National Soil Quality Review and Programme Design

January 2003

Hill, R.B., Sparling, G., Frampton, C. and Cuff, J.

Acknowledgements

The following people are thanked for their comments, discussion and enthusiasm throughout the course of this review: Wayne Smith, Environment Bay of Plenty, Tony Thompson, Auckland Regional Council, Wayne Bettjeman, Ministry for the Environment and Malcolm Todd, Horizons m.w. The review represents the continued effort made by all members of the National Land Monitoring Forum including representatives from Northland Regional Council, Auckland Regional Council, Environment Waikato, Environment Bay of Plenty, Hawke's Bay Regional Council, Taranaki Regional Council, Gisborne District Council, Horizons m.w., Marlborough District Council, Tasman District Council, Environment Canterbury and Southland Regional Council. The authors thank Ministry for the Environment for their support, financial and otherwise.

Table of Contents

List of Figures and Tables

Executive Summary

To increase soil quality understanding in New Zealand a Sustainable Management Fund Project (#5089), Implementing Soil Quality Indicators for Land was initiated in 1999 and recently completed. The project, popularly titled and referred to in this report as the “500 Soils Project”, collected new soil quality data from approximately 500 sites (508 sites, roughly one site per 25 km^2) selected by the various participating Regional Authorities from April 1999 to June 2001. Prior to the 500 Soils Project there was no nationally consistent or scientifically based soil quality monitoring data for New Zealand.

This review provides recommendations to help define future national soil quality monitoring policy and actions in New Zealand. The recommendations presented are derived as part of a review of the 500 Soils Project requested by the members of the National Land Monitoring Forum (NLMF) and completed by a sub-committee of the NLMF with continual input from all Forum members.

Ministry for the Environment (MfE) and Regional Authorities participating in the NLMF are evaluating the 500 Soils Project, to ascertain how well the project has met the needs of the councils and of MfE, and to help define future monitoring policy and actions. The evaluation includes project design and implementation, data evaluation, and objectives and recommendations for subsequent design. Project methods and design are evaluated broadly using SWOT (strengths, weaknesses, opportunities, and threats). The 500 Soils Project data are analysed by statistical methods and the main findings are provided in this review together with comments on other related issues raised by the NLMF. The main points and recommendations provide guidance for developing an ongoing National Soil Quality Monitoring Programme.

The NLMF identified broad objectives for a continued soil quality monitoring programme; provide an early-warning system to identify effects of primary land uses on soil quality; identify and track long term soil quality issues; utilise soil quality results for State of the Environment reporting and policy development, and where possible, integrate a soil quality monitoring programme with other regional monitoring.

A set of seven soil quality properties (total C, total N, mineralisable N, pH, Olsen P, bulk density and macroporosity) validated in this work by Principal Component Analysis (PCA), should form part of any soil quality monitoring programme. Both Soil Order (Hewitt 1998) and land use type are useful criteria for explaining the variability of the soil properties used to measure soil quality and are recommended for national reporting. Although preferable, stratifying data by land use type and Soil Order combinations is impractical because the sample numbers required are a magnitude greater than for stratification by land use type combined with sampling weighting by Soil Order. To establish rates of change on rapidly changing sites, resampling at 1-to-3 year intervals should be considered. Stable sites can be resampled on a 5–10 year basis or on an even longer cycle if there is no cause for concern and the sites appear stable (e.g. indigenous vegetation sites). A single sample representation approach is preferred for a national monitoring programme because it allows different land uses to be compared on a broad scale and for a wider-ranging survey to be completed. Further work is required to validate and refine critical limits for soil quality. Based on actual costs from the 500 Soils Project the estimated cost per site is $1155. The scientific robustness and “usability” gained from adopting the “500 Soils Project” indicators is greater than using a reduced set of soil quality indicators.

The review sub-committee recommend that the 500 Soils Project provides suitable methods and scientifically based criteria for an ongoing nation-wide Soil Quality Monitoring Programme. Sampling and analysis methods need to be standardised and documented by way of nationally agreed guidelines. The Ministry for the Environment (central government) have a role of co-ordinating a full commitment to national soil quality monitoring by all Regional Authorities. Furthermore, they should facilitate a move toward nationally agreed and adopted soil quality methodologies and outputs within a set timeframe.

1 Introduction

1.1 Background

Awareness of soil quality is growing globally as land use intensifies. New Zealand requires this information to show that primary production industries are sustainable over the long term and continually improve soil management practices.

To increase our knowledge of soil quality in New Zealand a Sustainable Management Fund Project (#5089), Implementing Soil Quality Indicators for Land was commenced. The project, popularly known as and referred to in this report as the "500 Soils Project", has collected soil quality data from sites selected by the various participating Regional Councils since April 1999, and finished in June 2001.

Prior to the 500 Soils Project there was no nationally consistent or scientifically based soil quality monitoring data. The 500 Soils Project has during its course collected soil quality information for approximately 500 sites nationally; roughly one site per 25 km^2. The general findings of the project indicated that soil quality issues were apparent and were different depending on land use.

The 500 Soils Project has come to an end and the NLMF has indicated a keenness to continue soil quality monitoring at a regional level. Ministry for the Environment is also committed to developing a national soil quality scheme with nationally consistent methodology. Continued information sharing and inter-regional consistency of soil quality monitoring would be beneficial both regionally and nationally.

This review assesses the success of the 500 Soils Project and the value gained by regional authorities (regional councils and district councils). The review includes recommendations to help define future national soil quality monitoring policy and actions. The recommendations will form the basis for National Soil Quality Guidelines being developed by MfE. Some guidance is also given for Regional Authorities (regional councils and district councils) for regional scale soil quality monitoring.

1.2 Review process

MfE and the participating councils are evaluating the 500 Soils Project, to ascertain how well the project has met the needs of the councils and of MfE, and to help define future monitoring policy and actions. Evaluation will cover (1) project design and implementation, (2) data evaluation, and (3) objectives and recommendations for subsequent design. A sub-committee, on behalf of the Land Monitoring Forum (LMF) will undertake the evaluation, probably between October–December 2001. The panel consists of Dr Chris Frampton (Lincoln University), Dr Graham Sparling (Landcare Research), Dr Reece Hill (Environment Waikato) and Jeromy Cuff (Environment Canterbury). The NLMF have indicated the broad areas they wish to review. Dr Graham Sparling (Landcare Research) has addressed a number of these as part of the 500 Soils Final Report (Sparling et al. 2001). The review sub-committee has provided additional comments to represent the Regional Council perspective.

1.3 National Soil Quality Monitoring Programme development process

The NLMF discussed a draft outline of the process for developing a national soil quality monitoring programme (Figure 1).

