CAN INORGANIC FERTILISER SUBSTITUTE FOR ORGANIC AMENDMENTS IN THE REHABILITATION OF SALINE, SODIC ORE REFINING RESIDUES?

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1. ABSTRACT

Organic amendments would generally be attractive additions for revegetation of ore refining residues that mostly contain negligible organic matter. However organic materials may not be available on mine sites in sufficient quantities and are bulky to handle. In the present study, the opportunities for substituting inorganic fertilisers in place of organic materials (poultry manure, and straw) were investigated for three alkaline, variably saline residues: Bauxite residue (mixed sand and clay fractions), Bauxite Residue sand, and Gold oxide residue. On gypsum-amended, leached Residue sand and Bauxite residue N, P, and Mn were potentially deficient for plant growth. On the Residue sand, complete inorganic fertiliser was effective in stimulating plant growth because it corrected the deficiencies of N and P and partially corrected Mn deficiency. By contrast, on bauxite residue and gold oxide residue which remained saline, sodic and alkaline even with gypsum amendment and leaching, inorganic fertiliser alone was not effective in correcting nutrient deficiencies on these residues and plant growth was strongly limited by excessive Cl uptake. Maximum growth on Bauxite and Gold oxide residues was obtained with a combination of inorganic fertiliser and poultry manure. On the strongly saline and alkaline silty clay residues, inorganic fertiliser alone was a poor substitute for organic amendments which supplied nutrients and increased plant tolerance to saline substrate.

Keywords: bauxite residue, gold residue, nutrient deficiency, residue sand, salinity

2. INTRODUCTION

Ore refining residues are particularly difficult substrates to revegetate because they often contain extremely low plant-available levels of one or more essential elements (Hossner and Hons, 1992). If these materials were simply low in plant-available nutrients, judicious use of fertilisers should be sufficient to overcome nutrient constraints to successful revegetation (Bell, 1999). However, in ore refining residues, nutrient supply to plants often occurs in a substrate where extremes of other soil chemical properties limit plant growth and nutrient availability (Hossner and Hons, 1992). In addition, the grinding of ores to facilitate mineral extraction produces substrates with atypical particle size distribution.

Ore refining residues contain negligible organic matter and are devoid of most soil biological activity (Hossner and Hons, 1992; Jasper *et al.*, 2000). Organic amendments would generally be attractive additions for revegetation of such residues. Not only could they inoculate the residue with microorganisms, they supply organic matter for the initiation of soil biological activity, nutrients for plant growth (Avnimelech, 1986), and the organic materials may ameliorate potentially toxic levels of elements or salts.

Poultry manure has been used for revegetation of residue sand (Jasper *et al.*, 2000) and was also found to be effective for stimulating plant growth on gold oxide residues (Ho *et al.*, 1999) and bauxite residue (Wright *et al.*, 1995). In previous studies with gold oxide refining residues, poultry manure at 35-70 t/ha was found to greatly increase the growth of plants (Ho *et al.*, 1999). On Residue sand, the rate commonly used is 10-70 t/ha (Jasper *et al.*, 2000).

However, whilst the above prescription appeared effective for Gold Oxide and Bauxite Residue revegetation, poultry manure is an expensive amendment, can be of variable quality, and may introduce weed species into the area. In addition, organic materials may not be available on mine sites in sufficient quantities and are bulky materials to transport and handle. In addition some of the benefits of organic amendments can be obtained by the application of topsoil on residue.

In the present study the opportunities for substituting inorganic fertilisers in place of organic materials (poultry manure and straw) were investigated for three alkaline, variably saline residues: Bauxite residue (mixed sand and clay fractions), Bauxite Residue sand, and Gold oxide residue.

3. MATERIALS AND METHODS

Bauxite Residue sand was collected from the Pinjarra Refinery of Alcoa. Gold oxide residue was collected from the residue storage area of Hedges Gold Mine. Bauxite residue was collected from Bauxite Residue Disposal Area at the Collie refinery of Worsley Alumina. Glasshouse experiments were carried out to evaluate the response of triticale (*Triticosecale* spp. cv. Muir) to organic and inorganic fertiliser applications. Triticale was used in previous investigations on gold oxide residue as an effective indicator of plant response to saline conditions (Ho *et al.*, 1999).

