STONY SOILS ARE A MAJOR CHALLENGE FOR NUTRIENT MANAGEMENT UNDER IRRIGATION DEVELOPMENT

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Abstract

The last 20 years has witnessed large-scale conversion of alluvial soils into intensive dairy farming. In the South Island most of the expansion of dairy farming has occurred on irrigated stony soils that are vulnerable to nutrient leaching losses. This vulnerability to leaching may make it difficult for land owners of intensive farming systems to meet water quality objectives arising from the 2011 National Policy Statement on Freshwater Management and revised/proposed regional council plans. This paper presents a stocktake of the distribution, state of knowledge, and agricultural development on New Zealand's stony soils and highlights the urgent need for research to be undertaken to determine the environmental risks of intensive development on this land and to find land-management solutions to these risks.

Stony soils (soil depth < 45 cm to gravels), that have potential for intensive land use (land less than 15^{o} slope), are extensive with 1.68 million hectares mapped Fifty-three percent occur in Canterbury, 12% in Otago, with 9% each in Southland and the West Coast.

Significant land-use change has occurred on stony soils since 2000. Agribase 2012 showed the major land uses on stony soils are sheep and beef (427,000 ha), sheep (256,000 ha), and dairy (232,000 ha). By comparing with data from Agribase 2000, this represents a 38–43% decline in sheep farming, and increases in sheep and beef (22–44%) and dairying (47–95%) over the last 12 years (gaps in Agribase data preclude precise figures). Most dairy expansion on stony soils occurred in Canterbury where areas have doubled over 12 years and amounted to 143,000 ha in 2012. Similar dairy expansion occurred in the West Coast, Southland, and Otago, although the areas are smaller with 21,000 ha, 20,000 ha, and 12,000 ha, respectively, in 2012. In Canterbury, irrigation is extensive on stony soils, with analysis of satellite images collected from 2008 to early 2011 estimating at least 196,000 ha under irrigation.

Our analysis shows that 42% of stony soils have low P-retention (<30%), 77% have moderate to rapid permeability, and 58% have low water storage capacity (30–90 mm). These attributes are all indicators of soils with high vulnerability to leach nutrients.

This study clearly shows that stony soils have been a hotspot of land-use change and intensification over the past decade that under irrigation may be creating conditions where there is a high risk of nutrient leaching. There needs to be a focus on developing targeted management practices developed to reduce leaching losses on stony soils.

Introduction

The last 20 years have witnessed large-scale conversion of alluvial soils (particularly in the South Island) into intensive dairy farming. This is likely to continue with the planned expansion of the irrigated area by 340,000 ha, with almost two-thirds of the new irrigation expected to be in the Canterbury Region (The Beehive 2013). The growth in irrigated area will see significant land use change, with 80% expected to be used for dairy and arable (cropping) (The Beehive 2013).

Underpinning this irrigation expansion will be the development and application of irrigation science and technology for both maximising productivity, as well as meeting water quality objectives arising from the 2011 National Policy Statement on Freshwater Management (MfE 2011), and the subsequent revised/proposed regional council plans. It is important that this science and technology investment is targeted at the soil natural capital of the irrigated areas. This paper presents a stocktake of the distribution, state of knowledge, and agricultural development on New Zealand's stony soils, which are extensive in both the proposed and currently irrigated areas.

Methods

Definition of stony soils

Stony soils were identified as occurring where the soil depth has been mapped as < 45 cm to gravels. This definition includes the rounded-stony, angular-stony, and fragmental soil-profile-material classes used in the New Zealand Soil Classification (Webb and Lilburne 2011). Because the focus of this project is on soils with the potential for intensive land use, only stony soils that have been mapped on land less than 15° slope have been included for analysis.

Spatial mapping of stony soils

The mapping of stony soils is based on the combined spatial coverage of the S-map database (Landcare Research 2012), growOTAGO regional soil survey (growOTAGO 2003) and the Fundamental Soils Layer (LRIS 2012). S-map is a spatial database that is compiling all the previous New Zealand soil surveys, at a minimum detail of 1:50,000 mapping scale, into a single standardised database (Lilburne *et al*. 2012). Where previous soil surveys do not exist, or old surveys have inadequate detail, new soil survey is being completed. Whilst the eventual aim is for a complete S-map coverage of New Zealand, this had not occurred by the time of this study, and other data sources were required to fill in the coverage gaps. The growOTAGO soil survey is also at 1:50,000 cartographic scale, but is yet to be incorporated into the S-map database. The growOTAGO survey uses the same criteria as S-map to define soil properties and therefore has the compatibility needed for the analysis in this project. The Fundamental Soils Layer (FSL) was used to delineate remaining stony soils not identified by the S-map or growOTAGO spatial datasets. The FSL coverage was developed as part of the New Zealand Land Resource Inventory (Newsome 1992), with the FSL compiled at a nominal scale of 1:63,360, from the best available soil maps at a range of scales up to 1:253,440 (Wilde *et al*. 2000). The stony soils landscapes mapped in this project mostly occur in the areas of S-map and growOTAGO coverages, with only the valleys of the South Island hill country, Westland and parts of the Manawatu and Hawke's Bay regions derived from the FSL coverage.

