Sustainable Minerals Institute
18 April 2023

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

Demonstrating the effect of mulch on rehabilitated land at the Gulkula Mine in northern Australia

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Abstract

Bauxite operations in the tropics of Australia usually clear and burn existing forests to prepare a site for mining. Subsequently, topsoils and subsoils down to 50 cm depth are stripped and transported to other mined areas to begin the mine rehabilitation process. This soil stripping process leads to a loss of nutrients and changes to many of the physicochemical properties of the soil. Australia's first Indigenous-owned and -operated bauxite mine, the Gulkula Mine in East Arnhem Land in northern Australia, has a land-clearing procedure which requires timber products to be salvaged from the forest prior to mining, with the remaining material being mulched. This presented an opportunity to use forest biomass residues (mulch) as an amendment to rehabilitated soils with an aim to improve the quality of mine rehabilitation. The primary objectives of this study were to compare soils with, and without mulch, to a reference native forest, to assess the effect of mulching on soil quality indicators. The key findings of this study were that the addition of mulch improved most soil chemical and physical properties, including Electrical Conductivity (EC), Total Carbon (TC), Total Nitrogen (TN), Organic Carbon (OC), Water soluble Organic Carbon (WOC), Cation Exchange Capacity (CEC), and Bulk Density (BD), and these were more similar to the native forest than the un-mulched soils. Thus, the mulch amendments in the trial sections showed significant improvements to mine rehabilitation soils and should be used more widely to promote better rehabilitation outcomes.

Introduction

Progressive rehabilitation during a mine's life provides an opportunity for testing rehabilitation practices and improve the long-term outcomes and trajectory of rehabilitation efforts (Mine Rehabilitation, 2006). The goal of land rehabilitation on many mine sites is to restore the land and vegetation to their pre-mining conditions and to create a functional ecosystem. A common practice to support this outcome includes preserving topsoil which contains the necessary nutrients and seed bank needed to rapidly regenerate ecosystem properties.

However, when preparing land for bauxite mining, traditional methods practiced in northern Australia require the forests to be cleared and burnt. Then the top 50 cm of soil is removed, whereby the nutrient rich topsoil is mixed with sub-soils. This practice depletes the quantity of soil organic matter, plant nutrients, soil microbial diversity, and changes the soil structure. These changes will inevitably impact the success and long-term sustainability of post-mining revegetation and ecosystem rehabilitation (Hall et al, 2020). An alternative approach includes the addition of unburnt forest mulch which may help to restore the ecological balance of mined areas and create a more aesthetic value, as well as for the long-term sustainability of the mined land rehabilitation project.

Burning practices in mine sites removes the potential to use valuable forestry products for the benefit of local social and environmental projects. Demonstrating the benefit of the pre-mining collection and use of forest biomass residues (mulch) in mine-site rehabilitation is what this study is about. The addition of cleared forest biomass residues to soil has the potential to ameliorate soil quality in terms of functionality and fertility over the specified timescales.

Background

Gulkula Mining Company (Gulkula) is Australia's first Indigenous-owned and -operated bauxite mine located on the Dhupuma Plateau in East Arnhem Land, NT – the Traditional Lands of the Yolngu people. The Gulkula Mine is a small-scale bauxite mining operation that commenced operations in late 2017. The mining lease encompasses an area of nearly 900 ha. The impact and extent of disturbance are much lower than most other bauxite mining operations with no requirement to wash/treat bauxite ore or manage tailings (Menon, 2022).

Gulkula's land-clearing procedure does not permit the burning of native forests. Rather, it specifies the salvage harvesting of high-value timber products and the remaining forest residues being mulched. The mulch is then utilised in progressive mine rehabilitation where it is intended to aid the establishment of a suitable growth media complete with nutrient-cycling capabilities. Gulkula is interested in identifying soil conditions that promote optimal revegetation outcomes. A trial plot has been established to demonstrate the effects of mulch addition on soil physicochemical conditions and tree growth, versus the traditional method of overburden and topsoil replacement without mulch. The results of this study will guide future rehabilitation efforts at the Gulkula Mine and potentially inform land management practices that could be an alternative to business-as-usual practices within the mining industry (Menon et al 2021).

Materials and methods

The rehabilitated site at the Gulkula Mine to be assessed in this study (Figure 1) is composed of two replicated mulch treatments (M) and two un-mulched treatments (NoM) (figure 2). These trials were compared to a neighbouring *Eucalyptus tetrodonta* native forest (NF) to assess differences in rehabilitation treatments with the soil properties at the NF reference site.

