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FURTHER INVESTIGATIONS UNDERPINNING HOT-WATER EXTRACTABLE C (HWC) AS A SOIL QUALITY INDICATOR

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Abstract

This study reports on the results of further investigations underpinning the introduction of hot-water extractable C (HWC) and hot water nitrogen (HWN) as soil quality indicators, fitting with the purposes and legal obligations of regional councils. An earlier study was able to set provisional critical limits for HWC. The study also modelled mathematical relationships between the existing Anaerobically Mineralised N (AMN) soil quality indicator and hot water extracts as HWC is a suggested replacement for AMN. Further data from a wider range of soils are now available. In addition, methods in the international literature for setting targets for soil quality parameters were recently reviewed, which showed using multiple approaches incorporating expert knowledge were better able to consider the range of environmental services provided by soil, so setting more relevant targets. The models from the previous study are tested using this new information and targets are refined.

Introduction

The hot water carbon test

Hot water carbon (HWC) has been found to be a quick, sensitive and consistent indicator with significant correlations between it and N mineralisation, Anaerobically Mineralised N (AMN), microbial biomass C, microbial nitrogen, total carbohydrates and aggregate stability (Haynes et al. 1991; Sparling 1998, Ghani et al. 2003; Kim et al. 2011). It extracts water soluble fractions of SOM as well as C derived from the denaturing of soil enzymes, amino acids and soluble C compounds from microbial cells. HWC is suggested as a replacement for the existing AMN soil quality indicator (Mackay et al. 2013; Haynes 2005). This paper brings together and tests the results of earlier unpublished studies on HWC as a soil quality indicator.

HWC is considered to consist of two pools of carbon; very active and labile and slowly labile pools (Akinete & Nortcliff 2014; Gregorich et al. 2003, 2000). A high extraction temperature (80˚ C) enables the extraction of both the active and labile dissolved organic fraction and some of the recalcitrant compounds that increase soil stability (Ros et al. 2009).

A large proportion of root exuded compounds are water soluble and can improve nutrient availability, alleviate metal toxicity and serve as a carbon and energy source, rapidly respired by microorganisms (Hütsch et al. 2002). Microbial–dissolved organic carbon (DOC), and dissolved organic matter (DOM) in general, are important in regulating the fluxes of DOC in surface soil horizons (Neff and Asner 2001). HWC can also play a critical role in stabilisation of SOM, carbon dynamics and contributes to soil hydrophobicity (Atanassova et al. 2014; Ros et al. 2009).

Earlier research for regional councils on soil quality monitoring indicators

Earlier unpublished studies for the Land Monitoring Forum, a Regional Sector Special Interest Group, reported on the suitability of HWC as a soil quality indicator, with HWC being a more sensitive and precise measurement than AMN (Taylor et al. 2017, WRC 2016). Thus, HWC results are more easily repeatable and can be related more easily to soil degradation. Sites were chosen according to national guidelines (Hill and Sparling 2009; Frampton 2009). Samples were analysed for HWC and HWN following the method described by Ghani et al. (2003). Land use categories were long-term (>10 years) pasture for dairy cattle, sheep, beef cattle and deer, cropping for vegetables, grain and maize silage (tilled annually or more often), long-term (>10 years) production forestry (radiate pine; 1st - 3rd rotation, trees aged 3-75 years), horticulture for apples and kiwifruit (trees left in place) and native podocarp–broadleaf forest (Table 1). Soils were classified according to the New Zealand Soil Classification (Hewitt 1998).

Soil degradation at sites was observed at <1800 mg/kg. Thus, a provisional target of 1800 mg/kg for HWC was derived using data from the four regions trialling HWC (Taylor et al. 2017).

The earlier studies showed Soil Order affected HWC values with Organic Soils being significantly different at the 95% level from other Soil Orders (Figure 1), which skewed results, even when corrected for bulk density. So, the provisional target of 1800 mg/kg was only applied to mineral soils. Similarly, Organic Soils were not addressed in this work due to their identification as outliers. Further work remains to evaluate if HWC could be a useful indicator for Organic Soils and this would be part of a separate study.

The earlier studies also showed land use significantly impacted HWC values. Undisturbed native sites had the highest HWC concentrations followed by pasture and pine forestry, while disturbance, such as cultivation, resulted in lower concentrations. Arable land had significantly lower (at the 5% level) HWC concentrations than any of the other land uses.

