EFFICIENCY OF DCD EXTRACTION FROM SOILS

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Abstract
The soil nitrification inhibitor, dicyandiamide (DCD), has gained increasing attention in New Zealand pastoral agriculture as a mitigation strategy to reduce nitrogen losses to the environment. Quantifying the amount of DCD present in soil is critical in the assessment of DCD effectiveness to inhibit nitrification. Currently the DCD content in soil is determined by a water extraction method and reported in kg ha^{-1} which accounts for the soil depth, bulk density and a moisture factor. However, research has suggested that DCD interacts with soil organic matter potentially reducing the recovery of DCD in water extractions. A laboratory study was undertaken to assess the variability in the efficiency of DCD extraction across nine soil profiles covering different soil groups throughout New Zealand to ascertain if a correction factor is warranted in the calculation of soil DCD content. DCD was added to field-moist soil at rates between 0 and 40 µg DCD g^{-1} oven-dry soil equivalent. The soil was then extracted with water for DCD analysis and the recovery was calculated as a percentage of DCD applied. The efficiency of DCD extraction was variable across soils, ranging from 65 to 94% in the top soil (0-100 mm), and generally increased with soil depth. A pooled regression analysis revealed that the efficiency of DCD extraction was strongly correlated to the soil organic matter content (R^2 = 0.81; P < 0.001). The inverse linear relationship indicates that an increase in soil organic matter results in a decrease in the recovery of the DCD applied. Given the organic matter content of a soil the following linear equation has been proposed to obtain a precursory estimate of the recovery of DCD; *DCD recovery (%) = -0.823 x soil organic matter (%) + 95.6*. This study highlights the importance of using a correction factor when measuring soil DCD to adjust for incomplete recovery, particularly in soils with high organic matter.

Introduction
Application of the soil nitrification inhibitor, dicyandiamide (DCD), to grazed pasture has gained increased attention in New Zealand pastoral agriculture as a mitigation strategy to reduce nitrogen losses to the environment. Quantifying the amount of DCD present in soil is critical in the assessment of DCD effectiveness to inhibit nitrification. Currently the DCD content in soil is determined by a water extraction method and reported in kg ha^{-1} which accounts for the soil depth, bulk density and a moisture factor. However, Zhang *et al.* (2004) studied the sorption-desorption behaviour of DCD in two soils with contrasting levels of organic matter and showed that DCD was adsorbed onto the surface of organic matter. Adsorption of DCD onto the surface of organic matter could potentially reduce the recovery of the applied DCD in soil and result in an underestimation in the actual amount of DCD present in soil.

A preliminary laboratory study was undertaken to examine the variability in the efficiency of DCD extraction across nine soil profiles covering different soil groups throughout New Zealand to ascertain if a correction factor is warranted in the calculation of soil DCD content.

Methods

Nine soil profiles covering different soil groups throughout New Zealand were sampled at selected intervals to a maximum depth of 600 mm (Table 1).

Table 1: Description of New Zealand soils used in the laboratory study.

Soil name	NZ soil classification	Soil order
Te Kowhai silt loam	Typic Orthic Gley Soil	Gley
Whakapara silty clay loam	Mottled Fluvial Recent Soil	Recent
Oropi sand	Allophanic Orthic Pumice Soil	Pumice
Tokomairiro deep silt loam	Fragic Perch-gley Pallic Soil	Pallic
Stratford fine sandy loam	Typic Orthic Allophanic Soil	Allophanic
Harihari stony silt loam	Mottled Fluvial Recent Soil	Recent
Otorohanga silt loam	Typic Orthic Allophanic Soil	Allophanic
Taupo sand	Immature Orthic Pumice Soil	Pumice
Motumaoho shallow silty peat	Acid Humic Organic Soil	Organic

Field-moist soil samples were sieved (4 mm) and mixed thoroughly before determination of soil moisture content at 105^{o}C (Blakemore *et al*., 1987). For each soil sample, 1 mL of 0, 100, 400 or 1000 ug mL^{-1} DCD stock solutions were applied to replicate subsamples of 40 g field moist soil to achieve equivalent DCD rates of between 0 and 40 µg DCD g^{-1} oven-dry (OD) soil equivalent. The soil samples were thoroughly mixed and equilibrated for 48 hours to allow sufficient time for DCD to interact with soil organic matter. Soils were then extracted with distilled water at a 1:2.5 soil-to-water ratio on an end-over-end shaker for 1 hour and filtered prior to DCD analysis.

