2.1 Construction practices

2.1.2 Soil amendment for urban gardens and lawns

Description

Many areas in Western Australia have sandy soils with low ability to retain moisture, nutrients and trace elements. Urban development may also diminish the capacity of soil to support plant growth, through processes such as the removal of topsoil and soil compaction.

Soil amendment is a technique used to create fertile topsoil by increasing the soil's ability to retain moisture and nutrients, and filter some contaminants, such as heavy metals, before they infiltrate into groundwater.

Soil amendment involves adding an agent to the soil to improve its structure, porosity, water holding capacity and nutrient recycling capacity. Potential amendment agents in an urban environment include compost, organic-rich soils, loam soils, natural clay, crushed limestone and gypsum.

'Soil amendment agents' are generally distinguished from 'fertilisers' by having a lower nutrient content, and a greater ability to retain and recycle both moisture and nutrients.

Soil amendment in urban areas is still an experimental technique in Western Australia. Some industrial by-products are not approved for use in urban areas. Refer to Recommended Practices for further information.

Applicability

The technique has potential applicability in urban areas where fertilisers are likely to be added (e.g. traditional residential gardens, lawns and parks). However, prior to applying the technique, consideration should be given to potential impact on groundwater dependent ecosystems (e.g. wetlands). For example, *widespread* use of soil amendment on sandy soils in Perth may decrease groundwater recharge, reducing the flow of groundwater to ecosystems down-gradient from the site. However, widespread use of soil amendment material may also reduce groundwater abstraction requirements for irrigation due to an increase in the soil's ability to retain water. This may potentially reduce the stress to groundwater dependent ecosystems caused by lowering of the groundwater table due to water abstraction. Such impacts should be assessed on a site-by-site basis by suitably qualified professionals.

Where soils have the potential to be compacted during development (e.g. Guildford Clays), soil amendment with an organic compost or loam could produce many of the hydrologic and pollutant reduction benefits demonstrated by overseas studies (see below).

In areas with sandy soils, soil amendment has potential as a way of retaining and recycling nutrients and water in the top 30 cm of soil beneath lawns and gardens.

Recommended Practices

The soil amendment process during urban development typically involves the following steps:

- Initial soil disturbance.
- Breaking up of the subsoil.
- Rock removal (where relevant).
- Distribution of imported soil amendment agent.

- Application of lime and fertiliser (if required after soil analyses have been undertaken and expert advice has been received).
- Soil integration (e.g. tilling 10 cm of compost placed on the surface of the soil, to a total depth of 30 cm).
- Grading and rolling the site prior to lawn or garden establishment.

Loams with a high organic content and composted green waste are recommended for use as urban soil amendment agents on the Swan Coastal Plain.

Where large-scale application of soil amendment agents is proposed, approval may be required under the *Environmental Protection Act 1986*. Contact the Department of Environment or the Environmental Protection Authority (EPA) for more information.

Industrial by-products as soil amendments

Any soil amendment using industrial by-products should be consistent with the Department of Environment's Water Quality Protection Note - *Soil Amendment to Improve Land Fertility Using Industrial By-Products* (DoE, 2004).

Widespread application of industrial by-products (e.g. gypsum-neutralised red mud or red sand (RMG/RSG), fly ash and synthetic rutile production (SRP) wastes, also known as Titanium Dioxide residues) is not currently allowed in urban areas. Special restrictions may also apply in sensitive environments, such as Public Drinking Water Source Areas (i.e. drinking water catchments) and near conservation value wetlands, waterways and native vegetation. Refer to the Water Quality Protection Note for the latest recommendations.

Further information about research trials is available in the Research Trials on Industrial By-Products section.

Benefits and Effectiveness

Enhancement of soils with *inorganic* soil amendment agents (e.g. natural clays) has great potential to increase the amended soil's Phosphorus Retention Index (PRI) and reduce the export of phosphorus (P) to stormwater and/or groundwater. For example, the PRI for Bassendean Sands is 0 – 0.5, while natural clays or loam soils have a PRI of 30 - 1,000 (WRC, 1998). However, more local research is needed in an urban context, to demonstrate and quantify the effectiveness of soil amendment using a range of amendment agents.

