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Farm soil carbon monitoring developments & land use change: unearthing relationships between paddock carbon stocks, greenhouse gas emissions & productivity in Western Australia

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Abstract
This research provides a synthesis of soil organic carbon (SOC) densities in a range of Australian soils and land use types to decrease uncertainties in agricultural soil carbon sequestration investments. This work provides information on existing Australian carbon soil stocks, the relationships between SOC with various agricultural and forestry land use changes, and options available for agriculturalists to cultivate and safeguard their carbon investments. This work also includes recent developments in carbon rights, soil carbon monitoring, and verification technologies and procedures now in use for carbon stock inventories. This work has a special focus on known changes in SOC stocks, technological and methodological developments in the agricultural region of southern Western Australia.

Keywords
Carbon, forestry, land-use change, organic, revegetation, soil, Western Australia.
Introduction

At present, climate change is unlikely a first-order issue for most Australian farms, as farm carbon sequestration and mitigation options and incentives are rarely understood, or have a insignificant market value. As a consequence the short-term fundamental elements of farming are likely to be remain dependent on good farm entrepreneurial decisions and investment (Kingwell 2006). In Australia, the agricultural sector is the second largest emitter of greenhouse gases behind the stationary energy sector. As such, climate change policy will inevitably encroach into the Australian agricultural sector and farmers will be well advised to strategically assist carbon market-based policy development and progress new agricultural mitigation measures. One practical strategy to reduce the uncertainty of farm mitigation investments by exploring regional and industry specific synergies between conventional production systems and climate change mitigation options.

As more than 80% of the land-based organic carbon stores are contained in soils, finding means of increasing this carbon sink in agricultural soils is a logical option for farms (Intergovernmental Panel on Climate Change 2000). Unfortunately, the infancy of this area of interest is illustrated by the lack of convergence of techniques and policies to sequester carbon in agricultural soils. As large agricultural investments require robust and clear incentives over a reasonable amount of time, the current assortment of climate change mitigation options and policies entail too much uncertainty to deliver much private sector investment (Barker, Bashmakov et al. 2007). To accomplish robust agricultural mitigation, policy developments will need to parallel field investigations of new soil management practices and their affect on conventional existing production systems.

Despite the current lack of support for soil carbon sequestration projects under the Kyoto Protocol, farmers are cautiously enthusiastic about developing new markets that encompass soil organic carbon (SOC) offsets (Smith, Martino et al. 2007). As the nuances of particular markets emerge, prepared and informed farmers can take advantage of their local natural resource expertise to profit through market mechanisms such as carbon trading. However, there remain some fundamental barriers to the successful realisation of soil carbon markets. These include the development of practical and cost-effective methods to sequester carbon in soils, and the ability to monitor and verify changes in soil carbon stock performance according to market requirements. As carbon is in a constant state of flux between plants,
Relationships between carbon stocks and Australian soils

Soil organic carbon (SOC) includes plant, animal and microbial residues in all stages of decomposition (Post and Kwon 2000). The amount of SOC stored within the soil ecosystem is dependent on a number of factors including the quality and quantity of organic matter returned to soil, the soils ability to retain organic carbon, soil temperature and rainfall (Grace, Post et al. 2006). These factors determine the equilibrium of SOC through two biotic processes: the production of organic matter by terrestrial organisms, and; decomposition of organic matter by soil organisms (Kirschbaum 2000); (Post, Izaurralde et al. 2001). Soil carbon density differs between soil types, increases with increasing rainfall and decreasing temperature and characteristically declines down the soil profile (Valzano, Murphy et al. 2005); (Grace et al. 2006). In the cooler and wetter southern regions of Western Australia (WA), soils generally have higher carbon densities than most of Australia, although a lower carbon density than most other parts of the world (Valzano et al. 2005).

