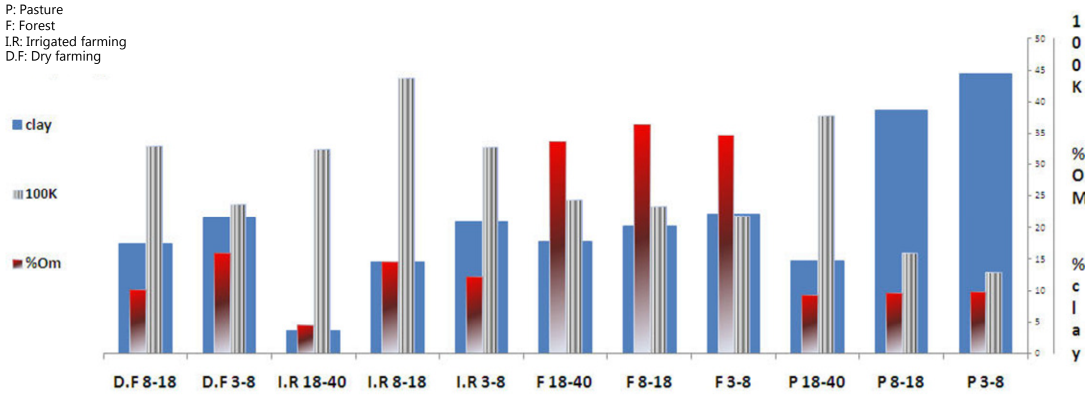

Figure 3. K values for four adjacent land-use types and different slope classes

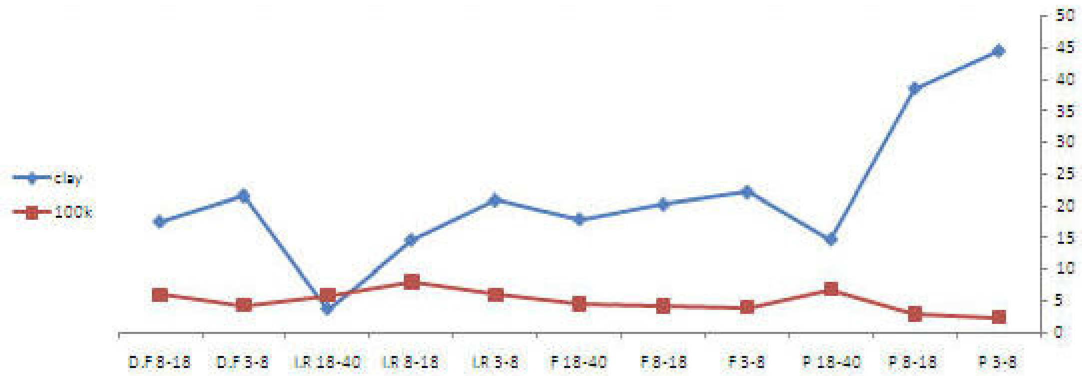

Figure 4. The spatial relationships of clay content and measured K factor

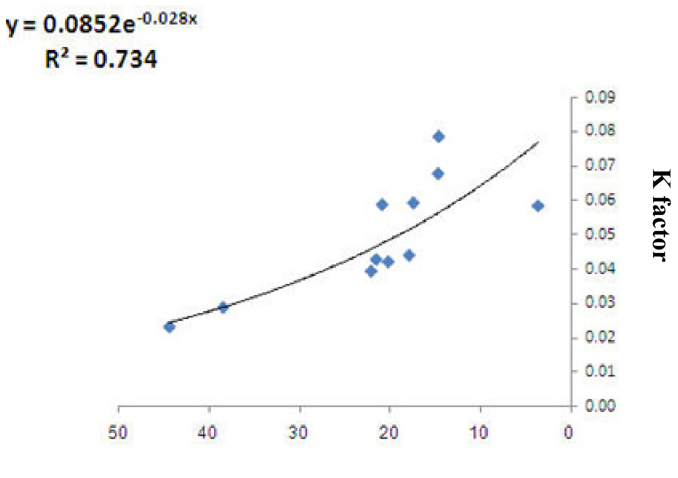

Figure 5. The relationship between clay content and the measured K factor

Dissection

We have proposed a relationship between clay content and the *K* factor using the data from the four sites if there is no significance difference in percent organic mater (Figure 5). With decreasing clay percent, the erodibility factor will be increased (Figure 4), In samples which were collected from site used for irrigated farming and pasture with 18-40 percent slope the effect of other factors led to an improbable erodibility factor. Relationships between percent slope and percent clay indicate that percent of clay decreases when slope increase.

Conclusion

In Iran priorities are given to pastures, forests, dry framing, and irrigated farming respectively. The first and the most important issue for all land uses, is try maximise pastures and forests to limit erosion. The preferred land type for each category of land use is the one with low slope.

References

Bayramin I, Basaran M, Erpul G, Canga MR (2008) Assessing the effects of land use changes on soil sensitivity to erosion in a highland ecosystem of semi-arid Turkey. *Environ. Monit. Assess.* 140, 249–265.

Riezebos H, Loerts AC (1998) Influence of land use change and tillage practice on soil organic matter in southern Brazil and eastern Paraguay. *Soil and Tillage Research* 49, 271– 275.

USDA (1983) National Soil Survey Handbook. No. 430. US Department of Agriculture, Wahsington, DC.

Wischmeier WH, Johnson CB, Cross BV (1971) A soil erodibility nomograph for farmland and construction sites. *J. Soil Water Conserv*. 26, 189–193.

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook No. 537. US Department of Agriculture, Wahsington, DC.

Zhang K, Lia S, Peng W, Yub B (2004) Erodibility of agricultural soils on the Loess Plateau of China, *Soil and Tillage Research* 4, 39–46.

Field evaluation of selected yam (*Dioscorea alata*) accessions in acid soils and saline-prone areas

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Abstract
In the context of agricultural problem soils, salinity and acidity dominate the problems related to agricultural landuse. This study was conceptualized to determine the possibility of utilizing some problem soils into yam production. Selected yam accessions were assessed for their performance in acid soils and saline-prone areas. The accessions planted in the saline-prone area, a Balongay clay at Sta. Teresita, Canaman, Camarines Sur, Philippines were Accession 5, Accession 6, Accession 8, Accession 9, Accession 10 and Accession 12 while the Accession 6, Accession 10, Accession 11, Accession 12, Accession 13 and Accession 21 in an acid soil, a Caroyroyan clay loam at Pacol, Naga City, Philippines. This was conducted using Randomized Complete Block Design (RCBD) with three replications. Accession 6 and 10 were both economically viable in saline-prone areas and acid soils as shown by the highest return on investment compared with other treatments.

Key Words
Acid soils, saline-prone areas, problem soil, yam accessions.

Introduction
In Camarines Sur, some farmers had been engaged in growing yam but encountered problem in selling the produce and how they can process and preserve yam and package into other high value yam-products. These are some of the reasons of their resistance to engage in yam production. Hence, very few farmers are cultivating this crop because of lack of information about yam production, processing, product development, preservation and market-linkaging. Yam (*Dioscorea alata*) is considered as a high value crop. They are cultivated in small patches of land, oftentimes less than a hectare, particularly in some regions of the Philippines like the Ilocos, Southern Tagalog, Bicol, Central Visayas and Northern Mindanao. It is an upland crop and usually planted in a well-drained field. Optimum yields are obtained from sandy loam and silt loam soil although acceptable yields are also obtained from clay loam soils, particularly those high in organic matter. Stony and highly compacted soils are not good for yam production.

In the context of agricultural problem soils, salinity and acidity dominate the problems related to agricultural landuse. This study was conceptualized to determine the possibility of utilizing some problem soils (location specific) into yam production so that, lands without constraints for crop production could be utilized for other high value crops and provide information about the yield of yam in these areas. Saline-prone areas and acid soils can be converted into productive agricultural lands considering the necessary information with regard to soil and water management for these problem soils.

The information generated could help farmers with problem soils to increase their income through yam production. This could answer the goals and objectives of the Department of Agriculture which are food security, poverty alleviation, improved productivity and increased income, resource sustainability and global competitiveness.

Methods
Collection and preparation of soil sample
Soil samples at a depth of 20 cm were randomly collected from the experimental area for soil analysis prior to the establishment of the study. One-kilo composite soil samples were mixed, pulverized and placed on trays and large clods were broken into smaller sizes and spread thinly on plastic sheets, passed through 2mm sieve and air dried at room temperature.

Experimental design and treatments
The Randomized Complete Block Design was used. The experimental area covered about 320 sq m, divided into 3 blocks and 6 plots in each block. The treatments for the saline-prone area were as follows : T1- Accession 5, T2 - Accession 6, T3 - Accession 8, T4 - Accession 9, T5 - Accession 10 and T6 - Accession 12 while for the acid soils the treatments were : T1 – Accession 6, T2 – Accession 10, T3 – Accession 11, T4 – Accession 12, T5 – Accession 13 and T6 – Accession 21. while the T1-Accession 6, T2 - Accession 10, T3 - Accession 11, T4 - Accession 12, T5- Accession 13 and T -6 Accession 21.

Cultural management practices
Land preparation. The area was ploughed and harrowed once followed by harrowing after one to two weeks.
Sett preparation. Seed pieces or setts were prepared a few days before planting. The roots were cut into pieces containing at least 2-3 eye-buds and weighing about 250 grams each.
Fertilization. The fertilizer used was 14-14-14 at the rate of 15g/plant and 0-0-60 at the rate of 2g/plant and 1 kg of compost. The amounts applied were based on soil analyses.
Planting. Planting of seed pieces or setts was done late afternoon. The distance of planting was 1 meter between rows and 0.75 meter between hills.
Staking. As soon as sprouts emerged from the soil staking was done with the use of split bamboos. Vines need stakes for better display of leaves. This practice was advisable because studies show that tuber yield was increased. Stakes about 2.0-2.25 meter tall were placed per plant.
Weeding and cultivation. Weeds compete with yam plants in terms of soil nutrients, light and space especially during the early growth stages; hence, hand weeding was employed as needed.
Control of pest and diseases. Furadan was used at the rate of 0.5g/plant to control pest and diseases.
Harvesting. Harvesting was done when the leaves turned yellowish or brownish in color. This was 6 to 11 months after planting. Harvesting of the tubers was done with digging tools. Care was exercised so as not to injure them while digging. Tubers were cleaned, collected and placed in plastic sacks depending upon tuber size.

Data gathered
Average tuber yield**.** This was determined by weighing the tubers per plant and the average yield was determined for the sample plants and multiplied with the number of plants per hectare. The average tuber yield was expressed in tons per hectare.
Pests and diseases**.** Observation of the pests and diseases which affected the yam plants was done regularly.
Statistical analysis**.** The mean was computed instead of using the analysis of variance (ANOVA) for the saline-prone area because some of the accessions did not produce any yield. However, for the acid soils, the ANOVA was used.
Economic Analysis**.** A simple cost and return analysis was used. This was computed to determine the economic viability of the different treatments in the saline-prone area and acid soil.

Results
Average tuber yield
The highest tuber yield was obtained from Accession 10, with 99.83 tons/ha. This was four times higher than the average tuber yield obtained by Ruiz (2000) using similar accession (Table 1). This accession is considered much favorable to plant in saline-prone areas if compared to the yield obtained by Ruiz in a non-saline area. Similarly, accession 6 showed an average tuber yield of 48.4 tons/ha. This yield was three and a half times higher than the average tuber yield obtained by Ruiz using similar accession. The rest of the accessions yielded lower than that of Ruiz (2000). The most suitable accession in saline-prone area in a decreasing order was Acc. 10 with the highest yield of 99.83 tons/ha, followed by Acc. 6 with a yield of 48.4 tons/ha, then Acc.5 with 13.612 tons/ha and Acc. 9 with 13.2 tons/ha and the lowest was Acc. 8 and Acc. 12 which did not produce any yield due to infestation by insect pests. These accessions were infested with white grubs and ants fed on the tubers at about five months old.

In the acidic soil, the highest tuber yield of 52.58 t/ha was obtained from Accession 10, followed by Accession 6 which got an average tuber yield of 48.25 t/ha. Accession 11, 12, 13 and 21 did not differ significantly in terms of yield which ranged from 10 to 15 tons per hectare (Table 1). Only Accession 6, Accession 10 and Accession 12 out yielded the results obtained from the study of Ruiz (2000). The increase ranged from 345%, 214% to 113%. The rest of the accessions yielded lower.

Table 1. Tuber yield of yam accessions in saline-prone area and acid soils

Treatments	Saline-Prone Area Average Tuber Yield ton/ha	Average Tuber Yield ton/ha (Ruiz 2000)	Treatments	Acid Soils Average tuber Yield ton/ha		Average Tuber Yield ton/ha (Ruiz 2000)
T1 - Acc 5	13.6	19.2	T1 - Acc 6	48.3	b	14.0
T2 - Acc 6	48.4	14.0	T2 - Acc 10	52.6	a	24.6
T3 - Acc 8	0	25.1	T3 - Acc 11	10.2	c	14.9
T4 - Acc 9	13.2	18.7	T4 - Acc 12	13.9	c	12.3
T5 - Acc 10	99.8	24.6	T5 - Acc 13	13.8	c	14.4
T6 - Acc 12	0	12.3	T6 - Acc 21	15.8	c	16.0

Means followed by the same letter are not significantly different

Accessions 6 and 10 showing potential for acid soils and saline-prone areas have more or less the same agronomic characteristics (Table 2). They have both white color flesh and are liked moderately and liked slightly, respectively. Because of the white flesh, these accessions can undergo product development since most people would prefer yam which are violet in color.

Table 2. Agronomic characteristics of the yam accessions.

Characteristics	6	10	11	12	13	21
1. Growth habit	Medium	Large	Small-medium	Small-medium	Medium	Small-medium
2. Length of petiole	medium	Long	Short	Short	medium	medium
3. Color of petiole	White	White	Purple-green	Purple	Purple-sepia	Purple-green
4. Length of internodes	Medium	Long	Short	Short	Short	Short
5. Emerging leaf color	Light Septa	Light Septa	Dark Septa	Dark Septa	Dark Septa	Dark Septa
6. Leaf shape	Entire Cordate	Entire Cordate	Sagitate	Sagitate	Sagitate	Entire-cordate
7. Vine	Winged	Winged	Winged	Winged	Winged	Winged
8. Method of climbing	Right	Right	Right	Right	Right	Right
9. Flowering habit	None	Heavy-flowering	None	None	None	None
10. Arial tuber formation	None	Heavy	Slight	None	Slight	Slight
11. Tuber shape	Long tapering	Oblong	Round - branching	Round - Branching	Round - branching	Round - branching
12. Root skin	smooth	Rough	smooth	smooth	smooth	smooth
13. Root color						
-skin	violet	white	violet	violet	violet	violet
-flesh	white	whitish-yellow	violet	light-violet	White-violet	White-violet
14. Maturity	8-10 months	8-10 months	6 -8 months	6 - 8 months	6 - 8 months	6 -8 months
15. Pest resistance						
Insect	Resistant	Resistant	Mod Resistant	Mod Resistant	Mod Resistant	Mod Resistant
Diseases	Resistant	Resistant	Mod Resistant	Mod Resistant	Mod Susceptible	Mod Resistant
16. Storage life	4-6 months	4-6 months	3-6 months	3-6 months	3-6 months	3-6 months
17. Yield (t/ha)	14. 0	24.58	14.93	17.34	14.44	16.03
18. Aroma	Mild	Mild	Natural	Natural	Mild	Natural
19. Flavor	Slightly sweet	Flat	Slightly sweet	Slightly sweet	Slightly sweet	Slightly sweet
20. Texture	Dry tough	Dry tough	tender	tender	tender	tender
21. General acceptability	Like Moderately	Like Slightly	Like Moderately	Like Moderately	Like Moderately	Like Moderately

Pest

The only pest observed in the experimental area specifically in the saline-prone area which affected the yield of some of the accessions was white grubs. Grub infestation was noted from 3 to 6 months after planting. Yellowing of the leaves and wilting were the observed above ground symptoms. Examination at the base of the plant showed white grubs feeding on the tubers. Moreover, the climatic condition during the months where infestation was observed was favorable for the insect because of low rainfall. Grubs feed on the roots of plants, and also cause mechanical damage as they tunnel through the soil. In addition to damaging roots and stems of potatoes, white grubs feed on tubers, leaving large shallow circular holes in them. The infested plants often do not show symptoms on aboveground parts. As a result, considerable damage was done before the grub problem is discovered. In heavy infestations, the soils become soft and fluffy due to grub movement.

Cost and Return Analysis

In the saline-prone area, the simple cost and return analysis showed that only Accession 6 and 10 was economically viable. Accession 10 had 900% while Accession 6 had 387% returns on investment. Similarly, in the acid soil, the Accession 6 and 10 had 372% and 414% return on investment, respectively.

