OM PLUS WITH TAILINGS SAND GREENHOUSE RECLAMATION RESEARCH

FINAL REPORT

By

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1. INTRODUCTION

As part of a research program developed at the University of Alberta to evaluate the potential use of Organic Matter Plus (cooked feedlot manure) in the reclamation industry, a greenhouse experiment was conducted using the product to amend tailings sand. The tailings sand was from the oil sands at Fort McMurray, Alberta, a material with poor physical and chemical properties including low nutrient and water holding capacities and hydrocarbons. OM plus was also used to amend a mix of tailings sand and commercial peat moss. Peat is a material used and required in oil sands reclamation practices.

Several native grasses and agronomic grass species used in reclamation and suitable for the Fort McMurray area were used for this experiment. Soil chemical properties before and after the experiment provided information on changes in soil conditions due to OM Plus utilization.

2. RESEARCH OBJECTIVES

- To determine appropriate application rates of OM Plus to amend tailings sand and tailings sand with peat.
- To assess the effect of various rates of OM Plus alone and in combination with fertilizer on plant establishment and biomass production.
- To evaluate changes in chemical properties of tailings sand amended with OM Plus.

3. EXPERIMENTAL DESIGN AND METHODS

OM Plus was tested on tailings sand (TS) and tailings sand and peat (TSP) at four rates equivalent to field scale application rates of 0 (control), 4.9, 11.1 and 17.3 Mg ha^{-1} (2, 4.5 and 7 Mg acre^{-1}, respectively). Half of the treatments were fertilized. Fertilizer rates were 0 (control) and 1.1 Mg ha^{-1}. The experiment was completely randomized (2 substrates x 4 OM Plus rates x 2 fertilizer rates x 5 replicates = 80 pots).

The tailings sand was procured from the oil sands at Fort McMurray. The tailings sand and peat substrate was prepared as a 1:1 by volume mix. The peat was Sunshine Peat Moss (Sun Gro Horticulture Ltd) to provide organic matter to the substrate from partially decomposed plant material. It resembles the common source of peat used in oil sands reclamation which is coarser and has bigger, undecomposed plant fragments compared to the regular garden peat moss. Properties of the OM Plus, TS and TSP are presented in Table 1. Admixing TS and peat is not a current practice for oil sands reclamation; normally peat in placed on top of the TS. However, the available peat in the oil sands area is rapidly decreasing. Therefore the combination of peat and TS could potentially reduce the amount of peat required for reclamation if an amendment such as OM plus can improve the characteristic of the substrate.

The OM Plus was incorporated with the TS and TSP substrates and evenly mixed prior to potting. Ten 15 cm diameter pots were filled with each amended substrate and application rate. Half of them were fertilized with slow release Nutricote 14:14:14 NPK type 100 placed about 1.5 cm below the pot surface and covered with amended substrate. The Nutricote fertilizer is a formulation of 14 % total nitrogen (7 % ammonium nitrogen and 7 % nitrate nitrogen), 14 % available phosphoric acid (P_2O_5), and 14 % soluble potash (K_2O) derived from ammonium nitrate, ammonium phosphate, potassium nitrate, potassium sulfate and calcium phosphate.

A mix of native and agronomic plant species suitable for oil sands reclamation was seeded. Species were slender wheat grass (*Agropyron trachycaulum* (Link) Maltex H.F. Lewis.), sheep fescue (*Festuca saximontana* Rydb), tickle grass (*Agrostis scabra* Willd.), fringed brome (*Bromus ciliatus* L.), alfalfa (*Medicago sativa* L.) and barley (*Hordeum vulgare* L.). Five seeds of each species were hand broadcast on the surface of the pots and the substrate lightly tilled to improve soil seed contact (Figures 1 and 2). Treatments were randomly placed in the greenhouse where conditions were maintained at 21 ^{o}C with a 16 h photoperiod.

The experiment was conducted for 12 weeks, from October to December 2008 (Figure 3). Germination and survival were recorded weekly. At the end of the experiment the height of the tallest and shortest plants from each species in each pot was measured to estimate average height; health and vigour were visually assessed by foliar colour. Plants were then clipped at ground level and above ground biomass was oven dried at 80 ^{o}C for 24 hours. Roots from each pot were separated from substrate material, collected and oven dried to constant weight.

Soil analyses were conducted before and after the experiment. Three samples of each substrate and OM Plus were analysed at the beginning of the experiment for total nitrogen, available ammonium (NH_4), total inorganic carbon, total organic carbon, cation exchange capacity (CEC), electrical conductivity (EC) and pH from saturated paste, sodium adsorption ratio (SAR), sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), available nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and total hydrocarbons. At the end of the experiment, the substrate of 3 pots from each treatment was collected during root cleaning and the same analyses performed, with the exception of hydrocarbons. The analyses were performed at ALS Laboratories in Edmonton. To determine the average concentration of nutrients added per OM Plus application rate per pot, nutrient value from the laboratory (mg/kg) was multiplied by the number of grams of OM Plus per pot equivalent to the 4.9, 11.1 and 17.3 Mg ha^{-1} treatments, (9, 20.24 and 31.37 g, respectively), then divided by 1000 (1 kg = 1000 g).

Three way analyses of variance (ANOVA) were used to detect differences among treatment groups. The significance level used was $p = 0.05$. A pair wise multiple comparison procedure (Holm-Sidak method) was used to isolate groups that differ from the others. The data were analyzed using SigmaPlot 11 software.

4. RESULTS AND DISCUSSION

4.1 Plant Performance

Above ground biomass of seeded grasses was significantly different among treatments. On TS, above ground biomass was significantly higher if fertilized than non fertilized (Figure 4). Biomass was significantly higher with 17.3 Mg ha^{-1} OM Plus application vs no OM Plus or lower application rates. Above ground biomass in TSP was significantly higher in fertilized than non fertilized treatments (Figure 5). With OM Plus biomass was significantly higher with 17.3 and 11.1 Mg ha^{-1} application rates than in the control (0) and 4.9 Mg ha^{-1} treatments. Differences between 17.3 and 11.1 Mg ha^{-1} and between 0 and 4.9 Mg ha^{-1} application rates were not significant. This result is consistent with previous greenhouse experiments where plants established in ERO (now OM Plus) and ERO enriched amended limestone substrate had proportionally more biomass than plants in non amended substrate (Cohen-Fernandez and Naeth 2008). The positive effect of OM plus on established plant biomass is expected to continue over time. In a previous OM plus nutrient release experiment nutrient release of the product lasted at least 229 days under greenhouse conditions (Cohen-Fernandez and Naeth 2008). In the field, with the short growing season and cold temperature, nutrient release time could be expected to last longer.

The organic matter in the peat likely improved physical and chemical properties of the substrate, resulting in greater above ground biomass. The 17.3 Mg ha^{-1} OM Plus application with fertilizer had the greatest above ground biomass in TS, however, with TSP, maximum biomass could be achieved with a lower rate of OM Plus (11.1 Mg ha^{-1} application rate) and fertilizer. This indicates a response to OM Plus not achieved with fertilizer alone.

Above ground biomass of individual species was generally higher in TSP than TS treatments and higher in fertilized than non fertilized treatments (Figures 6 to 9). Species response to OM Plus varied. These differences were statistically significant for slender wheat grass, tickle grass, alfalfa and barley. Although treatment differences were not significant for brome and fescue there was a statistically significant interaction between substrate and OM Plus rate for fescue.

Barley responded most noticeably to OM Plus, with biomass generally increasing directly with increasing application rate after 4.9 Mg ha^{-1} (Figures 6 to 9). When combined with fertilizer, greater response to OM Plus occurred at the highest rate. On a TSP substrate barley responded with or without fertilizer to rates of 11.1 or 17.3 Mg ha^{-1}. Its tolerance to the higher EC of the high OM Plus rate treatments may be an explanation (Brady and Weil, 2008).