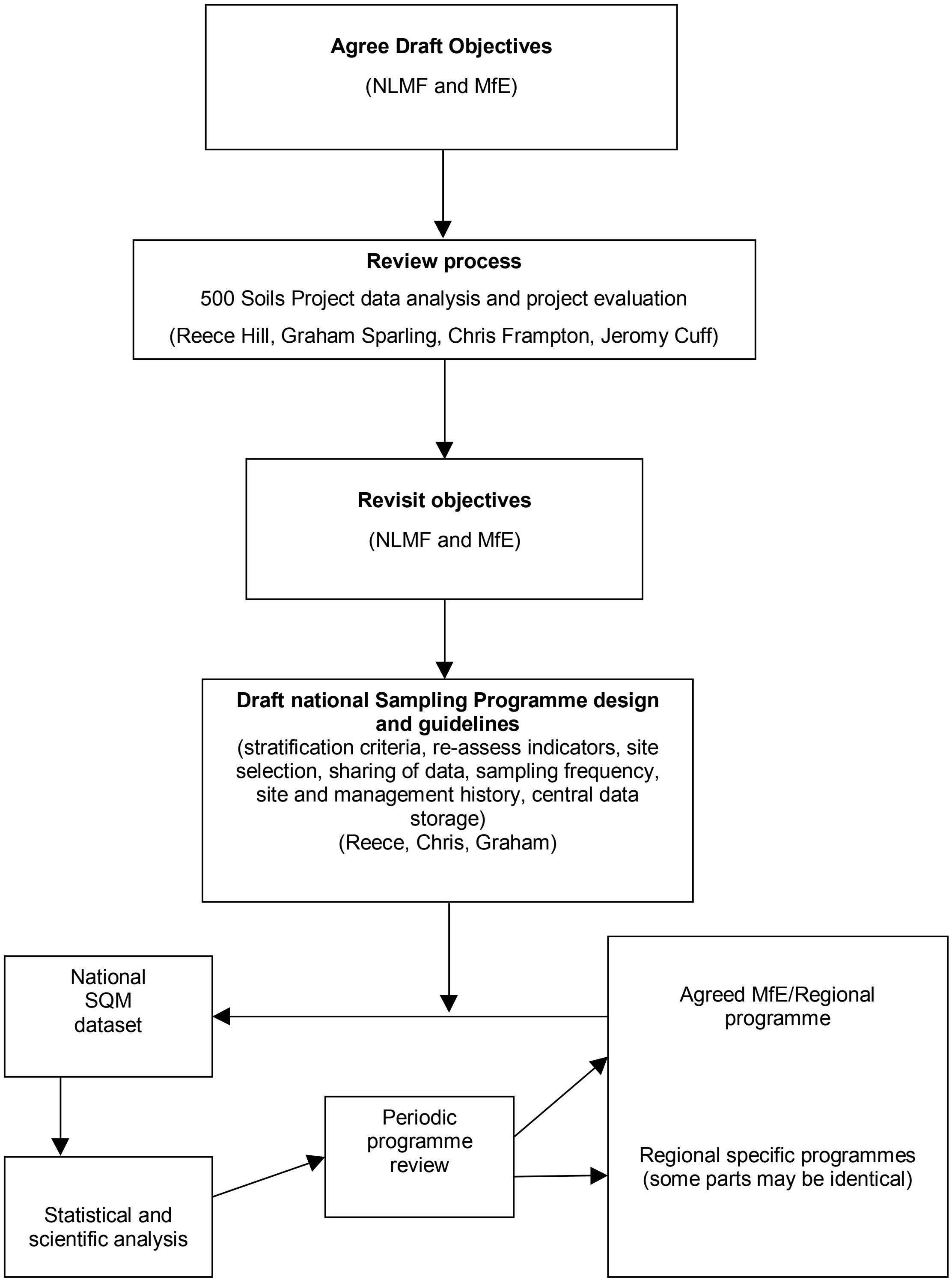

Figure 1: National Soil Quality Monitoring review and programme design process.

1.4 Soil quality monitoring objectives

Discussion involving NLMF members centred on finding commonality of broad level objectives for a continued soil quality monitoring programme.

The following high-level objectives emerged.

1. Provide an early-warning system to identify effects of primary land uses on long-term soil quality (physical, chemical, biological).
2. Track and identified issues relating to the effects of land use on long-term soil quality (may also be district/area specific)
3. Utilise the results for State of the Environment reporting and policy development.
4. Where possible a soil quality monitoring programme should be integrated with other regional monitoring (e.g. water, especially groundwater)

The 500 Soils Project has provided initial data that partially addresses objective 1, objective 3 and 4. Only 3 sites (in the Waikato Region) were resampled therefore objective 2 was not addressed. A continued soil quality monitoring programme will provide long term data for addressing all objectives, including Objective 2.

2 Project design and implementation

2.1 SWOT evaluation

The 500 Soils Project methodology and design are evaluated broadly using SWOT (strengths, weaknesses, opportunities, and threats).

Strengths

- The soils properties and indicators are scientifically robust.

All of the soil chemical and physical properties used as indicators in this and previous trials (Project 5001) are well established, internationally recognised and have been recommended for soil quality monitoring (e.g. see review by Doran et al 1994). Our use and interpretation of the properties for soil quality monitoring in New Zealand have been reported in peer-reviewed international journals (e.g., Francis & Knight 1993; Francis *et al*., 2001; Schipper & Sparling 2000; Singleton *et al*., 2000; Sparling *et al*., 2000b, c).

The earlier trial (Project 5001) and other published reports established that soil properties such as infiltration rates were too variable to be practical monitoring tools (Beare *et al.,*1999; Schipper & Sparling, 2000), while interpretation of microbial biomass and respiration measures was problematic (Schipper & Sparling 2000; Carter *et al*., 1999). However, the inclusion of additional properties such as the aggregate stability test and Olsen P was desirable. The indicator set used in the 500 Soils Project comprised: total C, total N, mineralisable N, soil pH, Olsen P, exchangeable cations, bulk density, total- and macro-porosity, total- and readily available water, and aggregate stability. In addition, the site and soil profile were described and location and brief management history recorded. This data set has now been applied to more than 500 sites and the performance on varied land uses and soil can be examined more critically. The multivariate technique of principal component analysis was used to identify those soil characteristics that best explained the variability in the data set. In addition, the cost and practicality of the measure was considered, and the robustness of the interpretation regarding soil management.

- Dynamic approach

The methodology used in the project has continually been refined as the project has progressed. Changes have been made in response to end user requirements and improvement of methodology highlighted by assessment of annual results.

- National and local participation and awareness

The project has served to increase the national and local profile of soil quality. The level of national participation has increased. Five Regions participated in the project in 1998–1999 and 1999–2000 (Auckland, Bay of Plenty, Canterbury, Taranaki and Waikato). Ten Regional and District Councils participated in 2000–2001, these being Auckland, Bay of Plenty, Canterbury, Hawkes' Bay, Marlborough, Northland, Taranaki, Tasman, Waikato and Wellington.

- Strong foundations for national monitoring programme

The 500 Soils Project has provided a comprehensive national soil quality database.

Weaknesses

- National and local focus

There has been some confusion regarding national and regional focus and objectives. Essentially the differences are related to scale of sampling and detail of soil quality information required regionally and nationally. For national reporting the sampling requirements are less intensive than for those required for more detailed regional reporting. Spatial coverage and capture of state are important nationally, whereas many regions adopt targeted, issue specific sampling.

- Sample depth

There has been some criticism that only the topsoil (0-10 cm) is sampled and not the entire soil profile. The concerns are mainly because the topsoil sample analyses may not be representative of the actual soil quality (e.g. compaction occurring below the topsoil or leaching of nutrients below the topsoil). Comment on these issues is presented latter in this review.

- Spatial coverage (national)

There are currently some Soil Order/land use combinations that have not been sampled (e.g. Semiarid Soils under horticulture) largely because some Regional Councils have not participated in the 500 Soils Project. For a complete national representation of soil quality all existing site combinations should be sampled and represented.

- Commonality of land use selection

There has been a lack of consistency between local government organisations (LGOs) in terms of land use classification and selection. A common hierarchical land use type classification is being developed for future monitoring. Targeted monitoring will remain the approach of some LGOs in the future but any national monitoring programme will be more able to incorporate these sites as required.

- Centralised data management

Data management has been partially a LGO and Landcare Research task. Centralised data management with national accessibility was not a priority of the 500 Soils Project. Efficient sampling and information sharing will result from centralised data management, a consideration for any future monitoring.

- Critical limits refinement

Initially there was an absence of critical limits for measured soil characteristics on which to base soil management decisions. Two workshops, involving soil scientists, were held and initial critical limits developed for different soil land use combinations. Application of these limits has been incorporated into the SINDI web site (http://sindi.landcare.cri.nz/).

Opportunities

- Strong foundations for national monitoring programme

The 500 Soils Project has not only provided a comprehensive national soil quality database but has paved the way for a scientifically based national soil quality monitoring programme. Internationally this is unique.

- Future research/funding

A sound foundation has been set to secure future funding to continue soil quality monitoring in New Zealand. The success of the programme to date should make it less difficult to secure long term funding at local and national government level.