Although HWC has been suggested as a replacement for the existing AMN soil quality indicator for several years (Mackay et al. 2013, Haynes 2005). However, soil quality monitoring in New Zealand has included AMN since its inception in 1995. For HWC to replace AMN, there needs to be a strong mathematical relationship between the two measurements. After successive reduction of the model complexity by dropping non-significant terms, a relatively simple model that accounts for 86.3% of the variance was derived. This model has slopes and intercepts for each land use for HWC and C% and a single slope for HWN; Soil Order is not used (Table 1).

No negative impact on soil function at high HWC was observed or has been reported, so no upper target was determined.

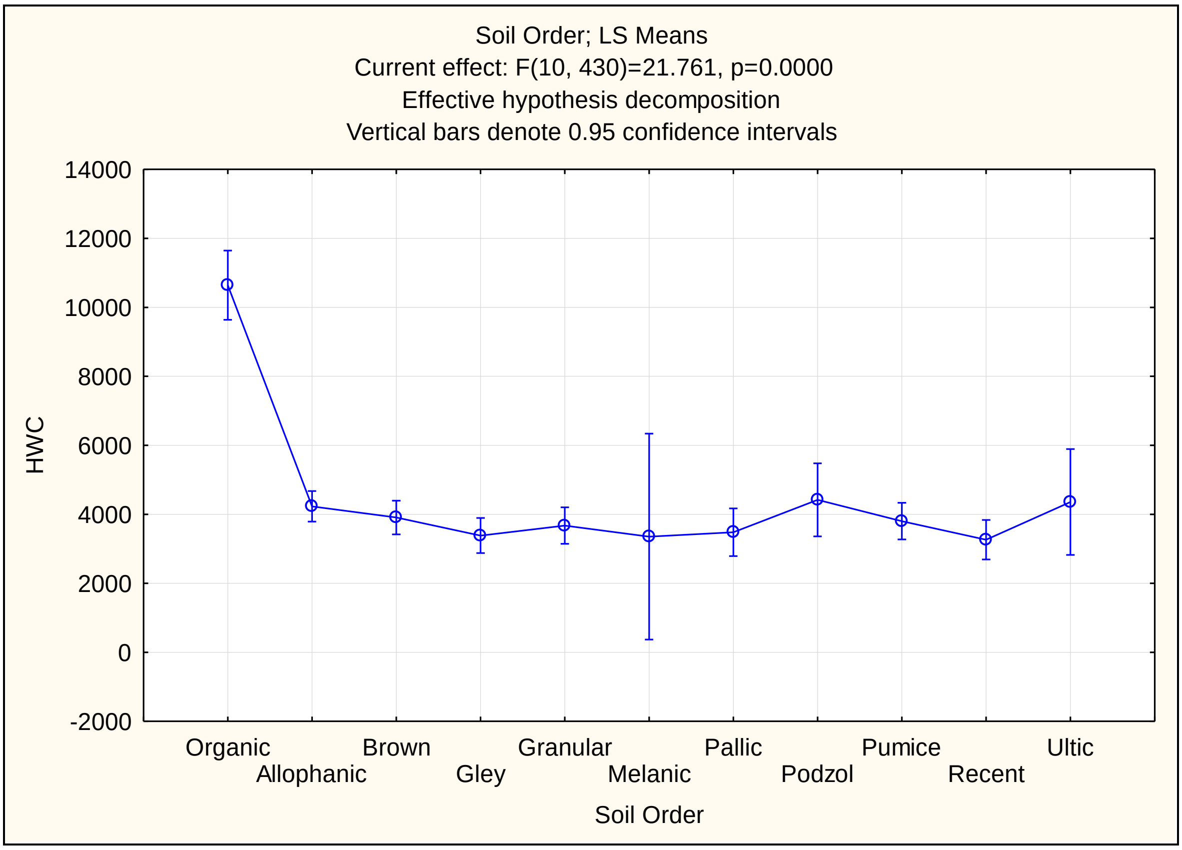

Figure 1. Organic soils are the only soil order significantly different from other soil orders. All mineral soil orders are not significantly different (95% confidence). Note, few samples for Ultic, Podzol and Melanic soils leading to wider confidence intervals. HWC units are mg/kg.