The biomass of the other species in the seed mix was comparatively low relative to barley but this was expected for native grasses with their slower growth rate (Figures 6 to 9). Native grasses tend to increase cover above initial levels as individual plants shift resource allocation into above ground biomass and reproduction (Noyd et al. 1996). Slender wheatgrass generally showed a negative response to the highest rate of OM Plus despite its tolerance to salinity (Dewey 1960). A similar reduction of slender wheat grass biomass was found at greater than 17.3 Mg ha^{-1} rate when growing in ERO amended limestone substrate (Cohen-Fernandez and Naeth 2008). Tickle grass responded to OM Plus in the TSP substrate, with a positive growth response at 4.9 Mg ha^{-1}, then declined at the highest rates. Alfalfa responded to OM Plus only when on TSP.

Below ground biomass of seeded grasses was not significantly different among OM Plus rate treatments. There was a statistically significant interaction between substrate and fertilizer. Below ground biomass was significantly higher in TSP than TS substrates. Below ground biomass in TS was generally higher in fertilized than non fertilized treatments (Figure 10) but was higher in non fertilized treatments in TSP (Figure 11). Although the root extraction method didn't account for differences in root production per species, it is likely that a greater portion of roots came from the larger barley and slender wheat grass plants. The higher nutrient input from fertilizer was more readily available in the TSP due to its higher CEC.

Although caution should be taken when interpreting results for individual species in a seed mix since the performance of individual species is affected by competition, general observations can be made regarding individual species density. Total number of plants at the end of the experiment was not significantly affected by OM Plus rate. There was a significant interaction between substrate and fertilizer. More plants established in the TSP substrate than in the TS substrate and in the non fertilized than fertilized treatments (Tables 2 and 3). Slender wheat grass density was significantly affected by substrate and fertilizer being higher in TSP and non fertilized treatments. Fescue density was negatively affected by fertilizer and there was a significant substrate and OM Plus rate interaction. Tickle grass density was not significantly different between substrates but there was a significant fertilizer and OM plus rate interaction. In non fertilized treatments 11.1 vs 17.3 Mg ha^{-1} and 4.9 vs 17.3 Mg ha^{-1} application rates were significantly different indicating higher rates of OM Plus favoured plant density in non fertilized treatments. Fringed brome density was significantly negatively affected by fertilizer. Alfalfa density did not differ among OM Plus rates but there was a significant substrate and fertilizer interaction with fewer plants in fertilized treatments on TS than on TSP. Barley density was not significantly different among treatments.

4.2 Substrate Amelioration

At the end of the experiment, C:N, total C and N, CEC, EC and pH varied among treatments (Tables 4 and 5). Organic matter in the peat and OM Plus resulted in higher C:N. C:N was significantly different among TS and TSP treatments. Within substrates no significant differences were found between the 0 and 4.9 Mg ha^{-1} or 11.1 and 17.3 Mg ha^{-1} application rates. C:N among all other rates was significantly different.

Total C and N were significantly different among substrates. Within substrate no significant differences were detected between 0 and the 4.9 Mg ha^{-1} application rate, and for TSP 17.3 and 11.1 Mg ha^{-1} application rates. Total C among all other rates was significantly different. Most N from OM Plus would be readily available since C:N of OM Plus is 12.78 (Table 1). N release from peat would not be as readily available since C:N is >25:1.

Cation exchange capacity was not significantly affected by fertilizer. The effect of substrate depended on rate of OM Plus, with a significant interaction between substrate and OM Plus rate (Table 4 and 5). Within TS and TSP all OM Plus rates were significantly different except between 0 and 4.9 Mg ha^{-1} application rates. A high CEC is favourable because it means the soil will adsorb more cations (e.g. Ca^{2+}, Mg^{2+}, K^{+}) that will be readily available for plants. OM Plus helped to increase CEC in both TS and TSP. TSP had higher CEC than TS due to the better structure and proportion of organic matter in the peat. TSP and OM Plus treatments increased the level of calcium, potassium and magnesium in the soil. This is important because in potentially saline substrates (such as TS) calcium and potassium will help plant growth by maintaining ion balance (Renault et al. 2004).

Electrical conductivity was significantly different between substrates, among fertilized treatments and OM application rates (Table 4 and 5). Within substrates no significant differences were detected between the 0 and the 4.9 Mg ha^{-1} or between 11.1 and 17.3 Mg ha^{-1} application rates. EC among all other rates was significantly different. SAR varied with treatment at the end of the experiment (Tables 6 and 7). It was significantly different among OM Plus rates, significantly so between 17.3 vs 0 and 17.3 vs. 4.9 Mg ha^{-1}. There was a significant interaction between substrate and fertilizer. Differences in SAR were statistically significant in TS fertilized treatments but not in TSP fertilized treatments. Differences in SAR were greater in non fertilized treatments than in fertilized treatments. SAR of OM Plus rate within fertilized treatments was significant at 17.3 vs control (0) Mg ha^{-1} application rates. EC and SAR help in determining high concentrations of salts that could adversely affect plant establishment and growth. All treatments had increased EC and SAR over the controls. For example, in TS EC in the control non fertilized treatments was 0.45 dSm^{-1}, in control fertilized treatments it was 1.20 dSm^{-1} and in the 17.3 Mg ha^{-1} OM Plus fertilized treatment it was 1.90 dSm^{-1} (Table 4). Similarly, in control non fertilized treatments SAR was 0.5, in the control fertilized treatment it was 0.67 and in the 17.3 Mg ha^{-1} fertilized treatment it was 1.57 (Table 6).

Concentration of specific ions varied among treatments (Tables 6 and 7, Figures 12 to 15). Chloride (Cl) concentration was significantly different among OM Plus application rates, significantly so between 17.3 vs 0 and 17.3 vs. 4.9 Mg ha^{-1}. Calcium (Ca) concentration was significantly different among TS and TSP and among fertilized and non fertilized treatments. Potassium (K) concentration was significantly different among fertilized and non fertilized treatments and among OM Plus application rate treatments, significantly so between 17.3 vs 0 and 17.3 vs. 4.9 Mg ha^{-1}. Magnesium (Mg) concentration was significantly different among TS and TSP, fertilized and non fertilized treatments and OM Plus application rates. Within OM Plus rates 17.3 vs 0 Mg ha^{-1} were significantly different. For sodium (Na) concentration, there was a statistically significant interaction among substrate and fertilizer. Within TS, there were significant differences among fertilized vs non fertilized treatments. Within non fertilized treatments, there were differences among TS vs TSP. There was also a statistically significant difference among OM Plus application rates, significantly so between 17.3 vs 0 and 17.3 vs. 4.9 Mg ha^{-1}. Specific components of salinity such as Cl^- or Mg^{2+} at high concentrations may affect plant germination or growth. For example, alfalfa germination is affected more by Cl^- or Mg^{2+} than by Na^+ and other ions, choice of cultivar, osmotic tension and pH (Rumbaugh et al. 1993). Despite the increases in EC and SAR in amended treatments, the values remain within acceptable levels for germination and crop growth.

Values of pH did not differ significantly among OM Plus rates treatments. There was a statistically significant interaction between substrate and fertilizer. Within substrate treatments, pH was significantly different among OM Plus rates except between 0 vs. 4.9 and 11.1 vs 17.3 Mg ha^{-1} application rates. Mean pH was higher in TS than TSP treatments, 8 vs. 5.07 in control non fertilized treatments (Tables 4 and 5). Variation of pH within treatments was greater among the TS fertilized treatments where pH was lowered close to neutral indicating a significant reduction due to fertilizer. Ammonium nitrate and ammonium phosphate which are components of the fertilizer formulation used in this experiment, may reduce substrate pH. Monitoring of pH is recommended in the field to detect excessive acidification that could result from an excess of nitrogen in the form of ammonium that is not immediately used by plants (Brady and Weil, 2008). A neutral pH is beneficial for plant growth of many species.