- Increasing soil quality knowledge

Excellent progress in developing critical limits for soil quality indicators in response to LGO requests the refinement of use of soil characteristics for determining soil quality status and estimates of recovery times for poor quality soils. Further work required to fully develop this research would greatly benefit soil quality knowledge.

- Integration with other projects

The preliminary soil quality information is being used to refine targeted soil quality assessment and benefit soil related research. There is potential to correlate results with other soil research and extension projects (e.g. Visual Soil Assessment, Land Management Index and compaction trials on dairy and forestry).

- Centralised data management

Centralised data management would allow inter-regional use of soil quality data to reduce sampling costs, increase national sampling efficiencies, increase local soil quality knowledge and promote interaction and collaboration between LGOs.

Threats

- Long term commitment

The main threats to the success of an ongoing programme are the securing of funding, primarily at a regional level but also nationally. Buy-in from Regional and District councils and continued financial assistance to maintain core national monitoring are essential.

- Long term commitment

Long-term commitment to monitoring soil quality is required at local and national levels because of the long time scales over which soil quality can change (10s to 100s of years).

Regional Councils and Unitary Authorities have the responsibility for environmental monitoring. They are also answerable to their regional ratepayers and will inevitably concentrate on environmental matters of local concern. Some regional councils have pursued independent lines that are not readily integrated into national reports. For this reason and the assurance of a successful national overview and for “gap-filling” there is clearly a role for central government participation.

- Loss of key personnel

There are a number of key personnel involved at the national and regional level. These personnel are involved with ongoing development of research, year to year site selection and on-ground sampling. This area of soil science is, in one respect, relatively new to New Zealand and in another requires acquired knowledge and field experience. Personnel with knowledge of soil quality and more so, pedological experience, are becoming increasingly difficult to find in New Zealand. Those personnel currently involved stem from a previous science environment where these skills could be fostered. Nowadays, the science education and research environment does not provide the same opportunities and there has emerged a shortfall of such personnel.

3 Project methodology and data evaluation

3.1 Summarised 500 Soils Project results and conclusions

3.1.1 Results

- A total of 511 sites (including three sites repeat sampled) across 10 regions were sampled using comparable methodology. Sites were selected according to land use and the type of soil. There was a strong bias towards the more intensive land uses of greatest concern to the regional authorities, including research sites, degraded sites and sites of specific interest.
- Data was grouped by land use and soil order, these two categories and their interaction, explained about two thirds of the total variability in soil quality data.
- Similar trends in soil quality were obtained across all 10 regions indicating land use as the major driver of soil quality.
- Data for individual sites were compared against other land uses on the same soil or against target values established at soil quality workshops.
- The soil quality characteristics of most sites in the survey fell within acceptable limits for those soil types and land uses.
- Pastures generally had high total C and N contents, and some dairy pastures had very high Olsen P contents.
- More than half the pastures had macroporosity below recommended limits
- Some horticultural and market garden sites had very high chemical fertility
- There was evidence of structural degradation on more than half of the arable cropping and vegetable production sites.

3.1.2 Conclusions

- A total of 511 sites across 10 regions were sampled using comparable methodology. Three of these sites were resampled.
- There was a strong bias towards the more intensive land uses of greatest concern to the regional authorities.
- The soil quality characteristics of most sites in the survey fell within acceptable limits for those Soil Order and land use combinations.
- Similar trends in soil quality were obtained across all 10 regions indicating land use as the major driver of soil quality.

- Sites identified as “at risk” of low soil quality fell into four categories: depletion of organic resources, loss of macropores, decreased aggregate stability, and risk of nutrient leaching because of high nutrient loadings.
- Soil most at risk of high nutrient loadings were those under cropping, horticulture and dairy farming.
- Soils most at risk of soil physical deterioration were those under cropping (loss of aggregates) or dairy farming (compaction).
- There was no evidence that soil acidity under plantation forests differed from that under indigenous forests.
- Appropriate management could reverse the majority of instances of poor soil quality. While low fertility and acidity could be rapidly corrected by the application of lime and fertiliser, loss of organic matter could take many tens of years to restore.
- The original set of 11 soil properties can be reduced to 7 key soil properties. The available water measures, which were not highly responsive to land use can be discarded. The aggregate stability measures can be restricted to arable and horticultural soils. Exchangeable cations can be best measured by QuickTest methodology, where nutrient depletion or balance is of importance.
- An abbreviated soil profile description recording soil type, series, classification to subgroup, depth of A horizon, total potential rooting depth and nature, and depth of any limiting horizon, could replace a full soil profile description for subsequent site sampling or if a suitably skilled pedologist was not available.

3.2 Soil indicators

All of the soil chemical and physical properties used as indicators in this and previous trials (Project 5001) are well established, internationally recognised and have been recommended for soil quality monitoring (e.g. see review by Doran et al 1994). Our use and interpretation of the properties for soil quality monitoring in New Zealand have been reported in peer-reviewed international journals (e.g., Francis & Knight 1993; Francis *et al*., 2001; Schipper & Sparling 2000; Singleton *et al*., 2000; Sparling *et al*., 2000b, c).

The earlier trial (Project 5001) and other published reports established that soil properties such as infiltration rates were too variable to be practical monitoring tools (Beare *et al.,*1999; Schipper & Sparling, 1999), while interpretation of microbial biomass and respiration measures was problematic (Schipper & Sparling 2000; Carter *et al*., 1999). However, the inclusion of additional properties such as the aggregate stability test and Olsen P was desirable. The indicator set used in the 500 Soils Project comprised: total C, total N, mineralisable N, soil pH, Olsen P, exchangeable cations, bulk density, total- and macro-porosity, total- and readily available water and aggregate stability. In addition, the site and soil profile were fully described and location and brief management history recorded. This data set has now been applied to more than 500 sites and the performance on varied land uses and soil can be examined more critically. The multivariate technique of principal component analysis was used to identify those soil characteristics that best explained the variability in the dataset. In addition, the cost and practicality of the measure was considered and the robustness of the interpretation regarding soil management.

From the current data set, available water in the 0–10 cm depth of soil is considered to be of limited use as a quality indicator (Sparling et al., 2001). Instead, it is the total water storage in the whole soil profile that is of greater relevance. Data from the soil profile information such as topsoil depth, total rooting depth and depth to limiting horizon, are probably more relevant than storage in the top 10 cm. Sparling et al. (2001) recommends that RAW and TAW be dropped from the data set but that topsoil depth, and depth of soil available for rooting, be collected as part of the monitoring set. Soil depth information has been systematically collected in the last two years of the 500 Soils Project and it can be derived from the soil profile descriptions.

The exchangeable cation content was useful to characterise the soil orders but was not highly responsive to management. It is also useful to have a measure of exchangeable cations for assessing soil fertility status (particularly Ca, Mg and K). If the prime need is for fertility monitoring, then I recommend that QuickTest values be obtained, for which crop responses are well established. Approximate QuickTest values can be derived from the Landcare Research/DSIR methodology (Lee *et al*., 1991), but it makes more sense to use the recommended QuickTest methodology.
Aggregate stability by the wet sieving method was useful to characterise the soil condition of those land uses involving tillage, but of little value in characterising pasture, indigenous vegetation or plantation forestry. Further, critical limits have so far only been defined for arable cropping systems. While aggregate stability is a useful measure, it should be restricted to cropping and horticultural soils. Conversely, macroporosity is not so meaningful for arable soils, because it is greatly influenced and distorted by the tillage regime.

Particle density was not sufficiently responsive to be a useful indicator but is needed to calculate macroporosity. Macroporosity was a much more sensitive indicator of soil compaction than was bulk density, and seems particularly suitable for pastures. However, bulk density information still needs to be collected to make the appropriate volume and area conversions, and for valid site comparisons. Consequently, bulk density and particle density should continue to be measured, plus moisture release characteristics to calculate macroporosity. Soil organic matter (measured as total C, total N and mineralisable N), should be retained as this is an important integrating characteristic, and retention of organic matter is desirable for soil structural stability, nutrient storage and C storage. The original set of indicators therefore reduces to seven key laboratory measures plus some specific "add-on" measures (Table 1).

