Measurement of land-use effects on soil carbon and related properties for soil monitoring: a study on two soil landscapes of northern New South Wales, Australia

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Abstract
In Australia, and internationally, there is a growing need for information relating to soil condition, its current status, and the nature and direction of change in response to management pressures. Monitoring is therefore being promoted regionally, nationally and internationally to assess and evaluate soil condition for the purposes of reporting and prioritisation of funding for natural resource management. We present a dataset designed to assess differences in carbon and related soil properties across a range of land-use types within a basalt and granite landscape of northern NSW generated through the NSW Statewide Soil Monitoring Program. Clear and significant differences were detected between land-use types for the various soil properties determined but these effects were restricted to the near-surface soil layers (0-5cm and 5-10cm). Soil properties between the other, non-woodland land-use types were largely similar apart from a modest C increase but increased soil acidity under improved pasture. Woodland soils had larger quantities of C (T/ha corrected for equivalent mass) than any other land-use. Results from this work are being used to inform the further development the NSW State-wide Soil Monitoring Program and to populate the NSW soil carbon matrix and soil carbon models for application across the State.

Introduction
In Australia, and internationally, there is a growing need for information relating to soil condition, its current status, and the nature and direction of change in response to management pressures. This need has attained particular urgency with respect to soil carbon due to the growing perception that soil carbon sequestration might offer the potential to offset greenhouse gas (GHG) emissions. Monitoring is now being promoted regionally (Chapman *et al.* 2009), nationally (McKenzie and Dixon 2006) and internationally (e.g. Wang *et al.* 1995, Jones *et al.* 2008) to assess and evaluate soil condition for the purposes of reporting, and to prioritise investment in natural resource management. The concepts and definitions of soil health, quality and condition have been widely discussed in the scientific literature (e.g. Doran 1996, Karlen *et al.* 1997) but no consensus has yet been reached regarding the suite of soil properties that is universally appropriate to define and evaluate change in any or all of these. Most broad-scale monitoring programs that have been proposed identify soil carbon as a key "headline" indicator alongside a number of other soil properties that can be used to detect change and trend in soil condition (e.g. McKenzie *et al.* 2002, Jones *et al.* 2008). In Australia, for example, soil C and pH have been selected as key indicators of soil condition for the purposes of national soil monitoring (McKenzie and Dixon 2006) while other, regionally specific datasets have been identified in NSW (e.g. Wilson *et al.* 2008). A great deal of information currently exists in the scientific literature regarding the impact of specific management practices on soil properties in various regions of Australia (Greenwood and McKenzie 2001, Zhang *et al.* 2007 etc.). However, these studies have employed a range of methodological approaches and examined a wide range of soil properties and often single land-use systems. Here we sought to quantify land-use imposed differences in a defined set of soil indicators (bulk density, pH, carbon and nitrogen: after Wilson *et al.* 2008) in this region. We present a dataset designed to accurately and verifiably account for differences in the selected soil properties under different land-use types. The dataset presented was part of the provisional 'baseline' data layer gathered under the NSW Statewide Land and Soil Condition Monitoring Program.

Methods
Two study areas were located on the Northern Tablelands of NSW in SE Australia on Tertiary Basalt and Permian Granodiorite (Granite) around the townships of Guyra & Uralla respectively. The soils of these selected geological types were Red and Black Ferrosols and Yellow Chromosols/Kandosols (Isbell 2002) and have been grouped to form the Northern Tablelands Basalt and Bundarra Granite Soil Monitoring Units,

for the purposes of state-wide soil condition monitoring. The altitude across the region is approximately 1000m and has a temperate climate with a mean annual rainfall of 880mm which is summer dominant (i.e. total rainfall 108.3mm in January and 56.1mm in July). Maximum mean monthly temperatures in January are < 30ºC for all of the selected locations. Mean monthly minimum temperature is < 0ºC across the sample area, with frosts common from April to September.

Site Selection
Five 'site clusters' were established on privately owned farms across each study area. Each site cluster consisted of four 'treatments': i) a cultivation paddock, ii) improved pasture, iii) unimproved native grass, and iv) remnant woodland. Each of the individual treatments was in an adjacent paddock located on common soil type, landscape position, aspect and slope angle. At one property no improved pasture site was available so the design was not wholly balanced. Each treatment within a cluster was a maximum of 500m from the other treatments.

