Recycled Organics in Catchment Management

A review of the scientific literature

Department of
Environment and Conservation (NSW)

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Executive Summary

This review was commissioned by the Department of Environment and Conservation to

– identify the forms and sources of soil erosion in the Australian landscape and focus on factors relevant to New South Wales catchments

– identify the methods used in Australia as well as overseas in combating soil erosion and catchment degradation

– examine the benefits of recycled organics (RO) products derived primarily from garden organic for improving soil health and remediating degraded soils, and

– examine the role of RO products and vegetation in controlling run-off and soil erosion, and rehabilitating degraded areas within NSW catchments.

In conjunction with local experience, it is envisaged that the review will allow the identification of specific RO products and “best bet” approaches to permit experimental verification of overseas research data in replicated field trials and to assess their relevance to NSW catchments.

Australia generates substantial quantities of urban wastes annually (over 21 million tonnes in 1996/7) and is among the top 10 solid waste generators within the Organisation of Economic and Cooperative Development (OECD) countries. To reduce the pressure on shrinking landfill space near densely populated metropolitan areas and on environmental grounds, Australian State governments have legislated to reduce or ban garden organics from landfills. This has accelerated the pace of compost-recycling of garden organics and some segments of the RO industry are now faced with an oversupply of RO products. The markets identified for the products have mainly been in urban landscaping, intensive horticulture, viticulture and agriculture. However, RO products may potentially be used for rehabilitating large areas of degraded farming land and natural catchments, which has come about largely through unsustainable human activities and attendant soil erosion.

Soil erosion is a serious threat to sustainable agricultural production as well as a major problem for watershed management and conservation of the natural resource base. Soil erosion and deposition cause not only on-site degradation of land resources but also off-site problems such as down-stream sediment deposition. Suspended sediments in water bodies affect water quality and cause pollution because of the various nutrients and toxic agrochemicals adsorbed on the sediments. The sediments also cause loss of reservoir storage capacity and eutrophication of water bodies.

The most critical factor in protecting soils from erosion by water and wind is the maintenance of ground cover that is fixed or in close contact with the soil surface (e.g. trees, shrubs, pasture, plant residues and forest litter). Any event that reduces the protective ground cover increases the risk of soil loss. Excessive clearing of vegetation, conventional bare cultivation of agricultural land, stubble burning, together with overgrazing by introduced animals, has led to structural damage to much of the topsoil in NSW, resulting in continuing soil erosion. Bushfires also remove both the native plants and the vegetation litter covering the ground, exposing these areas to erosion. The subsequent lack of ground cover increases the intensity of water run-off and hence soil erosion, because no vegetation or litter are present to moderate the raindrop impact on the bare soil or to slow the flow rate of run-off water across the ground. In recent years, new gullies have formed in the Sydney water supply catchments in the Blue Mountains in the wake of bushfires.

The restoration of degraded landscapes depends on the reinvestment of soil carbon and nutrient resources into the soil. RO products are valuable sources of organic carbon and can improve soil health, thereby promoting more consistent and rapid vegetation establishment. Improved plant establishment leads to the addition of more organic carbon from the plant residues and the development of a rooting system through the soil, which contribute to minimising run-off and mitigating soil erosion. In many overseas countries, the use of RO products for land rehabilitation is increasingly being considered as a technical solution to reversing environmental degradation and promoting re-establishment of vegetation cover.

Research in the United States has shown that any disturbed or excavated site with a 25% slope or less can be protected from erosion by an application of a layer of RO product of 25-75mm depth, with the higher rates being used on steeper slopes. Some gradual slopes may require as little as 25mm depth. Particle sizes should be a mix of fine grades (10-13mm) and coarse grades (50-75mm). A mixture ratio of 3:1 (fine: coarse) has been recommended in many studies. Coarse grades may be larger if rapid vegetation establishment is not a primary goal. For steeper slopes, more aggressive techniques like netting and hydroseeding in conjunction with stickers or "tackifiers" may be necessary to hold the RO products in place.

Rainfall simulation studies in the US and Europe have shown that runoff and sediment loss are usually reduced significantly and water quality improved compared to degraded areas untreated with RO products. Further, there is usually little export of heavy metal contaminants or nutrients into the runoff water, if the RO products are derived primarily from "yard wastes" or garden organics. If biosolids are used in the compost production, there may be some concern regarding the export of nutrients like phosphorus and nitrogen. As such, in Australia at least, RO products conforming to the Australian Standard (AS 4454-2003) should be used to ensure that the environmental risks are minimised, if not eliminated.

In general, there are three basic methods of using RO products in erosion control: erosion control blankets, vegetation establishment blankets and filter berms. Each method has its advantages and will depend on the slope of site, amount of potential rainfall, activity around the site and intended vegetation establishment. In many cases, more than one method can be used in combination. For steeper slopes, filter berms are used to slow the rate of water flow and filter out the soil sediments and pollutants. Specifications for RO products used in erosion control normally include particle size, moisture content, organic matter content, pH, soluble salt content and synthetic inert contents e.g. plastics, glass, etc. In the United States, special specifications for compost blankets and filter berms have been developed for various locations e.g. housing development sites, highway projects, etc. However, the vastly different climatic conditions of continental USA have required modifications to these specifications to suit local needs.

In Australia, there is little documented information on the use of RO products in the rehabilitation of degraded land in water catchments. The NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) has traditionally used a layer of cereal straw or meadow hay (5-10cm) as an erosion blanket, oversown with a seed mixture of exotic pasture grasses (cocksfoot, tall fescue and ryegrass) and legumes (white and subterranean clovers). When available or economically feasible, native grasses and shrubs (planted as tube-stocks) have also been used for longer-term revegetation. However, in recent years, with the advent of a protracted drought and the concomitant high price of cereal straw and meadow hay, DIPNR has successfully been using a composted soil conditioner product (Nitrohumus®) produced from garden organics and biosolids as an alternative. The composted soil conditioner is surface applied (about 1cm layer) as a vegetation establishment blanket, followed by sowing with the usual seed mixture.