Table 1: Soil properties recommended for soil quality monitoring

Soil property	Soil quality information	Applicable to
Total C	Organic C content	All soils
Total N	Organic matter N status	All soils
Mineralisable N	Readily decomposed organic N	All soils
Soil pH	Soil acidity	All soils
Olsen P	Phosphate available to plants	All soils
Bulk density	Soil compaction	All soils
Macroporosity	Soil aeration and compaction	All soils
QuickTest Cations	Ca, Mg and K available to plants	Only necessary where nutrient status/balance is important
Aggregate stability	Stability of soil crumbs	Cropping and horticulture soils

Principal component analysis using only the seven key indicators showed they all contributed to explaining variation when applied in a 4-factor model with Varimax rotation (Table 2). Figures in bold type were highly significant. In general, the indicators fell into 4 broad categories: Factor 1 (37%) = organic matter, Factor 2 (20%) = compaction and aeration, Factor 3 (15%) = fertility, and Factor 4 (15%) = acidity. Total variance explained by the 4 factors was 87.5%.

Table 2: Significance of the various soil properties in explaining total variance using Principal Components Analysis

Soil property	Factor 1	Factor 2	Factor 3	Factor 4
Total C	**0.883**	-0.112	0.118	-0.146
Total N	**0.943**	0.059	0.150	0.010
Mineralisable N	**0.751**	0.355	-0.154	0.109
Soil pH	-0.031	0.160	0.146	**0.970**
Olsen P	0.090	0.165	**0.947**	0.149
Bulk density	-0.499	**0.698**	0.212	0.251
Macroporosity	-0.338	**-0.853**	-0.124	-0.094

Soil quality is assessed using only the 0–10 cm depth of soil (Sparling et al., 2001). However, deeper soil layers and subsoils can also greatly influence soil suitability for use. We have collected reasonably detailed soil profile information which has proved valuable to confirm the soil type, series and classification, and for textural information. However, collection of such information requires a skilled pedologist to undertake the description, and in many cases a simplified soil profile description may suffice. In particular the depth of the topsoil and the potential rooting depth need to be recorded. The nature and depth of any limiting horizon (if one exists) should also be recorded. To extrapolate information to unsampled areas the soil series and type need to be known, so that similar soils in other areas can be identified. A full soil classification to Soil Order and Suborder is required for stratification, as described below.

The NLMF identified seven main soil management issues of concern. It is imperative that these issues are assessed as part of the soil quality monitoring. The soil characteristics recommended in the final 500 Soils report (Sparling et al., 2001) reaffirms that the soil characteristics used to assess soil quality achieved this (Table 3).

Table 3: Soil characteristics used to assess soil quality issues

Issues	Soil characteristic used to assess this issue
Structural decline	Aggregate stability, Bulk density and Macroporosity
Nutrient depletion	Total N, Oslen P and QuickTest Cations
Carbon depletion	Total C
Nutrient saturation (N, P)	Total N, Oslen P
Biological activity change	Mineralisable N
Ph changes (acidity)	PH*
Contaminants	Additional specific heavy metal analyses, chemical residues and other contaminants as required

In general the outcomes from the '500 Soils' would identify the core indicators that could be used. The seven that had emerged to date were Total C, Total N, Mineralisable N, pH, Oslen P, Bulk density and macroporosity.

Main points

- ☐ A set of 7 soil quality properties (total C, total N, mineralisable N, pH, Olsen P, bulk density and macroporosity) validated in this work by PCA, should form part of any soil quality monitoring programme.
- ☐ Additional soil properties (QuickTest exchangeable cations Ca, Mg and K) should be measured where soil nutrient status is of importance, and for nutrient budgets.
- ☐ Aggregate stability should be measured on tilled (cropping) soils, but is not necessary for pastures or forestry.
- ☐ A basic soil profile description including horizon depths colour and texture, combined with potential rooting depth and depth and character of any limiting layer are recommended.
- ☐ Classification to Soil Suborder level (Hewitt 1998) is trequired for stratification purposes.
- ☐ Identification of soil series and type where possible, are useful for spatial extrapolation to unsampled with the same land use and soils.
- ☐ Soil quality monitoring should address the seven main soil management issues identified by the NLMF (structural decline, nutrient depletion, carbon depletion, nutrient saturation, biological activity change, pH change and contaminants as required).

3.3 Stratification

3.3.1 Introduction

Stratification is the process of sub-dividing a monitoring area into strata in a manner that maximises differences in the attributes of interest between strata and minimises variation within each stratum. A stratum is then an area in which the attribute being measured is relatively homogenous and it is likely that there are profound differences in the attribute between strata. Strata are then sampled with sufficient replication of sampling units so that generalisations may be made about each.

Stratification serves two related purposes. Firstly, it enables generalisations to be made about each stratum. This assumes that the inherent differences between strata would make statements overall strata combined largely irrelevant. Secondly by 'removing' the inherent differences between strata from the variation among the sample units, attribute estimates are made with greater precision. The confidence intervals associated with the estimates are consequently smaller. So that stratification can effectively reduce the sample sizes required for specific levels of statistical confidence.

Usually stratification can be planned prior to sampling so that adequate replication can be used for each stratum. However, distinct differences among sample units may not manifest until samples are collected. In this situation stratification is still appropriate but there will potentially be an imbalance of replicates between the strata. In these circumstances it is suggested that additional replicates be added to the strata with small numbers.

If overall estimates of attribute levels are required then these estimates need to be based on weighted estimates from each stratum. An approach for weighting strata is presented later in this report. These weightings would usually be in direct proportion to the area of each stratum.

For the analyses reported here, sites were organised by land use type and Soil Order categories. The assumption is that soil characteristics will differ depending on the land use (and land use management) and the type of soil.

Both categories could be further subdivided, but in that case the number of occurrences in each cell would become very small and could not be considered representative. However, further subdivision would be desirable for specific examples where greater detail is needed. For example, organic farms could be separated from conventional; drystock farming could be further divided to sheep, sheep and beef, beef, or deer. Horticultural and arable cropping could also be further divided. The soil orders could be subdivided to group and subgroup. All this information is available in the various reports, but requires effort to extract. A single electronic database showing all the available information that would allow manipulation of the data into the desired formats and would be highly desirable, but was not part of the original specification of the project. With additional resources, such a table could be compiled from the existing electronic files. Before any compilation, the form and layout, of the design and ownership of the electronic database should be carefully considered, to allow maximum future utility and access to the data.

The type of stratification will depend on user requirements. We have generally organised data by land use class and by Soil Order. Preliminary analyses of the data showed that the degree of variability explained depended on the soil property being examined. Examples for total C and Olsen P are shown in Table 4. All values were significant at $P < 0.001$.

Table 4: Percentage of variability in total C and Olsen P explained by land use and Soil Order categories, and their interaction

Soil property	Land use	Soil order	Order x Land use	Unexplained
Total C	21%	43%	61%	39%
Olsen P	31%	12%	52%	48%

Clearly, Soil Order was more important in explaining total C content than was land use, but land use was more important in explaining variability in Olsen P. The interaction was almost additive for total C, but for Olsen P the interaction was greater than the sum of the individual categoricals. This type of analyses is useful to show what are the major drivers of variability in the soil attributes. The same approach can be used for other categoricals and attributes, but care needs to be taken that sample sizes do not become too small, otherwise they will not reach a desired level of significance. It is likely that land use will remain a major category to stratify data.

Results from the 500 Soils Project suggest that some combination of land use and Soil Order criteria will provide a meaningful partitioning of soil quality variability. There have been a number of options presented for stratification criteria, either for soil, land use, combinations of these, or indirect representations of these (e.g. LENZ classification). In this section the stratification criteria are defined and the merits and limitations assessed individually.

