

# **Recycled Organics in Mine Site Rehabilitation**

**A review of the scientific literature**

**by**

**Dr Georgina Kelly**

Department of **Environment and Conservation** NSW



This Report was prepared for the Department of Environment and Conservation NSW  
by Dr Georgina Kelly, Senior Research Officer, Research and Development Division,  
State Forests, NSW Department of Primary Industries.

© Department of Environment and Conservation NSW

The State of NSW and Department of Environment and Conservation NSW has made all reasonable efforts to ensure that the contents of this document are factual and free of error. However the Department of Environment and Conservation NSW shall not be liable for any damage or loss which may occur in relation to any person taking action or not on the basis of this document.

Published by:

Department of Environment and Conservation NSW  
PO Box 644  
Parramatta NSW 2124

Ph: (02) 8837 6000

Ph: 131 555 (environment information and publications requests)

Fax: (02) 8837 6099

Email: [sustainability@environment.nsw.gov.au](mailto:sustainability@environment.nsw.gov.au)

Website: [www.environment.nsw.gov.au](http://www.environment.nsw.gov.au)

DEC 2006/184

ISBN 1 74137 701 3

Published June 2006

## Table of Contents

<b>Executive Summary</b>	<b>5</b>
<b>Scope of the Review</b>	<b>11</b>
<b>What are ‘Recycled Organics’ and Where are the Markets</b>	<b>11</b>
<b>Background to Mine Site Rehabilitation</b>	<b>13</b>
Current Rehabilitation Practices	
<b>Opportunities for Recycled Organics on Mine Sites</b>	<b>16</b>
<b>Considerations when Incorporating Residuals</b>	<b>19</b>
NSW Legislation, Planning and Environmental Approvals	
Existing environmental guidelines	
Site suitability	
Residual product quality and quantity	
Transport	
Weed Control	
Public Opinion	
Costs	
<b>Evidence of Use of Recycled Organics from Published Literature</b>	<b>23</b>
<b>1 Biosolids</b>	<b>23</b>
1.1 Use of Biosolids—Australia	
1.1.1 Mine Sites	
1.1.2 Forestry	
1.1.3 Landscaping	
1.1.4 Agriculture	
1.2 Use of Biosolids—General	<b>29</b>
1.2.1 Mine Sites	
1.2.2 Forestry	
1.2.3 Agriculture	

<b>2</b>	<b>Mulch</b>	<b>34</b>
2.1	Mulch in Australia	
2.1.1	Mine Sites in Australia	
2.2	Mulch in General	
2.2.1	Mine Sites and Mulch	
<b>3</b>	<b>Compost</b>	<b>36</b>
3.1	Compost in Australia	
3.2	Compost in General	
3.2.1	Mine Sites and Compost	
<b>4</b>	<b>Municipal Solid Waste</b>	<b>38</b>
4.1	Municipal Solid Waste in Australia	
4.2	Municipal Solid Waste in General	
<b>5</b>	<b>Flyash</b>	<b>40</b>
5.1	Flyash in Australia	
5.1.1	Sugar Cane Flyash	
5.2	Flyash in General	42
5.2.1	Minesite Flyash	
5.2.2	Agri-silvicultural Use of Flyash	
5.2.3	Wood Ash	
<b>6</b>	<b>Food Sludges</b>	<b>44</b>
<b>7</b>	<b>Manure</b>	<b>45</b>
<b>8</b>	<b>Mixed Recycled Organics</b>	<b>46</b>
8.1	Mixed Recycled Organics in Australia	
8.2	Mixed Recycled Organics in General	
8.2.1	Growth Effects	
8.2.2	Physical and Chemical Effects	
8.2.3	Amendment Form and Application Rate	
8.2.4	Mixed Recycled Organics on Mine Sites	
<b>9</b>	<b>Other Recycled Organics</b>	<b>51</b>
9.1	Pulp and Paper sludge	
9.2	Suint	
9.3	Hair	
	<b>References</b>	<b>52</b>

## Executive Summary

Recycled organics is a generic term used to describe compostable organic materials, including garden organics, food organics, residual wood and timber, biosolids and agricultural residues (ROU, 2001). Organic amendments have the potential to replace or supplement mineral fertilisers. Organic residues act not only as a source of nutrients and organic matter but also increase the size, biodiversity and activity of the microbial populations in the soil.

Opportunities exist to utilise this organic material in rehabilitation of mine sites where the substrate is low in organic matter - thus improving the efficacy of revegetation programs. Since the 1970s, the minerals industry in the Hunter Valley has been looking for ways to rehabilitate mining operations to meet not only the increasingly high standards set by regulatory authorities, but to match the high expectations of the community.

To contend with the difficult substrates of mine rehabilitation sites, the use of organic, nutrient-rich residual products can provide benefits as a soil amendment, topsoil substitute, or fertiliser (depending on the rate of application) such as:

- Improved soil structure, moisture retention, soil aeration
- A rich source of plant nutrients and water
- Rapid establishment of microflora and microfauna needed for plant growth
- No need for separate and repeated fertiliser applications.

Most mines fall short of topsoil (18-27%) due to the swell factor (Phillips, 1994b), so the quality of the nutrient poor overburden is often the limiting factor when revegetating. An alternative option is to use topsoil substitutes or overburden/spoil enhancers, such as nutrient-rich residuals and mining process wastes. RO (recycled organic) products have high soil amendment values, but their cost of treatment, transport and application is a major barrier to their widespread use in land rehabilitation.

There is extensive international literature on the use of recycled organics in agriculture, forestry and mine rehabilitation. Much of the focus is on biosolids or biosolids composts. The absence of published data from Australia is notable, though a number of studies have been conducted. Biosolids has been used in Australia in a range of landscape rehabilitation projects, agriculture and forestry research, with positive results.

While there is little formal literature, investigations have revealed that biosolids has been used as an amendment prior to establishing seedlings, direct seeding or sowing pasture on the following mines: Rix's Creek, Bloomfield, Camberwell mine, Bulga South Mine, Drayton's Colliery, Ravensworth east (owned by Macquarie Generation), Howick Mine (Brown and Grant 2000, Kelly 2002c,d, 2004), Coal and Allied, Bayswater Power Station and Narama Mine (Kelly 2002c,d).

Mulches can improve forage establishment on mine spoil where they reduce water loss by reducing evaporation, protect the soil from erosion and minimise soil crusting (McGuinnies 1987; Schuman et al 1990). Organic residuals combined with surface mulches, such as low sodium/sulphur coarse coal reject, are considered good for providing a microclimate suitable for germination, reducing crust formation and improving water infiltration (Hannan & Gordon, 1996). Also the use of amendments for improved soil stability, such as gypsum on alkaline soils and lime for acid soils, can balance mixtures.

Panwar and Bhardwaj (2000) examined the effect of soil amendment and mulch on the establishment of trees in sandstone mine spoil (India). They showed that farmyard manure (FYM) when added as a soil amendment and mulch, increased survival, height and biomass, however root shoot ratio was maximum in mine spoil alone.

Composted MSW could be a valuable resource. The addition of organic materials adds nutrients and can also improve the soil biological, physical and chemical properties. The key advantage of compost application is the replenishment of organic matter in the soil. Top-ups of conventional inorganic fertilisers (typically N) may still be required, but the improved organic carbon bank will ensure a greater efficiency of use, with losses through leaching and volatilization less likely (Pittaway 1999).

No scientific literature was found on the use of compost on mine sites in the Hunter Valley or NSW. A number of trials are currently being carried out in Australia on Bedminster Compost. At Ravensworth South a trial compares the use of Bedminster compost with Biosolids for mine site rehabilitation. The compost and Biosolids were applied in Autumn 2003. No formal data is published in the literature on the results of these trials but Bedminster claim that the Bedminster compost produces good early growth and excellent water holding capabilities.

From the available literature a compost rate of 70-150t/ha of MSW appears to be required to elicit a significant benefit. Cuevas et al (2000) concluded that rates of 80 Mg MSW/ha are required to improve soil chemical properties.

As coal is burned in the boiler of a coal-fired power plant, ash is partitioned into bottom ash (or slag) which remains in the furnace and flyash, which rises with flue gases and is collected separately (Bhumbla et al 2000). Coal fly ash has physical and chemical characteristics that make it useful as a soil amendment, one of the more important being the potential to permanently improve the soil water relations of sandy, drought-prone soils. The potential for the agronomic utilisation of fly ash produced in Australian power stations has received little consideration (Aitken et al 1984).

In the Hunter Valley 150 dry t/ha of flyash and bottom ash was used to ameliorate compacted soils (Kelly 2002c, 2002d). Flyash on agricultural crops at the rate of 50dryt/ha resulted in no significant effect (NSW Dept Agr.). The literature indicates that rates of 150 dry t/ah appear to be required for a positive significant effect to be achieved.

Manure is a valuable resource on increasing soil fertility. It supplies nutrients for plant growth and organic matter for improving and maintaining soil physical properties. Manures don't provide a perfect balance of nutrients and too much added at one time can lead to loss by leaching. Combinations of recycled organics (together with liming agents) have been found to be effective in mine site rehabilitation.

Pulp and paper (P&P) sludge is a by-product of paper production and may be suitable as a soil amendment or mulch. There are typically two types of P&P sludges. The main constituent of primary P&P sludge is waste wood fibre; high in carbon and low in nutrients, thus potentially acting as a nutrient sink (Henry et al 1995). However, the microbial biomass of secondary sludge generally will release nutrients into soil as it decomposes. Few studies have been undertaken.

*Table 2* gives a summary of experimental application rates, results and recommended rates for some recycled organics. Australian literature was used for the biosolids entries, however, due to lack of published literature, international papers have been used for all other amendments. Based on the literature the rates of amendment application for mine site rehabilitation are outlined in *Table 1*.

***Table 1*** Rates of amendment application for mine site rehabilitation

<b><i>Amendment</i></b>	<b><i>Recommended Application Rate*</i></b>
Biosolids	50dt t/ha
MSW	80 dt/ha
Flyash	150 dt/ha
Mulch	10-30cm or 150-300 t/ha
Compost	10-20cm or 70-150 t/ha

\* *mine site rehabilitation*

Table 2: Summary of Amendments, rates and results from published literature\*

Amendment	Study Period / Location	Application Rate/Crop	Land Type	Results	Reference
<b>Biosolids</b>					
Biosolids	1-5 yrs Hunter Valley	50 dt Eucalypts	Mine Site and Buffer land	Increased growth and soil C and P	<i>Kelly 2002a,b,c,d, 2004</i>
Biosolids	12 yrs Mossvale	20 -150 dt pine	Plantation	Increased growth and foliar nutrition	<i>Kelly 2000</i>
Biosolids		48 dt	Mine Site		<i>Barry 1999</i>
Biosolids	Hunter Valley	160 dt	Mine Site		<i>Pearce 1994</i>
Biosolids	Valley	100 and 200dt native grass	Mine Site	Greater surface cover, but no difference between rates	<i>Parker and Grant 2001</i>
Biosolids	WA	38.5 to144 dt	Mine Site	Reduced bulk density and particle density % plant cover increased	<i>Wong and Ho 1991</i>
Biosolids	SA	0-72 dt crops and trees		24 dt was suitable	<i>De Vires and Merry 1980</i>
Biosolids	Hunter valley	50-150 pasture and trees	Mine Site	More biomass	<i>Pearce 1991, Rawlinson and lane 1992 Phillips 1993</i>
Biosolids	Hunter Valley	60	Mine Site	Suitable topsoil replacement	<i>Sydney Water</i>
Biosolids	QLD	90 dt pine		No particulate movement overland, no increase in erosion	<i>Costantini et al 1995</i>
Biosolids		30, 60 and120 dt		Increased earthworm abundance peaking at 30dt and no sig. diff. between rates	<i>Baker et al 2000</i>
Biosolids	Goulburn 1.5 years	0-120 dt grazing land		Reduced runoff and increased surface retention of rainfall	<i>Joshua et al 1998</i>
Biosolids	Canberra	100 dt pot trial		50 dt optimal; increase dry matter	<i>Armstrong and Koen 1994</i>
Biosolids	NSW	125 dt vegetable crops		provided C and N requirements	<i>Sarooshi et al 2002</i>
Biosolids		5,10 and 25dt lucerne		25 dt gave better yield than chemical fertilisers and improved soil physical properties	<i>Willet et al 1986</i>



<b>Composts and Mulches</b>					
Mulch	WA	5-6cm	Orchards	Improved tree growth	<i>Paulin 2000</i>
Compost	WA	15-200 m <sup>3</sup> /ha		Yield improved with applications from 15-60 m <sup>3</sup> /ha	<i>Paulin 2000</i>
Compost		5-10cm		Greater moisture retention in summer	<i>Pickering et al 1987</i>
Chipped 'greenwaste'	4 yrs Hunter Valley	150 dt Eucalypts	Mine Site and Buffer land		<i>Kelly 2002d</i>
Soil conditioner	< 1yr Hunter Valley	10cm Eucalypts	Mine Site		<i>Kelly 2004 (in progress)</i>
Mulch	< 1yr Hunter Valley	10cm Eucalypts	Mine Site		<i>Kelly 2004 (in progress)</i>
Compost		50 and 300 t		Increased crop yield at 300t /ha	<i>Pearson et al 1998</i>
Garden organics	UK	0-150t ha barley		Minimum of 150 t required for a measurable benefit	<i>Cook et al 1998</i>
<b>Municipal Solids Waste</b>					
MSW	< 1yr Hunter Valley	75 t Eucalypts	Mine Site		<i>Kelly 2004 (in progress)</i>
MSW		72 t		Increased organic C	<i>Zinati et al 2001</i>
Bedminster co-compost		82.7 t			<i>Zinati et al 2001</i>
MSW	Spain	40,80 & 120Mg ha	Degraded shrubland	80Mg/ ha required to improve soil properties	<i>Cuevas et al 2000</i>
MSW		21 Mg	Tomato plants	Increased OM and nutrients, increased yield	<i>Madrid et al 1998</i>

<b>Flyash</b>					
Flyash	4 yrs Hunter Valley	150 dt Eucalypts	Mine Site and Buffer land		<i>Kelly 2002d</i>
Bottom ash	3 yrs Hunter Valley	150 dt Eucalypts	Mine Site		<i>Kelly 2002c</i>
Flyash		50 dt vegetables		No significant results	1) NSW Dept Agr. 2)Cline et al 2000
Flyash		10% bu weight		Increased water holding capacity	<i>Campbell et al 1983</i>
Pulverised fuel ash		0,20,60 and 180 Mg ha ryegrass		Increased dry matter yield due to S	<i>Hill and Lamp 1980</i>
Flyash	WA	0-100 t/ha clover		Maximum yield at 50 t ha	<i>Summers et al 1998</i>
Flyash	WA	100 t ha		doubled soil moisture content	<i>Luke 1983</i>
Flyash	Germany	0,100,200 and 400 t ha Barley	Mine Site	Increased soil water and soil heat capacity. Barley yield increased at intermediate rates but reduced at 400 t	<i>Hammermei ster et al 1998</i>
<b>Manure</b>					
Manure	Since 1852; UK	35 farmland	farmland	Increased SOC	<i>Poulton 1995</i>
Manure		22 t ha annually		Provided fertiliser needs for wheat corn and sorghum	<i>Mathers and Stewart</i>
Manure		22 and 44 t ha		Increased soil water penetrability	<i>Abdel Rahman et al 1996</i>
Manure		17-55m3 ha			<i>Prins and Snijders 1987</i>
Manure		5 and 15 t		Increased crop yield	<i>Pearson et al 1998</i>

\* Given the extent of the literature only Australian references were used for Biosolids. Given the lack of the literature, all references were used for other amendments.

## Scope of the Review

*"Conduct a literature review of the documented outcomes of the application of recycled organics in mine site rehabilitation. Australian, and particularly NSW evidence is sought." (Res NSW 2003)*

## What are 'Recycled Organics' and Where are the Markets?

There is a range of potential markets for RO products:

- Agriculture (intensive cropping, pastures, irrigated land and grazing land)
- Forestry
- Composts (commercial landscaping, parks and household gardening)
- Land Rehabilitation/reclamation: regeneration of vegetation on degraded or disturbed land such as minespoil, quarries and industrial sites.

Except for land farming systems and dedicated disposal sites, the only reason to apply an amendment to the soil is the beneficial effects it may have on the crops/plants grown on the land (Mullins and Mitchell 1995).

Recycled organics is a generic term used to describe compostable organic materials, including garden organics, food organics, residual wood and timber, biosolids and agricultural residues (ROU, 2001). ROU (2002) estimated that compostable organics are entering the waste stream at the rate of 1.3million tonnes per year. Composted RO products contain nutrients such as nitrogen, phosphorus and an number of micro nutrients in higher concentrations than in agricultural soils (McConnell et al 1993). Opportunities exist to utilise this organic material in rehabilitation of mine sites where the substrate is low in organic matter - thus improving the efficacy of revegetation programs.

Many specific blends and mixes exist, however, there are two basic composted RO products defined by their end use (ROU 2001): 1). Composted mulch is applied to soil surfaces and has at least 70% of its mass with a particle size of >15mm, and 2) Composted soil conditioners are suitable for incorporation into the soil and have at most 15% of its mass with a particle size of >15mm.

Organic amendments have the potential to replace or supplement mineral fertilisers. Increased mineral fertiliser is applied to accommodate a lack of soil quality. As more fertiliser is added, the microbiological activity in the soil reduces and the soil becomes more unstable (Horan and Hartmann 2000). The higher the instability if the soil the greater the probability of wind and water erosion. As more nutrients are applied to the soil, there is the increase likelihood of nutrient runoff. Use RO may provide nutrients whilst ameliorating the negative effects of mineral fertiliser.

Organic residues act not only as a source of nutrients and organic matter but also increase the size, biodiversity and activity if the microbial populations in the soil. Sherwood and Uphoff (2000) noted that diverse microbial populations play a crucial

role in soil quality and sustainability. Microbial populations are responsible to the decomposition organic material, thus transforming and releasing and cycling nutrients and essential elements such as carbon, nitrogen and phosphorus (Stirling 2001). In most cases composted RO additions to agricultural soils or for the rehabilitation of mine site soils substantially increased microbial biomass (Pera et al 1983, Guidi et al 1988, Press et al 1996, Pascual et 1999a, Garcia-Gil et al 2000). Gibson et al (20002) give a specific and detailed review of the role of RO products in improving soil biological properties.

Soil physical properties, such as soil moisture characteristics and hydraulic properties, bulk density and porosity can be linked to soil structures (Gibson et al 2002).

Enhanced soil structural properties are linked with increased soil organic matter (Tidsdall and Oades 1982) and the literature contains considerable evidence that a range of RO amendments increases the organic matter of soil (Khaleel et al 1981, Albiach et al 2001, Zinati et al 2001). Details of the mechanisms for such improvement are beyond the scope of this review.

While a range of RO products are discussed, this review focuses on composted RO products, primarily derived from the garden organics and biosolids components of the RO stream. In addition the focus is on use of recycled organics in minesite rehabilitation. Mullins and Mitchell (1995) give an extensive review of research relating to agronomic crop response to soil amendment while Gibson et al (2002) review the mechanisms for soil structural improvement from RO amendments and improvement in soil chemical fertility.

## Background to Mine Site Rehabilitation

Open-cut and underground coal mining commenced in the Hunter Valley, New South Wales over 200 years ago and more than 20 mines are still operational in the region (Parker and Grant 2001). During mining, topsoil is removed and stockpiled. This topsoil is used in the rehabilitation of areas once the coal is extracted. In many areas of the Hunter Valley, topsoil, sufficient for good vegetation establishment, is in short supply. Mines are therefore also obliged to revegetate directly into overburden. Hannan (1995) notes that the current rehabilitation process aims to return open-cut coal mines to grazing production together with areas for biodiversity and stock shelter.

Since the 1970s, the minerals industry in the Hunter Valley has been looking for ways to rehabilitate mining operations to meet not only the increasingly high standards set by regulatory authorities, but to match the high expectations of the community. The mining process exposes thousands of tonnes of nutrient-poor waste rock, subsoils and process wastes that have to be stabilised and revegetated. The Hunter Valley mines face further difficulties with re-establishment of vegetation due to low rainfall and poor quality topsoils in some areas.

Overburden and spoils from open cut coal mining are characteristically alkaline, often sodic and have moderate to high salt levels (Burns, 1998). Heavy metals can be present in high levels. Essential plant nutrients such as nitrogen and phosphorus are commonly deficient. In the Hunter Valley, pHs of spoils are often greater than 8.5 and bind what little nutrients are present, making them unavailable for plant use.

Topsoil that is stripped before mining operations for reuse in rehabilitation is typically shallow, sandy, slightly acidic, lacks structure, contains competing weed species seed, and is low in organic material and nutrients (unless previously amended) (Croft & Associates and Costain Australia, 1985). Annual rainfall in the area is also low, around 650mm.