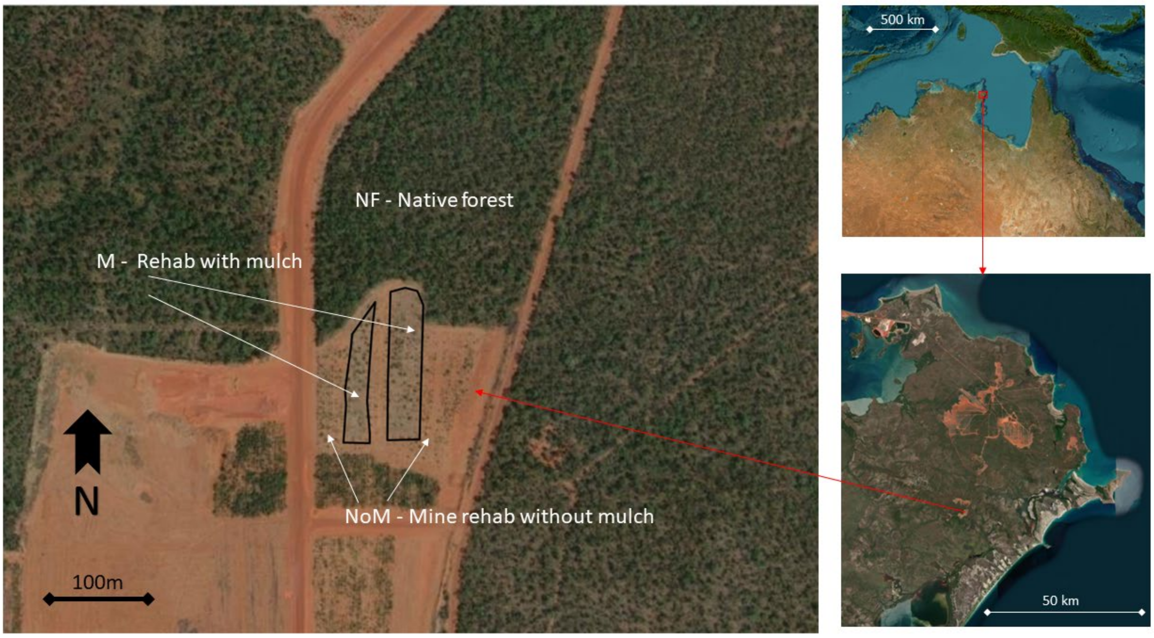


Figure 1. The mine rehabilitation trial at the Gulkula Mine and location of study site in East Arnhem Land, NT.

Sample Collection

Nine sampling sites were randomly selected in each treatment plot using a random point generator. The GPS location of each of these sampling points was recorded and samples were collected with a trowel from the surface soil (top 10 cm, figure 2B) for nutrient analysis (including carbon and nitrogen), packed in labelled sealed plastic bags, kept in an air-conditioned room, air-dried in the laboratory, and passed through a 2 mm sieve prior to analysis. Matching intact soil samples were also collected using a soil corer (60 mm diameter) to represent the *in-situ* characteristics for Bulk Density (BD), Hydraulic Conductivity (HC), and Water Retention curves. Both these sample types were packed, sealed, and labelled appropriately. Every care was taken to avoid contamination and ensure appropriate storage so that the soil physical and chemical properties were not affected.