However, relatively little research has been undertaken to characterise the effects of composted soil conditioner products on reducing runoff, soil loss and the export of nutrients in the runoff from treated areas in the NSW context. Nor has there been research conducted on the effectiveness of coarser RO products (mulches) for stabilising steeper slopes in NSW. Therefore, there is a need for scientific performance data to verify the usefulness of specific locally-produced RO products for catchment management in NSW and to develop guidelines for their optimal and economic use.

1 Introduction

1.1 Background

In Australia, substantial quantities of urban wastes are generated annually. For 1996-97, the Australian Bureau of Statistics estimated that 21.2 million tonnes of solid wastes were received and disposed at landfills nationwide (ABS 1998). This equates to a per capita solid waste disposal of 1.1 tonnes/year, placing Australia among the top 10 solid waste generators within the Organisation of Economic and Cooperative Development countries (OECD 1999). Approximately 40% of all solid wastes are municipal wastes, much of it from domestic households. The per capita disposal rate for municipal waste in Australia is 620 kg/year, placing it second only to the USA (OECD 1999). Domestic or household waste streams typically include garden wastes, paper, glass, plastic and food wastes.

To reduce the pressure on shrinking landfill space near densely populated metropolitan areas and on environmental grounds, Australian State governments have legislated to reduce or ban garden organics from landfills. This has accelerated the pace of compost-recycling of garden organics and some segments of the recycled organics (RO) industry are now faced with an oversupply of RO products. The markets identified for the products have mainly been in urban landscaping, horticulture, viticulture and to a lesser extent, agriculture (Love and Rochfort, 1998). However, there is now recognition that RO products may potentially be used for rehabilitating large areas of degraded farming land and natural catchments. This land degradation has come about largely through unsustainable farming practices and urban development in catchment areas.

Soil erosion and associated sediment deposition have become a serious threat for sustainable agricultural production as well as a major problem for watershed management and conservation of the natural resource base (Lal 2000; Walling 2001). A recent report by the United Nations Environment Program (UNEP 2000) highlights the seriousness of soil degradation, in particular soil erosion, at a regional and global level. Soil erosion and deposition cause not only on-site degradation of land resources but also off-site problems such as down-stream sediment deposition in fields, flood plains and water bodies. Suspended sediments in water bodies affect water quality and cause pollution because of various nutrients and agrochemicals adsorbed on the sediments. The sediments also cause loss of reservoir storage capacity and eutrophication of water bodies (Clark 1985).

The negative impacts of soil erosion and deposition are ecological as well as socio-economic. Globally, the current economic costs of the on-site and off-site impacts of erosion of agricultural land have been estimated to amount to some US $ 400 billion per year (Bernard and Lavardiere 2000). However, effective soil conservation programs can successfully counter soil erosion losses. For instance, in the USA, it has been estimated that total erosion of cropland was reduced by 42% between 1982 and 1997 as a result of the removal of cropland susceptible to erosion from production and improved soil conservation measures (Bernard and Lavardiere 2000). Similarly, it was reported that the recent reduction in the sediment load of the Yellow River in China partly reflected the extensive implementation of soil and water conservation measures within the highly erodable region of the middle Yellow River basin (Mou 1996).

1.2 Scope of the literature review

This review will:

- identify the forms and sources of soil erosion in the Australian landscape and focus on factors relevant to New South Wales catchments
- identify the conventional methods used in Australia as well as overseas in combating soil erosion and catchment degradation
- examine the benefits of recycled organics products for improving soil health and remediating degraded soils
- examine the role of recycled organics products and vegetation in controlling run-off and soil erosion, and rehabilitating degraded areas within NSW catchments.

In conjunction with local knowledge, it is envisaged that the review will allow the identification of specific RO products and “best bet” approaches to erosion and run-off control for experimental verification in field trials in NSW catchments.

2 Soil erosion and land degradation

2.1 The Australian landscape

Soil erosion is a major and continuing issue for Australian agriculture and catchment management. It also impacts on river, estuary and marine resources. It causes unsustainable losses of soil for agriculture and in some areas exceed rates of soil formation by up to 50 times. Hill-slope erosion (sheet and rill erosion) is serious in Australia's tropical northern regions, particularly at the onset of the wet season but also affects the semi-arid woodlands and arid interior. Maintaining vegetative cover, minimising soil disturbance and building sediment-trapping wetlands and riparian areas remain imperatives throughout much of the country.

Gully erosion persists as the major erosion process affecting river health in southern and eastern Australia. Sediment from these previously active gullies has affected about 10,000 kilometres of stream length in the Murray-Darling Basin alone. These rivers with coarse sand accumulations in stream beds exacerbate flooding and smother the habitats of Australian native fish. Active gully erosion is still occurring in northern Queensland and in south-western regions of Western Australia. Changes to agricultural practices that minimise gully erosion are urgently required from both on-farm and off-farm perspectives.

River bank erosion is also a major problem. Extensive lengths (120,000 kilometres) of riparian vegetation along eastern Australia's rivers and streams are degraded and require rehabilitation. Where these landscape resources are intact, they protect the integrity of banks against erosion. Priority areas include much of the Murray-Darling Basin, South Australia and south-western regions of Western Australia.

Sediment delivery to streams, rivers, estuaries and near-shore marine zones is high in many catchments. Deposition of sand and suspended sediments in streams and rivers is worst in the Murray-Darling Basin, coastal regions of New South Wales, south-east Queensland and the south-west of Victoria. From a near-shore marine and estuary perspective, approximately 90% of suspended sediment loads reaching marine and estuarine environments are derived from 20% of agricultural catchments, particularly in coastal regions of Queensland and New South Wales.

