Improvement of Soil Quality by Waste Amendment

[A study into the use of natural clays and industrial residues with green waste compost to improve the quality of Perth coastal plain soils.]

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Executive Summary

A survey of soils from residential gardens conducted by the Chemistry Centre in 2000 indicated that many sandy soils had exhausted their ability to retain phosphorus. This was attributed to over-fertilisation with both inorganic and organic sources of phosphorus. If these practices were to continue, much of the applied phosphorus has potential to leak into groundwater and eventually pollute surface water systems such as the Swan-Canning River system and freshwater lakes on the Swan Coastal Plain.

It was subsequently shown that a significant proportion of phosphorus in composted green waste is water-soluble and therefore prolonged use on sandy soils is not sustainable. To address this issue, the Chemistry Centre applied for funds from the Department of Environmental Protection through the Waste Management and Recycling Fund to evaluate the effect of adding inorganic soil amendments with compost to improve the condition of sandy soils for plant growth and minimise leaching losses of phosphorus. The results of this investigation are presented in this report.

The results from a plant glasshouse indicated that addition of inorganic soil amendments such as natural clays and mineral processing residues, all of which are readily available within the Perth Metropolitan area, significantly increased the yield and quality of the test crop (radish). With the exception of supplementary nitrogen and potassium, the compost was able to supply all the nutrients required by the high yielding crop. The phosphate adsorption capacity of the soil increased significantly, and as a result, leaching losses of phosphorus decreased to manageable levels.

The combination of composted green waste and inorganic materials as an amendment for sandy soils results in other soil improvements such as reducing soil acidity and countering soil hydrophobicity ("non-wetting" behaviour). Although heavy metals are present in both the green waste and some of the mineral processing residues, the uptake of these metals by radish was below the maximum permissible concentration proposed by ANZECC. The addition of these amendment materials, however, had little effect on the leaching losses of nitrogen.

Further work is required to extend these findings to other plant species under field conditions. If this work is successful, a sustainable nutrient management system will be available for the use of composted green waste as a nutrient source and soil amendment for sandy soils on the Swan Coastal plain.

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Abstract

The soils of the Swan coastal plain are dominated by acid, sandy soils that are naturally infertile and have limited capacity to retain applied nutrients, particularly nitrogen and phosphorus.

Addition of organic composting materials has resulted in soils with near neutral pH values, increased nutrient content, and a tendency to become non-wetting (hydrophobic). These practices have resulted in further reduction of the ability of the soil to retain phosphorus.

The addition of clay materials and some mineral processing residues has been shown to improve soil quality by increasing nutrient retention, reducing soil hydrophobicity, raising soil pH and improving the cropping potential of the soil with reduced reliance on chemical fertilisers.

This study was designed to investigate the effect of amending infertile sandy soil with a variety of natural clays, industrial residues and composted green waste materials. The study focused on the ability of the amended soil to supply nutrients for plant growth while preventing loss of excessive amounts of nutrients by leaching, the reduction in soil hydrophobicity and the impact of amendment material on heavy metal uptake. This paper presents the final results of that study.

Key words: compost, clay material, process residues, sandy soils, soil quality, environment, contamination, eutrophication, sustainable systems.

Introduction

The Swan coastal plain is characterized by sandy soils that are acidic, naturally infertile and have limited capacity to retain applied nutrients. Repeated additions of organic materials, such as animal manures, biosolids and composted green waste, have resulted in soils with near neutral pH values, increased soil nutrient loading with consequent increased leaching potential and a tendency for the soil to become hydrophobic (non-wetting). Consequently, these practices have resulted in a reduction in the ability of the sandy soil to retain phosphorus. Approximately 30% of the soils analysed, in an earlier survey [1], are completely saturated by phosphorus. In terms of sustainable land management systems for the soils of coastal plain, the indications are that these practices may eventually lead to the contamination of groundwater, coastal lakes and rivers by leaching of phosphorus from the topsoils. Contamination is more pronounced in locations where the depth to groundwater is low and the subsoils are dominated by sands with low phosphorus adsorption capacities. Such conditions are common in the Bassendean series of the coastal dune system of the Swan Coastal Plain.

The Chemistry Centre received funding from the DEP Waste Management and Recycling Fund in 2001 to determine the effectiveness of amending infertile sandy soil with a variety of natural clays and industrial residues in combination with green waste materials to:-

- improve the nutrient retention capacity of sandy soils;
- to offset nutrient leaching in our waterways, and
- prevent algal blooms.

The study was carried out through:-

1) A glasshouse experiment:
- to determine the performance of radish as a result of amended soil; and
- to monitor the uptake of essential and or toxic metals as a result of addition of composted green waste and amendment materials.

2) A laboratory leaching experiment:
- to determine the amount of N and P retained by soils after amendment; and
- to determine the potential of amended soils for nutrient leaching.

This paper presents the final results of that study.

Materials and Methods

Glasshouse experiments and incubation-leaching column trials were conducted to establish the efficiency and performance of these amendment materials on sandy soil. Laboratory analysis was undertaken in conjunction with both facets to provide a numerical basis for the observations taken.

Materials

Composted green waste was obtained from a commercial supplier. It was screened to less than 12 mm before use in both experiments. Four of the natural clay amendment materials were obtained locally from the Darling Range area. Two bentonite clays came from Watheroo while the zeolite came from Indonesia. Industrial process waste residues were obtained from companies associated with the bauxite and mineral sand industries. The base soil used for both the glasshouse and laboratory experiments consisted of a grey sand collected from the Bassendean dune series about 40 km north east of Perth.

Properties of the soil and amendment materials are listed in Table 1. The chemical composition of the screened compost is listed in Table 2. Deionised water (DI) was used throughout in both the glasshouse & laboratory incubation trials. The procedure used in both the glasshouse and leaching trials comprised a factorial design of two rates of compost blended with three rates of each of the various soil amendment materials. "Control" treatments consisted of:

i) sand without any compost
ii) sand with the lower rate (1.7%) of compost; and
iii) sand mixed with soluble nutrients to match the concentrations of nutrients present in the compost.

The suitability of an amendment material for plant growth will vary from plant to plant. This trial used the "scarlet longs" variety of radish (*Raphanus sativus*) to obtain a crop that would provide both root and leaf material at harvest. The root-crop also provided the opportunity to observe any deformity that may result from use of any of the amendment materials.

Samples of soil from both the glasshouse and laboratory leaching trials were collected for analysis. Electrical conductivities (EC) of the soil samples were measured on a 1:5 extract of samples of the dried soil with water. pH of a 1:5 extract of the soils in 0.01 M $CaCl_2$ solution was measured by a pH meter with a combination glass-calomel electrode. Phosphorus retention index (PRI) was measured by the method of Allen and Jeffery [6]. Soluble reactive phosphorus (SRP) was measured using the method of Murphy and Riley [7]. Ammonium and nitrate forms of nitrogen were measured by segmented flow analysis (SFA). Molarity ethanol droplet test (MED) was conducted on an air dried sample with standardised concentrations of ethanol in water in accordance with procedures outlined by King [8]. The leachate solutions were analysed directly for EC, pH, total P, SRP, ammonia and nitrate. Leaf and root tissue were analysed for nitrogen, phosphorus and potassium by segmented flow automated analysis (SFA) following digestion of the samples with sulphuric acid and hydrogen peroxide [4]. Calcium, magnesium, sodium, sulphur, boron, iron, copper, manganese and zinc were analysed by inductively coupled plasma – atomic emission spectrophotometry (ICP – AES) after digestion of the samples with a mixture of nitric and perchloric acids [5]. Cadmium in the root material was measured by electrothermal atomic absorption spectrophotometry (ETAAS) following nitric acid digestion.

Table 1. Properties of the soil amendment materials.

SAMPLE	EC (1:5) mS/m	pH (H2O)	pH (CaCl2)	Cl %	OrgC (W/B) %	N (total) %	CEC (NH4Cl) me%
Red Clay	4	7	5.9	<0.01	0.36	0.03	6a
Yellow Clay	8	6.9	6.2	<0.01	0.43	0.028	9a
Chittering	4	6.9	6.1	<0.01	0.19	0.012	1a
Gravel	4	7	6.5	<0.01	0.28	0.005	3a
Zeolite	14	9.5	8.5	<0.01	0.05	0.008	54c
IOMS2:8	410	9.1	9.1	0.18	0.72	0.009	2c
IOMS8:2	450	8.6	8.5	0.18	1.39	0.017	2c
Red Mud	410	10.4	10.1	0.33	0.33	0.004	17c
Bentonite-A	590	8.6	8.5	0.67	0.52	0.05	28c
Bentonite-D	1800	8.3	8.2	3.36	0.38	0.015	58c
Control Sand	2	5.9	3.9	<0.01	2.78	0.068	2a

SAMPLE	P (total) Mg/kg	P (HCO3) mg/kg	P (PRI) mL/g	Ca (exch) me%	Mg (exch) me%	Na (exch) me%	K (exch) me%
Red Clay	95	2	140	1.18a	2.33a	0.14a	0.20a
Yellow Clay	61	<2	>1000	1.82a	3.01a	0.30a	0.70a
Chittering	76	<2	140	0.15a	1.01a	0.14a	0.10a
Gravel	170	2	260	0.42a	0.30a	0.06a	0.03a
Zeolite	170	<2	3.9	31.47c	3.20c	23.02c	0.53c
IOMS2:8	340	18	>1000	6.37c	15.20c	1.32c	0.06c
IOMS8:2	480	10	>1000	6.28c	5.24c	1.24c	0.06c
Red Mud	550	44	120	0.04c	<0.02	39.65c	<0.02
Bentonite-A	96	6	220	11.37c	9.79c	15.00c	0.69c
Bentonite-D	63	5	48	2.42c	31.08c	49.82c	1.60c
Control Sand	19	<2	0	1.41a	0.61a	0.15a	0.04a

pH = pH in 0.01 M $CaCl_2$ (1:5 ratio)
EC = Electrical conductivity, 1:5 extract — mS/m = milliSiemens per metre
PRI = Phosphorus Retention Index (Allen and Jeffery 1991) — me% = milliequivalents per 100 grams
CEC = Cation Exchange Capacity – *a* at pH 7.0, *c* at pH 8.5 — mL/g = millilitres per gram

Table 2. Nutrient composition of screened compost.

Analyte	Concentration	Analyte	Concentration
Moisture	48.9 %ar	**Sodium**	0.14 %db
pH	7.8	**Sulphur**	0.30 %db
Nitrogen	1.41 %db	**Boron**	0.043 %db
Phosphorus	0.83 %db	**Copper**	0.027 %db
Potassium	0.30 %db	**Iron**	0.030 %db

Analyte	Concentration	Analyte	Concentration
Calcium	4.2 %db	**Manganese**	0.021 %db
Magnesium	0.27 %db	**Zinc**	0.020 %db

(ar = as received: db-= oven dry basis)

Glasshouse Experiment

Pots containing 3 kg of blended material were prepared by adding compost, at 50 or 100 grams application rates, the appropriate amount of each of the inorganic soil amendment materials and mixing with the balance of the stock sandy soil material.
The rates of the amendment materials were determined in respect of their phosphate adsorption capacity (as indicated by their PRI values) and their alkalinity/salinity contents (Table 3). Each treatment consisted of three replicates.

Table 3. Soil/clay amendment rates used in the glasshouse treatments.

Amendment Material per 3 kg soil:	Rate 1 (R1)	Rate 2 (R2)	Rate 3 (R3)
Red clay	150 (5)	300 (10)	600 (20)
Yellow clay	150 (5)	300 (10)	600 (20)
Chittering clay	60 (2)	150 (5)	300 (10)
Gravel screenings	150 (5)	300 (10)	600 (20)
Zeolite	150 (5)	300 (10)	600 (20)
IOMS 2:8	30 (1)	60 (2)	150 (5)
IOMS 8:2	30 (1)	60 (2)	150 (5)
"Red Mud"	30 (1)	60 (2)	150 (5)
Bentonite A	60 (2)	150 (5)	300 (10)
Bentonite D	60 (2)	150 (5)	300 (10)

Weights are expressed as grams per pot. The values in parentheses are the percentages by weight of the amendment materials in the amended soil mixes.

The pots were watered to field capacity, allowed to stand for 3 days and then sown with 15 radish seeds *R. sativus* (*cv "Long Scarlet"*). Regular watering was continued throughout the growing period. Germination occurred after 6 days. The number of plants in each pot was then reduced to five after a further 14 days. At this stage, most of the plants were showing symptoms of leaf yellowing, indicating severe nitrogen deficiency, which was confirmed by chemical analysis of the leaf tissue (Table 4). A basal treatment of 94.2 milligrams (mg) of ammonium sulphate and 144.4 mg of potassium nitrate was then applied to each pot to overcome the possibility of nitrogen, sulphur and potassium deficiency. Plant tissue analysis indicated that trace elements (B, Cu, Fe, Mn, Mo and Zn) were unlikely to cause yield reductions in the treatments containing compost. Thus, phosphorus was considered to be the nutrient most likely to cause yield responses.

Table 4. Radish leaf analysis –nutrient deficiency check.

N %db	P %db	K %db	Na %db	Ca %db	Mg %db
0.87	**0.17**	**5.26**	**1.10**	**5.33**	**1.01**

S	B	Cu	Fe	Mn	Zn
%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
0.77	**33**	**2.9**	**140**	**71**	**51**

N= nitrogen; P= phosphorus, K= potassium – each analysed by segmented flow colorimetry.
Na= sodium, Ca= calcium, Mg= magnesium, S= sulphur – each analysed by ICP-AES.
B= boron, Cu= copper, Fe= iron, Mn= manganese, Zn= zinc - each analysed by ICP-AES.
%db =per cent dry basis mg/ kg = milligrams per kilogram dry basis.

With the exception of treatments containing high rates of the bentonite clays or bauxite residues ("red mud"), good germination rates of the radish seeds were observed. Subsequent growth was very poor until additional nitrogen, sulphur and potassium were added several weeks after sowing. This was due to the low concentrations of nitrogen, sulphur and potassium in the sand, compost and most amendment materials.

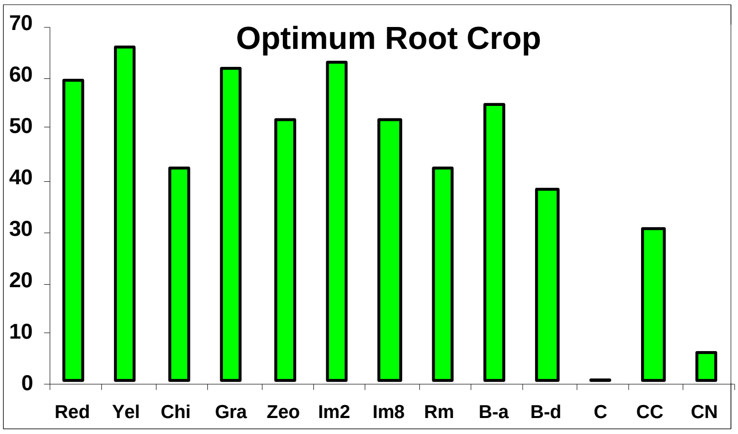
After 9 weeks from sowing, the number of plants in each pot was further reduced to three and a second application of ammonium sulphate/potassium nitrate, at the same rate as previously described, was made. After 11 weeks, the plants were harvested, weighed and separated into leaves (shoots) and roots. Figures 1 and 2 show a sample of the crop at harvest, while figure 3 graphically represents the amendment rate that produced the best crop yield for each amendment material.