Generally, there will be a “trade-off” in determining the stratification criteria, depending on the differing requirements for regional and national monitoring. For example, differentiating between Tussock and Indigenous forest may be of interest at a regional level but at a National level soil characteristics may not vary significantly and therefore not warrant differentiating as separate strata.

3.3.2 Soil criteria

Soil Order

Soil Order is the highest level of classification in the New Zealand Soil Classification (Hewitt, 1998). The New Zealand Soil Classification (NZSC) provides a means of communicating, recognising and correlating soils within New Zealand by drawing together soils with similar properties and important similarities (Hewitt, 1998). Soil Order provides a means for stratifying soils from around New Zealand at a broad level to meaningfully partition the variability of the soil characteristics used to assess soil quality. There are 15 Soil Orders. Definitions for these are provided in Hewitt (1998). At a Regional level soil series or soil type may be a useful level of soil stratification criterion if the sampling programme can afford sufficient replicates. Alternatively weighting the sites by the most common soils will help ensure the range of soils is representative of the region. However, for national reporting Soil Order is considered of sufficient detail and more practical in terms of sampling number requirements. The hierarchy presented in Table 5 presents a way of provides a framework for aggregating soils at a regional level for a meaningful national stratification.

Table 5: Soil stratification hierarchy

Soil stratification hierarchy			
Soil classification based		**Soil taxonomic based**	
Level 1 Soil Order	**Level 2 Soil Group**	**Level 3 Soil Series**	**Level4 Soil Type**
e.g. Pumice Soils	e.g. Orthic Pumice Soils	e.g. Taupo series	e.g. Taupo sand Taupo loamy sand

3.3.3 Land use criteria

Land use type

The importance of identifying the primary land use and Soil Order at each site for stratification purposes was highlighted at the NLMF meetings. For land use criteria the main focus was agreeing on a common classification, ensuring commonality with the Land Cover Database, and agreeing on the level of detail for the classification. The term *land use type* combines recognised land uses and land cover classes from LCDB1. For instance, the land cover class “primarily pastoral” can be divided into intensive and extensive pasture land use types, in turn consisting of more than one specific land use may make up a land use type (e.g. extensive pasture includes deer, and sheep and beef land uses). A nested hierarchical classification is presented (Table 6) consisting of three levels of detail. The classification is based on discussions held in NLMF meetings and will for the basis for the stratification criteria used for statistical analyses in this document. The categories suggested are by no means definitive and for the lower levels (2 and 3) are only there to provide guidance for regional level monitoring.

Table 6: Levels of land use classification for national and regional stratification

Land use type			
Level 1a (based on LCDB1)	**Level 1b**	**Level 2**	**Level 3**
Primarily Horticultural	*Cropping:* Mixed (has crop rotation including a pasture ley) Arable (cropping, usually with a winter fallow or cover crop) Vegetable growers (market gardens typically with multiple cropping each year)	*Cropping:* Arable	Rotations/cultivation/time
		Cropping: Mixed Market gardens	Rotations/cultivation/time
	Horticulture: Orchards Vineyards/berry-fruit	*Horticulture:* Orchards Vineyards/berry-fruit	Type/time
Planted Forest	Planted Forest	Planted Forest	Species/rotation/silviculture
Indigenous vegetation (Indigenous forest, Inland Wetland, Coastal Wetland and Mangroves)	Indigenous vegetation	Forest type	Forest type/association
		Non-forest vegetation type	Vegetation type/association
Primarily Pastoral	*Intensive pastoral systems:* Dairy Intensive beef	*Intensive pastoral systems:* Dairy Intensive beef	Time/irrigation/stocking rate System/stocking
	Extensive pastoral systems: Sheep/beef Deer	*Extensive pastoral systems:* Sheep/beef Deer	Pasture/stocking Pasture/stocking
Scrub/ shrubland	Scrub/shrubland	Scrub/shrubland dominated by exotic spp.	Scrub/shrubland type e.g. gorse
		Scrub/shrubland dominated by indigenous spp.	Scrub/shrubland type e.g. manuka
Tussock Grassland	Tussock Grassland	Tussock Grassland	Grazed/ungrazed

Level 1 provides the broadest stratification, appropriate for national and possibly regional stratification. These classes are currently in line with the Land Cover Database (LCDB1). A GIS analysis using the LCDB1 and Soil Order can be used to approximate the proportions of each combination. However, the use of a map derived from such an analysis may be of limited use for locating actual sampling sites because of the error and scale associated with the LCDB (e.g. Cropping and Horticulture land is not fully identified). Level 2 provides more detailed separation of land use type more suited to Regional stratification. These classes can not be identified using the Land Cover Database; such land use types do not exist in the LCDB at this level of detail, and require identification on-site. Level 3 proposes the most detailed stratification criteria based on vegetation species, land management practices etc. This level of stratification is more appropriate for targeted monitoring. These classes can not be identified using the Land Cover Database and require identification on-site.

Univariate analysis of variance was used to determine whether soil properties were significantly different for land use types, primarily to see if there was statistical justification of separating predominantly indigenous vegetation types (forest, shrubland/scrub and tussock) (Table 7).

Table 7: Significant differences (p<0.05) for soil properties by land use types

Pr >F*		Soil property						
		pH	TC	TN	Olsen P	ANN	BD	MP
Land use type	Arable cropping	0.033	0.001	0.001	ns	0.045	0.002	ns
	Dairy	0.41	<0.001	<0.001	<0.001	<0.001	<0.001	ns
	Drystock	0.001	<0.001	<0.001	<0.009	<0.001	0.001	0.007
	Forestry	0.005	0.017	0.05	ns	ns	<0.001	0.004
	Indigenous	ns	0.024	0.035	ns	ns	<0.001	ns
	Horticulture	ns	0.024	0.035	ns	ns	<0.001	ns
	Mixed Cropping	0.017	ns	0.001	0.005	0.007	ns	ns
	Scrub	ns	ns	ns	ns	ns	ns	ns
	Tussock	ns	ns	ns	0.015	ns	0.007	ns

* ns = not significant (p>0.05)

For all soil characteristics except total carbon there were no significant differences in values comparing indigenous vegetation types. Similarly for cropping types, only Mineralisable N displayed significant differences for cropping types. The absence of significant differences in soil characteristics within land use types (i.e. indigenous vegetation and cropping) justifies the grouping of all indigenous vegetation types into a single stratum, and similarly all cropping land uses into a single cropping land use type. There are compromises to be made and requirements for information for a specific land use type, for example tussock, may warrant retaining a separate land use type.

For the purpose of national soil quality monitoring the LCDB1 provides a simplistic stratification of land use. This level of stratification is possibly suitable for broad soil quality reporting at a Regional scale but separation of cropping and horticulture, and pastoral into intensive and extensive is recommended. The inclusion of tussock and shrubland/scrub in indigenous vegetation is also acceptable at a regional and national level because there is no significant difference in soil properties between these three strata. However, at a national level of reporting there is sufficient interest in each of these strata to warrant their separation.

Spatial representation of land use types

Spatially quantifying land use type is required to proportionally weight (by area) sampling for individual strata. This is difficult to achieve for pastoral systems, cropping and horticulture. For pastoral systems intensive and extensive pasture can be approximated using Land Use Capability (from the NZLRI database); LUC 1-4 approximating intensive pasture and LUC 5-8 extensive pasture. Alternatively, AgriBase farm type data is becoming readily available in many regions. However, for this project collating this data for a complete national coverage was not feasible. For cropping and horticulture there is no readily available data to estimate the spatial extent and location of these two land use types on a national basis. Either the land types could remain combined or an assumption made that the two land use type occupy similar area and soils.

3.3.4 Alternative stratification criteria

Alternative stratification criteria such as AgResearch soil grouping and LENZ classes were proposed as alternative stratification criteria. This section discusses the potential for using such stratification criteria.

AgResearch soil grouping

An alternative stratification, AgResearch soil groupings, was examined. soil orders were reclassified as shown in Table 8. Sample size distribution for the AgResearch soil grouping is also presented.