The concentration of DCD in soil-water extracts was determined by high performance liquid chromatography (Shimadzu Corporation, Kyoto, Japan), fitted with a Bio-Rad Aminex® organic acid column HPX-87H (300 x 7.80 mm I.D.), using a method based on that of Schwarzer and Haselwandter (1996).

The efficiency of DCD extraction was calculated by dividing the amount of DCD recovered by the amount applied and expressed as a percentage (%). The standard error of the mean was 1.1% (pooled over soils and concentrations of DCD stock solutions applied).

Results and Discussion

The efficiency of DCD extraction was variable across soils, ranging from 65 to 94% in the top soil (0-100 mm; Table 2). In most soils the efficiency of DCD extraction was relatively high (>80% recovery) in the topsoil, except for the Motumaoho shallow silty peat soil which had the lowest recovery of DCD at 65% of that applied.

Table 2: Efficiency of dicyandiamide (DCD) extraction (% of applied) from the top 0-100 mm soil depth in nine New Zealand soils.

Soil name	DCD extraction efficiency (%)
Stratford fine sandy loam	84.5
Otorohanga silt loam	82.5
Te Kowhai silt loam	94.2
Motumaoho shallow silty peat	65.1
Tokomairiro deep silt loam	93.6
Oropi sand	88.3
Taupo sand	78.9
Whakapara silty clay loam	87.2
Harihari stony silt loam	86.8

Soil depth sampling revealed that the efficiency of DCD extraction generally increased with soil depth and this was mirrored by a decrease in soil organic matter content (Figure 1, next page). There was some variability in the efficiency of DCD extraction between soil layers, which suggests that for optimal assessment of DCD content in a soil profile individual DCD recovery values should be assigned to each measured soil layer.

A pooled regression analysis showed that the efficiency of DCD extraction was strongly related to the soil organic matter content (R^2 = 0.81, P < 0.001; Figure 2). The inverse linear relationship indicates that an increase in soil organic matter results in a decrease in the recovery of the DCD applied.

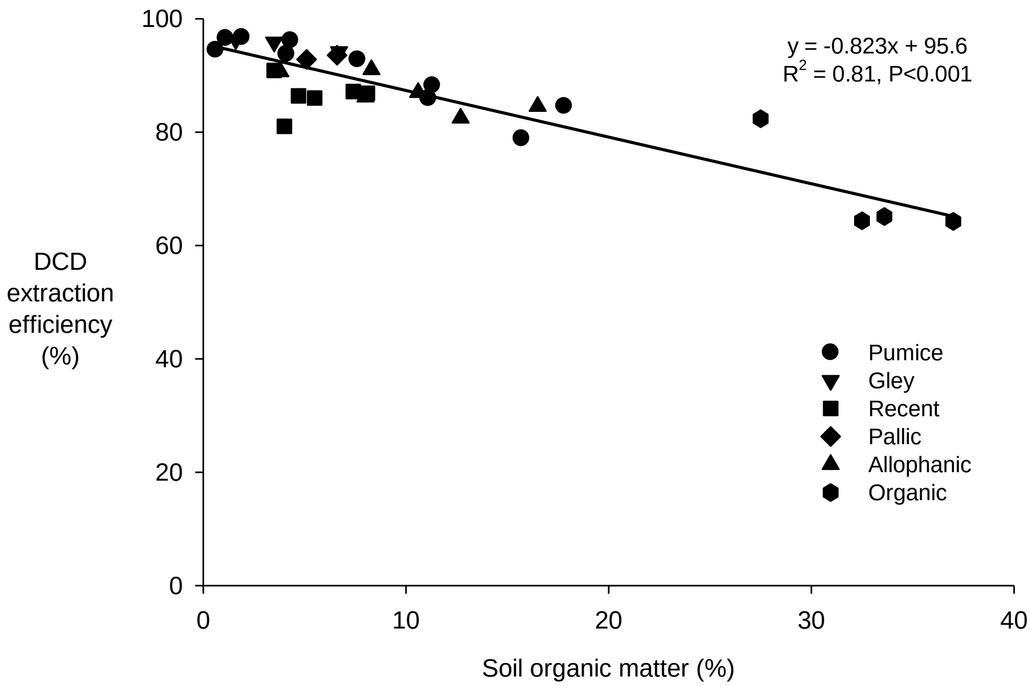

Figure 2: Relationship between the efficiency of dicyandiamide (DCD) extraction (% of applied) and soil organic matter content (%) in nine New Zealand soil profiles (including different depth intervals).