For the Great Barrier Reef Lagoon, about 25% or 12 million tonnes of sediment delivered to streams is discharged each year on average across all contributing catchments. This is predicted to be approximately three times greater than natural loads, with consequent impacts on estuaries and marine fisheries, seagrasses and near-shore coral reefs. However, for catchments such as the Burdekin and Fitzroy, loads can be more than 20 times the natural loads.

Nutrient loads to Australian rivers and estuaries are also a matter of concern. Nearly 19,000 tonnes of total phosphorus (P) and 141,000 tonnes of total nitrogen (N) are exported to Australia's coast each year from areas of intensive agriculture. The highest exports are in northern Queensland, Moreton Bay in southern Queensland and New South Wales. Efficiency of phosphorus delivery from Australia's rivers to the coast varies from as low as 3% in the Murray-Darling Basin to over 90% in Tasmania.

Targeted erosion control and soil management provide significant contributions to managing the supply of nutrients in sediment loads to most rivers. Where a large part of the increase is caused by increases in either surface run-off loads or point source discharges, close attention needs to be paid to fertiliser application, animal waste retention on-farm, and sewage treatment plant and septic tank effluent management.

However, the impact of erosion has not always been negative. Soil erosion and deposition by wind has had a major role in creating landforms and soils across large parts of Australia, with much of the landscape being built of materials of aeolian origin. Natural wind erosion during the past two million years has been responsible for transporting fine sands, silts and clays from the Riverina plains of western NSW onto the higher lands to the east, where they have been deposited. These materials have improved the nutrient content and soil structure on the higher lands (ABS 1996).

2.2 Soil erosion in NSW catchments

The clearing of native vegetation since European settlement has been directly associated with the spread of soil erosion in NSW. Excessive clearing, together with overgrazing by introduced animals, leaves the soil unprotected by ground cover, resulting in structural damage to the topsoil through erosion. This problem was exacerbated by the introduction of the European rabbit, which multiplied to plague proportions before the use of a biological control agent, the myxoma virus, in 1950 to reduce its impact (Austin 1999). However, there has been a resurgence of this pest in recent years and land degradation in farming country continues. Natural variations in climate, especially cyclic droughts and rainstorms of high intensity, are also highly instrumental in aggravating soil erosion (Connors 1999).

The removal of the protective cover of native vegetation and the decline of soil structure (such as compaction or soil crusting) have led to a massive increase in surface run-off of water. This is because less water infiltrates the surface of the soil when the topsoil is eroded and degraded soil surfaces are exposed. Increased surface run-off has created excessive hydrologic loads for streams, leading to gully and stream-bank erosion and flooding where the streams have failed to contain the extra loads within their boundaries. This dramatic change to the catchment hydrology appears to have resulted from a series of catastrophic events following European settlement (Olley 1995), adding to the land degradation problems that are experienced today. However, there is some scientific evidence that topsoil erosion by water has declined in recent years. This suggests that modern farming techniques are not further stressing the hydrology of catchments and that a new equilibrium may be developing from the changed catchment pattern (Olley 1995; Wasson et al. 1998).

Soil erosion is one of the most significant forms of land degradation and is greatly influenced by land use and management (Woods 1984; Edwards 1991; Erskine and Saynor 1996a,b). Although the soil formation rates are poorly defined in Australia, they are certainly less than the soil loss rates from all the most conservation-oriented land uses (Edwards 1991). Neil and Galloway (1989) concluded that the sediment yield in the Southern Tablelands of New South Wales from cropped area were about 2.8 times greater than from native forest. Neil and Fogarty (1991) have also obtained data for the same area to demonstrate that native pastures produced 3.8 times, improved pastures 5.4 times, cropped areas 21 times, over-grazed pastures 27 times and pine plantations 38 times more sediment than native forests.

From the same area, Neil and Richardson (1990) found that sediment yield from a saline seepage scald was about 600 times that from grazed catchments and about 200 times that from tilled catchments. Edwards (1987) reported that summer cropping increased mean annual sediment yields by up to 25 times over minimally disturbed pastures at the Research Stations of the Soil Conservation Service of New South Wales (Cowra, Gunnedah, Inverell, Scone, Wagga Wagga and Wellington). Erskine and Saynor (1996a) documented orders of magnitude increases in soil loss rates between land that had been “retired” from agriculture and returned to pasture, wheat fields and bare fallow in central eastern New South Wales. In a recent study conducted at small basins of Triassic sandstone near Sydney, Erskine et al. (2002) found that land use is the dominant factor determining sediment yield and soil loss rates. Cultivated basins produced an average sediment yield of 7.1 t/ha/year whereas grazed pastures and forest/woodland basins exported an average of only 3.3 and 3.1 t/ha/year respectively.

Soil erosion leads not only to a loss of organic matter and soil nutrients from the surface, causing soil and land degradation, but also the deposition of sediment and nutrients in streams. In gully and rill erosion, the subsoil is the major source of sediment. Sediment eroded from catchment surfaces and stream channels may either be redeposited within the catchment system or exported from the catchment as fluvial sediment load (Olley 1995; Wasson et al. 1998). Deposition of eroded sediment can lead to nutrient enrichment of streams and subsequent eutrophication of waterways. The levels of nutrients generated from various forms of rural land use can be substantial. A study in the Hawkesbury-Nepean catchment indicated that 11kg of P and 127kg of N per hectare was lost in storm water from various land use activities (Hollinger et al. 2001).

