Soil factors affecting vegetation establishment after sand mining on North Stradbroke Island

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Abstract
A study was undertaken to investigate causes for poor native vegetation establishment and erosion in rehabilitated sand dunes following sand mining at North Stradbroke Island, Australia. The problem was mainly associated with the use of topsoil from old rehabilitated sites from earlier mining ventures (designated as pre-mined topsoil) as opposed to using topsoil from unmined native areas (designated as unmined topsoil). The approach was to characterise the soil properties pertinent to soil erosion and measured poor plant growth from two rehabilitated areas of similar age but using the different topsoils, pre-mined and unmined. Results indicated that the greatest soil physical difference between the topsoil areas was the severity and frequency of water repellency (ratings 6-severe and 5- moderate to severe) that occurred in the pre-mined topsoil. Ca and Mg contents were also lower in the pre-mined topsoil area compared to that of the unmined topsoil, as was the lower Ca:Al ratio (<1), indicating a possible impact of poor cation balance on vegetation growth. Despite differences in surface stability and vegetation growth, soil carbon was not a differentiating factor between the unmined and pre-mined topsoil areas.

Key Words
Mined land rehabilitation, water repellency, Ca:Al ratio, dune rehabilitation.

Introduction
A requirement of sand mining operations on North Stradbroke Island is to produce a landform similar to pre-mining and to establish vegetation communities on post-mine dunes constructed from mined residues or tailings. During rehabilitation, reconstructed sand dunes are first overlain with a layer (0.2-0.3 m) of topsoil that had been removed from unmined areas ahead of the mine path. Following this, a sorghum (*Sorghum bicolour*) cover crop is sown along with a mixture of native seeds and blended fertilizer. Once seeded the soil surface is sprayed with Terolas®, an aqueous bituminous emulsion at a rate of 1.8 L/m^2. Terolas® is used for two reasons: (i) to produce surface stability against wind and water erosion, and (ii) to maintain soil moisture for germination and establishment. Problems of poor native vegetation establishment and high incidence of gully erosion have occurred at certain revegetated sites. These sites were associated with the use of topsoil collected from areas that had been rehabilitated in the late 1970s to early 1980s and are currently re-mined (designated as pre-mined topsoil), as opposed to topsoil from unmined native areas (designated as unmined topsoil) which is the case in newly mined areas. The aim of this study was therefore, to characterise the soils in the rehabilitation areas, and to compare the soil physical and chemical properties pertinent to soil erosion and poor plant growth from rehabilitation areas of similar age but using the two types of topsoil.

Site location and climate
The study was conducted at a mine site situated ~ 2.5 to 5.5 km south of the township of Point Lookout (27° 26' S, 153° 32' E) on North Stradbroke Island (NSI), 40 km east of Brisbane in Moreton Bay. Rainfall is summer-dominant (mean monthly precipitation ranging from ~ 10 - 370 mm) with short intense rain events, particularly associated with summer storms. Evaporation exceeds rainfall (almost double the rainfall), and mean annual daily temperature ranges from 15 to 25^{o}C. Natural landform at NSI mainly consists of dune sands of different ages with low inherent fertility (but sufficient to support a range of eucalyptus-dominated communities), wallum vegetation (coastal vegetation on sandy acidic soils) and dystrophic (poorly nourished) lakes with peaty brown, acidic water. Soils can be excessively dry in young dunes and permanently waterlogged in swamps and wetlands. The most common natural soil type is the Podosol (Isbell 2002) with deep yellow or pale brown siliceous sandy subsoils containing iron and aluminium compounds. The source of soil nutrients are a small quantity of weatherable minerals in the sand and salt from sea spray (Pillai-McGarry and Mulligan 2008). The study mine site was operational from 1966 for a period of 20 years and mining recommenced at the site in early 2000.