Table 1. For HWC to replace AMN, there needs to be a strong mathematical relationship between the two measurements. Prediction equations for AMN derived from HWC, total C and HWN measurements for different land uses are presented (Taylor et al. 2017). Note that all logs are natural (base e) logs.

Arable	Predicted log AMN = -4.352 + 0.957 * log HWC - 0.344 * log total C + 0.421 * log HWN
Forest to pasture	Predicted log AMN = 2.548 - 0.102 * log HWC + 0.466 * log total C + 0.421 * log HWN
Forestry	Predicted log AMN = 2.718 - 0.125 * log HWC + 0.359 * log total C + 0.421 * log HWN
Horticulture	Predicted log AMN = -2.642 + 0.684 * log HWC + 0.042 * log total C + 0.421 * log HWN
Native	Predicted log AMN = 5.368 - 0.524 * log HWC + 0.774 * log total C + 0.421 * log HWN
Pasture	Predicted log AMN = 1.111 + 0.107 * log HWC + 0.347 * log total C + 0.421 * log HWN

Units for AMN, HWC and HWN are mg/kg; unit for total C is %

Materials and methods

Land use and soil classification

Sites were chosen and sampled according to national guidelines (Hill and Sparling 2009; Frampton 2009). Land use categories were long-term (>10 years) pasture for dairy cattle, sheep, beef cattle and deer, cropping for vegetables, grain and maize silage (tilled annually or more often), long-term (>10 years) production forestry (radiata pine; 1st - 3rd rotation, trees aged 3-75 years), horticulture for apples and kiwifruit (trees left in place) and native podocarp–broadleaf forest (Table 1).

Soils were classified according to the New Zealand Soil Classification (Hewitt 1998).

Soil Analysis

Sieved archived soil samples (each a composite of 50 cores, 2.5 cm diameter and 0-10 cm depth, taken from a transect of 50 m) were analysed for HWC and HWN following the method described by Ghani et al. (2003) at AgResearch or Plant & Food Research. The earlier work used 317 Waikato samples to derive a provisional target and equations to back calculate AMN from HWC, HWN and total C. This larger study of consisted of samples from the Waikato (n=459), Hawkes Bay (n=146), Marlborough District (n=41), Canterbury (n=722) and Wellington (n=89) samples. This sample set includes sites from a wider range of soils than the earlier work, provides an independent dataset and gives provisional results for validating the equations presented in Table 1, and further investigates of the provisional target for soil quality monitoring.

Supporting Data

The AMN results and other supporting data had been collected as part of the soil quality monitoring programme according to national guideline methods set-out in the Land and Soil Monitoring Manual (Hill and Sparling 2009) by Waikato Regional Council, New Zealand. Total C was analysed using a

Leco CNS2000 Analyzer (Leco 2003). The AMN values were estimated using an incubation method, where the sieved soil sample is incubated under waterlogged condition for 7 days at 40° C (Hill and Sparling 2009, Keeney 1982). The increase in NH4+-N extracted in 2 M KCl over the 7 days gives a measure of potentially mineralisable N. Both analyses were carried out at Manaaki Whenua – Landcare Research.

A soil pit was dug to about 1 m at the initial sampling of each soil quality site and the soil profile described, including horizons, colour, texture, aggregation, presence of mottles and/or coarse fragments, rooting depth and any disturbance, e.g. from pugging or tree stump removal. Land use and land management were detailed at the time of sampling and historic land management noted where this was available. In addition, Visual Soil Assessment (VSA) was carried out on 199 samples (Shepherd 2009). Briefly, VSA is designed as a quick and simple method to assess soil condition and plant condition. Soil quality is ranked, based on the combined scores of indicators of soil quality and plant condition. Each indicator is given a visual score between 0 (poor) and 2 (good) based on field observations compared with photographs in a field guide and comparing with a sample from under the fence protected from livestock, wheel traffic and cultivation.

Setting targets for HWC

Methods in the international literature for setting targets for soil quality parameters were recently reviewed (Taylor 2021). This showed using multiple approaches incorporating expert knowledge were better able to consider the range of environmental services provided by soil, so setting more relevant targets. Two approaches were used to estimate alternative targets to compare with the provisional target; as soil physical properties were expected to relate to HWC, raw scores from field observation using the Visual Soil Assessment (VSA, Shepherd 2009) were combined and relationships investigated; and a comparative approach in which indicator values or scores of a given reference sampling point are put in relation to other sampling points.