3 Forms of erosion

3.1 Water erosion

Water erosion results from the removal of soil material by flowing water. A part of the process is the detachment of soil material by the impact of raindrops. The soil material is suspended in run-off water and carried away. Water erosion includes sheet, rill and gully erosion, all of which occur in NSW. 'Sheet' erosion is the removal of the thin layer of topsoil by raindrop splash and/or water run-off. 'Rill' erosion refers to soil removal by run-off that collects into small drainage lines (generally less than 30 cm deep) called rills. The Soil Conservation Service of NSW (SCS) reported that recently cultivated or disturbed soils are particularly susceptible to rill erosion (SCS 1989). Sheet and rill erosion hazards commonly occur on cropped lands with slopes generally above 3%. 'Gully' erosion occurs when smaller water flows concentrate and cut a channel, down which water flows only during or just after rain. It can result in the removal of the entire topsoil, then much of the subsoil, and the sedimentation of waterways. Gully erosion occurs on most land types. The Department of Land and Water Conservation (DLWC 2000) has estimated that some form of water erosion affects more than 35% of the NSW landscape.

Gully erosion in NSW occurs mainly in the uplands on the margins of the Murray-Darling Basin. A large proportion of the gully erosion evident today reflects past land-use practices (Wasson et al. 1998), particularly excessive clearing of native vegetation followed by overgrazing by introduced animals and pests. On the slopes of the Great Dividing Range of NSW, in regions where both cropping and grazing are practised, sheet and rill erosion tend to be the predominant forms of water erosion.

Fires also remove both the native plants and the vegetation litter covering the ground, exposing these areas to erosion. For example, new gullies are being formed in the Sydney water supply catchments in the Blue Mountains in the wake of fires. These areas are subjected to hot dry seasons alternating with a wet season with a total rainfall greater than 500 mm (ABS 1996). However, throughout Australia, infrequent but high-intensity destructive storms are responsible for a significant proportion of total soil loss. This is caused by significantly more run-off and less infiltration to the soil during heavy rain compared with usual rainfall events (Hairsine et al. 1993). Lack of ground cover increases the intensity of water run-off and hence soil erosion because no vegetation is present to moderate the raindrop impact on the bare soil or to slow the flow rate of run-off water across the ground.

3.2 Wind erosion

Wind erosion is a particular feature of the drier parts of the State, especially those areas with fine sandy soils such as the mallee lands of the central and south-western plains of the Murray-Darling Basin (MDB). Cultivation of these soils for wheat production or for pasture establishment can easily lead to a breakdown of the soil particles into sizes that are more susceptible to wind erosion, especially as wind erosion involves the loss of the finer soil particles (MDBC 2000).

Wind erosion is the detachment and movement of soil by the action of wind. Most wind erosion occurs in the semi-arid and arid lands, where annual rainfall is less than 400-600 mm and lighter sandy soils prevail. Nevertheless, all of NSW is subject to drought from time to time and soils of high and moderate risk in normally wetter areas can be expected to become mobile in such circumstances. In many instances, the only evidence that wind erosion is occurring may be atmospheric haze, where the dust consists of fine mineral and organic particles of soil. These particles can have nutrient concentrations many times greater than the soil from which they came. Selective loss of finer soil particles leaving only coarse particles is a particular problem and has the effect of reducing soil nutrient levels and the ability of the soil to retain moisture for plant growth. In affected areas, large sand drifts can have substantial adverse impacts on agricultural production and local infrastructure.

4 Impacts of erosion

4.1 Agricultural productivity

Soil loss has clear economic impacts on agriculture. The most productive layer of soil is the topsoil layer. It has been estimated that the removal of 1 cm of topsoil (the equivalent of 120 tonnes of topsoil per hectare) from wheat-growing paddocks reduces wheat yields by an average of 150 kg/ha or 10% of the national average wheat yield in Australia (Malcolm et al. 1996). The impacts of erosion can be masked for many years, as they can be obscured by cultivation or plant growth. The most immediate impact is a loss of nutrients carried away in the soil. This reduces agricultural productivity but has been offset in the past by the use of fertilisers. A medium to long-term impact is the reduced water-storage capacity of the soil, which is critical where soil depth, and thus available water storage capacity, is already marginal. The reduced water storage causes a loss of productivity (Sullivan 1991) and eventually increased run-off.

4.2 Water quality and ecosystem health

The loss of topsoil also affects water quality and the viability of ecosystems. Most off-site impacts of accelerated erosion are associated with the deposition of sediment with adsorbed nutrients and/or toxic agrochemicals and a consequent reduction in water quality and loss of in-stream biota. In-stream impacts are exacerbated in areas where access of livestock to river frontages causes damage to riparian vegetation, bringing a change in the ecological balance, increasing stream bank erosion and causing a deterioration of water quality.

Stream sediments also degrade water supplies for municipal and industrial use, and provide an important transporting medium for a wide range of nutrients and chemical pollutants that are readily adsorbed on sediment surfaces. The increasingly common occurrence of algal blooms and fish kills in inland waters is also testimony to the load of plant nutrients released into the water by soil erosion. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals and fish.

5 Erosion control

5.1 Current methods

There are several accepted best management practices (BMPs) that are used currently in controlling wind and water erosion. They range from better utilisation of the natural environment to the construction of artificial devices. Some of these BMPs include crop rotation, contour cultivation, strip cropping, terraces, grass waterways, diversion structures, riparian strips and conservation tillage. Maintenance of 70% plant cover on agricultural land is usually considered sufficient to substantially inhibit erosion. Other techniques for erosion control, such as contour banks, reduced tillage and strip cropping, provide supplementary measures. Studies (e.g. Wylie 1993) have found a clear trend towards decreased erosion with farm management practices that result in increased ground cover, such as mulching or zero tillage. However, it is recognised that there are many soil and climatic environments where reduced or zero tillage has led to an interim period of lower crop yields. A mid-1990s study found that such techniques were used on under 36% of cropping land in NSW (ABS 1996) but there has been greater adoption of lower impact methods by farmers in recent years (NSW Agriculture 1999).

