# Changes in soil quality following humping/hollowing and flipping of pakihi soils on the West Coast, South Island New Zealand

S.M. THOMAS[1], M.H. BEARE[1] C.D. FORD[1] and V. RIETVELD[2]
[1]*Crop & Food Research, Private Bag 4704, Christchurch*
[2]*Landcorp Farming Limited, 11 Deans Avenue, Christchurch*
thomass@crop.cri.nz

## Abstract

Humping/hollowing and flipping are land development practices widely used on the West Coast to overcome waterlogging constraints to pasture production. However, there is very limited information about how the resulting "new" soils function and how their properties change over time following these extreme modifications. We hypothesised that soil quality will improve in response to organic matter inputs from plants and excreta, which will in turn increase nutrient availability. We tested this hypothesis by quantifying the soil organic matter and nutrient content of soils at different stages of development after modification. We observed improvements in soil quality with increasing time following soil modification under both land development practices. Total soil C and N values were very low following flipping, but over 8 years these values had increased nearly five-fold. Other indicators of organic matter quality such as hot water extractable C (HWC) and anaerobically mineralisable N (AMN) showed similar increases. With large capital applications of superphosphate fertiliser to flipped soils in the first year and regular applications of maintenance fertiliser, Olsen P levels also increased from values <10 μg/g to values well within the target range (20-30 μg/g) after about 7 years. Humps and hollows responded differently following modification. The increases in total soil C and N, HWC and AMN levels on humps were similar to those of flipped soils over 8 years of development, whereas soil quality changes in the hollows were much slower. This has important implications for nutrient availability and losses. As soils develop, fertiliser and effluent applications should be adjusted to optimise production while minimising nutrient losses.

**Keywords:** humping and hollowing, flipping, soil quality, soil organic matter, effluent

## Introduction

Dairy production is important to the economy of the South Island's West Coast, with an estimated farm-gate value (2005/06) of $170m (assuming 41m kg MS x $4.15/kg MS (S. Cotton pers. comm.). The West Coast dairy industry wants to grow in an economically and environmentally sustainable manner. Recent growth of the industry has involved expansion of dairy farms onto poorly drained "pakihi" soils, which are typically acidic, infertile and podzolised with distinct iron pans that strongly impede drainage. Owing to very high rainfall on the West Coast, waterlogging and nutrient availability remain major constraints to sustainable production and growth of the industry.

Humping/hollowing and flipping are two land development practices extensively used on the West Coast to improve soil drainage and thereby overcome these major constraints to sustained high levels of dry matter production (DMP). Flipping is a technique that involves the use of an excavator to "flip" (i.e. invert) the top 1-3 m of soil and break up the buried iron pans that restrict vertical drainage. In contrast to flipping, humping/hollowing is a technique designed to increase the surface runoff of water. Both practices result in the displacement and loss of top soil organic matter (SOM) that is important in retaining nutrients, thereby reducing the capacity of these soils to recycle nutrients and increasing the risk of leaching or runoff of nutrients.

A recent study by Morton and Roberts (2006) described pasture production responses to fertiliser (N, P, K and S) on newly modified (by flipping or humping/hollowing) pakihi soils on the West Coast. They concluded that high rates of N, P and K are required to maximise dry matter production in the early stages of post-modification development. However the capacity of these soils to retain and recycle the nutrients returned in excreta (i.e. urine and dung) is undoubtedly limited by their very coarse texture (high sand gravel and/or stone content) and low organic matter content.

Recently flipped soils have very low concentrations of organic matter and quick-test nutrients (Olsen P, Ca, Mg, $SO_4$-S) in their top soils and a very limited capacity to supply nutrients (especially N) from mineralisation. They are also expected to have a low water-holding capacity (WHC), a limited ability to retain nutrients applied in fertiliser, a high risk of nitrate leaching, and increased susceptibility to compaction from stock treading.