Available nitrate did not differ due to substrate or OM Plus application rate alone, but there was a significant interaction between substrate and fertilizer (Tables 8 and 9). Within both fertilized and non fertilized OM Plus treatments, no significant differences were detected except among the 17.3 and 0 or 4.9 Mg ha^{-1} application rate. Within fertilized OM Plus treatments, significant differences were also detected between the 11.1 and 0 or 4.9 Mg ha^{-1} application rate. Available ammonium in TS was mainly under detectable levels, but there were significant differences among TS and TSP and fertilizer vs non fertilizer treatments. The effect of OM Plus rate on available nitrate was greater in TSP than in TS. Available ammonium was higher in TSP than TS treatments and in fertilized than non fertilized treatments. Effect of OM Plus rates on available ammonium was dependant on substrate with greater effect on TSP than TS. In TSP, the 17.3 Mg ha^{-1} application rate with fertilizer had the highest value. For example, in TS available ammonium in non fertilized treatments was 0.85 mg/kg, available ammonium in fertilized treatments was 5.36 mg/kg and in the 17.3 Mg ha^{-1} OM Plus fertilized treatment it was 4.76 mg/kg (Table 8, Figures 16 and 17). In contrast, in TSP, available ammonium in non fertilized treatments was 1.73 mg/kg, in fertilized treatment was 20.13 mg/kg and in the 17.3 Mg ha^{-1} OM Plus fertilized treatment it was 39.17 mg/kg (Table 9, Figures 18 and 19).

Available phosphate was significantly different among OM Plus application rates and there was a significant interaction between substrate and fertilizer. Phosphate in OM Plus rates in TS treatments was not significantly different except at the 17.3 vs 0 Mg ha^{-1} application rate. In the TSP treatment significant differences occurred at 17.3 vs 0 Mg ha^{-1} and 17.3 vs 11.1 Mg ha^{-1} application rates. In non fertilized treatments significant differences occurred at the 17.3 vs 0 Mg ha^{-1} and the 17.3 vs 4.9 Mg ha^{-1} application rates. In fertilized treatments significant differences were found at the 17.3 vs 0, 4.9 and 11.1 Mg ha^{-1} application rates. Available phosphate was significantly different among OM Plus treatments increasing at greater application rate regardless of the substrate. The OM Plus contributed to the amount of available phosphate. For example, available phosphate in TS with no fertilizer or OM Plus was 2 mg/kg, with no OM Plus but with fertilizer it was 23.83 mg/kg and in the 17.3 Mg ha^{-1} OM Plus fertilized treatment it was 29.66 mg/kg (Table 8, Figures 16 and 17). In TSP, available phosphate in the 0 OM Plus non fertilized treatment was 1 mg/kg, in the 0 fertilized treatment it was 14.67 mg/kg and in the 17.3 Mg ha^{-1} OM Plus fertilized treatment it was 66.33 mg/kg (Table 9, Figures 18 and 19).

Available potassium was significantly affected by fertilizer and OM Plus rate. In OM Plus treatments K was significantly different among 17.3 vs 0 and 17.3 vs 4.9 Mg ha^{-1} application rate. Available K was significantly different among fertilized treatments and increased directly with OM Plus application regardless of substrate. For example, in TS, available K in non fertilized treatments was 13.15 mg/kg, in fertilized treatments was 44 mg/kg and at 17.3 Mg ha^{-1} OM Plus fertilized treatments it was 72.33 mg/kg (Table 8, Figures 16 and 17). In TSP, available K in non fertilized treatments was 8 mg/kg, in fertilized treatments was 43 mg/kg and in the 17.3 Mg ha^{-1} Om Plus fertilized treatment it was 145.33 mg/kg (Table 9, Figures 18 and 19).

Available sulphate was significantly different among all treatments. In OM Plus treatments, no significant differences were detected between 0 vs 4.9 Mg ha-1 or 11.1 vs 17.3 Mg ha-1 OM Plus application rates. Available sulphate among all other rates was significantly different.

Available sulphate was greater in TSP and fertilized treatments and directly increased with OM Plus application rate. For example, in TS available sulphate in non fertilized treatments was 14.5 mg/kg, in fertilized treatments was 20.33 mg/kg and in the 17.3 Mg ha-1 OM Plus fertilized treatment it was 46 mg/kg (Table 8, Figures 16 and 17). In TSP, available sulphate in non fertilized treatments was 47.67 mg/kg, in fertilized treatments was 77.67 mg/kg and in the 17.3 Mg ha-1 OM Plus fertilized treatment was 135.00 mg/kg (Table 9, Figures 18 and 19).

Hydrocarbons are naturally present in the oil sands. Fractions 2 and 3 were analyzed for in the TS and TSP substrates before the beginning of the experiment to determine baseline data and verify that the values were within CCME standards. Average values were 796.67 and 1220.00 mg/kg for TS and TSP substrates, respectively (Table 1). The greater concentrations of hydrocarbons were found in the TSP substrate due to naturally occurring plant waxes in the peat material. The amount of F2 and F3 fractions were within CCME standards for coarse and fine grained soils with industrial and commercial end land use but below standards for agricultural use. This is not an issue since the amended TS and TSP are not expected to be used for an agricultural end land use.

5. CONCLUSIONS AND RECOMMENDATIONS

- Reclamation in the oil sands usually involves a layer of peat over TS. In the greenhouse, plant establishment occurred on TS and TSP by amending with OM Plus.
- OM Plus application increased above ground biomass in amended TSP and TS, particularly when used together with fertilizer. Maximum above ground biomass was achieved in TS with 17.3 Mg ha^{-1} OM Plus and in TSP with 11.1 Mg ha^{-1} OM Plus.
- TSP was a better substrate than TS to increase plant establishment and above and below ground biomass, and to retain the organic matter and nutrients supplied by OM Plus and fertilizer applications.
- Barley and slender wheat grass above ground biomass directly increased with OM Plus application rate indicating its suitability for oil sand reclamation with OM Plus.
- In TS, most plant species in the mix achieved a higher biomass at the OM plus rate of 11.1 Mg ha^{-1} for both fertilized and non fertilized treatments (Figures 6 and 7)
- In TSP, most plant species in the mix achieved a higher biomass at the OM plus rate of 4.9 Mg ha^{-1} for both fertilized and non fertilized treatments (Figures 6 and 7)

- Average above ground biomass of slender wheatgrass in TSP non fertilized treatments at the 17.3 Mg ha^{-1} rate was 328 mg. The fertilized TSP treatments produced 428 mg at the 11.1 Mg ha^{-1} OM plus rate. Both values were higher than those obtained by Renault et al. (2004). In their experiment slender wheatgrass above ground biomass was 254 mg growing on tailings covered with 15 cm of peat and fertilized with slow release fertilizer (10-30-15-04/N-P-K-S) at a 0.5 Mg ha^{-1}.
- Barley responded favourably to increasing rates of OM plus. Its above ground biomass was higher in all treatments at the 17.3 Mg ha^{-1} OM plus rate.
- Below ground biomass was not significantly different among OM Plus application rates. Fertilizer use resulted in less below ground biomass in the TSP substrate.
- Although barley and tickle grass plant density increased at higher OM Plus application rates, a clear relationship can not be ascribed since the performance of individual species in a plant mix may be affected by numerous factors.
- EC and SAR in all treatments remained within acceptable levels for germination and establishment of most plants. EC increased with fertilizer and at the 11.1 and 17.3 Mg ha^{-1} OM Plus application rate. SAR increased significantly only when OM Plus was applied at the 17,3 Mg ha^{-1} rate together with fertilizer. Because consecutive applications of OM Plus and fertilizer may raise EC and SAR, the 11.1 Mg ha^{-1} of OM Plus is preferred over higher rates.
- The use of fertilizer may reduce pH in TS, which could be favourable for some plant species that prefer more neutral than alkaline substrates. Monitoring of pH is recommended to avoid excess acidification.
- For a more rapid establishment of grass and better plant growth in the first growing season in TS and TSP, supplementing of nitrate and ammonium is recommended with OM Plus.
- OM Plus is a good source of available phosphate, potassium and sulphate for TS and TSP. Use of OM Plus could reduce or eliminate the need for fertilizer containing P, K and S to amend TS and TSP, especially at the 11.1 or 17.3 Mg ha^{-1} application rate, although the longevity of these effects are not known. Maximum relative growth rate of plants in relation to optimum relative addition of nutrients will depend on factors such as species, day length, moisture among others (Ingestad 1982).
- Additional research on changes in EC and SAR after consecutive applications is recommended.

6. REFERENCES

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Figure 1. Tailings sand and tailings sand with peat amended with OM Plus and seeded in the greenhouse. OM Plus was evenly incorporated with TS (lighter colour material) and TSP (darker colour) before placement in the greenhouse.