Understanding the propensity of local soils to gain or lose carbon is a useful means to reduce uncertainties of conventional production and potential carbon sequestration investments. Australian subsoils are characterised by high soil acidity and high concentrations of toxic elements (Cransberg and McFarlane 1994). If SOC stocks decline, more mineral surfaces are exposed which increases acidity and the influence of soluble and dissolvable levels of aluminium, especially in kandosols, podosols and chromosols (Dalal 2001). Kandosols occur to a small extent along the western coast of the southwest from Perth down to north of Augusta and are mostly structureless soils that are highly permeable (See Figure 1). Kandosols are often used for a range of horticultural crops, but has limited fertility and can become acidic when carbon inputs are reduced through cropping (Brown, McKenzie et al. 1997); (Dalal 2001). In some areas between the Kojonup, Walpole and northeast of Albany there are significant amounts of podosols. These soils contain high amounts of organic matter, aluminium and sometimes iron and are extremely infertile and exhibit poor water retention (Brown et al. 1997). Podosols have a lower level of microbial activity, which can reduce carbon turnover (Dalal 2001). Chromosols are soils with an abrupt increase in clay and are common in some areas of the southwest between Geraldton, Northam...
and Albany (Brown et al. 1997). These soils are known to form complexes between organic matter and aluminium, which also reduce the rate of carbon turnover, and thus can increase the net pool of soil carbon. As microbial SOC decomposition activity decreases alongside soil pH, the result is an overall increase in organic carbon in soils (Dalal 2001).

The variability of soil types between and within regions cautions the use of generalised measures to simply attempt to increase SOC stocks. While lower microbial activity and the formation of aluminium and organic matter complexes can slow carbon turnover, the increased toxicity and acidity is often detrimental to the productivity of the soil. Some poorer structured soils, such as sodosols and kandosols, often contain less organic carbon regardless of tillage and soil management practices, and will likely respond poorly to sequestration activities (Valzano et al. 2005).

Sodosols are common in the lower rainfall areas between Esperance, Narrogin, Geraldton and Laverton, and contain high levels of sodium with abrupt increases in clay down the profile (Brown et al. 1997). Correspondingly, well-structured soils with high soil carbon levels such as ferrosols and dermosols are rare in the south of Western Australia (Brown et al. 1997). While these approximate soil classifications and corresponding organic carbon levels are useful for much conventional output, they are inadequate carbon market investments.

**Monitoring carbon in the soil for carbon markets**

Most soil carbon data sets in Australia have limited use for carbon markets as they have been collected for a variety of unrelated reasons using inconsistent methodologies. To minimise disturbance and research time, many soil samples have been taken from road reserves, which may have lead to an overestimation of carbon stocks for the Australian National Greenhouse Gas Inventory (NGGI) (McKenzie, Ryan et al. 2000).

Currently, there is no internationally agreed methodology to verify changes in SOC, in part, because there is a lack of robust science-based, cost-effective, practical and flexible options for monitoring and verification (Post et al. 2001). The default depth for soil sampling by the Intergovernmental Panel for Climate Change (IPCC) is up to 30 cm (Polglase, Paul et al. 2000). However this shallow depth can lead to problems in the changes in the bulk density by the loss, addition, shrinking or swelling of soil.
material (McKenzie et al. 2000). Research by Post et al. (2001) documented a variety of methods and standards for measuring soil properties including (Klute, 1986); (Carter, 1993); (Cully, 1993); (Weaver et al., 1994); (Sparks, 1996); (Magdoff et al., 1996); (USDA-NRCS, 1996). The Walkley-Black procedure is a common method of determining SOC in Australia and is often recommended for SOC analyses when a total carbon analysis is not required. However, the procedure is also known to have a number of important limitations, such as when soils contain substantial quantities of inorganic carbonate (MacDicken 1997). These methods are effective for evaluating SOC changes only at relatively low precision (20-50 % error) (Post and Kwon 2000); (Byrne, Kiely et al. 2007). Thus, such coarse carbon stock information is unlikely to provide sufficient detail over short periods of 3 to 5 years to be of use in carbon market SOC monitoring (Post et al. 2001).

Verification and compliance to national accounting schemes of SOC and other carbon species would require a consistent and reliable soil sampling methodology and testing techniques (Graetz and Skjemstad 2003). One promising option in use in Australia is the mid infrared (MIR) spectroscopy services offered by CSIRO Land and Water. CSIRO has gained considerable expertise in MIR and provide a cost-effective soil analysis service to predict soil properties, including SOC. This technique uses light (2500 to 20,000 nm) to detect signatures and predict a wide range of physical and chemical properties using only small amounts of soil (CSIRO Land and Water 2008). MIR may be used with high precision and accuracy when a local calibration set exists. At present a number of monitoring sites are being established in WA for such a calibration set (National Land & Water Resources Audit 2008). As the MIR predictions advance in parallel with the development of calibration sets, this technology can be effectively used in conjunction with a consistent soil sampling strategy.