Enhancement of soils with *organic* soil amendment agents (e.g. compost) will increase the soil's water holding capacity, but does not always reduce nutrient export (see below). The following benefits of composted amended soils have been reported from overseas studies, where surface water flow dominates the post-development hydrologic regime.

Water quality management benefits include:

- Slow passage of potential pollutants so that soil microbes can decompose them.
- Reduced need for fertilisers and irrigation, as the compost supplies more nutrients, which are slowly released to plants.
- Increased soil stability, leading to reduced erosion potential.
- Added protection to groundwater resources, especially from heavy metal contamination.

- Reduced thermal pollution by detaining surface runoff (LID Centre, 2003).

Water quantity management benefits include:

- More rainwater being held on-site, this attenuates peak flows and decreases runoff.
- Base flows to local water bodies are maintained (important during dry periods).
- Increased groundwater recharge (compared to compacted clays) through better infiltration and by detaining the water on-site longer (LID Centre, 2003).
- Increased soil moisture.

Refer to the Examples / Case Studies section, below for further information.

When applied to sandy soils, such as those on the Swan Coastal Plain, compost amendment is not likely to produce all the benefits listed above, as the soils already have a very high infiltration capacity. However, when compared to the scenario of highly fertilised non-amended soils (i.e. in European-style residential gardens and lawns), the technique does have the potential to significantly reduce the export of nutrients (particularly phosphorus) to groundwater and reduce the need for irrigation.

Challenges

The following challenges may need to be addressed to improve implementation, where approved soil amendment application is appropriate:

- In urban areas and sensitive environments, such as Public Drinking Water Source Areas, and adjacent to conservation value wetlands, waterways and native vegetation, there may be constraints placed on the *widespread* use of soil amendment agents.
- Determine the phosphorus retention capacity of the amendment agents, as these can vary considerably.
- Amended soils may re-release bound phosphorus if conditions become anaerobic. This limits the use of soil amendment to levels above the groundwater saturation zone.
- There is potential for re-release of phosphorus from amended soils if the pH of the stormwater becomes too acidic (e.g. pH < 5).
- Some areas may be unsuitable for the application of soil amendment agents, such as areas with acidic or alkaline parent soils that may mobilise heavy metals in some amendment agents (DoE, 2004).
- Amendment may reduce the permeability of some soils (e.g. sandy soils), and reduce groundwater recharge. Reduced groundwater recharge could adversely affect the health of groundwater dependent ecosystems that exist nearby. A buffer zone around such ecosystems may be required.
- Amended soils have a finite effective lifespan, if nutrients are not recycled by plants and microorganisms.
- Care is needed to prevent the introduction of contaminants in the amendment agents (e.g. heavy metals, poly aromatic hydrocarbons, radio-active materials, pathogens), that may be hazardous to human health, particularly in the context of residential premises where children or animals may ingest soil and vegetables may be grown. Care is required in what material is used and where.

Industrial by-products

There are concerns about the suitability of some industrial by-products (e.g. RMG/RSG, fly ash and SRP wastes) for widespread soil amendment in urban areas, for example, the potential for leachate from RMG/RSG, fly ash and SRP wastes to cause heavy metal contamination.

Refer to the Department of Environment's *Soil Amendment to Improve Land Fertility Using Industrial By-products* Water Quality Protection Note for up-to-date guidance (DoE, 2004). This note currently recommends that industrial by-product soil amendment agents should not be used in urban areas and, as a general guide, should not be placed within 1.5 metres of the maximum seasonal water table. This criterion is based on an appropriate buffer distance to maintain the aerobic zone for plant roots and to stabilise any potential contaminants. It also allows for any groundwater mounding which may result from irrigated systems associated with intensive land use.

Cost

The technique is relatively inexpensive, with costs including purchase, transportation and application of the amending agents, monitoring the effectiveness of pollutant removal, and replacement of amended soil if its pollutant removal capacity diminishes over time.

Taylor and Wong (2002c), citing Brosnan (2002), estimated the potential cost of soil with a high phosphorus retention capacity in Perth (delivered to sites within the metropolitan region) as approximately \$25 - \$30 per m^3.