Figure 2. Various species of grasses growing in a TSP treatment in the greenhouse.

Figure 3. Grasses before clipping at the end of the OM Plus tailings sand experiment.

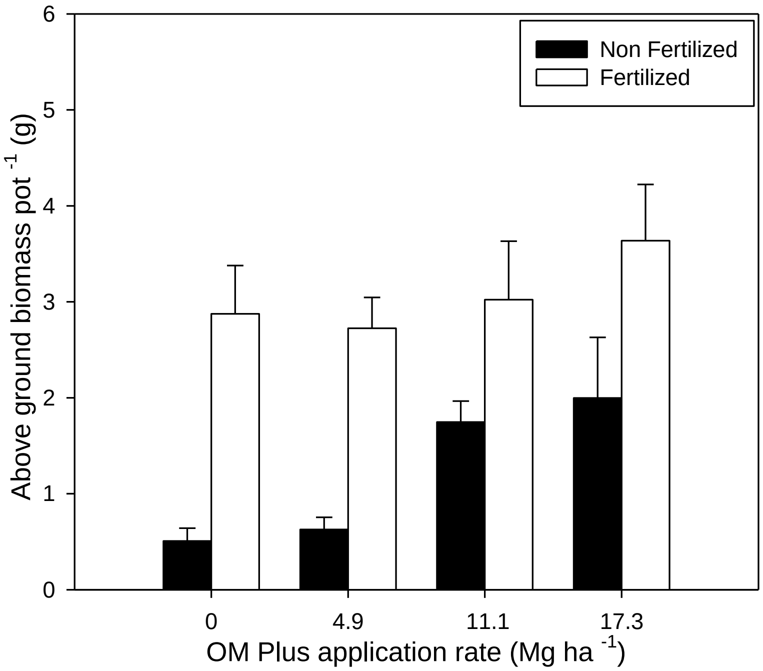

Figure 4. Average above ground biomass on amended tailings sand. Bars represent overall means ± SE.

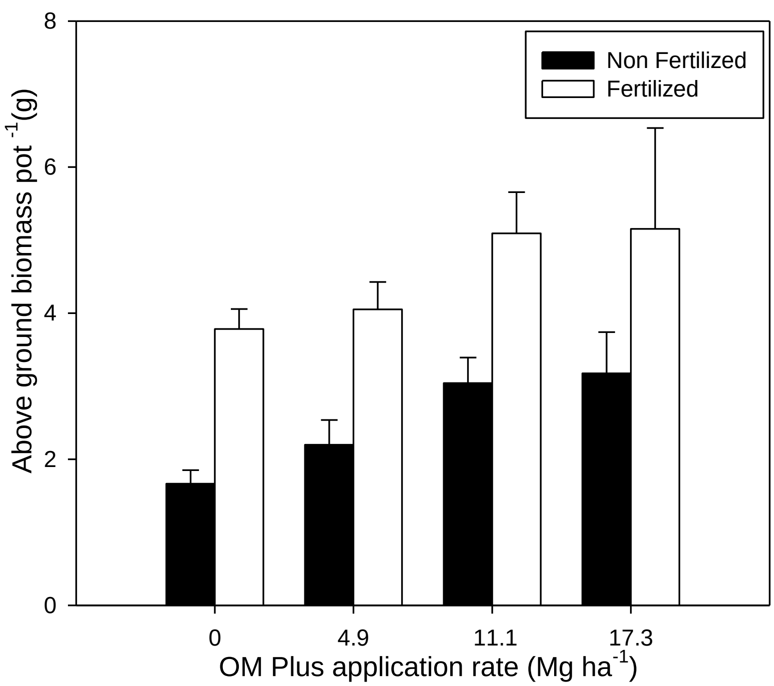

Figure 5. Average above ground biomass on amended tailings sand and peat. Bars represent overall means ± SE.

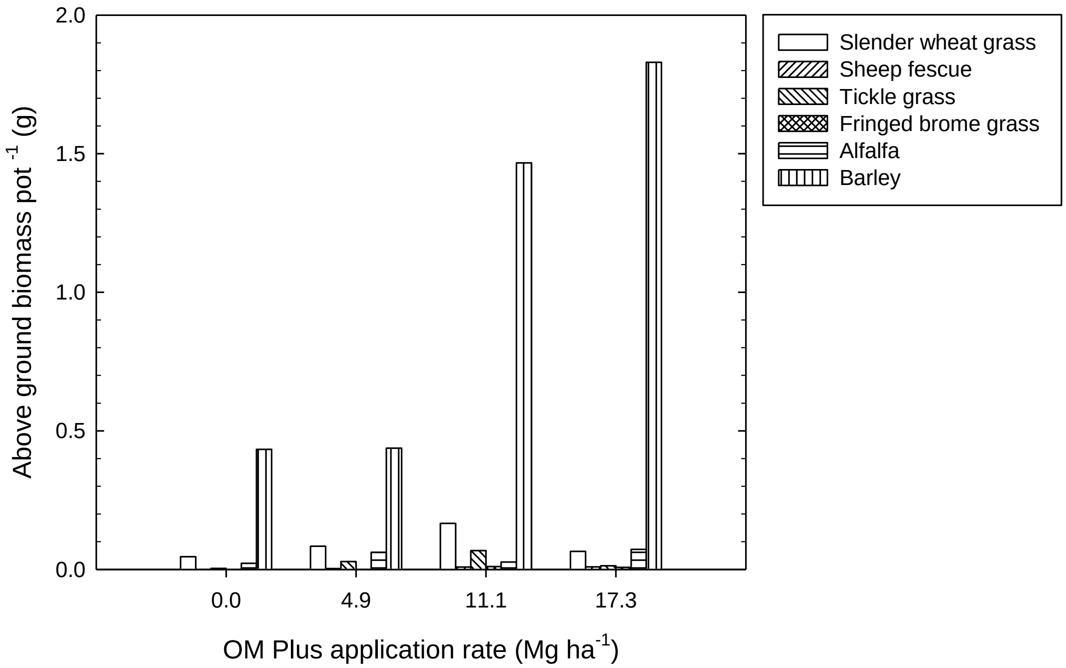

Figure 6. Average above ground biomass per individual plant species in OM Plus amended tailings sand without fertilizer

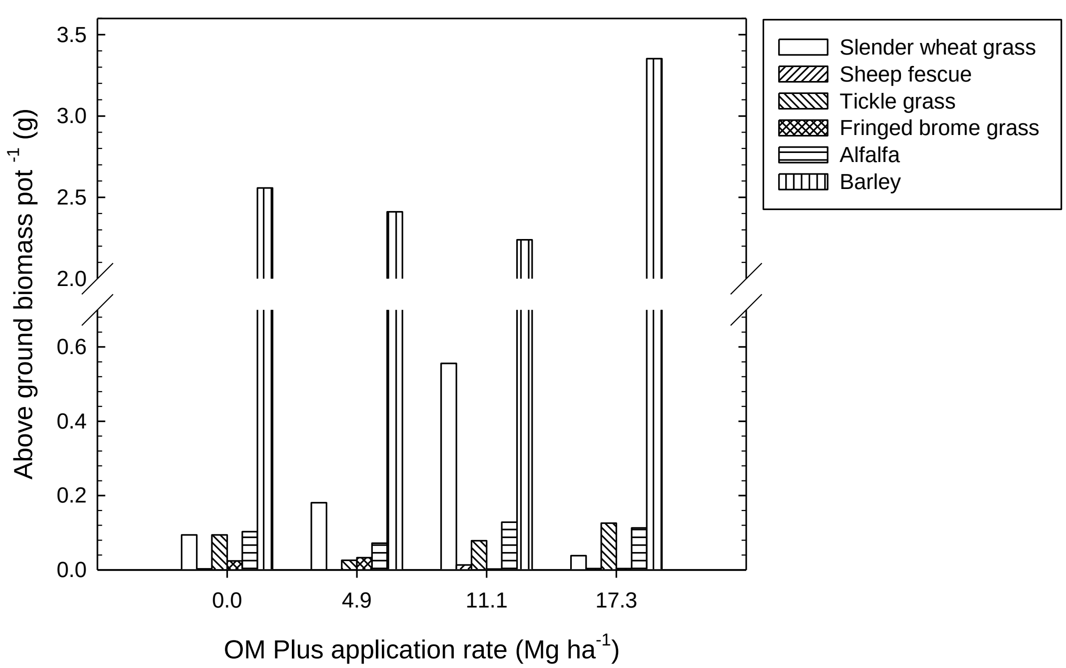

Figure 7. Average above ground biomass per individual plant species in OM Plus amended tailings sand with fertilizer.