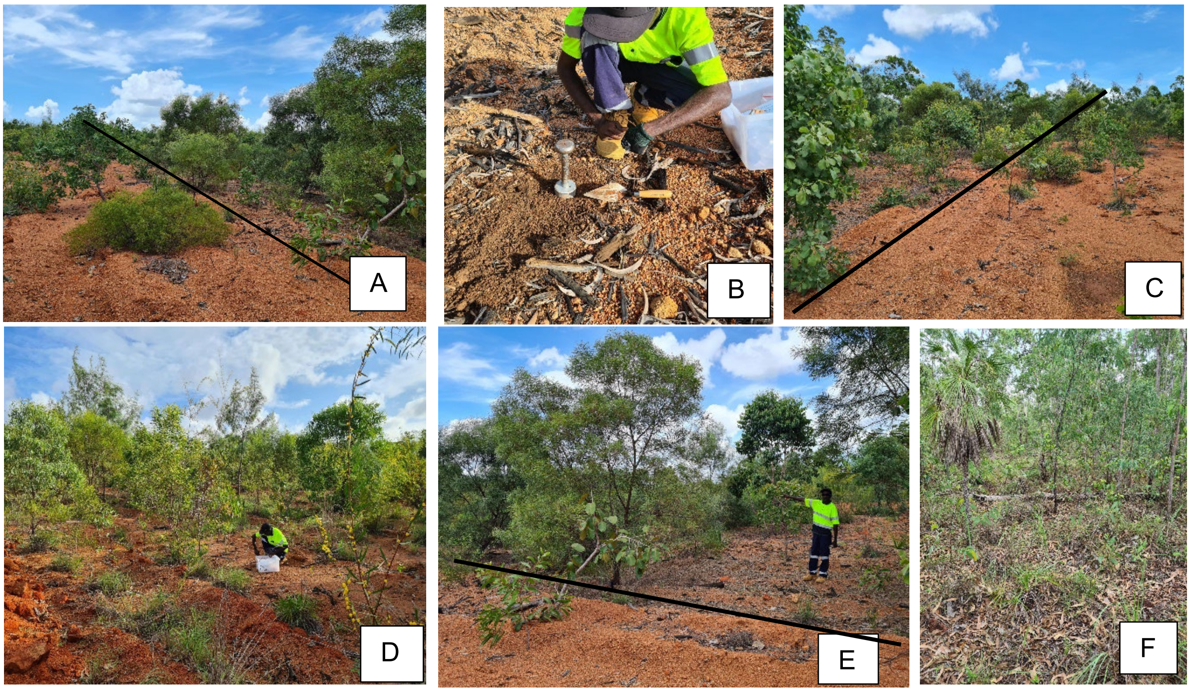


Figure 2. The NoM, M and NF soil sampling sites at Gulkula Mine. A. NoM at left and M at right; B. Core sampling on the mulched section; C. R0 at the right, and M at left separated; D. Rehabilitation with no mulch section; E. Line separates the mulch (with person) and the no mulch treatment sites; F.Native Forest reference site.

Chemical and physical analysis

Soil samples were dried at 40°C and then sieved to 2 mm for chemical analysis. Soil pH and Electrical Conductivity (EC) were measured in 1:5 soil:water suspensions, using a TPS 901-CP meter. These suspensions were subsequently filtered through 0.45 µm and analysed for Water soluble Organic Carbon (WSOC) using Heanes wet oxidation with dichromate and sulfuric acid (Heanes 1984). Cation Exchange Capacity (CEC) using exchangeable cations were analysed using the Ammonium Chloride extraction method where 3 g of sample was weighed into a centrifuge tube and 30.0 ml of 1 M NH_4Cl was added into each tube, giving a 1:10 soil solution ratio shaken onto an end-over shaker, centrifuged, filtered, and prepared for by Inductively Coupled Plasma – Optical Emission Spectroscopy (Rayment, G.E., 2011). Total organic carbon and total nitrogen (TOC/TN) were measured via combustion in a LECO 928 analyser.

Soil water holding capacity (WHC) was measured (hPa/cm^3) by weighing method, steel rings were sealed on one side with lightweight geotextile material for draining off free water and were put through a series of pressure through a ceramic membrane for the extraction of water from the intact soil samples (Shaygan, M., 2017). Hydraulic conductivity (HC) was determined using saturated hydraulic conductivity (k) measured by the Constant Head Method (Klute, A., 1982).
Statistical analyses of soil data were carried out using Statistica (Ver 14.0.015 TIBCO Software). Descriptive statistics and analysis of variance with post-hoc Tukey HSD for unequal N (Spjotvoll/Stoline) tests were used to describe the significance at p-value <0.05.

Results and Discussion

The soil analysis tests resulted in values for pH and Electrical Conductivity (EC), Total Carbon (TC), Total Nitrogen (TN), Organic Carbon (OC), Water soluble Organic Carbon (WSOC), all of the cations (potassium, sodium, magnesium and calcium) to calculate Cation Exchange Capacity (CEC), Soil Bulk Density (BD), Hydraulic conductivity (HC) and soil water holding capacity (WHC). Average values at each site are summarised in Appendix B.

There was a significant difference between all parameters across the three sites (see Table 1 for ANOVA results). The soils in the mulched (M) and the non-mulched (NoM) sections were significantly different for all indicators of soil health measured in the rehabilitation trial.