The yields were measured before and after drying the harvested material in a fan-forced oven at 60°C. Samples of the soil from each pot were also collected, and dried in a fan-forced oven at 40°C before analysis.

The yields of dried plant material, both root and leaf, from most treatments ranged between 8 to 10 grams. In most cases, the yields of plant material from the amended soils were similar to or slightly higher than the yields from the soil treated with compost only (8.17g). Significantly lower yields were recorded in treatments containing high rates of "red mud" and bentonite D (Table 5).

Fig 1: Crop at harvest.

Fig 2: Root & Leaf material



ID	Code	Wt g
Red	Red-Clay 5% Comp 3.3%	59.4
Yel	Yellow 5% Comp 1.7%	65.7
Chi	Chittering 2% Comp 1.7%	42.2
Gra	Grav-20% Comp 1.7%	61.7
Zeo	Zeolite - 5% Comp 3.3%	51.3
Im2	IOMS2:8 –1% Comp 1.7%	63.0
Im8	IOMS8:2 –2% Comp 1.7%	51.7
Rm	Rmud- 1% Comp 3.3%	42.5
B-a	BentoniteA-2%Comp 3.3%	54.5
B-d	BentoniteD-2%Comp 3.3%	38.3
C	Control	0.8
CC	Compost 1.7%	30.2
CN	Nutrient	6.4

Fig 3: Best fresh root yield (gram) for each amendment material

Fig 4: Optimum crop from each clay amendment

Fig 5: Optimum crop from each alternate amendment material

The reduced yields were attributed to the toxic effects of either the alkalinity or salinity of the amendment materials. Reduction of yield with increasing rates of amendment material could also be attributed to a reduction in the availability of moisture as the tendency of clays to more tightly retain moisture becomes a factor. The yield of plant material from the control soil was very low (0.55 g), indicating that the soil was unable to supply the essential nutrients required for plant growth.

Table 5. Dried total plant yields of radish grown in glasshouse with amended soils.

Rate of Amendment :	**R1-C1** gms	**R2-C1** gms	**R3-C1** gms	**R1-C2** gms	**R2-C2** gms	**R3-C2** gms
Red clay	9.25	8.63	8.57	8.29	10.49	8.64
Yellow clay	11.36	8.84	8.06	9.12	8.32	6.83
Chittering clay	8.49	8.19	7.85	8.07	7.79	7.34
Gravel screenings	10.31	11.87	11.89	8.79	10.56	9.34
Zeolite	9.79	8.08	8.35	9.73	8.53	7.94
IOMS 2:8	10.51	9.51	8.35	7.60	8.97	8.75
IOMS 8:2	9.02	9.25	9.08	9.75	8.99	8.26
“Red Mud”	6.91	8.36	1.37	7.07	6.27	2.74
Bentonite A	7.89	9.49	7.31	8.13	8.24	6.73
Bentonite D	8.70	3.81	0	9.19	4.35	0
Control soil	0.55					
Control soil + compost	8.17					
Control soil + nutrients	5.80					

Note: Mean values in grams of triplicate treatments are reported. R value refers to amendment rate in Table 3. C1 indicates 50 g of compost per pot. C2 indicates 100 g of compost per pot.

With most of the soil amendment materials, there was a slight reduction in yield with increasing rates of soil amendment. For example, with increasing rates of yellow clay there was a significant decrease in the yield of above ground biomass as well as the below ground root mass (Fig 6). However, the soil amended with gravel screenings showed a reverse to the general trend by increasing yields with increasing rates of amendment (Fig 7). Using these criteria, the gravel screenings produced the best results, while the red mud amendment produced the worst. A more detailed graphical representation of the effect of amendment material on crop yield can be seen in Graph 1.

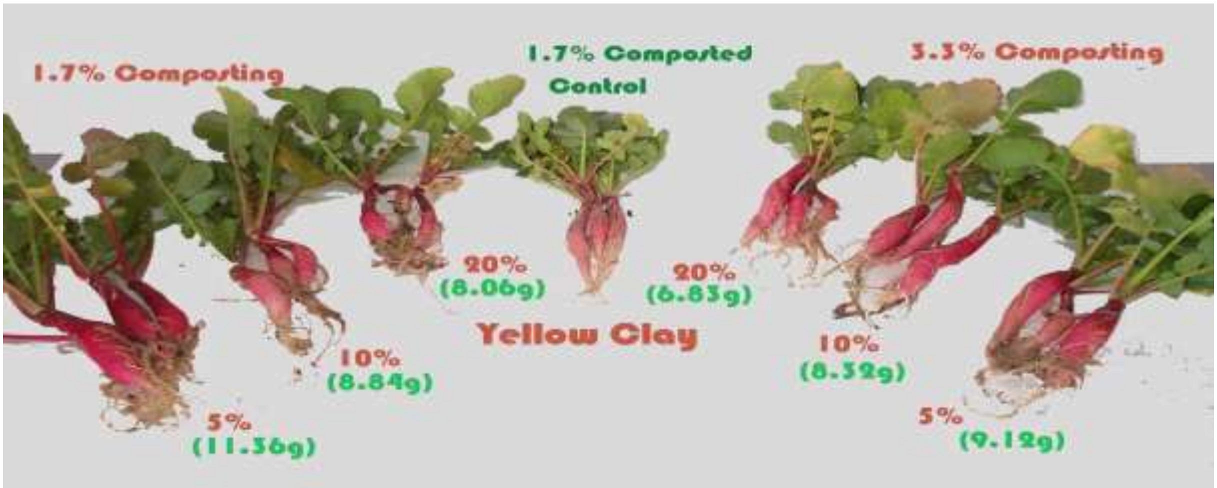


Fig 6: Yellow Clay Biomass

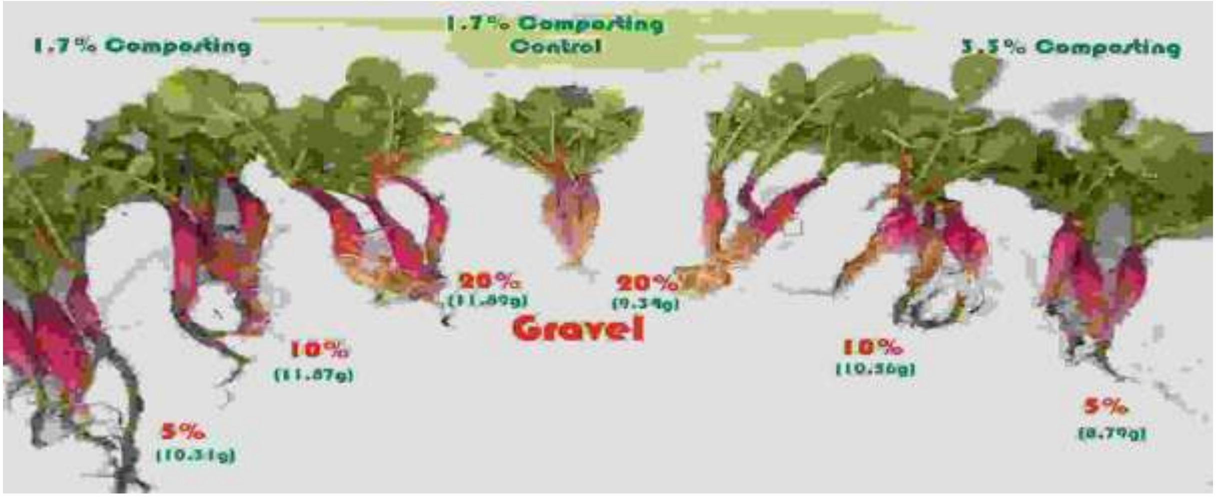
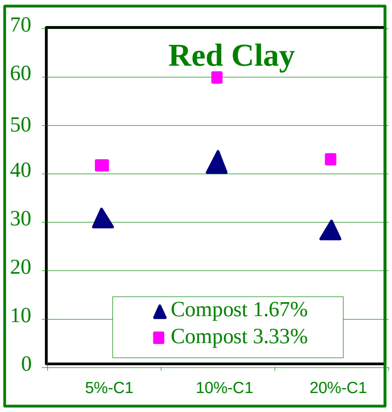
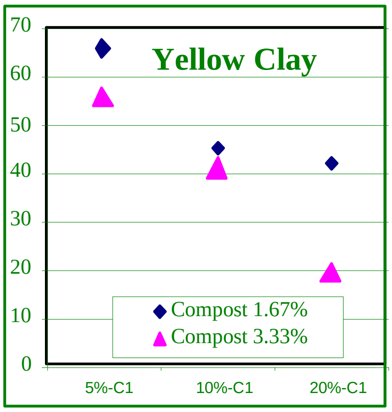


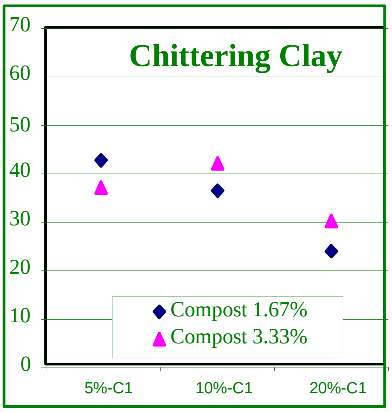
Fig 7: Gravel Screenings Biomass

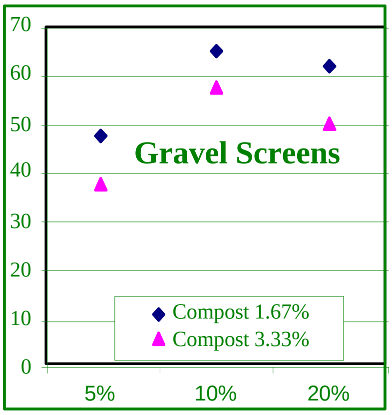
The yield response to the higher rate of compost does not appear to be significant, except possibly for the bentonite D treatment in which the compost may have helped overcome the effects of the salinity present in this material. There was a significant yield reduction in the treatment that received the same amount of nutrients as present in the compost, but in inorganic (water-soluble) forms. However, the leaves of the plant in these pots showed signs of nutrient toxicity which was subsequently identified by tissue analysis as boron toxicity (Figure 8).

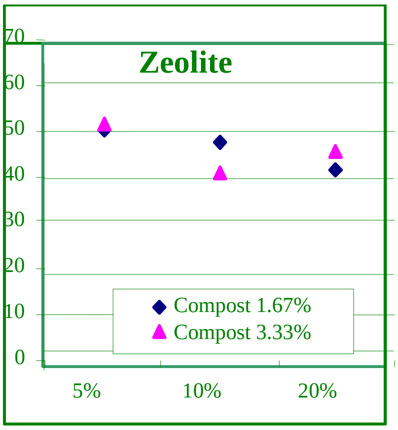
Fig 8: Nutrient Toxicity

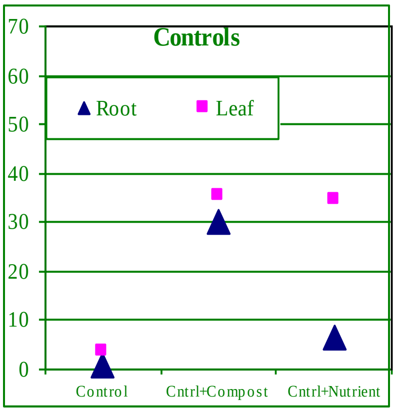


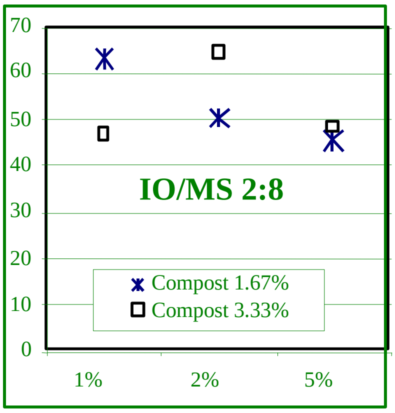


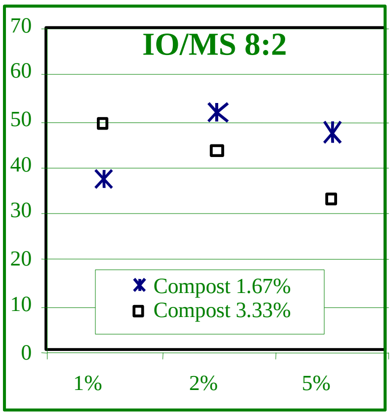


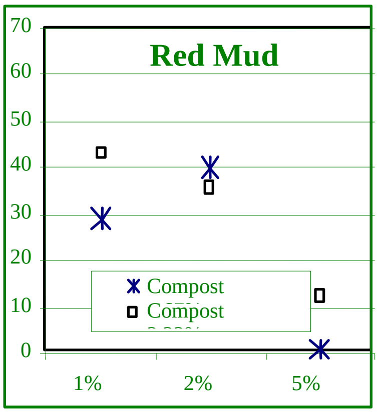


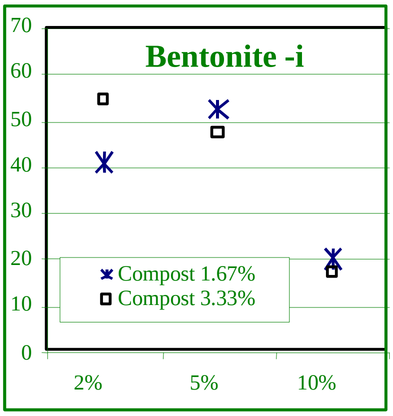


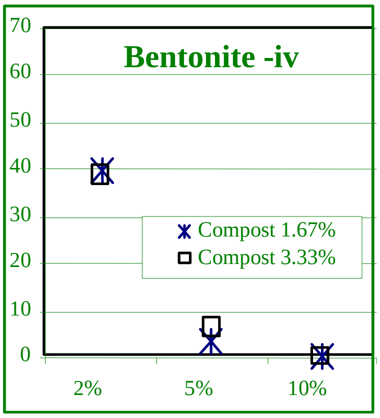












All results expressed in grams of fresh material harvested.

Values expressed on the x-axis are the percentage of amendment material added to the soil

Graph 1: Fresh root yield from each amendment material

There was some evidence that the concentration of phosphorus in the radish roots decreased with increasing rates of soil amendment, but increased with the higher rate of compost addition (Graph 2).

Concentrations of phosphorus in the radish roots grown in the amended soils were generally similar to those of the roots from plants grown in soil treated with compost only (Table 6). Although the concentration of phosphorus in the leaves was significantly less than that in the roots, similar trends were observed (Table 7, Graph 3).

Table 6. Concentrations of phosphorus (%db) in roots of radishes grown in amended soils.