Conclusion

In saline-prone areas and in acid soils, planting of yam accessions 6 and 10 would be beneficial to farmers. There is really a great potential for commercial exploration of yam considering the fact that it can thrive well even in soils with constraints in crop production. It can always be considered as a component of every farming system. However, since both accessions have white flesh color and most people prefer yam which are violet in color they could just undergo product improvement and development. To encourage farmers to go into yam production, it is recommended that the yam industry be promoted, package the yam-based products by way of capacity building such as trainings, seminars, demonstration and organizing them into cooperatives. Full government support for this value crop is enjoined to push the full development of the yam industry. This is one way of managing the soils for the future generations. The use of problems soils for crops than can adapt to the existing soil conditions.

References

Babiera *et.al*. (1998) 'Management of Coastal Saline Soils in the Philippines'. (BSWM).

Haseltine M (1996) 'Yield Reduction vs. Salinity for Field Crop Classification, Properties and Management of Aridisols'.

Krismurthy R *et. al.* (1987) 'Tiller Growth as an Index of Salinity resistance, IRRI, vol. 12. no. 5.'. (IRRI)

Oosterban RJ (2003) www.waterlog.info

Ruiz RB (2000) 'Generating Ubi Plants Variabilities, Observational Traits and Wide Crosses'. (CSSAC: Pili, Cam. Sur).

Geochemical regional surveys: comparative analysis of data from soils and stream sediments

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Abstract
Geochemical maps based on soils and on stream sediments were compared. It was found that the natural background for elements in the two media is quite similar. The same applies to their spatial patterns, except for P. The ratio stream sediment/soil element concentrations increases with increasing soil acidity for Ca, Cu, K, Ba, and also for Mn, Sr and Zn, suggesting that element mobilization under low pH is an important process controlling sediment composition.

Key Words
Geochemical surveys, soils, stream sediments, Portugal.

Introduction
Multi- element geochemical mapping has been a priority for many countries since it provides basic information required to environmental research and legislation and to many other fields of investigation such as agriculture, forestry and human and animal health. The entire continental area of Portugal is covered by a geochemical survey (Ferreira et al. 2001; Inácio et al. 2008). Both topsoils and active stream sediments were collected and analysed according to standardized methods, in order to achieve a high quality and consistent database recording the present composition of the surface environment. Stream sediments generally represent a composite of the geological materials in upstream areas, whilst soil samples are considered point-source data, providing site-specific information. The main purpose of the present study was to compare (i) the natural background of 18 selected elements (Al, As, Ba, Ca, Co, Cr, Cu, Fe, K, La, Mg, Mn, Ni, P, Pb, Sr, V and Zn) and (ii) their spatial variability in the two sampling media. Additionally, a relationship between topsoil pH and sediment composition was investigated.

Methods
Recommendations of the IGCP project 259 "International Geochemical Mapping" (Darnley and Garret, 1990; Darnley et al., 1995) were followed for sampling, sample preparation and analysis. A total of 652 sampling sites were obtained in this way, giving a sampling density of one site/135 km^2. At each site a composite sample of stream sediments was collected along a 200 m channel section, at a maximum depth of 30 cm; topsoil composite samples were collected in nearby upstream areas over an area of about 100 m^2, at a maximum depth of 25 cm.

The chemical analysis was performed in the ACME Analytical Laboratories (Vancouver, Canada). The samples were extracted with aqua regia and the extracts were analysed by ICP-AES for 31 elements: Ag, Al , Au, As, B, Ba, Bi, Ca, Cd, Co Cr, Cu, Fe, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sr, Th, Ti, Tl, U, V, W and Zn. Soil pH was measured electrometrically in a soil:water suspension (1:2.5). The color maps for all elements, as well as for pH, were plotted by kriging. Dot maps were used to superimpose the spatial distribution of elements in topsoils on stream sediment color maps. The dot maps were obtained using the technique described in Björklund and Gustavsson (1987) and Gustavsson et al. (1997).

Results
Summary statistics
Summary statistics of 18 elements selected after analytical quality control are shown in Table 1. The mean, median, geometric mean, observed range and expected range for these elements in the two media are quite similar and they generally agree with the figures reported for world soils in Adriano (1986), Angeloni and Bini (1992) and Kabata-Pendias (2001).

Table 1.Summary statistics of the analytical data for 652 topsoils and stream sediments (M, median; GM, geometric mean; Observed Range, minimum-maximum; Expected Range, 5th- 95th percentile).

Element	Stream sediments				Soils			
	M	GM	Observed Range	Expected Range	M	GM	Observed Range	Expected Range
Al (%)	1.59	1.40	0.22-4.40	0.45-2.78	1.84	1.69	0.19-9.30	0.43-4.50
Ba (mg/kg)	68	68	8-492	27-178	53	51	6-422	16-154
Ca (%)	0.21	0.30	0.01-23.55	0.05-5.82	.10	.11	.01-23.24	0.01-4.08
Co (mg/kg)	9	8	1-155	2-23	8	7	1-84	1-27
Cr (mg/kg)	23	21	3-305	6-60	21	18	1-336	4-59
Cu (mg/kg)	22	20	1-817	5-69	16	14	1-245	3-53
Fe (%)	2.45	2.19	.39-7.64	0.75-4.80	2.74	2.26	.23-6.45	0.56-4.67
K (%)	0.14	0.15	0.01-1.63	0.05-0.53	0.15	0.16	0.02-1.52	0.05-.68
La (mg/kg)	23	23	2-100	10-50	25	24	1-155	9-60
Mg (%)	0.38	0.32	0.01-2.69	0.07-0.88	0.29	0.26	0.01-4.24	0.04-1.03
Mn (mg/kg)	411	444	32-19878	110-1798	394	357	13-4965	59-1857
Ni (mg/kg)	19	14	1-371	2-52	16	13	1-880	3-56
P (%)	0.046	0.047	0.006-0.281	0.015-0.148	0.038	0.036	0.004-0.610	0.010-0.136
Pb (mg/kg)	19	20	3-1378	8-65	21	21	3-585	8-51
Sr (mg/kg)	15	16	2-280	6-63	10	11	2-217	3-40
Th (mg/kg)	4	5	2-61	2-20	5	5	2-87	2-23
V (mg/kg)	26	25	3-143	8-69	27	25	3-192	7-75
Zn (mg/kg)	74	66	7-2365	14-203	55	46	5-738	10-113

Soil concentrations were correlated with the corresponding stream sediment data. Mono-element correlations (Spearman rank order) are significant ($P < 0.00001$) particularly for Al, Co, Cr, Fe, K, La, Mg, Mn, Ni and V. Soils are relatively enriched in Al, and present slightly higher concentrations in Fe, K, La and Pb. Stream sediments have higher median for Ca and Sr, followed by Ba, Cu, Mg, P and Zn.

Spatial patterns

Maps of spatial distribution of the elements in the two media, as assessed by visual inspection, are generally similar except for P. The composition of soils and stream sediments appears to be chiefly controlled by provenance from the same rock source but the patterns can also be related to anthropogenic factors as illustrated in Figure 1. The spatial pattern of V, presented in Figure 1a, is given as an example of lithological control. The highest V concentrations in soils and sediments are chiefly related to the mafic/ultramafic lithologies observed in Figure 1b.

The spatial distribution of Pb in soils and sediments (Figure 1c) is not related to the bedrock lithology shown in Figure 1b. The high concentrations in the littoral west, namely around the urban and industrial areas of Oporto, Lisbon, Setúbal and around the industrial complex of Sines, where mineral occurrences are not known, are likely to be anthropogenic. Some spots of high Pb concentrations in the interior can be related to old mines. High P contents in both soils and sediments (Figure 1d) are found in areas underlain by granitoids. High P concentrations only in stream sediments occur in an extensive agricultural area north of Lisbon and might be related to the use of phosphate fertilizers.

Point by point comparison of the two data sets

In order to examine more carefully the regional distribution patterns, the two data sets were compared point by point. For each element at each sampling site the ratio R = (concentration in topsoil)/ (concentration in sediment) was calculated. The maps prepared (not included due to lack of space) show that the stream sediments are impoverished in the residual elements Al and La and enriched in the mobile elements Ca and Sr throughout the country. The pattern for the remaining elements is more complex.

The influence of soil pH on stream sediment composition

Soil pH is a major parameter controlling the mobilization of many elements from soils. As soils become more acidic, their ability to retain Ca, Mg, K and many trace elements decreases. As a result, these elements are then more able to be exported by drainage water and flow into streams where they may precipitate or become adsorbed on bed load material.

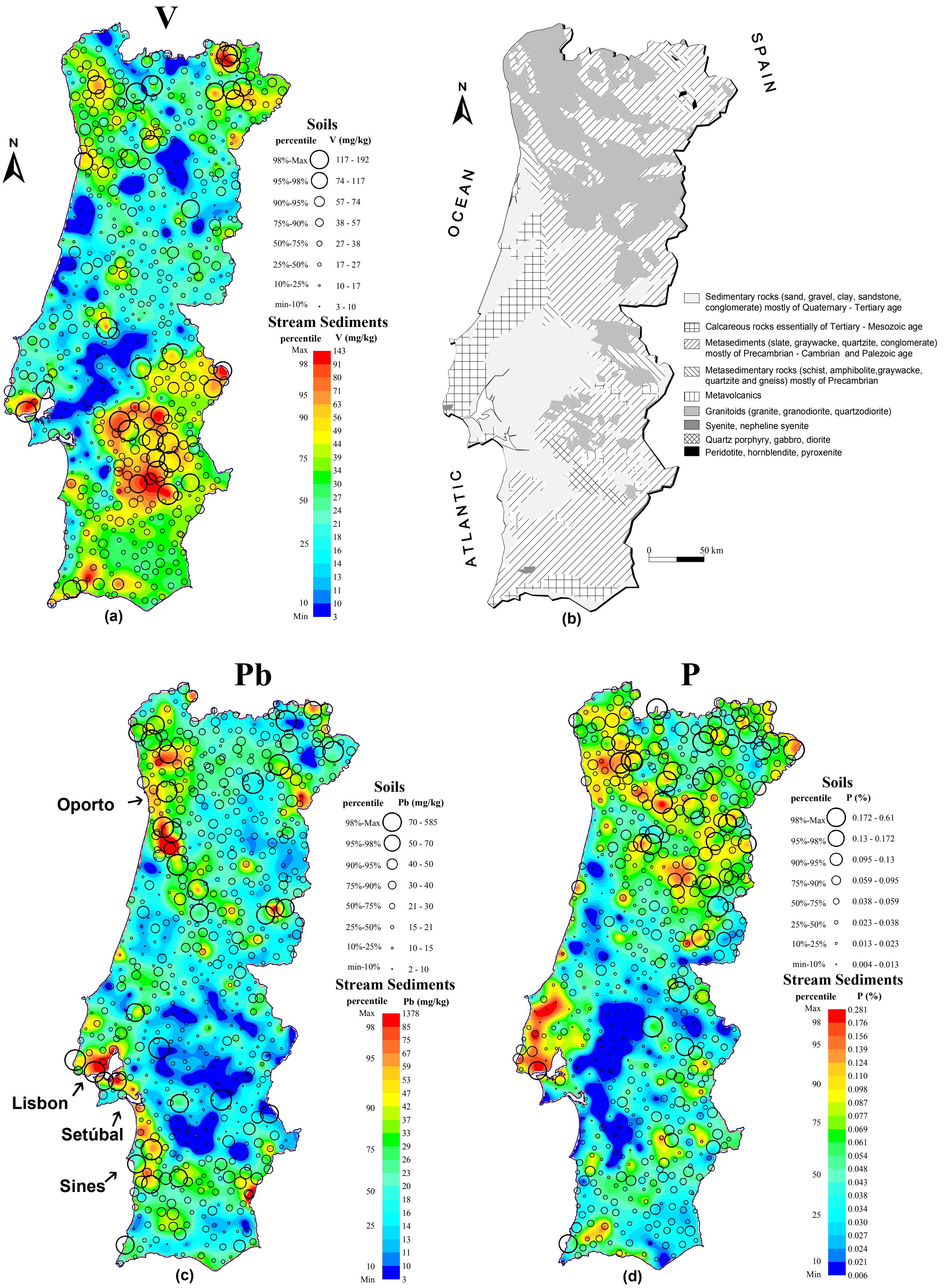

Figure 1. (a) Spatial distribution of V, in stream sediments and topsoils; (b) Lithological map of Portugal (simplified from Atlas do Ambiente, 1992); (c) Spatial distribution of Pb in stream sediments and topsoils; (d) Spatial distribution of P in stream sediments and topsoils.

The relationship between topsoil pH and sediment enrichment for the 18 elements was investigated adapting the procedure described in Hall et al. (2001) as follows. First, the R ratios (sediment/topsoil concentration) for each metal, calculated in the previous section, were grouped into three classes according to the pH of the topsoil: ≤4.50, 4.51-5.50 and ≥5.51. The three populations were then compared using the Kolmogorov-Smirnov test. The results showed that for Ca, Cu, K and Ba the median R ratio increases with decreasing pH. The same applies for Mn, Sr and Zn but the relationship with pH is weaker. This means that where the soils are more acid, the stream sediments are enriched in these 7 elements relative to topsoils. The R ratios for the remaining elements show non-significant correlation with top soil pH.

Conclusions

The two surveys give similar information on the background concentrations of 18 selected elements.
The composition of topsoils and stream sediments appears to be chiefly controlled by provenance from the same rock sources. The influence of anthropogenic factors such as mineral exploration, urban and industrial development and agricultural practices could also be detected as evidenced by the accumulation of Pb and P. The empirical relationships between the ratio stream sediment/topsoil element concentrations and topsoil pH suggest that mobilization of Ca, Cu, K, Ba, Mn, Sr and Zn from topsoils to stream sediments in acidic soils is a process not to be disregarded.

References

Adriano DC (1986) 'Trace Elements in the Terrestrial Environment'. (Springer-Verlag: New York).

Atlas Digital do Ambiente (1992) Ministério das Cidades, do Ordenamento do Território e Ambiente. www.iambiente.pt/atlas/.

Angelone M, Bini C (1992.Trace Element Concentrations in Soils and Plants of Western Europe. In 'Biogeochemistry of trace metals'. (Ed DC Adriano) pp. 19-60. (Lewis Publishers).

Björklund A, Gustavsson N (1987)Visualization of geochemical data on maps: new options. *Journal of Geochemical Exploration* **29,** 89-103.

Darnley AG, Garrett, RG (1990) International Geochemical Mapping. *Journal of Geochemical Exploration* **49,** 1-250.

Darnley AG, Björklund A, Bölviken B, Gustavsson N, Koval PV, Plant JA, Steenfel A, Tauchid M, Xie Xuejing (1995) A Global Geochemical Database for Environmental and Resource Management. Recommendations for International Geochemical Mapping. Final report of IGCP project 259. UNESCO Publishing.

Ferreira AM, Inácio M, Morgado P, Batista MJ, Ferreira L, Pereira V, Pinto MS (2001) Low density geochemi-cal mapping in Portugal. *Applied Geochemistry* **16,** 1323-1331.

Gustavsson N, Lampio E, Tarvainen T (1997)Visualization of geochemical data on maps at the Geological Survey of Finland. *Journal of Geochemical Exploration* **59,** 197-207.

Hall JR, ReynoldsB, Sparks T, Colgan A, Thornton I, McGrath SP(2001) The Relationship between Topsoil and Stream Sediment Heavy Metal Concentrations and Acidification. *Water Air and Soil Pollution* **130,** 1067-1072.

Inácio MM, Pereira V, Pinto MS (2008) The Soil Geo-chemical Atlas of Portugal: overview and applications. *Journal of Geochemical Exploration* **98,** 22-33.

Kabata-Pendias A (2001) 'Trace Elements in Soils and Plants (3rd edition.)'. (CRC Press: Boca Raton, FL)

Reimann C, ÄyrÄs M, Chekushin VA, Bogatyrev I, Boyd R, Caritat P, Dutter R, Finne TE, Halleraker J H, Jaeger Ø, Kashulina G, Niskavaara H, Lehto O, Pavlov V, RÄiSÄnen ML, Strand T, Volden T, (1998). Environmental Geochemical Atlas of the Central Barents Regions. NGU-GTK-CKE special publications, Geochemical Survey of Norway, Trondheim, Norway.

Gross soil modification of duplex soils through delving and spading

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Abstract
Duplex soils in South Australia present a number of constraints that have been observed to reduce root growth and plant yield. This paper investigates two soil modification processes that have been developed to mix soil horizons, thus reducing the impact of some subsoil constraints. One technique is called "clay delving", and involves using a specially designed ripping tine that peels clay from the B horizon, through the A horizons to the surface. The other technique is called "Spading" and involves the use of a "spader" machine. This machine uses a series of off-set, rotary "spades" to mix the surface horizons to a depth of approximately 30-40cm.