On the slopes of the Great Dividing Range of NSW, contour ploughing has been used to prevent water erosion and combat the early stages of sheet and rill erosion. Unlike rills, gullies cannot be removed by tillage. Gully erosion is a particular problem because it reduces or subdivides arable land and establishes permanent pathways for the movement of sediment and other pollutants such as nutrients or agrochemicals. Gully rehabilitation is also generally very costly. Wind erosion can be minimised by retaining vegetative cover and using windbreaks to reduce wind speeds at the land surface. It is also critical to maintain soil structure, particularly in light-textured soils. This is best achieved by minimum tillage and a low frequency of cropping.

5.2 Role of vegetation

The most critical factor in protecting soils from erosion by water and wind is the maintenance of ground cover that is fixed or in close contact with the soil surface (e.g. trees, shrubs, pasture, plant residues and forest litter). Any event that reduces the protective ground cover increases the risk of soil loss. In particular, salinity, acidity and poor soil fertility can all lead to poor development of protective vegetation and result in the exposure of soil to raindrop impact, water run-off and wind. Poor soil structure and/or water repellency problems aggravate soil erosion by reducing infiltration and increasing run-off. Land clearing and cultivation can also lead to a decline in soil structure from the physical breaking up of the soil into smaller units and the oxidation and loss of soil organic matter, which binds soil particles together. Excessive clearing of vegetation, together with overgrazing by introduced animals, has led to structural damage to much of the topsoil in NSW, resulting in continuing soil erosion.

6 Role of recycled organics

6.1 The recycled organics industry

"Recycled organics" (RO) is a generic term for a range of products manufactured from compostable organic material such as garden organics, food organics, residual wood and timber, biosolids and agricultural organics (ROU 2001). The composting process is essentially a controlled and more rapid version of the natural decomposition of organic material. The form of organic carbon in composted RO product is important for their potential role in carbon sequestration (Gibson et al. 2002). This review will focus on composted RO products primarily derived from the garden organics component of the RO stream.

In the composting process, organic materials are pasteurised and transformed microbially under aerobic and thermophilic conditions for a period not less than six weeks. This composting process is not complete after this time and many products are then typically matured for a further period of 12 to 16 weeks under mainly aerobic mesophilic conditions. The resultant products are stabilised materials with a high carbon content and free from viable pathogens and weed propagules. In Australia, compost quality is defined by an Australian Standard (Standards Australia 2003), which prescribes aspects such as contaminant limits, stability and maturity criteria and physical properties. In NSW, several RO products such as biosolids and liquid food organics are stablised by chemical treatment or digestion and applied directly to land. Use of biosolids in agriculture is regulated by the NSW Environment Protection Authority guidelines

(NSW EPA 1997), which define product standards, application limits, site limitations and documentation.

While there are many specific blends and mixes of RO products, they mainly fall into two basic categories as defined by their end use (ROU 2001). They are (1) composted mulch, which is applied to the soil surface and has at least 70% of its mass with a particle size of >15mm and (2) composted soil conditioners, which are suitable for incorporation into the soil and have less than 15% of its mass with a particle size of >15mm. The chemical composition of composted RO product can vary from batch to batch depending upon availability and chemical characteristics of particular raw materials. In the Sydney basin, raw materials are typically garden organics, which are composted in windrows either on their own or with animal manures or biosolids. Municipal solid wastes (MSW) are usually processed by in-vessel composting systems. The organic carbon content in composts can range from 20-30% (equivalent to 34-52% organic matter) [Fahy and Richard 2000]. The range of constituent compositions in some Australian composts is given by Wilkinson et al. (2000).

6.2 Use of RO products in agriculture

RO application offers an approach that can reverse the associated decline in soil physical, chemical and biological properties (Navas et al. 1998) while at the same time reducing the stress placed upon our waterways and atmosphere. The incorporation of RO products into soil can reduce the use of inorganic fertilisers resulting in economic and environmental benefits for the whole community. Although RO products may not necessarily replace all the inorganic fertiliser inputs for crop production, they can be used in conjunction with inorganic fertilisers (Malik et al. 1999) to substantially reduce chemical fertiliser use. If the transport distances from composting facilities to the farms are relatively short, RO products have been shown to be an economic partial replacement for inorganic fertilisers (Hansson et al. 1999).

The existence of available and residual N forms in mature, composted RO products can provide an initial short-term release of available N (nitrate and ammonium) at the time of RO application and a more sustained release of the residual N during the subsequent growing seasons (Malik et al. 2000). Despite this pattern of N availability, application rates should not exceed agronomic rates (based on N content and estimated mineralisation rate) so that nitrate leaching to ground water is avoided (He et al. 2000; Buchanan and Gliessman 1991; Iglesias-Jiminez and Alvarez 1993). This is the approach taken by regulatory guidelines for the application of RO products such as biosolids to agricultural land (NSW EPA 1997).

6.3 Role of RO products in improving soil quality

“Soil quality” has been defined by the Soil Science Society of America (1997) as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". This definition portrays a “good quality" soil as a living and dynamic system, which is stable, resistant to stress and disturbance (buffering capacity) and with an ability to regenerate after disturbance (resilience) [Van Bruggen and Semenov 2000; Sherwood and Uphoff 2000]. The benefits of the use of RO products on soil quality have been extensively reviewed by Gibson et al. (2002).

RO products have been shown to improve soil biological fertility (microbial biomass/function and mineralisation potential), chemical fertility (pH, cation exchange capacity and nutrients) and physical fertility (soil porosity, aggregation, structure, bulk density, water holding capacity and hydraulic conductivity). The increase in soil biomass and biological abundance, diversity and activity resulting from the higher levels of organic matter present in the soil positively influenced soil structure, nutrient cycling and availability, buffering capacity and disease control in conventional system (Dick 1992; Pankhurst et al. 1994). Earthworm numbers were also increased (Edwards and Lofty 1982), which improved soil permeability and hydraulic conductivity (Jones et al. 1993). The consequence of improved soil quality is that the soil will be less susceptible to erosive forces.