Methods

Fifteen trenches (1m x 2m x 1.5 m deep) were mechanically dug in two areas that were rehabilitated in 2006 and managed in a similar manner. Nine of the trenches (T1 to T9) were located in the area where pre-mined topsoil was used (designated as Block A) and six (T10 to T16) in the area where unmined (native) topsoil was used (designated as Block B).

Field sampling and measurements

At each trench, the following field measurements and observations were undertaken:
(i) Site and soil description- visual estimates of vegetation type and percent cover, slope and aspect and basic soil description (McDonald *et al.* 1990) to 1 m depth of a freshly exposed vertical face; (ii) three replicated soil samples were collected at 0.05 m intervals to 0.2 m, at 0.1 m intervals to 0.4 m and 0.2 m intervals to 1 m depth, transported to the laboratory, air-dried and prepared for analysis by passing through a 2 mm sieve; (iii) four replicated cores for bulk density determination (70 mm dia. x 60 mm or 20 mm long) were vertically inserted at each of 0 m, 0.03 m, 0.06 m, 0.15 m, 0.3 m, 0.5 m, and 0.7 m depths using hand pressure applied to a flat stainless steel plate, placed on top of the core, the core with soil was excavated with a knife, soil oven-dried (105^{o}C) in the laboratory and bulk density calculated using core volume; (iv) water repellency of the surface soil was tested and rated using the water drop penetration test (WDPT) (NSW Department of Sustainable Natural Resources 2005) by placing a droplet of de-ionised water, using a 10 mL syringe, onto the soil surface bounded by a steel ring (70 mm dia. x 20 mm long) inserted into the surface, and time for penetration recorded. Five replicated readings were made so that a range of penetration times were obtained.

Laboratory analyses

The aim of the laboratory analyses was to provide a comparison of soil fertility from the different rehabilitation sites for use as a possible indicator for plant growth differences. All chemical analyses except for total carbon were carried out on the <2 mm fraction of the soil. Unless otherwise stated, all analytical procedures were as outlined by Rayment and Higginson (1992). Measurements made were: (i) $pH_{1:5\ water}$ using a TPS pH meter following end–over- end shaking for 1 h, (ii) total C and N of ground soil passed through a 0.5 mm sieve, by combustion using an Elementar Vario Macro CHNS Analyser; (iii) exchangeable basic cations and Al, Fe and Mn were measured using an ICP-AES (SPECTROFLAME MODULA E) after a 16 h extraction with unbuffered 0.01 M silver-thiourea (1:50 soil:solution ratio).

Water repellency test

To standardise soils, the WDPT was also conducted in the laboratory on air-dry samples. Soil subsamples were placed in cylindrical containers (0.02 m dia. x 0.15 m deep) and repellency rating was measured on replicated samples.

Results

The most striking differences in visual features between Blocks A and B were the greater density and diversity of above-ground native vegetation and the low weed population in Block B compared to Block A. The mean live vegetation groundcover was lower for Block A (32.2%; range: 5-50%) compared to Block B (45%; range: 10-80%). A typical profile of the reconstructed soil (Plate 1) indicated an abrupt transition between a generally hardsetting topsoil and a less cohesive subsoil (tailings) with minimal evidence of a transition zone despite two years of formation.

Plate 1. Typical profile of a two-year old reconstructed and rehabilitated sand dune. The topsoil exhibited a hard-setting zone below 0.05m depth and above the subsoil (tailings). Hard-setting refers to the strength of a soil tested under a specified moisture condition (moist and/or dry). In this profile the soil was hard below 0.05m, but the subsoil crumbled.

Topsoil depth varied spatially (0.16 to 0.39 m) across the study area. In Block A, rooting depth was mainly confined to the topsoil (mean depth was 0.22 m), whereas in Block B it extended into the subsoil (mean depth 0.36 m). A common feature noted while soil sampling, particularly in Block A, was the extensive lateral growth of thick (>50 mm dia.) roots in the 0-0.15 m depth (mainly associated with adjacent plants of *A.concurrens*) while finer roots were found at deeper depths where conditions were generally moister.