Each residue was air dried, crushed, and sieved through a 4 mm sieve. Equal volumes of residue were added to each pot: weights were 3 kg for gold oxide residue, and 4.5 kg for the other residues. Gypsum (calcium sulphate) was added to each pot at 5 % (w/w) and mixed thoroughly. Each residue was leached with deionised water (DI) equivalent to 100, 200 and 300 mm rainfall for Gold oxide, Bauxite Residue and Residue sand, respectively. After leaching, the residue was air-dried. When dry, half of each type of residue had inorganic fertilizers added as solutions. Complete inorganic fertiliser comprised the following (mg salt/kg residue): KH_2PO_4, 362.7; K_2SO_4, 174.0; NH_4NO_3, 93.3;$MgSO_4.7H_2O$, 24.6; $ZnSO_4.7H_20$, 9.57; $MnSO_4.H_2O$, 8.47; $CuSO_4.5H_2O$, 1.30; H_3BO_3, 0.83; $CoSO_4.7H_2O$, 0.47; $Na_2MoO_4.2H_2O$, 0.40. When the nutrient solution had dried on the residue, the organic material was added to each pot as required and then the contents were mixed thoroughly. The mixed residue was added to 200 mm diameter plastic pots, double lined with intact plastic bags and covered with a 350 g layer of coarse and medium sand (1:3) to facilitate seed emergence. The surface area of residue in pots was 254 cm^2. Fifteen, 5-6 day old seedlings were transplanted into the sand layer. After planting the pots were arranged in a randomized complete block design. The pots were rotated within the replicates blocks weekly to minimise positional effects on growth. Plants were watered as required for ten days, after which time they were watered by weight twice a week to 80 % of field capacity (FC) and as required at other times.

Ten days after transplanting, plants were thinned to 12 per pot. The plants were harvested for dry matter six or seven weeks after transplanting when tops of plants were cut at ground level, washed in DI water, and dried an oven at 70^oC for 3-4 days. The dry material was analysed for elemental composition by Leco Furnace (N, S), spectrophotometry (P) and by atomic absorption spectrometry (K, Ca, Mg, Fe, Mn, Zn, Cu).

3.1 Experiment 1: Response of triticale to poultry manure and inorganic fertilisers.

A factorial combination of the following treatments was imposed in triplicate on all three residue types: Poultry manure (PM) - 0, 50, 150, 300, 600 m^3/ha. Inorganic fertilizer: -I - no inorganic fertilizer; +I - inorganic fertilizer added at rates given above. Poultry manure composition was as follows: (%) N, 3.92; P, 0.89; K, 0.79; Ca, 1.93; Mg, 0.29; S, 0.34; Na, 0.18; Cl, 0.29; (mg/kg) Cu, 94; Zn, 315; Mn, 272; Fe, 720; NO_3 42.

3.2 Experiment 2: Response of triticale to N and P on Residue Sand.

A factorial combination of the following treatments was imposed in triplicate: Nitrogen - 40, 80, 120, 160 kg N/ha (N1, N2, N3, N4); Phosphorus - 150, 300, 600 kg P/ha (P1, P2, P3). Inorganic fertiliser application was as for Experiment 1 with the exception of N and P. Phosphorus treatments consisted of 50 %, 100 % and 200 % of optimal phosphorus addition, based on pre-determined phosphorus retention index (Allen and Jeffery, 1990). Nitrogen was supplied basally for N1-N4. Two later applications of 46.7 mg NH_4NO_3/kg, 93.3 mg NH_4NO_3/kg, and 140 mg NH_4NO_3/kg were applied for N2, N3 and N4, respectively. These values correspond to field applications of 40 kg N/ha, 80 kg N/ha, 120 kg N/ha and 160 kg N/ha, respectively for N1-N4.