Table 1. Analysis of Variance of the results of the soil samples from Gulkula Mine.

	Analysis of Variance of soils at Gulkula Mine - significant at p < .05000							
Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
EC (µs)	2997	2	1499	1530	42	36.42	41.14967	0.000000
pH	1	2	0	1	42	0.02	22.10890	0.000000
TC Wt %	101	2	51	24	42	0.58	86.99256	0.000000
TN Wt %	0	2	0	0	42	0.00	57.67455	0.000000
OC Wt %	95	2	48	23	42	0.54	88.84442	0.000000
WSOC	4372	2	2186	2683	41	65.43	33.41134	0.000000
K mg/kg	4208	2	2104	13822	42	329.11	6.39246	0.003770
Na mg/kg	1418	2	709	1013	42	24.11	29.40564	0.000000
Mg mg/kg	792002	2	396001	521546	42	12417.76	31.88990	0.000000
Ca mg/kg	5314131	2	2657066	3696423	42	88010.07	30.19047	0.000000
CEC (mEqv)	362	2	181	231	42	5.49	32.91726	0.000000

Figure 3 demonstrates that the average soil pH was significantly lower at the M site (6.01) compared to the NoM site (6.19), probably due to increased mulch breakdown leading to a release of organic acids. The native forest (NF) reference site had a significantly higher pH (6.36) than both trial sites. Electrical Conductivity (EC) illustrated in Figure 4 was lowest at the NoM site (8.8 µs), with double the value at the M site (18.8 µs) and higher again (30.9 µs) in the Native Forest (NF).

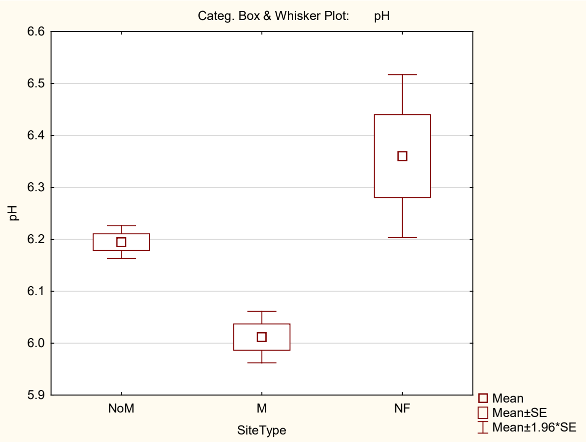


Figure 3. Soil pH across the three sites

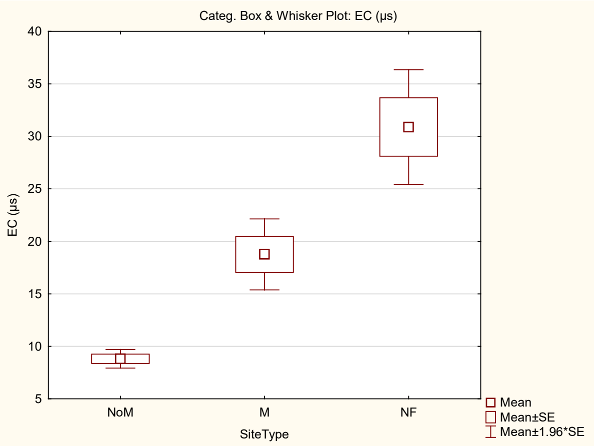
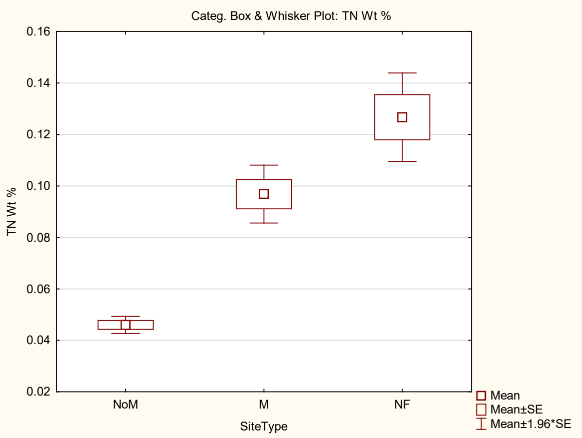


Figure 4. Soil EC from each site

The Total Nitrogen (TN) and Total Carbon (TC) levels were significantly higher in the mulched section of the rehabilitation compared to the NoM section (Figures 5 & 6). The soil in the mulched section had 2.5 times higher soil TC and 2 times higher TN but both of these values were still significantly lower than the NF site.