Rate of Amendment	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	0.62	0.56	0.50	0.66	0.58	0.60
Yellow clay	0.43	0.45	0.49	0.57	0.61	0.59
Chittering clay	0.61	0.53	0.54	0.64	0.62	0.60
Gravel screenings	0.64	0.57	0.46	0.70	0.65	0.56
Zeolite	0.60	0.53	0.44	0.60	0.72	0.62
IOMS 2:8	0.38	0.40	0.38	0.60	0.47	0.45
IOMS 8:2	0.62	0.53	0.44	0.58	0.60	0.52
“Red Mud”	0.38	0.39	0.34	0.62	0.44	0.21
Bentonite A	0.40	0.32	0.21	0.60	0.48	0.42
Bentonite D	0.44	0.29	-	0.66	0.35	-
Control soil	-					
Control soil + compost	0.66					
Control soil+ nutrients	0.99					

Note: Mean values in grams of triplicate treatments are reported. R value refers to amendment rate in Table 3. C1 indicates 50 g of compost per pot. C2 indicates 100 g of compost per pot.

Table 7. Concentrations of phosphorus (%db) in leaves of harvested radish plants.

Rate of Amendment :	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	0.30	0.28	0.27	0.34	0.32	0.30
Yellow clay	0.21	0.22	0.24	0.27	0.30	0.36
Chittering clay	0.28	0.31	0.28	0.41	0.42	0.41
Gravel screenings	0.28	n/r	0.20	0.43	0.30	0.29
Zeolite	0.32	0.28	0.26	0.29	0.33	0.29
IOMS 2:8	0.18	0.18	0.18	0.28	0.22	0.23
IOMS 8:2	0.28	0.27	0.24	0.27	0.29	0.24
“Red Mud”	0.24	0.22	0.19	0.30	0.21	0.18
Bentonite A	0.23	0.18	0.17	0.24	0.21	0.21
Bentonite D	0.25	0.14	n/r	0.33	0.25	n/r
Control soil	0.09					
Control soil + compost	0.39					
Control soil+ nutrients	0.59					

Note: Mean values in grams of triplicate treatments are reported. R value refers to amendment rate in Table 3. C1 indicates 50 g of compost per pot. C2 indicates 100 g of compost per pot. n/r = no result reported.

Crop yield was clearly impacted on by the medium. Graph 1 shows the effect of the medium at the two rates of compost application for each amendment. Table 8 provides a detailed breakdown.

The majority of amendment materials and application rates produced better radish root crops than the unamended soil/compost blend. Zeolite and yellow clay produced the best results at the 1.7% composting rate. Red clay produced the best results at the higher composting rate of 3.3%. Bentonites generally performed poorly at the lower composting rate and only marginally better when the composting level was doubled. Bentonite (D) had a high salinity (EC 2400 mS/m), which may have been the dominant factor in low germination and cropping failures. Bentonite (A), with a much lower salinity (EC 590mS/m), produced average yields at the two lower levels of application. The red mud performed poorly at the 5% application rate. Lower rates gave marginally better returns. The result from the Chittering clay at 20% application was also only marginally acceptable. The iron oxide/ mineral sands residues produced high yields.
Based on the harvest yields, use of amendment materials can be seen to benefit crop production. However, application rate is critical and further trials will be required to determine optimum rates for other crops.

Table 8. Yield of dry leaf and root material

Average Yield of Leaf Material (grams dry matter)				**Average Yield of Root Material (grams dry matter)**			
1.67% Compost		**3.33% Compost**		**1.67% Compost**		**3.33% Compost**	
Treatment	**Yield**	**Treatment**	**Yield**	**Treatment**	**Yield**	**Treatment**	**Yield**
Control (sand)	0.04	Control (sand)	0.41	Control (sand)	0.51	Control (sand)	0.5
Control + compost	3.4			Control + compost	4.79		
Control + nutrient	1.1	Control + nutrient	4.73	Control + nutrient	4.73	Control + nutrient	4.7
Bentonite “d” R3	0.0	Bentonite “d” R3	0.0	Bentonite “d” R3	0.00	Bentonite “d” R3	0.0
Red mud R3	0.0	Bentonite “d” R2	0.5	Red mud R3	1.34	Red mud R3	1.9
Bentonite “d” R2	0.5	Red mud R3	0.8	Bentonite “d” R2	3.32	Bentonite “d” R2	2.4
Bentonite “a” R3	1.8	Bentonite “a” R3	1.8	Bentonite “a” R1	3.96	Red mud R2	3.4
Chittering R3	2.6	Chittering R3	2.9	Red mud R1	4.08	Red mud R1	3.5
Red mud R1	2.8	Red mud R2	2.9	Yellow clay R3	4.12	Yellow clay R3	3.7
Bentonite “d” R1	3.0	Yellow clay R3	3.2	IO:MS 2:8 R3	4.18	Bentonite “a” R1	3.8
Red clay R1	3.5	Bentonite “d” R1	3.2	Red clay R3	4.29	Yellow clay R1	3.8
Gravel screen R3	3.5	Gravel screen R2	3.4	Red mud R2	4.40	IO:MS 2:8 R1	3.9
Chittering R2	3.6	Gravel screen R3	3.6	Gravel screen R2	4.40	Chittering R2	4.0
Gravel screen R2	3.7	Red mud R1	3.6	Chittering R1	4.43	IO:MS 2:8 R2	4.1
IO:MS 8:2 R1	3.9	Chittering R1	3.6	Yellow clay R2	4.47	IO:MS 8:2 R3	4.1
Bentonite “a” R1	3.9	Bentonite “a” R2	3.7	Red clay R2	4.57	Red clay R1	4.2
Yellow clay R3	3.9	IO:MS 2:8 R1	3.7	Chittering R2	4.58	Yellow clay R2	4.3
Red mud R2	4.0	Chittering R2	3.8	IO:MS 8:2 R3	4.63	Red clay R3	4.3
Gravel screen R1	4.0	IO:MS 8:2 R2	3.9	IO:MS 8:2 R2	4.67	Gravel screen R3	4.4
Chittering R1	4.1	Zeolite R1	4.0	IO:MS 2:8 R2	4.77	IO:MS 2:8 R3	4.4
Red clay R2	4.1	Yellow clay R2	4.0	Gravel screen R3	4.83	Chittering R1	4.4
IO:MS 2:8 R3	4.2	Red clay R1	4.1	IO:MS 8:2 R1	5.15	Zeolite R3	4.4
Bentonite “a” R2	4.2	IO:MS 8:2 R3	4.1	IO:MS 2:8 R1	5.19	Chittering R3	4.5
Red clay R3	4.3	Red clay R3	4.3	Chittering R3	5.24	Bentonite “a” R2	4.6
Yellow clay R2	4.4	Bentonite “a” R1	4.3	Yellow clay R1	5.29	Zeolite R1	4.8
IO:MS 8:2 R3	4.5	IO:MS 2:8 R3	4.4	Bentonite “a” R2	5.30	Bentonite “a” R3	4.9
IO:MS 8:2 R2	4.6	Gravel screen R1	4.4	Bentonite “a” R3	5.51	Red clay R2	5.0
Zeolite R1	4.6	IO:MS 8:2 R1	4.6	Bentonite “d” R1	5.66	IO:MS 8:2 R2	5.1

Average Yield of Leaf Material (grams dry matter)						Average Yield of Root Material (grams dry matter)					
1.67% Compost			3.33% Compost			1.67% Compost			3.33% Compost		
Treatment		Yield	Treatment		Yield	Treatment		Yield	Treatment		Yield
IO:MS 2:8	R2	4.7	IO:MS 2:8	R2	4.9	Zeolite	R1	5.67	Gravel screen	R2	5.1
IO:MS 2:8	R1	5.3	Zeolite	R3	4.9	Zeolite	R2	5.68	IO:MS 8:2	R1	5.2
Zeolite	R3	5.6	Zeolite	R2	5.3	Red clay	R1	5.78	Zeolite	R2	5.3
Yellow clay	R1	6.1	Yellow clay	R1	5.3	Gravel screen	R1	5.79	Gravel screen	R1	5.3
Zeolite	R2	6.2	Red clay	R2	5.5	Zeolite	R3	6.27	Bentonite “d”	R1	6.0

Shaded area = yield from amended soil that is greater than yield from unamended soil treated with 1.7% compost.

Laboratory Leaching Experiment

Soil blends, weighing 600 grams, were prepared from sand, sand and the amendment materials in the same proportions as for the glasshouse experiment. The blended soils were transferred to a sealed plastic bag, adjusted to field capacity with deionised water and then incubated for 7 days at 40°C while maintaining an average soil moisture content of 14%w/w (around the moisture level at field capacity). A sub-sample of each blend, weighing approx 300 g (dry basis) was then transferred to a 125 by 50 mm leaching column (Fig 9). The remaining soil was air-dried at 40°C for further chemical analysis.

Fig 9: Leaching Apparatus

Fig 10:Leaching column & Receiver

Fig 11: ICP Analysis Instrument

The material in the leaching column was leached, by upward displacement, with deionised water at a rate of 1 mL per minute for approximately 15 hours. The volume of leachate was measured, then analysed for pH, electrical conductivity, soluble reactive phosphorus (SRP) and ammonium and nitrate-nitrogen. SRP was measured using the method of Murphy and Riley [7]). Ammonium and nitrate forms of nitrogen were measured by segmented flow automated colorimetry (SFA).

The air dried soil sample was analysed for electrical conductivity (EC), pH (0.01 M $CaCl_2$), bicarbonate-extractable phosphorus (P_{bic}), bicarbonate-extractable potassium (K_{bic}), and Phosphorus Retention Index (PRI) using the methods described earlier.

Analytical Results

Phosphorus Retention:

The grey sandy soil used for both experiments effectively had no capacity to retain applied phosphorus (PRI value is 0.0 mL/g). Addition of compost to the sand resulted in a desorbing soil (PRI = -0.8 mL/g). Thus, a proportion of phosphorus present in the compost would be expected to be lost by leaching from these soils treated with compost only (Table 9). However, addition of the amendment materials resulted in significant increases in phosphorus retention, as indicated by higher positive values for PRI. This indicates the creation of additional phosphorus adsorption sites in the blended soil.

With an increase in the rate of yellow clay added to the sand blended with the lower rate of compost, a significant increase in PRI values (1.2 mL/g to 17 mL/g) was observed. However, when the composting rate was doubled, the PRI still increased, but to significantly lower values (-0.4 mL/g to 3.8 mL/g). This confirms the desorbing contribution of the compost on the soil blend and the reduction in its ability to retain phosphorus.

Table 9. Phosphorus Retention Index (mL/g) values of amended soils.

Amendment Material	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	0.2	1.4	4.6	-0.6	0.0	0.8
Yellow clay	1.2	5.6	17	-0.4	0.7	3.8
Chittering clay	0.0	0.6	2.2	-0.8	0.6	0.6
Gravel screenings	0.2	1.4	4.6	-0.6	0.0	0.8
Zeolite	-0.6	-0.3	0.1	-0.9	-0.7	-0.3
IOMS 2:8	0.8	2.4	12	0.7	2.0	11
IOMS 8:2	-0.2	1.9	5.5	0.0	-0.2	0.6
"Red Mud"	0.3	0.8	2.1	0.0	0.2	1.7
Bentonite A	0.4	1.4	3.3	0.0	0.8	2.4
Bentonite D	-0.1	0.5	1.2	-0.8	-0.2	0.6
Control soil	0.0					
Control soil + compost	-0.8	-0.9				
Control soil+ nutrients	-2.5					

Note: *Mean values of triplicate treatments are reported on various rates of composted green waste and soil amendment materials following incubation at field capacity for one week at 40°C. R value refers to amendment rate in Table 3. C1 indicates 50 g of compost per pot. C2 indicates 100 g of compost per pot.*

The iron oxide/mineral sands residue (2:8) was also an effective amendment material in terms of increasing the PRI of the blended soils, but it too displayed the same pattern as the yellow clay when composting rates were doubled (Graphs 4a,b).

The inability of the unamended soils to prevent leaching of the phosphorus from the compost is demonstrated by the presence of significant concentrations of soluble reactive phosphorus in the leachate (Table 10). However, addition of some of the soil amendments, such as the yellow clay and the iron oxide/mineral sands 2:8 residue, resulted in significantly lower concentrations of phosphorus in the leachate *(Graph 5).*

The addition of clay materials and some mineral processing residues has previously been shown to improve soil quality by increasing nutrient retention of soils of the Swan coastal plain [3]. While each material itself contributes to the supply of available phosphorus, the phosphorus concentration in the compost is the major contribution source in the amended mixture. Table 1 shows the total phosphorus concentrations in the various materials used in this project. Graph 6 shows that, at the amendment ratios selected for each material, the phosphorus loading on all systems is similar for each ratio of compost application – 82.6 mg/kg at the 1.7% level and 146.5 mg/kg at the 3.3% level.

The effectiveness of an amendment material is provided by its ability to retain phosphorus whilst still making it available to crops as a nutrient source. Some of the phosphorus will be tightly bound to the soil component of the mixture with a proportion more weakly adsorbed.

Table 10. Concentrations of soluble reactive phosphorus (SRP) mg/L in leachates.

Amendment Material	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	1.6	1.0	0.5	2.5	2.2	1.8
Yellow clay	1.0	0.4	0.1	2.0	1.6	0.9
Chittering clay	1.6	1.0	0.6	2.6	2.3	1.9
Gravel screenings	1.1	0.6	0.2	2.0	1.5	1.2
Zeolite	1.9	1.4	1.0	2.9	2.6	2.4
IOMS 2:8	0.2	0.1	<0.1	0.4	0.2	0.1
IOMS 8:2	1.0	0.7	0.3	2.6	1.4	0.6
“Red Mud”	1.0	0.9	0.8	1.6	1.7	1.6
Bentonite A	0.9	0.7	0.3	1.6	1.3	0.9
Bentonite D	3.1	1.9	0.8	4.7	3.6	1.5
Control soil	0.3					
Control soil + compost	1.8			2.8		
Control soil+ nutrients	9.4					

Note: Mean values of replicate treatments are reported on various rates of composted green waste and soil amendment materials following incubation at field capacity for one week at 40°C then leached with deionised water at 1 mL/ min for 15 hours. The R value refers to amendment rate in Table 3. C1 indicates 50 g of compost per pot. C2 indicates 100 g of compost per pot.

The available phosphorus is designated as that determined by the measurement of the amount of phosphorus that dissolves in a solution that imitates the conditions near plant roots (estimated by P_{bic}). A second component of the available phosphorus “pools” is the portion that does not bind with the soil mixture and is readily leached by water (P_{srp}). From these laboratory trials, a comparison of the relative amounts of these components is presented in *Graph 7* at the lower composting rate, and *Graph 8* at the higher composting rate. All results are expressed in terms of the weight of phosphorus in the 3 kg of amended soil used in the glasshouse trials. These graphs clearly illustrate the extent of phosphorus binding in the medium. Under the laboratory leaching trial conditions approximately fives times the available phosphorus is retained in the amendment medium. At the same time sufficient phosphorus is available for plant nutrition.

Nitrogen Retention:

The elution of nitrate from sandy coastal plain soil is a significant factor in estuarine eutrophication. Loss of nitrogen under horticultural production systems based in sandy soils has earlier been observed [11]. Inefficient use of nitrogen fertilizers results in higher production costs as well as the contamination of waterways. The possibility of the amendment materials reducing leaching losses of nitrogen in the form of either ammonium or nitrate ions was of particular interest.