4. RESULTS AND DISCUSSION

4.1 Physical and chemical properties of residues and organic amendments

All residues were strongly alkaline, especially the Bauxite residue. Bauxite residue also contained an order of magnitude more water-soluble alkalinity than the Residue sand and two orders of magnitude more than Gold oxide residue (Table 1). Thus, neutralisation of the alkalinity in Bauxite residue will be substantially more difficult than for Gold oxide residue. Bauxite and Gold oxide residues were both strongly saline in contrast to Residue sand that was non-saline to marginally saline. Residue sand had low clay levels in contrast to the other residues. Bauxite and Gold oxide residues had similar clay content but the Gold oxide residue contained much less sand. Variations in silt and sand among residues were consistent with differences in water holding capacity.

Growth responses of triticale on the silty clay residues were quite different from those on Bauxite residue sand so the results are presented for the two bauxite residue types and gold residue is only discussed briefly.

Table.1. Chemical and physical properties of untreated residues

Soil properties [A]		Residue Sand	Bauxite Residue	Gold Oxide Residue
pH (1:5 H_2O)		10.3	10.6	9.3
Alkalinity - Water Soluble (g $CaCO_3$/kg)[A]		1.97	15.5	0.37
Electrical Conductivity (1:5) (mS/m)		60	750	385
Exchangeable sodium %		81	54	62
Cation exchange capacity (cmol(+)/kg)			17	22
Phosphorus adsorption maxima (g kg^{-1})		2.0	1.2	0.6
Organic Carbon (%)		0.04 - 0.08	0.24 - 0.3	0.18
Field Capacity (%)		11.8	28.4	37.3
Texture:	(% clay)	2	38	43
	(% silt)	11	24	39
	(% sand)	87	38	18

[A] Rayment and Higginson (1992).

4.2 Residue sand

Promising positive growth responses were obtained with inorganic fertiliser alone in the Residue sand (Table 2). Maximum growth in residue sand was as high as in well-watered, well fertilized triticale plants in sand culture (data not shown). These results suggest that no major growth constraints limited triticale growth on residue sand when it was supplied with a combination of poultry manure and inorganic fertilizer.

Despite leaching and gypsum addition to the Residue sand, shoot Na and Cl concentrations were still appreciable (Table 3). Whilst there was no indication of Na or Cl toxicity in triticale in the present experiment, the potential impact of appreciable levels of Na and Cl in Residue sand warrants further consideration. Toxicities of Na and Cl are likely to become more acute as plants age because of their progressive accumulation in leaves. In addition high levels of Na and Cl in Residue Sand would be potentially more damaging to plant growth in the field when plants are not kept in a well-watered condition. On the other hand, leaching of Na and Cl from the root zone in the field is probable given the concentration of rainfall in winter in south west Australia.

Nitrogen supply is the most complex to optimize. In the short term, N must be supplied at appropriate rates and times to achieve vigorous growth during establishment of revegetation on Residue sand (Fig. 1). Rates of N applied in agricultural crops may be appropriate for pasture species and trees. Since the Residue sand is very permeable, leaching of N is a risk, and split applications of inorganic N fertilizers should increase the effectiveness of N fertilizer.

Table 2. Effect of poultry manure (PM) and inorganic fertiliser (-I - no inorganic fertilizer; +I - inorganic fertilizer added) on the shoot yield of triticale (g/pot) grown on (a) Residue Sand, (b) Gold Oxide Residue and (c) Bauxite Residue for 42 days. Values are means of three replicates ± standard errors. Experiment 1.