Both soil mixing procedures have been used to bring up and mix in clay from the B horizon, as well as to mix in surface materials such as hay, green manure crops, surface applied clay, lime and gypsum. Trial data gathered from measuring changes in the soil, as well as measured changes in plant yield are presented from 2 field trials. Significant improvements in subsurface and subsoil root growth have been observed, and plant dry matter growth has been recorded to improve considerably.

Key Words
Bleached, waterlogged, infertile, root abundance, soil morphology, yield.

Introduction
Soils with duplex (Northcote 1979) properties often present restrictions to plant root development (Hall *et al.* 2009). Investigations into methods that significantly alter the condition of the upper profile in duplex soils have indicated that the performance of crops and pastures could be improved (Groocock pers. comm.; Bailey unpublished data). A significant amount of research has been undertaken to investigate the potential for improving sandy soils by working dispersive clays to the surface horizon (Ma'shum *et al.*1989; Cann 2000).

This paper presents findings from a pair of trials that further modify the soil by mixing the horizons of the upper profile through the use of a "spader" machine, and through a technique known as "clay delving". Clay delving is described in detail in Desbiolles *et al.* 1997, and involves using a specially modified ripping tine, a metal prong that peels clay from the B horizon, through the A horizons to the surface. "Spading" using the spading machine uses a series of off-set, rotary "spades" to mix the surface horizons to a depth of approximately 30-40cm. Both soil mixing procedures have been used to bring up and mix in clay from the B horizon, as well as to mix in surface materials such as hay, green manure crops, surface applied clay, lime and gypsum. Some of the data gathered from measuring changes in the soil, as well as measured changes in plant yield are presented here.

Methods
Sand over clay site on the Fleurieu Peninsula (south of Adelaide)
The soil at the Fleurieu Peninsula site was classified as a Brown Sodosol (Isbell 2003), and had a thick sandy A horizon with a strongly bleached A2. The B horizon was a coarsely structured and mottled clay. The A2 horizon presented indications of being highly infertile, and of having been subject to frequent seasonal waterlogging from water perched on the sodic clay sub-soil.

The trial treatments were established between 10th March and 5th May 2009. The trial design comprised 80m long by 15m wide strips of each treatment, placed parallel to each other within the paddock. The trial was divided into 3 replicates. Within each replicate, the 4 treatments were randomly allocated. The treatments comprised a control, a treatment with one pass of the spader machine, a treatment with one pass of a clay delver, and a treatment with one pass of a clay delver followed by one pass of a spader machine. The site was sown to Triticale on 14th June 2009. Dry matter cuts made on 10th September 2009. Each plot had ten cuts made to assess dry matter production, with each cut being 1 meter long by a single plant row wide. A total of

30 cuts per treatment were made. Samples were dried until no more weight was lost at 40°C in a drying oven, then weighed. Soil profiles were excavated within each treatment on 7th October 2009, with observations made regarding soil morphology and root distribution.

Loam over clay site near Naracoorte (in south eastern SA)
The soil at the Naracoorte site was classified as a Brown Chromosol (Isbell 2003), and had a thick, light sandy clay loam (Northcote 1979) A horizon with a paler A2 that contained significant amounts of ironstone gravel. The A2 horizon presented indications of some degree of seasonal waterlogging from water perched on the clay sub-soil.

The trial treatments were established between 22nd April and 6th May 2009. The treatments comprised a control, a treatment with one pass of the spader machine, and a treatment with one pass of a clay delver followed by a single pass of off-set discs. The trial design comprised plots of 10m times 15m, with 4 randomly allocated reps of the control, and 8 randomly allocated reps of each of the other 2 treatments. The site was sown to Barley on 17th June 2009. Dry matter cuts were made on 14th October 2009. Each plot had one cut made to assess dry matter production, with each cut being 0.5 of a meter long by a single plant row wide. A total of 4 cuts were taken from the control plots, and 8 cuts from the other 2 treatments. Samples were dried until no more weight was lost at 60°C in a drying oven, then weighed.

Results

Sand over clay site on the Fleurieu Peninsula
The changes in soil morphology are illustrated in Figure 1. The spading has mixed the A1 and A2 horizons to a depth ranging from 30-35cm. The delving has produced some mixing of clay into the A1 and A2 horizons, and significant mixing of sandy material to a depth of about 60cm into the B2. Root abundance in the A2 of the control was classified as "few" (McDonald *et al.* 1990), while the root abundance in the portion of the A2 modified by spading, and the A2 and B2 modified by delving, portrayed root abundances of "common to many" (McDonald *et al.* 1990).

Figure 1. The left hand profile illustrates the control soil, the middle profile shows the effect of spading, and the right hand profile shows the impact of clay delving.

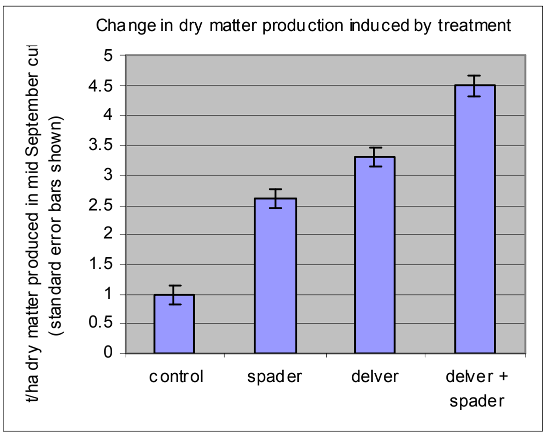

Figure 2. Plant productivity responses to the soil modification treatments.

Dry matter cut from the crop at mid-September showed large improvements in plant growth as a response to the soil modification processes implemented. Table 1 and Figure 2 present the mean results from the dry matter cuts made of the treatments in September 2009, and the means are presented with error bars generated from the standard error.

Table 1. Plant productivity responses to the soil modification treatments.

Treatment	Mean t/ha	Standard deviation
control	1	0.4
spader	2.6	1.1
delver	3.3	1.4
delver + spader	4.5	1.8

Loam over clay site near Naracoorte, SA

Significant changes in surface soil condition were observed, including clay brought to the surface in the delved plots, and paler A2 material and large amounts of ironstone gravel in the spader plots. Excavations were not made to observe subsurface and subsoil changes in soil morphology and root distribution.

Figure 3. A photograph of the soil surface of a delved plot taken 26th June 2009, illustrating the clay worked into the soil surface.

Dry matter cut from the crop at mid-October showed significant improvements in plant growth as a response to the soil modification processes implemented. Table 2 and Figure 4 present the mean results from the dry matter cuts made of the treatments in October 2009, and the means are presented with error bars generated from the standard error.

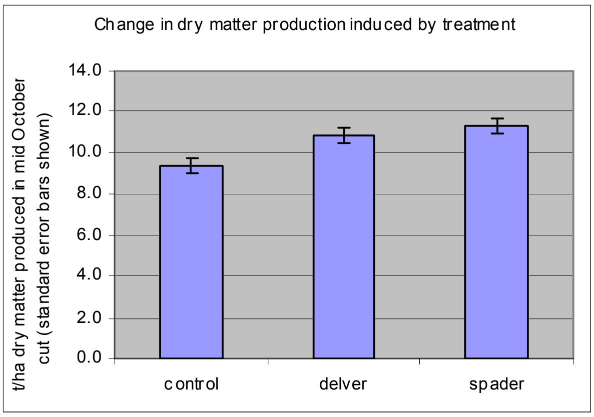

Figure 4. Plant productivity responses to the soil modification treatments.

Table 2. Plant productivity responses to the soil modification treatments.

Treatment	Mean t/ha	Standard deviation
control	9.4	1.5
delver	10.8	1.1
spader	11.3	2.1

Conclusion

Both the spader machine and the clay delving process grossly altered the morphology of the two soils investigated. The spader machine appeared to improve the condition and root abundance of the upper A2 horizon, while the clay delving appeared to improve root development well into the clayey B horizon. Early growth results appear to confirm previous anecdotal evidence, that modifying texture contrast soils through the mixing of the surface horizons significantly improves plant productivity. The large increases achieved include changes to weed populations and disease incidence, as well as the observed root growth and soil modification changes. Consequently, monitoring over time will be required to determine the long term response to the soil morphological changes.

Acknowledgements

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References

Hall JAS, Maschmedt DJ, Billing NB (2009) 'The Soils of Southern South Australia'. Dept of Water Land and Biodiversity Conservation, Government of South Australia.

Cann M (2000) Clay spreading on water repellent sands in the south east of South Australia- promoting sustainable agriculture. *Journal of Hydrology*. **231-232**, 333-341.

Desbiolles JMA, Fielke JM, Chaplin P (1997) An Application of Tine Configuration to Obtain Subsoil Delving for the Management of Non-Wetting Sands. *Third International Conference on Soil Dynamics (ICSD III)*, Tiberias, Israel, 3-7 August 1997.

Ma'shum M, Oades JM, Tate ME (1989) The use of dispersive clays to reduce water-repellency of sandy soils. *Australian Journal of Soil Research* **27,** 797-806.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) 'Australian Soil and Land Survey Field Handbook Second Edition'. Inkata Press, Melbourne and Sydney, Australia

Isbell RF (2003) 'The Australian Soil Classification- Revised edition'. CSIRO Publishing, Collingwood, VIC.

Northcote KH (1979) 'A Factual Key for the Recognition of Australian Soils'. Rellim Technical Publications P/L, Adelaide, South Australia.

Integrating soil and water resources in local development framework : the ASTUCE & TIC program

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Abstract
Urban growth is a factor of productivity but urban spreading is a major threat for soil and water resources. Local development must consider a city with its hinterland (Figures 1 and 2). Soil and water resources are needed for food production, water supply and their degradation can impair the possibilities of cities to generate wealth and the economic resources for financing local development and managing public resources (Figure 3). Data are generally available but dispersed. There exist already numerous models, separately calibrated and checked, that allow the users to take into account land use change and climate change to evaluate the modifications of soil properties due to urbanization, the crop requirements of water and nutrients, the geochemical interactions between soils and water and economic models based upon cost/benefits approach. The ASTUCE & TIC program aims at showing that different models of the type above can be integrated to help policy-markers to cope more efficiently with urban spreading.

Key Words
Soil, water, cities, urbanization, development.

Introduction
Occurrence of crisis and transitions in food products, climates, environments and energies are abundantly described, analysed and commented on, especially in collective studies and consultations (e.g. Pachauri and Reisinger 2007; Taylor 2008). These crisis and transitions have in common that they concern the agricultural, urban and industrial domains simultaneously, the land uses and the division of the resources (water, foods, energy) which are in interrelationship ones to another. They contribute to come back to the first plan of the international concerns of the policy (FAO 2009). For these challenges, the efforts may care on the capacity to: (i) analyse the territories at different organisation levels; (ii) increase the capacity of expertise by working in different domains together; (iii) aggregate and make technological innovations of other sectors suitable for the development of new tools for analysis and expertise. Historically cities were built up in territories where Humans could find easily foods and water. The present urban spreading in the world threatens significantly and with irreversible impacts the most fertile and the most easily to work agricultural soils. This increases the energy demand, transport infrastructure, contributes to the green house gases emission and has a negative impact on the natural resources of the territories. Degradation of soils and waters thus impair the capacity of cities to develop and satisfy the needs of populations who live in. The legitimate claiming for an environmental planning based on the sustainability of the systems meets with numerous difficulties, e.g. benefits in short time in agriculture, financial deregulation in exchanges, migration of population to the cities… which are limiting factors for soil and water management.
In this context, the main goal of ASTUCE & TIC program is to build up an integrative approach of the landscape by mixing knowledge and know how developed until today independently in agronomy, soil science, geochemistry, geography, urbanization and economy. This method of integrating data can be used within the conceptual framework of the ECOLOC (Club du Sahel/OECD 2001) or Agenda 21, which combines study, debates encouraging ownership and policy discussion, and the implementation of development actions.

Methods

Basic concepts

The basic concept is that urban growth cannot be considered independently of its surrounding rural areas, i.e. its "hinterland". A city and its "hinterland" can be considered as a system consisting of several subsystems which exchange matter, such as water, dissolved elements, biomass, and information, such as internal and external signals (Figure 1). The topology of the relationships between the subsystems is an important property of the system (Figure 2). Data are generally available but in such a dispersed way that policy makers lack a synthetic view of the environmental impacts of their decisions.

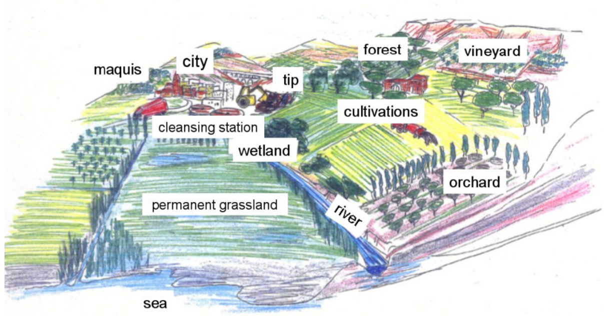

Figure 1. A city and its surrounding areas

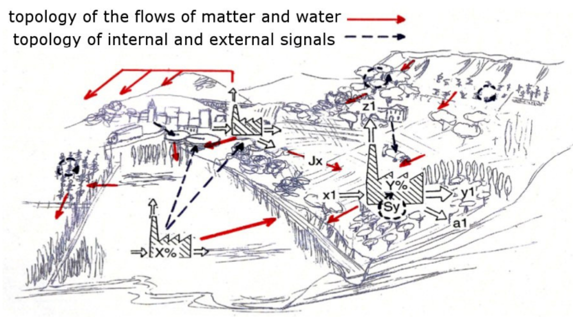

Figure 2. Fluxes and matter transformations in the city/hinterland viewed as a system

The now classical approach is: Driving force – Pressures – State – Impacts – Responses. Driving forces are twofold, population change and climate change, and result in land use changes from agriculture to urban use, including roads, airports etc. and a modification of water and soil resources that can be integrated in scenarii. These pressures modify the state of the system both in urban areas where soil permeability is impaired and soils are destroyed irreversibly, and in rural areas where food demand requires soil, water and nutrients. This results – through the modification of flux of water in the "critical zone" and of water quality through biogeochemical cycles in soils – in changes of the quantitative and qualitative inputs to groundwater. Eventually, different hazards are estimated: loss of soil resources and biodiversity, increase of runoff in non permeable areas, decrease of potability of water, decrease of food production and economic resources for the population, increase of water salinity and soil salinity, degradation of soil physical properties due to sodicity if swelling clay minerals are present. Ecosystem goods and services must thus be evaluated during the land transition dynamics in different domains and require a framework able to mobilize local authorities, academic organisations and private firms, ensuring the involvement of local actors from the very beginning of the study phase (Figure 3).

Demonstration area

The tools are tested on the Crau's plain as an area of demonstration. This territory is localised in the Bouches-du-Rhône department in the south of France. The area covers 60,000 ha between the Rhône river at West, the Berre's pond in East, the Alpilles mountains at North and Mediterranean Sea at South. The alluvial plain of Crau is divided into a semi-arid steppe of 9,200 ha with a remarkable ecosystem (a natural, cultural and economic exception at the departmental, national and European scales) and the Crau of the grasslands of 12,500 ha where is grown the renowned hay "foin de la Crau" AOC (Appellation d'Origine Contrôlée). Today the intensive fruit growing overrun the pastoral areas progressively. The Crau's plain has a large underground water table. The waters of the Durance's river constitute 70% of the input of this water table via the agricultural irrigation. This area of 20,000 ha determines the supply of drinking water to 250,000 inhabitants and of water to the large industries located in the south of the territory. This area is submitted to diverse pressures, all in relationships with the spreading of the cities: (i) urban and industrial pressures concentrated in the South in relationships with the Fos's industrial zone; (ii) spreading of urbanization from the districts of Saint-Martin de Crau, Miramas, Salon-de-Provence and Arles; (iii) increase of pressures on the underground water table: uptake, urban sludge spreading, diffuse pollution; (iv) increase of greenhouse fruit production.