North American studies of compost amended soils below lawns have concluded that:

- Irrigation needs (and therefore costs) may be reduced by up to 60%.
- Fertilisation requirements and costs also decrease.
- Mowing and aeration requirements and costs remain the same.
- Weed control requires monitoring, as composts can contain weed seeds. The spread of weeds may be of significant concern if the development is adjacent to sensitive bushland or wetlands.
- Routine lawn maintenance and costs are reduced.
- Overall, the benefits offered by the technique outweigh the installation cost.
- For a case study in Seattle, the total estimated amended soil cost was approximately US\$11 - US\$33 per m^2 (in 1996 dollars), and the payback period was five to six years when compared to traditional topsoil and seeding, and within the first year when compared to traditional topsoil and turfing.

Additional Information

Potential soil amendment agents for the management of phosphorus

Possible amendments to retain phosphorus are crushed limestone (applicable to loam soils but may not be necessary on alkaline coastal sands), natural clay, loam soils. Optimum soil to amendment ratios have been determined from previous studies for some of the industrial by-products (see McAuliffe & Evangelisti, 1991). For other materials, the optimum ratios should be determined by phosphorus retention and permeability tests.

The following industrial by-products are not approved for use in urban areas. However, field trials have shown they retain phosphorus when used as soil amendments: RMG/RSG, SRP wastes, and alkaline industrial by-products such as fly ash and lime kiln dust.

Relative permeability and PRI of various substrates

The Phosphorus Retention Index (PRI) ranges given in the table below are intended for comparative purposes only. The PRI test was developed to compare the P retention capacities of virgin Western Australian soils, particularly those on the Swan Coastal Plain. When making an assessment of the P retention capacity of industrial by-products, more exhaustive procedures and expert advice must be adopted, as chemical properties such as high pH may affect PRI results (see DoE, 2004 for details). The PRI test gives no indication of either the long-term cumulative capacity of amendments, the mechanisms controlling P retention, or the effect of solution P concentration on P retention. After these have been assessed from laboratory or field studies, the PRI test may be useful as part of a monitoring or quality control program for the industrial by-product. For natural soils, a reasonable estimate of P retention capacity from PRI is possible. Table 1 displays the relative permeability and PRI for various substrates.

Table 1. Relative permeability and Phosphorus Retention Index (PRI) for various substrates

Substrate	Permeability (m/day)	PRI
Bassendean Sands	30+	0 - 0.5
Karrakatta Sands	10+	2 – 4
Cottesloe Sands	10 +	5 – 12
Crushed limestone or lime sands	2 - 5	5 – 20
Natural clay or loam soils	<0.4	30 – 1,000+
Leached RMG*	May depend on local soil type and blend.	170 – 600
Leached RSG*	May depend on local soil type and blend.	13 – 54
SRP Wastes*	May depend on local soil type and blend.	90 – 1,000++

* = Not currently allowed as a soil amendment agent in urban areas. Primary sources: WRC (1998) and Davidson (1995).

Crushed limestone and lime sands

The adsorptive potential of calcium carbonate from crushed limestone or lime sands has been found to vary considerably between samples from different locations (Ho and Monk, 1988). A potential advantage of using limestone as a substrate amendment is that phosphorus is not released in response to failing redox potentials caused by oxygen stress (McAuliffe and Evangelisti, 1991). Due to inconsistency and uniformity between limestone samples, thorough testing is required to determine the most suitable mix and site from which to obtain limestone.

Natural clay or loam soils

Natural clay or loam soils (e.g. Gingin loam and Marybrook loam) have been used as amendments to increase the phosphorus retention capacity of sands under agricultural production, and for sewage effluent disposal.

Research Trials on Industrial By-Products

Industrial by-products (e.g. RMG/RSG, fly ash, SRP wastes and lime kiln dust) are not currently approved for widespread soil amendment in urban areas. However, this information may help to build a knowledge platform for future trials.

There is a national initiative to develop environmental guidelines for the application of industrial by-products as soil amendments. A draft discussion paper *Development of a National Framework for the Reuse and Recycling of Industrial Residues to Land Management Applications* has been prepared by the Environment Protection and Heritage Council.

Refer to the Recommended Practices section for further information.