Soil Sampling
To measure differences in selected soil properties between land-use types, 10 soil cores were collected from each treatment at each site cluster. These 10 soil cores were spatially arranged within each 25 x 25 m sample plot (after Chapman *et al.* 2009), using a random, 'latin square' sampling design. Soils were sampled at a random location within the 10 selected 2.5 x 2.5 m cells using a manual coring device of 50mm diameter, driven to a depth of 30cm. The soil core was sub-divided into discrete depth increments (0-5cm, 5-10cm, 10-20cm and 20-30cm depths) in order to detect change with increasing soil depth. This sampling approach provided samples of known volume which allowed for the subsequent determination of bulk density for each individual sample. At a limited number of sample points, rock was encountered and the 20-30cm depth increment could not be sampled. Soil samples were stored in cool (< 5ºC) dark conditions until they could be processed. Samples were dried at 40ºC for 48 hours and then crushed to pass a < 2 mm sieve. Bulk density was determined on each individual sample. Each individual sample was then analysed for pH (1:5 $CaCl_2$) and Total Carbon and Nitrogen using LECO Dry Combustion method at the Environmental Analysis Laboratory, Southern Cross University, Lismore.

Statistical Analysis
For each geology, data collected from each treatment at each site (25x25m sample area) were analysed using a repeated measures analysis of variance. Since depth observations were taken at non-equally spaced intervals (0-5, 5-10, 10-20, 20-30cm), a power model was used to investigate the correlation of the residuals as being dependent upon the distance between depths calculated from their midpoints (2.5, 7.5, 15, 25cm). Significance of the fixed effects of Land Use, Depth and their interaction was examined using approximate F statistics. Differences between total carbon density (t/ha) was determined using one-way ANOVA and post-hoc lsd analysis (P<0.05).

Results
For both geological types, soil properties differed between the four land-use types examined (Table 1). When all the data for all sites, land-uses and soil depths were considered, a significant land-use effect was found only for soil bulk density with woodland bulk densities being significantly lower at all soil depths compared with the other land-use types. No significant main-order land-use effect was observed for soil pH, carbon and nitrogen.

The magnitude of the various soil properties determined on the basalt and granite soils differed but the relative patterns between lad-uses within each geological type were consistent. All soil properties determined showed a significant depth effect indicating that soil properties differed significantly between the soil depths sampled. Bulk density was typically lower in the surface soil layers compared with deeper soils. Soil pH had significantly lower values in the 5-10cm and 10-20cm layers compared with other soil layers across all land-uses sampled while carbon and nitrogen both declined significantly with increasing soil depth. A strongly significant land-use.depth interaction was also found for all soil properties determined, indicating different depth profile characteristics between land-uses. Examination of the depth distribution of soil properties indicated that soil pH was significantly lower at all soil depths under improved pasture compared with all other land-uses on both geologies. For carbon however, woodland had significantly higher values in the surface layers (0-5cm and 5-10cm) compared with all other land-uses (P<0.05 using LSD post-hoc). In the 0-5cm layer, the improved and unimproved pasture sites had similar carbon levels but both were larger

Table 1. Mean values of soil properties for each land-use type.

	Soil Depth (cm)	Bulk Density (T/m^3)		pH		Carbon (%)		Nitrogen (%)	
		Basalt	Granite	Basalt	Granite	Basalt	Granite	Basalt	Granite
Cultivation	0-5	1.31	1.39	5.17	5.07	2.81	1.58	0.22	0.11
	5-10	1.47	1.54	5.12	4.95	2.05	0.98	0.16	0.07
	10-20	1.40	1.64	5.11	4.98	1.40	0.47	0.10	0.03
	20-30	1.39	1.76	5.22	5.05	1.24	0.32	0.08	0.02
Improved pasture	0-5	1.09	1.47	4.91	4.94	3.77	1.99	0.31	0.13
	5-10	1.42	1.52	4.80	4.88	1.97	0.87	0.16	0.05
	10-20	1.42	1.64	4.99	4.96	1.31	0.51	0.10	0.02
	20-30	1.42	1.77	5.15	5.05	1.05	0.28	0.08	0.01
Unimproved pasture	0-5	1.13	1.30	5.22	5.07	3.54	2.03	0.25	0.11
	5-10	1.46	1.53	5.12	4.98	1.83	0.91	0.12	0.04
	10-20	1.34	1.59	5.17	5.02	1.16	0.45	0.07	0.02
	20-30	1.54	1.71	5.23	5.06	0.77	0.40	0.04	0.01
Woodland	0-5	0.83	1.18	5.19	5.13	6.90	2.72	0.39	0.12
	5-10	1.21	1.42	5.09	5.04	3.22	1.20	0.20	0.06
	10-20	1.15	1.46	5.11	4.93	1.70	0.67	0.11	0.02
	20-30	1.38	1.55	5.15	4.82	1.53	0.49	0.08	0.02

