The potential for a rehabilitated coal mine soil to support livestock grazing in south-east Queensland

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Abstract
Land that is disturbed by mining activities is required to be suitably rehabilitated. A trial was initiated to compare the performance of livestock grazing pasture sown on land that was rehabilitated after coal mining activity with that of livestock grazing pasture on unmined land. Pasture biomass, and soil structural, nutritional and hydrological properties important for pasture production and sustainability were intensively monitored on three sites rehabilitated at different stages over the last 10 years, and one unmined Control site. A further 18 unmined grazing sites were monitored for benchmarking purposes. Preliminary results for soil ammonium, nitrate and potentially mineralisable nitrogen suggest little difference in terms of benefits or constraints to pasture production between the rehabilitated and Control sites. Plant-available phosphorus was sufficiently high in the two oldest rehabilitated sites that a fertiliser response would not be expected. Subsoil and rooting depth of the rehabilitated sites was within the range observed across the benchmark sites and shallower than in the Control site. Higher pasture biomass in the rehabilitated sites compared with the Control at the initiation of the trial was attributed more-so to differences in grazing history than differences in soil attributes. Analysis of year one monitoring data is ongoing.

Introduction
Land that is disturbed by mining activities is required to be suitably rehabilitated. The New Acland coal mine in south-east Queensland is undertaking a program of continuous improvement of processes used to rehabilitate disturbed land to minimise the environmental and social footprint of its coal mining operations and to comply with legal requirements for future relinquishment of rehabilitated land (SKM, 2013). At the mine, most of the disturbed land is being rehabilitated for cattle grazing and some areas will be rehabilitated to water storages. To rehabilitate land, the mine uses best industry practice to remove, stockpile and subsequently reform the subsoil, and spread the topsoil before sowing pasture species. Topsoil is defined by the mine as the O and A horizons, and subsoil is defined as the B horizon and/or 'the first flitch of material traditionally removed by an excavator in shot ground' (New Hope Group, 2012). The target dimensions for topsoil stockpiles are 3 m height, 14 m width and 35 m apart. Before topsoil is spread, the subsoil between rows is deep ripped. Topsoil is then spread to a target depth of 300 mm. Pasture species sown can include the exotics Katambora Rhodes grass (*Chloris gayana*) and both green and Gatton Panic (*Panicum maximum*) grasses as well as native Queensland Bluegrass (*Dicanthium sericeum*). Once established and stable, the rehabilitated land is grazed with cattle. Soil conditions monitored after the wet season in 2013 were found to be generally favourable for plant growth and good soil aggregate stability was observed (SKM, 2013).

The mine is conducting a five-year trial to compare the livestock production performance of rehabilitated land with that from unmined land. The trial includes livestock, pasture and soil monitoring over five years. The soil monitoring component of the study compares soil fertility and structure of the rehabilitated soils with an unmined soil recently sown to similar pasture species (the Control site) and analyses the relative benefits and constraints to pasture production. The study also compares soil characteristics between the Control site and 18 nearby grazed soils (Benchmark sites) to identify how indicative the Control site is of surrounding land. A range of soil structural (e.g. sodicity, soil stability and particle size analysis), nutritional (e.g. cation exchange capacity) and hydrological (e.g. soil moisture characteristics) properties important for pasture production and sustainability were analysed. Preliminary data on plant-available soil phosphorus (P) and nitrogen (N), depth to subsoil and rooting depth from the first year of soil sampling are presented here. The complete first year of soil analysis will be presented at the conference.