To map the spatial distribution of stony soils each dataset was first filtered to identify land of < 15° slope. The FSL coverage was also clipped to remove the area covered by the S-map and growOTAGO coverages. The final step involved filtering each dataset to identify polygons that contain stony soils. Because multiple soil types are often identified in a polygon, the derived stony soil coverage was further refined to identify the proportion of stony soils occurring. This proportion enabled calculation of the area of stony soils within each polygon.

Spatial mapping of land use on stony soils

The land use on the stony soils layer was estimated using the AgriBase™ enhanced Land Cover Database II (AsureQuality 2012). To evaluate land use change the AgriBase™ land use database was compared for the years 2000, 2006, and 2012.

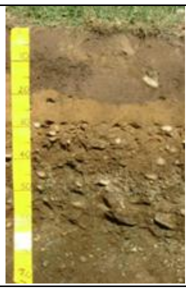
Results and discussion

Types of stony soils

There are a wide variety of stony soils mapped in New Zealand, spanning 10 soil orders and 71 subgroups under the New Zealand Soil Classification (Hewitt 2010). Our analysis shows that 42% of the area of stony soils has low P-retention (<30%), 77% has moderate to rapid permeability, and 58% has low available-water storage capacity (30–90 mm). These attributes are all indicators of soils with high to very high vulnerability to leach nutrients (Carrick 2002; Webb *et al*. 2010).

In this paper we clustered stony soils into five broader groups (Table 1).

Table 1 Broad grouping of stony soils, with the defining soil attributes highlighted

Primary soil class	Very light	Light	Moderate	Slowly permeable	Poorly drained
					
Area	269 000 ha	384 000 ha	515 000 ha	285 000 ha	115 000 ha
Drainage class	Well drained	Well to imperfectly drained	Well to imperfectly drained	Well to imperfectly drained	Poorly drained
Profile available water to 1m depth	Very to extremely light (<60 mm)	Light (60–90 mm)	Moderate (90–120 mm)	Very light to moderate (30–120 mm)	Very light to moderate (30–120 mm)
P-retention	Low to moderate (<60%)	Low to moderate (<60%)	Low to moderate (<60%)	Low to moderate (<60%)	Low to moderate (<60%)
Permeability	Moderate to rapid	Moderate to rapid	Moderate to rapid	Slow	Moderate to slow
Representative soil families	Rangitata and Rakaia	Lismore and Eyre very stony	Lismore stony and shallow	Darnley, Lowburn, Ranfurly	Waterton, Dipton

Spatial distribution of stony soils

A total 1.68 million hectares of stony soils are mapped across New Zealand that occur on land of <15° slope, and therefore have potential for intensive land use (Figure 1). The majority of stony soils occur in the Canterbury Region with 891,156 ha, followed by Otago with 197,937 ha, Southland with 159,561 ha, and the West Coast with 155,226 ha. Other regions with substantial areas of stony soils include the Tasman, Marlborough, Wellington, the Manawatu–Wanganui, and Hawke's Bay regions with 75,234 ha, 56,602 ha, 56,217 ha, 48,949 ha, and 31,022 ha, respectively.