In the first approach, the sum of the colour, structure, and bare ground scores of the VSA gave the best fit from all the VSA parameters. HWC for the same sites was plotted against the summed VSA score and a linear relationship established. The score indicating moderate soil damage (3 for the added scores) was used to derive a value for HWC of >2017 mg/kg, which we rounded to >2000 mg/kg as the target (Figure 2). However, the 5-95% confidence interval is about 700 – 4400 mg/kg indicating considerable scatter.

The secondary approach, in which indicator values or scores of a given reference sampling point are put in relation to other sampling points, was applied using sites in the natural state as the reference. Using sites in the natural state may be a useful guide for indicators if seeking protection of environmental services. The 1st percentile of the 52 native sites (Figure 3) was used to derive a value of >1669 mg/kg, which we rounded to 1700 mg/kg as the target. However, only native sites in the Wellington and Waikato regions were representative of production soils. Native sites were not available for other regions.

Tentative critical limits were compared with field observations of changes in soil physical nature, such as porous structure and aggregation, which indicate a potential change in soil water regulation, biological habitat, and stability.

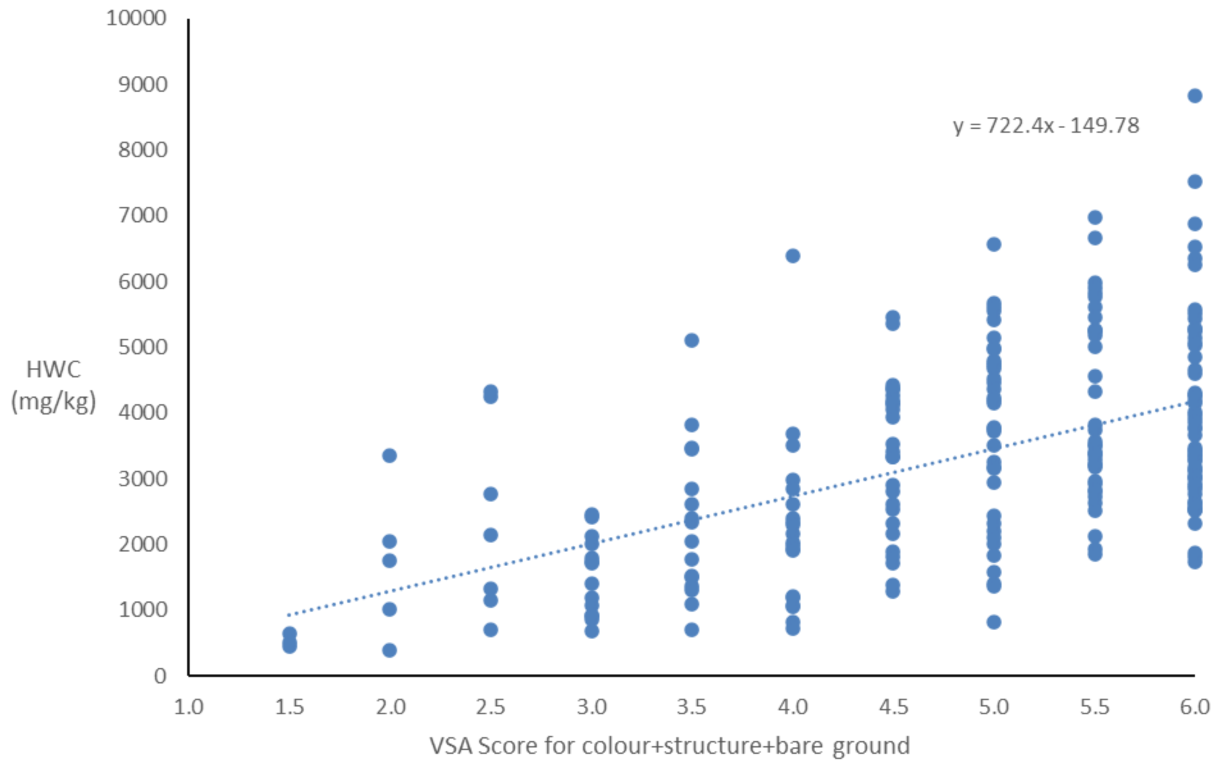

Figure 2. HWC plotted against the unadjusted colour, structure, and bare ground scores of the Visual Soil Assessment for the same 223 Waikato sites. The score indicating moderate soil damage (3) was used to derive a target value for HWC of >2000 mg/kg.