Although the topsoil was less dense to ~0.35 m (related to where the subsoil commenced) in Block B, there was no significant difference in bulk density for comparable depths between Blocks (Figure 1). The gradual increase in bulk density below the 0.1m depth was associated with the hard-setting layer and a decrease in rooting density and porosity in this layer. The lower bulk density in Block B may be associated with the better plant establishment and root growth contributing to improved porosity.

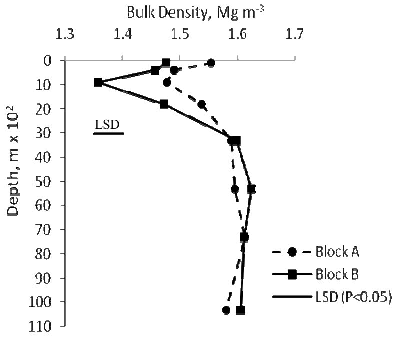

Figure 1. Mean dry bulk density profile of the soils in Blocks A (●) and B (■). LSD (P<0.05) compares means at any given depth.

Field testing for water repellency gave similar results to those from laboratory testing presented in Figure 2, and variability between laboratory replicates was close to zero. Repellency was particularly severe in Block A with soils from over 65% of the trenches in Block B having ratings of severe (6) or moderate to severe (5) repellency on the soil surface. Water repellency also extended to depths below the immediate surface.

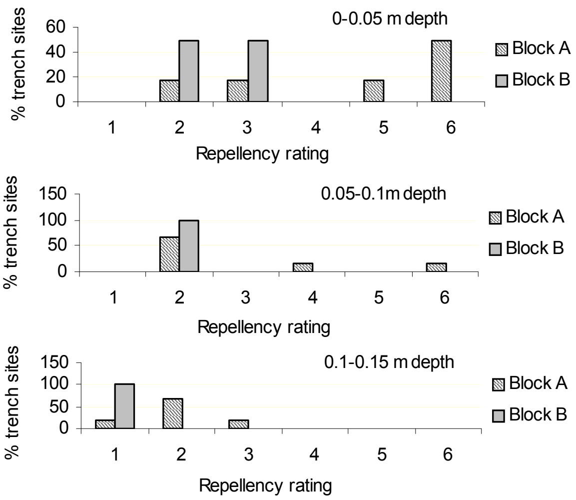

Figure 2. Water repellency ratings of soils tested under standard air-dry conditions in the laboratory 1 = not significant, 2 = very low, 3 = low, 4 = moderate, 5 = moderate to severe and 6 = severe.

Visual evidence of poor water infiltration caused by water repellency was recorded in the field (Plate 2) where uneven vertical infiltration of water, following an overnight rain event of 108 mm, occurred through root channels and other macro-pores (e.g. rotting plant material, faunal channels) resulting in patchy wetting of the soil.

Plate 2. Water repellency: irregular wetting in the vertical soil profile in Block B after overnight rainfall of 108 mm

The greatest difference in soil chemical properties between Blocks (Table 1) was in exchangeable Ca and Mg contents with more than double the amount of Ca and nearly double of Mg in Block B compared to Block A. The Ca:Al ratios in Block A was >1 in the topsoil compared to Block B where ratios were > 1. Surprisingly, % total C was low for all soils (<1%) with no difference between Blocks, possibly indicating low carbon accumulation in early years of rehabilitation.

Table 1. Means of selected soil chemical properties of the soils in Blocks A and B at six depths. Means with similar lettered superscript are not significant at P<0.05, for any given property.