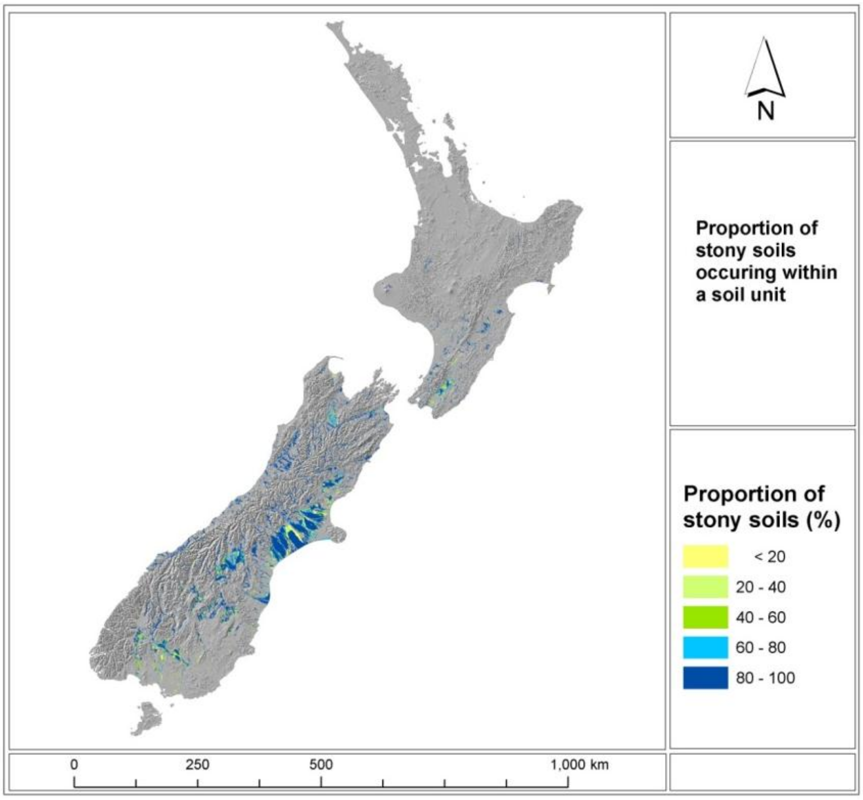


Figure 1 Map showing the extent and proportion of stony soils occurring within a soil polygon across New Zealand.

Land use on stony soils

Significant land use change has occurred on stony soils since 2000. In 2012 the major land uses are sheep and beef (427,000 ha), sheep (256,000 ha), and dairy (232,000 ha), representing a 38–43% decline in sheep farming, and increases in sheep and beef (22–44%) and dairying (47–95%) since 2000. Precise figures on land use change are not possible, due to some polygons of the AgriBase™ land use database having an undefined land use in the year 2000. By 2012 these polygons had a defined land use, but it is not possible to know what the previous land use was. The range we have presented for each land use represents the minimum and maximum range in land use change. For example in relation to dairy land-use, the minimum change of 47% represents the possibility that all of the undefined land use in the year 2000 that had changed to dairy land use by the 2012 was actually dairy in 2000. Conversely the maximum change of 95% represents the possibility that of the undefined land use in the year 2000 that had changed to dairy land use by 2012, none of this land was being used for dairying in 2000.

Most dairy expansion on stony soils has occurred in Canterbury, with a total of 143,000 ha in 2012 (Figure 2). Similar dairy expansion occurred in the West Coast, Southland, and Otago, although the areas are smaller with 21,000 ha, 20,000 ha, and 12,000 ha, respectively. In Canterbury, irrigation is also extensive on stony soils. Of the 302,000 ha of irrigated land that could be detected with analysis of satellite images collected from 2008 to early 2011(Pairman *et al*. 2011), 196,000 ha occurs on stony soils.