Inorganic fertilizer	Poultry manure (m^3/ha)				
	0	50	150	300	600
	Residue Sand				
-I	0.2 (0.05)	1.3 (0.35)	2.3 (0.15)	1.2 (0.40)	0.25 (0.05)
+I	1.95 (0.05)	3.15 (0.50)	2.85 (0.40)	3.1 (0.25)	0.6 (0.20)
	Gold Oxide Residue				
-I	0.2 (0.02)	0.63 (0.08)	0.96 (0.31)	0.8 (0.4)	0.08 (0.02)
+I	0.47 (0.12)	1.37 (0.18)	1.25 (0.25)	0.6 (0.12)	0.15 (0.05)
	Bauxite Residue				
-I	0.13 (0.02)	0.8 (0.15)	0.6 (0.22)	0.47 (0.08)	0.07 (0.02)
+I	0.35 (0.02)	1.08 (0.17)	0.8 (0.28)	0.47 (0.12)	0.08 (0.05)

Table 3. Effect of poultry manure (PM) and inorganic fertiliser (I) on N, Ca, Cl and Mn concentration in whole shoots of triticale grown for 42 days on Residue Sand. Values are means of 3 replicates with standard errors in parentheses. Experiment 1.

Treatments[A]	N (%)	P (%)	Na (%)	Cl (%)	Mn (mg/kg)
PM$_0$ -I[B]	2.1	0.09	1.0	0.5	9
PM$_0$ +I	2.2 (0.10)	0.23	0.8 (0.04)	0.9 (0.08)	12 (0.4)
PM$_{50}$ -I	5.2 (0.08)	0.33	0.6 (0.06)	1.9 (0.29)	17 (5.2)
PM$_{50}$ +I	4.7 (0.14)	0.39	0.6 (0.04)	2.2 (0.10)	11 (1.1)

[A] PM0- no added poultry manure, PM50 – 50 m^3 poultry manure /ha; -I – no inorganic fertiliser; +I – complete inorganic fertiliser applied

[B] Insufficient sample size for analysis so replicate samples were bulked.

The longer term N supply issues are more difficult to assess. The incorporation of fertilizer N into the nutrient cycle is an important issue for long-term success of revegetation. However the quantities of N required for a new self-sustaining ecosystem on Residue sand greatly exceed amounts applied during establishment. A functioning Jarrah forest ecosystem stores about 1500 kg N/ha in the soil to a depth of 30 cm (Ward and Koch, 1996). It is not possible to supply 1500 kg N/ha in a single dose without causing toxicity to crops, and massive losses to the groundwater. Two options exist for testing depending on the rehabilitation and management goals. Firstly, the revegetated Residue sand can be treated as an agricultural system requiring annual N fertilizer additions. Alternatively, the vegetation mix can be selected to favour legumes, which fix nitrogen and hence build an organic nitrogen pool. To achieve high rates of N_2 fixation, P supply should be optimized. Indeed maximum growth by triticale required the equivalent of 300 kg P/ha (Fig. 1). For revegetation, relatively high P rates would restore soil P pools for long term turnover. The risk of P leaching from Residue sand even at relatively high rates in the establishment year is not great (Sampson, 1994).

The low levels of Mn measured in triticale shoots on Residue sand (Table 5) are consistent with reports of Mn deficiency symptoms in plants from the Pinjarra Residue storage areas (Gheradi and Rengel, 2000, 2001). Low Mn uptake by plants is probably the consequence of the high alkalinity that rapidly converts Mn to forms that are not readily available to plants (Gherardi and Rengel, 2001).