6.4 RO products for controlling soil erosion and run-off

In Australia, RO products have so far been used mainly in urban landscaping, horticulture, viticulture, and to as lesser extent, agriculture. However, their role may be extended to managing disturbed landscapes in catchments, where the environmental issues of soil erosion, run-off and soil degradation are just as important as the previous emphasis on agricultural production.

In agriculture, soil erosion is associated with a suite of on-farm and off-farm problems such as nutrient loss, yield decline, flooding, sedimentation and eutrophication (Pimental 1993; Conacher and Conacher 1995). Under good management in both conventional and organic agriculture, such problems have been reduced substantially (Arden-Clarke and Hodges 1987,1988; Pimental et al.1995). Comparisons of effects are often difficult because of the variability in RO products and in the test soils used in different studies (Albiach et al. 2000). The effects of RO mulch treatments will also differ from RO treatments incorporated into the soil. The initial effects of the former on the soil properties would primarily be restricted to surface effects at the RO/soil interface until further decomposition and natural mixing had taken place.

The restoration of degraded landscapes depends on the restoration of soil carbon and nutrient resources. As RO products improve the soil health, plant establishment is more consistent and rapid. Improved plant establishment leads to the addition of more organic carbon from the plant residues and the development of a rooting system through the soil (Garcia et al. 1992; Giusquiani et al. 1995; Northcliff 1998), which contribute to minimising run-off and mitigating water erosion (Harris-Pierce et al. 1995; Moffet 1997). The use of RO products for land rehabilitation is increasingly being considered as a technical solution to reversing environmental degradation and promoting re-establishment of vegetation cover (Zier et al. 1999). When applied as a surface mulch, the RO products protect the soil from direct sunlight, reduces sediment loss by wind and increases water infiltration from rainfall. Therefore, their use has been incorporated as an additional strategy in erosion control (Edwards et al. 1994). The organic matter in the RO products has the potential to improve water infiltration and retention in soils (Epstein et al. 1976; Schneider et al. 1981; Ross et al. 1991).

Run-off and erosion of soils increase with decreasing vegetative cover and increasing slope (Hernandez et al. 1989). Plant cover reduces the energy associated with raindrop impact and slows surface water flow promoting greater infiltration while reducing run-off. Therefore, increased plant cover may result in reduced run-off and sediment yields (White et al. 1997; Pierce et al. 1998).

Ros et al. (2001) conducted a two-year field experiment to evaluate the effect of adding different RO products on land with a 15% slope. The organic materials were incorporated into the top 20 cm layer of soil in sufficient amounts to increase the soil carbon content by 2%. They found that the addition of the stabilised municipal waste, aerobically digested sewage sludge and MSW compost reduced soil loss by 78, 80, and 94% respectively compared to the control. They recommended a single application of 250-300 wet t/ha of these materials to control erosion in susceptible lands.

Nutrients and heavy metals can be transported off-site by surface run-off. Surface run-off in soils occurs when rainfall intensity exceeds the infiltration capacity of the soil. Most of the loss in run-off occurs from a few high intensity rainstorms and the concentration of the chemicals in run-off can be high during those events (Hubbard et al. 1982). The total volume of the run-off is affected by climatic factors as well as precipitation intensity, duration and distribution, watershed topography, geology, soil type, vegetative cover characteristics and soil moisture conditions.

Demars and Long (1998) showed that compost application reduced soil loss by 86% compared to bare soil, and sediments reaching nearby surface waters decreased by 99% when compared to silt fences and 38% when compared to hydromulch applications. In a 3-year study, Bazzoffi et al. (1998) reported that the single application of compost at the rate of 64 t/ha to a trial site with a 15% slope brought about a significant reduction in runoff of up to 399 m^3/ha during the cropping period of a maize crop, while soil loss was reduced by up to 2.4 t/ha. At the end of the above study, Bazzoffi and Pellegrini (2000) concluded that compost was highly effective in reducing run-off and soil erosion.

In a laboratory study, Agassi et al. (1998) evaluated the effect of the amount and mode of application of MSW compost on run-off. A control, three mulching treatments of 100, 200 and 300 m^3/ha and a soil incorporation of 200 m^3/ha were exposed to 400 mm/h simulated rainfall for about 40 minutes to obtain a total of 260mm of rainfall. It was possible to control the run-off effectively by mulching at the rate of 100 m^3/ha (1 cm mulching depth). Compared with the control, there was a reduction of 74.5, 74.2 and 70.9% reduction at 100, 200 and 300 m^3/ha respectively. In contrast, the incorporation treatment of 200 m^3/ha decreased run-off by only 17.3%, suggesting that the surface spreading of compost rather than its incorporation was more effective.

Bresson et al. (2001) investigated the impact of MSW compost application mixed with soil under simulated rainfall of 19 mm/h for 60 minutes. They found that the compost application reduced the sediment concentration of run-off by 69.7 %. This was attributed to the stabilisation of the aggregate framework of the soil, which allowed the particles detached from the top of surface aggregates to penetrate deeper. They also suggested that in highly unstable soils, MSW compost application was efficient in combating soil surface structure degradation and its consequence on run-off and erosion.

In NSW, there is little documented information on the use of RO products in the rehabilitation of degraded land in water catchments. The Department of Infrastructure, Planning and Natural Resources (DIPNR) has traditionally used a layer of cereal straw or meadow hay (5-10cm) as an erosion blanket, oversown with a seed mixture of exotic pasture grasses (cocksfoot, tall fescue and ryegrass) and legumes (white and subterranean clovers). When available, native grasses and shrubs may also be used for longer term revegetation (Frank Exon, personal communication). In recent years, with the advent of a protracted drought and the concomitant high price of cereal straw and meadow hay, DIPNR has attempted to use a composted soil conditioner (Nitrohumus®) produced from garden organics and biosolids as a replacement product for the rehabilitation of degraded areas. The product was used as a surface application (1-2cm layer), followed by sowing with the usual seed mixture.