Recently an Australian SOC “National Monitoring and Evaluation Framework” has been developed by The National Heritage Trust’s National Land & Water Resources Audit. The framework recommended monitoring SOC against a baseline expressed as a percentage, as a density (t/ha), and as a change in SOC over time. The framework was designed to collect sample data that is suitable for quantifying changes in SOC for land use change management and carbon accounting over a minimum period of 5 to 10 years. The soil samples are taken at depths of 0-5, 5-10 and 10-30 cm, (and in some cases 30-100 cm depth), using a corer with vertical sides (National Land &
Water Resources Audit 2008). The vertical samples are obtained using a bulk density corer with a 50cm diameter (Specht and West 2003) (National Land & Water Resources Audit 2008). Manual coring is physically difficult at depths greater than 50 cm in clay, stony, woody or sandy soils, so in some cases known volumes of soil can be taken from the face of a pit (MacDicken 1997).

Volumetric estimates of soil carbon are required for most carbon accounting purposes. This entails weighing the soil carbon content, measuring soil bulk density and the volumetric proportion of coarse fragments, such as gravels (McKenzie et al. 2000). Converting estimates of carbon from concentration to mass requires data or estimates of bulk density, rock content, depth of sampling, and root components. These parameter measurements require a quantified measurement error to be confident of the quality and usefulness of the data set (Post et al. 2001). General soil sampling practices also need to take into account seasonal variations in the water and root content of soil columns, which often affect bulk density calculations. Most issues can be avoided by not disturbing or compacting the sample areas and by synchronising sampling schedules between years. Thus the difficulty of obtaining a 95% confidence levels with SOC measurements over large sites can require around 20 to 30 per site (or more) to achieve an accuracy of around ±10 of the mean, depending on the soil (Post et al. 2001). To reduce the costs of data collection and analysis, the sampling procedure can consist of using composite samples that represent multiple plots to provide a reasonable estimate of SOC stock changes (MacDicken 1997).

**Land use change and changes in soil carbon stocks**

Establishing or clearing plantations of forests fundamentally changes the soils physical, chemical and biological properties by modifying the quantity and type of organic carbon inputs, nutrient inputs, and stimulates SOC decomposition through soil disturbance (Murty, Kirschbaum et al. 2002). It has been estimated that up to 39% of organic carbon in cultivated surface soils of Australia has been lost between 1860 and 1990 (Gifford et al., 1990) as cited in (Grace et al. 2006). Highly productive Australian pastures have the highest carbon densities at 0-30 cm of depth, followed by forest soils, grazed pastures, and lastly, cropped soils (Valzano et al. 2005).

Changes in soil and vegetation management can impact strongly on the rates of carbon accumulation and loss in soil, even over short periods of time (Post et al.
Average declines in soil carbon stocks of around 30% can occur in the first 20 years after cultivation for some soils (Murty et al. 2002). When soils are cropped, the associated biological and physical processes can result in a release of SOC over time, often up to 50% or more, depending on soil conditions and agricultural practices (Kirschbaum 2000); (Antle, Stoorvogel et al. 2007). Clearing native vegetation or removing well established pastures with high biomass can result in soil carbon losses of 10 to 30 tonnes of carbon per hectare (tC/ha) in the 0-30 cm depth region in some Australian soils (Valzano et al. 2005). Even converting from pasture to tree plantations can result in losses of carbon soil stocks, as woody plants are less effective than perennial grasses in some environments at storing carbon in the soil. This is due to the long lifetimes of tree root systems and present less organic material each season to be stored as more permanent carbon stocks than pasture grass roots with annual cycles (Guo and Gifford 2002). Unfortunately, as the loss or gain of carbon is dependent on a myriad of factors, and developing simple relationships for groups of soil types and land uses is unrealistic and requires site specific research.

There is much misinformation surrounding the effectiveness of land use change and their effect on SOC, which can lead to an increase in risk for farmers when selling the rights to soil carbon stocks. Returning pasture to trees may actually reduce SOC levels for several decades, with the loss of SOC potentially outweighing tree biomass carbon assets. Research by Guo and Gifford (2002) conducted a meta-analysis of five hundred and thirty-seven observations in 16 countries that indicated that soil carbon stocks declined after converting pastures to plantations. The research encompassed 74 publications, of which 14 were from Australia, that examined how much the SOC stocks in soils changed after the conversion from one land use to another. They found that soil carbon declined 10% after conversion from pasture to plantation, 13% for native forest to plantation, and 42% from native forest to cropping. The largest losses of soil organic carbon stocks were from conversion of pasture to cropping (59%). They also found that soil carbon stocks increased 8% after the conversion from native forest to pasture, 18% for crop to plantation, and 19% for crop to pasture. The largest soil carbon stock gains of 53% were from converting crops to secondary forest regrowth (Guo and Gifford 2002).