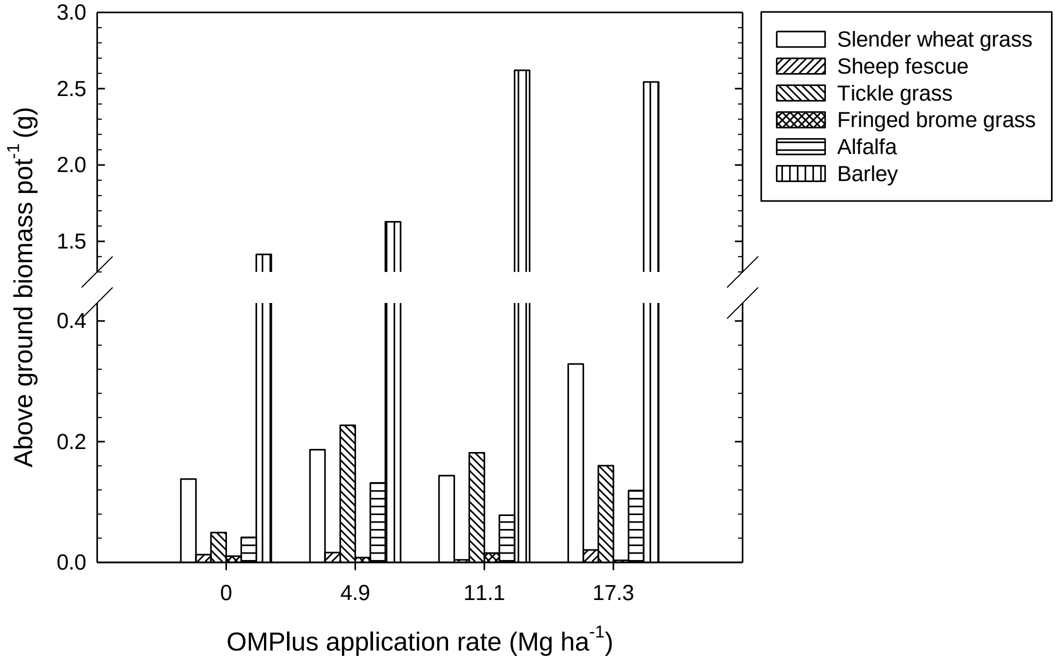

Figure 8. Average above ground biomass per individual plant species in amended tailings sand and peat without fertilizer.

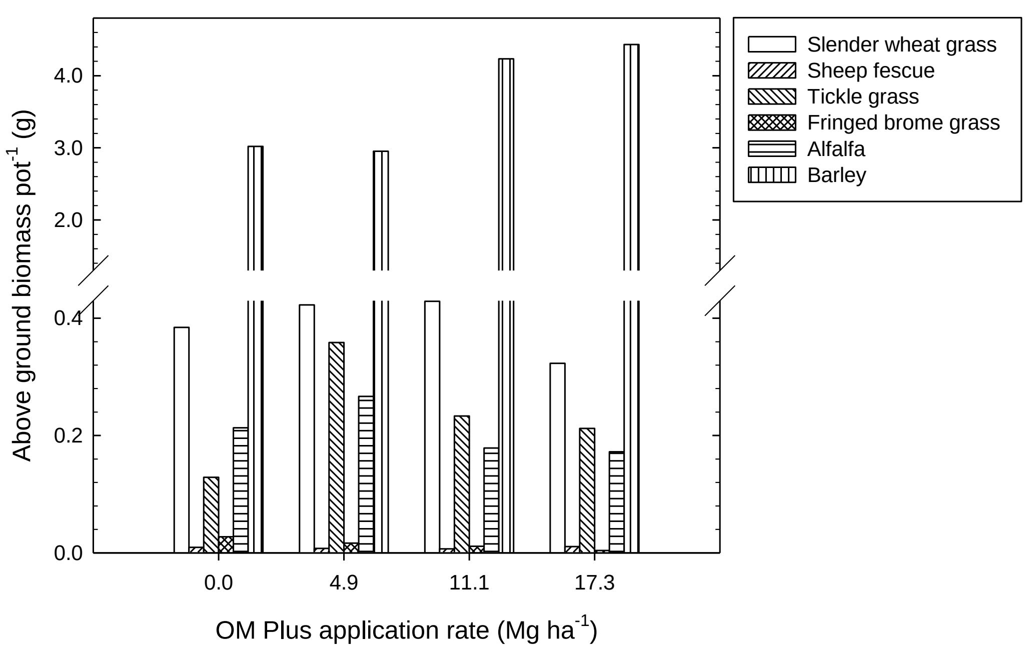

Figure 9. Average above ground biomass per individual species in amended tailings sand and peat with fertilizer.

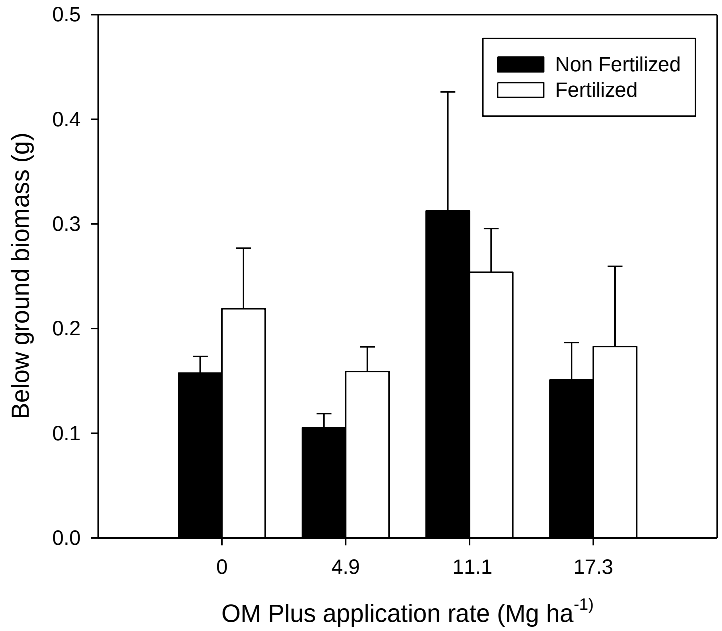

Figure 10. Average below ground biomass on amended tailings sand. Bars represent overall means ± SE.

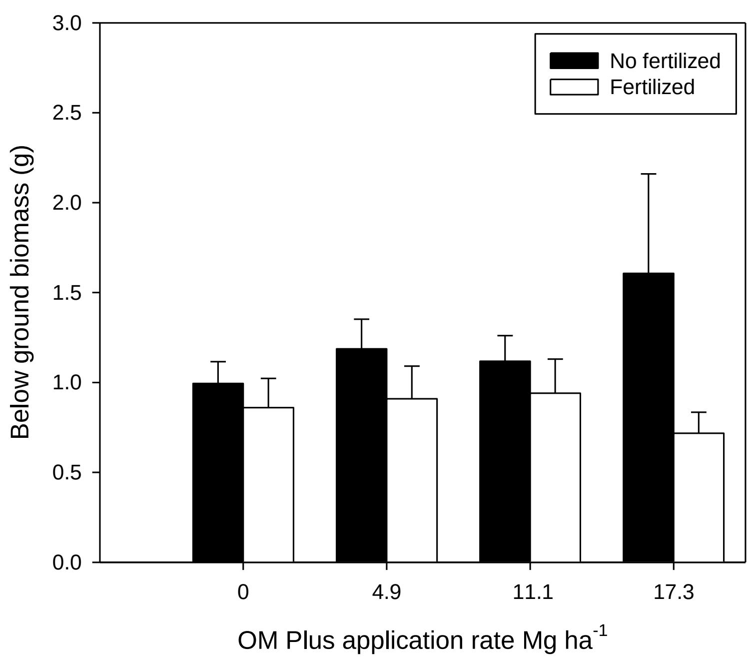

Figure 11. Average below ground biomass on amended tailings sand and peat. Bars represent overall means ± SE.