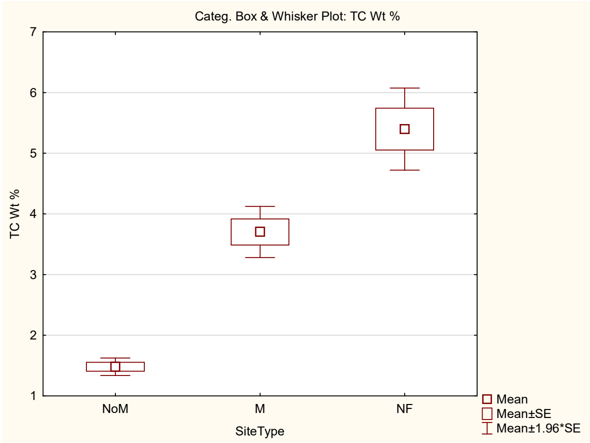


Figure 5. Soil Total Nitrogen for each site

Figure 6. Soil Total Carbon for each site

Soil TC and TN also appeared to be highly correlated at all sites (Figure 7).

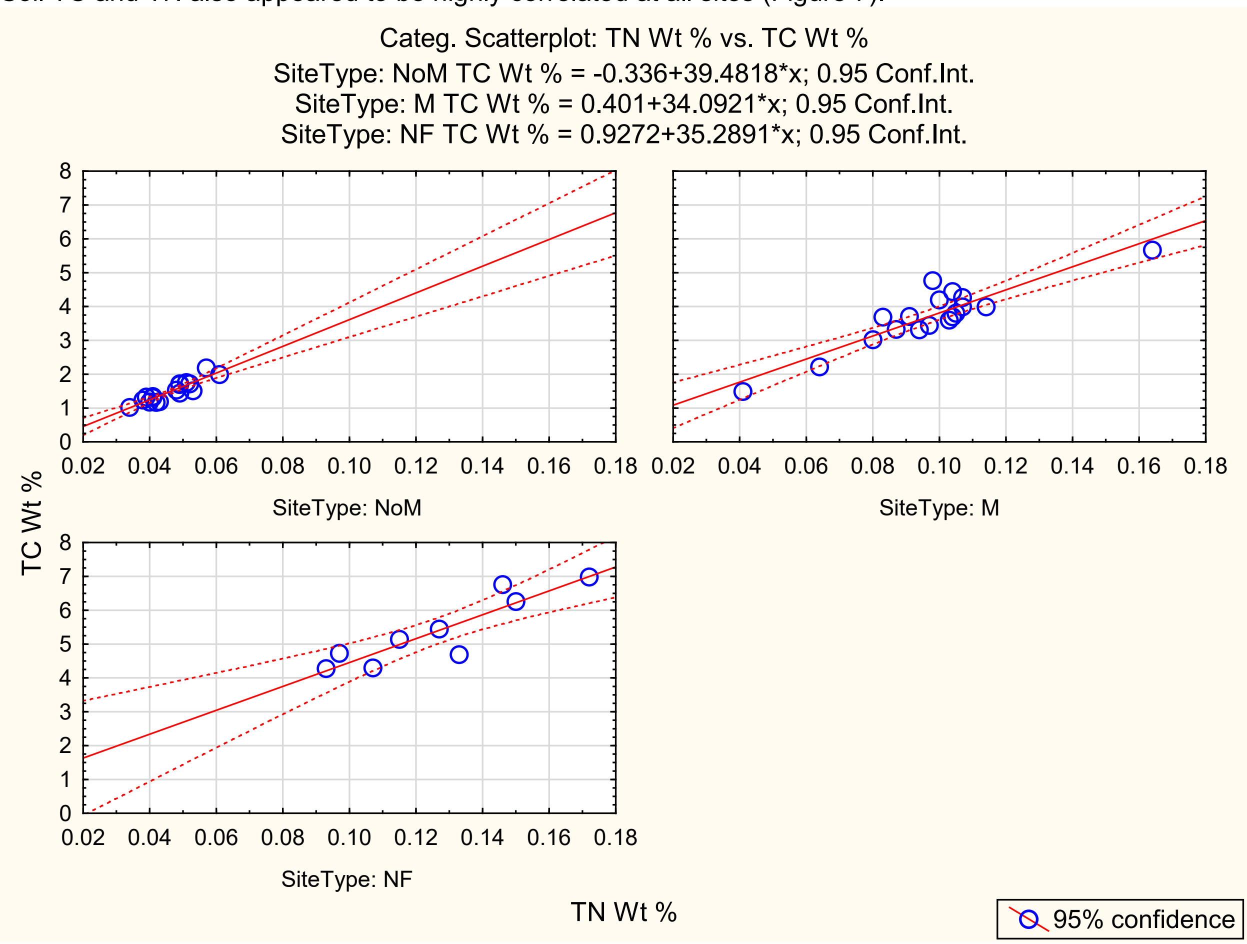


Figure 7. Correlations between Total Nitrogen vs Total Carbon for soils from each of the three sites

Soil organic carbon followed a similar pattern to soil TC (Figure 8) whilst Water Soluble Organic Carbon (WSOC) followed a different trend, as the mulched site had the highest average value, followed by the NF site and then the NoM site (Figure 9). It is likely that the breakdown of the mulch was providing this higher soluble fraction through increases in the rate of organic matter decomposition which will probably also stimulate microbial activity (Hall et al, 2020).