Over time it is expected that levels of soil organic matter will increase, leading to increased levels of quick-test nutrients, soil microbial activity and N availability. Soil physical properties, including soil WHC, are also expected to improve. In addition to improved nutrient availability, soil development may help to reduce the risk of nutrient losses provided that fertiliser additions are also moderated over time to address the increased supply of nutrients from the soil.

The results presented in this paper are part of ongoing research to quantify the rate of change in soil organic matter and plant available nutrients on flipped and humped/hollowed paddocks using a chronosequence of paddocks at different stages of development following modification.

## Methods

### Site information and fertiliser history

Paddocks at different stages of development following modification by humping/hollowing (total of 15 paddocks) or flipping (total of 20 paddocks) were selected and sampled during the autumn of 2005 and the autumn of 2006. Flipped paddocks were selected on dairy units near Cape Foulwind (10 km west of Westport, whereas the humped/hollowed paddocks were located near Moana (27 km east of Greymouth) on the South Island West Coast. In both cases, care was taken to select paddocks that represented soils with the same or similar sedimentary parent material and that were modified using similar practices. Most of the paddocks selected were free of dairy shed effluent (DSE) applications, but a small number of DSE paddocks were included for comparison.

Typical fertiliser management consisted of large capital applications of N and P (as superphosphate) plus trace elements (Cu, Mo, Se), lime (3000 kg) and dolomite (2000 kg) in the first year following modification and lower maintenance fertiliser applications applied in subsequent years (Table 1).

**Table 1** Typical fertiliser applications during early development stages following flipping and humping/hollowing.

| | Nutrient (kg/ha/yr) | | | |
|---|---|---|---|---|
| | N | P | K | S |
| Year 1 [1] | 500 | 120 | 80 | 180 |
| Year 2 onwards [2] | 320 | 40-45 | 80 | 70 |

[1] capital + maintenance fertiliser

[2] maintenance fertiliser only

### Sampling collection and analyses

Soil organic matter and nutrient availability measurements were made from composite soil samples collected within each paddock, taking care to avoid atypical areas such as those around gateways, water troughs, fence lines, or where there was evidence of recent supplementary feeding. Separate transect samples were composed of 15 sub-samples collected along a W- or Z-shaped transect across the paddock and composited for soil organic matter and chemical fertility analysis (pH, Olsen P, exchangeable Ca, Mg, K and Na; $SO_4$-S; anion exchange capacity [ASC]; cation exchange capacity [CEC]; base saturation; total C and N; hot water extractable carbon [HWC]; and anaerobically mineralisable nitrogen [AMN]).

### Flipped soils

Composite samples were taken using a soil corer (2 cm diameter, 0-15 cm). At each of three representative sample locations, three soil cores (5 cm diameter, 0-15 cm) were collected and composited for analysis of bulk density.

### Humped/hollowed soils

The humps and hollows at Moana were sampled and analysed separately. Owing to the high stone content of these soils, standard soil fertility coring for the composite core was not possible. Instead a spade was used to collect 15 representative sub-samples of fine earth soil from the top 15 cm of the soil profile near (i) the top of the humps and (ii) the base of the hollows. Stone content was measured from a sample of known volume (approx. 20 x 20 x 15 cm deep) taken from two humps and two hollows in each paddock in order to determine the fine earth bulk density and correct the organic matter and chemical fertility analyses for stone content.