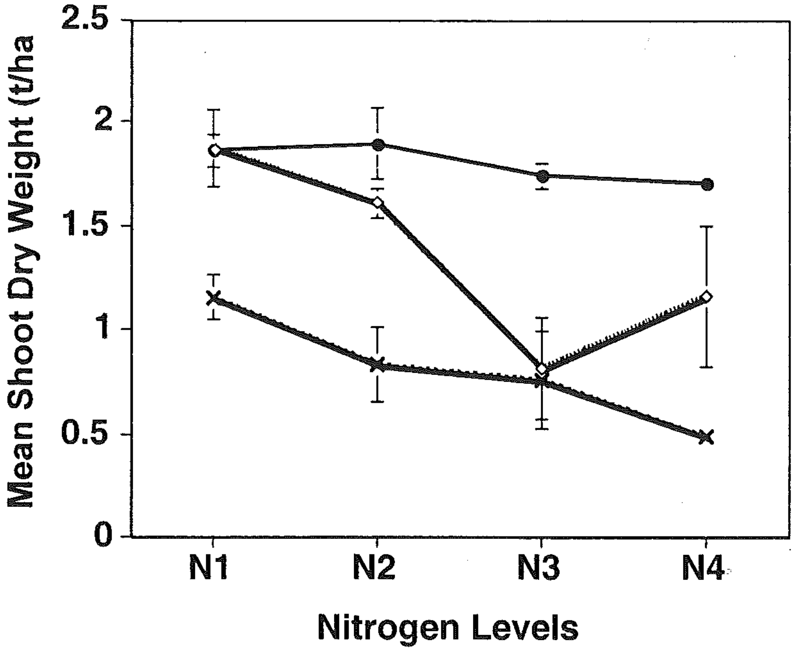

Figure 1. Effect of nitrogen (N) and phosphorus (P) on the shoot yield of triticale grown on Residue Sand for 49 days. Values are means of three replicates. Vertical bars denote standard errors. Experiment 2.

The present project has used triticale, a rapidly growing agricultural species, as its test plant. Its behaviour in Residue Sand and response to inorganic and organic amendments may be a reasonable reflection of the response of a range of non-leguminous pasture and crop species. If an agricultural system is to be established on the Residue Sand disposal areas then the present results provide a useful guide to the potential for replacing poultry manure with inorganic fertilizers. However, field-testing the effectiveness of inorganic fertilizers for emergence and survival of plants is necessary before it can be recommended for revegetation. On the other hand, trees and other non-agricultural species may be the desired vegetation for Residue Sand disposal areas. Trees in particular are important on most Residue Sand disposal areas to reduce wind speed and minimize wind erosion risks. The response of native trees and shrubs to organic and inorganic amendments on Residue Sand can be expected to differ from that of triticale. Firstly, the response to nutrients may be suppressed in the more salt-sensitive species than triticale. Secondly, native species tend to be more sensitive to high soil P levels and the rates of P found optimal for triticale may be excessive. Thirdly, leguminous native species will achieve satisfactory growth at lower rates of N fertilizer, provided rhizobium bacteria are present in the Residue Sand.

4.3 Bauxite residue

For Bauxite Residue, the use of inorganic fertilizer as a replacement for organic amendment cannot be recommended at present. In part, the weak response to inorganic fertilizer (Table 2) can be attributed to the alkalinity and salinity of the Bauxite Residue. In addition, achieving an appropriate level of nutrient supply and balance of nutrients with inorganic fertilizer proved difficult as levels of inorganic fertilizer supplied were inadequate in N, P, Ca, Mg, Zn and Mn (Tables 4, 6). However, further experimentation with fertilizer rates and combinations should result in improved growth potential. By contrast, poultry manure at 50 m^3/ha supplied adequate levels of all nutrients apart from Mn, and it suppressed Cl levels (Tables 4, 6).

Subsequent experiments suggested that combinations of lower levels of poultry manure (12.5 m^3/ha), together with inorganic fertilizer may be a feasible option for revegetation (data not shown).

The longer term nutrient supply from poultry manure would need to be assessed in the field, especially if rates lower than 50 m^3/ha were used. On the other hand, the present studies emphasise the variable nature of a material like poultry manure, and the risk of ammonia toxicity (Bennett, 1974) to plants when excessive amounts are applied (Table 2). Prior analysis of batches of poultry manure is therefore recommended to determine the composition of poultry manure before use. Ammonia toxicity risk can be minimized by early application and incorporation of poultry manure well before planting.

Finally, it should be recognized that Bauxite Residue despite the growth responses obtained from organic amendments, with or without inorganic fertilizers, was still a difficult substrate for plant growth. Even after leaching and gypsum amendment, alkalinity, salinity and sodicity were severe constraints. Growth potential was still low on Bauxite Residue compared to Residue Sand.

