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Improved soil fertility from compost amendment increases root growth and reinforcement of surface soil on slopes

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ABSTRACT

Vegetation such as grasses and shrubs can improve slope stability, reducing the risk of shallow failures once roots have permeated soil to enhance cohesion. However, establishment of vegetation is hindered by poor soil fertility, frequently a characteristic of disturbed soils used in engineering projects. We evaluated whether compost could improve the rate of vegetation establishment and hence soil mechanical reinforcement by plant roots and therefore protect against shallow failures. Over 1200 t of material was formed into a slope 40 m long × 15 m wide, with an experimental soil slope angle of 20°. Washings from recycled mineral fill were used for the surface soil. Five amendment treatments were replicated three times in strips of 1.5 m by 8 m in a randomised block design on this slope; treatments were a no compost control, standard compost addition at a rate of 35 t ha^{-1} and a high level compost amendment at 300 t ha^{-1}, applied either to the surface or incorporated into the topsoil to 10 cm.

Thirteen weeks after planting an amenity grass mix, vegetation cover increased up to 6 times compared to the control for 35 t ha^{-1} surface applied compost and similarly 20 times for 300 t ha^{-1} compost that had been surface applied. Root length density was about 3 km m^{-3} with no added compost and about 30 km m^{-3} for 300 t ha^{-1} added compost. At 35 t ha^{-1} compost, peak shear stress of the vegetated soil at 5 cm depth was not affected, but it almost doubled with 300 t ha^{-1} compost compared to no amendment. Cohesion from plant roots was 8.1 kPa for 300 t ha^{-1}, in comparison to 2.1 kPa for no amendment and 2.3 kPa for 35 t ha^{-1} compost. Whereas surface application resulted in better vegetation cover, there were no differences in peak shear stress between plots with surface application or incorporation of compost. This study provided experimental evidence in the field that compost improvement to soil fertility has a positive impact on soil stabilisation by plant roots.

1. Introduction

Composts and other organic residues are increasingly used in slope stabilisation projects and agriculture as a mulch to provide surface protection against soil erosion (Bazzoffi et al., 1998; Edwards et al., 2000; Hansen et al., 2009). It is well known that organic residues can improve plant performance, as shown in agricultural (Warman et al., 2009), agroforestry (Gruenewald et al., 2007), soil restoration (Ohsowski et al., 2012; Vaidya et al., 2008) and engineered slope studies (Faucette et al., 2009; Persyn et al., 2004). To our knowledge, however, no systematic study has investigated the combined impact of composts and potential improved vegetation growth on the mechanical reinforcement of soil slopes by plant roots. Such findings would be useful in developing new green engineering solutions for slope stability, where potential improved plant performance and the use of a recycled material will produce multiple environmental benefits (Mickovski et al., 2013). Plant roots bind the soil across potential slip planes so that at shallow depths where root density is abundant there is a decreased risk of shallow soil failures. Roots act as natural anchors resulting in a smaller carbon footprint from engineering projects.

The relative impact of organic residues on plant growth and soil stability tends to be greater for soils with poor initial fertility (Diacono and Montemurro, 2010; Fernandez-Getino et al., 2012). In engineering projects, physical disturbance of soils that are excavated, stockpiled and then used to cover embankments and cuttings can decrease fertility, thereby hindering the success

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of revegetation (Cao et al., 2010). In urban or mine reclamation projects, soils can be extremely infertile so revegetation is limited to hardy species that may fix nitrogen or requires intervention to improve soil conditions (Boyer and Wratten, 2010; Mallik and Karim, 2008; Montoro et al., 2000). Recycled soils formed from crushed building waste, or mine spoils that have low concentrations of organic carbon, are also used as fill in some engineering projects (Marando et al., 2011; Said-Pullicino et al., 2010). These produce a challenging environment for establishment and growth of vegetation.

Quality green composts can provide nutrients for plants and can also improve soil physical conditions for plant growth (Cogger, 2005). Such composts contain a wide range of micronutrients, including magnesium, copper and iron as well as important concentrations of nitrogen, phosphorus and potassium. The effects of compost on plant available water (PAW) are dependent on soil type and the properties of the compost such as density and organic matter content (Curtis and Claassen, 2009). Composts improve the mechanical properties of amended soils, including shear strength, even at quite large application rates of up to 30% by volume (Hejduk et al., 2012; Puppala et al., 2007). There is conflicting evidence from Hemmat et al. (2010), who found that at application rates of 100 t ha^{-1} cohesion (binding between particles) decreased and internal friction (frictional resistance between particles) increased at drier water contents (17.1%), but no differences were found at a wetter water content tested (20.9%) for a silty clay loam soil. In the dry condition shear strengths dropped by 60% due to compost amendment, but as most failures occur at small effective stresses (when capillary cohesion by pore water is small), the similarity of the wet measurements suggests composts alone will not affect slope stability due to decreased shear strength. If the addition of compost does not affect the shear strength at typical water conditions where failures occur, improved root growth associated with the compost amendment could enhance slope stability.