Results and Validation

Like the previous study (Taylor et al. 2017), undisturbed native sites had the highest HWC concentrations followed by forestry and pasture, while arable land had significantly lower (at the 5% level) HWC concentrations than any of the other land uses (Figure 3).

Organic soils were outliers in the previous study and were not included in this work. However, Pallic and Brown soils had noticeably lower HWC than the other soil orders (Figure 4). More than half the Pallic soil samples and 40% of the Brown soils were in arable land use, a greater proportion than in other soil orders. Arable soils had significantly lower levels of HWC than other land uses (Figure 3) and may be the cause of the lower levels of HWC in Pallic and Brown soils.

The prediction equations from the previous work (Table 1) were still valid for the wider range of samples of this work and overlaid the results of the previous study (Figure 5).

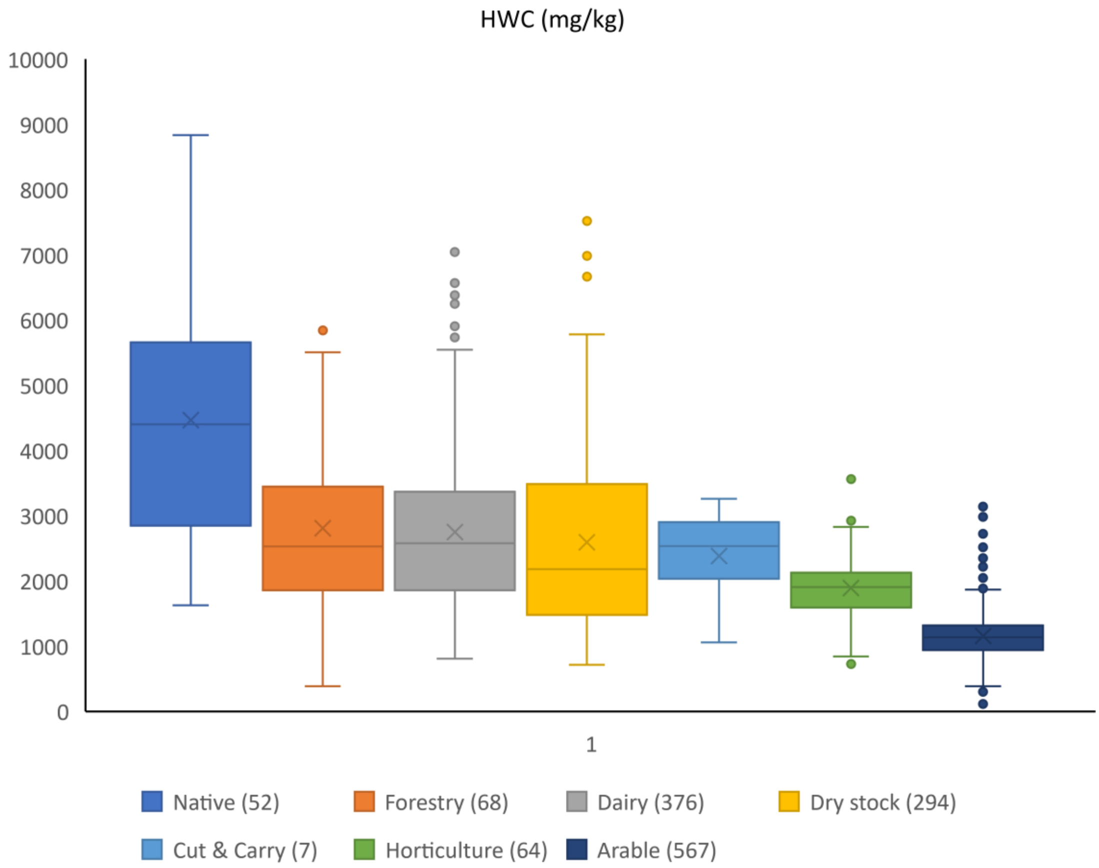

Figure 3. HWC by Land use (number of samples): Undisturbed native sites had the highest HWC concentrations followed by pasture and forestry, while disturbance such as cultivation resulted in lower concentrations. Boxes are median, 25th and 75th percentiles, whiskers are 5th and 95th percentiles, × = mean.