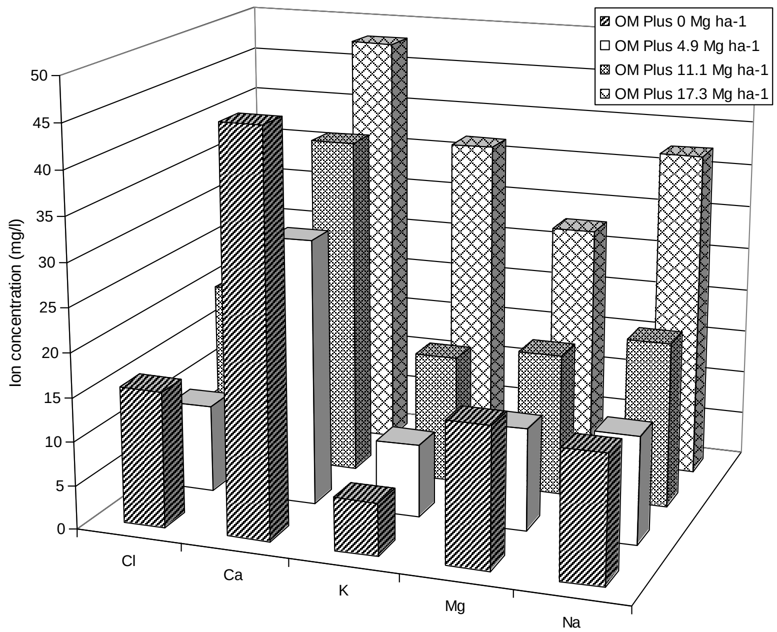

Figure 12. Ion concentration of Cl, Ca, K, Mg and Na (mg/l) in non fertilized tailings sand treatments amended at four OM Plus application rates.

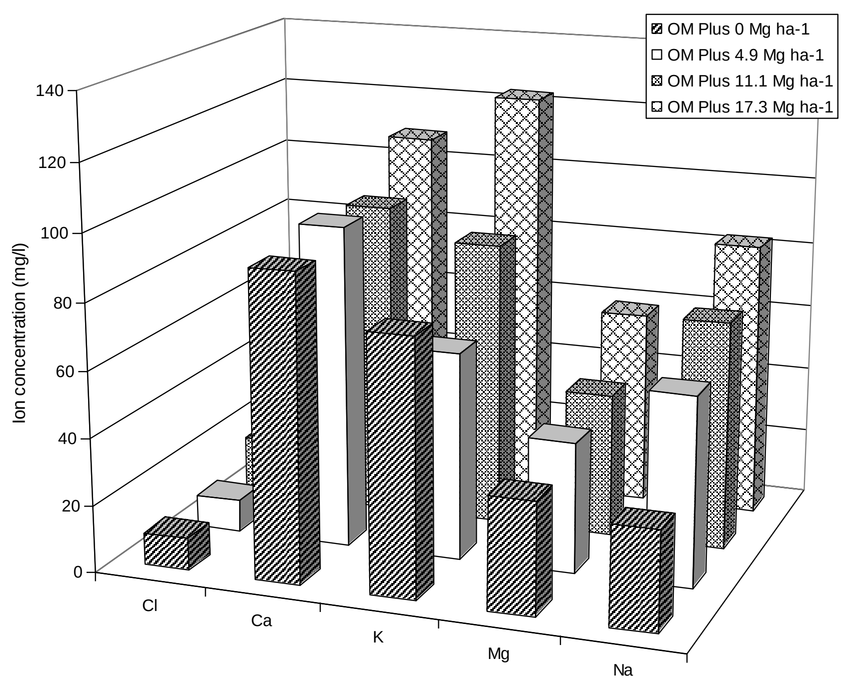

Figure 13. Ion concentration of Cl, Ca, K, Mg and Na (mg/l) in fertilized tailings sand treatments amended at four OM Plus application rates.

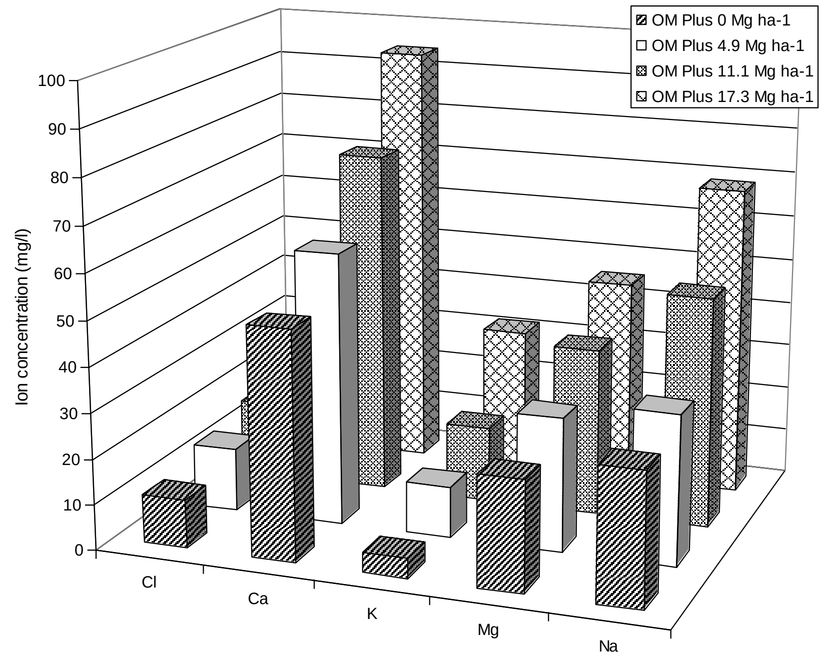

Figure 14. Ion concentration of Cl, Ca, K, Mg and Na (mg/l) in non fertilized tailings sand and peat treatments amended at four OM Plus application rates.

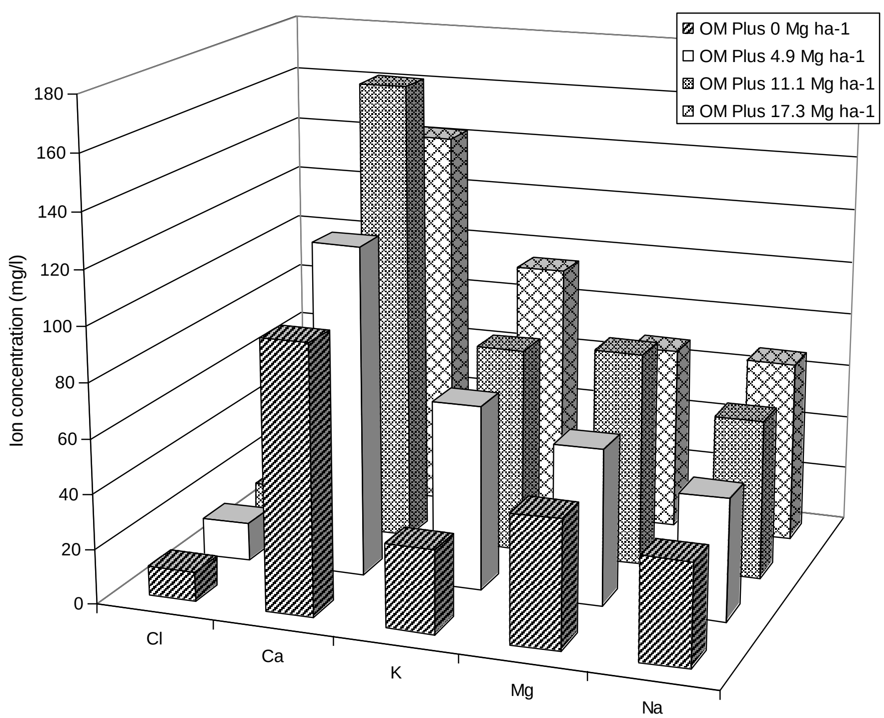

Figure 15. Concentration of Cl, Ca, K, Mg and Na (mg/l) in fertilized tailings sand and peat treatments amended at four OM Plus application rates.