Methods
The mine is located in south-east Queensland which has summer-dominant rainfall of between 500-700 mm annually on average. Four trial site paddocks were fenced for cattle grazing. The sites represent pasture rehabilitated seven to ten years ago (R1, 22 ha), five years ago (R2, 32 ha) and three years ago (R3, 22 ha)

and a Control site which had not been disturbed and was sown with the same pasture mix three years ago (C, 21 ha). Benchmark sites were chosen to represent the main soil types used for grazing within a surrounding unmined area of approximately 10000 ha. In November-December 2013 (time zero, T0), composite samples from at least five soil cores were collected from depths of 0-10 cm, 10-20 cm and 40-60 cm in each trial site to obtain an indication of the soil nitrogen (N) and phosphorus (P) status at the beginning of the growing season and before cattle started grazing the sites. Pasture yields were visually assessed just prior to T0 and assessed using the Botanal technique (Tothill JC, Hargreaves JNG *et al.* 1992) prior to the introduction of cattle in January 2014. Colwell P (Method 9B), KCl-extractable nitrate-N and ammonium-N (Method 7C2) and hot KCl-extractable potentially mineralisable N (Method 7D1) were measured using methods from Rayment and Lyons (2011) on samples that were dried at 40^{o}C and sieved to 2mm. All P and N analyses were conducted by staff at the Agricultural Chemistry Ltd laboratory in Ipswich, Queensland. During February-March 2014 (T1), five soil cores were collected along transects within five subsample areas in each trial site. Subsample areas were stratified to represent the major topographic and vegetative (measured by NDVI survey in October 2013) variation in the landscape. Sampling was avoided in atypical parts of the landscape. Three cores were also collected during T1 at each Benchmark site. Depth to subsoil and presence or absence of root growth to 60cm was measured by direct observation in the field for each soil core.

Results

AT T0, pasture yields were estimated to be up to 15,000 kg/ha of Dry Matter (DM) in the R2 and R3 sites, consisting of old growth accumulated from recent years of above average rainfall and a small proportion of new growth from the current season. To make green pasture more readily accessible for grazing stock, R1, R2 and R3 paddocks were slashed to a height of approximately 30 cm at T0. The Control site had been "crash" grazed and at T0 had very low pasture yields (< 300 kg/ha DM) and low ground coverage by pasture. In January 2014, the rehabilitated sites R1, R2 and R3 yielded 3300, 5300, 5000 and kg /ha DM, respectively, and the Control site yielded 1300 kg/ha DM.

Time zero analysis of plant-available N (Figure 1a, b, & c) suggests similar levels of ammonium-N across all sites and depths, variable nitrate-N availability with some accumulation at depth in the mid-aged rehabilitated site, similar amounts of potentially mineralisable N in the control and R3 sites, which were sown to pasture at the same time, and higher potentially mineralisable N particularly at 40-60cm depth in the two older rehabilitated sites (R2 and R3). There was more plant-available P (Figure 1d) in the two older rehabilitated soils compared with the more recently sown rehabilitated (R3) and control (C) sites. Colwell P levels (0-10 cm) in the oldest (R1) and mid-aged (R2) rehabilitated sites indicated that pasture was not likely to respond to P fertiliser.

Soil layers classed as 'topsoil' by visual assessment in the field tended to include components of B horizon material in the control and benchmark sites where there was a gradational change in texture , and in the rehabilitated soils, where pre-existing O, A and B horizon material had been mixed to varying extents during the stripping and stockpile process. At T1, the mean (± standard error of the mean) depth to the subsoil horizon in the Control site (85 ± 24.3 cm) was within the variability exhibited by the 18 benchmark sites (63 ± 28.6 cm) and deeper than the upper layer depths measured in the rehabilitated sites (Figure 2). Variation (expressed as the standard error or the mean) in depth of upper layers across the rehabilitated sites was fairly uniform (40 ± 21.4 cm, 50 ± 21.5 cm and 44 ± 21.3 cm at sites R1, R2 and R3 respectively). There was a similar rate of presence or absence of roots to 60 cm across the benchmark (78%) and rehab (80%, 63% and 77% at R1, R2 and R3 respectively) sites and a higher rate of 100% at the control site.