Currently, the general practice is to use the topsoil for pasture establishment and to sow or plant directly into overburden for tree establishment. In recent times there has been significant pressure on Hunter Valley coal mines to consider the establishment of timber plantations on their buffer lands and overburden. However, since commercial growth rates have not been clearly demonstrated in the Hunter Valley, mining companies have been reluctant to commit to use of plantations. The Upper Hunter Commercial Forests Technical Working Party (UHCFTWP) has identified and prioritised a range of research issues that need addressing. One of the immediate and top priorities is:

“Improved site preparation techniques for forestry plantations on reshaped mine spoil. This can be divided into 2 major classes;

- use of ameliorants such as biosolids, vermicast, green manures etc and
- physical aspects of ground preparation, eg ripping, contours, mounding, slopes”

The Department of Mineral Resources has formed the Environment Unit to ensure and encourage the adoption of environmentally responsible management practices throughout the NSW mining industry. They regulate the environmental impact of mining in NSW through the use of environmental impact assessment (EIA),

environmental management plans (EMPs), audit processes and conditions of title. (DMR NSW 1997). DMR have a mandatory requirement that existing stockpiled topsoil be used. This is mainly to help start the revegetation process. However, the continued growth of the plants is dependent on the quality of the underlying material or the hardy nature of the vegetation. Most mines fall short of topsoil (18-27%) due to the swell factor (Phillips, 1994b), so the quality of the nutrient poor overburdens is often the limiting factor when revegetating. An alternative option is to use topsoil substitutes or overburden/spoil enhancers, such as nutrient-rich residuals and mining process wastes. RO products have high soil amendment values, but their cost of treatment, transport and application is a major barrier to their widespread use in land rehabilitation.

### *Current Rehabilitation Practices*

Under the NSW Mining Act 1992, the Department of Mineral Resources (DMR) can place and enforce conditions on mining companies to rehabilitate any area adversely impacted by the mining process (s239(1)). These conditions become part of the Environmental Management Plan (EMP) and overall the Mining Operational Plan, and are based on best practice guidelines produced for the mineral industry. The main coal mining guideline is “Mine Rehabilitation – A Handbook for the Coal Mining Industry” (Hannan, 1995).

The exploration and mining industry must rehabilitate all land disturbed by returning the site to a condition which:

- is stable and permanent,
- is suitable for an agreed subsequent land use as far as possible compatible with the surrounding land fabric and land use requirements,
- has landforms, soils, hydrology, and ecosystems with maintenance needs no greater than those of surrounding land,
- has no adverse environmental effect outside the disturbed area (McGlynn 1998)

Mine planners and mine managers must consider post mining rehabilitation requirements and the operational strategies to achieve those outcomes as an integral part of mine planning and operation. Rehabilitation must commence as soon as practical in the life of a mining operation and continue steadily through mine life.

The conventional best practice method for rehabilitating open cut coal mine sites consists of:

- reshaping and contouring the spoil to stabilise and prevent erosion;
- removing large rocks from surface soil;
- adding of topsoil/ topdressing;
- seeding with a mixture of grasses and legumes;
- applying fertiliser;
- incorporating the seed and fertiliser into the topdressing;
- once established, fertiliser is applied annually to the pasture;
- weed control is often included (modified from Phillips, 1994).

Exotic grasses are commonly used (eg Rhodes grass) as it provides a rapid cover and can support grazing (Marschke et al 1994). However, it is very invasive and out-competes most other grasses and legumes. In addition it required significant fertilizer inputs. Leigh (1990) notes that native grasses are a viable alternative since they do not require high fertiliser input. Tree establishment has been mainly through direct seeding, though work by SFNSW, since 1999, has shown that good survival and growth rates can be achieved by planting seedlings. Appropriate establishment techniques and species selection is critical (Kelly 2004).

Alternatively, direct seeding or tubestock planting of tree species can be used in preference to topdressing with grasses/legumes when rehabilitating raw overburden, due to the heavy weed and pasture competition that occurs in topdressed sites. Currently, several large companies choose to direct seed hardy tree species in 30-50% of their rehabilitated areas (Burns, 1998). Full revegetation with tree species in preference to pasture topdressing is also better for soil retention (Dyson *et al.*, 1983).

## Opportunities for Recycled Organics on Mine Sites

A characteristic of overburden spoil is the lack of organic matter in a form that will breakdown. Much of the organic material in the form of coal which remains stable for long periods and does not contribute to the soil quality. Organic carbon is a significant component of RO and its application to soils should increase SOC levels (Pagliai et al 1981; Zinati et al, 2001). Field trials at Rothamstead UK, where annual applications, since 1852, of 35t/ha (fresh weight) farm yard manure, have increased SOC to over 3% compared to 1% in non-manured soils (Poulton, 1995).

The surface mining process has been reported to increase the content of exchangeable bases in the reclaimed surface layer by bringing us fresh material that weathers and results in mine spoil with high base saturation and greater concentrations of basic cations for plant utilization compared to the other overlying natural soils (Dixon et al 1980). Successful restoration depends on accumulating N in the system and establishing a functional N cycle.

Phosphorus is another major limiting nutrients in fresh mine spoil due to rapid fixation into unavailable forms and generally low total amount present (Berg 1975; Bennett et al 1978). P fixation is least in the pH range between 6-7. Organic matter addition may increase P availability directly by mineralization of the organic matter or indirectly by releasing organic constituents that block soil sites that might otherwise lock up existing or added P (Ditsch and Collins 2000).

Potassium does not often limit plant growth on mine soils because of the presence of weatherable minerals that provide plant-available K reserves (Vogel 1981). Neither Ca or Mg have been identified as a limiting nutrients in mine soils (Mays and Bengston 1978) although Ca and Mg imbalances have reduced vigor of plants in reclaimed soils (Vogel 1981)

Muchovej and Pacovsky (1997) note that addition of organic residues to a soil results in stimulating soil microbial activities and building soil biomass in a fashion that is not duplicated by inorganic fertilisers. Since microbial decomposition is required for the release of N, P and S into a plant available form, organic fertilisers supply nutrients in a slow-release form. Such controlled release of nutrients usually results in significantly less leaching of nitrates and phosphates into the ground water.

Soil microbial biomass is a source and sink for essential plant nutrients and is fundamental to the transformation and flow of various plant nutrients (Paul and Voronery 1980). Mycorrhizae also play an important role tin the growth of plants on the minespoils (Marx 1980) by regulating the uptake of various nutrients or by keeping some nutrients below toxic levels. Stable and productive minespoils require active microbial populations - for both nutrient cycling and the improvement of the physical properties of the soils (Rao et al 2001). This can be achieved by either directly using microorganisms or indirectly through the incorporation of amendments. Plass (1978) and Dadhwal and Katiyar (1989) improved the biological environment of mine spoils with amendments such as sewage sludge, farmyard manure or topsoil.



Rao et al (2001) also examined the effect of sewage sludge, farm yard manure and pond silt on trees on gypsum overburdens. Amendment of the spoil with sewage sludge (1:1) showed the maximum increase in plant growth, compared to all other treatments. They found all organic amendments improved NPK and Mg, the maximum improvement being with sewage sludge. Other amendments such as wood residue, peat, flyash, paper-mill sludge etc, have been found to improve nutrient uptake in minespoil vegetation (Latterall et al 1978; Voorhees and Uresk 1990)

Animal and municipal wastes can be applied to land to help improve physical properties, chemical characteristics (Hue 1995) and biological properties (Stratton et al 1995). The resultant decomposition, transformation of N<S and P, and modifications of metal solubilities together with the rates of nutrient release influence the potential impact (Sommers et al 1979). Although organic fertilisers compare favourably with commercial fertilisers, they lack a balance of essential nutrients and cannot be "created" to fully meet crop requirements. The future role may be in conjunction with inorganic fertilisers, thereby reducing commercial fertiliser inputs Muchovej and Pacovsky (1997).

Beneficial and possible harmful effects of organic amendments are discussed in reviews by Raviv et al (1995) Eck and Stewart (1995), Hue (1995), Mullins and Mitchell (1995) and Stratton et al (1995)

Before inorganic fertilisers were used, producers used considerable amounts of manures and green manures in their farm operations on a routine basis (Keely 1990). Reports on beneficial effects on manures on plant growth and nutrition are abundant in the literature (Eck and Stewart, 1995)

Increasingly, residuals are becoming an option as potential fertilisers and soil amendments to improve degraded or marginal lands. Organic residuals, such as biosolids, sewage effluents, green organics, animal wastes and food wastes, introduce nutrients, organic matter and moisture back into poor soils. Industrial wastes, such as steelmill slag, flyash and papermill wastes, also provide carbon, calcium and other minerals to stabilise and amend soils. The potential exists to use these wastes, individually or in combination, to create optimal soils on marginal lands for the establishment of any type of vegetation.

To contend with the difficult substrates of mine rehabilitation sites, the use of organic, nutrient-rich residual products can provide benefits as a soil amendment, topsoil substitute, or fertiliser (depending on the rate of application) such as:

- Improved soil structure, moisture retention, soil aeration
- A rich source of plant nutrients and water
- Rapid establishment of microflora and microfauna needed for plant growth
- No need for separate and repeated fertiliser applications

A unique quality of some organic residuals is that they can lock up not only the heavy metals found in the residuals themselves but also within the spoil substrate (Chaney *et al.* 1995). The metals in the overburden become organically bound and are less likely to cause environmental contamination.

The Hunter typically has low annual rainfall and poor quality soils. Studies in the Upper Hunter region (Burns 1998) suggest that some unamended soils and spoils have low productivity (1m<sup>3</sup> per hectare year). However, more recent trials have shown that with application of soil amendments, viable eucalypt plantations rotational yields of 5m<sup>3</sup> per hectare year (with the potential on some sites of 10m<sup>3</sup> per hectare year) may be possible. Green organics (chipped line clearings) have been incorporated in a trial at Bayswater Power Station and has proved valuable in increasing foliar nutrition and soil carbon (Kelly 2002d).

The Upper Hunter Valley has approximately 20,000 ha of land requiring rehabilitation. Residuals and organic wastes have potential as fertilisers, topsoil substitutes or soil amendments in the rehabilitation of those lands. Experience of SFNSW to date, indicates that these products can have a role in developing a viable commercial hardwood venture. SFNSW research trials also indicate that recycled organics can contribute to the soil carbon pool in a significant way (Kelly 2002c, 2003).

Mines have an obligation to rehabilitate after the mining process. Due to the nutrient poor nature of the unconsolidated overburden, considerable time and money is spent getting the nutrient cycling process started again. Traditionally, rehabilitation has been back to pasture and often with applications of fertiliser for 5 years. The rehabilitated land represents little return to the mining companies. SFNSW have shown in current trial that trees can be established with a one off application of organic waste (not requiring expensive and repeat applications of fertiliser) (Kelly 2002a, 2002d, 2004). In addition this trees provide a potential income from carbon credits, biomass or sawlogs.

The significant factor determining the availability of nitrogen to plants is the carbon to nitrogen ratio (Brown and Grant 2000). Elliot et al (1980) found that the nitrogen content of overburden in the Hunter Valley was low and the carbon to nitrogen ratio was high. Under these conditions existing and added nitrogen is immobilized (Dyson et 1983). Care should be taken in adding more carbon (without nitrogen) to these sites. High levels of calcium are likely to bind the phosphorus in the system. The calcium irons react with phosphorus to form insoluble calcium phosphates and further reduce the availability of phosphorus (Lockwood et al 1998). This reinforces the need for chemical assessment of amendments and a chemical assessment of their impact on soil and vegetation post application.

Soil quality research has focused on intensively managed agricultural and forest soils, but the concept and importance of soil quality is also pertinent to reclaimed mine soils and other disturbed ecosystems. Adding organic amendments has been used as a means for ameliorating mine soils and improving their quality, but the long-term effects of amendments on soil quality are not known. Bendfeldt, et al (2001) showed that organic amendments improved short-term production, but their cost of transport and application may be difficult to justify based on long-term soil quality improvement.

## Considerations when Incorporating Residuals

The qualities of residual products make them all potential fertilisers and soil amenders, depending on the combinations and quantities used. However, the major considerations are availability and associated costs. The main cost is transport of the products.

To include residuals into the current rehabilitation process would require consideration of these factors:

- NSW Legislation, planning and environmental approvals;
- Existing environmental guidelines;
- Site suitability;
- Residual product quality and quantity;
- Transport;
- Weed control;
- Public opinion; and
- Costs.

### *NSW Legislation, Planning and Environmental Approvals*

In regards to environmental protection, coal mining operations are bound by the following legislation administered by several government bodies:

- Mining Act 1992 (DMR)
- Environment Protection Operations Act 1997 (EPA)
- Environmental Planning and Assessment Act 1979 and regulation 1994 (DUAP)
- Clean Air Act 1961 (EPA)
- Clean Waters Act 1970 (EPA)
- Noise Control Act 1975 (EPA)
- Pollution Control Act 1970 (EPA)
- Environmental Offences and Penalties Act 1989 (EPA)
- National Parks and Wildlife Act (NPWS)
- Native Vegetation Conservation Act 1997(DLWC)
- Threatened Species Conservation Act 1995 (NPWS)

Land applications of residuals are also bound to comply with these same acts.

The application of residuals when defined as ‘beneficial land application’ is considered ancillary to normal mining rehabilitation operations. Therefore, there is usually no need to apply for additional approvals under State Planning Instruments. However, application of wastes usually requires additional consideration of the pollution potential. This entails completing a Review of Environmental Factors (REF), or an Environmental Impact Statement (EIS) depending on the relevant part of the EPA Act 1979. Also, pollution control approvals or licences are often sought, though not always required by the EPA, for protection of the landholder is the case of a pollution event.

### *Existing environmental guidelines*

Currently, guidelines exist only for the use of biosolids in land rehabilitation. The Environmental Guidelines for the Use and Disposal of Biosolids Products (1997a) require consideration of site suitability and product quality. However, these guidelines are able to be adapted for other wastes. They classify residuals into quality grades based on allowable contaminant levels in the existing environment. There are also EPA guidelines which clearly define the requirements before a product is classed as an A-grade Compost. However, guidelines for greenwaste do not currently exist.

### *Site suitability*

Under the Biosolids Guidelines (EPA, 1997a), slope, soil characteristics, proximity to waters/groundwaters, sensitive areas and dwellings are assessed for any residual use. Most of these are already under consideration for routine mining operations during the development approval process and have been factored into the mining plan before mining commences. Accessibility may also limit where residuals can be spread.

One major limitation is the preferred slope for biosolids application (less than 18% or 10°). Applications can be made to steeper slopes depending on the stability of that slope and the method of application. Residuals with good structure such as biosolids mixed with greenwaste or flyash and/or tailings are preferred on stable steep slopes over biosolids alone (Sopper, 1993).

Mine sites are required to attenuate water movement off site as part of normal mine operations. Zero discharge of waters to creeks is often a condition of the mine's environmental plan. Therefore, the addition of residual amendments, which may contain contaminants, is very unlikely to pollute local waterways, and there should be no need for extra water attenuation earthworks to occur.

There is a low groundwater pollution risk from residual use when rehabilitating mine pits filled with overburden. The water table is generally replenished by surface infiltration so it may take some time before any quantity of groundwater is renewed. Ground water levels on older sites need to be investigated. The ability of the soil to bind contaminants and the quality of the residual will determine the contamination potential, but depths of one metre to seasonal water table are usually sufficient to stop groundwater contamination (Phillips, 1994).

### *Residual product quality and quantity*

The residual products and their combinations need to provide benefits to the existing soils or spoils and therefore encourage revegetation, while not contaminating the substrate. Characteristics of a beneficial residual are:

- high in macro nutrients, such as nitrogen, phosphorus and potassium, and containing micronutrients, such as copper, zinc, magnesium for fertilisation
- pH around neutral, providing buffering capacity for both the alkaline and acid soils found in the Hunter Valley
- reasonable moisture content to provide water in a low rainfall area

- high in organic matter, microflora and microfauna to encourage plant growth and reestablishment of soil structure
- carbon/nitrogen ratio of between 10:1 to 25:1 to make nitrogen available for plant use
- low available contaminants, such as heavy metals, pesticides, salts, and nutrients in excess of plant requirements.

Existing technologies are available to tailor the required residual quality to any site, depending on the availability of the resource. For materials such as green waste, there may need to be a composting facility on-site. At least, this might consist of an area with a hardpacked clay base surrounded by earth bunds. At most, it could be a permanently covered area with specialised compost turning machinery. This type of structure would only be justifiable if there were large amounts of uncomposted residuals available. On-site composting or mixing is preferred over storage or composting in nearby facilities when the amendment product is a tailored mixture and/or the mine site has appropriate environmental safeguards in place.

Uncomposted Sydney garden organics may harbour an aphid (family *Phylloxeridae*) that can potentially cause disease in grapevines. While the likelihood of the aphid surviving in non living material is virtually nil, precautions, such as composting Sydney garden organics before transport or using local garden organics, may be options to eliminate risk to any nearby vineyards.

#### *Transport*

Transport of residuals is often a major consideration of an application program. Obviously, the further the wastes have to be transported, the more expensive the operation becomes. This can be offset by backloading with other commodities, such as coal and mineral fertilisers. Investigation of the local sources of wastes and backloading opportunities is essential. Transporting dewatered and composted materials further reduces haulage costs.

#### *Weed control*

Top-dressing of spoils and overburden introduce aggressive weed species (e.g. *Galenia* in the Hunter Valley) that compete with the establishing crop. Because of this, it has become common practice to allow the establishment of direct seeded tree species on non-dressed sites (Hannan & Gordon, 1996). This has reduced the weed competition problem but often leaves the site severely nutrient deficient. With the addition of nutrients, weed control again becomes an issue. In some cases, the residual introduces its own weed species. In the short term, these species need to be controlled at early establishment, so that the commercial crop is not out-competed, but in the long term they act as a cover crop which will protect the soil and increase organic matter (Newton & Whitehead, 1998).

#### *Public Opinion*

Public reaction to the use of recycled ‘wastes’ as an amendment is often divided. If the product has an associated risk perception of disease and contamination, then it is likely

that some consultation and information sharing with local communities will be required.

### *Costs*

One of the most important cost considerations when using residuals is transport cost. Transporting organics for long distances of 250km can cost up to \$20-25 per product tonne. This is a conservative figure based on periodic backloading. Therefore, the choice of residual will often depend on its close proximity. However, it is also the case that close waste producers may be amenable to helping cover transport costs to dispose of the waste effectively.

The application of wastes has the associated costs of appropriate spreading equipment and incorporation into the soil. Hire of spreading equipment may cost around \$12 per tonne of product (including labour). Other equipment needed, such as tractors and front-end loaders, would generally also be used or available for a normal mineral fertiliser/topdressing operation.

## Evidence of Use of Recycled Organics from Published Literature

There is extensive international literature on the use of Recycled organics in agriculture, forestry and mine rehabilitation. Much of the focus is on biosolids or biosolids composts. The absence of published data from Australia is notable, though a number of studies have been conducted. In NSW, several RO products are stabilized and applied directly to land (eg biosolids and liquid food organics). Biosolids use in land rehabilitation, forestry and agriculture is regulated by EPA guidelines (NSW EPA 1997). Sydney Water began its biosolids reuse program in the early 1990s and by 2000, they were using 97% of biosolids produces in beneficial land application (Sydney Water 2000). Wilkinson et al (2000) assessed a range of RO products from Victoria and NSW. Although the data generated did not account for the nutrient availability for plant growth, it was concluded that these RO products offered significant fertiliser potential.

### 1 Biosolids

#### 1.1 *Use of Biosolids—Australia*

Biosolids has been used in Australia in a range of landscape rehabilitation projects, agriculture and forestry research, with positive results. Biosolids is the nutrient-rich organic material resulting from the treatment of wastewater. After treatment and being spun in a centrifuge to extract excess water, dewatered biosolids are produced. The result is a product that has the appearance of damp soil. Biosolids contain large amounts of moist organic matter. When added to soil, biosolids act as a soil conditioner, similar to the addition of mulch in a garden.

Biosolids are rich in nitrogen and phosphorous. These nutrients are released into the soil very slowly. Approximately 30-40% of the nutrients in biosolids is released in the first year, with declining rates over the next two to four years.

In some parts of NSW dewatered cake is currently applied free of charge by authorities such as Sydney Water. The net cost to Sydney Water is \$45-\$55 per tonne 18% solids), which includes transport, spreading, site permitting and monitoring.

Biosolids have been trialled on both pasture and treed areas in the Hunter Valley coal fields (Turvey and Burns 1999). On treed areas growth enhancement had been excellent. The process of tree growth converts constituents of organic waste into longer-term wood and carbon products that are stored within the tree. Spoil material often has unfavourable characteristics such as high pH, low CEC and can be sodic or saline. These can all be offset by the addition of RO products (Turvey and Burns 1999).