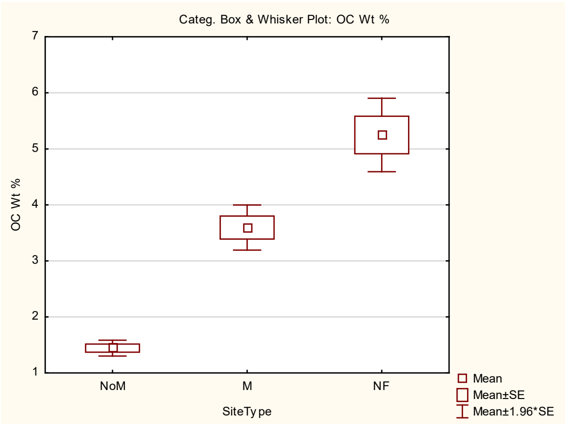


Figure 8. Soil Organic Carbon measurement of soils from all the three sites.

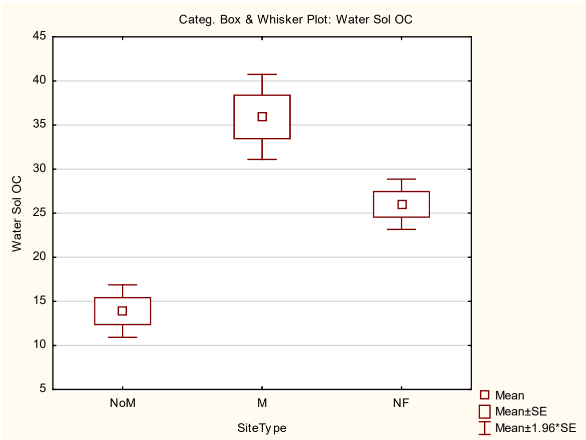


Figure 9. Water-soluble organic carbon measurements of soils at the three sites

Mulch addition improved the cation exchange capacity (CEC) of the rehabilitated soils. CEC was twice as high in the M site than the NoM site but still significantly lower than the NF (Figure 10). The CEC value was higher in NF soils, which may be due to the abundance of decomposing organic materials in the topsoil and was significantly different compared to the rehabilitation sections. Much of the difference in the CEC can be explained by the calcium (Ca) concentrations in the soils (Figure 11), with the mulch retaining more than twice the level of Ca than the NoM site.