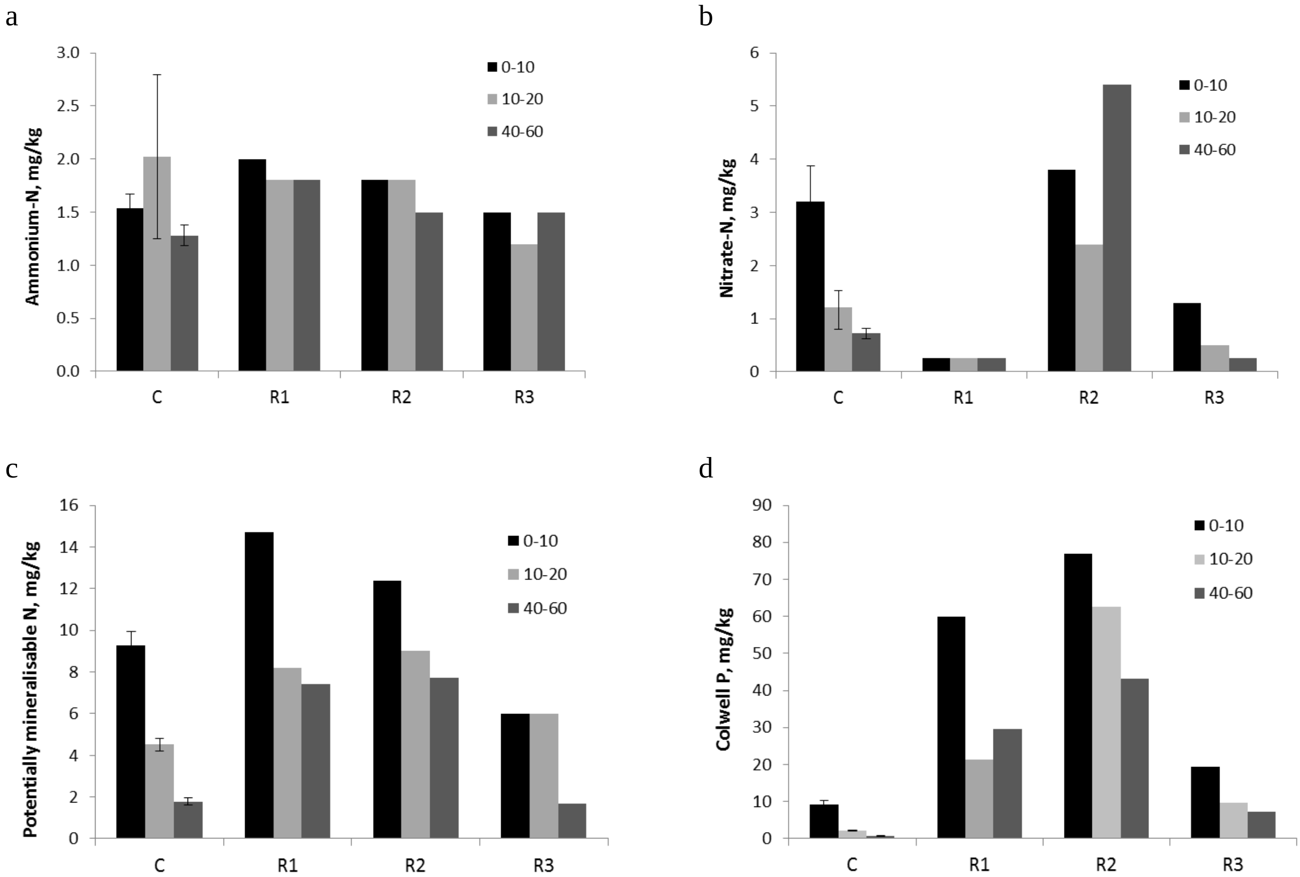

Figure 1. Soil (a) ammonium-N, (b) nitrate-N, (c) potentially mineralisable N and (d) Colwell P (mg/kg) in the 0-10, 10-20 and 40-60 cm depth increments of samples collected in November and December 2013 that represent the rehabilitated (R1, R2, & R3) and Control (C) sites. Standard error of the mean presented as error bars for the control site. Data for the rehabilitated sites represented composite multi-core samples from a single subarea per site.