The early growth of plants in our glasshouse trial showed evidence of nitrogen deficiency (yellowing leaves) in the closed (non drained) pot environment (Fig 12). Additional applications of nitrogenous fertilizer were made to overcome this deficiency and maintain normal growth of the crop (Fig 13). Laboratory leachate trials were then carried out to determine the effect of amendment on nitrogen nutrient retention. Table 11 and Graph 9 show that only a marginal impact on the retention level is achieved through the use of soil amendment materials. In these trials, the average retention over all materials was marginally greater than that of the soil alone, the nutrified soil and the composted soil. It is significant to note that, in general, over 50% of the nutrient is retained by the amended soil. The lowest amendment rate of red clay, at the lower composting rate, resulted in an apparent reduction in nutrient N retention. Similarly, the higher amendment rates of the residues and bentonite clays also resulted in an apparent reduction in nutrient N retention.

Fig 12: Nutrient Deficiency in Plants

Fig 13: Nutrient Balance in Plants

The combination of increased application rate with the higher (3.3%) level of compost application increased the level of nutrient nitrogen retention in the local natural clays and zeolite. The higher compost rate improved the retention for the residues, but increasing the amendment rates then reduces the degree of retention. There considerable variability between replicate treatments in the limited runs undertaken in this trial and more work on this area is needed.

***Table 11.* % Nitrogen retained in incubated soil.**

Amendment	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2	All Ave
Red clay	45.6	48.3	57.3	54.2	56.2	59.0	*53.4*
Yellow clay	49.8	62.6	47.1	55.9	59.8	57.5	*55.4*
Chittering	50.6	50.8	48.3	54.1	56.5	61.1	*53.6*
Gravel	48.8	66.2	43.9	58.6	55.6	62.2	*55.9*
Zeolite	49.5	62.0	54.4	58.2	56.3	58.7	*56.5*
IOMS 2:8	46.9	45.5	44.4	34.7	n/a	49.9	*44.3*
IOMS 8:2	53.2	45.5	32.5	56.3	52.8	50.7	*48.5*
"Red Mud"	60.0	50.8	42.1	61.5	64.5	52.0	*55.2*
Bentonite A	53.1	61.4	37.7	58.3	55.3	50.7	*52.7*
Bentonite D	51.4	57.6	47.1	55.8	38.8	45.3	*49.4*
Control soil	50.0						
C+compost	46.5						
C+nutrients	42.2			Applied N=108 mg/kg			

Of concern, in respect of the run-off impact of fertilization, is the demonstrated rapid loss from the soil of over 40% of the nitrogenous component of applied fertilizer, irrespective of type and rate of the amendment material used.

Soil Hydrophobicity

Sandy soils containing elevated levels of organic material from decomposing plant matter often become hydrophobic or "non wetting" due to the presence of waxy organics which coat the soil particles. The extent that a soil is hydrophobic can be measured by the Molarity Ethanol Droplet test (MED). There is also a negative correlation with the Phosphorus Retention Index (PRI). Previous work carried out by the WA Department of Agriculture showed that soils amended with clay contents greater than 5% were not hydrophobic [10]. The use of some mineral processing residues is shown here to also improve soil quality by reducing soil hydrophobicity.

Table 12. Hydrophobicity expressed as a function of the Molarity Ethanol Droplet Test.

Material	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	2.0	1.1	0.2	1.4	-	0.9
Yellow clay	3.0	2.4	2.1	2.5	2.7	2.2
Chittering clay	3.0	2.8	1.9	2.8	2.2	2.1
Gravel screening	2.0	2.2	1.2	2.2	2.1	1.6
Zeolite	2.2	0.9	0	1.4	0.4	0
IOMS 2:8	2.4	2.1	0.7	2.4	1.1	0.8
IOMS 8:2	2.6	2.9	2.2	2.9	2.8	2.5
"Red Mud"	2.9	1.9	0.3	2.5	1.7	0
Bentonite A	2.4	1.4	0.7	2.0	1.9	1.9
Bentonite D	1.9	1.2	0.4	1.6	1.3	1.2
Control soil	2.9					
Control + compost	2.9					
Control + nutrients	3.2					

Table 12 and Graph 10 show the effect on the soil MED with each amendment rate at the two levels of compost application. It has been shown that the repeated application of organic soil amendments will increase the hydrophobicity (MED)[1]. The addition of clay amendment materials increases the number of hydrophilic sites available within the amended mixtures for the absorbance of moisture. A soil MED rating above 3.0 is rated a very severely hydrophobic, greater than 2.4 is severe, greater than 1.2 is moderate, an MED between zero and 1.0 is rated as low while a zero MED is rated as non-hydrophobic [8]. The red clay and gravel screenings applied at rates greater than 10% produce soil of low hydrophobicity. The mineral sand residue (oxide/residue 2:8), red mud and bentonite "D" at 5% also resulted in low hydrophobicity. The negative correlation with the phosphorus retention index can be seen in Graph 5.

In general, increasing the rate of amendment material decreased the degree of hydrophobicity of the soil mixtures. The effect was more pronounced at the higher rates of composting indicating that the organic matter on its own, when incorporated into sandy soils, can increase hydrophobicity, whereas in combination with clay materials the overall effect is a significant decrease (Graph 10). This indicates that compost should not be incorporated into sandy soil on its own. The implications could be more severe in terms of nutrient and water run-off that could lead to faster eutrophication. The potential of reducing the hydrophobicity potential of extended use of compost by adding clay during the composting stage should be investigated as a high priority.

Soil Acidity

The Swan coastal plain is characterized by the acid, sandy soils of the Bassendean series of the coastal plain dune system. Coastal sand pH values have been measured as low as 3.9 pH units. With limited buffering potential, the topsoils of these soil types eventually assume the pH of the water applied to it. Addition of organic composting materials to this type of soil can produce soils with near neutral pH values while increasing the soil's nutrient content. The addition of clay materials and some mineral processing residues has been shown to improve soil quality by raising soil pH.

The sample of Bassendean sand selected for this project had an average soil pH of 3.9 before incubation, but this increased to 6.6 after incubation (Table 13). The application of 1.7% compost marginally raised the pH above this (7.0). It was to be expected that the addition of amendment materials with pH values above that of the bulk soil mixture would also raise the overall pH of the mixture. The reality is that the effect of amendment on soil pH is inconsistent with the pH of the amendment material itself and more dependent on the relative pH buffering capacities of the compost and the amendment material used.

Table 13. pH of Raw Amendment Materials & Incubated Soils

Material	Raw	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	**5.9**	**6.9**	**7.0**	**7.1**	**7.0**	**7.1**	**7.2**
Yellow clay	**6.2**	**7.0**	**7.0**	**7.0**	**7.0**	**7.2**	**7.2**
Chittering clay	**6.1**	**6.9**	**7.0**	**7.0**	**7.0**	**7.0**	**7.2**
Gravel screenings	**6.5**	**6.9**	**7.1**	**7.1**	**7.0**	**7.0**	**7.2**
Zeolite	**8.5**	**7.0**	**7.4**	**7.4**	**6.9**	**7.1**	**7.1**
IOMS 2:8	**9.1**	**7.8**	**7.9**	**7.9**	**7.7**	**7.8**	**8.0**
IOMS 8:2	**8.6**	**7.2**	**7.7**	**7.8**	**6.8**	**7.6**	**7.8**
"Red Mud"	**10.1**	**8.0**	**8.4**	**8.7**	**7.8**	**8.3**	**8.8**
Bentonite A	**8.5**	**8.2**	**8.2**	**8.2**	**8.0**	**8.2**	**8.3**
Bentonite D	**8.2**	**8.0**	**7.9**	**8.1**	**7.4**	**7.8**	**8.2**
Control soil	**3.9**	**6.6***					
Compost	**7.8**	**7.0****		***Soil pH 1:5 in*** $CaCl_2$			
Ctrl+nutrients		**7.0**					

Note *= pH of raw soil after incubation. **=pH of 1.7% Compost in sand after incubation.

Table 14. pH of Raw & Amendment Material Leachates

Material	Raw	R1-C1	R2-C1	R3-C1	R1-C2	R2-C2	R3-C2
Red clay	**7.0**	**7.2**	**7.1**	**7.4**	**7.4**	**7.5**	**7.5**
Yellow clay	**6.9**	**7.2**	**7.2**	**7.4**	**7.5**	**7.6**	**7.4**
Chittering clay	**6.9**	**7.2**	**7.3**	**7.4**	**7.4**	**7.4**	**7.5**
Gravel screenings	**7.0**	**7.3**	**7.2**	**7.5**	**7.4**	**7.6**	**7.6**
Zeolite	**9.5**	**7.4**	**7.5**	**7.6**	**7.4**	**7.6**	**7.6**
IOMS 2:8	**9.1**	**7.6**	**7.6**	**7.6**	**7.6**	**7.6**	**7.6**
IOMS 8:2	**8.6**	**7.4**	**7.4**	**7.6**	**7.4**	**7.5**	**7.6**
"Red Mud"	**10.4**	**8.3**	**8.5**	**9.3**	**8.0**	**8.7**	**9.4**
Bentonite A	**8.6**	**8.4**	**8.3**	**8.6**	**8.2**	**8.5**	**8.6**
Bentonite D	**8.3**	**8.1**	**8.2**	**8.6**	**8.2**	**8.4**	**8.4**
Control soil	**5.9**	**7.2***					
Compost	**7.8**	**7.3****	leachate pH direct read, raw				
Ctrl+nutrients		**7.7**		soils 1:5 in water			

Note *= pH of raw soil after incubation. **=pH of 1.7% Compost in sand after incubation.

At the lower rate of compost amendment (1.7%), the baseline pH of the incubated soil is approximately 7.0. The four clay/gravel Darling Scarp amendment materials have pH values slightly lower than the incubated sand (pH 6.6) and could therefore be expected to slightly lower the pH of the amended mixture. This was not evident. Even zeolite, with a much higher natural pH value (pH 8.5), responded to the pH buffering effect of the compost. The bentonite clays and mineral processing residues, with alkaline pH's (pH 8.2 - 10.1), were also strongly buffered by the compost in the amendment mix. The red mud displayed the most marked effect. From a raw material pH of 10.1, the incubated composting returned pH values ranging from 8.0 - 7.8 at 1% amendment and 1.7% - 3.3% compost rate to 8.7 - 8.75 at 5% amendment and 1.7% - 3.3% compost rate.

The laboratory leaching trial produced leachate solutions from the amended materials with pH values of approximately 7.5 units for all of the clays and, perhaps surprisingly, the mineral sand residues. The leachates from the red mud and the bentonite clays reflected the result trends from the analysis of the incubated soils, rising in pH as the amendment material concentration increased.

The improved modifying effect on the pH of the amended soil materials, seen in both the laboratory incubation and leachate determinations, reflects the pH buffering effect of the breakdown of the compost under the incubation conditions.

Heavy Metal Uptake: Cadmium

One of the major concerns with the use of composting materials is the potential for heavy metals, such as cadmium, which may be present in either the composts or amendment materials, to be taken up by plants. This concern is due to their tendency to be retained and accumulate in the human body to toxic levels. Heavy metals may be present in green waste based composts as a result of previous fertilizing applications, particularly from superphosphate. The maximum permissible concentration (MPC) for in plants used for human consumption is 0.1 mg Cd/kg [9].

The root crop material was analysed for cadmium to determine the effect of soil amendment on the cadmium uptake. Table 15 and Graph 14 shows that none of the amendment materials, even at their highest rate of application along with the highest composting rate, produced cadmium levels in the plants that were above or near the MPC.

However, we note that no result was available for the higher composting rate for yellow clay. Crop harvest material was not produced by the red mud and the bentonites at the highest amendment application rates. Radish roots grown on zeolite and the lower iron content mineral sand amendments (IOMS2:8) had the highest concentrations of cadmium, approximately 0.05 mg Cd/kg. The elevated levels cannot be explained by virtue of the additional contribution from the higher composting rate. The zeolite uptake is more than the double that which would be expected if cadmium in the compost was the main contributing agent. The cadmium uptake from the low iron residue ratio mineral sand waste, at the highest application rate and low composting application, is twice the uptake of that when the composting application is doubled. This may be a function of the increased number of adsorption sites for cadmium made available by the addition of the extra amending material.

Table 15. Cadmium uptake in root material.

Blend	%Amend	1.7% Compost	3.3% Compost
Red Clay R3	20	0.013	0.006
Yellow R3	20	0.024	insuff
ChitterR3	10	0.025	0.009
Gravel R3	20	0.01	0.007
Zeolite R3	20	0.019	0.051
IO/MS2/8 R1	1	0.012	0.013
IO/MS2/8 R2	2	0.041	0.018
IO/MS2/8 R3	5	0.009	0.018
IO/MS8/2 R1	1	0.013	0.023
IO/MS8/2 R2	2	0.014	0.012
IO/MS8/2 R3	5	0.017	0.012

It is also noted that the concentration of cadmium in the plants grown in soil amended by clays decreased with the higher rate of composting. Amorphous clay materials have higher adsorption sites due to their negatively charged surface atoms at higher pH values.

Insufficient harvest material was available to enable confirmation and further investigation into this aspect of the investigation. However, results for other metal analyses were available from the comprehensive ICP suite carried out on the samples of plant material.

Zinc is a useful indicator of heavy metal uptake by plants. Graphs 15 and 16 show that the zinc concentration in the root decreases with increasing rate of clay amendments, while the zinc concentration in the leaf increases. On average there is a marginally higher accumulation of zinc in the leaf over the root material.

Conclusions

The suitability of an amendment material for agriculture is likely to vary from crop to crop. In this investigation, each amendment material produced a different response on the crop (radish). In most cases the incorporation of amendment material had a beneficial affect in terms of quantity and quality of the crop compared to the crop from the soil treated with compost alone.

Using the criterion of the harvest yields, the use of amendment materials can be seen to benefit crop production. However, application rate was seen to be critical for the optimum performance of crop and further in-situ validation is necessary to determine the optimum application rates for various crops.