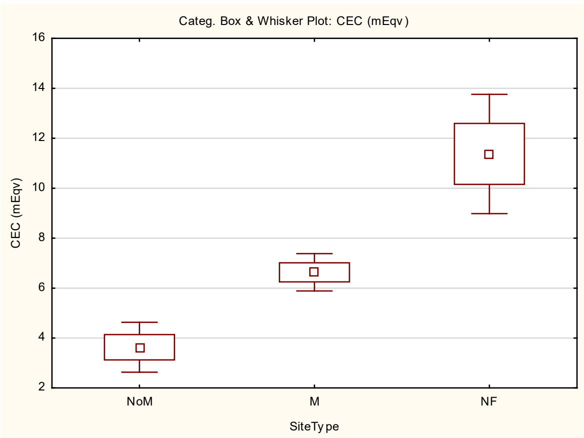


Figure 10. Cation exchange capacity (CEC) for each site

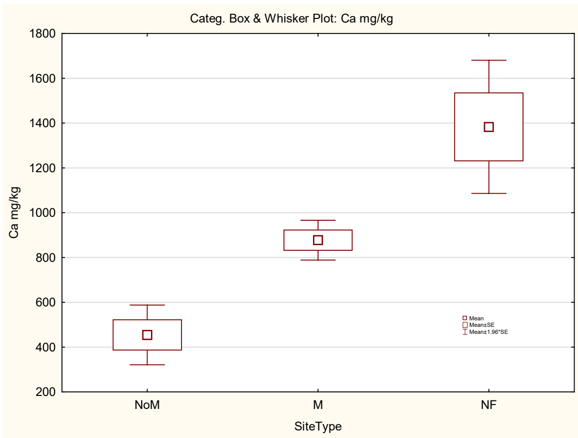


Figure 11. Soil total calcium for each site

Figure 11 demonstrates that the Bulk Density (BD) was highest in the NoM site (1.48g/cm³), whilst the M site (1.17 g/cm³) was not significantly different to the NF (1.03 g/cm³). Higher BD values indicate greater soil compaction, and lower values are better for plant growth and soil health. Organic matter addition appears to significantly decrease soil BD. Hydraulic Conductivity (HC) of the M soil (k-.002 cm/s) was lower than the NF (k-.009 cm/s) and NoM (k-.006 cm/s) soils (Figure 13), which may be due to several factors such as pore clogging, and aggregation caused by the decomposition of mulch which has the potential to bind soil particles.

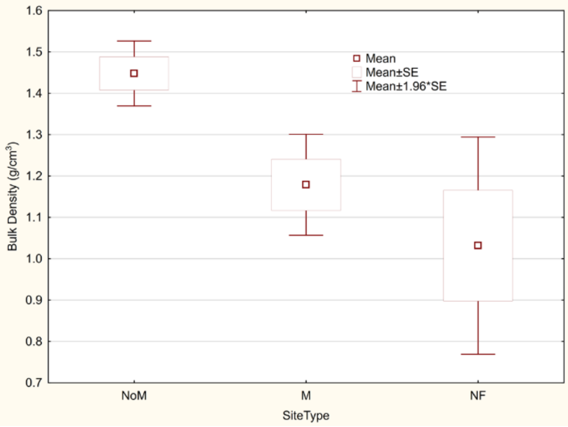


Figure 12. Bulk density results of soils from the three sites

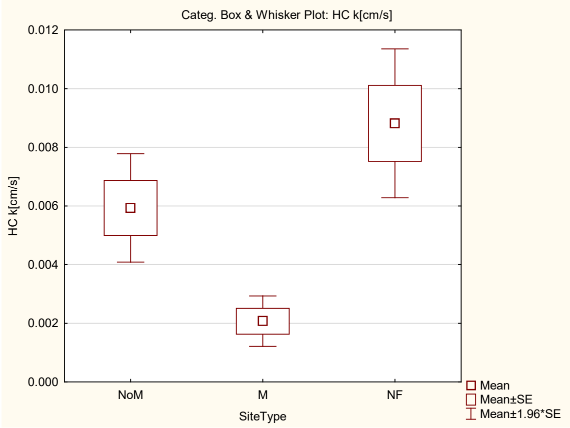


Figure 13. Hydraulic Conductivity of the soils

Soil water retention data (Appendix A), represents the relationship between the amount of water held in the soil and the soil water potential, which is a measure of the energy required to extract water from the soil. The mulched and non-mulched sections were similar and lower that the native forest reference site. Soils with higher levels of organic matter tend to have greater water retention capacity due to their ability to hold onto water and nutrients. Soil structure, or the arrangement of soil particles into aggregates or clumps, can affect soil water retention by influencing the size and connectivity of soil pores. Amongst the samples from the 3 sites, the NF soil indicated better water retention. Mulched soils showed slightly better water retention than the NoM sites.