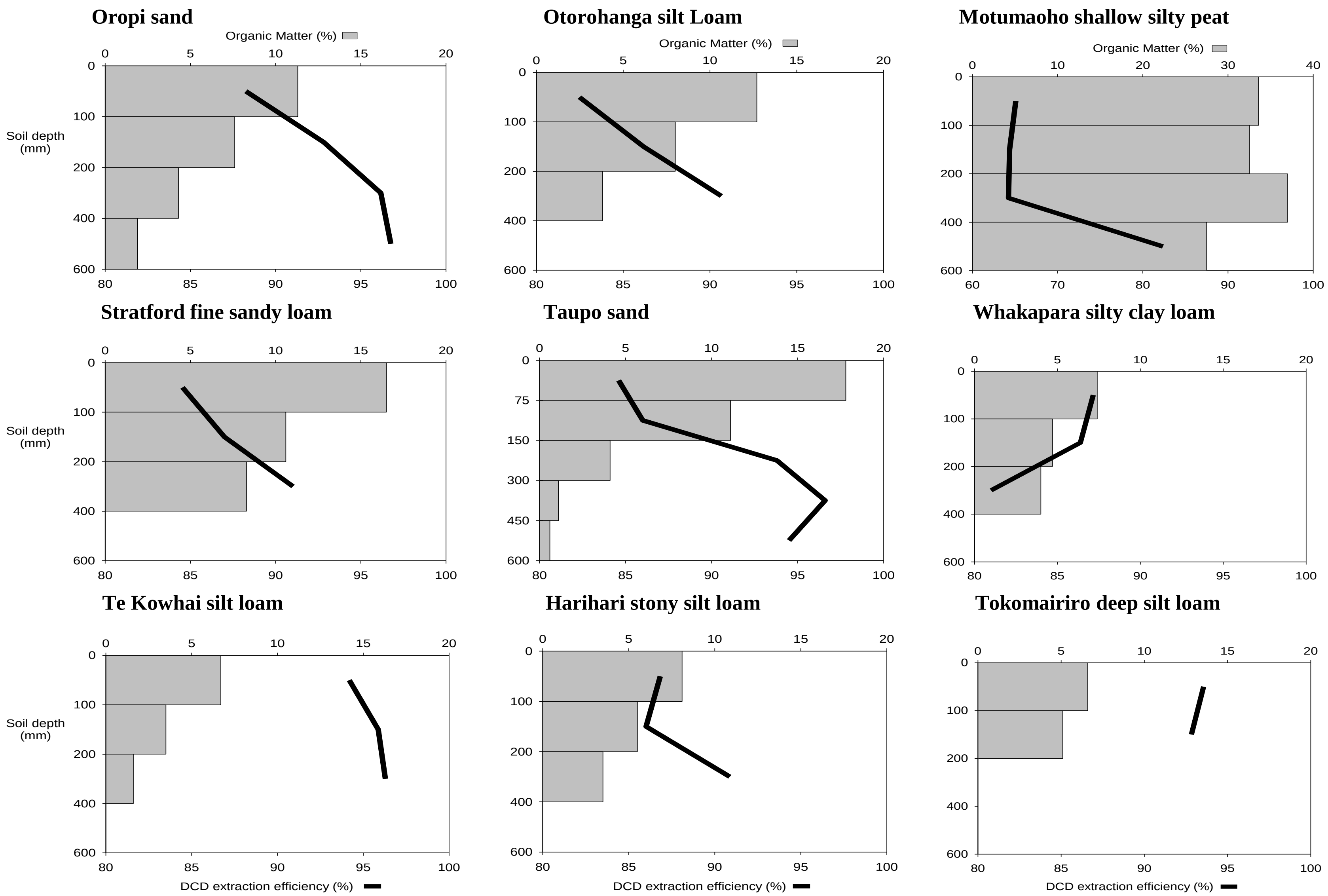

Figure 1: Changes with soil depth in the efficiency of dicyandiamide (DCD) extraction (% of applied) and soil organic matter content (%) in nine New Zealand soil profiles (0-600 mm maximum depth).

Given the organic matter content of a soil the following linear equation has been proposed to obtain a precursory estimate of the recovery of DCD;

$$DCD\ recovery\ (\%) = -0.823 \times soil\ organic\ matter\ (\%) + 95.6.$$

Based on the above linear equation an increase in the soil organic matter content from 5 to 15% would result in a decrease in the efficiency of DCD extraction from 91 to 83%. This finding highlights the importance of using a correction factor when measuring soil DCD to adjust for incomplete recovery, particularly in soils with high organic matter.

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