Table 8: Soil stratification using the AgResearch groupings

***AgResearch* soil grouping**	**Soil Order**	**Sample size in 500 Soils**
Peat	Organic	12
Podzol	Podzol	8
Pumice	Pumice	54
Sands	Raw, Recent	91
Sedimentary	Anthropic, Brown, Gley, Melanic, Oxidic, Pallic, Ultic	229
Volcanic	Allophanic, Granular	114
Total		**508**

The sedimentary grouping has the greatest number of samples. This highlights the weakness in applying the AgResearch soil grouping for two reasons. Firstly, the groupings would not "usefully" stratify variability in the data, most obviously the sedimentary stratum is too broad. Secondly, all samples in the South Island were reclassified as sedimentary, providing no soil stratification for South Island data.

Land Environments of New Zealand (LENZ) Classification

The LENZ classification was not tested in this review because the spatial data (GIS data) was not readily available at the time of analysis. The time requirement for entering 500 soil grid reference points and the GIS work to determine the LENZ Level 1 classification for each site was beyond the time limits for this review. The LENZ classification was thought to provide a useful link to other programmes because of its growing prominence. A separate or later assessment of the value of this classification should be undertaken. LENZ criteria should be included in site information in any future programme. It is likely that the LENZ classification will be widely available from July 2002. It is likely a number of regional councils have already input site grid references into a spreadsheet. A preliminary request from Regional Councils for electronic (spreadsheet) versions of site grid reference points would be worthwhile as it could reduce the amount of data entry required. Also, attaching additional information such as, site characteristics, soil taxonomy, soil classification and soil morphological descriptors would be useful for further data stratification. Where possible data should be in a format that is compatible with other computer applications.

3.3.5 A combined criteria stratification

A stratification combining both soil and land use criteria is recommended. Ideally the stratification criteria should comprise soil and land use criteria because the 500 Soils Project has demonstrated that the variability of soil characteristics was meaningfully partitioned by both by land use and soil criteria. The level of detail (the number of strata) requires some compromise between creating too many strata to sample and partitioning the variability of soil characteristics in a way that improves the interpretation of results. A hierarchical stratification does allow more detailed breakdown of sites at a regional sampling level if required, and allows for any future improvement of the detail of the Land Cover Database classes. In any case if sites within a region can be identified on-site then the hierarchical stratification allows for aggregation of classes and spatial portrayal using the LCDB1 to approximate land use type.

A stratification based on Soil Order and six land use types (using level 1a in Table 6) provides is suitable at a national level. This combination potentially produces 90 (15 soil orders * 6 land use classes) strata. To estimate the national and regional areas for each strata LCDB and LRI data have been analysed using GIS (Arc/Info). Only two strata do not exist according to the analysis, Oxidic Soils under tussock and Granular Soils under tussock. The total number of possible strata is therefore 88.

Main points

- ☐ Both Soil Order (Hewitt 1998) and land use type are useful criteria for explaining the variability of the soil properties used to measure soil quality.
- ☐ Soil and land use criteria should be "multi-level" to facilitate classification at national, regional and sub-regional levels.
- ☐ Soil and land use criteria should, where possible, coincide with present spatial database classifications (e.g. LCDB) or be flexible to coincide with future soil and land use classifications if required.
- ☐ AgResearch soil grouping and LENZ classification are not recommended as an alternative soil criteria for stratification. However, they may provide a useful way of comparing other monitoring data to the soil quality data collected in this study.
- ☐ The Soil Order and land use type stratification criteria are recommended for national reporting.
- ☐ More detailed stratification may be more appropriate for regional level reporting but may require a greater number of samples.

3.4 Sample distribution and size

3.4.1 National sample distribution

Are the land uses represented by the 500 Soils sampling? To estimate the national and regional areas for each land use type the LCDB data has been analysed using GIS (Arc/Info). The proportions by land use type are compared with the actual distribution of the 500 Soils samples (Table 9).

Table 9: The distribution of samples by land use type

		Proportions		
		LCDB (% by area)	**500 Soils sampling(% of samples)**	**Difference (+/-%)**
Land use type	Cropping[1]	0.1	6.3	+6.2
	Horticulture[1]	0.1	13.4	+13.3
	1.Crop+Hort	**0.2**	**19.7**	**+19.5**
	2.Exotic forest	**7.1**	**13.2**	**+6.1**
	3.Indigenous forest	**25.5**	**12.0**	**-13.5**
	Pasture – extensive	19.6	24.6	+24.6
	Pasture – intensive	22.5	23.8	+1.3
	4.Pasture – all	**42.1**	**48.4**	**+6.3**
	5.Shrubland, scrub	**10.5**	**2.2**	**-8.3**
	6.Tussock	**14.6**	**4.5**	**-10.1**

This combination potentially produces 90 strata. To estimate the national and regional areas for each strata LCDB and LRI data have been analysed using GIS (Arc/Info). To achieve representative samples nationally, sampling for land use types should be weighted according to the relative area of each Soil Order (Table 10). Not all strata occur (see Table 10) reducing the total number of strata to 88.

Table 10: proportions of samples required for each land use type by Soil Order (%)

Soil Order	Cropping[1]	Horticulture[1]	Cropping and horticulture	Intensive pasture[2]	Extensive pasture[2]	All pasture	Indigenous vegetation	Exotic vegetation	Shrubland/scrub	Tussock
Anthropic (A)	0.1	0.1	0.1	0.2	1.5	0.9	0.0	2.3	1.0	0.0
Brown (B)	6.7	6.7	6.7	23.3	36.6	29.9	45.3	25.6	45.7	57.4
Melanic (E)	1.2	1.2	1.2	1.3	2.9	2.1	0.5	0.8	1.4	0.9
Gley (G)	10.7	10.7	10.7	11.7	1.2	6.5	0.8	1.1	1.3	0.4
Allophanic (L)	16.8	16.8	16.8	10.9	9.6	10.3	3.3	2.2	3.7	1.6
Pumice (M)	15.1	15.1	15.1	4.0	7.2	5.6	10.3	25.8	5.3	1.1
Granular (N)	2.2	2.2	2.2	2.7	1.3	2.0	1.3	1.0	1.8	0.0
Organic (O)	2.4	2.4	2.4	2.8	0.7	1.7	0.7	0.2	1.0	0.1
Pallic (P)	7.1	7.1	7.1	21.8	21.3	21.6	0.4	10.2	10.1	11.2
Recent (R)	20.1	20.1	20.1	13.3	7.5	10.4	9.2	8.5	7.6	7.3
Semiarid (S)	1.7	1.7	1.7	1.6	1.1	1.4	0.0	0.1	0.2	1.7
Ultic (U)	4.4	4.4	4.4	3.8	5.0	4.4	2.1	4.5	4.9	0.0
Raw (W)	3.9	3.9	3.9	0.1	0.5	0.3	1.0	1.6	2.0	4.3
Oxidic (X)	7.2	7.2	7.2	0.6	0.6	0.6	0.1	0.5	0.5	0.0
Podzol (Z)	0.4	0.4	0.4	1.7	2.9	2.3	24.9	15.5	13.4	14.2

[1] From LCDB and based on the assumption of equal national proportions of horticulture and cropping nationally.

[2] From LCDB and New Zealand Land inventory (NZLRI). Based on the assumption that nationally, the area of primarily pastoral land with a LUC 1-4 approximates dairy pasture and LUC5-8 approximates drystock.

Are the soil orders appropriately represented by the 500 Soils sampling? To estimate the national and regional areas for each land use type the LCDB data has been analysed using GIS (Arc/Info). The proportions by land use type are compared with the actual distribution of the 500 Soils samples (Table 11).