However, relatively little research has been undertaken to characterise the effects of composted soil conditioner products on reducing runoff, soil loss and the export of nutrients in the runoff from treated areas in the NSW context. Nor has there been research conducted on the effectiveness of coarser RO products (mulches) for stabilising steeper slopes in NSW. Therefore, there is a need for scientific performance data to verify the usefulness of specific locally-produced RO products for catchment management in NSW and to develop guidelines for their optimal and economic use.

6.5 Rehabilitation of mine-sites and drastically disturbed land

Mining, excessive farming and industrial activities often create soils that are barren, physically and chemically degraded and unable to support plant growth (Norland 2000). There is often extensive soil erosion, acidity, chemical pollution and salinity as well. RO products as soil amendments have enhanced soil physical, chemical and biological properties, resulting in improved plant growth and successful revegetation of these sites. However, many NSW soils have inherent problems of salinity, sodicity and acidity (Northcote 1983) and RO product may also be useful in these situations by providing a better soil environment and starting the remediation process.

Disturbed and degraded areas respond exceptionally well to the high levels of organic matter and plant nutrients in RO products containing biosolids. Lime-stabilised biosolids can also rectify acidic soils. Biosolids alone have been used successfully to revegetate and rehabilitate many sites including the Sydney Airport’s third runway, Springwood Golf Course, mine-sites and quarries. At the BHP’s Port Kembla Steelworks site, biosolids have been mixed with coal wash and granulated slag from the steel making process to produce a soil substitute. More than 350,000 trees have been planted around the Port Kembla site using this soil substitute (Sydney Water Corporation 2000b) and is an example of successful rehabilitation of a disturbed area.

7 Specifications of RO products for erosion control

7.1 Application methods and specifications

There are three basic methods of applying RO products for erosion control: (a) compost blankets or erosion control blankets, (b) vegetation establishment blankets and (c) filter berms. Each method has its advantages and will depend on the slope of site, amount of potential rainfall, activity around the site and intended vegetation establishment. In many cases, more than one method can be used in combination (Rissie and Faucette 2001)

The usefulness of a particular type of RO product will depend on many factors including the feedstocks and processes used to produce it. Specifications for RO products used in erosion control include particle size, moisture content, organic matter content, pH, soluble salt content and other parameters. An example of specifications for an erosion control blanket and a filter berm are given in Table 1.

Table 1. Examples of specifications for an erosion control (compost) blanket and a filter berm for use in Georgia, USA (adapted from Rissie and Faucette 2001)

Property	**Erosion Control Blanket**	**Filter Berm**
Particle size	10-13mm screen & 50-75mm screen (ratio = 3:1)	10-13mm screen & 50-75mm screen (ratio = 1:1)
Moisture content	20-50%	20-50%
Soluble salt	3.0-6.0 dSm^{-1}	4.0-6.0 dSm^{-1}
Organic matter	40-70%	40-70%
pH	6.0-8.0	6.0-8.0
N content	0.5-2.0%	0.5-2.0%
Human made inert content	0.0-1.0%	0.0-1.0%
Application rate	25-75mm depth	30-60cm height x 75-120cm width
Maturity	Yes/High	Yes/High

Generally, a mix of fine and coarse grades of compost is best for controlling erosion. The fine compost (passing though a 10-13mm screen) will penetrate the soil surface and increase water infiltration and water holding capacity. In addition, the fine compost is essential for rapid vegetation establishment and long-term soil and plant health. Coarse grades of compost (passing through a 50-75mm screen), although harder to plant into, help to prevent raindrops splashing directly on the soil surface and are less likely to be disturbed by rainfall and storm run-off. The coarse grades also act as filters by ‘stopping’ or ‘catching’ soil particles already in motion. Applications rates usually are based on the chosen method and the severity of slope.

7.2 Erosion control blankets

Erosion control blankets or compost blankets are surface applications of designated high quality composts on areas with erosion risk. Compost blankets can control erosion on disturbed areas such as construction sites, highway projects, exposed stream banks (Goldstein 2002a) and any disturbed or degraded area with a 1:4 slope or less. Application rates are generally 25-75mm in depth with the higher rates used on steeper slopes. Some gradual slopes may require as little as 25 mm depth. Particle sizes should be a mix of fine grade (10-13mm) and coarse grade (50-75mm). A mixture ratio of 3:1 (fine: coarse) has been recommended in many studies. Coarse grades may be larger if rapid vegetation establishment is not a primary goal.

Blankets are easiest to apply using a pneumatic blower, especially on slopes where spreaders may not be an easy option. Compost and manure spreaders are effective application devices but only work well on open gradual slopes. It is preferable to apply the compost layer on the slope contour or up and down the slope to prevent water from sheeting between the compost and soil surface. It is also recommended to apply compost at least 1m over the shoulder of the slope or into existing vegetation where possible to prevent rill formation and transport of the compost.

The primary purpose of the compost blanket is to protect the soil surface until vegetation is established. Therefore, it is important to ensure that the compost material will encourage plant growth and the slope is seeded following compost application.

7.3 Vegetation establishment blanket

When vegetation cover is an urgent priority, a vegetation establishment blanket comprising a high quality composted soil conditioner may be used to promote rapid plant growth. Soil conditioners are not as coarse as mulches, which provide better seedbeds for the establishment of the pasture and/or shrub seeds sown into the RO product. Being finer, they will also provide more readily available plant nutrients compared to the composted mulches. The nutrient status of the materials again will depend on the feedstocks from which they are derived e.g. garden organics alone, garden organics plus biosolids, etc. Compared to erosion control blankets, it is not known how effective soil conditioners on their own are in combating runoff and soil erosion before a vegetation cover has been established. However, in practice, the special specifications by some states in the US requiring a mixture of fine and coarse materials (see Table 1) will ensure that erosion control and vegetation cover are achieved by the same product.