Chapman (1996) estimates that a typical Queensland application of 150 wet t/ha of biosolids cake provides 100kg/N in the first year. The CRC Sugar project indicates positive effects on soil properties from application of sugar byproducts (Barry et al 1999). In field trials in Bundaberg, biosolids were spread at rates up to 48 dry t/ha. (Barry et al 1999)

### **1.1.1 Mine Sites**

The rehabilitation of disturbed involves re-creating pasture ecosystems. Some sites are rehabilitated using topsoil, whereas others are established directly into the overburden mine waste due to the low availability and poor quality of topsoil. Vegetation (pasture and trees) on both substrate types are then maintained by periodic applications of fertilizer. Long-term management options to improve the nutrient status of rehabilitated coal mines in the Hunter Valley are required.

While there is little formal literature, investigations have revealed that biosolids has been used as an amendment prior to establishing seedlings, direct seeding or sowing pasture on the following mines: Rix's Creek, Bloomfield, Camberwell mine, Bulga South Mine, Drayton's Colliery, Ravensworth east (owned by Macquarie Generation), Howick Mine (Brown and Grant 2000, Kelly 2002c,d, 2004), Coal and Allied, Bayswater Power Station and Narama Mine (Kelly 2002c,d).

Trials investigating pasture and tree establishment were undertaken, several on coal mine sites in the Hunter Valley (Pearce, 1991; Rawlinson & Lane, 1992; Logan, 1993; Phillips, 1993; Newton & Whitehead, 1998). These have shown that addition of biosolids at rates of 50-150dt/ha, despite problems such as drought and weed infestation, produced more plant and tree biomass than ordinary fertiliser applications.

In the early 1990's a field trial involving 24 different treatments of sewage sludge, topsoil and inorganic fertiliser was conducted in a small (1.44ha) area of Rix's Creek Mine, near Singleton, NSW. Sewage sludge gave superior dry biomass yields to that of non-sludge treatments (Phillips 1994). Trials of dewatered sewage sludge on open cut mine rehabilitation, have also been undertaken at Ravensworth Mine in the Upper Hunter Valley (Pearce 1991, Walsh pers comm). Pearce used rates of 160 dry t/ha. Pearce (1994) suggested that the potential exists for sewage sludge to be used as a replacement for topsoil in minesite rehabilitation. The Sydney Water trial used rates of 60 dry t/ha. Sydney Water also trial and mixture of biosolids and non-sewage organic matter, which had been composted ('Nitrohumus').

State Forests of NSW is conducting research into the effectiveness of biosolids as an amendment for growing plantation timber in the Hunter Valley. This work has been established since 1999 and includes work on reshaped overburden and buffer lands. The rate of biosolids application has been 50dry t/ha (Kelly 2002a, 2002d, 2002c, 2003, 2004). Biosolids has also been combines with mulch and flyash (Kelly 2002d). Biosolids, incorporated at 50 dry t/ha prior to planting has been a very effective amendment in improving tree growth

In August 1999, biosolids were spread over an area at the Bulga open cut coal mine near Broke. Seedlings of spotted gum, river red gum, two eucalypt hybrids and a wattle were planted three months later.

In 2000, in conjunction with Macquarie Generation and the Natural Heritage Trust, a 40 hectare plantation was established at the Bayswater Power Station near Muswellbrook to trial a variety of soil amendments including fly ash, biosolids and greenwaste (vegetation resulting from clearing for power lines). Species planted included spotted gum, Chinchilla white gum and Ironbark – species chosen for their



drought and salt tolerance. After 12 months, some plantings matched the growth rates from established plantation regions (Kelly 2002d, Macquarie Generation 2001 - Annual Report).

At Coal & Allied's Hunter Valley operations, a research program is under way looking at the processes affecting the successful establishment, survival and growth of trees on rehabilitated mine and buffer lands. Various combinations of bottom ash (a by-product of coal-fired power generation) and biosolids were added to the soil and the results compared to the use of conventional chemical fertilisers. The trial was planted with river red gum/flooded gum hybrids (*E.camaldulensis\*grandis*) and spotted gums. The trees are growing well, with hybrids established in soils treated with bottom ash and biosolids having growth comparable to coastal plantations. Biosolids are providing nutrients and organic matter while the granular, alkaline bottom ash is assisting the soil structure (Kelly 2002c).

Reliance on introduced grass species for revegetation after coal mining in the Upper Hunter Valley (New South Wales, Australia) has not been considered ideal. Non-native species have tended towards a monoculture on rehabilitated coal mines and have high fertilizer requirements, increasing long-term management inputs. Furthermore, rehabilitation is undertaken directly into mine waste (overburden), while topsoil is used in other cases. Biosolids (dewatered, digested sewage) have been increasingly used as a cheap fertilizer and topsoil substitute in a number of previous rehabilitation programmes.

Hannan (1995) found increasing rates of grass cover if biosolids application led to significantly increased grass cover. This is important in the early stabilization of rehabilitated sites.

Parker and Grant (2001) investigated the potential of sewage sludge to improve establishment, growth and surface cover of native (*Agrostis avenacea* and *Danthonia richardsonii*) and introduced grasses (*Phalaris aquatica* and *Secale cereale*) on mine overburden and topsoil. They used biosolids rates of 100 and 200 t/ha. These rates were based on rates in the studies of (Philips 1994a, 1994b). The 100 and 200 t/ha application rates resulted in significantly greater surface cover than no application. However there was no difference in effect between rates of biosolids application. Parker and Grant (2001) found that response to biosolids was similar to that of topsoil, leading to the conclusion that biosolids may be a potential topsoil substitute. Results indicated that the application of biosolids in open-cut coal mining rehabilitation in the Hunter Valley has the potential to increase the growth of native and exotic grass species.

In the Hunter region, green waste, fly ash, bottom ash, lime and gypsum have all been blended with biosolids to improve pasture growth around disused open-cut mining sites. Pasture dry matter yields from these sites have been up to 100 times greater than on those areas left untreated (Bio-Recycle 2003). In addition, those areas receiving processed organics sustained pastures with a much greater legume content, thereby establishing a much more viable soil-plant ecosystem.

In 1994 the Soil Conservation Service used sewage sludge as a topsoil substitute in the construction erosion controls at a Peelwood (a derelict mine with toxic dump material). (DMR NSW 1996)

On Bayswater Colliery and Drayton Colliery (near Muswellbrook, NSW) there have been trials to assess the effectiveness of effluent irrigation and saline irrigation (in combination with biosolids, compost and fertiliser) (Shallvey and Joyce 2001). Results indicate that it may be possible to increase tree growth on rehabilitated mine sites through the application of nutrient amendments and irrigation. Joyce (2002) examined the feasibility of enhancing tree growth by using nutrient amendments and saline mine water. Four native hardwood species (*Corymbia maculata*, *Eucalyptus botryoides*, *E. occidentalis* and *E. tereticornis*) and five nutrient amendments (compost, biosolids, fertiliser, topsoil and overburden as a control) were used. Irrigation was from a main storage dam containing water originating from groundwater inflow to the pit and has an average salinity of 3600 mS/cm.

Early results show that growth is enhanced with no physiological impacts on tree growth. A marginal increase in surface salinity of irrigated plots has occurred. Results suggest that an alternative, sustainable industry based on forestry and irrigation with saline mine water could contribute to the regions social, economic and environmental well-being (Joyce 2002).

Recycled organics can also be used in other degraded sites. Revegetation of industrial sites can require large amounts of topsoil, which is often very costly. Broken Hill Pty Ltd (BHP) created an artificial topsoil from industry by products at its Wollongong site (Cox 2001). The soil mix was coal washery refuse, blast furnace slag and sewage sludge in a 2:1:1 RATIO. It was spread 15cm deep over coal wash mounds and vegetated with tubestock (Thompson and Makin 1990). The available nitrogen and phosphorus resulted in good plant growth. It is well known that biosolids application increase plant growth (Topper and Sabey 1986; Wong and Ho 1994). Initially the soil mix contained a suite of microorganisms and high amounts of organic nutrients (C, N and P). This was attributed to the biosolids and the soil was deemed to be fertile and active (Cox 2001)

In a bauxite mine (Western Australia), red mud, was amended with gypsum (38.5 and 77 t/ha) and sewage sludge (38.5, 77, and 144 t/ha) to evaluate their effects on soil physical properties in a field experiment. Sewage sludge amendment significantly reduced soil bulk density (25%) and particle density (9%), and increased the total porosity of red mud (8%). Both sewage sludge and gypsum contributed to the increases in hydraulic conductivity of red mud (from 1.3 to 24 X 10<sup>-5</sup> m/s) after one growing season. Plant cover % and dry weight yield of *Agropyron elongatum* increased with an increase in gypsum and sewage sludge amendment. Plant growth did not significantly affect soil physical properties, but the enhanced growth was due to improved soil structure and hydraulic conductivity. An application of 77 t/ha gypsum and 144 t/ha sewage sludge exerted the maximum effect on soil physical properties of red mud and should ensure the initial establishment of plants (Wong and Ho 1991)

Biosolids produced from Western Australian sewage treatment plants are currently being reused as organic humus and as a fertiliser substitute on selected agricultural properties, incorporated into commercial composts, and are being trialled for minesite rehabilitation and forestry applications (Biosolids Working Group 2002)

De Vires and Merry (1980) experimented with biosolids at rates of 0, 8, 24 and 72 dry t /ha from Adelaide's metropolitan area. They found that 24 t ha was suitable for growing crops and trees. The limitations were due to heavy metals, the risk of which, with improving trade waste policies in the last 2 decades, has significantly reduced - thus allowing higher and more effective application rates.

In 1999 a market assessment indicated that there was sufficient potential in the intensive agricultural sector in the metropolitan and outer Adelaide alone to absorb the increase in recycled organics (EPA SA 1999). However, this was predicated on two things - the quality of the goods produced and that there was no excessive competition from the release of biosolids. In NSW, unlike SA, the use of biosolids significantly preceded that of garden organics and therefore has established itself as a very cost efficient competitor. The SA assessment recognised this fact and recommended that biosolids target markets that do not compete with RO derived products. It may be difficult for RO derived products to post-hoc compete with Biosolids in the mine rehabilitation market - principally due to price.

Hunter Water has successfully use biosolids in mine site rehabilitation in the Hunter Valley. Biosolids has been used for site rehabilitation, under tree and pasture, at South Bulga Colliery, Drayton Coal and Oceanic, Macquarie Coal CHPP (Hunter Water 2000)

During 2000, Hunter Water Corporation transported approximately 872 dry solid tonnes of Restricted Use 2 grade biosolids to mine sites within the Hunter for beneficial reuse in land rehabilitation programs. In addition, Hunter Water Corporation delivered approximately 119 dry solid tonnes of Restricted Use 2 grade biosolids to mine sites within the Hunter for beneficial reuse in plantation establishment trials. Overall, approximately 991 dry solid tonnes were beneficially reused on Hunter mine sites (NSW Legislative Council, 2001).

### ***1.1.2 Forestry***

Since the early 1990s, State Forests of NSW have embarked on a number of trials using organic wastes such as biosolids to assess the impacts such soil ameliorants may have on tree survival and growth (Kelly 1993, 1994, 2000, 2002a, 2002b, 2002c, 2002d, 2004).

The earlier period of research was focused on the use of biosolids on pine plantations in the central west and southern highlands of NSW (Kelly 2000b). More recently, research efforts have turned to using biosolids and other soil amendments such as bottom ash (a by-product coal-fired power generation) and green organics on low rainfall hardwood plantations in the Upper Hunter Valley (Kelly 2002a,b, c, d, 2004).

In 1991, State Forests began applying biosolids to 120 hectares of plantations in eleven sites across the southern tablelands and central west. Initially, biosolids were added to the surface of existing pine plantations to promote growth. Researchers were encouraged when increased growth rates of 30 per cent were achieved (Kelly 1994).

Building on this success, in 1995 biosolids were incorporated into the soil prior to establishing the plantation. After five years of monitoring, it was found that tree height was improved by as much as 50 per cent and tree diameter by 85 per cent. Additionally, researchers found that the extra growth achieved with biosolids had not impacted on timber density – an important characteristic of timber quality and use (Kelly 2000b).

Andrade et al (2000) applied biosolids to a recently planted (4 months) area of *E. grandis*. The biosolids was applied to the soil in rates of 10, 20 and 40 t ha<sup>-1</sup> (dry weight basis), in inter-row spaces without incorporation. Biosolids application did not change total and inorganic nitrogen concentration in soil, although N concentration in the leaves increased with the rate of biosolids applied. SFNSW data (Kelly 2002c) shows similar trends for N, although P is significantly increased with biosolids application. SFNSW data also shows that for eucalypts, incorporating (into mounds) prior to planting is more effective than surface application post planting (Kelly 2002b).

Costantini et al (1995) experimented with biosolids in Queensland, on pine, at rates of 90 t/ha. Loch et al (1995) found that biosolids broadcasting caused no significant increase in erosion. In fact downslope flows were typically slow and any entrained particulate sludge would have been filtered out by pine needles. They concluded that movement of particulate sludge by overland flow is not a significant risk.

### **1.1.3 Landscaping**

Australian Native Landscapes Pty. Ltd. used composted material, including 72,000 cubic metres of composted sewage sludge, at Sydney Airport (Biocycle 1995).

Cox et al (2000) created an artificial soil mix made out of industry wastes and sewage sludge, for the revegetation of an industrial site. This study has shown that soil development had occurred in the short and longer terms, with rapid changes seen in the first 12 months. High levels of N and P remaining after 11 years, and abundant organic C for microbial decomposition, indicate the potential for nutrient cycling.

### **1.1.4 Agriculture**

Baker et al (2002) applied dewatered biosolids (DWB) to infertile agricultural, acidic soils at the rates of 30, 60 and 120 tonnes ha<sup>-1</sup> and compared to a fertilized and limed control. Application of DWB increased earthworm abundance (an indicator of improved soil condition, peaking in the 30 tonnes ha<sup>-1</sup> treatment, with no significant difference between the three rates of DWB).

Dewatered biosolids (DWB) were applied at 0-120 dry t/ha to 3 types of soils in a sheep grazing trial at Goulburn and over a period of 1.5 years data were gathered on the surface and subsurface movement of nutrients and metals in the runoff water and soil profile, respectively. The biosolids reduced runoff and increased surface retention of rainfall. Surface and subsurface movement of nitrate and some metals were detected in the trial. However, the actual amounts of these plant nutrients were low and almost negligible in treatments applied at rates of 30 dry t/ha (Joshua et al 1998).

A grazing experiment was carried out at Goulburn, NSW, in 1992 to assess the benefits and risks associated with recycling sewage waste products on pastures. Results showed that sewage waste application increased yield of green dry matter and perennial grass content. Nutrient content in plant tops was improved by dewatered cake. Production (liveweight and wool yield) and health of ewes and their offspring were not significantly affected by these sludge induced changes (Michalk et al 1996). Armstrong and Koen (1994) found in a pot trial that surface application of 100t/ha of biosolids to degraded soils in Canberra significantly improved dry matter production of ryecorn, while incorporation of 50 dry t/ha was optimal.

Munn et al (2000) found that more available N occurred in soils treated with sludge than in unamended soils, and available N increased with the amount of sewage sludge added. Soil amendment with sludge increased the concentrations of total N, C and exchangeable cations, as well as pH, in the soil. Sarooshi et al (2002) also found that biosolids compost at the rate of 125t/ha maintained the C and N requirements of a number of vegetable crops in NSW

A field experiment was conducted with lucerne on a strongly acidic and phosphorus deficient soil to determine the liming and phosphorus and nitrogen fertilizer value of an undigested, lime-treated sewage sludge (Willet et al 1986). The sludge was a source of lime, phosphorus and nitrogen. The sludge (5 or 10 t ha<sup>-1</sup>) phosphorus was 49% as effective as the fertilizer phosphorus in raising extractable phosphorus in the soil to the level required for crop growth. It was not possible to achieve the yield obtained with 25 t ha<sup>-1</sup> of sludge with combinations of agricultural lime, and nitrogen and phosphorus fertilizers at high rates of application. This was attributed to the effects of the sludge on improving soil physical properties (Willet et al 1986). In Western Australia, Wong and Ho (1991) also reported improvements in soil structure with the use of biosolids. They found that the addition of biosolids improved soil structure and hydraulic conductivity of red mud.

## 1.2 Use of Biosolids—General

One of the potential long-term advantages of municipal biosolids application is an increase in site quality through permanently higher organic matter and nutrients (Henry et al 1994). Harrison et al (1995) observed that added P from biosolids was more strongly retained than N. This supports the work of Kelly (2002c).

Czekala, (1999) investigated the attribute of biosolids in Poland. There were large amounts of organic matter (31.2-73.3% dry matter), and the organic carbon levels range from 39.7 to 83.0%. Sewage sludges contained N (on average 3.2%), phosphorus (on average 1.66%), calcium (on average 3.12%), magnesium (on average 0.54%) and sulphur (on average 0.87%). Hence, one ton of dry matter of sewage sludge contains the a mean of 543 kg of organic matter, 32 kg of nitrogen and 16.6 kg of phosphorus (Czekala, 1999).

Akhtar et al (2002) mixed anaerobically digested sewage sludge was with three soils at a rate equivalent to 80 Mg sludge ha<sup>-1</sup>. They concluded, based on time trends, that sludge as a P source on a P-limited soil should be applied well before the period of maximum plant demand. Elevated temperature (37°C) typical of mid-summer,

promotes depletion of more available (strip-P and soluble P) fractions compared with lower temperature (25°C). Soil texture and the presence of carbonates strongly influence the fate of P from applied sewage sludge. Data from SFNSW trials indicates that biosolids should be applied and incorporated 2-3 months prior to planting.

The influence of sewage sludge application on some soil properties was investigated in Greece by Tsadilas et al (1999). Sewage sludge was applied at rates ranging from 0 to 300 t ha<sup>-1</sup> year<sup>-1</sup>. Organic matter content was significantly increased while soil pH was slightly decreased; available P was greatly increased in the surface layer; nitrate N was greatly increased in the whole soil depth. Phosphorus was strongly correlated with organic matter content (Tsadilas et al 1999).

Aguilar et al (1996) examined the effects of biosolids applications of 0, 22.5, 45, and 90 t/ha to a degraded rangeland, on the soil chemical properties and N mineralization potentials 8 and 9 years after the application. Nitrogen mineralization potentials were significantly higher ( $P < 0.05$ ) in the 45 and 90 t/ha applications after 9 years, indicating that site fertility remained higher even though most soil chemical properties were returning to untreated levels

Zaman, et al (2002) showed that the soils amended with sewage sludge composts displayed larger and more active microbial biomass than those treated with chemical fertilizer. This has implications for current interests in shifting from chemical fertilizer application to organic wastes for promoting efficient nutrient cycling in agro-ecosystems (Zaman, et al 2002)

It has been found that the addition of 10% w/w sewage sludge improved soil structure, increased water capacity and decreased bulk density of the plough layer in a sandy soil (Baran et al 1996). El Shafei, (1997) found that sludge may increase the ability of sands to store water for plant use. Holz et al (2000) found that application of sewage sludge significantly increased soil moisture and organic matter contents in the top 3 cm of soil.

An anaerobically digested sewage sludge was applied to silt loam in Columbus, USA, at rates of 0, 7.5, 15, 30, 60, 90, 120, 150, 188, 225, and 300 Mg/ha. Surface soils (0-15 cm) were sampled 4 years after sludge application. Bulk density significantly decreased, and porosity, moisture retention increased with increasing sludge application. Physical property responses to sludge application were linear except for aggregate stability and mean weight diameter of aggregates that showed a maximum effect at 60 Mg/ha sludge application rate. Organic C increased linearly with sludge application, and 4 years after application there was three times as much C in the 300 Mg/ha plots as in the zero sludge control plots. Many of the observed differences in soil physical properties were due to the effects of added organic matter and these effects persisted for at least 4 years (Lindsay and Logan 1998).

### **1.2.1 Mine Sites**

The surface layers of mine spoils are extremely poor in plant nutrients and organic matter and are unable to sustain plant growth if left unamended (Bryon and Bradshaw

1991). The use of biosolids to restore these disturbed lands has been very successful (EPA 1984, Hinesly et al 1984, Sopper 1991).

Zier et al (1999) note that as a result of lignite mining, areas around Lustian, Germany, lack soil nutrients as well as humus. Efforts have been made to improve the soil conditions by application of organic materials such as compost, sewage sludge and brown coal sludge (Haubold-Rosar et al 1993; Katur and Haubold-Rosar 1996).

Results from the Rhineland lignite mining area show that the regular input of organic matter (manure, waste compost, sewage sludge) favours the accumulation of soil organic matter (SOM). The type of organic matter applied seems to be less important to the long-term accumulation process than the application rate (Delschen 1999).

When rehabilitating a tailings area from a Molybdenum mine, Margolis et al (2001) found that a combination of wood chips and biosolids, spread over waste rock produced a suitable medium for grass seeds and shrubs.