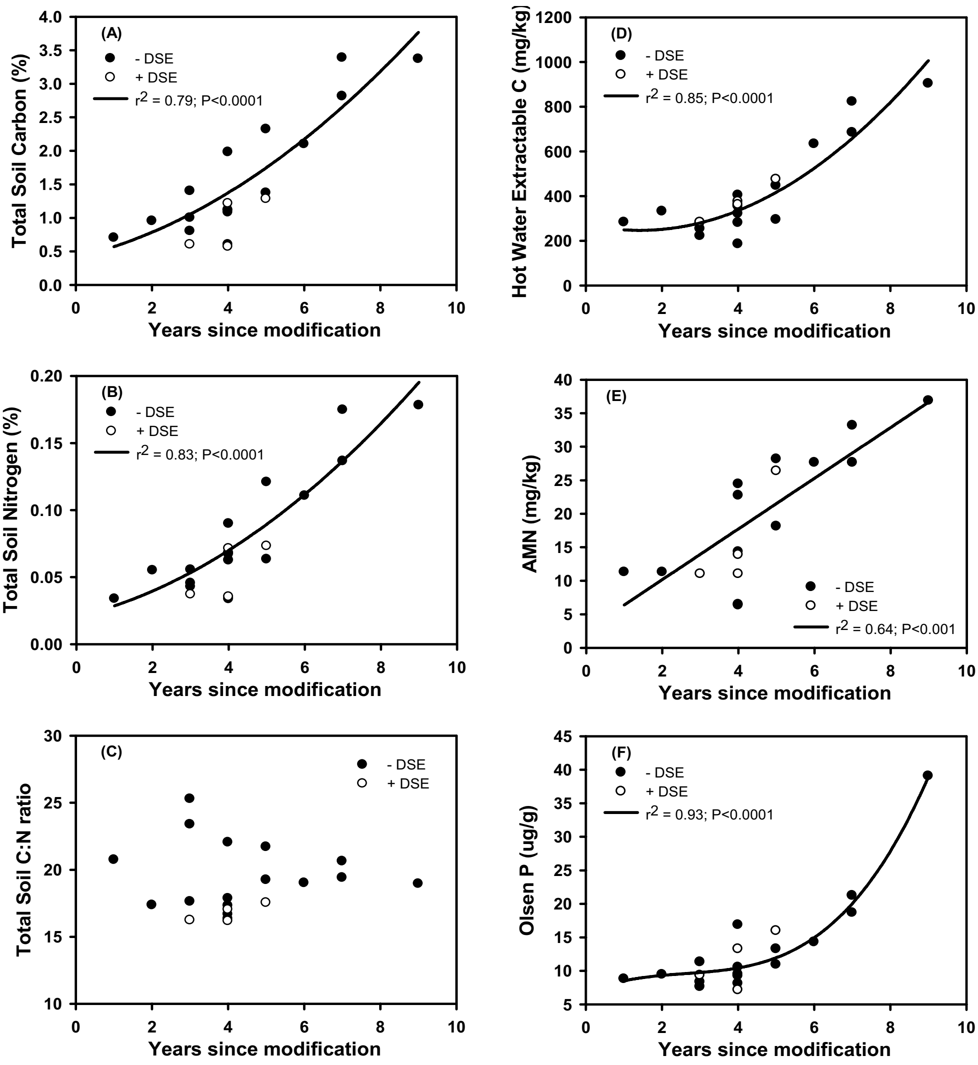
## Results and Discussion

### Flipped soils – Cape Foulwind

Recently flipped soils had very low levels of organic matter, total soil N, mineralisable nitrogen and plant available nutrients. Soil organic matter concentrations increased with increasing time following modification (total soil C, Fig. 1A). This is the likely result of increasing organic matter inputs from pasture growth (roots) and excreta (dung) additions. Similarly total soil N concentrations also increased with time since flipping (Fig. 1B).

Hot water extractable carbon (Fig. 1D) and anaerobically mineralisable N (Fig. 1E) also increased with time after flipping, but the increase in AMN was relatively linear and similar in pattern to total C, whereas hot water extractable C was slow to accumulate in the early stages of development. Both these measures are useful indicators of biologically active C and N pools, and suggest that there is greater biological cycling of the soil organic matter and nutrients as the soil develops. Olsen P also tended to increase with time after flipping (Fig. 1F), although the accumulation of P appears to be very slow in the early stages of soil development. Olsen P levels were initially very low despite large capital applications of superphosphate and phosphate containing fertilisers, and well below the target Olsen P level for sedimentary soils which is typically 20-30 µg/g for soils that are sampled to a depth of 7.5 cm (Roberts & Morton 1999). Increasing Olsen P levels are consistent with a