than the cultivation land-use. On both basalt and granite, woodland soils also had significantly larger nitrogen content compared with all other land-uses at 0-5cm. Below these depths however, no significant difference existed between the land-uses except for a slight but significantly ($P<0.05$) lower carbon and nitrogen concentration under unimproved pasture at 20-30cm.

Soil carbon densities (to 30cm deep) were also calculated for each land-use across the two study areas using the measured percentage carbon profiles and associated bulk densities of the individual soil samples collected from the various land-uses. In order to compare carbon densities between land-uses, it is now generally considered appropriate to calculate carbon densities between different land-uses expressed as an equivalent soil mass to 30cm depth. Again, the magnitude of values differed between basalt and granite but trends were consistent between the two geologies. For calculated carbon densities in the soils studied, woodland had a larger quantity of soil carbon to 30cm depth compared with unimproved pasture only. However, when carbon density was expressed on an equivalent mass basis, woodland carbon density was significantly higher than all other land-uses but there was still no significant difference in carbon density between the other land-uses.

Discussion

A number of significant patterns and trends were found in the data from the various land-use types and sites across the Northern Tablelands Basalts and Bundarra Granites. Soil BD had a significant land-use effect and was significantly lower under woodland compared with all other land-use types. This is a common finding in this region and is indicative of generally higher organic matter contents and soil porosity under trees compared with other land-uses (Young *et al.* 2005, Wilson *et al.* 2008). For all soil properties however, the differences between land-uses, were restricted to the surface soil layers. Differences between land-uses for the various soil properties diminished with soil depth and by 20-30cm depth, differences between land-uses was undetectable. This result confirms the findings of other work from the region previously reported in Young *et al.* (2005) and Wilson *et al.* (2008). Where differences between land-uses were found, woodland had higher pH, carbon and nitrogen contents and lower BD compared with all other land-use types. Much of the woodland within the study area was cleared during the late eighteenth and early nineteenth centuries in order to develop land for agriculture (Reid *et al.* 1997) and the surviving woodland in the region therefore represents little modified and minimally managed sites by comparison with the remainder of the cleared landscape. The consistently higher concentration of carbon, nitrogen and pH of these sites might therefore provide an insight into the potential pre-clearing soil condition in the region and indicate the value of this land-use as a 'reference' against which other soils and land-uses might be compared.

Soil properties between the other, non-woodland land-use types were largely similar apart from the very strong acidity under improved pasture on both geologies. This was particularly so in the 5-10cm layer of these pasture soils which is the zone of legume root activity and therefore potential nitrogen leaching. This process has been well documented in its association with soil acidification (e.g. Lockwood *et al.* 2003, Rengel 2003). Soil pH in the 5-10cm layer of these improved pasture soils was found to be as low as pH4.8, a significant threshold below which plant growth and potentially pasture productivity can be greatly impaired (Lockwood *et al.* 2003). This result is all the more surprising on the clay rich, basalt soils that are commonly believed to be well buffered against significant acidification. Our results suggests that soil carbon and nitrogen increased modestly under improved pasture in this region but that this soil change was associated with a significant and potentially damaging reduction in soil pH. Given the recent interest in land-use types and potential carbon storage, we also calculated the carbon density (to 30cm) across the various land-uses examined. When the carbon density was corrected for equivalent mass, using cultivated soils as the standard mass, the woodland sites had a larger quantity of carbon than any other land-use, while the other land-uses remained statistically similar. On an equivalent mass basis, the woodland soils contained, on average, 28 T/ha more carbon than any other land-use sampled. Comparing the various land-use systems sampled, it is therefore clear that in order to maintain the largest quantity of carbon in the landscape of the study area, retaining trees and woodland is the most effective option.

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