7.4 Compost filter berms

Compost filter berms are contoured run-off and erosion filtration methods usually used for steeper slopes with high erosive potential (Goldstein 2002b). The berms allow run-off water to penetrate it and continue to flow while filtering sediments and pollutants from the water. It also slows the flow allowing water particles to settle out. Berms work well in many of the same areas as blankets but are the preferred method if the slope exceeds 25%.

Berm size and construction may vary depending on the slope severity and amount of expected rainfall; larger berms are recommended for steeper slopes. Compost berms are typically contoured to the base of the slope but a second berm may be used on the shoulder contour of steeper slopes for added protection. Berms may be windrow or trapezoidal (allowing maximum water penetration) in shape and should be placed uncompacted on bare soil. Windrow shape berms should be between 30-60cm high and 75-120cm wide. Trapezoidal berms should be approximately 60cm high, 60-90cm wide at the top and at least 120cm wide at the base. It is advisable not to construct compost filter berms in run-off channels, ditches or gullies. A schematic diagram of the use of filter berms is shown in Figure 1.

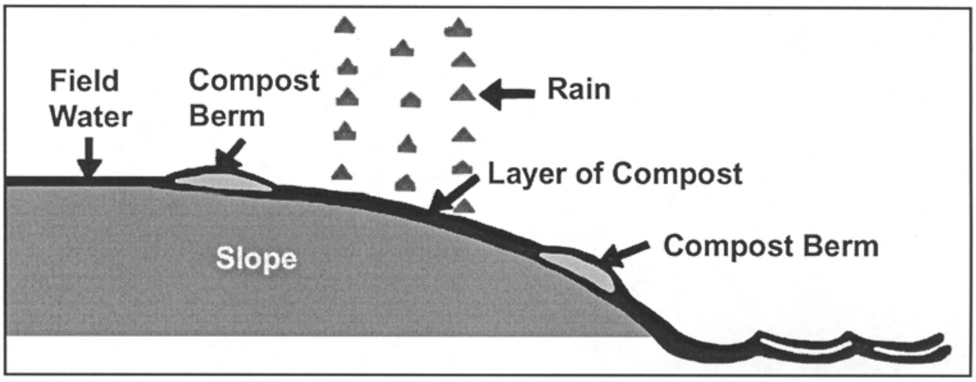

Figure 1. Use of compost filter berms (US EPA 1997).

Particle sizes should be a mix of fine (6-13mm) and coarse grades of compost with particle size not exceeding 75mm in length. The mixture ratio may include a greater fraction of coarser grade compost (1:1) compared to compost blankets if vegetation establishment on the berm is not a primary goal or if there is a high run-off potential. Application and construction of compost berms is easiest using a backhoe, bulldozer or gradient blade. Manual application may be an option in tight or small areas. Compost filter berms can be planted and/or seeded at the time of application for permanent vegetation establishment.

8 Conclusions

Benefits of the use of composted RO products for the rehabilitation of disturbed or degraded land are well established from the literature, with positive flow-on environmental effects in reducing run-off, soil erosion and improving water quality. These products have commonly been used to stabilise housing development sites and roadside areas, and several states in the US have developed desirable quality parameters and standards for their use. The verification of the overseas scientific data on the benefits of RO products for erosion control and revegetation of the landscape by local research on specified locally-sourced RO products should add confidence to the promotion by government and catchment authorities for their increased use. Depending on the economics, the benefits for their use in catchment areas can be maximised by the strategic placement of appropriate RO products to stabilise targeted, high-risk areas.

Currently, the supply of RO products manufactured from compostable organic materials in some areas of the Greater Sydney Region (GSR) is exceeding demand and leading to larger than normal inventories at composting sites. Therefore, the creation of a market segment to use these products in catchment management would be timely. In the American state of Texas alone, there is now an annual demand of around 100,000 cubic metres of composted RO products for erosion control, following the development of special specifications for their use.

9 Recommendations

Through consultation with the RO industry and governmental natural resource agencies, it is recognised that a moderate but unquantified volume of composted RO products is currently being used for erosion control and revegetation of erosion-susceptible sites around NSW.

Good erosion control has been obtained overseas when RO products derived from garden organics were used at depths of 25-75mm, equating to applications of 125-375 t/ha. However, Australian studies on the use of crop stubble residues to reduce soil erosion have shown that as little as 2t/ha of surface stubble has reduced erosion significantly on farming land (Felton et al. 1987). As such, the application rate of RO products for catchment management will have to be considered carefully if it is to be economically viable. For example, a range of application rates should be chosen in field experiments to determine whether erosion control is achievable at relatively low rates of application.

The physical composition of the RO products in Australia may be similar to those of other countries but their chemical compositions may vary because of the specific feedstocks used. Although the plant nutrient status of RO products are known to be generally low, there is still a need to demonstrate that the risk of these and other undesirable chemicals do not reach water catchments. The common overseas practice of using chemical fertilisers for revegetation at sites treated with RO products may not be appropriate in NSW as catchment managers are sensitive to nutrient movement beyond the sites of land-applied amendments. However, a compromise may be to use slow-release chemical fertilisers to limit the leaching of nutrients. Furthermore, from extensive consultation with government authorities, it is recommended that only RO products complying with the full requirements of AS 4454-2003 should be used for catchment management to eliminate any real or perceived risks of catchment contamination by heavy metals, toxic agrochemicals or plant, animal and human pathogens.

Scientific performance data should also be obtained for local RO products with special specifications for this market segment in order that guidelines may be developed for their optimal and economic use in NSW catchments.

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