Areas that have annual rainfall above 1500 mm can lose around 50% of the SOC when converted from forests to plantation, while areas with annual rainfalls between 900 – 1200 mm and 1200 – 1500 mm record smaller losses of around 5% and 20%
respectively (Guo and Gifford 2002). The average rainfall for the southwest of Australia varies considerably within the region (between 200 and 1600mm), although is generally lower than 1000mm except from one small area on the coast southwest of Walpole (Bureau of Meteorology and Australian Government 2008). Consistently, the Aggangan et al (1998) and other research in the southwest of WA found that there is no significant difference in 0-10 cm soil organic carbon levels between eucalypt plantations and adjacent pastures, suggesting that tree plantations in this region do not significantly reduce the soil carbon stocks when converting from pastures. Tree plantation age is also unlikely to have a significant effect on change in soil carbon following nitrogen fertiliser applications, as higher growth rates for these trees are dependent in a significant part to utilisation of stored nutrients in the soil in the southwest region (Polglase et al. 2000).

Aggangan et al. (1998) compared SOC stocks in the surface layers under an area with a 4 year-old blue gum plantation and pastures near Augusta, in Western Australia. The plantation soils were ripped and mounds constructed along the planting lines prior to planting with pasture soils receiving an annual dressing of 18 kg of phosphorus as superphosphate and 1 tonne of lime per hectare, one year prior to sampling. Four years after afforestation the SOC stocks increased by 112 and 80 grams per square metre per year in the 0-10 and the 10-20 cm soils depths respectively (Polglase et al. 2000).

**Strategies to improve SOC stocks on the farm**

Accounting for changes in carbon stocks requires knowledge of many variables including the sites productivity, vegetative cover, vegetative component turnover, carbon components of each vegetative component, land management and even disturbance history (Guo and Gifford 2002); (Department of Climate Change and Australian Government 2006). Previous land use practices determines soil fertility to a large degree, which affects the potential of to accumulate carbon (Wise and Cacho 1999). Evidence from long-term experiments suggest that carbon losses can be reversed with soil management practices that minimise soil disturbance and optimise plant yield through fertilisation (Dick, Blevins et al. 1998); (Janzen, Campbell et al. 1998); (Rasmussen, Albrecht et al. 1998); (Post et al. 2001). Carbon sequestration can be fostered by establishing perennial vegetation, conservation tillage methods, efficiently using fertiliser and increasing use of high yielding crop varieties (Post et
The maintenance of soil organic matter through carbon fixation, subsequent litter decay and nitrogen fixation by leguminous shrubs also encourages soil biodiversity (Patabendige, Scott et al. 1992). Maintaining cereal cropping production systems will produce lower carbon densities than other agricultural systems, however, rotations with pastures or legumes with assist cropping land to retain more SOC stocks (Valzano et al. 2005).

SOC densities are especially sensitive to the input of carbon from plant growth, so any environmental or management factors that limit plant growth will have a correspondingly negative effect on SOC stocks. Management factors that negatively affect plant biomass production include a long bare fallow period, overgrazing of stubble or pasture and soil nutrient deficiencies (Valzano et al. 2005). Several researchers have stated that nutrient deficiencies can also have an impact on the rate of carbon matter sequestered in some Australian soils. They suggest that it is often necessary to replace some sodium with calcium in sodic soils before increases in organic matter is able to improve the soil and allow plants to create biopores through harder soils (Naidu and Rengasamy 1993); (Cransberg and McFarlane 1994); (Rengasamy 2002).

If nutritional, physical soil properties and climate factors do not limit plant growth there is significant potential for some Australian soils to store large amounts of carbon. Some soils in the Amazonian basin have received large amounts of charred materials (bio-char) as the result of burning biomass before the arrival of Europeans. Some of these areas contain 250 tC/ha per metre of depth, which exceeds the potential for natural soil carbon sequestration and revegetation of bare soil to primary forest containing about 110 tC/ha (Sombroek, Ruivo et al. 2003). This shows that there is scope for supplementing soils with long-lived species of carbon. Unfortunately, there is no “magic bullet” for reliable carbon sequestration using conventional land management practices, as a low-cost high-benefit option does not yet exist (Graetz and Skjemstad 2003).