**Figure 1** A) Total soil carbon; B) Total soil nitrogen; C) Total soil C: N ratio; D) Hot water extractable carbon; E) Anaerobically mineralisable nitrogen (AMN); F) Olsen P measured for soils (0-15 cm depth) at different ages following flipping on the West Coast.



gradual accumulation of soil organic matter and ongoing maintenance applications of superphosphate fertiliser. Based on a maintenance P requirement of about 30 kg P/ha/year for pasture production and a fertiliser application rate of 40 to 45 kg P/ha/year, Olsen P levels would be expected to increase by about 2-3 units per year (Roberts & Morton 1999) in the top 7.5 cm of soil, but perhaps a bit less in the 0-15 cm soils sampled in this study. The slow build-up of Olsen P in the early stages of development may reflect high rates of P immobilisation in organic matter. Although P retention for these soils is relatively high (ASC values ranged from <7 to 46%), the highly permeable sands also pose a risk for leaching losses. The much higher Olsen P value measured in the oldest paddock suggests that additional fertiliser P may have been applied.

In the early stages of development, DSE was applied in addition to the typical fertiliser applications. However, this practice has now changed to account for the nutrient additions in the DSE when making fertiliser management decisions. Where DSE is applied in addition to fertiliser, it might be expected that DSE would increase the amount of soil organic matter compared with soils without DSE applications. This would be the combined result of higher organic matter inputs from the effluent and greater nutrient inputs increasing plant production leading to greater soil organic matter inputs from roots and livestock excreta. However, the limited data available to date do not support this hypothesis. Similarly there was no indication that N levels were higher where DSE was applied to paddocks, although total soil C:N ratios tended to be low (Fig. 1C). Also there was no clear effect of DSE on the other soil biological and biochemical indicators measured. On-going work is focussing on paddocks where DSE has been applied over a range of modification ages.

### Hump/hollowed soils – Moana

At Moana, the soils modified by humping/hollowing have a very high stone content, ranging from 38 to 80% of the top soil (0-15 cm) volume. Overall, the bulk density of the fine earth fraction (i.e. the mineral soil excluding stones) ranged from 0.4 to 1.3 g/cm$^3$.

Standard chemical fertility analyses are based on the fine earth fraction of soil that passes through a 2 mm sieve and the results are routinely expressed on a concentration basis. The target ranges recommended for these test results assume that the sample analysed is representative of the top soil volume as a whole. However, where the stone content of soil is high, the nutrient concentration in the fine earth fraction represents an overestimate of the nutrient availability in the topsoil volume as a whole. Examples of differences in the measured (fine earth only) and effective (stone-corrected) concentrations are given for four paddocks at Moana in Tables 2 and 3. The proportion of fine earth soil was greater on the humps than in the hollows. Owing to the variable and high stone content of these soils, the organic matter and chemical fertility test data from humped/hollowed paddocks at Moana are corrected for stone content by volume.

As for the flipped soils at Cape Foulwind, the soil organic matter and nutrient content of recently modified hump/hollowed paddocks was low (Fig. 2). Although the differences were relatively small, the total soil C content of humps was greater than the hollows in the early stages of development (Fig. 2A). This reflects (i) the removal of overlying organic matter-rich soil during the formation of the hollows and its redistribution to form the humps, and (ii) the higher productivity that many farmers report on the humps. In general, soil organic matter and nutrient content increased with soil development time (following modification) on the humps, but there was no clear effect in the hollows.