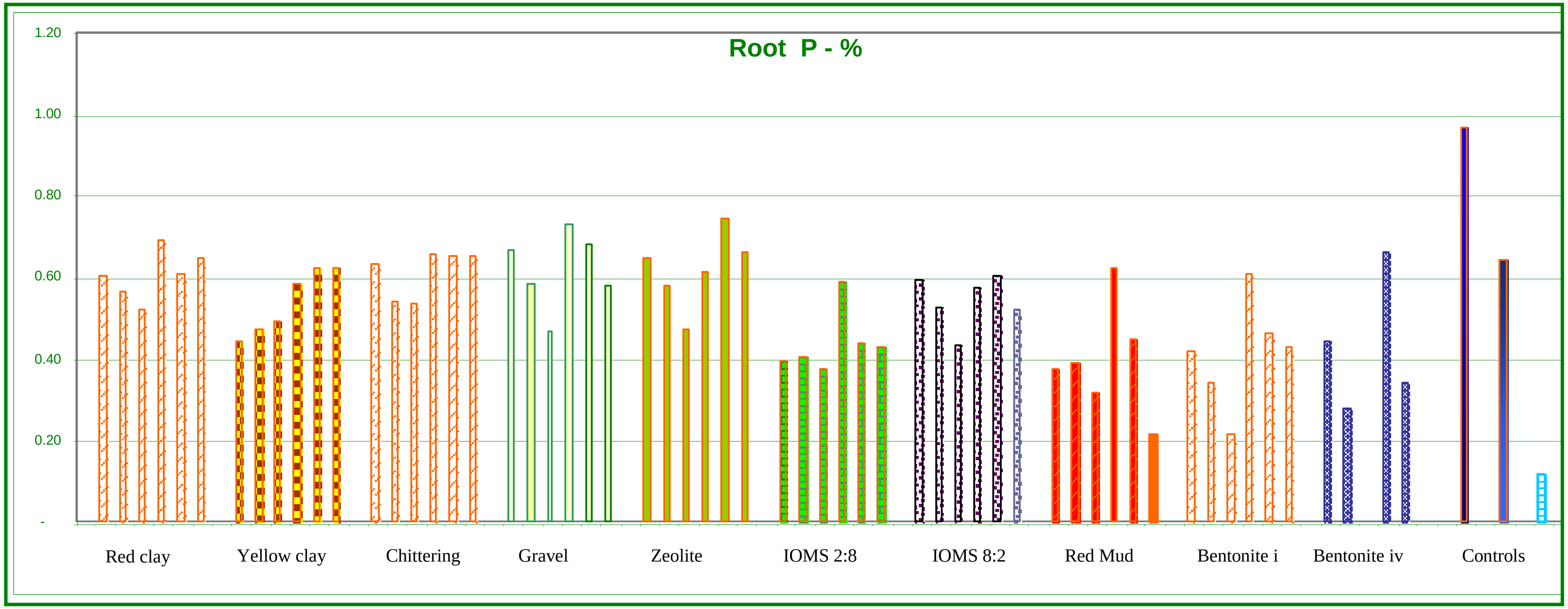
For composted green waste to provide the basis of a sustainable source of nutrients on grey sandy soils in high rainfall areas, it will be necessary to use inorganic soil amendments to not only reduce phosphorous leaching but also to increase the buffering capacity of the soil, which will minimise the influence of any contaminants in the soil environment. In addition the amendment material should prevent faster decomposition of the organic matter of the compost.

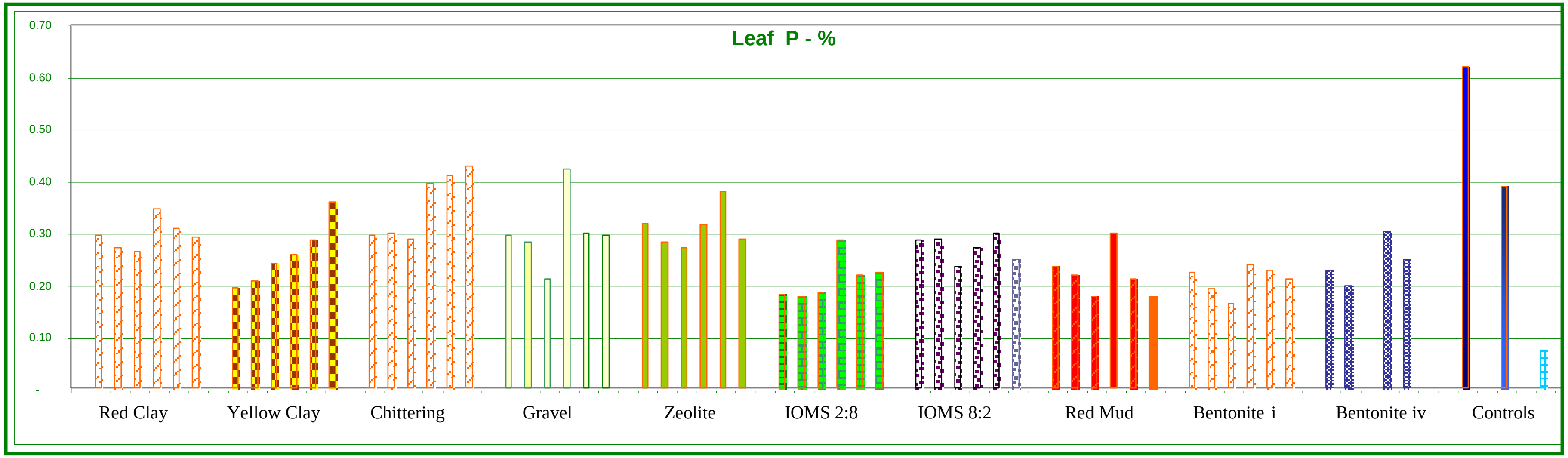
Suitable materials have now been identified that are located close to the Perth Metropolitan area. They are readily available at low cost and offer other beneficial properties to soil.

These benefits include reducing both soil acidity and the hydrophobicity while not contributing significantly to any increase in the uptake of heavy metals by plants. Reduced soil acidity increases the horticultural potential of the soil. Reducing the hydrophobicity improves the moisture penetration of the soil and hence increases the availability of soil medium nutrients to the plants, thereby allowing for deeper root penetration, plant health and stability. Countering soil hydrophobicity will provide the additional benefit of a reduction in water usage.

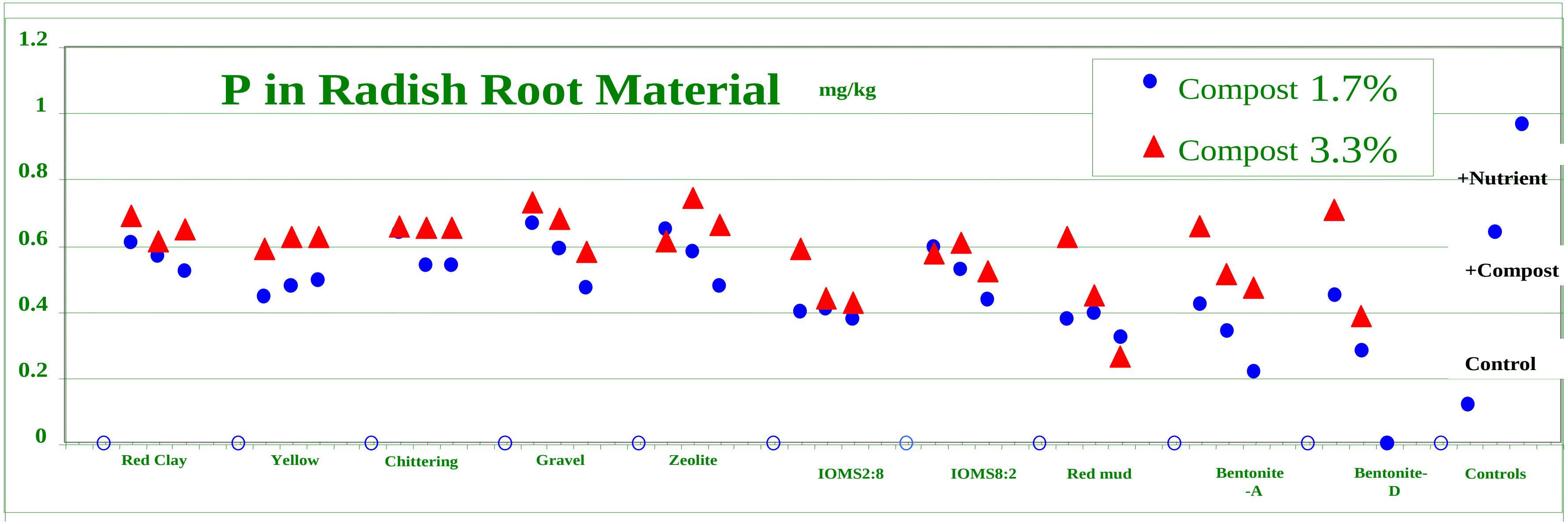
There are wastes produced by mining companies which have substantial amounts of clay content and other desirable attributes (basic cations-Fe, Mn, Ca, Mg) that an be treated as a resource, rather than a waste, to enhance the quality of sandy soils on the Swan coastal plain. This will not only minimise waste and release the pressure on land where stored, but will minimise the cost of maintaining sandy soil where regular nutrient and water applications are required to grow lawns, crops, vegetables etc.

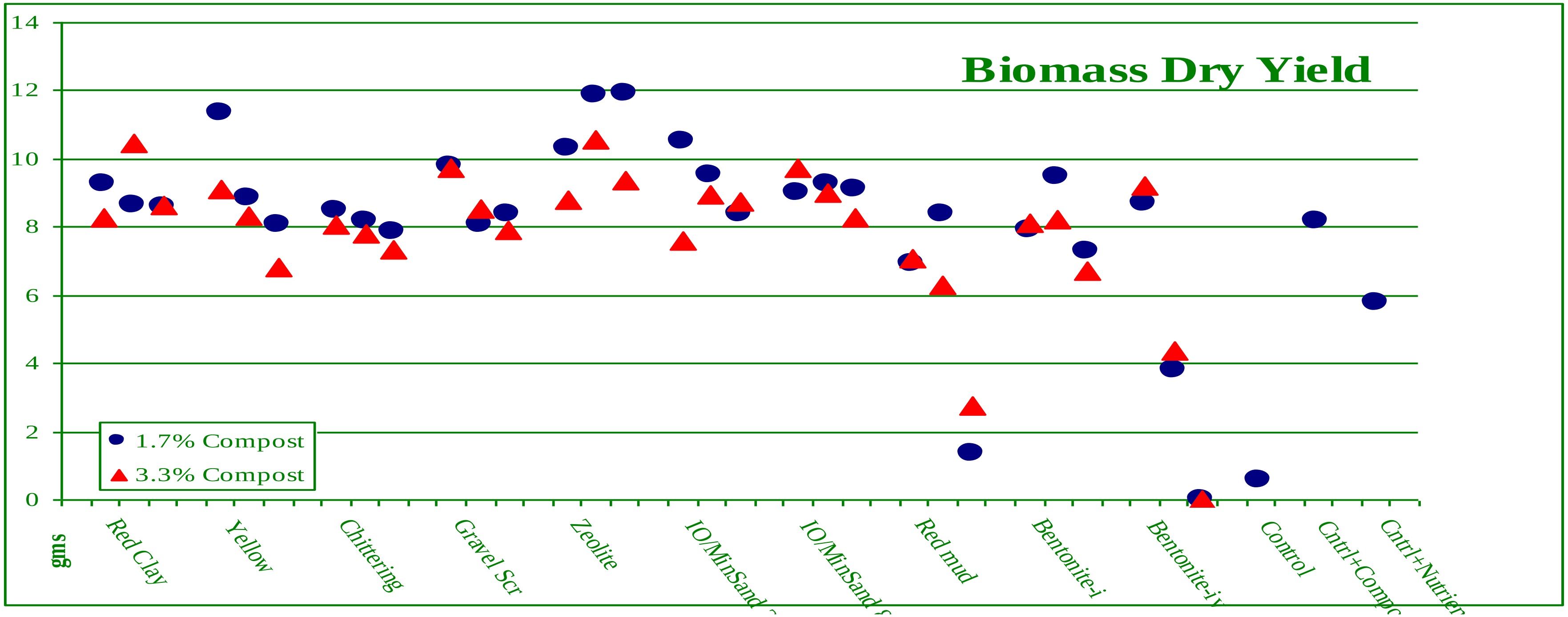
The use of industrial residue treatment is an encouraging prospect, but more detailed analysis needs to be undertaken particularly in the area of heavy metal residues in the soils and plant uptake. Additional research needs to be carried out to determine optimum rates of application for the various amendment materials required.



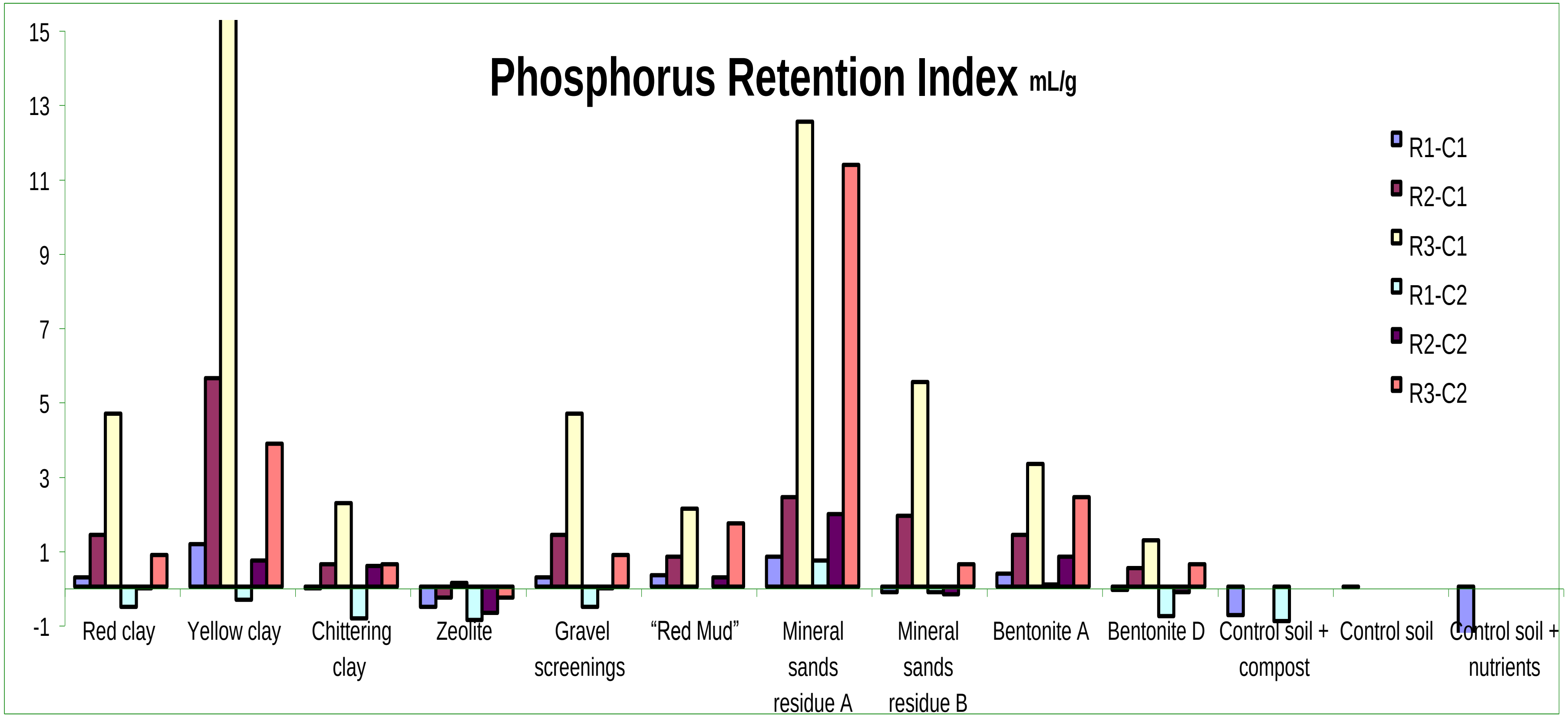


Graph 2 Phosphorus in fresh radish harvest material





Graph 3: Effect of Compost Rate on Crop Size



Graph 4. Phosphorus Retention Index (mL/g) values of amended soils..