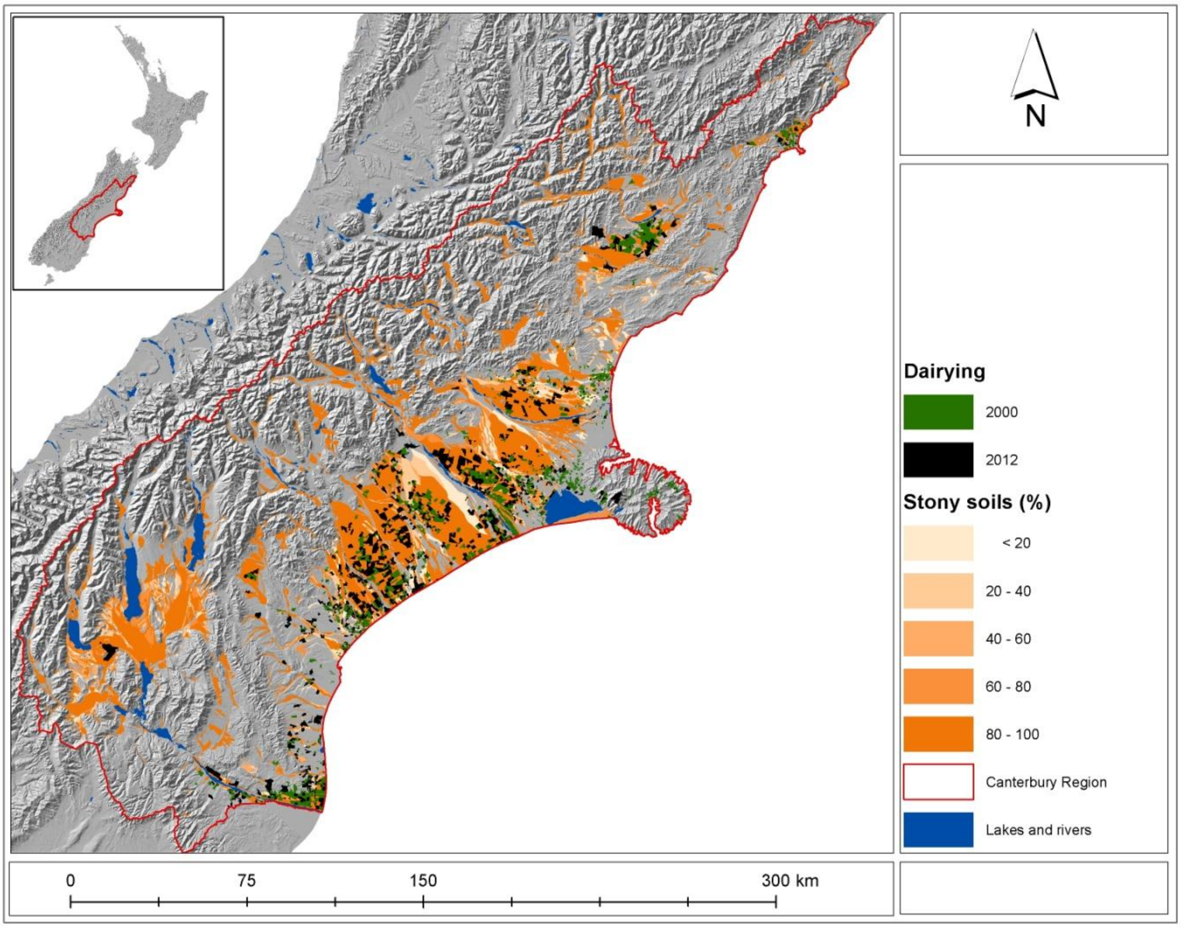


Figure 2 Increase in dairy land use on stony soils from 2000 to 2012 in the Canterbury Region.

Vulnerability of stony soils to nutrient leaching

The vulnerability of stony soils to nutrient leaching is primarily due to their low water storage capacity, and the predominance of moderate to rapid permeability, meaning excess rainfall or irrigation can readily drain to groundwater.

Environmental models consistently predict stony soils as a hotspot for leaching (Lilburne and Webb 2002; Green and Clothier 2009; Lilburne *et al*. 2010). Recent modelling with OVERSEER 6 also indicates large responses in nitrogen leaching to decreasing soil water storage capacity (Wheeler *et al*. 2011).

However there is very little experimental research on nutrient leaching from stony soils (Lilburne *et al*. 2010). Most research has been confined to the Lismore shallow and stony soils (Di and Cameron 2002a, 2002b, 2007; Toor *et al*. 2004, 2005). In one of the few experimental studies, nitrate leached from cow urine patches was measured under spray irrigation to be approximately double that of a similar experiment on the deep stone-free

Templeton soil (Di and Cameron 2005, 2007). The experiments of Toor *et al*. (2004, 2005) demonstrate the potential for stony soils to leach phosphorus under fertile grazed pastures, particularly under flood irrigation and following the application of farm dairy effluent.

It is important to note that the Lismore shallow and stony soils, which have been used for the limited research on nutrient leaching thus far, fit into the moderate stony soil class of Table 1. The analysis of this paper indicates that there are large areas of stony soils with a lower water-holding capacity (653,000 ha classified in the light and very light categories of Table 1) that environmental models predict to have a greater nutrient leaching vulnerability.

Conclusions

The results of this research show that stony soils are extensive, particularly in the South Island lowlands, and over the last decade have been subject to significant land use change, intensification and irrigation development. The area of intensification of land use on stony soils will increase when planned large-scale irrigation developments proceed. Current research indicates that because of the low water storage and good permeability, stony soils have a high vulnerability to nutrient leaching, which poses a significant challenge for intensifying land use on these soils whilst operating within water quality limits.

We suggest that environmentally-sustainable intensive farming on stony soils is dependent on application of targeted management practices. Development of these management practices will require substantial investment in research to quantify water and nutrient use efficiency for stony soils.

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