Lindemann et al (1989) assessed nitrogen mineralization in coal mine spoil and topsoil under various conditions. Sludge and straw were used as amendments. Sludge amendments increased N mineralisation, but straw amendment immobilized N through 12 weeks of incubation. N mineralization was slightly lower in stockpiled topsoil than in fresh topsoil or mine spoil. Mixing mine spoil with soil can increase plant available N more than soil or spoil alone, because spoil contributes mineralizable organic N while soil improves physical and chemical environment.

Dried aerobically digested sewage sludge applied at varying rates (0, 10, 20, 40, 60, 80, and 120 tonnes ha<sup>-1</sup>) which resulted in a significant increase in the available water capacity, concentrations of organic matter, total N, and extractable P (Olsen) of mine spoils (Brofas, et al 2000)

Sopper and Seaker have conducted biosolids research on degraded sites in the Pennsylvania coal fields (Sopper *et al.*, 1982; Seaker and Carrello, 1989). Their trials showed that dewatered biosolids and biosolids composts mixed with flyash were successful soil amendments for re-establishing hardwood species. A single biosolids application of 150dt/ha yielded 55dt/ha of woody biomass over 5 years, almost a tenfold increase (Sopper & Kerr, 1982). They also showed that organic matter increased readily, improving soil development and ecosystem recovery more so than fertiliser applications (Seaker & Sopper, 1988). However, these trials were done in areas with higher rainfalls and different site qualities.

Sopper (1991) used 184t/ha of stabilized dewatered biosolids to revegetate a compacted site that during the previous decade had failed to revegetate using lime and commercial fertilisers. One time application rates of 100-4000t ha for the purpose of mine site reclamation have been reported (Hue 1995).

At a Superfund site in Bunker Hill wood ash was applied at the rate of 100 wet t/acre to provide a calcium carbonate equivalent of 22t/a (Henry and Brown 1997). Biosolids were applied at 25 and 50 dry t/acre. In addition log yardwaste was added at a fixed

volume ratio of 1:5. Henry and Brown (1997) note that a period of time, prior to seeding, is required after amendment.

Dried aerobically digested sewage sludge applied at seven rates (0, 10, 20, 40, 60, 80, and 120 tonnes ha<sup>-1</sup>) in a field experiment on calcareous bauxite mine spoils on Giona mountain in central Greece significantly increased the available water capacity, concentrations of organic matter, total N, extractable P (Olsen), of mine spoils. Plant biomass, plant density, and foliar cover significantly increased with treatment rates in the first and fourth growing seasons but decreased with time (Brofas et al 2000).

### **1.2.2 Forestry**

Biosolids enhances forest productivity (Gaynore and Halstead 1976; Becket et al 1977) improves soil chemical and physical properties (Epstein et al 1976; Zasoski 1981). Many short-term benefits have been noted but the longer-term benefits of increased nutrients and organic matter, have received less research (Chang et al 1984; Jokela et al 1990).

Henry et al (1995) notes the successful use of liquid and semi liquid biosolids in young and older plantations. They note that potential benefits from applications of organic residuals to forested ecosystems can be classified into three categories: soil improvement, increased timber production and secondary benefits from the understorey vegetation response. Numerous studies have been conducted on growth responses following biosolids application. Increase tree growth has been reported in a number of symposium proceedings (Sopper and Kerr 1979; Bledsoe 1981; Sopper et al 1982; Cole et al 1986).

Researchers at the University of Washington recommend that sludge be applied at the rate of 47 t ha<sup>-1</sup> every five years to maintain good tree growth, yet minimise risk of leaching.

Ryans (2000) showed that spreading biosolids could be efficient, with spreading costs of \$5 wet tonne. The biosolids was spread at the rate of 55 dry t ha<sup>-1</sup>. This was then covered with a layer of bark that served as a mulch. Poplar cuttings were planted some 3months later.

In Spain, Andrade et al (2000) used 10,20 and 40 dry t ha of biosolids on *E grandis*. Biosolids application did not change total organic and inorganic nitrogen concentration in the soil, although the N concentration in leaves increase with the rate of biosolids applied. Vaz and Goncalves (2002) evaluated the effect increasing biosolids rates (0, 5, 10, 15, 20 and 40dry tha<sup>-1</sup>) on *E. grandis* stands. They found that increasing rates for 0-40 tha<sup>-1</sup> resulted in a quadratic response of wood production. The response to biosolids application increased with age, mainly due to the beneficial effects of increasing nutrient available for the trees.

Bramryd (2002) determined the effects of sewage sludge application on nutrient concentrations in soil and plant biomass fractions in Scots pine (*Pinus sylvestris*) forests. Application of 20 tonnes dw ha<sup>-1</sup> of sewage sludge significantly increased the concentrations of extractable N, P, K, Ca, Mg and Na, in both the mor layer and in the



upper 10 cm of the mineral soil. After 11 years the concentrations of P were still at the same level in the mor layer as after three years.

El Baha, (2001) added four levels of amendments to one-year-old seedlings of *Eucalyptus camaldulensis*. The site was a very dry, poor and sandy soil in Egypt. The amendments were applied in two dressings, organic fertilizer as sewage sludge (F1) (5 tonnes sludge/feddan – equivalent to 13t/ha)); inorganic fertilizer as NPK (F2), 100 kg N/feddan as urea, 50 kg P/feddan as superphosphate and 25 kg K/feddan as potassium oxide; the mixture of them (F3) (2.5 tonnes sludge+50-25-12.5 kg NPK)/feddan, and the unfertilized trees (F0). Results showed that dried sewage sludge was better than inorganic fertilizer and the mixture of them. Average stem volume of trees amended with sewage sludge, inorganic fertilizer and the mixture of them, was 128, 42 and 96% greater than the control.

### 1.2.3 Agriculture

Hemphill (1985) reported significant increase in lettuce and broccoli on soil amended with tannery waste at rates ranging from 32-192 t ha<sup>-1</sup>. Rappaport et al (1988) applied aerobically digested biosolids at rates from 0-210 Mg ha<sup>-1</sup>. Corn yields increased linearly with increasing sludge application rate (and metal concentrations in grain and leaves were within normal limits). For small grains, yields peaked when 90 Mg ha<sup>-1</sup> of composted sludge and 45 Mg ha<sup>-1</sup> of urban biosolids were annually applied for 7 years (Vlamiš et al 1985)

The N-Viro process involves the mixing of de-watered sewage sludge (25% dry matter) with alkaline admixtures. Crop yields from the N-Viro and liquid digested sludge treatments were greater than the control or inorganic N treatments (Chambers, et al 1998)

Cogger, et al (2001) evaluated the effects of seven years of biosolids applications on tall fescue (*Festuca arundinacea*) production and nutrient availability. Mean annual biosolids rates of 290, 580, and 870 kg total N ha<sup>-1</sup> year<sup>-1</sup> were compared with inorganic N and zero-N controls. Forage yields increased with biosolids rate. Apparent nitrogen recovery (ANR) for biosolids averaged 18% in 1993 (Year 1), 35% in 1994, and 46% in 1999. The ANR for inorganic N averaged 62% from 1994-1999. Biosolids increased soil organic C levels by 2 to 5 g kg<sup>-1</sup> and Bray-1 P levels by 300 to 600 mg kg<sup>-1</sup> (0-15 cm depth) (Cogger, et al 2001)

## 2 Mulch

### 2.1 *Mulch in Australia*

'Greenwaste' compost demonstration trials undertaken by NSW Agriculture and Landcare near Orange, investigated the establishment of native species such as *Casuarina*, *Eucalyptus* and *Acacia* (NSW Agriculture, unpublished). Combinations of 20% Nitrohumus (greenwaste and biosolids) and 80% composted greenwaste were used as mulch on newly planted seedlings and 18 month old seedlings. Mulching increased survival and growth in the first growing season.

In South Australia CSIRO has used recycled organics to improve soil conditions to sustain efficient plant production in intensive horticulture systems. In Melbourne, two field trials involved the use of recycled organic material in roadside landscaping and intensive vegetable cropping (Horan and Hartmann 2000).

In Western Australia, improved tree growth has been recorded for orchard trees where 5-6cm was applied as a mulch (Paulin 2000).

In Queensland shredded "green waste" products are used primarily as bulking agents for biosolids composting, and in commercial composting operations (Qld EPA 2002). The material is screened directly after shredding and sold as forest mulch or further processed for inclusion in landscape projects (Qld EPA 2002). A considerable amount of low priced mulch is used in large, commercial landscaping projects such as the Pacific Motorway.

Very little shredded mulch is sold for retail purposes because of issues including quality, weed seeds and pathogens. However, the market still exists and is price base (although the product will not comply with Australian Standards). Australian standards require the fine mulch to be pasteurised. The major competition for forest mulch from garden organics is low-grade bark and eucalypt mulch from commercial tree loppers. Compared with uncomposted mulches, garden organics compost will not break down quickly or compete with plants for soil nutrients (Qld EPA 2002).

#### 2.1.1 *Mine sites in Australia*

Organic residuals combined with surface mulches, such as low sodium/sulphur coarse coal reject, are considered good for providing a microclimate suitable for germination, reducing crust formation and improving water infiltration (Hannan & Gordon, 1996). Also the use of amendments for improved soil stability, such as gypsum on alkaline soils and lime for acid soils, can balance mixtures.

In Queensland rehabilitation is undertaken at least cost using materials on hand. Although the organic component of RO products would provide benefit, use of RO products is unlikely unless they were provided at a competitive price (QLD EPA 2002). Application rates of 30-50 dry t ha<sup>-1</sup> are used, with the product being incorporated into the topsoil and or subsoil. Some rehabilitation has been undertaken by using biosolids private contractors at Swanbank at a cost of \$25-\$38 product tonne. Plant growth was enhanced but odours, cost and industrial relations were an issue.

Gillespie et al (2003) investigated native understorey species regeneration at NSW coal mines and concluded that emergence and species richness is improved with irrigation. They also found that mulched topsoil is a more appropriate medium for native understorey species re-establishment than spoil, regardless of irrigation or any media amelioration.

## 2.2 *Mulch in General*

### 2.2.1 *Mine Sites and Mulch*

Mulches can improve forage establishment on mine spoil when they reduce water loss by reducing evaporation, protect the soil from erosion and minimise soil crusting (McGuinnies 1987; Schuman et al 1990). Norland (2000) and Daniels et al (2000) also discuss the benefits of mulching. Dyer and Sencindiver (1985) found that response to mulching varied with site slope and aspect. Mulching was found to be very beneficial to early cover on south-facing slopes receiving higher solar radiation (equivalent to north facing slopes in the southern hemispheres).

Panwar and Bhardwaj (2000) examined the effect of soil amendment and mulch on the establishment of trees in sandstone mine spoil (India). They showed that farmyard manure (FYM) when added as a soil amendment and mulch, increased survival, height and biomass, however root shoot ratio was maximum in mine spoil alone. Trees in degraded lands tend to elongate their roots to facilitate water and nutrient absorption. . These results are consistent, as it is known that root: shoot ratio increases in poorer drier substrates.

Singh et al (1994) reported that soil amendments increased biomass production. Topsoil, to a depth of 30cm, has been shown to produce enormous benefits for the establishment of plants on minespoil (Hannan and Bell 1986; Schuman et al, 1985). However, as little as 5cm can produce enormous benefits on zodiac spoil (Power et al, 1976, Hannan and Bell, 1986). This information may have implications for the selection of depth of any surface amendments or mulches. The physical soil size distribution of spoils can be a problem that is often worse on rapidly weathering spoils (Russell 1979). However, Russell (1985) found that mulching the surface with vegetation, coal reject or gravel will often correct this by maintaining a lower crust strength in the moister spoil.

Hay and straw mulches have been noted as being valuable in encouraging revegetation on saline scalds (Williams et al 1987) and in minimising erosion on difficult spoils (Lattanzi et al 1974). They largely eliminate raindrop impact as an erosive force, improve infiltration and reduce evaporative losses after rain (Plass 1978, Kelly 1981, Kay 1978). Where hay mulching is used, the hay should go on after the spoil (and topsoil) has been deep ripped (Silcock 1991). Crimping the hay into the surface is not recommended because the mulch's value as a moisture conserving blanket is reduced (Rickett 1973).

## 3 Compost

### 3.1 *Compost in Australia*

Paulin (2000) reported that current use of compost in WA tends to be ad hoc. Although a significant number of farmers were using compost, cost was cited as a major concern. However, trials indicate that compost could achieve a 30% reduction in fertilizer, pesticide and irrigation costs. Commercial compost made from both agricultural and urban residuals have been applied to vegetable plots at rates from 15 to 200m<sup>3</sup>/ha. Yield improvements of up to 25% have been achieved with compost applications from 15 to 60m<sup>3</sup>/ ha.

In Queensland limited quantities of composted green waste/biosolids are currently sold as a soil conditioner to the sugar cane industry at \$28m<sup>3</sup> delivered (Qld EPA 2002). Biosolids has been applied to forestry land at rates of 10-100dst ha<sup>-1</sup>, depending on the nutrient status of the soil.

### 3.2 *Compost in General*

The key advantage of compost application is the replenishment of organic matter in the soil. Top ups of conventional inorganic fertilisers (Typically N) may still be required, but the improved organic carbon bank will ensure a greater efficiency of use, with losses through leaching and volatilization less likely (Pittaway 1999).

Pickering et al (1987) applied greenwaste compost and conifer bark chips at a depth of 5 and 10cm. During summer the main differences were seen - the deeper the mulch the greater the moisture retention. Moisture content under greenwaste compost was significantly higher than under bark. Summer surface temperatures were significantly lower under bark than greenwaste compost. Composts made from biosolids and woodchips or sawdust may be used to grow many different horticultural crops under field and container conditions (Gouin 1993).

Uncomposted chicken manure (5 and 15 t/ha) and green waste compost (50 and 300 t/ha) were applied annually in a replicated trial. Application of organic amendments increased crop yields. N in uncomposted chicken manure appeared to be more available for plant uptake than N in green waste compost. Applying green waste compost at 300 t/ha increased soil organic carbon content from 2.7% in the control to 3.6% (Pearson et al 1998)

Uson et al (1995) investigated the soil-water status of 3 crops, under field trials of composted organic waste incorporated in the topsoil and applied as a surface mulch. Mulches maintained higher soil-water content near to the surface in the early season. Later in the season, soil-water deficits were reduced when weeds were suppressed.

In England, Cook et al (1998) applied green garden waste at four rates (0, 50, 100 and 150tha) and assessed its impact on barley. The minim application rate required to achieve a measurable benefit was 150 t/ha, where there was a 25% increase in plant dry matter.

From the available literature a compost rate of 70-150t/ha appears to be required to elicit a significant benefit.

### ***3.2.1 Mine Sites and Compost***

No scientific literature was found on the use of compost on mine sites in the Hunter Valley or NSW. However internationally mine overburden spoil has been mixed with compost in varying proportions, which found that after seed sowing under 1:2 spoil-compost combinations height of trees increased 364.9% and collar diameter increased 63.9%. Similarly, increase in biomass was also observed. The most beneficial combination found was equal proportion of spoil and compost and urea at 150 ppm N (Banerjee et al 1999).

In a Canadian Coal mine, deep ripping, with and without the use of organic matter amendments (manure and peat) was assessed. Some significant effects on physical and chemical properties of the substrate were observed. Specific management practices such as organic matter additions are recommended to overcome the detrimental changes in soil properties that have occurred due to mining (Bateman and Chanasyk, 2001)

## 4 Municipal Solid Waste

### 4.1 *Municipal Solid Waste in Australia*

A number of research trials are currently being carried out in Australia on Bedminster Compost. At Ravensworth South a trial compares the use of Bedminster compost with Biosolids for mine site rehabilitation. The compost and Biosolids were applied in Autumn 2003. At Rothbury a number of recycled organic products are being used in a viticulture trial. The compost was applied as a mulch to the vine rows. A peat replacement trial is being coordinated by the Queensland Department of Primary Industries and looks at potential substitutes for peat in potting mixes in Australia (Bedminster 2003). No formal data is published in the literature on the results of these trials but Bedminster claim that the Bedminster compost produces good early growth and excellent water holding capabilities.)

### 4.2 *Municipal Solid Waste in General*

Composted MSW could be a valuable resource. The addition of organic materials adds nutrients and can also improve the soil biological, physical and chemical properties. The improvement of plant establishment has a feedback effect with the addition of more organic biomass and the development of a rooting system through the soil (Nortcliff 1998). This is particularly critical in minesite rehabilitation.

Composted MSW has a high organic matter content and can be a source of slow release N and P, as well as microorganisms capable of activating the soil microflora (Albaladejo et al 1994; Garcia et al 1992; Fortun and Fortun 1997).

Zinati, et al (2001) found that compost has beneficial effects on soil fertility. Compost from municipal solid waste (MSW) (100% MSW), Bedminster co-compost (75% MSW and 25% biosolids) and biosolids compost (100% biosolids) at 72, 82.7 and 15.5 t ha<sup>-1</sup>, respectively, were each incorporated in soil beds and inorganic fertilizer (6-2.6-10) NPK at 2.8 t ha<sup>-1</sup>. A control (no amendment) treatment was also included. Amending soils with MSW compost significantly increased the organic carbon in humin. MSW compost has a potential to be used as a soil amendment to increase and sustain the organic carbon in calcareous soils. (Zinati, et al 2001)

Cuevas et al (2000) surface applied three rates of MSW (40, 80 and 120 Mg ha) to degraded shrubland in Spain. Total biomass increased as compost rates were added, but the rise was not proportional. Rates of 80 Mg MSW/ha are required to improve soil chemical properties.

Madrid et al (1998) compared the effect of MSW and a commercial compost made from sheep manure, on tomato plant growth. MSW was applied at a rate of 21Mg/ha and the commercial compost at 5 MG ha<sup>-1</sup>. Both these products caused an increase in organic matter and nutrients in the soil compared to the control. Fruit yield was higher than the control.

Applications of composted MSW to forests soils have been shown to improve the soil conditions for the developing stand (Smith and Evans 1977; Smith et al 1979). A

number of studies using MSW compost have been conducted in Florida and growth responses well documented (Smith et al 1979; Bengston and Cornette, Fiskell et al 1979; Jokela et al 1990). Incorporation on 4.4 to 44Mg ha showed significantly greater response than a similar surface application.

Enhanced soil and physical properties following application of MSW compost have been reported on several occasions (Haan 1981, Gallardo-Laro and Nogales, 1987, Chaney 1990). Co-composting of MSW and biosolids produces compost with a higher N content. Deboz et al (2002) used household's compost at the rate of 17t DM/ha-1 and found that 5 months after amendment, compost had increased potentially mineralizable N in the soil by a factor of 1.8.

## 5 Flyash

As coal is burned in the boiler of a coal-fired power plant, ash is partitioned into bottom ash (or slag) which remains in the furnace and flyash, which rises with flue gases and is collected separately (Bhumbla et al 2000)

### 5.1 *Flyash in Australia*

The disposal of fly ash from coal-fired power stations causes significant economic and environmental problems. A relatively small percentage of the material finds application as an ingredient in cement and other construction products, but the vast majority of material generated each year is held in ash dams or similar dumps. This unproductive use of land and the associated long-term financial burden of maintenance has led to realization that alternative uses for fly ash as a value-added product beyond incorporation in construction materials are needed (Iyer and Scott 2001).

In the Hunter Valley 150 dry t/ha of flyash and bottom ash was used to ameliorate compacted soils (Kelly 2002c, 2002d). Anecdotally it is also known to be used in combination with biosolids for the establishment of pasture (Macquarie Generation pers comm). While flyash has been trialled successfully as a bulking agent and soil conditioner on mine sites overseas (Sopper & Kerr, 1982), very little is known about its mode of action. However, the agronomic use of flyash has been trialled under a number of conditions.

Pot trials done by NSW Agriculture showed that flyash increases growth in sandy soils compared to clay soils. Characterisation trials by NSW Agriculture also show that pH varies widely from acidic (<5) to alkaline (>9), depending on the type of coal burnt. The power stations in the Hunter Valley produce alkaline flyash, ranging from 9-12. However, even alkaline flyash may still be desirable as a soil amendment because it is high in total and available phosphorus. Investigations of possible mixes with acidic residuals would need to be made to see if alkaline flyash was suitable.

Flyash on agricultural crops at the rate of 50dryt/ha resulted in no significant effect (NSW Dept Agr.). The literature indicates that rates of 150 dry t/ah appear to be required for a positive significant effect to be achieved.

Campbell et al (1983) found that the addition of 10% by weight of ash increased the available water capacity by factors of 7.2 (1.0-7.2 % by weight) and 13.5 (0.4-5.4% by weight) for the 'fine' and 'coarse' sands respectively. Menzies and Aitken (1996), substituted fly ash for a portion of either the peat or sand component of the UC mix, at rates of 10, 20, 30 and 50% of the mix volume. Incorporation of fly ash greatly increased the plant available water capacity (10-1500 kPa) of the substrate.

A pot experiment carried out with pulverised fuel ash (PFA) at rates equivalent to 0, 20, 60 and 180 kg Mg/ha used a perennial ryegrass as the indicator plant. PFA increased DM yield (thought to be due to S) and significantly increased Mg levels in the tissue to >0.4% on the highest treatment (Hill and Lamp1980).