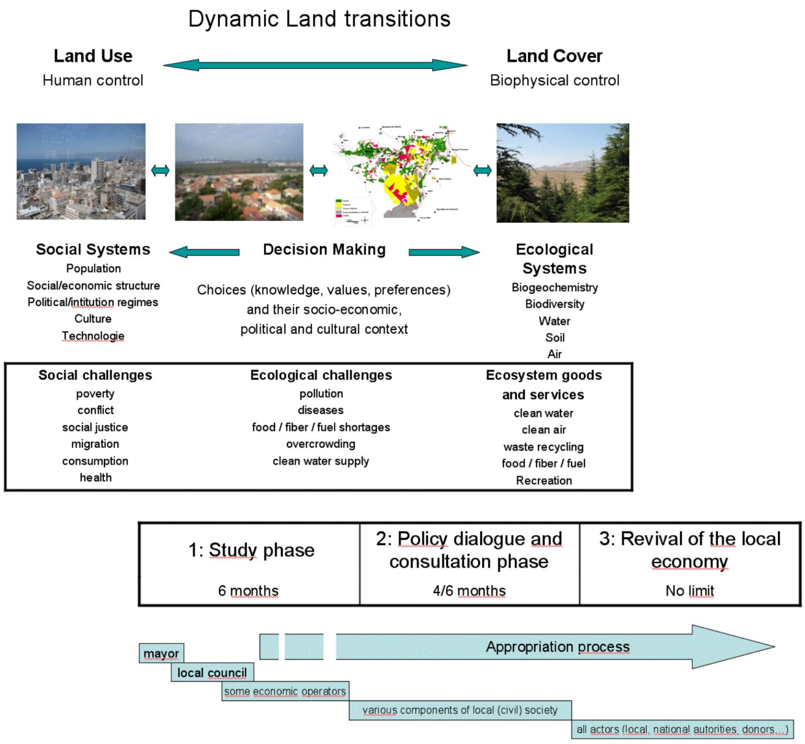

Figure 3. Analysis of land use changes and challenges and operational steps to apply this approach to a city and its hinterland (combined from Club du Sahel/OECD, 2001 and Global Land Project, IGBP, Aspinall 2009)

Results

The preliminary results are only available, as the study has been undertaken at the beginning of 2008. The models were chosen as explained hereafter to give birth to a partly integrated approach. This integrated approach is based upon modelling of land use changes, urbanization, soil changes in urban areas, crop models, geochemical interactions between soil and water and cost/benefits.

Land use changes are modelled on the basis of cellular automates, allowing to calibrate the rules of land use changes and to simulate the future changes on the basis on geographical data bases, both of spatial and socio-economic nature, of the accessibility of transportation networks, of land planning (zoning). Given its situation, properties and local dynamics, the model estimates for each cell the probability of the land use to change. After comparison of different models (MEPLAN, METRONAMICA, SLEUTH, SPACELLE) the model chosen here is METRONAMICA™, on the basis of speed of calculation and precision.

Changes of soil properties in urban areas are assessed in the following ways: (i) artificialised areas are classified in several types following an object oriented classification; (ii) soil water proofing is estimated for each class objects; (iii) soil quality is globally estimated using the water holding capacity as a synthetic index of soil quality, this being completed with secondary constraints (slope, hydromorphy, salinity). Soil pollution is evaluated for point-polluted areas.

Crop models are used to evaluate: (i) the ability of surrounding agricultural areas to provide foods; (ii) the water and nutrients requirements; (iii) the flow of water drainage below the root zone; (iv) the carbon budget in the topsoil. The model chosen is STICS as it is used by a large community (Brisson *et al.* 2003). It allows the users to compute the different terms of the water balance (soil moisture, evapotranspiration, drainage and runoff), the carbon and nitrogen budget, and the plant growth. This model incorporates crop system characteristics and can accept remote sensing data such as Leaf Area Index (LAI) as input. It has been recently used to model crop response to climate change (Brisson 2008).

Biogeochemical cycles in soils modify water quality and make groundwater potable. The input of water drainage to the groundwater is thus one of the essential ecosystem services. Well-managed agricultural areas protect water quality. The model chosen is PHREEQC as it is used by a large international community (Parkhurst and Appelo 1999). The input data of PHREEQC are water quality entering soil and crop model outputs, while output data of the PHREEQC model are water quality of groundwater, its safety, its salinity, its alkalinity and pH, soil salinity and soil sodicity. Soil salinity affects adversely soil fertility, while soil sodicity impairs the physical properties of soils, if swelling clay is present, due to the low permeability of sodic swelling clays.

Economic model is based upon a costs/benefits approach; built capital and environmental assets (forests, biodiversity, soils, water) must be considered together as part of economic patrimony of territories. This aims at demonstrating which local, regional or national decisions can be effective to counteract the degradation of natural patrimony due to land use and climate changes. Outputs of METRONAMICA™, STICS and PHREEQC are converted in economic values to give indicators.

A geomodel is used to integrate the results and obtain a spatial distribution of the data to test and develop scenarii, rather than a GIS representation. The major limitation of GIS is that these models are static and do not take into account the dynamics of the objects (e.g. soils). They give only a snapshot of the surface: representation of data by splitting them into information layers result in the loss of the intrinsic properties of the objects or subsystems. Instead, geomodels take into account the 3D geometry of geosystems, their heterogeneities (faults, folds, thickness of strata) and different types of data (geology, geophysics, geochemistry). Their development was funded by petroleum and mining industries and can be adapted to environmental dynamics (Bile *et al.* 2009). The geomodel retained is gOcad™ (Mallet, 2002).

Conclusion

The first results show that different tools can be interfaced so that output of a model is the input of another, and that dynamic data can be obtained at compatible times and frequencies. The economic analysis shows that for the territory studied the future development will be hindered by the shortage of available resources. Integration of available data on the basis of already existing tools is thus useful to help policy makers to face the ill-mastered consequences of urban spreading. This approach can be used within strategies of local development framework associating local public authorities, local or national academic organizations and local actors from the study phase to dissemination and debates.

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References

Aspinall R (2009) *Global Land Project: Major scientific questions for coupled modeling of land systems,* In: 'Regional aspects of climate-terrestrial-hydrologic interactions in non-boreal Eastern Europe' (Eds P Groisman, YaS Ivanov). (Springer-Verlag: Berlin).

Bile R, Viseur S, Trolard F, Revil A, Bourrié G (2009) gOcad modeling of self-potential data for 3-D reconstitution of soil heterogeneity and paleochannels in the Rhône river delta. In '29th gOcad Meeting Proceedings', (Ed G Caumon), (Nancy School of Geology: Nancy).

Brisson N (2008) Modéliser la réponse des cultures à la contrainte hydrique avec le modèle STICS pour comparer des stratégies et anticiper les changements climatiques, *Innovations Agronomiques* **2**, 9-18.

Brisson N, Gary C, Juste E, Roche R, Mary B, Ripoche D, Zimmer D, Sierra J, Bertuzzi P, Burger P, Bussière F, Cabidoche YM, Cellier P, Debaeke P, Gaudilère JP, Maraux F, Seguin B, Sinoquet H (2003) An overview of the crop model STICS*, European Journal of Agronomy* **18**, 309-332.

Club du Sahel/OECD (2001) Managing the economy locally in Africa, ECOLOC Handbook, Assessing local economics and their prospects, Vol. 1, Summary*,* Programme de Développement Municipal, Club du Sahel/OECD, SAH/D, 511, Paris.

FAO (2009) The state of food insecurity in the World 2009. (FAO: Roma).

Mallet JL (2002) Geomodeling, Applied Geostatistics Series, Oxford University Press, New York.

Pachauri RK, Reisinger A (2007) Climate change 2007: synthesis report. (IPCC: Geneva).

Parkhurst DL, Appelo CAJ (1999) User's guide to PHREEQC (Version 2), A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. *Water-Resources Investigation Report 99-4259*, U.S. Department of the Interior, U.S. Geological Survey, Denver, Colorado.

Taylor M (2008) Perspectives des technologies de l'énergie 2008 – Scénarios et stratégies à l'horizon 2050. (Agence Internationale de l'Energie: Paris).

Soil characteristics and their role in developing conditions favorable for denitrification

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Abstract
The use of riparian buffers and controlled drainage to reduce nitrate-nitrogen in groundwater has been documented in many field studies. Denitrification is the mechanism attributed to nitrate losses. For these Best Management Practices to effectively remove nitrate from groundwater, conditions must be favourable for denitrification. Critical factors for this biological transformation to occur include the presence of nitrate, a source of carbon, a favourable pH, and an appropriate range in temperature. Soil redox potential is an indicator that provides evidence as to whether or not nitrate reduction would occur. This research was conducted on four riparian buffers, each with five vegetative treatments, in order to determine if these factors were present and if so, if they were within the range required for denitrification. In addition, the effect of soil texture and its relationship to these factors was also studied. Soil texture had an influence on soil redox potential. Sandy textured soils generally had redox values too high for denitrification, while clayey textured soils provided lower redox values that were within the range for this biological transformation. Carbon was located at all locations on the buffers. While it generally was accumulated in the surface horizons, soil carbon content was also measurable at greater depths, especially where soils were sandy textured. Soil nitrate was also found deeper in the soil profile where soils were higher in sand content, which is a result of leaching. Soil nitrate patterns were similar. Soil temperature and soil pH did not appear to be limiting factors at the research site.

Key Words
Soil redox, soil texture, nitrate, soil carbon, riparian buffer, controlled drainage.

Introduction
Research efforts during the last several years have contributed to the knowledge that riparian buffers effectively remove pollutants, specifically nitrate-nitrogen from groundwater (Jacobs and Gilliam 1985; Lowrance *et al.* 1985; Jordon *et al.* 1993; Gilliam 1994). Nitrate-nitrogen is customarily found in groundwater in Eastern North Carolina as a result of agricultural practices and is affected by soil type and hydrology (Spalding *et al.* 1993). In recent years, efforts have been undertaken to reduce the amount of nitrate-nitrogen moving into groundwater and subsequently, to surface waters. Riparian buffers are commonly narrow forested or grassy areas located along small streams and rivers. Laterally flowing groundwater, frequently flowing above a restrictive layer located in the soil profile, flows into the riparian zone, which are generally characterized as having poorly drained soils. Denitrification, a major pathway through which nitrate-nitrogen is removed, occurs in this zone. However, the presence of nitrate in a saturated soil does not ensure denitrification. Other factors, i.e., amount and presence of organic matter, pH, the presence of denitrifying microorganisms, and soil temperature influence the occurrence of this biological reduction. Oxidation-reduction reactions occur as oxygen becomes limiting. In the absence of oxygen, anaerobic bacteria use other oxidized species as electron acceptors in a stepwise order. Nitrate becomes the electron acceptor upon the disappearance of oxygen, followed by MnO_2, $Fe(OH)_3$, SO_4^{2-}, and CO_2. Organic matter must be present for these oxidation-reactions to occur, as it is the energy source for anaerobic bacteria. A review of nitrate removal in stream riparian zones by Hill (1996) suggested the importance of a continuous supply of carbon as an energy source for denitrifying bacteria that further indicates the significance of the link between vegetation and denitrification. The ability of a soil to retain water or reduce its flow (permeability) is influenced by soil texture. Coarse textured soils have little structure, large pores, and permit rapid flow of water. In contrast, fine-textured soils have small pores due to aggregation and retard the transmission of water. This influences conditions that are required for denitrification, such as whether or not the oxygen status is high or low (saturated soil). Nitrate-nitrogen, which is of great concern with regard to water quality, is highly mobile and easily leached. Smith and Cassel (1991) estimated the

nitrate leaching ability of soil materials. They noted four aids in estimating nitrate leaching, which included permeability, available water-holding capacity, hydrologic group, and leaching class. Leaching class is based on soil texture. Soils that have a sandy texture are expected to have leaching losses in most years, while the finer textured soils, such as clays, will have insignificant losses. Texture is also an important element in decisions regarding the use of water table management. Soil permeability is the most important soil factor in determining the effective use of controlled drainage, a practice that has been shown to be useful in reducing the amount of N through reduced flow and higher denitrification rates due to favorable conditions provided by a higher water table (Doty *et al.* 1986). Megonigal *et al.* (1993) studied the effects of soil texture and relative positions of soil-forming processes. They showed that oxygen content and redox potential generally decreased with depth, except where a perched water table was present and concluded that soils with a high clay content reduce oxygen diffusion rates, resulting in sub-atmospheric oxygen levels even where soil was not saturated. Understanding the processes and factors that control the effectiveness of riparian buffers, as well as controlled drainage, are critical in determining where these practices will work. Redox potential is a good indicator of whether or not conditions are suitable for denitrification.

Methods

Soils investigations for this research study were conducted on buffers located at the Center for Environmental Farming Systems in Goldsboro, North Carolina. Several buffers, in conjunction with controlled drainage, were established along channelized drainage ways for the purpose of evaluating their use in reducing nonpoint source nutrients on water quality in the Neuse River. The site is geologically complex due to its location next to the Neuse River, which is subject to flooding. The soils are terrace and floodplain soils. Recent soil mapping by soil scientists from the government and private sector identify the soils of great extent at this site as Roanoke (fine, mixed, semiactive, thermic Typic Endoaquults), Tomotley (fine-loamy, mixed thermic Typic Endoaquults), Tarboro (mixed, thermic Typic Udipsamments), and Wickham (fine-loamy, thermic Typic Hapludults). However, soil maps are developed at a scale which permits inclusions of other soils and therefore, for site specific work, a soil investigation is required. During the installation of thermocouples on the site, soils were excavated to a depth of 152-cm using a hand auger. During the excavation, the soil was removed from the auger, the depth recorded, and the soil was carefully placed on a plastic sheet in the order in which it was removed. The entire 152-cm profile was described, photographed, and sampled (by horizon) for analysis, which included nitrate-nitrogen, total carbon, pH, and particle size. To easily compare soil profiles located at the ditch and field edges of each of the buffers, soil textures are divided into three group, i.e., sandy, loamy, and clayey texture groups. Generally, the use and management of these soil groups are similar. The sandy textured soils include the sands and loamy sands, while the clayey textured group includes the clays. The loamy textured group was divided into two groups, the moderately coarse-textured or medium textured soil materials and the moderately fine-textured soil materials. The moderately coarse-textured or medium textured soil materials included coarse sandy loam, sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, and silt. The moderately fine-textured soil materials included clay loam, sandy clay loam, and silty clay loam (Soil Survey Division Staff, 1993). General observations about the research site, field Eh measurements, and soil carbon are reported. Nitrate trends and nitrate/chloride ratio patterns were also studied, but they are not reported in this paper.

Results

Soil texture

Soil profiles described on the buffer with no water control structure (R1) and the buffer with a water control structure present (R2), at both the ditch and field edges, contribute information about redox behavior in the soil. Generally, soil horizons of moderately fine-textured or clayey soil materials permitted water to be retained longer, resulting in lower redox potential values by essentially acting as a temporary restrictive layer within the soil profile. This was demonstrated frequently throughout the study period following rainfall events. Soils with moderately fine-textured or clayey horizons exhibited decreases in redox potential values for a brief period. Values rebounded as the oxygen status of these horizons increased. In contrast, soils with sandy horizons in the upper profile provided little water holding capacity and redox potential values remained high throughout the study. However, soils inundated by floodwaters, as a result of devastating hurricanes, behaved similarly with regard to redox potential, for a very short period, regardless of soil texture. This was based on the presence of water and not texture. Differences as to how rapidly soils recovered to their pre-hurricane status were related to soil texture.

Site R1 – ditch edge:
With one exception, soils were fairly uniform along the ditch edge. Soils were generally moderately coarse-textured and medium textured in the upper part, followed by moderately fine-textured or clayey soil materials, which were underlain by sandy soil materials. The exception lacked the moderately fine-textured or clayey soil material within its profile. Redox values at the 76-cm depth were generally above 500 mV throughout the study period, except for the period following inundation by hurricane flooding. One location had a clayey horizon higher in the soil profile as compared to the other three locations and exhibited a fluctuating Eh values following rainfall events. At 152 cm, all soils had sandy soil materials present. In addition, soil colors had a hue of 7.5 YR or 10YR, values of 5 to 7, and chromas of 3 to 8, indicating that reducing conditions were not present. Redox potential values at this depth ranged from 600 mV to 800 mV, which are consistent with non-reducing conditions. It is most likely that when groundwater was present at this depth, it was oxygenated. Hurricane flooding had little effect on Eh values at this depth.

Site R1 – field edge
Soil profiles at the field edge were markedly different from soils at the ditch edge. The most obvious difference is the presence of a clayey layer located within 40 to 80 cm of the soil surface. At 76 cm, Eh values tended to have more variability and behaved accordingly, to rainfall events. At 152 cm, all locations had sandy soil materials present. Soil Eh values, averaging approximately 700 mV, were similar to those at the same depth along the ditch edge with the exception of one location. One electrode at this site consistently had Eh values that hovered slightly above –100 mV. It is interesting, however, that at this location, Eh values decreased dramatically at the 76-cm depth due to a rainfall event, and increased substantially at the 152-cm depth as oxygen was likely moved deeper into the soil profile.