Increased root length density, RLD, following soil amendment with organic compounds has been observed in many studies (Hati et al., 2006; Mosaddeghi et al., 2009). Organic matter and root length density improve soil aggregation (Materechera et al., 1992), which is accentuated by compost amendments (Daynes et al., 2013). For single species in laboratory conditions, RLD is related to increased shear strength (Normaniza et al., 2008), although plant succession (Osman and Barakbah, 2011), root age and environmental factors (Loades et al., 2013) are also important.

Using a purpose built experimental slope, we investigated the impact of compost amendment on soil fertility, plant establishment and soil reinforcement by plant roots. Two application rates of 35 t ha^{-1} and 300 t ha^{-1} were either applied to the surface of the soil as a blanket or incorporated into the top 10 cm of the soil surface. The soil was a mineral fill formed from crushed building waste and discarded soil from demolition projects. We focussed on the initial stage of revegetation within thirteen weeks of planting. During this period, exposed bare soil is particularly vulnerable to shallow instabilities. We hypothesised that improved plant establishment, caused by increased soil fertility from compost, would drive soil stabilisation by plant roots and that this would more than offset any weakness caused by potentially lower shear strength from the compost addition. The research has direct relevance to improving the effectiveness of slope ecoengineering projects.

2. Materials and methods

2.1. Slope design

An experimental slope was constructed adjacent to Dundee City Council's composting facility, located at the Riverside Landfill site (56°27′19″N; 3°2′32″W) facing southeast. Material from demolition and construction sites is processed into materials for reuse in the construction industry at an adjacent site.

The slope required the movement of 1200 t of material that was built up to defined dimensions using heavy earth moving machinery (Fig. 1A). The slope was about 40 m wide and had a slope length of about 15 m with a 3 m buffer before a road at the toe of the slope. Rubble was placed at the base to provide slope stability, and then soil was layered above to provide a 20° slope angle. This is shallower than some engineered embankments but ensured safety. A top layer of soil, produced from the washings of mineral fill waste, was then placed on the surface to a depth of at least 60 cm. This material was a silty-sand textured recycled soil, consistent with the surface cover over the remainder of the landfill site. In other parts of the landfill, surface vegetation had not been seeded but there was evidence of wind-blown seed resulting in patchy plant growth.

The surface of the constructed slope had compost applied in treatment blocks (Fig. 1B). We used a randomised block design with 3 replicates of each of the 5 treatments used. Compost was applied at 2 rates and either incorporated to a depth of 10 cm by harrowing or left as a surface mulch. The compost used was made from plant residues only that were processed using the windrow method, by Dundee City Council, to produce quality green compost in accordance with BSI PAS 100 standard before grading to <20 mm. Each tonne, fresh weight, of this compost contained approximately 8 kg of nitrogen, all organic, 3 kg of phosphorus, as P_2O_5, 3 kg of potassium, as K_2O and had a dry matter content of 62%. The treatments were applied on 2 April 2009 using smaller scale equipment commonly used for high-value horticulture. Amenity No. 2 grass seed mix (R M Welch and Sons Ltd, Broughty Ferry, United Kingdom) was then sown to establish a vegetation cover. Seed mix contained Creeping Red Fescue (*Festuca rubra*) (50%), Perennial Ryegrass (*Lolium perenne*) (30%), Chewing Fescue (*F. rubra* subsp. *commutata*) (10%) and Browntop Bent (*Agrostis capillaris*) (10%). Following seeding, we sampled for 13 weeks between 20th April and 17th July 2009.

2.2. Field sampling and measurements

Monitoring the slope focused on the critical period of vegetation establishment after slope construction when the surface was bare. At this time compost is likely to be of most benefit in reducing surface erosion and shallow failures by accelerating establishment of plant cover. Measurements of soil mechanical behaviour, fertility and plant growth were taken at pre-determined times between 0 and 12 weeks after completion of slope construction. Rainfall data were collected at the Mylnefield Weather Station, located less than 2 km away.

On several sampling dates, two sets of cores and a bulk soil sample were taken from the surface of the crest, middle and toe of each plot. Cores 100 mm × 100 mm were taken perpendicular to the slope for mechanical tests and the abundance of plant roots measured at weeks 1, 7 and 12. Cores 40 mm height × 55 mm diameter were taken for measurement of water retention in the laboratory at weeks 1, 2, 4, 8, and 12. Bulk soil samples for chemical analysis were taken by combining ten samples collected at random locations with a 10 cm length × 2.5 cm diameter corer at weeks 0, 1, 2, 4, 8 and 12. The bulk samples from each plot were combined, passed through a 4 mm sieve and mixed thoroughly.

On each sampling date the percentage cover of vegetation was measured on a 0.5 m × 0.5 m grid at the crest, middle and toe of the slope using a square quadrat. Digital images were taken and imported to ImageJ analysis software (National Institutes of Health, Bethesda, Maryland, USA) where they were converted to