PRI of Amended Soils

Red Clay

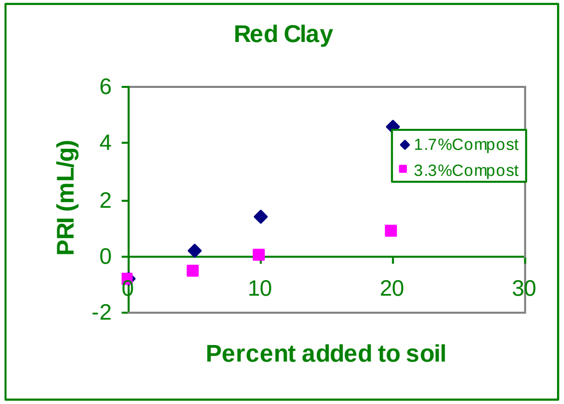
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	0.2	-0.6
10	1.4	0.0
20	4.6	0.8

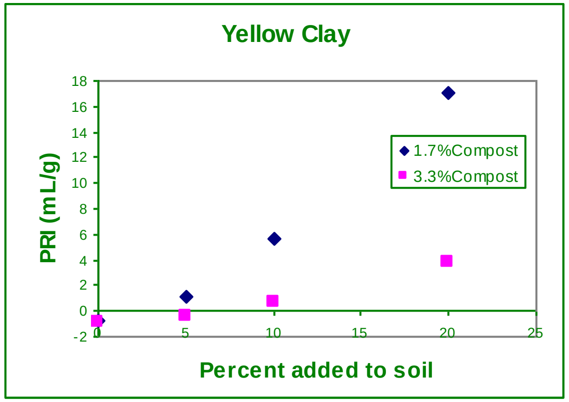
Yellow clay

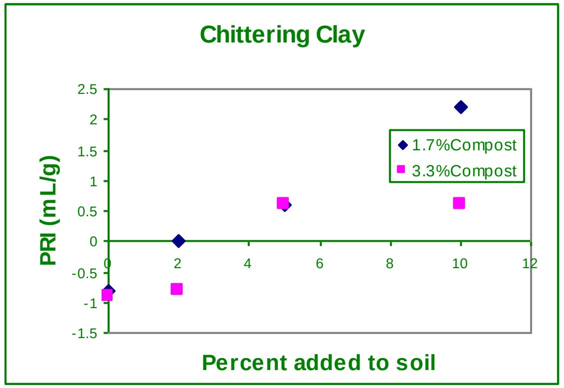
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	1.2	-0.4
10	5.6	0.7
20	17	3.8

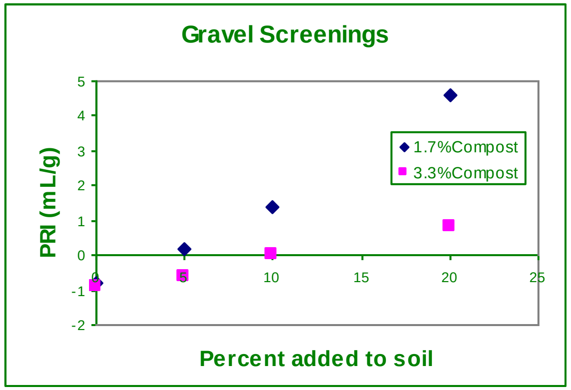
Chittering

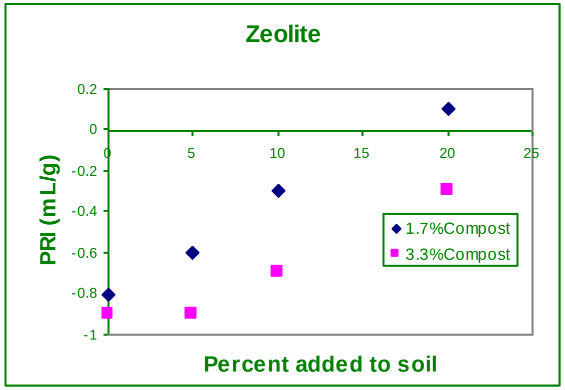
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
2	0	-0.8
5	0.6	0.6
10	2.2	0.6











Graph 4a. PRI – Clay Amendment Materials

Gravel screenings

Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	0.2	-0.6
10	1.4	0.0
20	4.6	0.8

Zeolite

Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	-0.6	-0.9
10	-0.3	-0.7
20	0.1	-0.3

PRI of Amended Soils

IO:MS 2:8

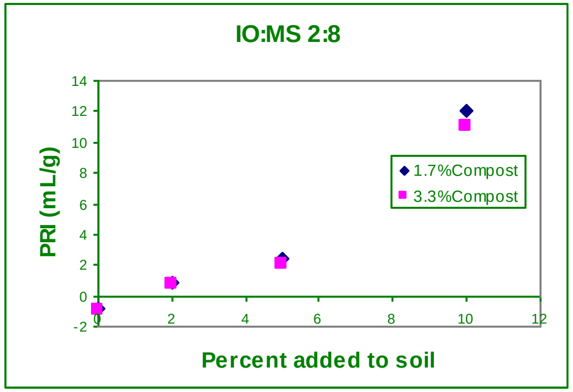
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
2	0.8	0.7
5	2.4	2.0
10	12	11

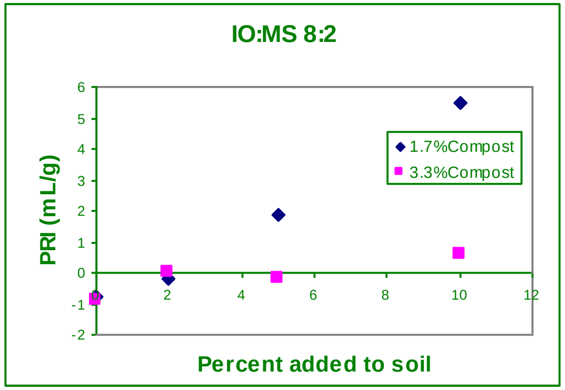
IO:MS 8:2

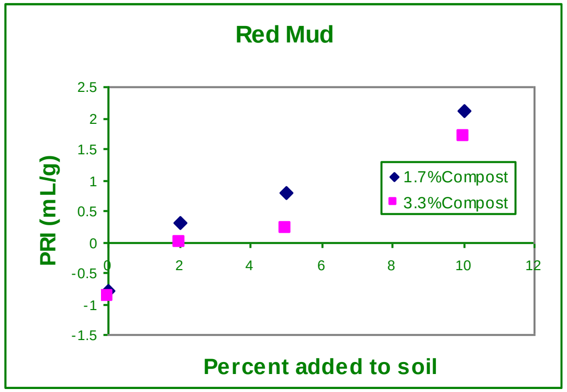
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
2	-0.2	0.0
5	1.9	-0.2
10	5.5	0.6

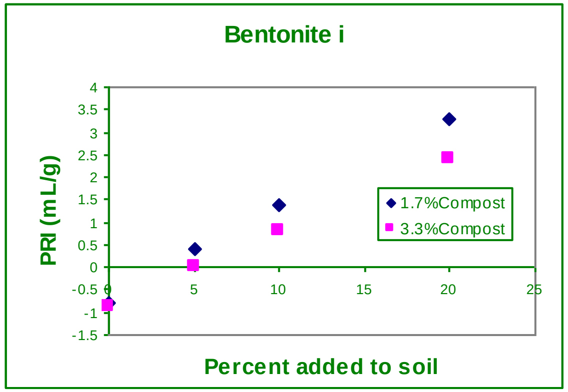
Red Mud

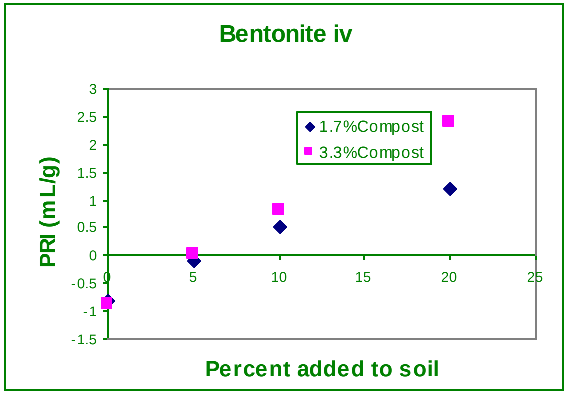
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
2	0.3	0.0
5	0.8	0.2
10	2.1	1.7











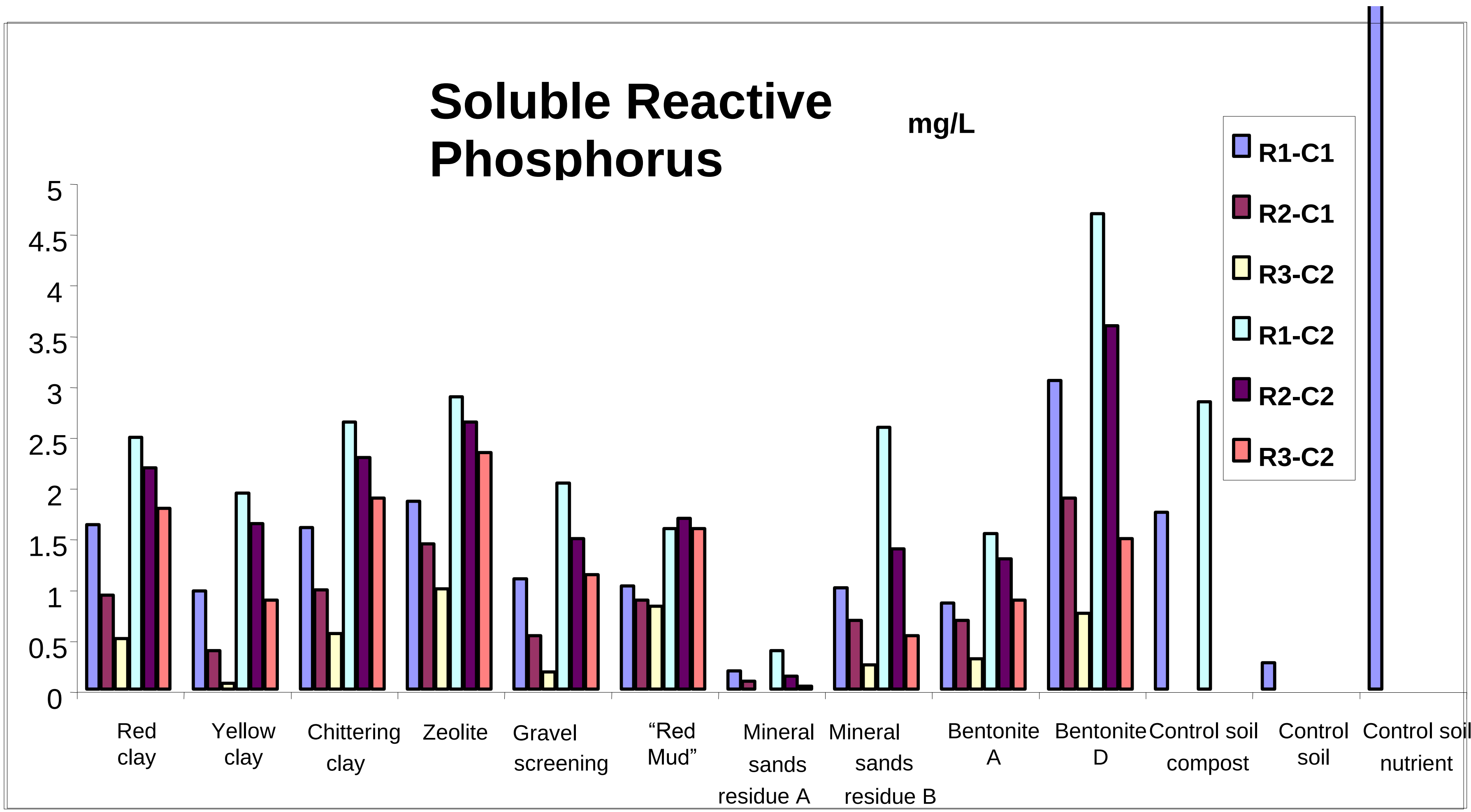
Graph 4b. PRI – Amendment Materials

Bentonite I

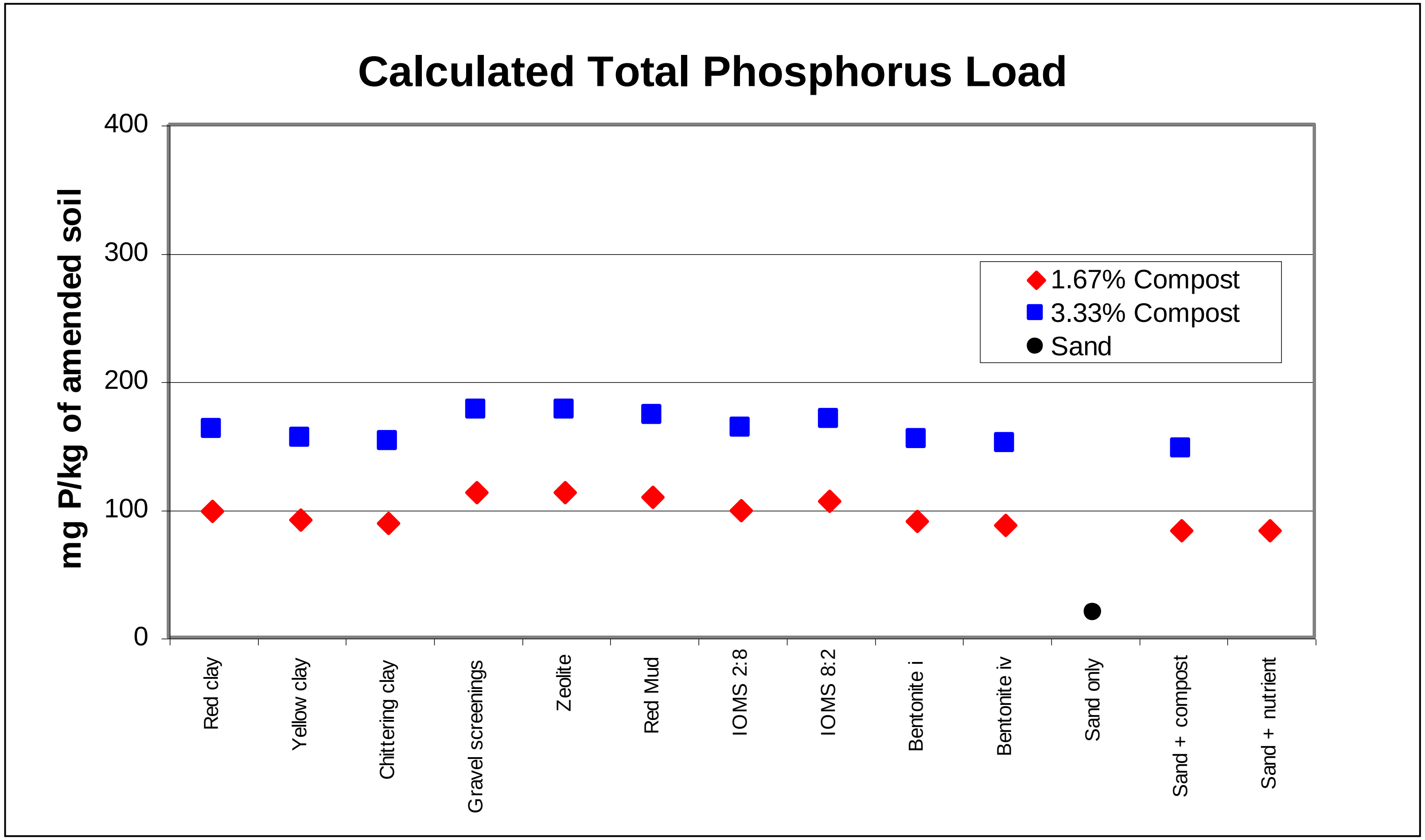
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	0.4	0
10	1.4	0.8
20	3.3	2.4