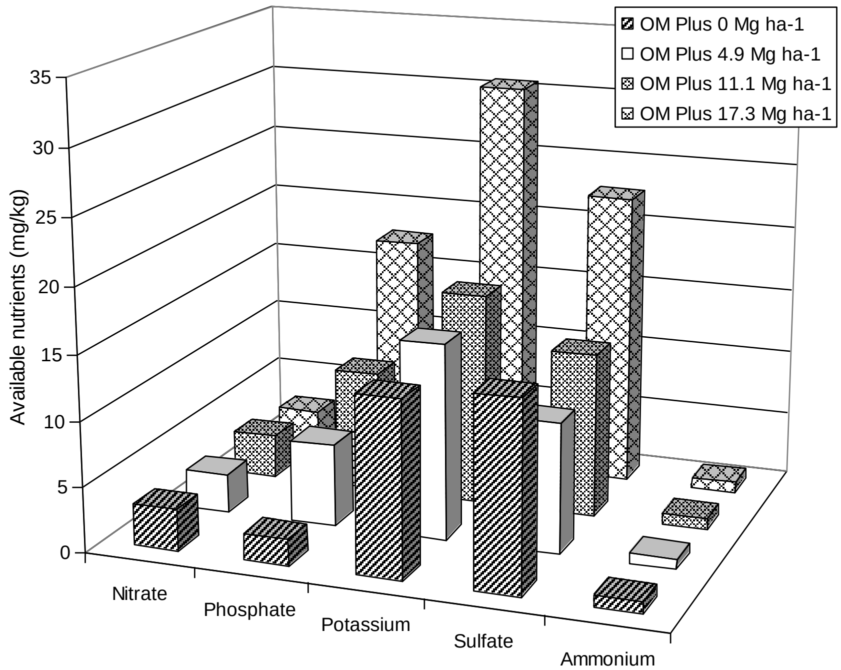

Figure 16. Average available nutrients in non fertilized tailings sand treatments amended at four OM Plus application rates.

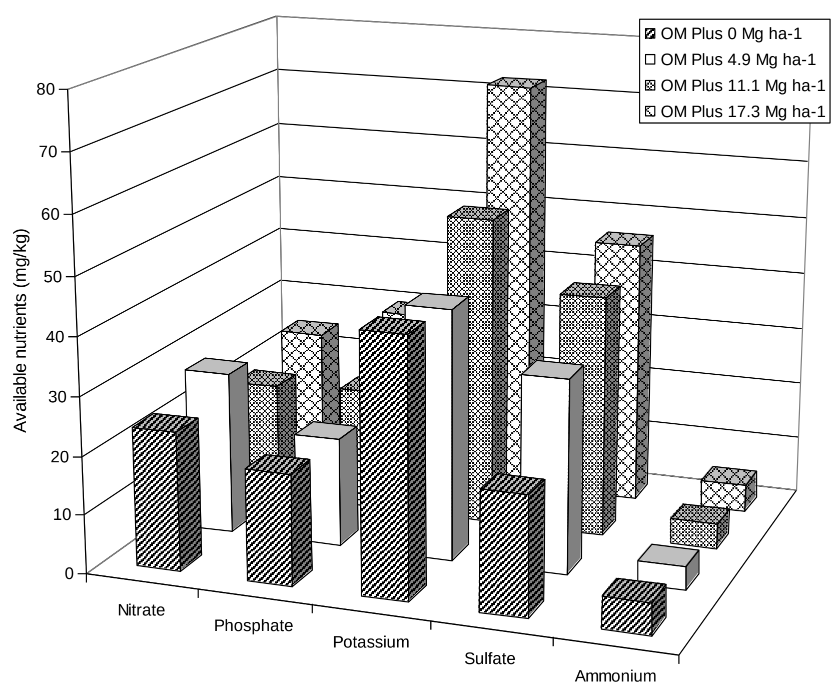

Figure 17. Average available nutrients in fertilized tailings sand treatments amended at four OM Plus application rates.

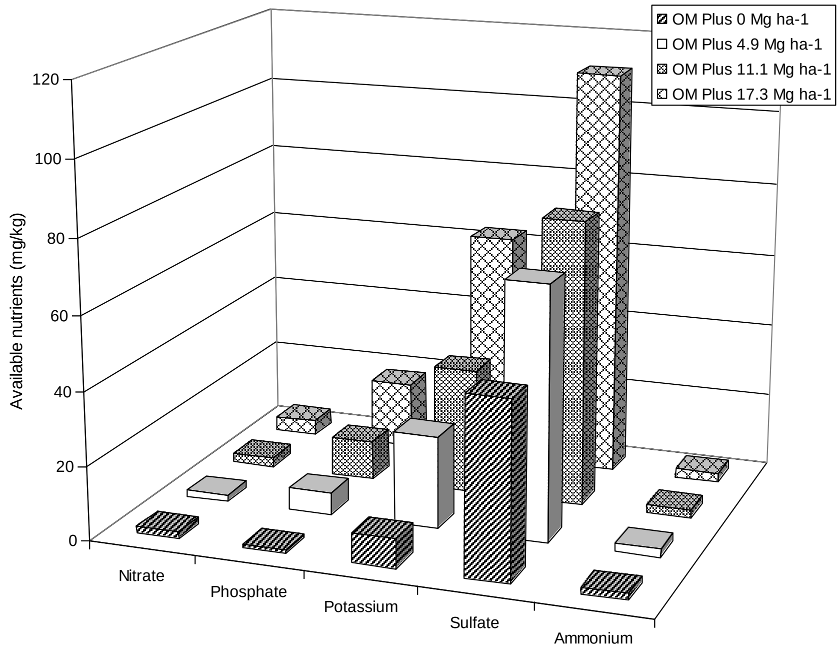

Figure 18. Average available nutrients at the end of the experiment in non fertilized tailings sand and peat (TSP) treatments amended at four OM Plus application rates.

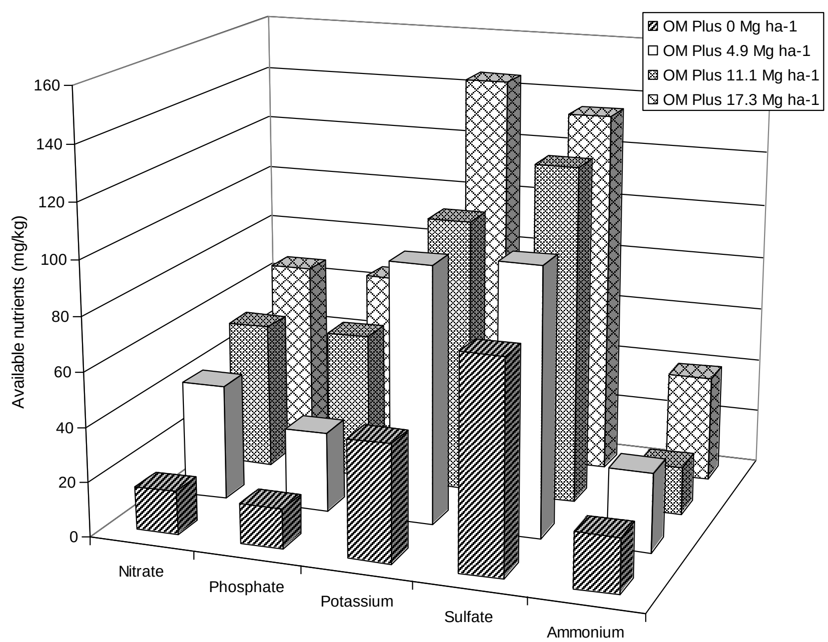

Figure 19. Average available nutrients at the end of the experiment in fertilized tailings sand and peat (TSP) treatments amended at four OM Plus application rates.

Table 1. OM Plus, TS and TSP chemical baseline data. Average values from 3 samples per material (ALS laboratory).