Site R2N – ditch and field edges
The soil profiles located along the ditch edge provide information as to how soil redox potential is affected by differences in soil texture on the same landscape position. Figure 1 illustrates differences between buffers and provides valuable information as to why there were noticeable contrasts in soil redox potential within buffers. The upper part of each soil profile uniformly consisted of moderately coarse-textured and medium-textured soil materials. However, the centre section of the buffer is different than locations at the ends of the buffer, i.e., Locations A, C, E, G, Y, J, K, and M. At the middle of the buffer, moderately fine-textured soil materials are present. Sandy soil materials at Locations G, W, and I dominate the lower part of the profile, while Locations E and J have moderately coarse-textured and medium textured soil materials. Locations K and M are underlain by moderately fine-textured soil materials. At the 76-cm depth, soil Eh values along the ditch edge averaged above 700 mV throughout the study period, decreasing temporarily following rainfall. Soil textures along the field edge were generally moderately coarse and sandy. Redox potential values averaging between 600 mV and 700 mV indicated the soils inability to retain water at this depth during periods following rainfall. It should also be noted that the water table averaged approximately 40 cm below the depth at which the electrodes were installed. Conditions favourable for denitrification were infrequent.

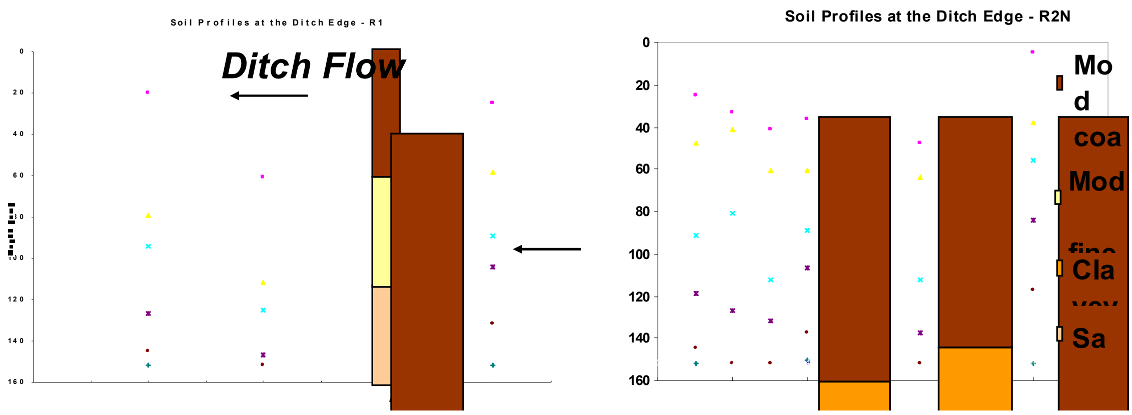

Figure 1. Soil textures at the ditch edges on buffers without (R1) and with (R2N) control structures. Redox potentials suitable for denitrification were measured where subsurface soils were clayey.

Carbon

The carbon content of the soils R1 and R2 are discussed in the following section. Comparisons are made by location on the buffer, i.e., ditch edge versus the field edge. Note that the average percent carbon (averaged over all horizons from the soil surface to 152 cm) by location is nearly identical on R1 and R2N. At the ditch edge, average % C was 0.85 and 0.84 on R1 and R2N, respectively. At the 7.6 m field edge, average % C was 0.47 and 0.44, respectively, which is a decrease of slightly more than fifty percent. In addition, the 15.2 m buffer on R2N had an average % C content of 0.25, which again, is slightly more than a 50% decrease. Of more important value is the carbon content of soils deeper in the profile. The higher carbon content along the ditch edge is likely a result of vegetation growing along and in the ditch providing carbon deep in the profile. At the field edges, the amount of carbon available at the deeper depths is probably a result of the vegetation that has been or is present at the site and whether or not it is translocated deeper in the soil profile.

Conclusion

Understanding the relationship between factors that influence the effectiveness of practices, such as riparian buffers and controlled drainage, for improving water quality is crucial as requirements to meet water quality standards become law. Improper recommendations not only defeat water quality improvement, but also question the validity of the use of these best management practices. Important factors as to their effectiveness include soil texture, the availability of organic matter, and a geographically appropriate pH range of 5.0-6.0. Soil texture has an important influence on soil redox potential. At the ditch edge on R2, the buffer with controlled drainage, all locations were in a similar landscape. However, soil texture in the middle part of the buffer at the ditch edge was different than the two ends of the buffer. Soils in the middle were sandy, while the ends had soil textures that were higher in clay content. At 152 cm, soil redox potential values were high in sandy-textured soils, indicating that reducing conditions were not favorable, while soil redox values in soils with higher clay content were low. Redox potential values, as well as the absence of nitrate-nitrogen in water samples located from these locations and decreasing nitrate/chloride ratios (these data not shown), indicated that denitrification was most likely the pathway of loss. Also, following periods of rainfall, clayey soils behaved as temporary restrictive layers that impeded water flow, permitted reducing conditions to temporarily occur. Sandy soils did not exhibit this behavior. Carbon was located throughout all soil profiles, though it was generally accumulated in the surface horizons. Mean carbon content was highest along the ditch on both buffers and its location within the soil profile was not limited in abundance to the surface horizons. At the 7.6-m field edge, mean carbon content decreased by approximately 50%. At the 15.2-m field edge, mean carbon content decreased another 50%. Curiously, the mean carbon content on the ditch edge on R2N, exhibited a pattern that most likely is related to soil texture. Vegetation along the entire length of the ditch was fairly similar and uniform in abundance. In the sandy soils located at the middle of the buffer, the mean carbon content was much lower as compared to the higher carbon content of the clay soils.

References

Doty CW, Evans RO, Gibson HJ, Hinson RD, Williams WB (1986) 'Agricultural water table management – "A guide for Eastern North Carolina"'. (North Carolina Agricultural Extension Service, North Carolina Agricultural Research Service, USDA Agricultural Research Service, and USDA Soil Conservation Service).

Hill AR (1996) Nitrate removal in stream riparian zones. *J. Environ. Qual.* **25**, 743-755.

Jacobs TC, Gilliam JW (1985) Riparian loses of nitrate from agricultural drainage waters. *J. Environ. Qual.* **14**, 472-478.

Jordan TE, Correll DL, Weller DE (1993) Nutrient interception by a riparian forest receiving inputs from adjacent cropland *J. Environ. Qual.* **22**, 467-473.

Lowrance RR, Leonard R, Sheridan J (1985) Managing riparian ecosystems to control nonpoint pollution. *J. Soil Water Conserv.* **41**, 266-271.

Megonigal JP, Patrick, Jr. WH, Faulkner SP (1993) Wetland identification in seasonally flooded forest soils: Soil morphology and redox dynamics. *Soil Sci. Soc. Am. J.* **57**, 140-149.

Smith,SJ, Cassel DK (1991) Estimating nitrate leaching in soil materials. In 'Managing nitrogen for ground water quality and farm profitability'. (Soil Science Society of America., Madison , WI).

Spalding RF, Exner ME (1993) Occurrence of nitrate in groundwater – a review. *J. Environ. Qual.* **22**, 392-402.

Soil Survey Division Staff (1993) 'Soil Survey Manual'. (Government Printing Office, Washington, D. C).

Soil erosion as an indicator of agricultural sustainability in tropical watersheds

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Abstract
A systems approach was utilised for operationalisation of the concept of agricultural sustainability. The process was prerequisite to deriving case- and site- specific sustainability indicators for agriculture-based tropical watersheds. The breakdown into functional units can be crucial for quantitative measurements of the degree of sustainability or could simply be valuable in developing alternatives to unsustainable farming practices. The most prominent indicator or measure of agricultural sustainability as determined from a causal loop diagram is the degree of erosion and runoff, which has also been identified by local stakeholders as the main driver of land degradation in their watershed area.

Key Words
Adaptive management, agriculture sustainability, erosion, systems analysis, socio-economics, tropical.

Introduction

A universal framework for the assessment of agricultural sustainability can be elusive due to location specific conditions as well as differences in data availability. Moreover, outcome and results of sustainability studies are usually not transferable to other sites due to a wide range of spatial and temporal variables. A systems approach is a promising method being promoted to natural resource managers to deal mainly with the complexities of agri-environmental and socio-economic parameters as well as to address the issue of insufficiently available data (Grant *et al*., 1997). This study is an attempt to employ systems analysis in determining indicators for agricultural sustainability. Specifically, this exercise focuses mainly on the conceptual modelling of what constitutes agricultural sustainability in a mostly agriculture-based tropical watershed. The breakdown of the important factors (variables) and their structure (interactions, feedback loops and delays) are crucial in the operationalisation for a case and site specific meaning of agricultural sustainability. The derived conceptual model may then be utilised as a basis for identifying key variables and eventually the corresponding sustainability indicators where quantitative measurements can be implemented. Hence, the operationalisation for a case and site specific meaning of agricultural sustainability and its breakdown into functional units are the main objectives of this study. A whole systems model which holistically describes an agriculture-based watershed with the relationships and linkages of the different variables will be established. And finally, sustainability indicators that can be used for evaluating agricultural sustainability will be identified.

Method

Preliminary logistics for this research were established during the project implementation of the Australian Centre for International Agricultural Research (ACIAR 2005) project LWR/2001/003, "Integrated watershed management for sustainable soil and water resources management of the Inabanga watershed, Bohol island, Philippines". The results and findings of that project formed the basis for applying the so-called "systems approach" to gain a holistic view of the current situation for the Bohol study area.

Concept mapping

A conceptual diagram was established, Figure 1, showing the complex interrelationships of factors (collective variables) potentially affecting sustainability in an agriculture-based watershed. Considering the collective variables, it is apparent that a key variable influencing agricultural sustainability is the 'Farming System' component. This is supported by the work of Ikerd (1993), which stated that sustainability depends on the nature of the whole farming system. An emphasis is also directed towards interventions that are practically attainable by local communities, who are the farmers themselves, hence encouraging participatory initiatives. As illustrated (Figure 1), the farming system dictates the type of land use that would develop across the watershed and also influences the infrastructure that would support it. Farm productivity is in turn, also a result of a suitable farming system in a given landscape with certain land qualities (climate, slope, soil type, *etc.*). Ultimately the farming system determines the degree of soil erosion and runoff which may threaten environmental quality.

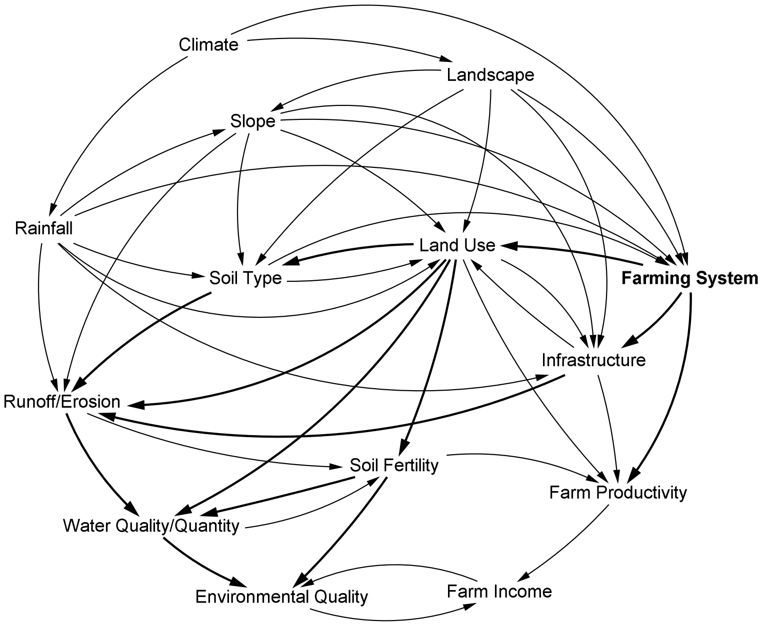

Figure 1. Interrelationships of variables potentially affecting the sustainability in an agriculture-based watershed.

Participatory approach
Participatory initiatives utilised as this approach promoted wider involvement and ownership. Consequently stakeholders were better prepared to adapt ideas and experiences (Kobus 2005; Magnuszewski *et al.,* 2005). Consultation of stakeholders' perception of agricultural sustainability was carried out using techniques in adaptive management, to explore and derive sustainable management options for the agriculture-based watershed systems. Implementing an adaptive environmental assessment and management (AEAM) process (Grayson *et al.,* 1994), achievable management actions that could address the perceived sustainability concept were tabulated (Table 1). Based on the stakeholders' insights, agricultural sustainability is attained when: (1) productivity is maintained in the long run, (2) resources are preserved, and (3) financial income of farmers is guaranteed. These management actions are predominantly in agreement with the ecological and economic arguments presented by von Wiren-Lehr (2001).

Causal loop diagram
Causal loop diagramming (CLD) is an effective method to generate conceptual models facilitating the interpretation of the system's structure, *i.e.* which variables are involved and how they are linked (Sendzimir *et al.,* 2007). Figure 2 shows a CLD which traces the interactions among factors of the farming system including socio-economic parameters, with the aim of addressing the highlighted stakeholders' sustainability goals from Table 1. In developing the CLD (Figure 2), it was considered that the number of farm families contributes to the amount of farm activities in the watershed, which consequently controls the farming area for the different combinations of cropping systems common in the study area. Non-farm commitments or employment are factors that can reduce farm activities. In general there is a direct correlation between farm area / crop diversity and security of income. The greater the farm area allocated to a number of different or combinations of cropping systems, the more potential for higher production, which can ultimately transform into a higher income for the farm families. This is true as long as standing crops are not significantly affected by natural calamities or major infestations occurring in the area. Also, favourable market conditions will always influence the financial income of farmers from produce. On the other hand, increasing farm area allocated for any of the cropping systems mentioned would imply more erosion and runoff within the watershed. This can be mitigated by employing erosion and runoff control measures into the cropping systems of choice or adopting only cropping systems that practice conservation techniques. Such control measures will also consume space within the farm area or essentially limit the choice of cropping systems to the farmers. Moreover, control measures will also involve additional farm inputs and thus incur extra expense at the outset. Selection of appropriate cropping systems or combinations thereof for a given farm area would be a function of local biophysical and socio-economic factors. Erosion and runoff will eventually contribute to further environmental problems like soil fertility and water quality/quantity issues, that will significantly result in negative feedback to crop production and eventually affect farmer's income in the long

run. Other considerable environmental concerns that are affected by the choice and setting-up of the cropping systems include depletion of soil nutrients, increase in water requirements, and destruction of natural ecosystems.

Table 1. Management actions as perceived by the stakeholders to achieve agricultural sustainability and its corresponding long-term goals (participatory inputs).

Management action	Perceived sustainability goal
Significant reduction of soil erosion	Resource preservation
Reforestation and/or vegetative cover on open areas	
Ploughing along the contours on sloping lands	
Alternative cropping for corn/cassava cultivation	
Alley cropping to minimise runoff on sloping lands	
Use of vegetative strips to stabilise slopes	
Higher planting densities	
Maintenance of cover crops on bare areas	
Other Sloping Agricultural Land Technology (SALT) activities	
Minimise nutrient loss from top soil	Resource preservation & Productivity maintenance
Crop rotation for high nutrient-depleting crops	
Use of legumes for nutrient replenishment to soil	
Utilisation of crop residues	
Growing of cover crops for organic matter residues	
Application of organic fertiliser	
Improved cropping strategies	Productivity maintenance
Inter-cropping with cash crops	
Allocation of different crops in a farm (diversifying)	
Multi-story farming and/or agro-forestry	
Management of water quantity and quality	Resource preservation & Productivity maintenance
Irrigation on serviceable areas	
Construction of small farm reservoir	
Responsible use and disposal of chemicals and pesticides	
Road bank and stream bed stabilisation	
Provision of support services	Guarantee of farm income
Road access	
Efficient agricultural extension services	
Irrigation services	
Availability of farm inputs	
Loans and funding support	
Marketing assistance	
Sustained farm family income	Guarantee of farm income
Engage in other income generating activities (non-farm)	

Conclusions

As a result of the systems approach presented above, an operational meaning based on case and site specific conditions was derived for agricultural sustainability. It is determined by an appropriate combination of cropping systems employing suitable erosion and runoff interventions that could help preserve soil and water resources while sustaining agricultural productivity and consequently ensuring financial income of farmers. Therefore, the primary indicator or measure of agricultural sustainability in this case, would be determined by the degree of erosion and runoff as it is the main driver towards land degradation. The breakdown into functional units can be crucial for quantitative measurements of the degree of sustainability or may simply be valuable in developing alternatives to unsustainable farming practices.