The total and hot water extractable C content (Fig. 2B) of the humps remained low during the first 3 years after modification, but both measures of organic matter were markedly higher on paddocks that had undergone 6-8 years of development following modification. In contrast to the humps, there was no change in the total or hot water extractable C content of the hollows during soil development. As for total C, hot water extractable C and total N (data not shown), the amount of mineralisable N (as measured by the AMN test, Fig. 2C) also increased with time after soil modification on the humps, but not in the hollows. These results suggest that the capacity of the humps to hold and supply N to the pasture sward may increase with time. The apparent lack, or very low rates, of soil organic matter increase in

**Table 2** Stone-corrected total soil C content on humps at Moana.

| | Paddock No. | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Stone content (%) | 43 | 51 | 68 | 80 |
| Total carbon [1] (%) | | | | |
| Fine earth only | 6.7 | 3.9 | 6.0 | 2.9 |
| Stone-corrected | 3.8 | 1.9 | 1.9 | 0.6 |
| Total carbon (t C/ha) | | | | |
| Fine earth only | 77 | 46 | 88 | 35 |
| Stone-corrected | 44 | 22 | 28 | 7 |

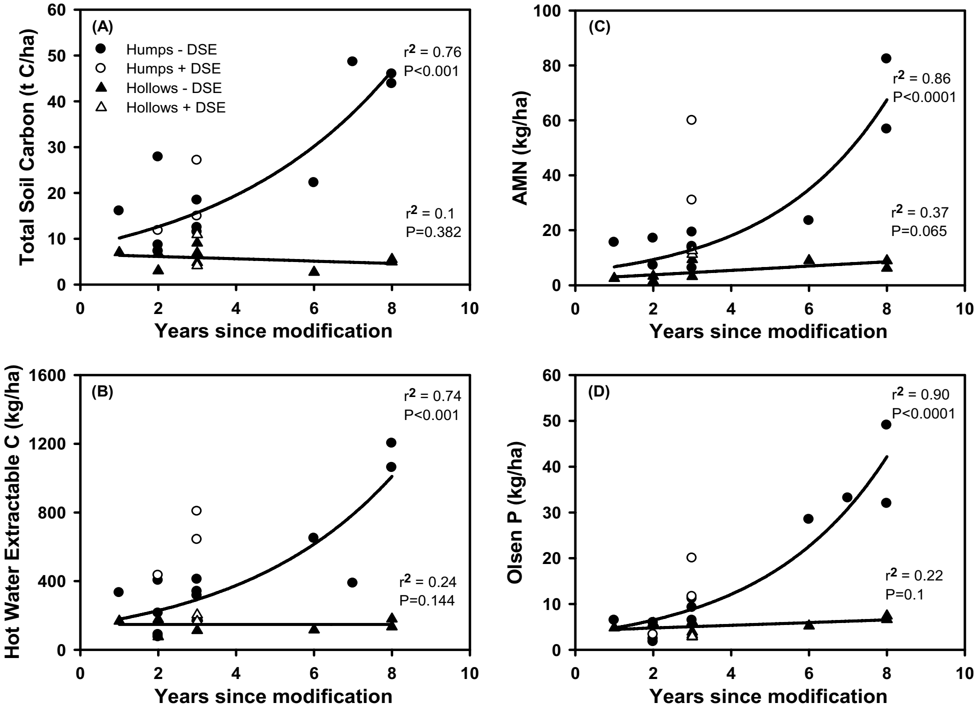
[1] Concentration of C in the fine earth soil collected for a standard chemical fertility test.

**Table 3** Stone-corrected Olsen P levels on humps at Moana.

| | Paddock No. | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Years since modification | 8 | 6 | 2 | 2 |
| Stone content (%) | 43 | 51 | 68 | 80 |
| Olsen P [1] (μg/cm$^3$) | | | | |
| Fine earth only | 58 | 49 | 10 | 24 |
| Stone-corrected | 33 | 24 | 3 | 5 |
| Olsen P (kg/ha) | | | | |
| Fine earth only | 86 | 57 | 18 | 30 |
| Stone-corrected | 49 | 28 | 6 | 6 |

[1] Olsen P levels in the fine earth soil collected for a standard chemical fertility test

**Figure 2** A) Total soil carbon; B) Hot water extractable carbon; C) Anaerobically mineralisable nitrogen; D) Olsen P measured for soils (0 to 15 cm depth) at different ages following hump/hollowing on the West Coast.



the hollows suggests that the organic matter inputs from plant roots and excreta are much lower than on the humps. This has important implications for the management of hump and hollow paddocks and is an important aspect of our future research focussed on improving the nutrient use efficiency of these soils.