Australian flyashes contain negligible amounts of N, but their P status is variable (Aitken et al 1984). Of the flyash produced in Australia a small amount is turned into a resource which is mainly used in the building industry (Beretka and Brown 1976).



Research in a number of countries has indicated that some ashes may have agronomic potential as liming agents (Doyle 1976; Hodgson et al 1982), boron fertilisers (Mulford and Martins 1971; Plank and Martents 1974) and as a physical amendment for soils (Doyle 1976; Chang et al 1977). The potential for the agronomic utilisation of fly ash produced in Australian power stations has received little consideration (Aitken et al 1984).

Campbell et al (1983) proposed that Australian ashes be used to improve the water holding capacity of sandy soils. Aitken et al (1984) considered a number of fly ashes including that of Liddell Power station in the Hunter Valley of NSW. The available water capacities of all ashes were moderate to extremely high, although in the dry state all ashes lacked any form of aggregation and tended to be incoherent, suggesting that both wind and water erosion may be a significant problem on unstabilised surfaces. A marked difference existed between the bituminous black coals of Queensland, NSW, SA and WA and the lignite brown coals of Victoria. Most ashes had a pH in excess of 8.5. The buffering capacities of ashes varied. The essential plant nutrient constituents indicate that flyash would be N deficient. P levels were generally low, although the Liddell flyash had a bicarbonate extractable level (available P) close to the critical level of 30 mg/kg. While other Australian Ashes had low levels of available K, the Liddell ash had a K content greater than the suggested critical level of 0.3 C g<sup>-1</sup>. The alkaline nature of the ashes was not considered a problem since most of the ashes are poorly buffered (Aitken et al 1984).

In WA, Summers et al (1998) found that flyash improved clover production (up to a rate of 100 t/ha). It provided the necessary phosphorus and the maximum yield was achieved with an application rate of 50t ha. Luke (1983) reported that 100 t ha of WA flyash significantly increased soil moisture content - the total soil moisture content was doubled by the addition of flyash.

Flyash was also trialled for its potential environmental benefits in Western Australia. The flyash retarded NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>, and P leaching in the sandy soil and was therefore a potential tool for improvement of nutrient management in sandy soils (Pathan, et al 2002).

Based on the literature and the experience of State Forests of NSW, intermediate rates of flyash application (100-200 t ha<sup>-1</sup>) are recommended

### **5.1.1 Sugar Cane Ash**

A mixture of equal parts of filter mud and fly ash from sugar mills applied to sugar cane at spreading rates of approximately 230 t/ha wet weight gave significant yield increases of the same order as those from filter mud alone. (Maclean, N. R.1976).

## 5.2 *Flyash in General*

Coal fly ash has physical and chemical characteristics that make it useful as a soil amendment, one of the more important being the potential to permanently improve the soil water relations of sandy, drought-prone soils.

Many research reports suggest the positive impact of flyash on soil properties (Deshmukh et al 2000). Giedroje et al (1980) reported that application of flyash at 200-288t ha<sup>-1</sup> improved the chemical and physical properties of sandy soil. Maciak (1980) reported rapid decomposition of organic matter in soil receiving flyash. Deshmukh et al (2000) that found that flyash was useful in the improvement of NPK and micronutrients as well as physical proprieties of the soil. They also found that flyash applied in rates 0-15t ha, that 10t ha was superior.

Studies with different fly ash concentrations showed that soil pH and water-holding capacity increased with increase in concentration of fly ash (Brahmachari, et al 1999). Gangloff et al (2000) used application of high rates of fly ash (up to 950 t/ha) and assessed the changes in the infiltration rate and water holding capacity of a sandy soil after. Fly ash amendment not only increased water holding capacity but also increased plant available water by 7-13% in the 100-300 kPa range.

Hammermeister, et al (1998) applied fly ash treatments (0, 100, 200, and 400 t ha<sup>-1</sup>) to clay loam soil at a coal mine site. Fly ash decreased percentage clay, soil water content, and soil heat capacity. Fly ash amendment did not significantly increase mean daily soil temperature under dry conditions. Yield of barley silage was significantly increased at intermediate rates of fly ash application, but significantly reduced at 400 t/ha (Hammermeister, et al 1998b). Generalizations in the literature regarding the influence of fly ash on soil temperature, bulk density, and water-holding capacity must be considered carefully since they generally relate only to coarse to medium textured soils (Hammermeister, et al 1998b).

Fly ash application improves the pH, and the availability of P, K and S. These amendments result in a significantly larger biomass production. However, because of the variability in soils and fly ash characteristics, specific site conditions need to be considered before deciding on the quantity of fly ash to be applied (Ajaya et al 2000).

### 5.2.1 *Minesite Flyash*

The feasibility of fly ash as compared to lime to ameliorate the low pH of acidic coal mine spoils has been assessed under a number of conditions. Applications of fly ash and lime significantly increase the pH of mine spoils, available phosphorus, exchangeable potassium, available sulphur and also uptake of phosphorus, potassium, sulphur and oven-dried biomass of both these test crops. The fly ash significantly decreases the bulk density of coal mine spoils, but there is no effect on bulk density due to lime application. However, when the spoils are amended with either fly ash or lime, the root growth occurs throughout the material. Fly ash and lime do not cause elemental toxicities to the plants. Results of work by Ajaya, et al (2000) indicate that fly ash to be a potential alternative to lime for treating acidic coal mine spoils.

Perkins and Vann (1997) assessed the impact of pulverise fuel ash (PFA) on soil physical properties of a badly compacted minespoil. PFA was applied at 16 and 28 kg m<sup>-2</sup>. Application was achieved by dumping at regular intervals along a strip, spread manually and incorporated by reploughing. Both treatments, together with the control (ploughing only) reduced the bulk density of the soil at 4 months. However, only the heavier rate of application maintained the reduction of bulk density at 12 months. Vann et al (1998) showed that a 50% by volume application improved water-holding capacity and reduced bulk density.

### 5.2.2 *Agri-silvicultural Use of Flyash*

Banerjee and Kashyap (1998) investigated the growth and survival of *E. tereticornis* and *Acacia auriculiformis* in mixes of soil sand flyash and compost. Growth was best in the soil + sand + fly ash + compost medium, and poor in the fly ash only medium.

Cline, et al (2000) evaluated various rates of flyash (0-80 t ha<sup>-1</sup> equivalent) on soil pH, soil and plant nutrient levels, and plant growth. After 90 days, dry weights of plants grown in the same soil types were unaffected by flyash rates. In a 3-yr field study, Cline, et al (2000), applied flyash to acidic clay and sandy loam soils at rates ranging from 0 to 50 t ha<sup>-1</sup> (dry wt. basis). In Year 1, maize plants were not significantly influenced by flyash applications, but soybean plants were. This is consistent with the non-significant effects found by Dept Agriculture NSW for similar rates (50 dry t/ha).

### 5.2.3 *Wood Ash*

Wood ash from a wood-fired, electricity generating plant was examined as a potential amendment in municipal biosolids and yard waste composting applications (Campbell et al. 1997). A pH neutralization study indicated that wood fly ash could be used as an economical substitute for lime which is commonly used to stabilize municipal biosolids prior to land filling or land application. Wood ash adds porosity to biosolids, increasing friability and improving oxygen transfer to the composting substrate. A significant advantage is its ability to reduce odours during composting and in the finished product. This is due to its high content of carbon as a result of incomplete fuel combustion. (Carpenter and Beecher, 1997)

Forest application of boiler ash is fast becoming a popular alternative to landfilling. Boiler ash is a good source of calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), manganese (Mn), and zinc (Zn), but it may potentially increase soil pH and electrical conductivity. Two application rates (900 and 1800 t ha<sup>-1</sup>) and two application methods (surface and subsurface) were used in a three-hectare area (Chirenje and Ma 2002). Soil pH increased from 5.6 to above 9 and the electrical conductivity increased by up to 2 orders in all plots compared to the controls. Plant-available water was doubled to 12% in the 1800 t ha<sup>-1</sup> treatment and soil bulk density was reduced from 1500 kg m<sup>-3</sup> to 1200-1360 kg m<sup>-3</sup>. Total and plant available macronutrients (Ca, Mg, K, and P) and micronutrients (iron (Fe), Mn, copper (Cu), and (Zn)) increased substantially after ash application. The rates trialled were extremely high and Chirenje and Ma (2002) recommend that ash application rates be lowered to agronomic rates, e.g., 10 t ha<sup>-1</sup>, based on liming equivalence, to maximize the beneficial effects of boiler ash on soil.

## 6 Food Sludges

Food processing wastes are suitable for land application but requires immediate incorporation to reduce their attraction for flies and vermin. Food processing wastes cannot be applied at very high rates. In addition they are highly variable in composition, but usually are low in metals and salts and can contain appreciable amounts of NPK (Sumner 2000). Many instances of positive crop response have been reported (Fuller and Warwick 1985). Mixtures of flyash, sewage sludge and poultry manure have resulted in products which are stable, supply balanced nutrition for crops and limit the application of materials of environmental concern (Schumann 1997)

Very little research has been done on the use of food processing or putrescible wastes, e.g. abattoir waste products, cannery wastes. Mostly liquid and unstable, these products are either landfilled or land applied by injection techniques. Some work has been successfully completed in Wodonga on thermophilic aerobic digestion of pet food wastes (Schwinning & Gray, 1996). This reduced the volatile solids, fats and pathogens without considerably changing the nutrient values. However, while there are food processing plants in the Hunter region, e.g. Steggles in the Lower Hunter, the wastes would be untreated, volatile and only available in small amounts in comparison to biosolids and greenwaste.

In Queensland, food sludges and biosolids have been used to manufacture bulk composts for topsoil replacement projects. (Bio-Recycle 2003).

Rigueiro Rodriguez et al (2000) showed that milk sewage sludge could be used as a fertilizer in silvopastoral systems.

## 7 Manure

Manure is a valuable resource on increasing soil fertility. It supplies nutrients for plant growth and organic matter for improving and maintaining soil physical properties. However, in fresh manure 60 to 80% of N and P occur in organic forms and must be mineralised before plants can absorb them. There are a range of views on the rate of mineralization over the first few years after application ranging from 30-60% in the first year (Turk and Weidemann 1945, Kesler, 1966, Robertson and Wolford 1970, Eno 1966, Martin 1972 and Pratt et al 1973).

The principal use or method of disposal of manure is land application as a fertiliser for crops or in disposal quantities (Eck and Stewart 1995). Some alternatives have been suggested including landscaping, nurseries and various urban applications. Whether wastes are in solid or liquid form, even distribution is required. Prins and Snijders (1987) applied rates from 17 to 55m<sup>3</sup> ha<sup>-1</sup>. Manures and slurries can vary in chemical content, moisture content and physical condition making uniform application of the material and distribution of plant nutrients difficult.

Cameron et al (1996) assessed surface application and subsurface injection of dairy pond sludge into field plots on a free draining pasture soil in New Zealand. They found that pasture plant production increased by up to 40% following both methods of waste application. The amount of nitrate leached was consistently higher following subsurface injection compared to surface application, although the concentration and amount lost in the drainage water was still relatively low. The low leaching losses were attributed to enhanced plant uptake of nutrients and denitrification within the soil.

Thornton et al (2000) found that organic N amendments (swine effluent or municipal sewage sludge) were superior to ammonium nitrate in terms of volume response in cottonwood trees. Swine effluent was superior to sewage sludge.

Animal manures are useful, not just for their fertilizer value, but also for the benefits in soil organic matter (Hickey 1992). The benefits include nutrients, stable aggregates which improves soil structure, improved aeration and water penetration, improved moisture holding capacity, improves CEC and acts as a buffering agent (Lott et al 1999). Abdel Rahman, et al (1996) determined the effects of organic amendments on cumulative evaporation, moisture distribution, and salt leaching. Organic amendments were mixed with the top 5 cm at the rate of 22 ton/ha for farmyard manure and water hyacinth and 44 ton/ha for chicken manure and dry sludge. Organic amendments increased soil water penetrability into clay soils and enhanced salt leaching.

Manures don't provide a perfect balance of nutrients and too much added at one time can lead to loss by leaching. Studies by Lott et al (1999) have shown that manure applications had the most dramatic positive effects on lighter soils. Mathers and Stewart concluded that annual applications of 22t ha<sup>-1</sup> supplied the fertiliser needs for irrigated corn, wheat and sorghum.

In contrast to manures, composts have a higher proportion of slow release nutrients. Cow manure releases N at a rate of 40% of the total in the first year, then 30, 20 and 20 % over the subsequent 3 years (Eck and Stewart 1994). Release rates for composts will be slower, with the result that the organic carbon levels in the soil will be enhanced over a longer period of time (Pittaway 1999).

## 8 Mixed Recycled Organics

### 8.1 *Mixed Recycled Organics in Australia*

Swanbank Environmental Recycling Park at Ipswich (QLD) composted many organic waste streams and used them to rehabilitated the 340acre open cut mining complex (Bio-Recycle 2003).

Off-cuts from the flower growing industry have the potential to be re-used as a soil conditioning agent. Maheswaran et al (1999) incorporated flower waste into the composting process. Glasshouse trials then determined its potential for use in the flower growing industry (Meehan et al (1999)).

### 8.2 *Mixed Recycled Organics in General*

#### 8.2.1 *Growth Effects*

Sludges and composts compare favourably to inorganic fertilisers. Baldoni et al (1996) found that sludges gave crop yields similar to those obtained with the highest rate of urea. Compost application gave yields as good as that obtained by the best inorganic fertilizer application, which often was the lowest rate of inorganic fertilizer.

Boquet et al (1999) found that application of the waste materials improved soil properties for 3 years. Cotton was given municipal biosolids with or without boiler ash, composted sewage sludge, paper mill sludge or paper mill boiler ash broadcast on the soil surface and incorporated or buried under the crop rows in a 6-inch-wide and 24-inch-deep trench. The highest increases were with municipal biosolids, with or without boiler ash, with both application methods. Paper mill sludge gave some yield increases as a residual effect in 1997. Boiler ash was beneficial as a liming material.

Coreil et al (1997) assessed four of the most abundant local organic wastes (paper mill sludge, paper mill fly ash, municipal sewage sludge, composted sewage sludge and selected combinations of these materials) were applied alone or as mixtures as vertical mulches or as broadcast treatments. Responses to these wastes applied as vertical mulches (6" trenches cut to a depth of 21") were compared to those of similar rates applied by broadcast and incorporation. Broadcast applied sewage sludge and sewage sludge plus fly ash significantly increased yields over conventional production practices. In contrast, paper mill sludge or a combination of paper mill sludge and fly ash significantly reduced yields. Overall, broadcast applications were as effective as vertical mulching. Yield responses were due to combinations of factors. For sewage sludge alone and with fly ash, sustained nutrient supplying ability, net mineralization of nutrients, pH buffering properties, and increased aeration and water holding capacity contributed to the increased yields. In the case of paper mill sludge, with and without fly ash, decreased yields were attributed to a net immobilization of nutrients (Coreil, et al 1997).

Roe et al (1997) applied a biosolids-yard trimming-mixed waste paper (MWP) compost and a biosolids-yard trimming-refuse-derived fuel (RDF) compost, at 0 or 134 t/ha with fertilizer at 0%, 50% or 100% fertilizer rates, respectively. Composts combined with low rates of fertilizer generally produced higher pepper yields than

other treatments. Residual compost increased yields of a subsequent cucumber crop. (Roe et al 1997).

A study by O'Brien and Barker (1995) evaluated the suitability of field-applied composts of mixed municipal solid wastes (MSW), biosolids + woodchips, leaves and agricultural wastes for the production of wildflower (Northeastern mix of wildflower seeds, and grass sods). The composts were applied one inch thick on the soil surface. In half the plots, the composts were left on the surface as a mulch and in the other half, composts were worked into the top 2 inches of soil. Using composts as mulches or incorporating them into the soil had no effect on wildflower and grass quality. During the first year, limited growth in apparently immature biosolids + woodchips and mixed MSW composts was attributed to high concentrations of ammonium or soluble salts. Weed control and mature compost with readily available N and low soluble salt concentrations are required for high crop quality in the first season (O'Brien and Barker 1995).

### **8.2.2 Physical and Chemical Effects**

Sandy, infertile soils can benefit from the addition of organic waste amendments. Annual applications of organic wastes for as long as 4 yr increased soil organic matter content, decreased soil bulk density, and increased soil water retention of a coarse-textured soil. However, soil water-holding capacity was not necessarily increased, and there was a limited effect on soil cation exchange capacity (Zebarth, et al 1999).

Aggelides and Londra (2000), produced an organic fertilizer by composting 62% town wastes, 21% sewage sludge and 17% sawdust by volume. This was applied at the rates of 0 (control), 75, 150 and 300 m<sup>3</sup> ha<sup>-1</sup> to loamy and clay soils. Most improvements (physical and chemical) were proportional to the compost application rate and were greater in the loamy soil than in the clay soil (Aggelides and Londra 2000).

Anaerobically digested biosolids and the organic fraction from a municipal solid waste were surface applied at 80 t/ha to a degraded highly carbonated soil from the southeast of Madrid (Spain) to determine the effects of these organic wastes on soil physical and chemical properties. The structure of the soil was slightly improved by a small decrease in particle and bulk densities, and an increase in water retention accompanied by an increase of organic matter (Illera, et al 1999).

The periodical supply of organic matter by organic fertilizers (manure, waste compost, sewage sludge) favours the accumulation of soil organic matter. The kind of organic fertilizer appears to be less important for the accumulation process than the amount of application (Delschen and Necker, 1995).

In order to study the decomposition and accumulation of soil organic matter, Hyvonen et al (1996) applied biannual applications of straw, peat, sawdust, farmyard manure, green manure and sewage sludge to clay loam in Sweden. Soil C was highest in the plots receiving peat and lowest in those receiving straw and green manure. Intermediate accumulations were found in plots receiving sewage sludge, sawdust and farmyard manure.

Organic amendments that are high in carbon may have a negative effect on nutrient availability. The C:N ratio needs to be considered when using organic amendments. Delgado et al (1999) assessed the total mineral nitrogen in three soils with three organic residues: pig slurry, urban waste and sewage sludge, after 42 weeks of laboratory incubation. N was more available in pig slurry/biosolids. In urban waste, nitrogen was immobilized in the three studied soils.

Klock and Fitzpatrick (1997) evaluated three composted urban waste materials (made from various combinations of biosolids, yard trimmings, and mixed paper, refuse fuel residues and municipal solids wastes). The MSW compost had a high C:N ratio (despite stockpiling). They found that compost alone is feasible for potting mix but required a bulk density of 0.30 to 0.75gcm<sup>3</sup>, a pH of 6.5-7.0 and a C:N ration of 15-20.

Rezaenejad and Afyuni (2001) tested four treatments including cow manure, sewage sludge, municipal compost (all applied at 50 t ha<sup>-1</sup>) and inorganic fertilizer (250 kg ha<sup>-1</sup> ammonium phosphate and 250 kg ha<sup>-1</sup> urea). Organic amendments significantly increased soil organic matter content and plant available P, K and N. Cow manure and sewage sludge treatments had the highest maize silage and grain yields, while the compost treatment had the lowest yields. (Rezaenejad and Afyuni 2001).

Delgado et al (2001) applied three different treatments were to the forest soil surface: (i) control (without fertilizer); (ii) 8000 kg/ha of solid urban waste; and (iii) 8000 kg/ha sewage sludge. Results showed that the variation of N, P and oxidizable C among treatments were at 0-15 cm depth. Higher differences for N and P were observed in the sewage sludge than in the refuse.

A study was conducted to estimate the amount phosphorus in crop residues (rice straw, wheat straw, maize shoot and chaff, beet leaves, oat silage and rice husk) and organic materials (farmyard manure, chicken manure, bark compost and sewage sludge compost), and to analyse the dynamics of organic, inorganic and available form of phosphorus in soil with organic matter application Results indicated that sewage sludge compost is a better source of phosphorus (Sugito et al 2001)

Organic amendments have also been assessed for their capacity to reduce the incidence of insect attack. In India, organic amendments (neem cake (250 kg/ha), sewage sludge (12.5 t/ha), poultry manure (12.5 t/ha), sheep manure (12.5 t/ha) and castor cake (250 kg/ha)) and inorganic fertilizers were assessed for their impact on the incidence of early sucking pests and yield of cotton. All treatments significantly reduced the incidence of early sucking pests of cotton over the untreated control (Balasubramanian and Muralibaskaran 2000).