Variation in alkalinity of batches of Bauxite residue appears to be significant for revegetation. Residue of extreme alkalinity appeared to strongly suppress growth of triticale in a following experiment (data not shown). By contrast, with *Agropyron*, a species known for its salinity tolerance, satisfactory growth was achieved. Thus species selection, and residue characterisation are key factors to ensure successful revegetation on Bauxite Residue.

4.4 Gold oxide residue

Gypsum amended, leached Gold Oxide residue was a poor substrate for the growth of triticale compared to Residue Sand (Table 2). High salinity remained the most serious constraint to plant growth and resulted in plants absorbing toxic levels of Na and Cl (Table 3). In the longer term, the success of vegetation comprising species which do not tolerate salinity will depend on the leaching of Na and Cl out of the root zone, and on strategies designed to accelerate the leaching process.

Gold Oxide Residue was low in N and P resulting in deficiencies of these elements in triticale in unfertilized residue. Poultry manure at 25 - 50 m^3/ha appeared to be an effective nutrient source for overcoming N and P deficiencies. Inorganic fertilizer at the rates used was less effective as a nutrient source. Whilst it may be feasible to adjust the rates of supply of inorganic fertilizers to achieve greater growth responses than achieved in the present study, inorganic fertilizer was less effective in suppressing Na and Cl uptake than poultry manure. Thus it can be concluded that the use of an organic amendment like poultry manure, used in the revegetation prescription developed (Ho *et al.*, 1999) probably represents the best strategy for nutrient supply on Gold Oxide residue. By contrast, *Agropyron* straw did not appear satisfactory as an organic amendment, even when supplemented by inorganic fertilizer (data not shown).

4.5 General Discussion and Conclusions

Whilst on Residue Sand there appears to be the opportunity to replace poultry manure with inorganic fertilizer for early growth of plants, on other residues inorganic fertilizers were not recommended as a substitute for poultry manure. However, the problems with poultry manure remain: *viz,* the introduction of weeds which is undesirable at sites in forest; the difficulty of obtaining enough poultry manure of consistent quality for large scale revegetation; and the cost of transport for application at the rates suggested. To retain the benefits of poultry manure as an organic amendment and slow release nutrient source, whilst minimising or eliminating the negative factors, the options to consider are: composted poultry manure; biosolids, and; combinations of inorganic and organic fertilizers. Whilst eliminating the problem of weed introduction, composting of poultry manure would not overcome the supply constraint. It would also require a composting facility capable of processing large volumes of compost and storing uncomposted and composted material. Biosolids have a nutrient composition comparable to that of poultry manure (data not shown), although significant variation in composition is also reported from time-to-time. Weed levels are expected to be very low in biosolids. However, levels of Zn and Cu, and the pathogens present in biosolids are issues that may limit their use for revegetation Table 4. Chemical properties of Residue sand, Gold oxide and Bauxite residue in response to treatment with fertilizer. Values are means of three replicates (standard errors in parentheses). Experiment 1.

	Residue sand		Gold oxide		Bauxite residue	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
pH ($CaCl_2$)	8.17 (0.05)	7.46 (0.06)	8.72 (0.03)	7.97 (0.03)	9.99 (0)	8.48 (0.09)
EC (mS/m)	73 (1)	226 (7)	274 (6)	357 (29)	464 (14)	139 (25)
Organic C (g/kg)	0.4 (0)	0.4 (0)	1.8 (1.2)	0.9 (0.1)	2.4 (0)	2.1 (0.1)
Mineral $NO_3 + NH_4$ (mg/kg)	2 (0)	12.3 (0.3)	2 (0)	10 (1.7)	2 (0)	3 (1)
Colwell P (mg/kg)	4 (2)	120 (13)	29 (1)	61 (11)	33 (4)	23 (1)
Colwell K (mg/kg)	37 (6)	289 (27)	264 (22)	240 (19)	80 (7)	52 (1)
Exchangeable cations (cmol(+)/kg)						
Ca	4.1 (0.2)	16.7 (0.5)	1.4 (0.1)	16.1 (1.3)	4.2 (0.2)	14^{A}
Mg	0.23 (0.01)	0.26 (0.01)	1.2 (0.1)	1.0 (0.1)	0.4 (0.01)	0.5^{A}
Na	7.1 (0.1)	1.0 (0.04)	17.3 (0.1)	9.6 (1.6)	37.4 (1.1)	11.2^{A}
K	0.10 (0.01)	0.49 (0.04)	0.27 (0.02)	0.36 (0.03)	0.7 (0.1)	0.2^{A}
DTPA (mg/kg)						
Zn	0.27 (0.04)	0.60 (0.16)	0.6 (0.1)	0.22 (0.01)	0.22^{A}	1.59 (0.07)
Mn	0.09 (0.05)	0.38 (0.06)	2.4 (0.1)	0.50 (0.04)	0.23^{A}	0.91 (0.08)
Cu	0.21 (0.02)	0.19 (0.01)	11.0 (0.1)	4.71 (3.0)	0.45^{A}	0.86 (0.12)