The adoption of agricultural management practices to sequester carbon will be constrained both by environmental conditions, such as climate and soil types, as well as economic and socio-political factors. The supply and demand of agricultural products, production costs, subsidies, environmental incentives, and political
acceptance for changes in the agricultural landscape will likely be as important as any technical sequestration potential (Paustian, Andren et al. 1997).

**Carbon rights and new markets**

The development of carbon markets for regenerative land management practices gives a financial value to natural resource management practices that provide environmental benefits (Jones 2007). In carbon markets, a “carbon credit” represents one tonne of carbon dioxide equivalent gas (tCO\(_2\)-e) that is sequestered and their value is dependent on supply and demand. As carbon trading accounts for tCO\(_2\)-e of carbon sequestered, the conversion of tonnes of pure organic carbon (tC) sequestered to (tCO\(_2\)-e) is achieved by multiplying the soil carbon stock by 3.67 (Jones 2007). Therefore an increase of one tonne of sequestered organic carbon in agricultural soils sequesters 3.67 tonnes of CO\(_2\)-e from the atmosphere, which also would represent 3.67 carbon credits in a trading scheme. The consensus appears to be that soil represents a finite carbon sink that provides a window of opportunity for investors to capitalise on resultant climate change markets and policies (Lehmann, Gaunt et al. 2006).

Prudent farmers will explore the potential to increase soil carbon stocks and quantify their potential profits and risk. The perception of risk in biological sequestration options may lead to a low value for carbon credits, as the potential for losses may reduce market demand (Lehmann et al. 2006). In terms of biological storage, SOC is less risky than many existing tree biomass carbon sinks that are susceptible to drought, disease and bushfires. These aboveground vegetative sinks are required to be maintained and/or replaced to sustain the investment over the often 100-year timeframe. Therefore, SOC sequestration investments may therefore receive a premium in future carbon markets, as a form of low-risk premium.

At the current time only newly afforested land put to tree plantations planted since 1990 are included in the Kyoto Protocol’s flexibility mechanisms for the commitment period of 2008 to 2012 (Brack, Coops et al. 2002). Neither avoided deforestation or carbon sequestration in agricultural cropland are currently allowable under the Protocol (Lehmann et al. 2006). The first government legislated carbon trade in Australia was registered in March 2005 and was valued at over A$1 million. The contract between Forests NSW and Energy Australia was for carbon sequestered in
the state of New South Wales in northern hardwood timber plantations (Jones 2007). Trading developments in WA include the Western Australian Parliament approved Carbon Rights Act 2003. The act gave landowners a statutory basis to register, and trade the carbon rights as a separate interest in the land (The Parliament of Western Australia 2003). This allows farmers in WA to register a portion of their land to obtain and sell the rights to the carbon stored “in [their] land or on anything on land” since January 1 1990.

As the level of accounting and administration costs for carbon monitoring and markets is likely to be expensive initially, the most likely form that most farmers will participate in such markets will be in “carbon pools”. Carbon pooling involves combining a number of small registered carbon rights in order to generate carbon credits of sufficient volume to obtain a positive financial return by sharing costs of technical measurement, certification and marketing of carbon credits (The CRC for Greenhouse Accounting & Tony Beck Consulting Services Pty Ltd 2003). Pooling of biomass resources to displace fossil fuels in conventional grid-connected generators may be yet another future market available to farmers if a sustainable biomass carbon supply can be integrated into their production systems.

This option gives Australian farmers the option of attracting another tradable entity that is outside of the Kyoto Protocol and Australian domestic carbon market policies: when biomass energy displaces fossil fuel energy sources and leads to a reduction in net greenhouse gas emissions (Lehmann et al. 2006). The Australian Renewable Energy (Electricity) Act 2000 set the framework for the national Mandatory Renewable Energy Target (MRET) legislation. This legislation created a tradable entity called a Renewable Energy Certificate (REC). One REC represents one megawatthour (MWh) of accredited renewable energy exported to electricity networks. Accredited generators can sell these RECs in a restricted market with the price determined by the interplay between supply and demand from legislated mandatory requirements of electricity retailers to obtain a number of RECs equivalent to a percentage of the electricity they sell to customers. Australian farmers are able to use their aboveground biomass resources to generate accredited renewable electricity to reduce net carbon emissions and claim RECs. Therefore farmers have the choice to either use their aboveground biomass resources as a feedstock for renewable energy generation, as plantation sinks under the Kyoto Protocol, to add to the soil organic carbon pool when such markets are developed.
Conclusion
The agricultural sector is well placed to utilise key mitigation technologies and practices if they can be also be used to benefit conventional production. However, without an implicit or real price of carbon for the conventional farming sector, businesses are unlikely to incorporate mitigation into their everyday activities. New market and technological developments together with quality research is now making the possibility of mitigation a viable supplement to agricultural region returns, although many unknowns remain.