### **8.2.3 Amendment Form and Application Rate**

The form of the organic amendment can have a significant effect on its efficacy. Hytonen (1998) applied pellets made of wood ash and of ash mixed with other wastes (composted mink dung, composted municipal sewage sludge, or dung from stomachs of slaughtered animals) to silver birch seedlings in a greenhouse experiment. The pellets were applied at 0, 6, 12, 24, 48 t ha<sup>-1</sup>. The pellets containing the highest



amounts of nitrogen increased growth most. As compared with the unpelleted-waste treatment, the use of pelleted waste material decreased seedling growth. This was probably due to the reduced solubility of the nutrients contained by the waste material when presented in pelleted form (Hytonen, 1998)

Pascal et al (1999) evaluated the effects of fresh and composted urban wastes on the organic matter in an arid soil. Improvement was more evident in soils amended with fresh residues (municipal solid waste and sewage sludge) than in those amended with composted waste. They also found that a favourable effect on soil biological activity was more noticeable with the addition of fresh wastes (municipal solid waste or sewage sludge) than with compost. In turn, this effect was more permanent when the soil was amended with municipal solid waste than when it was amended with sewage sludge.

Sewage sludges from Spain, were composted with tree pruning for one and fourteen weeks. The optimum rate of application was 60 t/ha (Fortun, et al 1995).

#### **8.2.4 Mixed Recycled Organics on Mine sites**

Alexander (1996) noted that farmers developed a complex manuring strategy involving the use of a combination of traditional organic manures, any available inorganic fertilizers and the use of town refuse ash. By this means, they raised significantly both the level of the major nutrients and the soil pH to a point where the sustained cultivation of in excess of 20 crops is possible. Given that this was achieved within a period of less than 12 months Alexander (1996) questioned institutional reclamation policies.

Combinations of recycled organics (together with liming agents) have been found to be effective in mine site rehabilitation. Delschen and Necker (1995) found that the periodical supply of organic matter by organic fertilizers (manure, waste compost, and sewage sludge) favours the accumulation of soil organic matter. Dry matter production was greatest with organic fertilizer and with annual forages (Favaretto et al 2000). A combination of lime and manure compost amendment at the rate of 80 t lime/ha and 100 t manure compost/ha, resulted in the highest dry weight yields (Ye et al 2000). The kind of organic fertilizer appears to be less important for the accumulation process than the amount of application.

Bendfeldt, et al (2001) investigated the use of a range of amendments on a mined site, in Wise County, Virginia, USA: a control (nothing added), 30 cm of native soil, 112 tonnes ha<sup>-1</sup> sawdust, and municipal sewage sludge (SS) at rates of 22, 56, 112 and 224 tonnes ha<sup>-1</sup>. The comparative ability of these organic amendments to positively affect organic matter content, total N, and other parameters was most apparent and pronounced after 5 years. However, after 16 years, soil organic matter (SOM) content and total N appeared to be equilibrating at 10 000 and 750 kg ha<sup>-1</sup>, respectively. Amendments improved short-term production, but there was no long term effect. However, in mine site rehabilitation it is the early advantage that is most important – to get vegetation established and the site rehabilitated. In forestry, early growth advantage is usually carried through to harvest.

In India a study was undertaken to evaluate the effect of soil amendments and mulch (forest soil + farmyard manure (FYM), forest soil, forest soil + grass mulch and mine spoil alone). The addition of forest soil and farmyard manure (FYM) increased the survival, yield/height and biomass of the grasses and five tree species (Panwar and Bhardwaj, 1999; Pankaj et al 2000)

Despite the scientific literature on the positive benefits of organic amendments, there is evidence that site establishment and management can have more impact on plant growth than organics matter addition. Effects of soil-covering and green manuring upon the cultivation of *Populus euramericana* was studied China. Methods of soil covering had a significant effect on tree growth. Generally, thicker soil coverings led to larger growth increments. Treatments of 30 cm wet soil mixed with 20 cm coal ash gave good results for tree growth. Soil dressing had larger effects on tree growth than intercropping with green manure species (Zhang, et al 1997)

## 9 Other Recycled Organics

### 9.1 *Pulp and paper sludge*

Pulp and paper (P&P) sludge is a by-product of paper production and may be suitable as a soil amendments or mulch. There are typically two types of P&P sludges. The main constituent of primary P&P sludge is waste wood fibre; high in carbon and low in nutrients, thus potentially acting as a nutrient sink (Henry et al 1995). However, the microbial biomass of secondary sludge generally will release nutrients into soil as it decomposes. Few studies have been undertaken.

Tripepe et al (1996) used raw and composted paper sludge (incorporated and as a mulch) and assessed its impact on soil quality and cottonwood growth. Rates of 45-180t/ha were used. Amended soils decreased in bulk density and increased in water holding capacity. The greatest growth response was with a rate of application of 135t/ha (whether used as a mulch or incorporated).

The incorporation of secondary P&P sludge produced excellent growth responses in nursery beds (Henry 1986). In contrast, incorporated primary P&P sludge significantly reduced growth. Secondary papermill sludge caused foliar nitrogen concentration and biomass to significantly increase in both over- and understory vegetation in a red pine plantation (Brockway 1983).

To enhance cotton production, papermill sludge, papermill flyash, biosolids and composted biosolids were applied alone or as mixtures as vertical mulches or as broadcast treatments (Coreil et al 1997). Broadcast application rates ranged from 45 to 100 dry t/acre, and achieved a 1-2" layer. Vertical mulches were applied by filling trenches (2' deep and 6' long) with material. Application rates ranged between 60 and 115 dry ton/acre. Rows were constructed directly over the trenches. Broadcast biosolids or biosolids plus flyash significantly increased yield over conventional practices. Overall broadcast applications were more effective than vertical mulches. Paper mill sludge decreased yields - probably as a result of net immobilization of nutrients. Raw sewage sludge was more effective than sewage sludge composted with pine bark (Coreil et al 1997).

### 9.2 *Suint*

The effluent that is generated from the wool scouring process is called suint. It is high in potassium content (11% w/w) (Maheswaran et al 1999). CSIRO Division of Wool and Technology applied diluted suint at various levels to pasture and potatoes and compared it to regular potassic fertilisers. The studies showed that suint could be used in agriculture without effecting the yield of the crop. Uptake of K and crop yield was similar to conventional potassic fertilisers (eg potash).

### 9.3 *Hair*

The processing of hides and skins generates a non-prescribed waste. The hair contains 12% nitrogen (Maheswaran et al 1999). Trials with lettuce were conducted in the Werribee market garden areas (Victoria) to evaluate hair as an alternative to nitrogen fertilisers. Results obtained showed that moisture retention under hair treatment was greater than under the control. Similar differences were found for plant N concentration, size, yield and N uptake (Maheswaran et al 1999)

## References

- Abdel Rahman, H. A.; Dahab, M. H., and Mustafa, M. A. (1996) Impact of soil amendments of intermittent evaporation, moisture distribution and salt redistribution in saline-sodic clay soil columns. *Soil-Science*; 161(11):793-802.
- Aggelides, S. M. and Londra, P. A. (2000). Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. *Bioresource-Technology*; 71(3):253-259.
- Aguilar, R.; Loftin, S. R.; Edge, W. D. (ed.), and Olsen Edge, S. L (1996) Use of sewage sludge biosolids to improve degraded rangelands. Proceedings of a Symposium on Sustaining Rangeland Ecosystems. 1996; (La Grande):Oregon. 29-31 August 1994.. Special-Report Oregon State University Extension Service; No. 953, 209-212.
- Aitken R.L. , Campbell D.J. , and Bell L.C. (1984). *Aust. J. Res.* **22**, 443-453.
- Ajaya Srivastava; Chhonkar, P. K., and Srivastava, A.(2000). Effect of flyash on uptake of phosphorus, potassium and sulphur by Sudan grass and oats grown on an acid soil. *Journal of the Indian Society of Soil Science*; 48(4):850-853.
- Akhtar, M.; McCallister, D. L., and Eskridge, K. M. (2002) Availability and fractionation of phosphorus in sewage sludge-amended soils. *Communications-in-Soil-Science-and-Plant-Analysis*; 33(13-14):2057-2068.
- Albaladejo, J., Stocking M. , Diaz, E., and Castillo land rehabilitation by urban refuse amendments in a semiarid environment: Effect on soil chemical properties. *Soil Technology* **7**, 260.
- Albiach, R.; Canet, R.; Pomares, F., and Ingelmo, F. (2001) Organic matter components, aggregate stability and biological activity in a horticultural soil fertilized with different rates of two sewage sludges during ten years. *Bioresource Technology*; 77(2):109-114.
- Alexander, M. J. (1996) The effectiveness of small-scale irrigated agriculture in the reclamation of mine land soils on the Jos Plateau of Nigeria. *Land Degradation and Development*; 7(1).
- Andrade, C. A. de; Mattiazzo, M. E., and de Andrade, C. A. (2000) Nitrates and heavy metals in soil and in trees after application of sewage sludge (biosolids) on *Eucalyptus grandis*. *Scientia Forestalis*; (No.58):59-72.
- Anjali Deshmukh, Matte, D. B., Bharti Bhaire, Deshmukh, A., and Bhaire, B. (2000) Soil properties as influenced by fly ash application. *Journal of Soils and Crops* 10[1], 69-71.
- Armstrong, J.L. and Koen, T.B. (1994) Evaluation of composted sewage sludge for improving plant establishment on degraded soils. Department of Land and Water Conservation, New South Wales.
- Baker, G.; Michalk, D.; Whitby, W., and O'Grady, S. (2002) Influence of sewage waste on the abundance of earthworms in pastures in south-eastern Australia. XIII International Colloquium on Soil Zoology; 38(3-4):233-237.
- Balasubramanian, A. and Muralibaskaran, R. K. (2001) Influence of organic amendments and inorganic fertilizers on the incidence of sucking pests of cotton. *Madras Agricultural Journal*. 2000; publ. 2001, 87(4-6):359-361.
- Baldoni, G.; Cortellini, L.; Dal Re, L.; Bertoldi, M. de (ed.); Sequi, P. (ed.); Lemmes, B. (ed.), and Papi, T. (1996). The influence of compost and sewage sludge on agricultural crops. *The Science of Composting: Part 1*; 431-438.
- Banerjee, S. K. and Kashyap, M. K.(1988) Environmental impact of fly ash and its management. *Advances in Forestry Research in India*; 1831-53.
- Banerjee, S. K.; Singh, A. K.; Sonkar, S. D.; Mishra, P. N., and Kashyap, M. K. (1999). Evaluation of effectiveness of compost and nitrogenous fertilizers on growth, biomass production and nutrient accumulation of *Dalbergia sissoo* in iron mine overburden. *Advances in Forestry Research in India*. 1999; 20145-161.
- Baran, S.; Domzal, H.; Slowinska Jurkiewicz, A.; Kwiecen, J., and Pranagal, J. (1996) The effect of sewage sludge on water content and aeration of a sandy soil. *Organic Waste and the Protection and Productivity of Agrocenosis*; 43753-60.

- Barry, G. A., Gardener, G. E., Rayment G.E , and Bloesch P.M. (1999). Recycling organic materials on agriculture. *Recycled Organics - Expanding the Horizons. Conference - Hyatt Coolool 23-25 November 1999*.
- Bateman, J. C. and Chanasyk, D. S. (2001) Effects of deep ripping and organic matter amendments on Ap horizons of soil reconstructed after coal strip-mining. *Canadian Journal of Soil Science*; 81(1):113-120.
- Beckett, P.H., Davus, R.D., Milward, A.F. and P.Brindley (1977) A comparison of the effect of different sewage sludges on young barley. *Plant and Soil* **48**, 129-141
- Bedminster (2003) Port Stephens Facility at Raymond Terrace NSW.  
[www.bedminster.com.au/pdf/case-study](http://www.bedminster.com.au/pdf/case-study).
- Bendfeldt, E. S.; Burger, J. A., and Daniels, W. L. (2001) Quality of amended mine soils after sixteen years. *Soil Science Society of America Journal*; 65(6):1736-1744.
- Bengtson, G. W. and Cornette, J. J. (1973). Disposal of composted municipal waste in a plantation of young slash pine: Effects on soil trees. *J. Environ. Qual.* **2**, 441.
- Bennett, O. L., Mathias, E. L., Armiger, W. H., and Jones, J. N. (1978). Plant materials and their requirements for growth in humid regions . In: Schaller, F.W. et al. (ed) *Reclamation of Drastically Disturbed Lands*. Madison, WI 286.
- Beretka, J. and Brown, T. (1976). Properties and pozzolanic behaviour of Australian fly ash. *J Aust. Ceram. Soc.* **12**, 13-19.
- Berg, W. A. (1975). Use of soil laboratory analysis in revegetation of mined lands. *Miner. Congr. J.* **61**, 32.
- Bhumbla, D. K., R.N. Singh , and R.F. Keefer (2000). Coal combustion by-product utilisation for land reclamation. In: R.I. Barnhisel et al. (ed.) *'Reclamation of Drastically Disturbed Lands.'* Agron. Monogr. 41. ASA, CSSA, SSSA, Madison, 489-512.
- Biocycle (1995) - Compost progress in Australia. *BioCycle* 1995 36, 6
- Bio-Recycle (2003) Forestry and Land rehabilitation.  
<http://www.biorecycleaustralia.com/forest.html>)
- Biosolids Working Group (2002), Department of Environmental Protection , Waters and Rivers Commission , and Department of Health . Western Australian guidelines for direct application of biosolids and biosolids products. 1-32.
- Bledsoe, C. S. (1981). Municipal Sludge Application to Pacific Northwest Forest Lands.
- Boquet, D. J.; Breitenbeck, G. A., and Coreil, C. B. Jr. (1999) Beneficial use of municipal and industrial wastes in cotton production. *Louisiana-Agriculture*; 42(2).
- Brahmachari, K.; Debnath, A., and Mondal, S. S. (1999) Effect of fly ash on yield and nutrient uptake in rice and its impact on soil properties. *Journal of Interacademia*; 3(3-4):293-300.
- Bramryd, T. (2002) Impact of sewage sludge application on the long-term nutrient balance in acid soils of Scots pine (*Pinus sylvestris*, L.) forests. *Water, Air, and Soil Pollution*; **140**(1-4):381-399.
- Brockway, D. G. (1983). Forest floor, soil and vegetation responses to sludge fertilization in red and white pine plantations. *Soil Sci. Soc. Am. J.* **47**.
- Brofas, G.; Michopoulos, P., and Alifragis, D. (2000) Sewage sludge as an amendment for calcareous bauxite mine spoils reclamation. *Journal of Environmental Quality*; **29**(3):811-816.
- Brown, G. M. C., Grant, C. D (2000) Nutrient status of pasture ecosystems established on rehabilitated overburden and topsoil sites in the Hunter Valley, New South Wales. Special Issue: Soil research for mine reclamation. *Australian Journal of Soil Research.* **38** 2, 479-491.
- Bryon K.L. and Bradshaw A.D. (1991) The potential value of sewage sludge in land reclamation. In: Alternative Uses for Sewage Sludge, Hall J.E. (ed) Permagon Press, Elmsford NY 21.
- Burns, M. (1998). Draft Feasibility Assessment of Large Scale Commercial Forestry Establishment on Mines in the Hunter Valley. Unpublished report for State Forests of NSW.
- Cameron, K. C.; Rate, A. W.; Noonan, M. J.; Moore, S.; Smith, N. P., and Kerr, L. E. (1996) Lysimeter study of the fate of nutrients

- following subsurface injection and surface application of dairy pond sludge to pasture. *Utilisation of Waste Organic Matter*; **58**(2-3):187-197.
- Campbell, A. G. Jr.; Folk, R. L., and Tripepi, R. R. (1997) Wood ash as an amendment in municipal sludge and yard waste composting processes. *Compost Science and Utilization*; **5**(1):62-73.
- Campbell, D. J., Fox, W. E., Aitken, R. L., and Bell, L. C. (1983). Physical characteristics of sands amended with fly ash. *Aust. J. Soil Res.* **21**, 147-154.
- Carpenter, A. and Beecher, N.(1997) Wood ash finds niche in biosolids composting. *BioCycle*; **38**(1).
- Chambers, B.; Nicholson, F.; Aitken, M., and Szmidt, R. A. K.(1988). Liming and nutrient supply properties of N-Viro treated sewage sludge. Proceedings of the International Symposium on Composting and Use of Composted Materials for Horticulture, Auchincruive, Ayr, UK, 5-11 April 1997; (No. 469):43-50.
- Chaney, R. L. (1990). *BioCycle* **Oct**, 68-73.
- Chaney, R.L., Brown, S., Li, Y-M., Angle, J.S., Homer, F. & Green, C. 1995. Potential use of metal hyperaccumulators. *Mining Environment Magazine*, **3**(3): 9-11.
- Chang, A. C., Lund, L. J., and Warneke, J. E. (1977). Physical properties of fly ash-amended soils. *J. Environ. Qual.* **6**, 267-70.
- Chang, A.C. Warneke, J.E. Page A.L. and Lund L.J. (1984) Accumulation of heavy metals in sewage sludge-treated soils. *J Environ. Qual.* **13**, 87.
- Chapman, L. S. (1996). Australian sugar industry by- products recycled plant nutrients. In : 'Downstream Effects of Land Use'. (Eds. hunter, H.M. Eyles, A.G. Rayment, G.E.).
- Chirenje, T. and Ma, L. Q.(2002) Impact of high-volume wood-fired boiler ash amendment on soil properties and nutrients. *Communications in Soil Science and Plant Analysis*; **33**(1-2):1-17.
- Cline, J. A.; Bijl, M., and Torrenueva, A.(2000) Coal fly ash as a soil conditioner for field crops in southern Ontario. *Journal of Environmental Quality*; **29**(6)
- Cogger, C., Bary, A. I., Fransen, C., and Sullivan, D. M. (2001). Seven years of biosolids versus inorganic nitrogen applications to tall Fescue. *J. Environ. Qual.* **30**, 2188-2194.
- Cole, D. W., Henry, C. L., and Nutter, W. (1986). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastewater and Sludge. *University of Washington Press, Seattle*.
- Cook, J. A., Keeling, A. A., and Bloxham P.F. (1998). Effect of green waste compost on yield parameters in spring barley (*Hordeum Vulgare*) V. Hart. In: R.A.K Szmidt. (ed). 'Composting and use Composted Materials.' 283-286.
- Coreil, C. B., Boquet, D. J., and Breitenbeck G.A. (1997). Soil application of papermill and municipal biosolids for cotton production. *1997 Proceedings Beltwide Cotton Conferences. January 6-10. New Orleans, L.A. National Cotton Council of America.* 652-653.
- Costantini A. , Loch R. J. , Glanville S.F. , and Orange D.N. (1995). Evaluation of the potential to dispose of sewage sludge. 1. Soil hydraulic and overland flow properties of Pinus plantations in Queensland. *Aust. J. Soil Res.* **33**, 1041-52.
- Cox, J. (2001) From mining waste to artificial soil. *Soil Health: The Foundation of Sustainable Agriculture*, Proceedings of a workshop on the importance of soil health in agriculture, *Wollonbar Agr. Inst.* June 2001 pp142-147.
- Cox, J. A.; Whelan, R. J.; Loch, R. (ed.), and Jasper, D. (2000) Soil development of an artificial soil mix: nutrient dynamics, plant growth, and initial physical changes. Special Issue: *Soil Research for Mine Reclamation*; **38**(2):465-477.
- Croft & Associates and Costain Australia, (1985). Environmental Impact Statement for Ravensworth South Coal Mine, Volume 2. Prepared for the Electricity Commission of NSW.
- Cuevas G., Blazquez R. , Martinez F. , and Walter I. (2000). Composted MSW effects on soil properties and native vegetation in a degraded semiarid shrubland. *Compost Science and Utilization* **8**, 303-309.