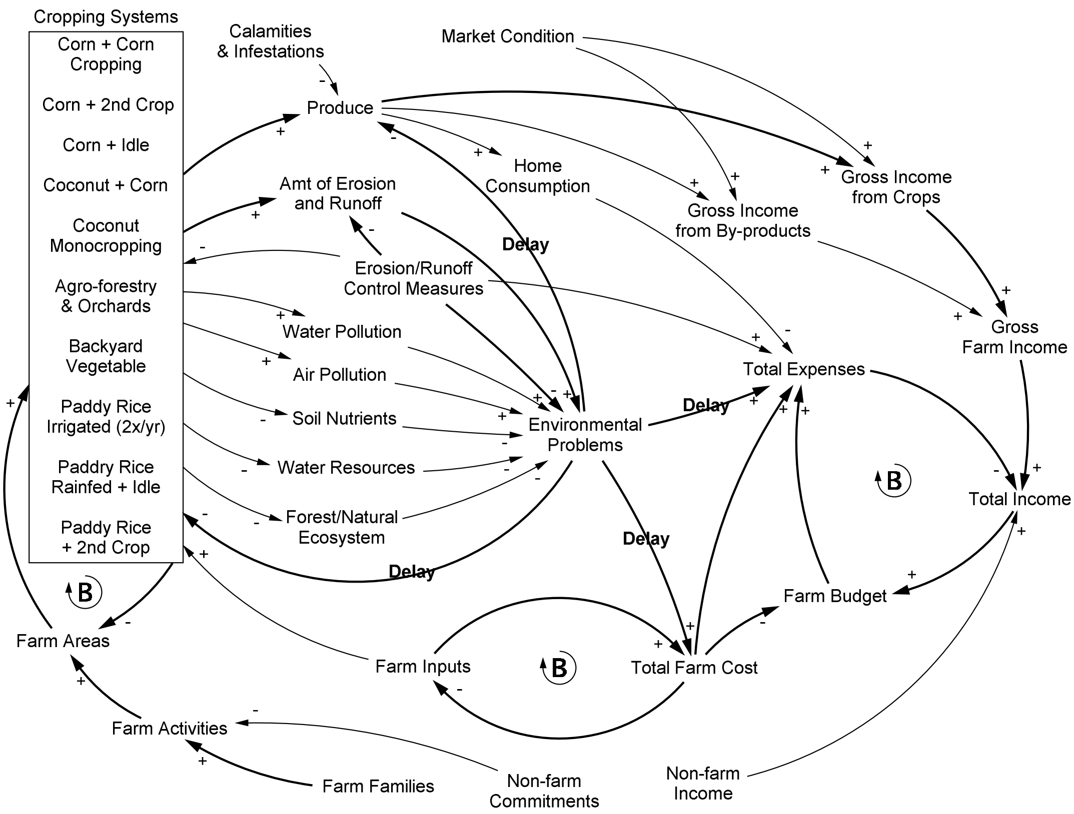

Figure 2. Causal loop diagram of farming system variables addressing agricultural sustainability goals. Darker arrows signify dominant routes or loops. Coiling arrows with a "B" symbolise balancing loops in the system.

Acknowledgements

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References

ACIAR (2005) Final report: Integrated watershed management for sustainable soil and water resources management of the Inabanga watershed, Bohol Island, Philippines (LWR/2001/003). Australian Centre for International Agricultural Research, Canberra.

Grant WE, Pedersen EK, Martin SL (1997) 'Ecology and natural resource management: Systems analysis and simulation.' (John Wiley & Sons: New York)

Grayson RB, Doolan JM, Blake T (1994) Application of AEAM (Adaptive Environmental Assessment and Management) to water quality in the Latrobe river catchment. *Journal of Environmental Management* **41,** 245-258.

Ikerd JE (1993) The need for a system approach to sustainable agriculture. *Agriculture, Ecosystems & Environment* **46,** 147-160.

Kobus D (2005) Development and testing of a conceptual framework for assessment of progress towards achieving sustainable development in countries in transition. *Journal of Environmental Assessment Policy and Management* **7,** 457-491.

Magnuszewski P, Sendzimir J, Kronenberg J (2005) Conceptual modeling for adaptive environmental assessment and management in the Barycz Valley, Lower Silesia, Poland. *International Journal of Environmental Research and Public Health* **2,** 194-203.

Sendzimir J, Magnuszewski P, Balogh P, Vári A (2007) Anticipatory modeling of biocomplexity in the Tisza River Basin: First steps to establish a participatory adaptive framework. *Environmental Modelling & Software* **22,** 599-609.

von Wirén-Lehr S (2001) Sustainability in agriculture - an evaluation of principal goal-oriented concepts to close the gap between theory and practice. *Agriculture, Ecosystems & Environment* **84,** 115-129.

Soil science in the management of multi-functional rural landscapes

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Abstract
Communities are concerned that we manage our landscapes to provide economic, social and environmental services for the future. Governments are making major investments in changing land use and seeking to improve land management. We describe a bio-economic approach for planning agricultural land use to meet multiple objectives. The analysis enabled quantification of the extent of different types of land use change required to meet salinity and water yield targets at least economic cost, and where land use change should best occur within a landscape. This and other land use planning approaches require knowledge of at least the distribution of soils, the surface and groundwater hydrology, the current land use, economic costs and returns of current and proposed land uses, and landholder capacity to change. Advances in digital soil mapping, proximal sensing, application of airborne geophysics, digital elevation models, terrain indices and land use mapping are reducing the cost of data acquisition. This facilitates better utilisation of modelling capacity in land use planning.

Key Words
Land use, planning, mapping, terrain analysis, agriculture, salinity.

Introduction
Rural landscapes in many parts of the world are changing from predominantly agriculture and forestry production to delivering an increasing number of other functions including environmental conservation, provision of water for consumptive use, carbon sequestration, infrastructure development, supply of raw construction materials, waste disposal, recreation, cultural values and space for housing. Landscapes are complex; they include people and their biological and physical aspects are overlain by social, cultural and economic dimensions. The multi-functionality and complex structure of the landscape (e.g. Degórski 2003) emphasises the need for interdisciplinary landscape research to support sustainable land development.

Sustainable rural land use must protect the natural resource base while maintaining an acceptable local economy and social conditions. Successful rural land use planning requires: i) demand and goal oriented identification of land use functions, ii) participative negotiations on possible land use combinations involving all groups, including science, and iii) an iterative decision making process that tolerates uncertainties and adapts to emerging information and knowledge (Wiggering *et al*. 2003). Science has a role in achieving sustainable land use - providing advice to the decision makers as part of a broad consensus-driven process.

Soil science can contribute to the multidisciplinary approach necessary to help us manage our landscapes well. Land use planning is driven by the spatial distribution of functional land attributes which dictates suitability for different uses. Soil processes and soil-plant-atmosphere interactions are at the centre of interdependencies between land use and landscape function. Quantitative land evaluation provides a useful integrating framework.

This paper outlines an approach to multi-objective land use planning by i) describing a bio-economic approach for planning agricultural land use to meet catchment salinity and water yield targets at least cost, ii) highlighting the important role of soil science in multiple objective rural land use planning, and iii) describing key soil and terrain data needs and recent advances in meeting those needs.

Bio-economic analysis - targeting farm scale land use change to reduce catchment salt load
In southern Australia, replacement of deep-rooted perennial vegetation with shallow-rooted annual crops and pastures has caused increased deep drainage, rising groundwater levels, and subsequent land and river salinisation. Successful management of salinity, including achieving adequate return on investment into

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salinity mitigation, is measured at the catchment scale. However, catchment scale responses are the result of action by individuals at the paddock or farm scale. Much salinity research in Australia has not adequately linked farm and catchment considerations. This study sought to assist farmers and catchment managers target investment in land use change so catchment salt and water targets could be met at least cost.

Materials and methods

Simmons Creek is located on the eastern Riverine Plain, north east of the township of Walbundrie in southern New South Wales, Australia. Approximately 98% of the 178 km^2 catchment is used for agriculture, mainly mixed cropping. Local farmers helped identify 8 broad classes of land use. Typical gross margins were calculated for each component (e.g. wheat or lucerne) of each land use, averaged over ten years to produce an annual gross margin ($/ha/year). The Agricultural Production Systems Simulator (APSIM) (Keating *et al*. 2003) was configured to simulate the crop/plant growth and water balance of each of the land use scenarios on each of five soil types found in the catchment (i.e. a matrix of 8 land uses x 5 soil types). Simulations used climate data from 1891 to 2006 (116 years). The APSIM model supplied estimates of run-off, drainage and gross margin from each land use and soil to a linear programming (LP) model.

The LP model calculated minimum-cost changes in land use to attain specified targets of future salt-loads and water-yields from the catchment. The model incorporated 13 sub-catchments with various levels of connectivity reflecting the conceptualisation of the catchment's hydrology (English *et al*. 2002). Within sub-catchments, the model accounted for lateral fluxes of surface water down-slope thereby changing the productivity and water balance of the land receiving run-on. Deep drainage and groundwater processes are considered at the sub-catchment scale. In the lower (southern) parts of the landscape deep drainage discharges as baseflow at a specified fraction of the salinity of the groundwater beneath that sub-catchment.

The LP modelling estimated: 1) changes to current land use extent and distribution that would maximise farm income (i.e. maximise catchment gross margin) while maintaining current salt export, and 2) the progressive changes in land use extent and distribution that would be required for least-cost reduction from current estimated salt export (10,000 t salt/year) to zero (in 1000 t salt/year steps).

Results and discussion

The model selects an arrangement of land use that preserves as much highly profitable agriculture as possible while meeting prescribed salt load and water yield targets (Cresswell *et al*. 2009). Seeking greater reduction in salt load shifts land used for pasture into tree growing, and then as a last resort, land used to grow highly profitable rotational crops is shifted into growing trees. Shifts in land use to reduce salt export from the catchment progressively reduce farm income from the maximum achievable catchment gross margin (~$3M) - although the reductions in gross margin are modest (< 5%) until annual salt load has been halved to 5000 t. For reductions greater than this the marginal cost (cost per each extra tonne of salt load reduction) of reducing salt load gets progressively more expensive as greater reductions in salt load are sought.

Most of the land use change (both in area and degree) suggested by the modelling is in a few sub-catchments in the south of the catchment. These are the sub-catchments underlain by saline groundwater and where reducing deep drainage will have the most direct impact in reducing salt load. The changes are to replace cropping rotations with tree plantations in saline catchments while maintaining water yield by adopting higher water yielding land uses, such as annual pastures, in non-saline catchments. These changes result in loss of income. Most of the cost of salinity management within the whole catchment would be borne by only a few farms; the majority of the catchment remains unaffected until high levels of salinity mitigation are sought. However, since our analysis estimates the cost of these land use changes, it could form the basis to negotiate cost sharing between the relevant parties.

There is considerable uncertainty in the 'current' baseline salt load contribution from Simmons Creek catchment. This translates to uncertainty in the unit cost ($/t) of salt mitigation. However, the sequence of land use change for least-cost meeting of salt targets remains the same, no matter what value is assumed for baseline salt load.

The careful targeting of changes in land use is essential for cost-effective salinity mitigation in this landscape. There are many locations in Simmons Creek catchment where land use change would not be effective. In fact, land use change to achieve reductions in salt load could easily cost more than the apparent value of benefit derived. This situation can be avoided by undertaking appropriate economic analysis as part of salinity management planning.

This analysis should not be seen as providing any sort of prescription for land use change, rather as a component input into a broader landscape planning process.

Reducing soil and terrain data constraints for multi-objective rural land use planning
Multiple objective land use planning requires soil, terrain and land use information. The ready availability of such data in Australia has been a constraint. Recent research has sought to address this as shown by the examples below.

Digital elevation models and terrain analysis
A new one-second digital elevation model (DEM), covering the whole of Australia, has been derived from space shuttle radar elevation data following a rigorous process of correcting for vegetation influence and other artefacts (JC Gallant *pers comm.* 2009). High resolution laser altimetry data is also available in some areas. DEMs and terrain indices such as the multi resolution valley bottom flatness index (MrVBF, Gallant and Dowling 2003) are used in delineating catchment boundaries, indicating hydrological flow direction, spatial landscape disaggregation, landscape stratification for biodiversity, and in digital soil mapping.

Digital soil mapping (soil functional attributes and their distribution)
Soil data for Australia is sparse and conventional survey is expensive and time consuming. New digital soil mapping technologies are showing much potential for broad scale application. McKenzie and Gallant (2007) combined the use of airborne gamma radiometrics data with the MrVBF terrain index and a conceptual model of landscape evolution to effectively map soil profile classes and assign functional soil attributes such as soil depth and water holding capacity to each class. The resultant data is required, for example, in prediction of the soil water balance, assessing land suitability for alternative agricultural systems, and predicting commodity production.

Proximal soil sensing
Functional soil attributes will soon be able to be inferred and mapped efficiently using new proximal sensing of visible and infrared spectrometry (Viscarra Rossel *et al*. 2006), electromagnetics and gamma radiometrics (Wong *et al*. 2009). Complementary sets of sensors will be used together with spectral libraries to enable estimation of mineral and organic content and composition, as well as related properties such as cation exchange, pH, salinity, available water capacity and bulk density. Predictions of functional attributes of soil and their spatial variation will enhance digital soil mapping for the purposes listed above.

Mapping land use and land management
Nationally consistent land use mapping at 'catchment' (1:25 000 – 1:250 000) and 'national' (approximately 1:2 500 000) scales is available for Australia (BRS 2006). Improved satellite image classification techniques are being used to classify land cover, land use and management practices (e.g. use of contour banks). Satellite remote sensing time series enable regularly updated land cover and fractional cover data that assists in the mapping of land use and key attributes linked to management (such as ground cover levels).

Surface and groundwater hydrology
As with soil mapping, a robust underlying conceptual model is an essential precursor to accurately representing surface and groundwater hydrology, including salinity processes if required, in studies of landscape process. Advanced terrain analysis (above) is enhancing understanding of surface hydrology. Airborne geophysical survey (e.g. English *et al*. 2004) is giving new insights into regolith structure and salt stores, and helping guide design of complementary groundwater monitoring and drilling.

Conclusion
Land use planning that utilises biophysical modelling and economic optimisation is only likely to be required in areas where large investments and/or changes in land use are to occur. Other circumstances warrant simpler approaches. Spatial multiple criteria analysis (MCA) is a useful land use planning approach (e.g. Hill *et al*. 2006). MCA is very well suited to a structured synthesis of information from people with relevant domain knowledge within a participative mode of operation. MCA can use modelling input and can incorporate social metrics such as landholder preferences and capacity to change, especially where these can

be quantified spatially. If more explicit cause-effect analysis is required then biophysical model predictions, economic gross margins, and knowledge from conceptual models of landscape function can be used together to add significant understanding. The integration (planning) framework is necessarily spatial and chosen to meet the needs of the local stakeholders. An essential prerequisite for this type of analysis is prior investment in understanding the catchment basics - including the distribution of soils, the surface and groundwater hydrology, the current land use, economic costs and returns, and landholder capacity to change. Soil science has an essential role in integrative landscape analysis including through reducing the cost of soil data acquisition and improving understanding of soil distribution and function.

References

Bureau of Rural Sciences (2006) Guidelines for Land Use Mapping in Australia: A Technical Handbook Supporting the Australian Collaborative Land Use Mapping Programme, Edition 3. (Bureau of Rural Sciences: Canberra).

Cresswell HP, Hume IH, Wang E, Nordblom TL, Finlayson JD, Glover M (2009) Catchment Response to Farm Scale Land Use Change. CSIRO and NSW Department of Industry and Investment. http://www.clw.csiro.au/publications/science/2009/saf-catchment-response-farm-scale-land-change.pdf

Degórski M (2003) Some aspects of multifunctional landscape character in the interdisciplinary environmental study. In 'Sustainable Development of Multifunctional Landscapes'. (Eds K Helming, H Wiggering) pp. 53-65. (Springer-Verlag: Berlin).

English P, Richardson P, Stauffacher M (2002) Groundwater and Salinity Processes in Simmons Creek sub-catchment, Billabong Creek, NSW. CSIRO Land and Water Technical Report 24/02. (CSIRO: Canberra).

English P, Richardson P, Glover M, Cresswell H, Gallant J (2004) Interpreting Airborne Geophysics as an adjunct to Hydrogeological Investigations for Salinity Management: Honeysuckle Creek Catchment, Victoria. CSIRO Land and Water Technical Report No 18/04. (CSIRO: Canberra).

Gallant JC, Dowling T (2003) A multi-resolution index of valley bottom flatness for mapping depositional areas. *Water Resources Research* **39,** 1347-1360.

Hill P, Cresswell HP, Hubbard L (2006) Spatial prioritisation of NRM investment in the West Hume area (Murray CMA region). Technical Report, CSIRO Water for a Healthy Country National Research Flagship, Canberra. http://www.clw.csiro.au/publications/science/2006/wfhc-MurrayCMAWestHume.pdf

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM, Smith CJ (2003) An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18,** 267-288.

McKenzie NJ, Gallant JC (2007) Digital soil mapping with improved environmental predictors and models of pedogenesis. In 'Digital Soil Mapping: An Introductory Perspective' (Eds P Lagacherie, AB McBratney, M Voltz) pp. 327-349. (Elsevier, Amsterdam).

Viscarra Rossel RA, Walvoort DJJ, McBratney AB, Janik LJ, Skjemstad JO (2006) Visible, near-infrared, mid-infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma* **131,** 59–75.