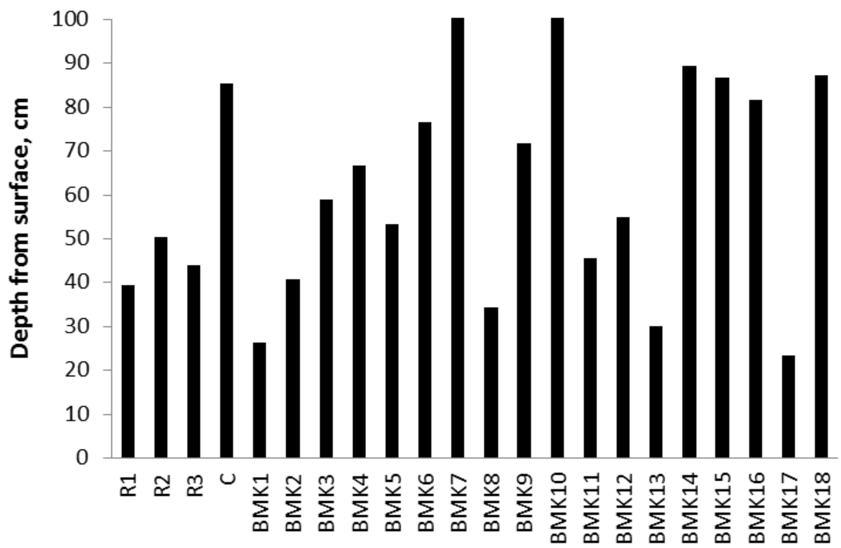

Figure 2. Depth to subsoil horizon in the rehabilitated sites (R1, R2, R3), the control site (C) and at nearby benchmark grazing sites (BMK1-18).

Discussion

The similar amounts of potentially mineralisable nitrogen, and evidence for root exploration to at least 60 cm across all the sites suggests that grazing management was likely to have been more important in determining the large variation in biomass between the rehabilitated and Control sites at T0 than enhanced root exploration or enhanced mineralisation of soil organic N in the disturbed rehabilitated soils. However high plant-available P in R1 and R2 may have played a role in supporting production in these sites, as would enhanced root access and vigour in the more recently disturbed topsoil in the rehabilitated sites. Quantification of root vigour deserves further investigation in terms of the sustainability of soil conditions favourable for root exploration in these soils.

The mean depth to subsoil in all rehabilitated sites (40-50 cm) exceeded the target depth of 30 cm. Forty percent of the sampled cores displayed shallower topsoil profiles in the oldest rehabilitated site (R1) and only 12% and 16% of observed topsoil depths were shallower than 30 cm in the more recently rehabilitated sites (R2 and R3, respectively). The latter rate of shallow topsoil occurrence was similar to the rate of shallow topsoils occurring across the benchmark sites (15%). The presence of the mine spoil subsoil layer in the top 60 cm of the soil in the rehabilitated sites did not appear to present any more of a physical barrier to root exploration than was observed across the benchmark sites. Soil pit analysis will be used to observe variation in root activity and investigate relationships between root depth and vigour and associated nutrient and water availability. The large variation in depth to subsoil across the benchmark sites indicated that the control site was representative of surrounding un-mined grazed land. Analysis of soil classification features will further refine the estimates of depth to subsoil.

Conclusion

Preliminary results suggest little difference, with the exception of higher plant-available P in two rehabilitated sites, in terms of benefits or constraints to pasture production between the rehabilitated and Control sites. To support these findings, differences in structural and nutrient supply and hydrological properties require analysis, including over time and between seasons. Furthermore, soil properties need to be investigated in relation to pasture composition, nutritional quality and biomass. These properties will be measured and issues addressed within the ongoing investigation.

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