- Czekala, J. (1999) Sewage sludges as a source of organic matter and nutrients. *Folia Universitatis Agriculturae Stetinensis, Agricultura*; (No. 77):33-37.
- Dadhwal, K. S. and Katiyar, V. S. (1989) *Indian Journal of Soil Science* **37**, 412.
- de Andrade, C. A. and Mattiazzo, M. E. (2000). Nitrates and heavy metals in soil and in trees after application of sewage sludge (biosolids) on *Eucalyptus grandis*. *Scientia Forestalis* **58**, 59-72.
- de Vries M.P.C. and Merry R.H. (1980). Effects of high application rates of a dried sludge to a market garden soil - investigations in mini-plots. *Aust. J. Exp. Agric. Husb.* **20**, 470-476.
- Debosz, K., Petersen, S. O., Kure, L. K., and Ambus, P (2002). Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. *Applied Soil Ecology* **19**, 3, 237-248.
- Delgado, M.; Miralles de Imperial, R.; Porcel, M. A.; Beltran, E.; Garcia, J.; Bigeriego, M.; Polo, A.; de Imperial, R. Miralles; Garcia Torres, L. (ed.); Benites, J. (ed.), and Martinez Vilela, A.(2001) Characterization of forest soil after application of different organic matters. Conservation-Agriculture,-a-Worldwide-Challenge.-First-World-Congress-on-Conservation-Agriculture,-Madrid,-Spain,-1-5-October,-2001.-Volume-2:-Offered-Contributions; 227-230.
- Delgado, M. del M; Angel Porcel, M.; Miralles de Imperial, R.; Bellido, N.; Bigeriego, M.; Beltran, E., and Calvo, R. (1999) Mineralization of nitrogen originating from organic residues. *Revista-Internacional-De-Contaminacion-Ambiental*; 15(1):19-25.
- Delschen, T. (1999). Impacts of long term application of organic fertilizers on soil quality parameters in reclaimed loess soils of the Rhineland lignite mining area. *Plant Soil* **213**, 43-53.
- Delschen, T. and Necker, U. (1995) Accumulation of organic matter in reclaimed loess soils. *Agribiological-Research*. **48**(2):101-114.
- Deshmukh, A. S.; Matte, D. B., and Kene, D. R. (2000) Effect of graded levels of fly ash and NPK on soil properties and yield of wheat. *Journal of Soils and Crops*; **10**(2):260-264.
- Distch, D. C. and Collins, M. (2000). Reclamation considerations for pasture and hay lands receiving sixty-six centimetres or more precipitation annually. *Reclamation of Drastically Disturbed Lands* **40**, 241.
- Dixon, J. B., Arora, F. M., Askenasy P.E. , and Hossner, L. R. (1980). Chemical, physical and mineralogical properties of soil, mine spoil and overburden associated with lignite mining. In: Reclamation of surface-mined lignite spoil in Texas. Texas agric. Exp. Stn., Ceter Energy Miner. Resour. 13.
- DMR (1996) Green at the Seams: Environmental Management of the New South Wales Mining Industry DMR NSW
- DMR NSW (1997) Environmental Management of the New South Wales Mining Industry DMR NSW 1997
- Doyle, W. S. (1976). Strip mining of coal - environmental solutions (Noyes Data Corporation: New Jersey).
- Dumont, S., Dinel, H., Schnitzer, M., Pare, T., and Scopa, A. (2001). Composting organic residues: trace metals and microbial pathogens. *Canadian Journal of Soil Science* **81**, 357-367.
- Dyer, K. L. and Sencindiver, J. C. (1985). Bark and mulch promotes establishment of vegetation on mine-soils with south and west exposures. In: D.H. graves (ed.) Symp. *Surf. Mining Hydrol., Sedimentol.Reclamat.*, Lexington, KY. Univ. Kentucky.
- Dyson, J. R., Elliot, G. L., Reynolds, K. C., and Dight, D. C. G. (1983) Coal mine revegetation : NSW coal - Sydney.
- Eck, H.V and Stewart, B. A. (1995). Manure. In : 'Soil amendmets and environmental quality' J.E Rechcigl (ed), Lewis Publishers, Boca Raton USA) 169-199.
- Eck, H. V. and Stewart, B. A. (1986). 'In 'Soil Amendmets and Environmental Quality' .' (J.E. Rechcigl (ed), Lewis Publishers Boca Raton, F.L. ) 169-198
- El Baha, A. M. (2001) Growth response of *Eucalyptus camaldulensis* as affected by thinning and sewage sludge or inorganic fertilizer on a poor quality site. *Alexandria*

- Journal of Agricultural Research.*; 46(1):269-295.
- Elliot, G. L., Hannan, J. C., and Cornally, M. J. (1980) Revegetation of opencut mine overburden at Foybrook, NSW. *Journal of the Soil Conservation Service NSW.* **36**, 24-240.
- El Shafei, Y. Z. (1997). Soil water retention characteristics of sands as influenced by sewage sludge. *Alexandria Journal of Agricultural Research*; **42**(3):279-293.
- EPA (1984). Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge EPA-625/10-84-003. EPA, Washington D.C.
- EPA, (1997) Environmental Guidelines for the use and disposal of biosolids products. Environment Protection Authority, Chatswood.
- EPA SA (1999). Synopsis of Landfill Audit Conducted at Metropolitan Adelaide Landfill during period 19 November to 9 December 1998; Confidential Draft.
- Epstein E., Taylor, J.M. and Chaney R.L. (1976) Effects of sewage sludge and sludges compost applied to soil on some soil physical and chemical properties. *J Environ. Qual* **5**,422.
- Eno, C.F. (1966) Chicken manure - its production, value, preservation, and disposition. University of Florida Agr. Exp. Sta. Circ. S-140.
- Favaretto, N.; Moraes, A. de; Motta, A. C. V.; Prevedello, B. M. S., and de Moraes (2000), A. Effect of revegetation of and fertilizer application to degraded land on dry matter yield and nutrient uptake. *Pesquisa-Agropecuaria-Brasileira.*; **35**(2):299-306.
- Fiskell, J. G. A., Pritchett, W. L., Maftoun, M. , and Smith, W. H. (1979). Effect of garbage compost rate and placement on a slash pine forest and metal distribution in an acid soil. *In ' 2nd Ann. Conf. of Applied Res, and Practice on Municipal Industrial Waste, Madison, WI 17-21 September'* 302.
- Fortun, C.; Diaz Burgos, M. A.; Fortun, A., and Polo, A (1995). The value of fertilizers from composting sewage sludge and slivers from pruning trees. *Agrochimica.*; **39**(2-3):134-142.
- Fortun, C. and Fortun, A. (1997). Changes in water-soluble and EDTA-extractable cations and enzymatic activities of soils treated with a composted solid urban waste. *Arid Soil Research and Rehabilitation* **11**, 265-276.
- Fuller, W. H. and Warrick, A. W. (1985) Soils in waste treatment and utilization. CRC Press Inc. Raton Fl.
- Gallardo-Laro F. and Nogales, R. (1987). *Biological Wastes* **19**, 35-62.
- Gangloff, W. J.; Ghodrati, M.; Sims, J. T., and Vasilas, B. L. (2000) Impact of fly ash amendment and incorporation method on hydraulic properties of a sandy soil. *Water, Air, and Soil Pollution.*; 119(1-4):231-245.
- Garcia, C., Hernandez, T., and Costa, F. (1992). Variation in some chemical parameters and organic matter in soils regenerated by the addition of municipal solid waste. *Environmental Management* **16**, 763-768.
- Garcia-Gil, Plaza, C., Soler-Rovira, P., and Polo, A. (2000). Long-term effects of municipal solid waste compost application on soil enzyme activities and and microbial biomass. *Soil Biology and Biochemistry* **32**, 1907-1913.
- Gaynora, J.D. and R.L. Halstead (1976) Chemical and plant extractability of metals and plant growth on soils amended with sludge. *Canadian Journal of Soil Science* **56** (1): 1-8
- Gibson, T. S., Chan, K. Y., Sharma G., and Shearman R. (2002). Soil carbon sequestration utilising recycled organics. *A review of the scientific literature, prepared for Resource NSW by the Organic Waste Recycling Unit, NSW Agriculture.*
- Giedroje, B., Fatyga J., and Hizncewics, Z. (1980) The effects of fertilisation with ashes from black coal burnt in electric power stations on the properties of sandy soils. *Polish Journal of Soil Science* **13**, 163-171.
- Gillespie, M., Mulligan, D. and K Baker (2003) Native Understorey Species Regeneration at NSW Coal Mines. Project C7010. [www.acarp.com.au/Completed/Open\\_Cut/briefs/oc/C7010brief.html](http://www.acarp.com.au/Completed/Open_Cut/briefs/oc/C7010brief.html)
- Gouin, F. R. (1993). *Horticultural Technology* **3**, 161-163.
- Guidi, G., Pera, A., Giovannetti, M., Poggio, M., and Bertoldi, M. (1988). Variations of soil structure and microbial populations in a



- compost amended soil. *Plant and Soil* **106**, 113-119.
- Hammermeister, A. M.; Chanasyk, D. S., and Naeth, M. A. (1998) Fly ash influence on near-surface temperature of a clay loam soil. *Canadian Journal of Soil Science*; **78**(2):345-350.
- Hammermeister, A. M.; Naeth, M. A., and Chanasyk, D. S. (1998) Implications of fly ash application to soil for plant growth and feed quality. *Environmental Technology*; **19**(2):143-152.
- Hann, S. (1981). *Neth. Journal of Agricultural Science* **29**, 35-62.
- Hannan, J.C. (1995). Mine Rehabilitation – A handbook for the coal mining industry. 2<sup>nd</sup> edition. NSW Coal Association, Sydney.
- Hannan, J. C. and Bell, L. C. (1986). Surface Mine Rehabilitation. In 'Australasian Coal Mining Practice' (ed. Martin C.H.) **12**, 233-52.
- Hannan, J.C. & Gordon, R.M., (1996). Environmental management of coal mines in the Hunter Valley, NSW. In *Environmental Management in the Australian Minerals and Energy Industries – Principles and practices*. David R. Mulligan (Ed). UNSW Press in association with Australian Minerals & Energy Environment Foundation, Sydney.
- Harrison, R. B.; Henry, C. L.; Cole, D. W.; Xue, D.; McFee, W. W. (ed.), and Kelly, J. M. (1995). Long-term changes in organic matter in soils receiving applications of municipal biosolids. Carbon Forms and Functions in Forest Soils.; 139-153.
- Haubold-Rosar, M., Katur, M., Schroder, J., and Schneider, R. (1993). Bodenentwicklung in grundmeliorierten tertiären Kippsubstraten in der Niederlausitz. *Mitteilgn. Dtsch. Bodenkundl. Gesellsch.* **72**, 1197-1202.
- Hemphill D.D., Volk V.V, Sheets, P.J. and Wickliff, C. (1985) Lettuce and broccoli response and soil properties resulting from tannery waste applications, *J. environ. Qual.*, **14**. 159.
- Henry C. and Brown S. (1997) Restoring a superfund site with biosolids and fly ash. *BioCycle* 79-83.
- Henry, C. L. (1986). Growth response, mortality and foliar nitrogen concentrations of four tree species treated with pulp and paper and municipal sludges. In: 'The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastewater and Sludge.' Cole, D., Henry C., Nutter W. (ed) University Press, Seattle. 258.
- Henry, C. L., Cole D.W and Harrison, R. B. (1994) Use of municipal sludge to restore and improve site productivity in forestry: Th Pack Forests Sludge Research Program. *Forest Ecology and Management* **66**. 137-149.
- Henry, C. L., Harrison, R. B., and Cole D.W. (1995). Forestry. In: J.E. Rechcigl (ed.) 'Soil Amendments: Impacts on Biotic Systems' Chapter 1. J.E., Lewis Publishers
- Hickey, M. G. (1992). Feedlot manure - benifit to the soil. In : Feedyard Manure a Farmland Fertiliser Seminar Proceedings.
- Hinslet T.D., Hansen L.G., Bray. D.H. and Redborg K.E. (1984) Long-term use of sewage sludge on Agricultural and disturbed Lands, Project Summary EPA-600/S2-84-128, EPA Washington D.C.
- Hodgson, L., Dyer, D., and Brown, D. A. (1982). Neutralization and dissolution of high-calcium fly ash. *J. Environ. Qual.* **11**, 93-98.
- Holz, S. C.; Ingelmo, F., and Canet, R. (2000) Long term effects of the application of sewage sludge and vegetal cover on some physical and physicochemical properties of a degraded arid soil. *Agrochimica*; **44**(3-4):132-139.
- Horan, E. and Hartmann, R. (2000). Composting developments in Australia and New Zealand. *BioCycle* 64-71.
- Hue, N. V. (1995). 'In 'Soil Amendments and Environmental Quality'. (Lewis Publisher: Boca Raton, FL.) pp 199-247
- Hunter Water Corporation (2000). Biosolids a newsletter on biosolids recycling.
- Hytonen, J. (1998). Pellets made of wood ash and other wastes as nutrient sources for silver birch seedlings. *Suo.*; **49**(2):49-63.
- Hyvonen, R., Agren, G. I., and Andren, O. (1996). Modelling long-term carbon and nitrogen dynamics in an arable soil receiving

- organic matter. *Ecological Applications* **6**, 1345-1354.
- Illera, V. Walter, I. Cuevas, G., and Cala, V. (1999). Biosolid and municipal solid waste effects on physical and chemical properties of a degraded soil. *Agrochimica.*; 43(3-4):178-186.
- Iyer, R. S. and Scott, J. A. (2001) Power station fly ash -- a review of value-added utilization outside of the construction industry. *Resources, Conservation and Recycling.*; 31(3):217-228.
- Jokela, E. J., Smith, W. H., and Colbert, S. R. (1990). Growth and elemental content of slash pine 16 years after treatment and garbage composted with sewage sludge. *J. Environ. Qual.* **19**, 146.
- Joshua, W. D.; Michalk, D. L.; Curtis, I. H.; Salt, M.; Osborne, F. G. J., and Naidu, R. (1998) The potential for contamination of soil and surface waters from sewage sludge (biosolids) in a sheep grazing study, Australia. Special Issue.; **84**(1-3):135-156.
- Joyce (2002) Sustainable utilisation of saline minewater: Early indicators from the Drayton Saline Irrigation Forestry Trial. [http://www.ecoman.une.edu.au/Postgrads/2002/mandy\\_joyce.htm](http://www.ecoman.une.edu.au/Postgrads/2002/mandy_joyce.htm)
- Katzur, J. and Haubold-Rosar, M. (1996). Amerlioration and reforestation of sulfurous mine soils in lusatia (East Germany). *Water Air Soil. Pollut.* **91**, 17-32.
- Kay, B. L. (1978). Mulch and chemical stabilisers for land reclamation in dry regions. In ' Reclamation of Drastically Disturbed Lands' (eds. Schaller F.W. and Sutton P.)
- Keely, W. C. (1990). *Horticultural Science* **22** , 168-169.
- Kelly, G.L. (1993), Application of Biosolids to Penrose and Belanglo State Forests. Soil Nutrition Conference - *Research Working Group 3. Gympie, Queensland.*
- Kelly, G.L. (1994), Biosolids on Forests of New South Wales. Water Environment Federation. *The Management of Water and Wastewater Solids for the 21st Century: A Global Perspective.* pp. 2.15-2.26. Washington DC. USA.
- Kelly, G.L. (2000), Stream water quality from pine plantations fertilised with biosolids – a catchment perspective. *WaterTECH Conference, Sydney, 9-13<sup>th</sup> April 2000.*
- Kelly, G.L. (2002)a, Biosolids program in forestry - from plantation pine to hardwoods for mine site rehabilitation. *Biosolids Specialty Conference*, June 19-20, Sydney. Australian Water Association.
- Kelly, G.L. (2002)b, A Decade of Successful Biosolids Reuse in Plantation Pine *Biosolids Specialty Conference*, June 19-20, Sydney. Australian Water Association.
- Kelly, G.L. (2002)c, The use of biosolids and residuals to maximise wood and carbon values from trees planted on overburden and buffer sites in the Hunter Valley. ACARP interim Report 1
- Kelly, G.L. (2002)d, Growing commercially viable eucalypt plantations on marginal lands using organic wastes (Hunter Region). Natural Heritage Trust Final Report October 2002.
- Kelly, G.L. (2004), Trial Plantation Project, Bulga Mine, NSW. Final Report and Progress Report #5
- Kelly , R. E. (1981). The use of mulches and contour surface preparation on crusting spoil material to promote moisture penetration. In ' Environmental Controls for Coal Mining' (ed. Hannan, J.C). Australian Coal Assoc. and Earth Res. 303-305.
- Kesler R.P. (1966) Economic evaluation of liquid manure disposal from confinement finishing if hogs, in Management of Farm Animal Wastes, Proc Nat; Symp. Am. Soc. Agr. Eng. Publ. SP-0366, 122.
- Khaleel, R., Reddy, K. R., and Overcash, M. R. (1981). Changes in soil physical properties due to organic waste applications: a review. *Journal of Environmental Quality* **10**, 133-141.
- Klock , K. A. and Fitzpatrick G.E. (1997). Growth of impatiens 'Accent Red' in three compost products. *Compost Science and Utilization* 26-30.
- Lattanzi, A. R., Meyer, L. D., and Baumgardner, M. F. (1974). Influences of mulch rate and slope steepness on inter-rill erosion. *Soil Sci. Soc. Amer. Proc.* **38**, 946-50.
- Latterall, J. J, Dowdy, R. H., and Lazson, (1978) W. E. *Environmental Quality* **7**, 435.

- Leigh J. (1990) Pastoral value and production from native pastures. Native Grass Proceedings, Australian Wool Corporation, Melbourne.
- Lindemann W.C., Fresquez P.R., and Cardenas M. (1989) Nitrogen mineralization in coal mine spoil and topsoil. *Biology and Fertility of Soils* **7**, 318-324.
- Lindsay, B. J. and Logan, T. J. (1998). Field response of soil physical properties to sewage sludge. *Journal of Environmental Quality*; **27**(3):534-542.
- Loch J., Costantini A., Barry G.A., and Best E.K. (1995). Evaluation of the potential to dispose of sewage sludge. 2. Potential for off-site movements of solids and solutes. *Aust. J. Soil Res.* **33**, 1053-1062.
- Loch, R. J. and Foley, J. L. (1994). Measurement of aggregate breakdown under rain: comparison with tests of water stability and relationships with field measurements of infiltration. *Aust. J. of Soil Res.* **32**, 1125-39.
- Lockwood, P., Macleod, D., and Heiko, D. (1988). Soil 212 - Foundations in Soil Science. University of New England: Armidale, NSW.
- Logan, (1993) The effect of sewage sludge upon the physical properties of overburden at mine rehabilitation sites. Project report, Bachelor of Natural Resources, University of New England, NSW.
- Lott, S., Klepper, K., Ahmad, R., Blair, G., and Petrov, R. (1999). Australia - your standing in it! *Recycled Organics - Expanding the Horizons. Conference - Hyatt Coolum 23-25 November 1999.*
- Luke, G. J. (1983). The use of precipitated fly ash as an amendment to a sandy soil in South Western Australia. *M.S. thesis, University of Western Australian.*
- Maciak, F. (1981). Effect of large amount of ash from coal and brown coal on some physiochemical properties of sandy soil. *Roczniki Gleboznaweze* **32**, 101-126..
- Maclean, N. R. (1976). Agronomic aspects of fly ash disposal by incorporation with filter mud in the Herbert River district. Proceedings of the 43rd Conference, Queensland Society of Sugar Cane Technologists; 83-88.
- Macquarie Generation (2001) Macquarie Generation Annual Report. Review 2001.
- Madrid, F., Trasierra, M., Lopez, R., and Murillo, M. (1998). Municipal solid waste compost utilization in greenhouse cultivated tomato. In: Szmidt R.A.K. (ed). 'Composting and use Composted Materials.'
- Maheswaran, J., Meehan, B., Pererill K., and Dziedic, A. (1999). Potential for agri-industry wastes as soil ameliorants. Recycled Organics - Expanding the Horizons. Conference - Hyatt Coolum 23-25 November 1999.
- Margolis, Z.; Scharp, M.; Olson, D., and Tardy, R. (2001) Biosolids, wood chips key to mineland reclamation. *BioCycle*; **42**(11).
- Marschke, G. Waterhouse, D. and Huxtable, C. (1994) The use of native pasture species for coal mine rehabilitation in the Hunter Valley, in Proceedings of a National Workshop on Native Seed Biology for Regeneration, Minerals Council of Australia, Canberra.
- Martin, W.E. (1972) Use of manure in agricultural production, Talk presented at 11<sup>th</sup> Annual Dairy Cattle Day, Department of Animal Science, University of California, Davis.
- Marx, D. H. (1980) Tropical Mycorrhizal Research, 93-105..  
Notes: Oxford University Press, London.
- Mays, D. H. and Bengston G.W. (1978). Lime and fertiliser use in land reclamation in humid regions. In: F.W. Scaller and P.Sutton (ed.) 'Reclamation of Drastically Disturbed Lands.' ASA. CSSA. and SSSA. Madison, WI. 307-328.
- McConnell, D. B., Shiralipour, A., and Smith, W. H. (1993). Compost application improves soil properties. *Biocycle* **34**, 61-63.
- McGinnies, W. J. (1987). Effects of hay and straw mulch on the establishment of seeded grasses and legumes on rangeland and a coal strip mine. *J. Range Manage.* **40**, 119.
- McGlynn (1998) Management of exploration and mining in NSW Environmental Policy. DMR NSW Environment Unit.
- Meehan, B. J., Baxter, F., and Maheswaran, J. (1999). Re-use potential of agriculture industry