Notwithstanding the immaturity of markets for agricultural cropland sequestration, there are ways that farmers can benefit from entering into contracts to sequester carbon. Firstly, farmers would be compensated for the carbon they sequester, based on the quantity and market price of carbon, minus soil analysis and administration costs. Secondly, farmers would benefit from any conventional productivity gains that is associated with the adoption of appropriate carbon management practices (Antle et al. 2007). The third, less conventional manner of benefiting from revegetation carbon assets is by using some of the energy contained in aboveground biomass resources to displace fossil fuel electricity generation. Some generation technologies also allow the capture of the solid carbon residues in the conversion process to be applied to soils or sold. This allows Australian farmers to derive revenues from markets outside the Kyoto Protocol to reduce investment risk.

References


Guidelines for local and regional level monitoring by natural resource management groups, The Natural Heritage Trust, 11.


Fig. 1 Relationships between daily soil temperature, rainfall and SOC density in Australia. These polynomials and their high coefficients of determination show the good relationship of two simple climatic variables with Australian SOC levels, mostly due to variations in SOC decomposition by soil biology. The temperature data was derived from dryland agricultural regions, and should not be extrapolated to indicate relationships between SOC and temperatures from colder, alpine areas. Source: (Valzano et al. 2005).
Fig. 2 Regional map of the southwest of Western Australia. (Courtesy of Landgate WA, 2008).
Fig. 3 Kandosols in Western Australia. (Brown et al. 1997).

Fig. 4 Podosols in the southwest of Western Australia. (Brown et al. 1997).
Fig. 5 Chromosols in Western Australia. (Brown et al. 1997).

Fig. 6 Sodosols in Western Australia. (Brown et al. 1997).
Fig. 7 Ferrosols in Western Australia. (Brown et al. 1997).

Fig. 8 Dermosols in Western Australia. (Brown et al. 1997).
Fig. 9 LUC and SOC changes at specific sampling depths. (Guo and Gifford 2002).

Fig. 10 LUC and SOC changes over time. (Polglase et al. 2000).

Table 1 Soil chemical, physical and mineralogical properties predicted using MIR, with indicative R2 values comparing MIR values against the conventional laboratory techniques used for soil assessments.

<table>
<thead>
<tr>
<th>Soil property</th>
<th>R²</th>
<th>Characteristic</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory lime requirement</td>
<td>0.85</td>
<td>Clay mineralogy</td>
<td>yes</td>
</tr>
<tr>
<td>pH&lt;sub&gt;ca&lt;/sub&gt;</td>
<td>0.88</td>
<td>Elemental analysis (XRF) - SiO₂</td>
<td>0.97</td>
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<tr>
<td>0.01 M CaCl₂ Al</td>
<td>0.69</td>
<td>Al₂O₃</td>
<td>0.92</td>
</tr>
<tr>
<td>0.01 M CaCl₂ Mn</td>
<td>0.46</td>
<td>Fe₂O₃</td>
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<tr>
<td>Exchangeable Ca</td>
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<td>MgO</td>
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<tr>
<td>Exchangeable Mg</td>
<td>0.88</td>
<td>P₂O₅</td>
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<tr>
<td>Exchangeable K</td>
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<td>Particle size - % sand</td>
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<tr>
<td>Exchangeable Na</td>
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<td>% silt</td>
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<td>Exchangeable sodium % (ESP)</td>
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<td>% clay</td>
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<tr>
<td>Sum exchangeable cations</td>
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<td>Bulk density</td>
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<td>CaCO₃ %</td>
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<td>Volumetric moisture % @ -10 kPa</td>
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</tr>
<tr>
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<td>Volumetric moisture % @ 15 bar</td>
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<td>Drained upper limit (Darling Downs)</td>
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<tr>
<td>Total N %</td>
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<td>Water stable aggregates</td>
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