Table 11: The distribution of sampling by Soil Order

		Proportions		
		NZLRI (NZSC) (% by area)	**500 Soils sampling (% of samples)**	**Difference (+/-%)**
Soil Order	Allophanic (L)	6.0	22.4	+16.4
	Anthropic (A)	0.6	0.8	+0.2
	Brown (B)	39.0	15.9	**-23.9**
	Gley (G)	3.4	6.9	+3.5
	Granular (N)	1.5	4.7	+3.2
	Melanic (E)	1.3	2.2	+0.9
	Organic (O)	1.1	2.4	+1.3
	Oxidic (X)	0.4	0.0	**-0.4**
	Pallic (P)	12.6	7.7	**-4.9**
	Podzol (Z)	11.9	1.6	**-10.3**
	Pumice (M)	7.5	10.6	+3.1
	Raw (W)	1.3	0.4	**-0.9**
	Recent (R)	9.3	17.5	+8.2
	Semiarid (S)	0.9	0.0	**-0.9**
	Ultic (U)	3.2	4.9	+1.7

Table 12: Significant differences for soil properties, stratified by land use type, Soil Order and their interaction

Pr >F (0.05 significance)			
	Stratification		
Soil property	**Land Use Types (LUT)**	**Soil Order (SO)**	**LUT*SO**
Total carbon	<0.001	<0.001	<0.001
Total nitrogen	<0.001	<0.001	<0.001
pH	<0.001	<0.001	<0.001
Olsen P	<0.001	ns	ns
Bulk density	<0.001	<0.001	0.041
Macroporosity	<0.001	<0.001	0.030
Anaerobic N	<0.001	<0.001	0.006

ns = not significant

Whether the 500 Soils Project has collected enough samples depends on the level of certainty required and the way in which the results are to be reported. The minimum sample size required is determined by the most variable soil property but some compromise may be necessary.

The sample size required for each soil property has been calculated using three different stratification criteria (Table 13). The first two stratification criteria (6 LUT and 8 LUT) use different groupings of land use type based on level 1a and level 1b in Table 6. The third stratification criterion (88 LUT/SO) uses land use types from level 1a combined with NZSC soil orders (of which there are 15). The sample size that is calculated in this analysis uses a 95% confidence interval that is +/- 20% of the anticipated mean level.

Table 13: Description of the three stratification criteria used for statistical analysis

Stratification	Abbreviation	Rationale for stratification
Using 6 land use types to give 6 strata	6 LUT	Groups by six land use types that are similar to the classes used for LCDB1.
Using 8 land use types to give 8 strata	8 LUT	Uses the same groupings as for 6 LUT but divides "primarily pastoral" into separate intensive and extensive classes, and differentiates between "horticulture" and "cropping" land uses.
Using 6 land use types for each of 15 soil orders (with 2 combinations not existing) to give 88 strata	88 LUT/SO	The most detailed stratification with unique strata for each land use types (used in 6 LUT) and Soil Order combination. There are 15 Soil Orders, providing 90 (6 x 15) possible combinations. However, a GIS analysis indicated only 88 probable combinations.

To calculate the total number of samples required for national soil quality monitoring the number of replicates required for each strata (e.g. for 6 LUT there are 6 strata) is multiplied by the number of strata. The sampling programme should be based on the samples required to be confident of estimating the most variable soil property value to a predetermined confidence and variance about the mean value for that property is used (in this analysis 95% confident that the mean level +/-20% is achieved).

A total of 516 samples are required to be 95% confident that the mean level +/-20% is achieved based on the sample size required for Olsen P, the most variable soil property (Table 14).

Table 14: Sample size estimations per stratum for different stratification options (national sample size requirements)

	Total number of samples required for national soil quality monitoring programme based on the variability of each soil property		
Soil property	**6 LUT**	**8 LUT**	**88 LUT/SO**
Total carbon	78	88	616
Total nitrogen	72	80	616
pH	6	8	88
Olsen P *	**516**	**616**	**6776**
Bulk density	36	48	264
Macroporosity	156	208	1848
Anaerobic N	102	128	1232

* Limiting soil property

When six (6 LUT) and eight land use types (6 LUT) a sample size of 500 samples is sufficient for all soil properties except Olsen P (n=516 is required). However, with the exception of pH and bulk density, 500 samples is not sufficient if stratifying by all land use type and Soil Order combinations. Using the 88 LUT/SO stratification requires a sample size nearly a whole magnitude greater than for 6 LUT and 8 LUT, rendering it prohibitive. The 8 LUT stratification requires 100 additional samples above that required for the 6 LUT stratification. There are potential gains to be made using the 8 LUT stratification because "primarily pastoral" is separated into intensive and extensive classes and horticulture and cropping are also separated. This improves the detail of reporting and the ability of the programme to specifically identify soil quality issues relating to extensive farming, dairy, cropping and horticulture land uses.

The preferable stratification option is to use either the 6 LUT or the 8 LUT stratification, with sampling weighted by the dominance of Soil Order to ensure the sampling incorporates a "soil effect". Weighting is best achieved using the proportions provided in Table 10.

To estimate the sample size requirements for regional level sampling divide the totals in Table 14 by the number of strata in a particular stratification. For example 516 divided by 6 (for the 6 LUT stratification) means 86 replicates for each of the six land use types will be required. Weighting the sampling according to the regional dominance of Soil Orders, as used nationally in Table 10 will incorporate the soil effect into the stratification.

An useful approach for determining the appropriateness of the selected variance about the mean that is to calculate the width of the 95% confidence interval that is achieved for each stratum by using the current sample size of 508 from the 500 soils project (Table 15).

Table 15: Variance about the mean for soil properties, using a sample size of 500 samples

Soil property	Mean value	% +/- mean value for n=508 and CI95%	Mean value range (CI95%)	Estimated critical limits
Total carbon	53.1	22	42.5 - 63.7	>30
Total nitrogen	4.2	22	3.3 – 5.1	2.5 – 7.0
pH	5.7	6	5.4 – 6.1	5.0 – 6.6
Olsen P	29.3	73	7.9 – 50.9	25 - 100
Bulk density	0.89	15	0.75 - 1.03	0.7 – 1.3
Macroporosity	14.9	39	9.1 – 24.0	8 - 30
Anaerobic N	110.7	32	75.3 - 146.1	

The main issue to consider is whether the uncertainty for a soil property with this sample size means that it may cross a critical limit for either production or environmental (see section 3.13). If this occurs more samples will be required for that strata to provide a more accurate mean value and hence determine which side of the critical limit the mean value lies.

Main points

- The 500 Soils Project sampling has targeted intensive land uses and soils capable of supporting intensive land use.
- A sample size of 516 samples is sufficient (with CI95% and +/- 20% of the mean) if the data is stratified using six land use types (6 LUT); cropping and horticulture, pasture, exotic forest, shrubland/scrub, indigenous forest and tussock.
- A sample size of 616 samples is sufficient (with CI95% and +/- 20% of the mean) if the data is stratified using the 8 LUT stratification. Increasing the sample size from around 500 to 616 is a viable option and the stratification does provide additional land use type strata, useful for reporting and identifying specific soil quality issues.
- A sample size of 500 is not statistically sufficient for the use of the 88 LUT/SO because the required sample size is a magnitude greater than required for either the 6 LUT stratification or the 8 LUT stratification.
- The preferable stratification option is to use either the 6 LUT or the 8 LUT stratification, with sampling weighted by the dominance of Soil Order to ensure the sampling incorporates a “soil effect”. Weighting is best achieved using the proportions provided in Table 10.

3.5 Sources of Variability

The main sources of variability in the 500 Soils Project are associated with land use and management, type of soil, systematic (e.g., analytical and sampling errors) and temporal (e.g. season variation.

Principal component analysis using only the seven key indicators showed they all contributed to explaining variation when applied in a 4-factor model with Varimax rotation (Table 16). Figures in bold type were highly significant. In general, the indicators fell into 4 broad categories: Factor 1 (37%) = organic matter, Factor 2 (20%) = compaction and aeration, Factor 3 (15%) = fertility, and Factor 4 (15%) = acidity. Total variance explained by the 4 factors was 87.5%.