Wiggering H, Müller K, Werner A, Helming K (2003) The concept of multifunctionality in sustainable land development. In 'Sustainable Development of Multifunctional Landscapes' (Eds K Helming, H Wiggering) pp. 3-18. (Springer-Verlag: Berlin).

Wong MTF, Wittwer K, Oliver Y, Robertson MJ (2009) Use of EM38 and gamma-ray spectrometry as complementary sensors for high resolution soil property mapping. In 'Proximal Soil Sensing for High Resolution Soil Mapping' (Eds RA Viscarra Rossel, AB McBratney, B Minasny). (Springer-Verlag: Berlin). (in press)

Spatial variability of soil enzymes in a sinkhole undergoing forage transition

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Abstract
Tall fescue is a dominant forage grass in the southeastern United States. The dominant fescue cultivar, KY 31, is infected with an alkaloid-producing endophyte, and research is evaluating new forage species and endophyte-free cultivars as pasture replacements. Spatial distribution of soil enzymes affecting soil processes in transitional forage systems is not well-studied. We evaluated the spatial variability of soil enzymes involved in C metabolism at a sinkhole site in central Kentucky, USA. Dehydrogenase and β-glucosidase were selected because they reflect soil microbiological activity status and play a key role in bioprocesses involving C cycling. There was evidence of spatial variability for enzyme activity across the sinkhole. Dehydrogenase activity showed moderate spatial structure at 15-30 cm depth compared to strong spatial structure over a 100 m range under endophyte-infected KYFA9301/A584 and KY31. There was moderate spatial correlation over a 60 m range under endophyte-free KYFA9301, and a complete nugget effect under the undisturbed control. Spatial analysis of β-glucosidase activity indicated a weak to moderate spatial structure over a 40 to 100 m range under different forage species, except for a pure nugget at 15-30 cm depth under KY31 and KYFA9301/A584. Spatial cross correlation analysis showed that both enzymes are spatially correlated for two soil depths over a range from 10 to 30 m. Cross semivariance analysis showed spatial independence between soil enzyme activity and TN, soil pH, and clay content.

Key Words
Enzyme activity, dehydrogenase, β-glucosidase, geostatistics, karst, nugget effect, cross variograms.

Introduction

Tall fescue (*Festuca arundinaceae* Schreb.) is a cool-season forage grass that dominates pastures in the southeastern United States. Kentucky 31 (KY 31) is a dominant cultivar in this region, but suffers from infection by the endophyte *Neotyphodium coenophialum*, which produces ergot alkaloids that are detrimental to animal growth and productivity. There has been research on the effects of endophyte-infected fescue on soil C dynamics (Franzluebbers and Stuedmann 2005) but relatively little is known about spatial variability of soil processes in fescue-dominated pastures, particularly those pastures undergoing transition to remove endophyte-infected species (Franzluebbers *et al.* 1999).

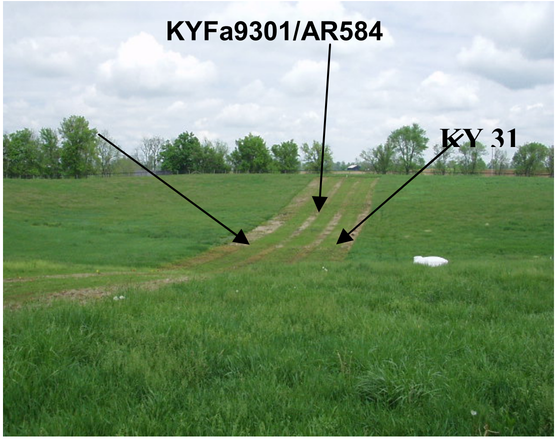
In central Kentucky, potential effects of forage transition are exacerbated by the underlying karst topography. Karst topography creates soil environments dominated by multiple sinkholes that differ in width and depth. These sinkholes provide rapid conduits for surface contaminants into shallow groundwater resources. Spatial variability of soil properties and processes is likely to be influenced within very short distances in this landscape. With respect to soil enzymatic properties, little is known about their spatial variability in such environments. Characterizing the effect of changing soil vegetation cover on spatially variable patterns of soil biological properties such as soil enzyme activity will help us understand the process of soil organic mass transformation and its impacts on other soil chemical and physical properties. Eventually, these types of studies will help us predict the environmental response of soil ecosystems to this change. The objectives of this study were to test the hypotheses that soil enzyme properties had spatial structure in a sinkhole environment and that this spatial structure was affected by transition from the existing forage.

Methods

Research Site

The research was performed at the University of Kentucky Animal Research Center in Woodford Co., Kentucky, USA, approximately 18 km east of Lexington. The soil at this site is classified as a Maury silt loam (Typic hapludalf) with 6-12% slopes. An existing sinkhole in permanent pasture – a mixture of Kentucky bluegrass (*Poa pratensis* Linn.) and tall fescue – was treated with glyphosate herbicide (Roundup™) to remove the existing vegetation in fall 2008, and again in spring 2009. Along with undisturbed sod, three tall fescue cultivars were direct seeded into the killed sod in April 2009 in individual strips of 160 x 3/m^2 spanning the center of the sinkhole (Figure 1) to give four treatments: 1). Control (OG) – Existing pasture; 2). KY 31 – Endophyte infected and alkaloid-producing tall fescue; 3). KYFa9301/A584 (NE) – Endophyte-infected, non alkaloid-producing tall fescue; 4). KYFa9301 (EF) – Endophyte- and alkaloid-free tall fescue.

In July 2009, after the new forages were well established, soils were collected at 10-m intervals along four transects, each transect representing one of the three forage treatments and the undisturbed control (Figure 1). Each location was sampled at two depths: 0-15 and 15-30 cm. Soils were manipulated to break up large aggregates, air dried, and stored at 4 ^{o}C until enzyme analysis for soil dehydrogenase and β-glucosidase.



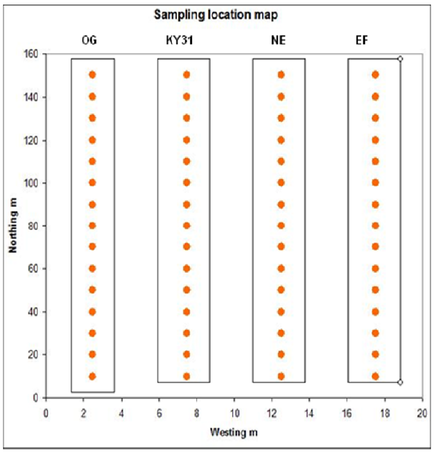


Figure 1. Distribution of forage treatments, transect locations, and sampling positions in the sinkhole research site at the University of Kentucky Animal Research Center in Woodford Co.

Spatial Analysis

Spatial structure and spatial variations of soil enzymes activities were described using omni-direction semi-variograms assuming horizontal isotropy (Goovaerts 1997; Deutsch and Journel 1998; Chiles and Delfiner 1999). Visual and statistical approaches were used for variogram modeling (Webster and Oliver 2001). Spherical and Gaussian models were identified for the best spatial model that fit soil enzyme variograms in different forage species based on the residual sum of squares (RSS) analysis. The ratio between the nugget variance and total variance was used to evaluate the spatial dependence and spatial structure in the different forage species (Cambardella *et al.* 1994). Nugget values of the two soil enzymes in the different forage species represent the undetectable experimental error, field variation associated with the minimum sampling distance, and inherent variability. Cross variogram analysis, Yates and Warrick (2002) and Nielsen and Wendroth (2003) was applied to test the cross continuity between the two soil enzymes.

Results

Spatial Variability

Because we collected samples in a systematic way with a fixed separation distance – a non randomized design – spatial dependency needed to be taken into account by using spatial analysis methods described below. Traditional statistics assumes that all samples are collected using a randomized sampling design. Our results show that assumptions of random spatial distribution of enzyme activities are not valid. Sampling separation distance was valid to capture the spatial structure, except under the OG treatment, where a shorter separation distance between samples needed to be applied. There is a spatial dependency between the two enzymes and between enzymes and the TC content under different all cultivars except for the original forage.

Sample comparison of the spatial semi-variance as a function of separation distance for the two soil enzymes under different forage species are presented in Figures 2 and 3. Spherical and Gaussian models were used to fit the semivariance as a function of separation distance. Strong spatial structure for dehydrogenase activity at 0-15 cm was observed under KY31 and NE compared with a moderate spatial structure under EF. Dehydrogenase activity under the original pasture showed no spatial structure, and the semivariance was modeled as a pure nugget, which indicated that a longer spatial domain or shorter sampling distance needed to be applied. For 15-30 cm, a strong spatial structure over an 80 m range was observed under KY31 and EF compared with a moderate to weak spatial structure over a shorter correlation range (30-40 m) under OG and

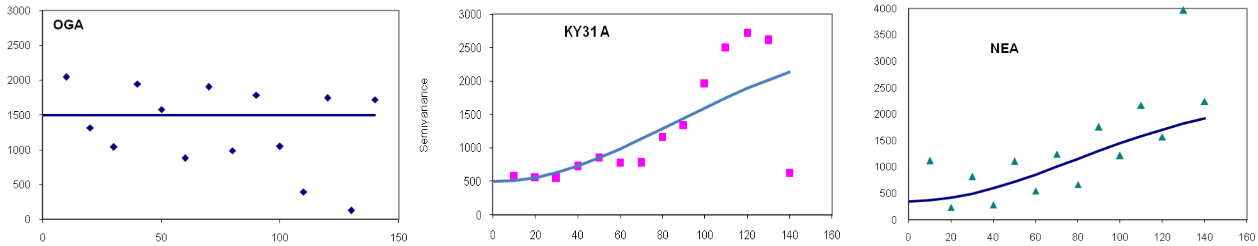


Figure 2. Dehydrogenase activity semivariograms for 0-15 cm under different forage species.

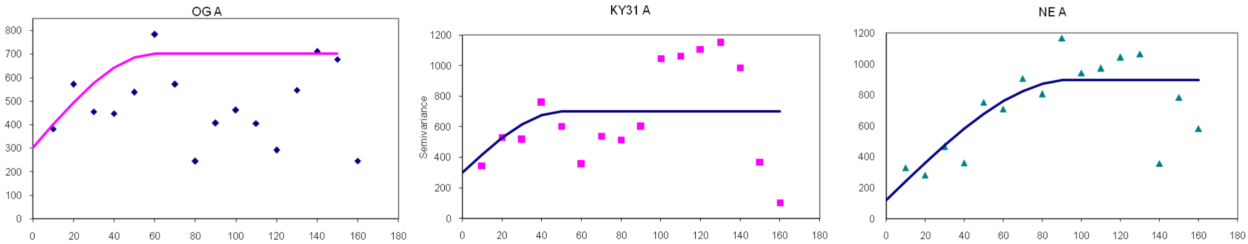


Figure 3. β-glucosidase semivariograms for 0-15 cm under different forage species.

NE. The dehydrogenase activity semivariograms under KY31 for the two soil depths and for the 15-30 cm depth under the EF show a trend effect starting after an 80 to 100 m range. This trend effect can be explained as a direct result of higher organic matter content in the northern part of the transect, compared with the first 100 m.

Semivariograms of β-glucosidase activity at 0-15 cm showed strong to moderate spatial structure over a 40 to 60 m correlation range in KY31 and NE compared with somewhat weak structure under OG and EF. β-glucosidase activity at 15-30 cm showed no spatial structure under KY31 and NE compared with somewhat moderate to weak spatial structure under EF and the control, respectively. Semivariograms of β-glucosidase showed a second increase in the semivariance starting between 80 to a 100 m of the transect. This trend is clear under the KY31 and NE at 0-15 cm depth and in OG and KY31 at 15-30 cm depth. This trend is also attributed to the higher content of soil organic matter content in the northern part of the transect. Cross variogram analysis between soil enzymes and selected soil properties (*i.e.* TC, TN, soil pH, clay content) showed a positive and strong cross correlation only between TC and the activity of the soil enzymes under OG, KY31, and NE in the two sampling depths. The cross correlation between TC and enzyme activity ranged between 50 to 120 m, which indicates strong spatial dependence between soil enzyme activities and TC. The cross correlation function (CCF) used to visualize the spatial dependence between the enzymes under different forage species is shown in Figure 4.

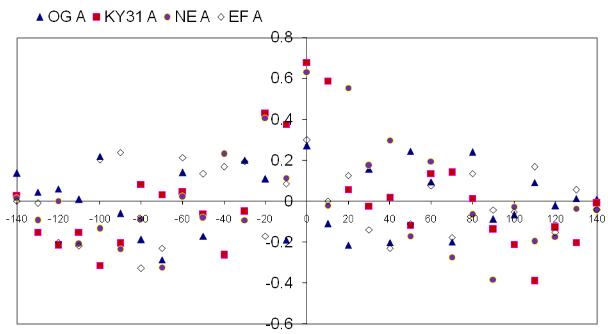


Figure 4. Cross-correlation function between the soil enzymes.

The CCF at lag equal zero is the same as the classical correlation coefficient between the two variables. Unlike classical statistics, the CCF analysis with distance gives insights about the spatial covariance structure between the two variables. There was spatial dependence between the soil enzymes in different forage species in a range of 10 to 30 m. A positive and significant cross correlation between the enzymes was observed in KY31 and NE compared to positive but non significant correlation in OG and EF at 0-15 cm. The results also showed positive and significant cross correlation between the two enzymes at 15-30 cm, but for a shorter range. This information can help in the spatial interpolation and estimation of the magnitude of a variable by knowing the magnitude of the neighborhood.

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Conclusion
Despite a symmetrical appearance, the sinkhole was asymmetric with respect to enzyme activity. Soil dehydrogenase and β-glucosidase exhibited strong to moderate spatial structure for the tested soil depths in different forage species. The degree of spatial structure within the tested domain was clearly affected by the forage species and inherited soil variability factors. Spatial patterns of enzyme activity were affected by forage species, and were associated with inherent soil organic carbon rather than total nitrogen content, clay content, or soil pH. These findings have important implications for understanding the process of soil organic mass transformation and for selecting an appropriate methodology of soil sampling for such studies. The factors responsible for the heterogeneity are only partially clear, and the source of the enzyme activity variation within horizontal and vertical domains remains to be clarified. For more accurate analytical results, such as more detailed spatial distribution patterns, it is necessary that a greater sampling density in both horizontal and vertical directions should be used.

Acknowledgements
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References
Cambardella CA, Moorman TB, Novak LM, Parkin TB, Karlen DL, Turco RF, Konopka AM (1994) Field – Scale variability of soil properties in central Iowa soils. *Soil Science Society of America Journal* **58,** 1501-1511.

Chiles JP, Delfiner P (1999) 'Geostatististics: Modelling Spatial Uncertainty'. (John Wiley and Sons: New York).

Deutsch CV, Journel AG (1998) 'GSLIB: Geostatistical Software Library and User's Guide, 2nd edition'. (Oxford University Press: New York).

Franzluebbers AJ, Nazih N, Stuedmann JA, Fuhrmann JJ, Schomberg HH, Hartel PG (1999) Spatial carbon and nitrogen pools under low- and high- endophyte infected tall fescue. *Soil Science Society of America Journal* **63**, 1687-1694.

Franzluebbers AJ, Stuedmann JA (2005) Soil carbon and nitrogen pools in response to tall fescue endophyte infection, fertilization, and cultivar. *Soil Science Society of America Journal* **69,** 396-403.

Goovaerts P (1997) Geostatistics for Natural Resources (Oxford Univ. Press, New York)

Nielsen DR, Wendroth O (2003) 'Spatial and Temporal Statistics—Sampling Field Soils and Their Vegetation'. (Catena, Reiskirchen: Germany).

Yates SR, Warrick AW (2002) Geostatistics. In 'Methods of Soil Analysis, part 4'. (Eds JH Dane, GC Topp) pp. 81-118. (Soil Science Society of America, Inc.: Madison, WI).

Webster R, Oliver MA (2001) 'Geostatistics for Environmental Scientists'. (John Wiley and Sons: New York).

Understanding variability in texture and acidity among sandy soils in Cambodia

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Abstract
Sandy soils occupy a large proportion of the Cambodian landscape, and improved understanding of these soils is critically important to support agricultural development. This study aims to identify variability in soil particle size distributions and acidity among sandy soils from different parts of southern and eastern Cambodia. Soil samples were collected from different layers at 8 sites within 4 study provinces and analysed for particle size distribution, soil pH and exchangeable Al. Clay and silt were minor fractions and comprised similar amounts at most sites. Clay fractions generally increased at about 1 m depth. Soils at a site close to the beach and sites nearby coarse grained granite mountains contained very high percentages of coarse sand (up to 87 %). At other sites, fine sands were dominant fractions. Very low pH_{CaCl2} values (< 4) in whole profiles were found at 2 sites in the coastal area, close to the beach and sandstone mountain and at one site in eastern Cambodia. Highest whole profile exchangeable Al (0.44-1.13 cmol/kg) were seen at a site close to sandstone mountain and a site in eastern area.