Bentonite iv

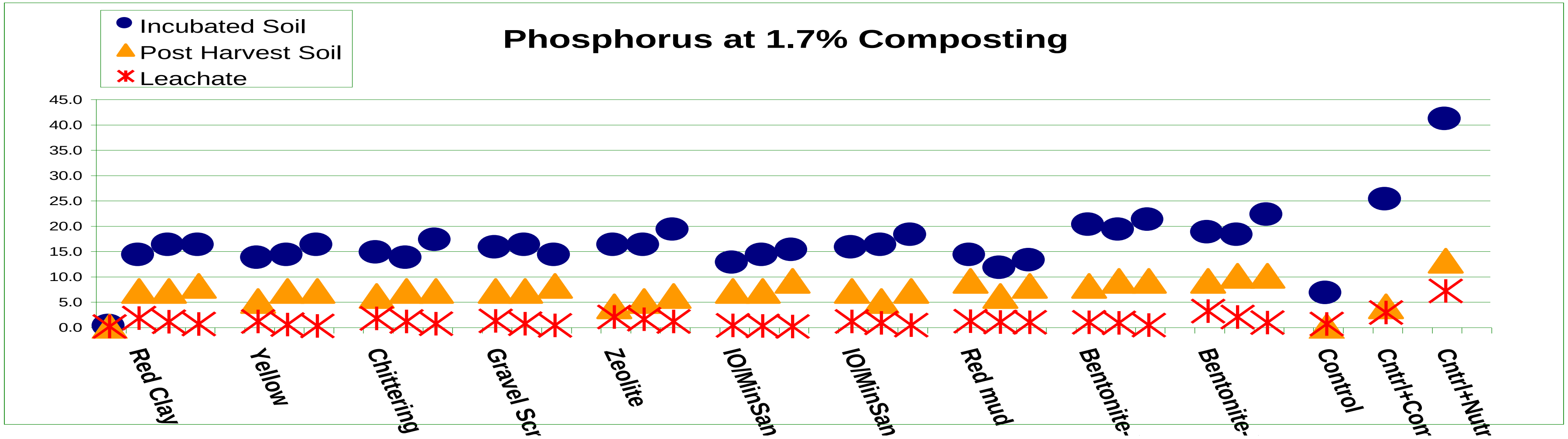
Rate	1.7% Compost	3.3% Compost
0	-0.8	-0.9
5	-0.1	-0.8
10	0.5	-0.2
20	1.2	0.6



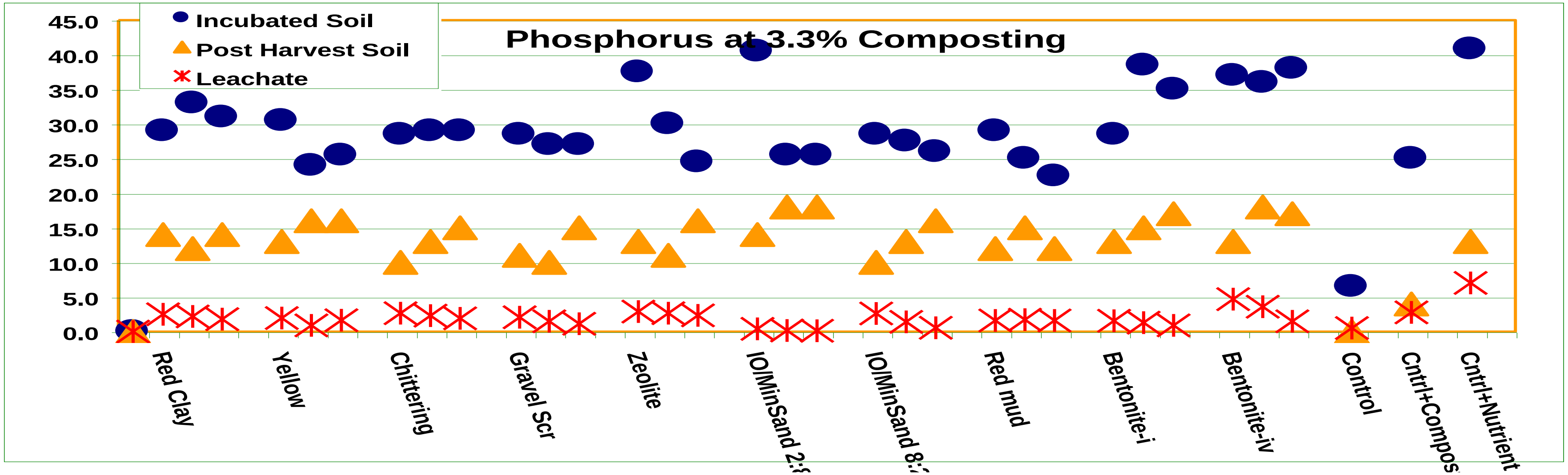
Graph 5. Soluble Reactive Phosphorus (mg/L) values of leachates from amended soils.



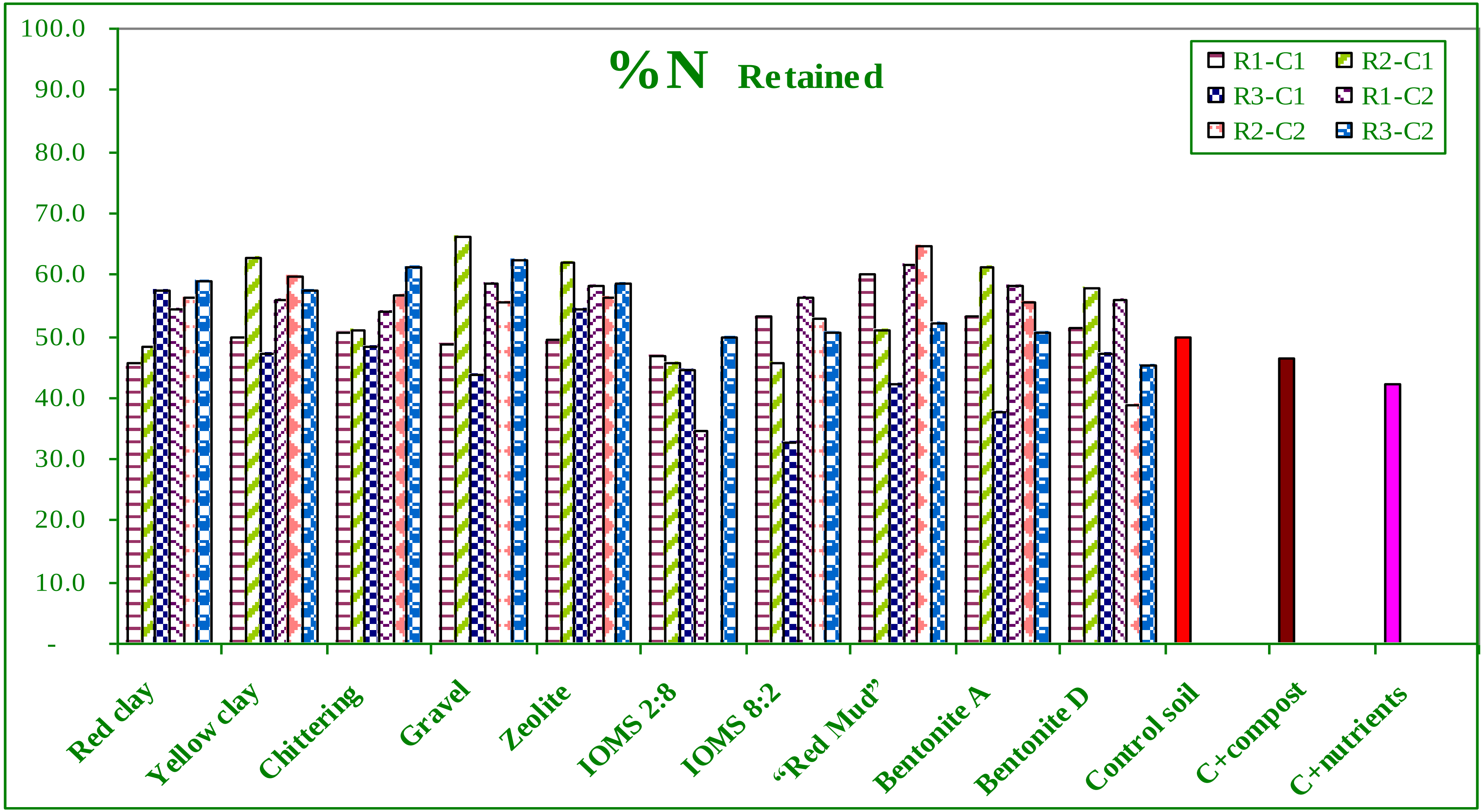
Graph 6: Calculated phosphorus loading from composting in each amendment material.



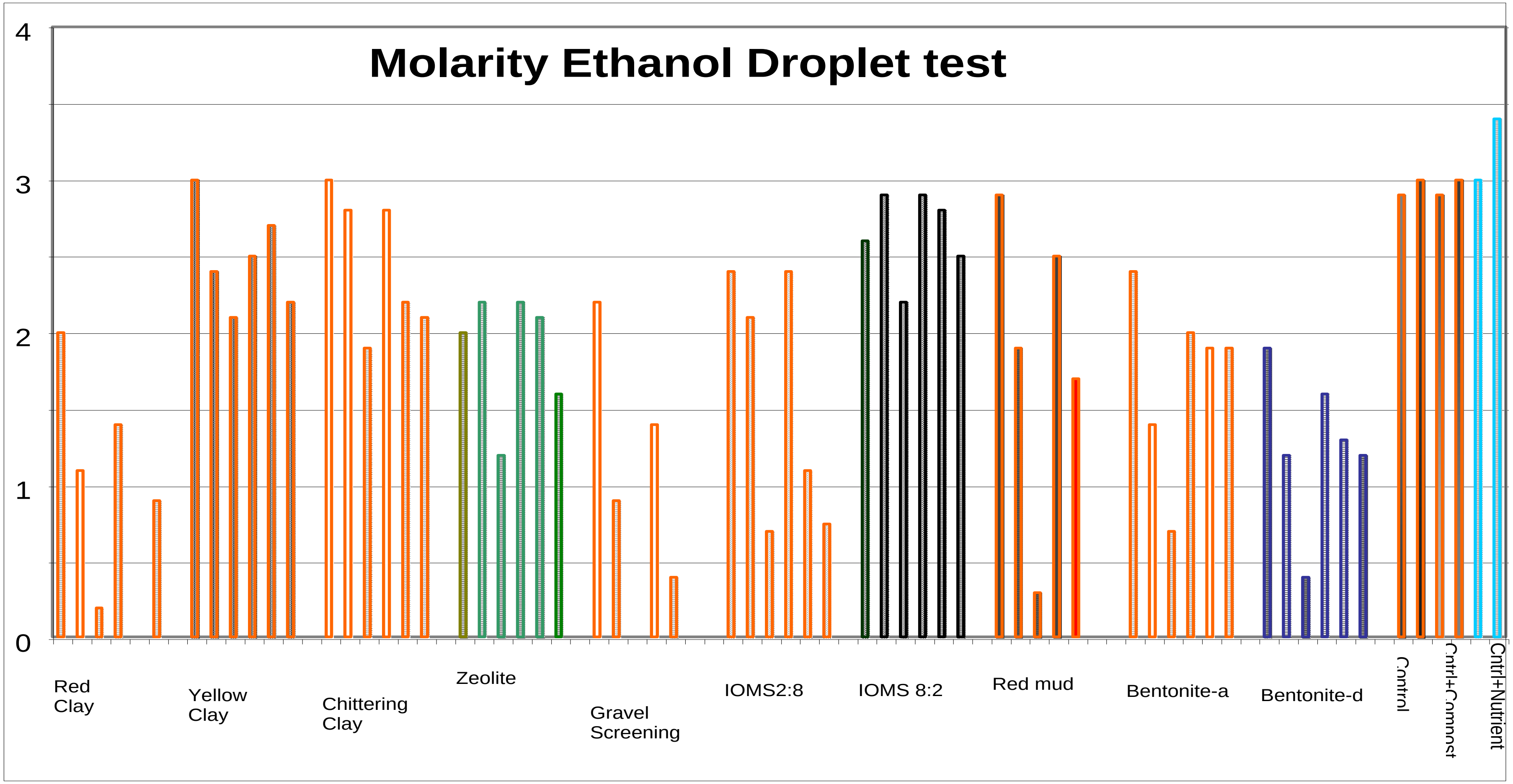
Graph 7: Leachable, soluble and residual phosphorus (mg P/L or mg P/kg) in amended soils at 1.7% composting.



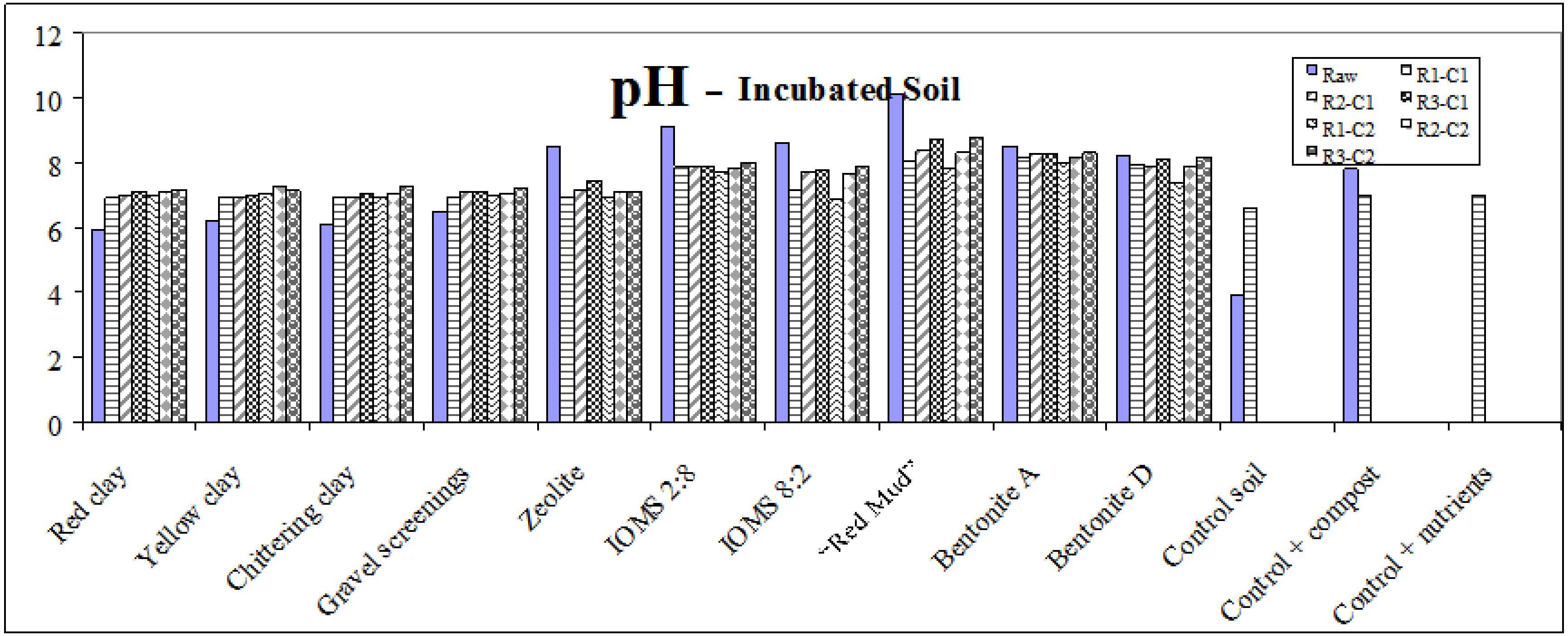
Graph 8: Leachable, soluble and residual phosphorus (mg P/L or mg P/kg) in amended soils at 3.3% composting.