Analyte	Units	OM Plus	TS	TSP
C:N*		12.78	11.67	30.18
Available Nitrate-N	mg/kg	5.07	2.10	5.17
Available Phosphate-P	mg/kg	3236.67	BDL	1.00
Available Potassium	mg/kg	10733.33	14.33	30.00
Available Sulfate-S	mg/kg	1046.67	20.33	50.33
Chloride (Cl)	mg/L	3676.67	35.33	29.33
Calcium (Ca)	mg/L	126.67	21.00	67.00
Potassium (K)	mg/L	4463.33	8.00	20.33
Magnesium (Mg)	mg/L	110.00	7.00	28.67
Sodium (Na)	mg/L	1233.33	123.67	64.00
SAR	SAR	19.53	5.97	1.63
Sulphate (SO_4)	mg/L	2566.67	235.67	346.33
% Saturation	%	188.67	30.33	59.67
pH in Saturated Paste	pH	7.60	8.17	4.70
Conductivity Saturated Paste	dS m^{-1}	18.83	0.77	0.90
Inorganic Carbon	%	0.60	BDL	BDL
Total Organic Carbon	%	18.43	0.30	2.30
$CaCO_3$ Equivalent	%	5.60	0.77	0.87
Total Carbon by Combustion	%	19.03	0.30	2.30
% Moisture	%	NA	0.77	6.20
Available Ammonium-N	mg/kg	596.00	BDL	4.87
Cation Exchange Capacity	meq/100g	53.47	1.10	6.37
TEH (C11-C30)	mg/kg	NA	796.67	1220.00
Total Nitrogen by LECO	%	1.49	0.03	0.08

*TC/TN
BDL: Below detectable levels
NA: Not analyzed

Table 2. Average percent of plants established at the end of the experiment in fertilized and non fertilized amended tailings sand with OM plus (0, 4.9, 11.1and 17.3 Mg ha^{-1}). Every pot was seeded with 5 seeds per species.

	OM Plus 0		OM Plus 4.9		OM Plus 11.1		OM Plus 17.3	
Species	NF	F	NF	F	NF	F	NF	F
Slender wheat grass	84	40	76	24	76	60	64	36
Sheep fescue	44	8	36	0	48	48	48	20
Tickle grass	20	24	56	20	36	32	12	36
Fringed brome	12	4	20	12	36	4	32	8
Alfalfa	44	44	64	24	36	24	40	40
Barley	52	56	60	56	56	48	68	56

Table 3. Average percent of plants established at the end of the experiment in fertilized and non fertilized amended tailings sand and peat with OM Plus (0, 4.9, 11.1and 17.3 Mg ha^{-1}). Every pot was seeded with 5 seeds per species.

	OM Plus 0		OM Plus 4.9		OM Plus 11.1		OM Plus 17.3	
Species	NF	F	NF	F	NF	F	NF	F
Slender wheat grass	84	76	80	92	84	76	64	68
Sheep fescue	60	44	52	28	36	36	52	48
Tickle grass	32	52	40	32	64	44	20	32
Fringed brome	24	32	20	8	36	16	20	16
Alfalfa	64	52	72	80	56	72	52	60
Barley	72	56	48	76	60	56	64	60

Table 4. Average C:N, total carbon, total nitrogen, CEC, EC and pH in TS treatments at the end of the experiment.

Fertilizer	OM Plus (Mg ha^{-1})	C:N	Total Carbon (%)	Total Nitrogen (%)	CEC Meq/100 g	EC dSm^{-1}	pH
None	0	6.67	0.20	0.03	0.80	0.45	8.0
	4.9	14.44	0.43	0.03	1.00	0.33	7.8
	11.1	5.56	0.20	0.04	0.80	0.43	8.1
	17.3	7.78	0.23	0.03	1.00	0.67	8.0
Fertilized	0	6.39	0.23	0.04	1.00	1.20	7.2
	4.9	7.78	0.23	0.03	0.93	1.20	7.3
	11.1	8.33	0.27	0.03	1.17	1.30	7.4
	17.3	7.78	0.23	0.03	1.13	1.63	7.4

Table 5. Average C:N, total carbon, total nitrogen, CEC, EC and pH in TSP treatments at the end of the experiment.

Fertilizer	OM Plus rate (Mg ha^{-1})	C:N	Total Carbon (%)	Total Nitrogen (%)	CEC Meq/100 g	EC dS m^{-1}	pH
None	0	36.61	2.53	0.07	8.60	0.57	5.1
	4.9	41.32	3.43	0.08	12.10	0.70	5.1
	11.1	29.17	2.83	0.10	12.53	0.87	5.2
	17.3	33.48	2.93	0.09	12.27	1.10	5.0
Fertilized	0	29.39	2.07	0.08	8.70	1.20	4.8
	4.9	30.78	2.70	0.09	10.75	1.60	4.9
	11.1	31.98	3.50	0.11	10.93	1.87	4.8
	17.3	35.00	3.20	0.09	13.20	1.90	4.8

Table 6. Average salinity values in TS treatments.

Fertilizer	OM Plus (Mg ha^{-1})	Cl (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	SAR	Saturation (%)
None	0.0	15.50	45.50	6.00	16.00	14.50	0.50	30.00
	4.9	10.00	30.33	8.33	11.67	12.33	0.47	27.67
	11.1	20.33	38.67	14.67	16.33	19.00	0.63	30.33
	17.3	19.00	48.00	36.67	27.67	37.33	0.97	29.67
Fertilized	0.0	9.67	91.67	76.67	33.67	29.67	0.67	30.67
	4.9	9.67	96.33	62.33	39.33	57.00	1.10	31.00
	11.1	17.00	94.33	85.67	43.00	68.67	1.40	30.67
	17.3	22.33	108.67	123.33	58.67	83.00	1.57	30.33

Table 7. Average salinity values in TSP treatments.

Fertilizer	OM Plus (Mg ha^{-1})	Cl (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	SAR	Saturation (%)
None	0.0	10.67	50.33	4.33	24.33	29.33	0.87	66.67
	4.9	14.00	60.00	11.33	29.33	33.00	0.87	75.00
	11.1	16.67	75.67	16.67	37.00	51.00	1.17	68.67
	17.3	23.67	94.33	31.67	45.33	68.67	1.43	75.67
Fertilized	0.0	11.00	98.00	30.33	46.67	37.33	0.77	57.00
	4.9	14.00	121.00	67.50	57.00	44.50	0.80	64.00
	11.1	13.33	169.67	75.67	78.67	58.67	0.93	75.00
	17.3	14.00	142.33	95.00	68.00	67.33	1.17	82.00

Table 8. Average available nutrients in TS treatments at the end of the experiment.

Fertilizer	OM Plus (Mg ha^{-1})	Available Nitrate (mg/kg)	Available Phosphate (mg/kg)	Available Potassium (mg/kg)	Available Sulfate (mg/kg)	Available Ammonium (mg/kg)
None	0	3.25	2.00	13.50	14.50	0.85
	4.9	3.00	6.33	15.00	10.00	<0.8
	11.1	3.33	9.33	16.33	12.67	<0.8
	17.3	2.70	17.67	30.67	22.67	<0.8
Fertilized	0	23.833	19.000	44.000	20.333	5.367
	4.9	27.867	18.667	43.000	33.333	4.133
	11.1	20.100	21.000	53.333	41.667	4.433
	17.3	24.233	29.667	72.333	46.000	4.767

Table 9. Average available nutrients in TSP treatments at the end of the experiment.

Fertilizer	OM Plus (Mg ha^{-1})	Available Nitrate (mg/kg)	Available Phosphate (mg/kg)	Available Potassium (mg/kg)	Available Sulfate (mg/kg)	Available Ammonium (mg/kg)
None	0	1.93	1.00	8.00	47.67	1.73
	4.9	1.80	6.00	25.00	68.67	2.23
	11.1	2.60	10.67	34.00	77.67	2.37
	17.3	4.13	18.33	63.33	111.00	2.47
Fertilized	0	16.13	14.67	43.00	77.67	20.13
	4.9	42.45	29.50	95.00	98.50	28.95
	11.1	54.27	54.33	101.33	124.33	17.80
	17.3	66.80	66.33	145.33	135.00	39.17