Olsen P concentrations tended to increase with time after soil modification in the humps consistent with the ongoing inputs of P fertiliser but the rate of increase was much lower in the hollows (Fig. 2D). There was no apparent difference in the P retention capacity of soil in the humps compared to the hollows (ASC values were high and ranged between 33 and 77%). The slow rate of P build up in the hollows may reflect lower pasture production and lower returns of excreted P, increased runoff and leaching in the hollows that are designed to rapidly drain the paddocks, and possible differences in fertiliser application rates on humps and hollows due to uneven spreading.

In comparison to flipped soils, soil organic matter, hot water extractable C and AMN levels tended to be higher on the few paddocks that had received regular applications of DSE. Because our sample numbers were limited, we are unable to conclude whether DSE applications affected Olsen P concentrations at Moana. Future sampling will help to identify whether DSE does affect the rate of change in these indicators during soil development.

Anecdotal evidence from farmers suggests that dry matter production is considerably higher on the humps than the hollows, an observation that is consistent with the differences in nutrient availability measured in this study. Owing to the particularly low organic matter content of the soil in the hollows and relatively low fine earth contents, they are also expected to have a relatively low WHC, and a limited ability to retain nutrients applied in fertiliser, thereby increasing the risk of nitrate and phosphate runoff.

## Conclusions

With appropriate capital applications of fertilisers and sustained dry matter production, topsoil organic matter levels appear to increase with time in humped/hollowed and in flipped soils of the West Coast. This should result in increased levels of quick-test nutrients, higher soil microbial activity and N availability, and a reduced risk of N and P runoff. However, further information is needed to confirm the rate of soil organic matter accumulation and associated effects on nutrient cycling and availability, and soil nutrient losses. Establishing the relationships between soil development stages following modification and nutrient availability may then help to modify fertiliser practices and increase nutrient use efficiency. Existing nutrient budget tools would benefit from an improved calibration for these modified soils and the changes that occur during their development.

The rate of soil organic matter accumulation in hollows is much slower than on humps. Current fertiliser, lime and DSE application practices that treat the humps and hollows in the same way will not use nutrients efficiently. Humps and hollows may need to be managed differently to meet pasture production needs and to avoid large losses of nutrients. The high stone contents in humped/hollowed soils affects estimates of plant available nutrients and fertiliser requirements compared with stone-free soils. More research is needed into appropriate recommendations for estimating fertiliser applications to account for soils with high stone contents. Such soils also need alternative sampling methods to traditional soil coring procedures.

## ACKNOWLEDGEMENTS

The authors are grateful to Craig Tregurtha, Denis Curtin, Peg Gosden, Lesley Corbett, Lyn Shorter and Catherine Scott for scientific and technical assistance with this project. The authors also thank the farmers (Mark Burnett, James Burnby, Dion Fox, Rob Evans, Shane Kelly, Scott Lovelock and Peter Crouchly) who provided access to their properties and management history information on their farms. Our research was funded by Landcorp Farming Ltd and Crop & Food Research.

## REFERENCES

Morton, J.D.; Roberts A.H.C. 2006. Pasture responses to fertiliser on renovated West Coast pakihi soils. *Proceedings of the New Zealand Grassland Association 68*: 331–338.

Roberts, A.; Morton, J. 1999. Fertiliser use on New Zealand dairy farms. New Zealand Fertiliser Manufacturers' Research Association, Auckland. 41 pp.