RMG and RSG

Gypsum neutralised bauxite residues have nutrient stripping potential. There are two by-products, red mud and red sand, which have different particle size distributions. When mixed with gypsum to produce RMG and RSG, the alkalinity of the residues is reduced, with the pH buffered at around 8.3 by calcium carbonate (Summers *et al*., 1988). The high phosphorus retention capacity of RMG is attributed to adsorption of P by high concentrations of iron and aluminium oxides, adsorption and precipitation by calcium carbonate ($CaCO_3$), and precipitation of P by soluble calcium (Ca) from gypsum. Leached RSG has a much smaller concentration of iron and aluminium oxides, and consequently its P retention capacity is only about one-fifth of leached RMG. There is also an approximate two-fold range in the P retention capacities of RMG and RSG from different alumina refineries.

Phosphorus adsorption to iron III (ferric) Fe^{3+} in oxidising conditions is a reversible process, so P has the potential to be re-released in anaerobic conditions. It is unclear whether this applies to RMG/RSG because a significant proportion of the P is precipitated with calcium. As the sorption characteristics of RMG are determined by the alkaline pH, nutrients bound to amended soil may be re-released if the calcium carbonate in the amended soil is neutralised by percolating acidic water (McAuliffe & Evangelisti, 1991).

Studies undertaken by Ho *et al*. (1989) found that the major salts in the leachate of RMG amended sands were by-products of the alkalinity neutralisation process. Salt concentrations in groundwater immediately below soils amended with RMG are expected to rise, but with negligible long-term effects. Background concentrations are expected to return after 1 to 2 years.

Alcoa and the Department of Agriculture have trialled the use of RMG/RSG in the Peel-Harvey catchment.

SRP wastes

There are two by-products of synthetic rutile production from mineral sands, both of which contain high concentrations of iron oxides. One is acidic and the other is alkaline (due to the presence of calcium carbonate). The latter product also contains gypsum and therefore resembles RMG in chemical composition. These by-products have a high capacity to retain P. The permeability of soil mixes is similar to soil mixes with RMG.

Fly ash and lime kiln dust

Fly ash and cement or lime kiln dust (CKD or LKD) have some potential for use as soil amendments. These materials are alkaline due to the presence of very finely divided calcium carbonate or calcium hydroxide and have a similar mode of action in the long term to very fine limestone.

Fly ash trials have been conducted in WA. For example, in-field trials by the University of WA Turf Research Program, fly ash applied at 150 tonnes per hectare in the top 15 centimetres (cm) of soil significantly increased the amount of water retained (Sports Turf Technology, 2004). Other research is being conducted by Boral Material Technology and Fly Ash Australia.

These industrial by-products require further testing to determine their capacity for pollutant removal and effect on permeability.

Examples / Case Studies

Refer to <www.lid-stormwater.net> for an overview of North American approaches to using soil amendments to reduce the rate of stormwater runoff, and reduce the overall nutrient export load.

Compost amended soil

Compost amended soils usually reduce the net export of nutrients compared to non-amended soils. For example, Harrison *et al*. (1997) reported a relative reduction of:

- 70% of total P load;
- 58% of soluble-reactive P load; and
- 7% of nitrate load.

These load reductions may be associated with a substantial reduction in water flux rates rather than improvements in water quality (i.e. less water may leave the amended soils via stormwater or groundwater). For example, concentrations of nitrate in water draining from the compost amended soils can be higher compared to non-amended soils.

The study by Harrison *et al*. (1997) found that when compost amended soils were used for lawns, they produced a grass that was uniformly aesthetic, and required little or no fertilisation over the three month trial period. Harrison *et al*. (1997) concluded that the reduced need for lawn fertilisation may be the biggest environmental benefit of compost amendment. This benefit has been demonstrated in several studies conducted over three to six month trial periods.

The US EPA (1999) evaluated the benefits of compost amended soils for impoverished soils where surface water runoff dominates the hydrologic regime. For example, composted amended soil was found to increase water infiltration (and reduce surface runoff), increase fertility, and significantly enhance the aesthetics of the turf. The need for continuous fertilisation to establish and maintain the turf was reduced or eliminated. The compost also increased the concentrations of many nutrients in the runoff, particularly when the site was newly developed. However, due to increased infiltration, the nutrient mass runoff should be significantly reduced.