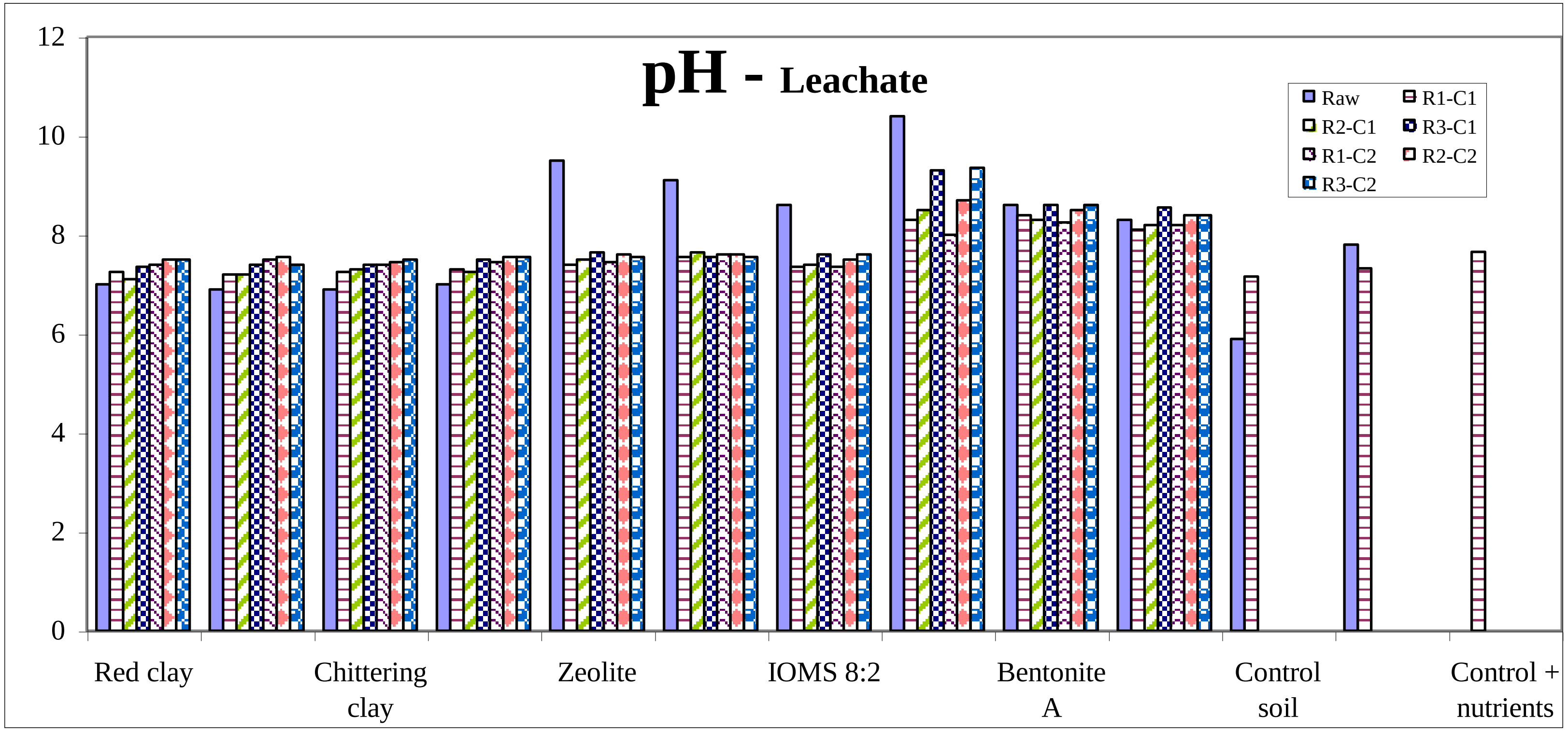
Graph 9: Percentage of nitrate nitrogen initially retained on amended soil



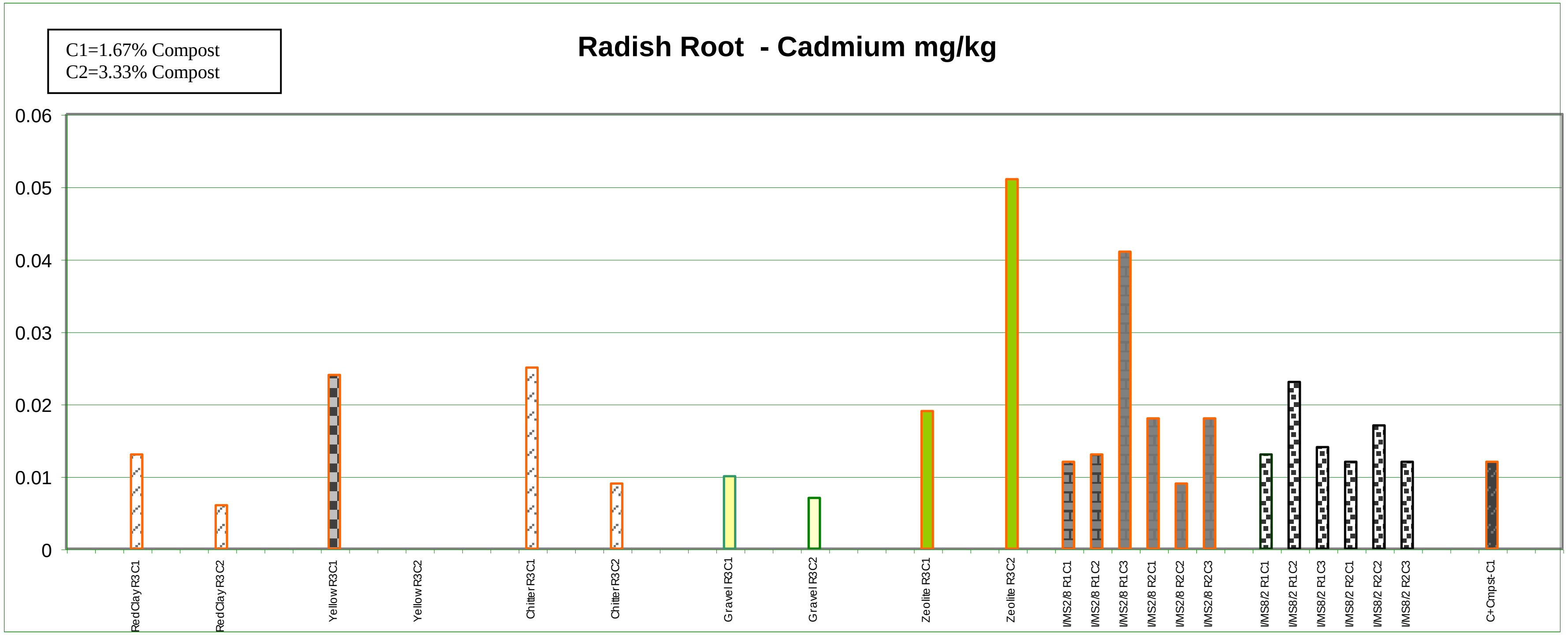
Graph 10: Hydrophobicity expressed in terms of the Molarity Ethanol Droplet test



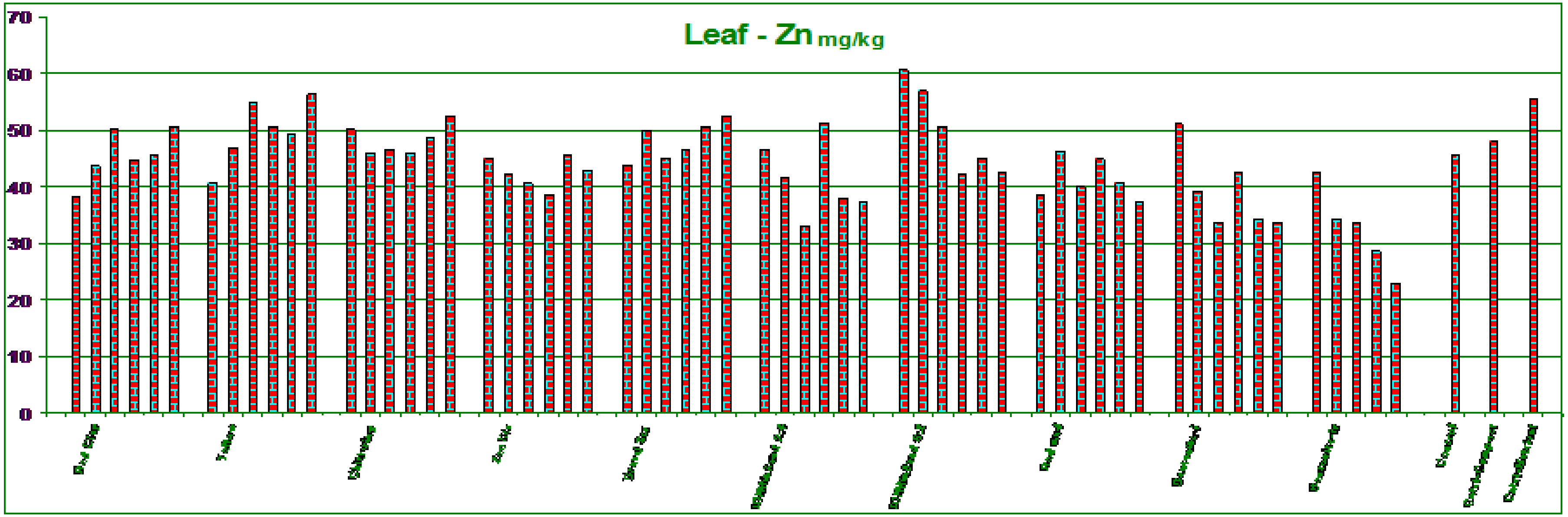
Graph 11: pH of amended soils after incubation

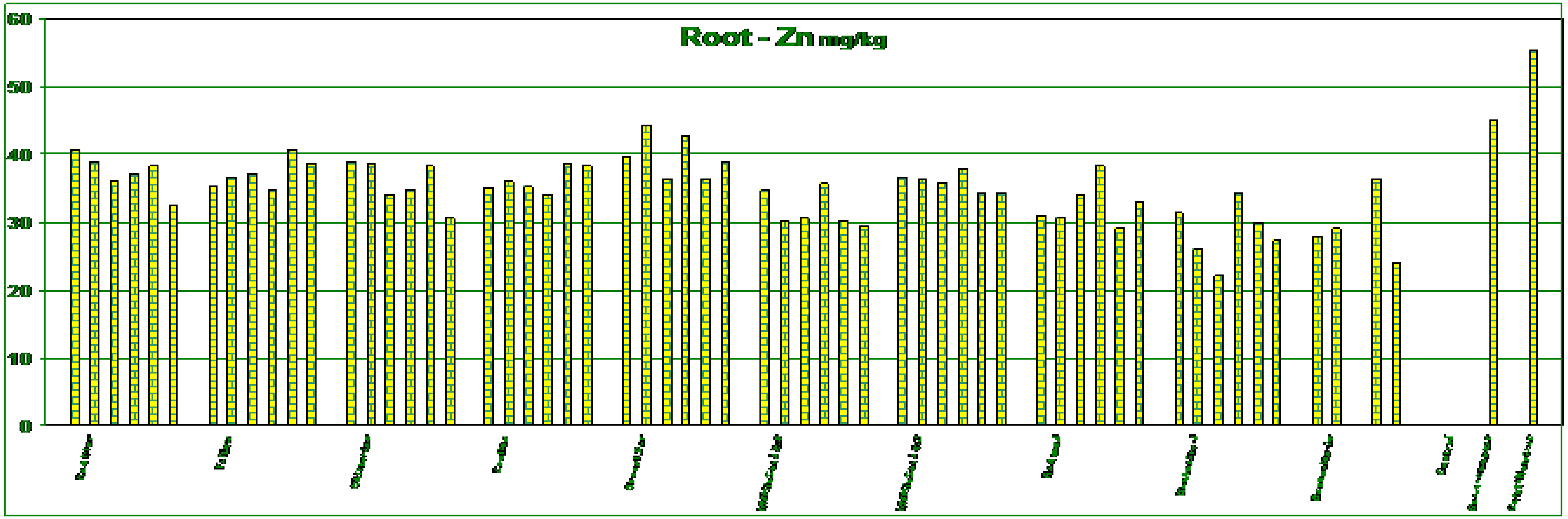


Graph 12: pH of leachate from amended soils after incubation



Graph 13: : Cadmium(mg Cd/kg) in Radish Root at Highest Amendment Rate





Graph 14 Zinc uptake in plant material

References

1. Allen D G, Mann S, Wilson I R, Managing soil nutrients in residential areas of the Swan coastal plain. Chemistry Centre Report, 2000.

2. Yeates J S , Deeley D M, Clarke M F and Allen D, Modifying fertilizer practices. *J. Agric. W.A.*, 25(3), 87-91, 1984.

3. Robertson W J, McPharlin I R and Jeffery R C, Yield and phosphorus nutrition of potatoes (*Solanum tuberosum* L.) cv 'Delaware' grown on a yellow Karrakatta sand containing freshly- and previously-applied Alkaloam gypsum. *Aust. J. Expt. Agric.* 39, 87-101, 1999.

4. Yuen S and Pollard A G, Determination of nitrogen in agricultural materials by the Nessler reagent. II. Micro-determinations in plant tissue and in soil extracts. *J Sci Food Agric*, 5, 364-9 (1954)

5. McQuaker R N, Brown D F and Kluckner P D, Digestion of environmental materials for analysis by inductively coupled plasma atomic emission spectrometry. *Anal Chem*, 51, 1082-84, 1979

6. Allen D G. and Jeffery R C, Methods of Analysis of Phosphorus in WA Soils. Chemistry Centre Report of Investigation No 37, 1991.

7. Murphy J and Riley J P, A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* 27, 31-36, 1962

8. King, P.M. (1981). Comparison of methods for measuring the severity of water repellence of sandy soils and assessment of some factors that affects its measurement. *Aust.J.Soil Res.* 19,275-285

9. Food Standard Code (1998), Australian and New Zealand Food Authority (ANZFA) 3-1201.

10. Carter D.J. Gilkes, R.J & Walker W (1988). Claying of water repellent soils: Effect of hydrophobicity, organic matter & nutrient uptake. Proc. 16th World Congress of Soil Science, Montpellier, France 1998, Symp.41

11. Ian McPharlain , 1998

Acknowledgements

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