Key Word
Particle size, soil pH, sandy soil, soil profile.

Introduction
Sandy soils occupy a large proportion of Cambodian land. Arenosols account for only 1.6 % of the land area; however, sandy surface soils cover a large proportion of the Cambodian landscape and are more widespread than Arenosols, *per se* (Seng *et al.* 2005). The Acrisol Soil Group, which commonly consists of sandy surface soils, occupies almost half of the land area of Cambodia.

Agriculture is expanding rapidly in Cambodia at the present, especially in the upland areas, where sandy soils account for a large proportion of land area. However, detailed information about upland sandy soils in Cambodia is very limited. Soil study by the Cambodia-IRRI-Australia Project during the 1990s focused on surface soils (0-0.50 m) in low land areas, where soils are mainly used for rice production (White *et al.* 1997). Recent sandy soil investigations in Tramkak, Ponhea Krek, and Kong Pisei District have been limited to describing soil-landscape relationships plus limited soil chemical analysis (Hin *et al.* 2007a; b; Hin *et al.* 2006). Sandy soil characteristics in these districts may not be common to other sandy terrains in Cambodia as more complete data is required. Preliminary analysis of a range of sandy soils in Cambodia indicates that large differences in Al saturation exist among profiles. Some profiles have > 80% Al saturation below 0.12 m depth, other profiles have less than 10 % Al saturation throughout (Seng and Bell unpublished data). The management of the highly acid forms of sandy soils will be quite different from those with non-acid profiles.

A more thorough understanding of the properties and constraints of sandy soils in the uplands of Cambodia will underpin an assessment of land suitability for non-rice crops and support the diversification of crop production in Cambodia in a sustainable manner. The present study aims to understand variability in texture and acidity among sandy soils from different parts of Cambodia. The underlying hypothesis is that parent materials have a strong influence on the key physical and chemical properties of sandy soils in Cambodia.

Materials and methods
Study areas, sites and soil sampling
The research was conducted in 4 study areas: Coastal zone in Kampot District of Kampot Province; Tramkak District of Takeo Province; Ponhea Krek District of Kampong Cham Province; and Kampong Chhnang Province (Figure 1). Soil samples were collected from 8 sites in the study areas. Two contrasting sites in each study area were selected with one at an upland location and another in a low lying part of the area. At each site, a pit was excavated to 1.50 m depth. From the bottom of the pit, the soil was augered until reaching approximately 2 m depth. Pits and cores were sectioned according to variation of texture, colour,

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size and amount of stones. Approximately 1 kg soil was collected from each layer at each site. Soil samples were air-dried and ground to pass a 2-mm sieve.

Particle size analysis
Laboratory measurement of the particle size distribution of soil was made on 50 g air-dry samples using sieving and the sedimentation method (Bowman and Hutka 2002). The samples were pre-treated with hydrogen peroxide to remove organic matter. Particle-size data were classified according to the conventional size intervals of the International System (coarse sand 2000-200 µm, fine sand 200-20 µm, silt 20-2 µm, clay <2 µm).

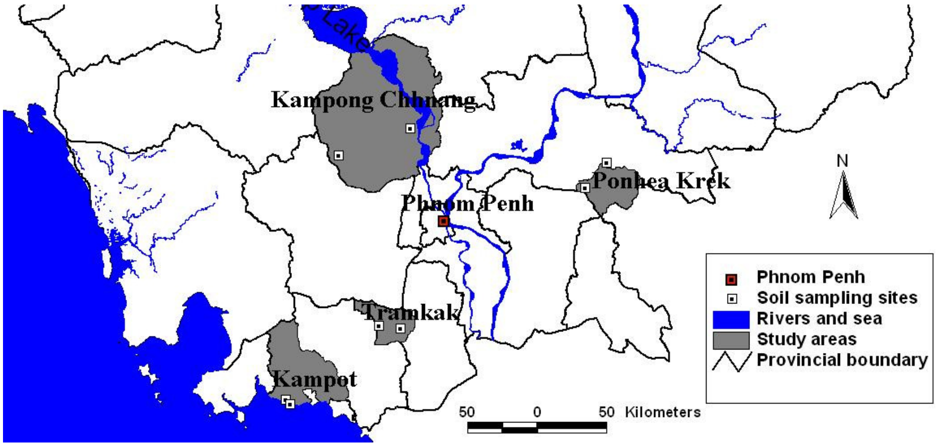

Figure 1. Study areas and sampling sites

Chemical analysis
Soil pH was measured in 1:5 ratio of soil to 0.01M $CaCl_2$ suspension. Determination of exchangeable Al was made using inductively coupled plasma atomic emission spectroscopy (ICP-AES). Soil extracts for Al determination were obtained by shaking end-over-end 1 g of air-dried soil with 50 ml of 0.01 M $(AgTU)^+$ at 25°C for 16 hours and then centrifuged to obtain a clear supernatant (Rayment and Higginson 1992).

Results
Particle size distribution
Fine and coarse sands were the prominent fraction at all study sites but their abundance within the profile decreased with depth, except at Kampot 1 and Kampot 2 (Table 1). High content (mostly >50%) of coarse sand fractions was found at Kampot 2 (56.6-79.8%), Kampong Chhnang 1 (28.4-54.35%) and Kampong Chhnang 2 (49.6-67.1%). At remaining sites, fine sand was the major size fraction (mostly >40%).

Silt content was only 0.4 to 9.2 % of < 2 mm fractions at most sites. Distinctive, high silt fractions were found at all layers of Tramkak 2, ranging between 19.8-34 %. At Ponhea Krek 2, the silt fractions considerably increased from 2.5 % in topsoil to 13.7 % at 2.10-2.50 m depth. Slight down-profile increase of the silt fraction was seen also at Tramkak 1, Ponhea Krek 1, and Kampong Chhnang 2. In other 4 profiles, there was no specific down-profile change in silt.

Low clay contents ranging between 0.8 and 5 %, were found in the top and middle layers of Kampot 2, Tramkak 1, Ponhea Krek 2, Kampong Chhnang 1, and Kampong Chhnang 2. Distinctive high contents of clay were found at the base of Kampong Chhnang 1(53.9%) and Ponhea Krek 2 (41.5%) profiles. In the whole profile of Ponhea Krek 1, clay content was relatively high and there was no down-profile change of clay contents below 0.15 m depth.

Chemical data
pH values of the whole profile of Kampot 1, 2 and Ponhea Krek 1 were 4 or less, the pH values of Tramkak 2 and Ponhea Krek 2 profiles were 4 or higher (Table 1). In the remaining profiles (Tramkak 1, Kampong Chhnang 1 and Kampong Chhnang 2), pH values of the upper 3-4 layers were generally higher and slightly decreased to the base of the profile. Exchangeable Al was variable among the sites and within each site. Kampot 1 and Ponhea Krek 1 have relatively high Al ranging between 0.44 and 1.13 cmol/kg. Most of remaining sites had exchangeable Al below 0.15 cmol/kg.

Table 1. Particle size and chemical data.

Site	Site location	Depth (m)	Particle size (%) Clay	Silt	Fine sand	Coarse sand	EC (dS/m)	pH (1:5 $CaCl_2$)	Exc. Al (cmol/kg)
Kampot1	N: 1168981, E: 393885, 19 m asl	0-0.18	5.1	5.7	56.0	33.2	0.03	3.4	0.53
		0.18-0.50	8.4	4.8	51.1	35.7	0.02	3.5	0.78
		0.50-0.90	7.1	4.1	52.6	36.2	0.02	3.7	0.57
		0.90-1.30	5.6	3.9	52.5	37.9	0.01	3.7	
		1.30-1.58	9.8	3.6	49.9	36.6	0.01	3.6	
		1.58-2.20	14.4	3.0	43.4	39.1	0.02	3.4	
Kampot 2	N: 1166086, E: 396319, 10 m asl	0-0.20	4.1	1.6	14.6	79.8	0.02	3.6	0.34
		0.20-0.57	2.3	0.9	9.4	87.4	0.01	3.8	0.13
		0.57-0.80	1.6	0.4	10.9	87.1	0.01	4.0	0.15
		0.80-1.05	1.9	0.4	11.9	85.8	0.01	4.0	
		1.05-1.45	10.7	1.6	16.0	71.7	0.01	3.7	
		1.45-1.75	18.6	2.8	22.0	56.6	0.01	3.9	
Tramkak 1	N: 1214584, E: 451562, 55 m asl	0-0.18	2.2	4.6	59.8	33.4	0.02	3.8	0.10
		0.18-0.55	0.9	3.6	60.1	35.5	0.01	4.0	0.05
		0.55-0.91	0.8	7.1	56.8	35.3	0.01	4.1	0.04
		0.91-1.60	1.2	6.7	55.6	36.6	0.01	4.3	
		1.60-1.90	2.0	8.5	56.7	32.8	0.01	3.9	
		1.90-2.25	11.2	9.2	47.2	32.4	0.01	3.6	
		2.25-2.50	20.4	8.2	41.8	29.7	0.02	3.2	
Tramkak 2	N: 1213007, E: 464503, 10 m asl	0-0.12	6.0	19.8	52.2	22.0	0.04	4.7	0.02
		0.12-0.25	7.9	22.7	42.4	27.0	0.02	4.2	0.01
		0.25-0.50	22.1	34.0	27.5	16.4	0.02	4.4	0.06
		0.50-0.95	36.0	22.8	24.2	17.0	0.02	4.1	0.90
		0.95-1.40	28.4	33.1	27.7	10.8	0.02	4.8	
		1.40-1.90	36.6	21.6	28.0	13.8	0.03	5.4	
Ponhea Krek 1	N: 1314599, E: 591781, 36 asl	0-0.15	8.8	3.2	52.6	35.3	0.02	3.9	0.44
		0.15-0.40	19.5	4.3	43.1	33.1	0.03	3.7	1.07
		0.40-0.72	22.2	5.1	42.6	30.1	0.02	3.7	1.13
		0.72-1.15	22.6	5.6	40.0	31.9	0.02	3.7	
		1.15-1.70	24.9	6.3	39.1	29.7	0.03	3.6	
		1.70-2.20	24.9	6.2	36.9	31.9	0.03	3.7	
Ponhea Krek 2	N: 1299062, E: 578138, 18 m asl	0-0.19	1.3	2.5	91.9	4.2	0.01	4.3	0.08
		0.19-0.44	1.5	3.0	91.0	4.4	0.01	4.4	0.10
		0.44-0.78	1.0	3.0	91.0	5.0	0.01	4.7	0.00
		0.78-1.03	0.8	5.7	88.2	5.3	0.01	4.7	
		1.03-1.30	5.0	8.4	82.2	4.5	0.01	4.0	
		1.30-1.48	6.3	8.9	80.3	4.6	0.01	4.0	
		1.48-1.80	18.0	11.4	66.4	4.2	0.02	4.3	
		1.80-2.10	29.4	11.9	55.0	3.6	0.03	4.5	
		2.10-2.50	41.5	13.7	43.3	1.6	0.03	4.6	
Kampong Chhnang 1	N: 1319465, E: 426532, 117 m asl	0-0.10	2.7	5.8	37.1	54.3	0.02	4.3	0.07
		0.10-0.22	2.8	4.6	36.0	56.6	0.01	4.2	0.10
		0.22-0.40	4.6	3.9	35.1	56.4	0.01	4.0	0.26
		0.40-0.69	7.8	3.6	33.3	55.3	0.02	3.9	0.57
		0.69-0.86	11.0	5.1	31.1	52.7	0.01	3.9	
		0.86-1.20	26.2	4.2	24.1	45.5	0.01	3.7	
		1.20-1.75	34.6	3.4	17.6	44.4	0.01	3.7	
		1.75-2.20	53.9	3.6	14.1	28.4	0.01	3.6	
Kampong Chhnang 2	N: 1336103, E: 470581, 10 m asl	0-0.15	1.6	2.6	28.7	67.1	0.02	4.0	0.14
		0.15-0.34	1.7	2.3	28.8	67.3	0.02	4.3	0.10
		0.34-0.62	1.0	2.0	34.3	62.7	0.01	4.5	0.04
		0.62-0.93	3.5	3.8	32.5	60.2	0.01	4.4	
		0.93-1.27	7.2	3.1	24.2	65.5	0.02	4.0	
		1.27-1.55	12.5	6.1	18.9	62.5	0.02	3.9	
		1.55-1.97	30.4	4.4	15.6	49.6	0.0	3.8	

Note: asl: above sea level, Particle size: Clay < 2 µm, silt 2-20 µm, fine sand 20-200 µm, coarse sand 200-2000 µm

Discussion

Differences of soil particle distributions between two profiles in the coastal area of Kampot District indicate likely different in source parent materials. Based on its proximity at the base of mountain, Kampot 1 is most likely formed under colluvial sedimentation, derived from the weathering and erosional products of the Mesozoic sandstone of Bokor Mountain. Kampot 2, located close to the beach with lower elevation (10 m asl), may have been formed under marine deposition. The similar profile particle distributions and soil pH between Kampot 1 and Tramkak1 could be explained by their locations in the upland areas at the base of mountains. Rocks of Bokor Mountain are sandstone while the rocks of Damrei Romeal Mountain are predominantly quartzite (Workman 1972). Soil derived from weathering products of quartzite can contain a high coarse sand fraction but this is not a case in Tramkak 1. Further investigation may be needed to verify geology of Damrei Romeal Mountain.

Coarse grained granite rocks of Oral Mountain located in the west of Kampong Chhnang Province and some hilly outcrops in the province (Workman, 1972) may have strong influence on development of sandy soils in this area. High coarse sand fractions of two sites in this area (Kampong Chhnang 1 and Kampong Chhnang 2) suggest the granitic influence on soil parent materials. Particle size distributions of two profiles in Ponhea Krek District were quite different from profiles in other areas. Although the amount of fine and coarse sand of Ponhea Krek 1 was similar to those of Kampot 1 and Tramkak 1, the clay content was much higher. Ponhea Krek 2 also had highest fine sand content. The parent material of this area is reported to be old alluvium (Workman 1972). Based on pH results (Table 1), acidity is a major constraint for many field crops grown on these sandy soils. Among 8 profiles only Tramkak 2 had pH > 4.7 in topsoil (0-0.12 m), but low pH at deeper layers of this profile is likely to limit root depth. Low pH values and relatively high exchangeable Al of Kampot 1 and Ponhea Krek 2, indicate that Al toxicity is a likely limiting factor for crop production.

Conclusion

Variations in particle size distribution and acidity of sandy soils from different parts of Cambodia might be related to the influence of different parent materials of these soils. Proximity to granite and the coast was associated with mostly coarse sand fractions while sandstone and quartzite geologies were associated with an abundance of fine sand. Clay contents were similar at most sites as they were low in top layers and they generally increased at > 1 m depth. Soil pH values were generally low at all the sites between 3.4 and 4.7 but only Kampot1 and Ponhea Krek 1 had high exchangeable Al.

References

Bowman GM, Hutka J (2002) Particle size analysis. In 'Soil Physical Measurement and Interpretation for Land Evaluation'. (Eds NJ McKenzie, KJ Coughlan, HP Cresswell) pp. 224-239. (CSIRO Publishing: Victoria, Astralia).

Hin S, Bell RW, Seng V, Schoknecht N, Vance W (2007a) Soil and Landscapes of Basaltic Terrain in Ponhea Krek District, Kampong Cham Province, Kingdom of Cambodia. Soil and Water Science Division, CARDI.Technical Note No. 14, Phnom Penh.

Hin S, Bell RW, Seng V, Schoknecht N, Vance W (2007b) Soil and Landscapes of Sandy Terrain in Kong Pisei District, Kampong Speu Province, Kingdom of Cambodia. Soil and Water Science Division, CARDI.Technical Note No. 15, Phnom Penh.

Hin S, Schoknecht N, Vance W, Bell RW, Seng V (2006) Soil and Landscapes of Sandy Terrain of Tramkak District, Takeo Province, Kingdom of Cambodia. Soil and Water Science Division, CARDI. Technical Note No.7., Phnom Penh.

Rayment GE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods.' (Inkata Press: Melbourne).

Seng V, Bell RW, White PF, Schoknecht N, Hin S, Vance W (2005) Sandy Soil of Cambia. In 'Management of Tropical Sandy Soils for Sustainable Agriculture'. Kon Kaen, Thailand. 27 Nov-02 Dec 2005 pp. 42-48.

White PF, Oberthür T, Pheav S (1997) 'The Soils Used for Rice Production in Cambodia, A Manual for their Recognition and Management.' (International Rice Research Institute: Manila, Philippines).

Workman DR (1972) Geology of Laos, Cambodia, South Vietnam and the eastern part of Thailand - A review. Institute of Geological Sciences19, London.