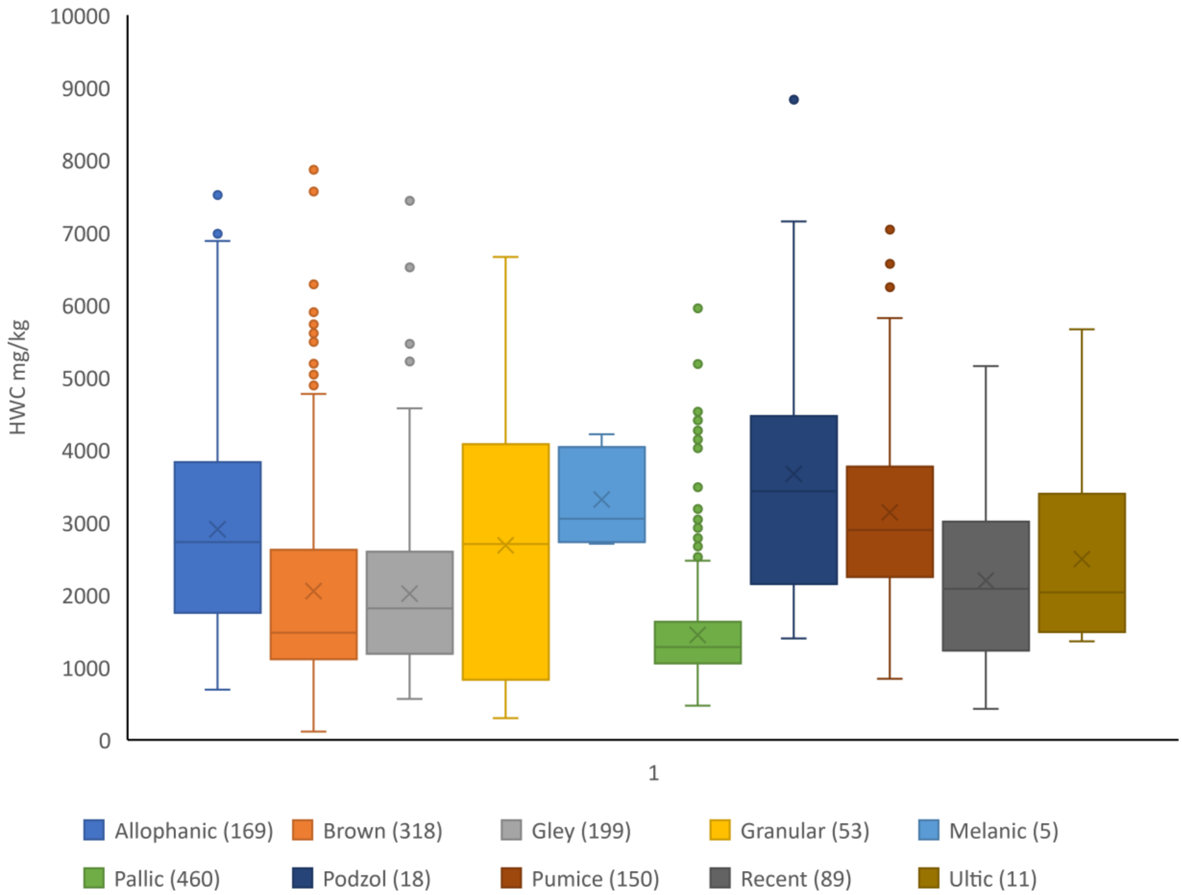

Figure 4. HWC by Soil Order (number of samples): Pallic soils and Brown soils had lower levels of HWC than other Soil Orders. Boxes are median, 25th and 75th percentiles, whiskers are 5th and 95th percentiles, × = mean.