^{A} Unreplicated

^{B} No samples analysed

Table 5. Response of shoot nutrient concentrations in triticale to inorganic N and P fertiliser rates on Residue sand. Values are means of three replicates (standard errors in parentheses). Experiment 2.

	N1P1	N1P2	N1P3	N4P1	N4P2	N4P3
N (%)	2.0 (0.15)	1.6 (0.16)	1.4 (0.09)	4.3 (0.25)	3.6 (0.30)	3.6 (0.11)
P (%)	0.10 (0.01)	0.14 (0.01)	0.18 (0.00)	0.08 (0.00)	0.12 (0.01)	0.18 (0.00)
Na (%)	0.6 (0.11)	0.7 (0.02)	0.6 (0.02)	1.7 (0.06)	1.2 (0.00)	1.2 (0.04)
Cl (%)	0.7 (0.14)	0.8 (0.04)	0.8 (0.13)	0.7 (0.00)	0.6 (0.02)	0.7 (0.04)
Mn (mg/kg)	21.5 (1.0)	12.5 (0.4)	10.7 (0.6)	10.9 (1.6)	9.4 (0.4)	8.7 (0.3)

Table 6. Effect of poultry manure (PM) and inorganic fertilizer (plus (+I) or minus (-I) inorganic fertilizers) on N, P, Na, Cl, and Mn concentrations in whole shoots of triticale grown for 42 days on Bauxite Residue. Values are means of 3 replicates (standard errors in parentheses). Experiment 1.

	-I				+I			
	PM 0[A]	PM 50	PM 150	PM 300[B]	PM 0[B]	PM 50	PM 150	PM 300
N (%)	1.95	3.97	4.48	5.18	2.58	3.83	4.14	4.53
		(0.17)	(0.21)			(0.33)	(0.94)	(0.33)
P (%)	0.17	0.30	0.27	0.24	0.14	0.30	0.27	0.23
		(0.029)	(0.003)			(0.040)	(0.107)	(0.030)
Na (%)	2.12	1.46	2.93	4.44	1.27	2.04	3.67	3.20
		(0.27)	(0.97)			(0.15)	(1.85)	(0.76)
Cl (%)	0.98	1.73	2.03	1.08	3.61	1.78	1.49	1.41
		(0.14)	(0.67)			(0.15)	(0.16)	(0.08)
Mn (mg/kg)	16.8	12.8	12.7	13.6	9.3	10.8	14.5	11.4
		(0.30)	(2.60)			(0.96)	(4.50)	(1.35)

[A] Treatments: 0, 50, 150, 300 m^3 PM/ha

[B] Insufficient plant material was available to analyse replicate samples separately.

At each site of residue revegetation, tailor-made mixes of organic and inorganic fertilizers could be developed to minimize the disadvantage of each. In the present study, the use of supplementary inorganic fertilizer at lower rates of poultry manure gave satisfactory results on Bauxite Residue and Gold Oxide residue (data not shown). *Agropyron* straw proved reasonably successful as an organic amendment on Bauxite residue, but only when supplemented with inorganic N to overcome the immobilization of soil N (data not shown).

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