Soil depth (m)	pH	Total C (%)	Exchangeable cations ($cmol_c$/kg)		Al ($cmol_c$/kg)	Ca:Al
			Ca	Mg		
Block A						
0-0.05	5.4^{a}	0.4^{a}	0.05^{a}	0.03^{a}	0.08^{a}	0.6
0.05-0.1	5.2^{ab}	0.4^{a}	0.08^{abc}	0.06^{b}	0.17^{b}	0.5
0.1-0.15	5.1^{b}	0.5^{a}	0.07^{ab}	0.05^{ab}	0.22^{c}	0.3
0.15-0.2	5.1^{b}	0.4^{a}	0.08^{abc}	0.04^{ab}	0.23^{c}	0.3
0.2 – 0.3	5.1^{b}	0.5^{a}	0.14^{c}	0.06^{b}	0.24^{c}	0.6
0.3-0.4	5.3^{ab}	-	0.12^{bc}	0.05^{ab}	0.05^{a}	2.4
Block B						
0-0.05	5.6^{a}	0.6^{a}	0.24^{d}	0.08^{c}	0.08^{a}	3
0.05-0.1	5.5^{a}	0.6^{a}	0.26^{d}	0.1^{c}	0.12^{a}	2.2
0.1-0.15	5.5^{a}	0.5^{a}	0.31^{e}	0.11^{c}	0.15^{b}	2.1
0.15-0.2	5.5^{a}	0.5^{a}	0.28^{de}	0.08^{c}	0.16^{b}	1.8
0.2 – 0.3	5.6^{a}	0.4^{a}	0.24^{d}	0.07^{bc}	0.13	1.8
0.3-0.4	5.6^{a}	-	0.1^{b}	0.02^{a}	0.06^{a}	1.7

Conclusion

Firstly, the greater incidence and severity of water repellency in Block A topsoil compared to Block B may have contributed to poor emergence and low surface stability in this area. Poor water infiltration and patchy soil wetting can affect germination and emergence particularly of small-seeded species and thereby hinder vegetation establishment. In addition when short intense storms typical of Queensland summers occur, rainfall concentration on the soil surface can create localised channels on sloping land leading to gully erosion once the non-cohesive subsoil is exposed. In this study, water repellency was not associated with differences in total C content, suggesting that water repellency may be attributed to differences in the nature of C in the topsoils of each Block associated with past vegetation history. The contributing factor to repellency in the topsoils is currently being further investigated. Secondly, lower levels of basic cations associated with greater aluminium content in the Block B soil may suggest a cation imbalance which may have impacted on plant growth. The Ca:Al ratio is considered to be a useful indicator for plant growth (Vanguelova 2007; Poschenrieder *et al.* 2008) in sandy soils, as Ca deficiency can occur by nutrient exclusion if exchangeable Al is significantly large. The effect of nutrient imbalance alone and in combination with water repellency in these soils is a focus of current studies. Based on the present study, rehabilitation strategies on mined sand dunes similar to the study site, should consider: (i) the application of an appropriate soil wetting agent at planting to overcome site water repellency and, (ii) a site specific fertilizer plan taking into account the soil nutrient imbalance.

References

Department of Sustainable Natural Resources (2005) ‘Soil survey standard test method. Water repellency, P22A/1’. (New South Wales Government).

Isbell RF (2002) ‘The Australian soil classification’ Revised edition. (CSIRO publishing: Australia).

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) ‘Australian soil and land survey-Field handbook’ 2nd edition. (Inkata Press: Melbourne and Sydney).

Poschenrieder C, Gunse B, Corrales I, Barcelo J (2008) A glance into aluminium toxicity and resistance in plants. *Science of the total environment* **400**, 356-368.

Pillai-McGarry UP, Mulligan D (2008) ‘Review of available soil data at Yarraman minesite. Report to CRL Pty Ltd.’. (North Stradbroke Island).

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

Vanguelova EI, Hirano Y, Eldhuset TD, Sas-Paszt L, Bakker MR, Puttsepp U, Brunner I, Lohmus K, Godbold D (2007) Tree fine root Ca/Al molar ratio – Indicator of Al and acidity stress. *Plant Biosystems* **141**, 460-480.