- wastes in the Melbourne metropolitan region. Progress report RIRDC Project No RMI-10A.
- Michalk, D. L.; Curtis, I. H.; Langford, C. M.; Simpson, P. C., and Seaman, J. T. (1996) Effects of sewage sludge on pasture production and sheep performance. Proceedings of the 8th Australian Agronomy Conference, Toowoomba, Queensland, Australia, 30 January-2 February, 1996.; 429-432.
- Muchovej, R. M. C., and R.S.Pacovsky (1997). Future directions of by-products and wastes in agriculture. In: Agricultural uses of by-products and wastes. R. S., Rechcigl, J. E. and MacKinnon, H. C., (ed.), ACS Symposium Series 668 pp1-19.
- Mulford, F. R. and Martens, D. C. (1971). Response of alfalfa to boron in fly-ash. *Soil Sci. soc. Am. Proc.* **35**, 296-300.
- Mullins, G. L. and Mitchell, C. C. (1995). Crops . In ' Soil amendments, Impacts on Biotic Systems' (ed: Rechcigl, J.E., Lewis Publishers) 1-39.
- Munn, K. J.; Evans, J., and Chalk, P. M. (2000) Mineralization of soil and legume nitrogen in soils treated with metalcontaminated sewage sludge. *Soil-Biology-and-Biochemistry.*; **32**(14):2031-2043.
- Newton, M.E. & Whitehead, J.H. (1998) Biosolids application and innovative seed treatment techniques in re-establishing native tree species on a coalmine spoilpile. WaterTech conference paper, AWWA, Brisbane.
- Norland, M. R. (2000). Use of mulches and soil stabilizers for land reclamation. In: R.I. Barnhisel et. al. (ed) Reclamation of drastically disturbed lands. Agron. Monogr. Madison. WI 645.
- Nortcliff, S. (1998). The use of composted municipal solid waste in land restoration. *Proceedings of the XVI World Congress of Soil Science* 20-26.
- NSW EPA (1997). Environmental guidelines, use and disposal of biosolid products. *NSW, Environmental Protection Authority.*
- NSW Legislative Council (2001) Questions and Answers for 3 April 2001. Parliament of New South Wales. No. 95. Legislative Council. Questions and answers. Second Session of the Fifty-Second Parliament.
- O' Brien, T. A. and Barker, A. V. (1995). Evaluation of field-applied fresh composts for production of sod crops. *Compost-Science-and Utilization.* 3(3):53-65.
- Pagliai, M., Guidi, G., La Marea, M., Giachetti, M., and Lucamante, G. (1981). Effects of sewage sludges and composts on soil properties and aggregation. *Journal of Environmental Quality* **10**, 556-561.
- Pankaj Panwar; Bhardwaj, S. D., and Panwar, P. (2000). Effect of soil amendment and mulch on establishment of trees in sandstone mine spoils in mid hill zone of Himachal Pradesh. *Annals of Forestry.* **8**(2):214-219.
- Panwar, P. and Bhardwaj, S. D. (1999) Rehabilitation of mined area through grasses. *Advances in Forestry Research in India.* 21162-172.
- Parker, T. and Grant, C. (2001) Biosolids and coal mine rehabilitation: effect of biosolids application on the establishment of native and exotic grasses on three substrates used in open-cut coal mine rehabilitation in the Hunter Valley, New South Wales. *Natural Resource Management.* **4** (2):29-34.
- Pascual, J. A., Garcia, C., and Hernandez, T. (1999). Comparison of fresh and composted organic waste in their efficacy for the improvement of arid soil quality. *Bioresource Technology* **68**, 255-264.
- Pathan, S. M.; Aylmore, L. A. G., and Colmer, T. D. (2002) Reduced leaching of nitrate, ammonium, and phosphorus in a sandy soil by fly ash amendment. *Australian-Journal of Soil Research* **40** (7), 1201-1211.
- Paul, E. A. and Voroney, R. P. (1980) In Contemporary Microbial. *Ecology* , 215-237..
- Paulin, B. (2000). Using compost to boost yields in Perth region. *BioCycle* 74-76.
- Pearce, S. H. (1991). The beneficial utilisation of dewatered sewage sludge for the rehabilitation of open cut coal mines - Hunter Valley. *Project report, Bachelor of Natural Resources, University of England.*
- Pearce, S. H. (1993). In ' Utilisation of Sewage Sludge for Minesite rehabilitation: Rix's Creek Mine Trial' Personal communication (The Sydney Water Board).

- Pearson, A. J. Spiers, T. M., and Cant, G. (1998) Crop uptake of nitrogen, phosphorus and potassium from soil amended with chicken manure and green waste compost. *Proceedings Annual Conference Agronomy Society of New Zealand*. 2831-34.
- Pera, A., Vallini, G., Sireno, L., Biachin, M. L., and De Bertoldi, M. (1983). Effect of organic matter on rhizosphere microorganisms and root development of Sorghum plants in two different soils. *Plant and Soil* **74**, 3-18.
- Perkins, P. V. and Vann, A. R. (1997) The bulk density amelioration of minespoil with pulverised fuel ash. *Soil Technology* **10**[2], 111-114.
- Phillips, C.P., (1993). Utilisation of sewage sludge for minesite rehabilitation. The Rixs Creek mine trial 1992-1993 – An Australian experience. Minor thesis, Masters of Environmental Studies, University of Newcastle, NSW.
- Phillips C.P. (1994a). Manual of Good Practice for the use of biosolids in Land Reclamation, Australian Minerals and Energy Environment Foundation, Melbourne.
- Phillips C.P. (1994b). Utilisation of Sewage Sludge for Minesite Rehabilitation: Rix's Creek Mine Trial . *Urban Water Research Association of Australia*.
- Pickering J.S., Kendle A.D. , and Hadley P. (1997). The suitability of composted green waste as an organic mulch: Effects on soil moisture retention and surface temperature. International symposium on composting and use of composted materials for horticulture. Convener: R.A.K. Szmidt SAC Auchincruive Scotland, UK 5-11 April 1997.
- Pittaway, P. (1999). Getting the right mix - composting from the microbiological viewpoint. *Recycled Organics - Expanding the Horizons. Conference - Hyatt Coolum 23-25 November 1999* 119-122.
- Plank, C. O. and Martens, D. C. (1974). Boron availability as influenced by the application of fly ash to soil. *Soil Sci Soc. Am. Proc.* **38**, 974-977.
- Plass, W. T. (1978). Journal of Soil Water Conservation **33**.
- Plass, W. T. (1978). Use of mulches and soil stabilisers for land reclamation in the eastern United States. In Schaller, F.W and Sutton, P.(ed) 'Reclamation of Drastically Disturbed Lands'
- Poulton, P. R. (1995). The importance of long-term trials in understanding sustainable farming systems: the Rothamstead experience. *Australian Journal of Experimental Agriculture* **35**, 825-834.
- Power, J. F., Ries, R. E., and Sandoval, F. M. (1976). Use of soil materials on spoils - effects of thickness and quality. *Farm Research*. 23-24.
- Pratt, P.F., Broadbent, F.E. and Martin J.P. (1973) Using organic wastes as nitrogen fertilisers, Calif. Agric. **27** (6), 10.
- Press, C. M., Mahaffee, W. F., Edwards, J. H., and Kloepper, J. W. (1996). Organic by-product effects on soil chemical properties and microbial communities. *Compost Science and Utilization* **4**, 70-80.
- Prins, W. H. and Snijders, P. J. M. (1987). Negative effects of animal manure on grassland due to surface spreading and injection. In 'Animal Manure on Grassland and Fodder Crops ' 119.
- Queensland Government - Environmental Protection Agency (2002). Green and organic waste processing and marketing in Queensland.
- Rao, A. V., Richa, T. A. K., and Tak, R. (2001) Influence of organic amendments on the growth of different trees and nutrient uptake in gypsum minespoils. *Journal of the Indian Society of Soil Science* **49** 2, 386-390.
- Rappaport, B.D., Martens, D.C., Reneau, R.B. and Simpson T.W. (1988) Metal availability in sludge-amended soils with elevated metals levels. *J Environ. Qual* **17**, 42.
- Raviv, M., Chen, Y., and Inbar, Y. (1986). In 'The Role of Organic Matter in Modern Agriculture'. 257-287.
- Rawlinson & Lane, (1992). Review of environmental factors for Costain Ravensworth Mine. Prepared for the Sydney Water Board, April 1992.

- Rehceigl, J. E. and MacKinnon, H. C. (1997). Agriculture uses of by-products and wastes. *American Chemical Society*.
- Rezaenejad, Y. and Afyuni, M. (2001) Effect of organic matter on soil chemical properties and corn yield and elemental uptake. *Journal-of-Science-and-Technology-of-Agriculture-and-Natural-Resources*. **4**(4):19-29.
- Rickert, K. G. (1973). Establishment of green panic as influenced by type, amount and placement of vegetative mulch. *Australian J. Exp. Agric. Anim. Husb.* **13**, 268-274.
- Rigueiro Rodriguez, A.; Mosquera Losada, M. R., and Gatica Trabanini, E. (2000). Pasture production and tree growth in a young pine plantation fertilized with inorganic fertilizers and milk sewage in northwestern Spain. *Agroforestry-Systems*. **48**(3):245-256.
- Robertson, L.S. and Wolford J. (1970) The effect of application rate of chicken manure on the yield of corn, in *Poultry Pollution: Problems and Solutions*, Sheppard, C.C. Ed., Michigan State University Agr. Exp. Sta Res. Rep. 177, 10.
- Roe, N. E.; Stoffella, P. J., and Graetz, D. (1997) Composts from various municipal solid waste feedstocks affect vegetable crops. II. Growth, yields, and fruit quality. *Journal-of-the-American-Society-for-Horticultural-Science*. **122**(3):433-437.
- ROU (2001). Greenhouse gas emissions from composting facilities. *University of New South Wales, Sydney. Report prepared for the Central Coast Waste Board, NSW*.
- ROU (2002). Guide to manufacturing value added recycled organics products for markets. *University of New South Wales, Sydney*.
- Russell, M. J. (1985). Glasshouse experiments to investigate spoil crusting problems. *Landline* **11**, 1-2.
- Russell, M. J. (1979). Spoil heap revegetation at opencut coal mines in the Bowen Basin, of Queensland, Australia. In: *Wall M.K ed ' Ecology and Coal Resource Development'*. **1**, 516-23.
- Ryans, M. (2001) An evaluation of spreading mill biosolids in a forestry operation. *Advantage -Forest-Engineering-Research Institute of Canada FERIC* **1** 25 , 1701-1715.
- Sarooshi, R. A.; Cresswell, G. C.; Tesoriero, L.; Milham, P. J.; Barchia, I., and Harris, A. M. (2002). Effect of biosolids compost on two NSW coastal soils used to grow vegetables. *Australian Journal of Soil Research*. **40**(5):761-774.
- Schuman, G. E., Booth, D. T., and Waggoner, J. (1990). Grazing reclaimed mine land seeded to native grasses in Wyoming. *J. Soil Water Conserv.* **45**, 653.
- Schuman, G. E., Taylor, E. M., Rauzi, F., and Pinchak, B. A. (1985). Revegetation of mined land: Influence of topsoil depth and mulching method. *J. Soil and Water Cons.* 249-52.
- Schumann, A. (1997). Plant nutrient supply from fly ash-biosolids mixtures. PhD dissertation, University of Georgia, Athens, GA .
- Seaker E.M. and Carrello, (1989) Ten year summary of environmental monitoring on coal mine spoil amended with sludge. In. *Proceedings of the status of municipal sludge management for the 1990's Alexandria, VA: Water Pollution Control Federation: p9-1 to 9-19*.
- Seaker, E. M. and Sopper, W. E.(1988) *Municipal Sludge for Minespoil Reclamation: I. Effects on Microbial Populations and Activity. Journal of Environmental Quality*.
- Shallvey, A. and Joyce A. (2001). Commercial Forestry as a post-mining land use. Paper presented at the *Minerals Council of Australia's Environmental Workshop ' Back to the Future'*. Adelaide, South Australia.
- Sherwood , S. and Uphoff, N. (2000). Soil health: research, practice and policy for a more regenerative agriculture. *Applied Soil Ecology* **15**, 85-97.
- Silcock, R. G. (1991). Pasture, trees and shrubs for rehabilitating mines in Queensland - Impediments to their use on opencut coal and alluvial mines in 1990. *Queensland Department of Primary Industries Brisbane*.
- Silcock, R. G., Brown, R. F., and McKeon, G. M. (1988). Effects of plant morphology and physiology on native pastures. In *'Native Pastures in Queensland. The Resources and their Management'* 34-51.

- Singh, A. K., Bhowmik, A. K., Williams, A. J. S. R. B., and Banerjee, S. K. (1994). Effect of compost and fertilizer on nutrient accumulation of *Albizia procera* in coal mine overburden. *Indian J. For.* **17**, 166.
- Smith, W. H. and Evans J.O. (1997). Special opportunities and problems in using forest soils for organic waste applications. In 'Soils for Management of Organic Waste and Waste Water'.
- Smith, W. H., Post, D. M., and Adrian, F. W. (1979). In 'Proc. of Impact of Intensive Harvesting on Forest Nutrient Cycling' (State University of New York, College of Environmental Science and Forestry, Syracuse.)
- Sommers, L. E., Nelson, D. W., and Silveira, D. J. (1979). *Journal of Environmental Quality* **8**, 287-293.
- Sopper W.E. (1991) Utilization of sewage sludge in the United States for mineland reclamation, In: Alternative Uses for Sewage Sludge, Hall J.E. Ed Permagon Press, Elmsford NY 21.
- Sopper, W.E., (1993). Municipal Sludge Use in Land Reclamation. Lewis Publishers, Boca Raton, USA.
- Sopper, W. E. and Kerr, S. N. (1982) Revegetating strip-mined land with municipal sewage sludge Westmoreland County demonstration.
- Sopper, W. E. and Kerr, S. N. (1979). Utilization of Municipal sewage effluents and sludge on forest and disturbed land.
- Sopper, W. E., Seaker, E. M., and Bastian, R. K. (1982). Land Reclamation and Biomass Production with Municipal Wastewater and Sludge. *Pennsylvania State University Press, University Press.*
- Stirling, M. (2001). Soil biology and its importance in soil health. In: 'Soil Health. the Foundation of Sustainable Agriculture'. Proceedings of a workshop on the importance of soil health in agriculture. (Ed: Line-Kelly. Woolonbar Agriculture Institute, NSW) 24-29.
- Stratton, M. J., Barker, A. V., and Rechcigl, J. E. (1995). In 'Soil Amendments and Environmental Quality'. (Lewis Publishers: Boca Raton, FL.) 249-304.
- Sugito, T.; Yoshida, K., and Nitta, T. (2001). Changes of phosphorus forms in soil with organic matter application. *Japanese Journal of Soil Science and Plant Nutrition.* **72**(2):195-205.
- Summers R. , Clarke M. , Pope, T., and O'dea T. (1998). Western Australian fly ash on sandy soils for clover production. *Commun. Soil Sci. Plant Anal.* **29**, 2757-2767.
- Sumner, M. E. (2000) Beneficial use of effluents, wastes, and biosolids. Opportunities for the 21st century: Expanding the horizons for soil, plant, and water analysis.1999 International Symposium on Soil and Plant Analysis, Brisbane, Queensland, Australia, March 22-26, 1999. *Communications in Soil Science and Plant Analysis.* **31**, 1701-1715.
- Sydney Water (2000). Annual Environmental and Public Health report 2000. *Sydney Water Corporation* 36.
- Thomson S.C. and Makin S.L. (1990) Recycling of steelworks by-products for land rehabilitation purposes. In effluent re-use conference - Wollongong NSW 1990. Australian Water and Wastewater Association.
- Thornton, F. C., Bock, B. R., Behel, D. A., Houston, A., and Tyler, D. D. (2000). Utilization of waste materials to promote hardwood tree growth. *SJAF* **24**.
- Tidsdall , J. M. and Oades, J. M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science* **33**, 141-163.
- Topper, K. F. and Sabey, B. R. (1986). Sewage sludge as a coal mine spoil amendment for revegetation in Colorado. *Journal of Environmental Quality* **15**, 44-49.
- Tripepi, R. R., Xiaoguang Z. , and Campbell, A. G. (1996). Use of raw and composted paper sludge as a soil additive or mulch for cotton wood plants. *Compost Science and Utilization* 26-36.
- Tsadiras, C. D.; Samaras, V.; Robert, P. C. (ed.); Rust, R. H. (ed.), and Larson, W. E. (1999) Influence of sewage sludge application on soil quality: I. Organic matter, pH, phosphorus, potassium, and inorganic nitrogen. Proceedings of the Fourth International Conference of Precision Agriculture, St. 1999;

- (Minnesota):USA, 19-22 July 1998. Part A and Part B.1709-1718.
- Turk, L. M. and Weidemann, A. G. (1945). Farm Manure. *Michigan State University Agr. Exp. Sta. Bull.*
- Turvey N.D. and Burns, M. (1999). Carbon sequestration and trading: opportunities for land management. *Recycled Organics - Expanding the Horizons. Conference - Hyatt Coolum 23-25 November 1999.*
- Uson, A.; Cook, H.; Cook, H. F. (ed.), and Lee, H. C. Water relations in a soil amended with composted organic waste. *Soil Management in Sustainable Agriculture*. 1995; (Wye College):University of London, UK, 31 August to 4 September 1993. 1995, 453-460.
- Vann, A. R., Hannington, L., Smith, S., Howard, J. A., and Hughes, I. C. (1988) The effect of ripping, ploughing and pulverised fuel ash on the bulk density of opencut minespoil. *Soil Technology* **1**, 263-269.
- Vaz, L. M. S. and Goncalves, J. L. M. (2002) Use of biosolids in eucalypt stand: effect on soil chemical attributes, and growth and uptake nutrient by the trees. *Revista Brasileira de Ciencia do Solo* **26** 3, 747-758.
- Vlams, J. Williams, D.E. Corey, J.E. Pages, A.L. and Gange T.J. (1985) Zinc and cadmium uptake by barley in field plots fertilized seven years with urban and suburban sludge. *Soil Sci* **139**, 81.
- Vogel, W. G. (1981). A guide for revegetating coal minesoils in the eastern United States. *USDA NE Forest Exp. Stn. Gen. Tech. Rep. NE-68 US. Gov. Print Office Washington, DC.*
- Voorhees, M. E. and Uresl, D. W. (1990) *Soil Science* 150, 663.
- Walsh, J. (1992). In 'Utilisation of Sewage Sludge for Minesite Rehabilitation: Rix's Creek Mine Trial ' personal communication (The Sydney Water Board, NSW).
- Wilkinson, K., Tee, E., and Hood, V. (2000). Adequately benchmarked compost quality? *Proceedings of the Compost 2000, Down Under Conference, 14-15 November 2000, Melbourne, Vic.*
- Willett, I. R.; Jakobsen, P., and Malafant, K. W. J. (1986). Fertilizer and liming value of lime-treated sewage sludge. *Fertilizer-Research*; **8**(3):313-328.
- Williams, A. R., Addison, J. S., Revell, M., and Bell, T. (unpublished (1987)). The effect of mulching treatments on perennial pasture establishment on a levee back slope soil of the Djada land system. *Project report WA Department of Agriculture.*
- Wong, J. W. C., Ho G. (1994), Effects of gypsum and Sewage sludge as organic ameliorant for revegetation of fine bauxite refining residue. *Resources, Conservation and Recycling*. **11**, 297-309.
- Wong J.W.C. and Ho G.E. (1991). Effects of gypsum and sewage sludge amendment on physical properties of fine bauxite refining residue. *Soil Science* **152**, 326.
- Ye, Z. H.; Wong, J. W. C., and Wong, M. H (2000). Vegetation response to lime and manure compost amendments on acid lead/zinc mine tailings: a greenhouse study. *Restoration-Ecology*. **8**(3):289-295.
- Zaman, M.; Di, H. J.; Sakamoto, K.; Goto, S.; Hayashi, H., and Inubushi, K. (2002) Effects of sewage sludge compost and chemical fertilizer application on microbial biomass and N mineralization rates. *Soil Science and Plant Nutrition*; **48**(2):195-201.
- Zasoski, R.J. (1991) Effects of sludge on soil chemical properties. In: *Municipal Sludge Application to Pacific Northwest Forest Lands*. C.S. Bledsoe (Ed) College of Forest Resources, University of Washington. 45-48.
- Zebarth, B. J.; Neilsen, G. H.; Hogue, E., and Neilsen, D. (1999) Influence of organic waste amendments on selected soil physical and chemical properties. *Canadian-Journal-of-Soil-Science*; **79**(3):501-504.
- Zhang JianGuo; Wang ShiJi; Liu YaRong; Leng GuoYou; Zhou ShuLi; Zhang, J. G.; Wang, S. J.; Liu, Y. R.; Leng, G. Y., and Zhou, S. L. (1997) Effect of soil-covering and green manuring on tree growth in the reclaimed area of coal ash. *Journal-of-Northeast-Forestry-University*; **25**(3):9-13.
- Zier, N., Schiene, R., Koch, H., and Fischer, K. (1999). Agricultural reclamation of disturbed soils in a lignite mining area using municipal and coal waste: the humas situation at the



beginning of reclamation. *Plant and Soil* **213**, 241-250.

Zier, N., Schiene, R., Koch, H., and Fischer, K. (1999). Agricultural reclamation of disturbed soils in a lignite mining area using municipal coal wastes: the humus situation at the beginning of reclamation. *Plant and Soil* **213**, 241-250.

Zinati, G. M., Li, Y. C., and Bryan, H. H. (2001). Utilization of compost increases organic carbon and its humin, humic and fulvic acid fractions in calcareous soil. *Compost Science and Utilization* **9**, 156-162.