Conclusion

The mine rehabilitation trials at the Gulkula Mine have demonstrated that the addition of mulch improved most measures of soil quality in rehabilitation. Based on the observed soil quality indicators presented here, it is apparent that using mulch in bauxite mine rehabilitation efforts in northern Australia will have a positive effect on soil health and therefore should result in improved plant growth. Forest residues (after timber product salvage) should therefore be used preferentially as a mulch material rather than being burnt as waste. However, the improvements demonstrated here may rely upon some specific factors which have not been tested in this study. These include the types of species, plant parts (leaves, small branches, bark, trunks, and roots) and mulching (fine to coarse) as well as the duration of the study. Vegetation productivity data would be useful for establishing a baseline to further compare the results of this field trial. A positive correlation with tree and vegetation growth would reinforce the effectiveness of mulch treatments in these soils.

It can be concluded that using mulch in mine rehabilitation soils can have a positive effect on plant growth and soil health in addition to what Gupta et al (1998) describe as decreases in maximum soil temperature, increased root and shoot growth, improved plant water status, and reduced weed populations. Forest residues, therefore, can be used favourably as a mulching material for increasing mine rehabilitation success.

Acknowledgments

The authors would like to acknowledge Gulkula Mining for their innovation and demonstration of a better way for bauxite mining operations to reduce environmental impacts. Nespresso supported this project by providing funds and the Aluminium Stewardship Initiative for their project support. A big thank you goes specifically to Ken and Tracy at Gulkula, for allowing us to carry out the trial at the rehabilitation site. Thanks also to Marcia Lopez for the ICP-OES analysis, Mandana Shaygan and Natasha Ufer for their assistance with the specific soil analyses.

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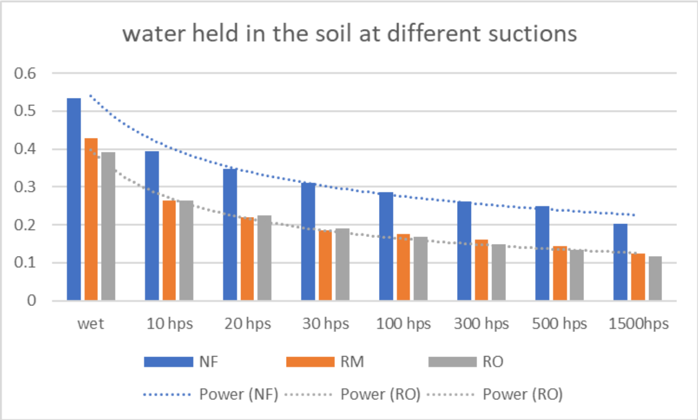
Appendices

A-1 Soil water holding retention capacity at the different pressure suction for the three sections.



A-2 Breakdown Table of Descriptive Statistics of soils sampled at Gulkula Mine –NoM (No mulch rehab), M (Mulched rehab) & NF(Natural Forest)

SiteType	EC (µs) Mean	EC (µs) Std.Dev	pH Mean	pH Std.Dev	TC Wt % Mean	TC Wt % Std.Dev	TN Wt % Mean	TN Wt % Std.Dev	OC Wt % Mean	OC Wt % Std.Dev	Water Sol OC Mean	Water Sol OC Std.Dev
NoM	8.81	1.91	6.19	0.07	1.48	0.31	0.05	0.01	1.44	0.31	13.90	6.46
M	18.76	7.31	6.01	0.11	3.70	0.91	0.10	0.02	3.60	0.87	35.92	10.44
NF	30.89	8.36	6.36	0.24	5.40	1.04	0.13	0.03	5.25	1.00	26.01	4.11
All Grps	17.21	10.14	6.15	0.19	3.15	1.69	0.08	0.04	3.07	1.64	25.11	12.81

SiteType	K mg/kg Mean	K mg/kg Std.Dev	Na mg/kg Mean	Na mg/kg Std.Dev	Mg mg/kg Mean	Mg mg/kg Std.Dev	Ca mg/kg Mean	Ca mg/kg Std.Dev	CEC (mEqv) Mean	CEC (mEqv) Std.Dev	BD (g/cm3) Mean	BD (g/cm3) Std.Dev
NoM	22.50	16.72	3.50	1.70	156.92	98.19	454.52	287.93	3.63	2.16	1.448	0.098
M	38.43	22.00	4.78	5.42	259.46	81.11	877.55	192.52	6.63	1.62	1.179	0.152
NF	46.81	10.25	18.10	7.62	519.40	175.28	1383.24	455.10	11.37	3.65	1.032	0.232
All Grps	33.73	20.24	6.93	7.43	270.43	172.78	809.48	452.53	6.38	3.67	1.220	0.161

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