Taylor and Wong (2002c) estimated the potential reduction in total phosphorus loads that may be obtained from amendment of sandy soils in the Perth region from the work of Kelsey (2001). In a pollutant export modelling exercise for a proposed development near Perth, Kelsey used the following total phosphorus export rates based upon the best available information:

Residential land use:

- Lateritic soils TP = 0.15 kilograms/hectare/year (kg/ha/yr)
- Sandy soils TP = 1.2 kg/ha/yr

Rural land use:

- Lateritic soils TP = 0.11 kg/ha/yr
- Sandy soils TP = 1 kg/ha/yr

From these rates, Taylor and Wong (2002c) concluded that the use of lateritic top soils to amend sandy soils could have pollutant removal efficiencies of *up to* 87.5% and 89% for stormwater from residential and rural land use, respectively. Actual efficiencies are likely to be lower than these percentages due to the blending process that occurs during soil amendment.

References and Further Information

Brosnan, J. 2002, Pers. comm., Senior Civil Engineer, PPK Environment and Infrastructure, Perth. Cited in Taylor and Wong (2002c).

Davidson, A. 1995, *Hydrogeology and Groundwater Resources of the Perth Region Western Australia*, GSWA Bulletin 142.

Department of Agriculture 2000, *Code of Practice for the Distribution and Application of Alkaloam (Bauxite Residue) for Broad-acre Agriculture and Horticulture in the Peel-Harvey Coastal Plain Catchment*, Department of Agriculture, Western Australia. Available by telephoning (08) 9368 3333.

Department of Environment 2004, *Soil Amendment to Improve Land Fertility Using Industrial By-Products*, Water Quality Protection Note, Department of Environment, Perth, Western Australia. Available from <www.environment.wa.gov.au> or by telephoning (08) 9278 0300.

Harrison, R. B., Grey, M.A., Henry, C.L. and Xue, D. 1997, *Field Test of Compost Amendments to Reduce Nutrient Runoff - Final Report*, University of Washington, City of Redmond, Washington.

Ho, G.E. and Monk, R. 1988, *Adsorption of Phosphate by Crushed Limestone*, unpublished report, Murdoch University.

Ho, G.E., Mathew, K. and Newman, P.W.G. 1989, ‘Leachate Quality from Gypsum and Neutralised Red Mud Applied to Sandy Soils’, *Water, Air and Soil Pollution*, vol. 47, pp.1-18.

Kelsey, P. 2001, Nutrient Export in Surface Water and Groundwater Under Various Land Uses’, Forum Proceedings of *Land Development in Areas of High Water Table*, 21 February 2001, Perth, Western Australia.

Low Impact Development Centre Inc. 2003. (The Centre provides a good website on various low impact development techniques, including soil amendment. Cited at: <www.lid-stormwater.net>.)

McAulliffe, T.F. and Evangelisti, M.R. 1991, ‘State of the Art Innovations in Stormwater Quality Control Basins’, *Proceedings of the Western Australian Local Government Engineers Association Eighth State Conference*, Perth, Western Australia.

Pitt, R., Chen, S. and Clarke, S. 2002, ‘Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs’, *Proceedings of the Ninth International Conference on Urban Drainage*, Portland, Oregon, 8-13 September 2002.

Sports Turf Technology 2004, *Turf Sustain – A guide to turf management in Western Australia*. Available via <www.sportsturf.net.au>. Further information is available by telephoning the Swan River Trust on (08) 9278 0900.

Summers, K.I., Vlahos, S. and Bell, D.T. 1988, *An Amendment of Sandy Coastal Soils with Red Mud Residue - Water Quality and Pasture Response*, Alcoa of Australia’s Environmental Technical Series No. 6, Perth, Western Australia.

Taylor, A.C. and Wong, T.H.F. 2002c, *Non-structural Stormwater Quality Best Management Practices - A Literature Review of Their Value and Life-cycle Costs*, Technical Report No. 02/13, Cooperative Research Centre for Catchment Hydrology, Melbourne, Victoria. Available via <www.catchment.crc.org.au> and <www.clearwater.asn.au/infoexchange.cfm>.

United States Environmental Protection Agency 1999, *Infiltration Through Disturbed Urban Soils and Compost Amended Soils - Effects on Runoff Quality and Quantity*, US EPA, Washington DC.

Water and Rivers Commission 1998, ‘Datasheet on soil amendment for lining infiltration systems (BMP R2)’, *A Manual for Managing Urban Stormwater Quality in Western Australia*, Water and Rivers Commission, Perth, Western Australia.