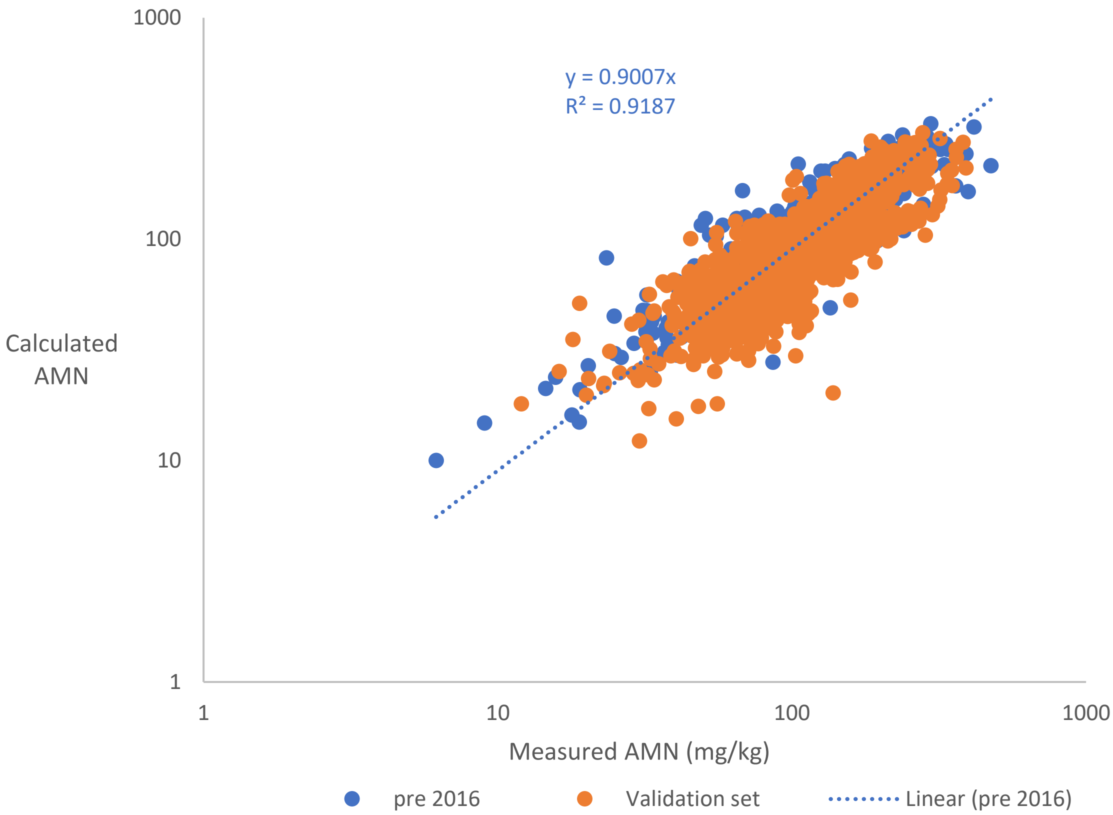

Figure 5. AMN (mg/kg) calculated using the equations in Table 1 compared with measured AMN for the same sites.

The proportion of sites the original HWC provisional target (1800 mg/kg) and the two new derived targets (1700 and 2000 mg/kg) were compared by land use. Note that all these targets remain provisional until ratified by the Land Monitoring Forum. Land management factors that were common where sites failed to meet targets were identified. A very large proportion of arable sites failed to meet any of the targets, due to cultivation, while nearly all native sites meet all targets, due to these being undisturbed except by tree throw (Table 2). Other sites that were below targets were pastural sites that had been badly pugged, especially on Gley or Recent soils, vineyards, kiwifruit orchards and forestry sites after harvest.

Table 2. Proportion of sites by land use meeting proposed HWC (units) targets

HWC		Background Low target	Provisional target	VSA best fit target
Land use	Count	>1700	>1800	>2000
Arable	567	6%	5%	3%
Forestry	68	88%	79%	68%
Horticulture	64	73%	56%	36%
Native	52	98%	96%	96%
Dairy	376	80%	77%	69%
Drystock	294	67%	63%	54%

Conclusions:

- This set of samples confirmed the prediction equations derived from the earlier work can back calculate AMN with reasonable certainty.
- Land use had greater effect on HWC levels than Soil Order
- All three potential HWC targets were of similar magnitude and identified degraded soils, so are acceptable targets for soil quality monitoring.
- Sites with HWC <2000 mg/kg are likely to have less than optimal physical structure and biological activity.
- Sites with HWC <1700 mg/kg are more degraded with lower carbon storage.
- The initial target of >1800 mg/kg based on the smaller early study, was in between the two targets derived in this work.

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