Table 16: Significance of the various soil properties in explaining total variance using Principal Components Analysis

Soil property	Factor 1	Factor 2	Factor 3	Factor 4
Total C	**0.883**	-0.112	0.118	-0.146
Total N	**0.943**	0.059	0.150	0.010
Mineralisable N	**0.751**	0.355	-0.154	0.109
Soil pH	-0.031	0.160	0.146	**0.970**
Olsen P	0.090	0.165	**0.947**	0.149
Bulk density	-0.499	**0.698**	0.212	0.251
Macroporosity	-0.338	**-0.853**	-0.124	-0.094

We assess soil quality using only the 0–10 cm depth of soil. However, deeper soil layers and the subsoil can also greatly influence soil suitability for use. We have collected reasonably detailed soil profile information which has proved valuable to confirm the soil type, series and classification and for textural information. However, collection of such information requires a skilled pedologist to undertake the description, and in many cases a simplified soil profile description may suffice. In particular the depth of the topsoil and the potential rooting depth need to be recorded. The nature and depth of any limiting horizon (if one exists) should also be recorded. For mapping purposes, and to extrapolate information to unsampled areas the soil map-unit, soil series and type needs to be known, so that similar soils in other areas can be identified. A full soil classification to order and suborder is useful for stratification, as described below.

3.6 Stratification

For the analyses reported here, sites were organised by land use and Soil Order categories. Both categories could be further subdivided but in that case the number of occurrences in each cell would become very small and could not be considered representative. However, further subdivision would be desirable for specific examples where greater detail is needed. For example, organic farms could be separated from conventional; drystock farming could be further divided to sheep, sheep and beef, beef, or deer. Horticultural and arable cropping could also be further divided. The soil orders could be subdivided to group and subgroup. All this information is available in the various reports, but requires effort to extract. A single electronic database showing all the available information would allow manipulation of the data into the desired formats and would be highly desirable, but was not part of the original specification of the project. With additional resources, such a table could be compiled from the existing electronic files. Before any compilation, the form and layout, of the design and ownership of the electronic database should be carefully considered, to allow maximum future utility and access to the data.

The type of stratification will depend on user requirements. The data was organised by land use type and by Soil Order. Preliminary analyses of the data showed that the degree of variability explained depended on the soil property being examined. Examples for total C and Olsen P are shown in Table 17. All values were significant at P < 0.001.

Table 17: Percentage of variability in total C and Olsen P explained by land use and soil order categories, and their interaction

Soil property	Land use	Soil order	Order x Land use	Unexplained
Total C	21%	43%	61%	39%
Olsen P	31%	12%	52%	48%

Clearly, Soil Order was more important in explaining total C content than was land use, but land use was more important in explaining variability in Olsen P. The combined variation explained was almost additive for total C, but for Olsen P the total was greater than the sum of the individual components. This type of analyses is useful to show what are the major drivers of variability in the soil attributes. The same approach can be used for other divisions and attributes but care needs to be taken that sample sizes do not become too small, otherwise they will not reach a desired level of significance. It is likely that land use will remain a major category on which to stratify data.

Results from the 500 Soils Project suggest that some combination of land use and Soil Order criteria will provide a meaningful partitioning of soil quality variability. There have been a number of options presented for stratification criteria, either for soil, land use, combinations of these, or indirect representations of these (e.g. LENZ classification). In this section the stratification criteria are defined and the merits and limitations assessed individually.

Generally, there will be a “trade-off” in determining the stratification criteria, depending on the differing requirements for regional and national monitoring. For example, differentiating between Tussock and Indigenous forest may be of interest at a regional level but at a national level soil characteristics may not vary significantly and therefore not warrant differentiating as separate strata.

3.6.1 Land use and spatial variability

Triplicate cores, or triplicate spade samples were taken along the transects for soil physical characteristics, and a more in-depth analyses of this data would allow within-site variability to be calculated for bulk density, porosity, available water and aggregate stability.

In the preliminary study (Project 5001), we examined variability at 5 points along a 35 m transect, at 65 sites, and for 4 main land use classes for 17 soil properties. There were differences in variability depending on land use (Table 18)

Table 18: Relative variability (Coefficient of Variance) by land use relative to pasture (Pasture = 1.00).

Land Use	Relative CV (all properties)	95% Confidence Interval
Crops	0.94	0.74–1.19
Indigenous forest	2.02	1.53–2.66
Pastures	1.00	11.00
Pines	1.57	1.22–2.03

The data indicate that (over the whole range of soil properties) sites under indigenous forest are about twice as variable as those under pasture; sites under cropping are probably somewhat less variable than those under pasture; sites under pine are probably more variable than sites under pasture but less so than sites under indigenous forest.

Data were grouped to allow the variability of the individual soil properties to be calculated (Table 19). Some soil properties such as macroporosity had high variability (CV = 29.4%), whereas others such as pH were low (CV = 2.3%).

Table 19: Coefficients of variation of soil properties. The variance is the sum of any systematic, spatial and land use effects

Soil properties	Co-efficient of Variation (%)
Total C	9.4
Total N	8.6
Mineralisable N	13.2
pH	2.3
Olsen P	15.6
Bulk density	7.2
Macroporosity	29.4

Soil properties that show large changes in response to land use can have large CV but still show significant differences. Macroporosity remains a useful measure even though it has a high CV because there are correspondingly large changes in the means in response to land use pressures. It is important to define the level of precision required before rejecting a soil property because the CV may appear high. A high CV can be lowered by increased replication. The number of samples required to achieve various levels of precision is shown in Appendix 2. The level of replication will sometimes be impractical.

Combining the observed average percentage changes in the means and the measured spatial variability, the present sampling for chemical characteristics (25 small cores bulked), provides 90% confidence that a 25% change in a mean value across sites and land uses was a significant effect. Where data can be replicated together because they have similar soils, land use or other categorical attributes, then conventional statistical tests can be applied.

3.6.2 Land use history

In the present study only brief details were recorded on land-use history and management. While this is acceptable for a broad scale survey, to provide advice to land managers on best management practices, it would be advantageous to know the management actions that have resulted in good or poor soil quality. Additional land management information should be gathered in any future survey. Information should include management history for the past 10 years, and preferably much longer, fertiliser use, stocking rates, any major events (flooding, landslips, etc.), cultivation methods, and any exceptional climatic patterns (drought, wet spring weather, etc.).

3.6.3 Systematic variability (laboratory error)

Laboratory error is expressed as change in value (expressed as the coefficient of variance = standard deviation/mean), of a repeated analysis on the same sample. Generally, this is only possible for air-dried, finely ground soils where no temporal change occurs. For those reasons, no estimate was possible for mineralisable N and the soil physical measures, as these analyses use coarsely sieved, moist soil, and the same soil cannot be subsampled for repeat analyses. Replicate samples can be analysed, but this is not quite the same, as there will inevitably be some spatial or temporal separation). The final stage of the mineralisable N measurement, which involves analysing for ammonium and nitrate, had a CV of 1.7% and 0.4%, respectively. Laboratory error (CV%) for chemical characteristics was 1–6% (Table 20).

Table 20: Variation due to laboratory error.

Soil property	Coefficient of variability (%)*
Total C	0.9 (n=20)
Total N	2.8 (n=20)
pH	1.0 (n=76)
Cation exchange capacity	5.9 (n=61)
Olsen P	6.1 (n=21)
Mineralisable N	Not determined

*Data supplied by Brian Daly, Environmental Chemistry Laboratory, Landcare Research, Palmerston North.

3.6.4 Temporal variability

There was no undertaking of any systematic study of temporal variability of less than one year. However, other studies have shown that some soil properties such as pH, fertility levels and macroporosity, can show marked changes from month to month depending on management and climate (Tate et al 1991a, b). Where samples are only collected infrequently, say once a year or longer, we recommend that samples be collected at standard sampling times to minimise seasonal variability in these measures. Preferred times are after harvest for cropping and horticulture, and in springtime for pastures and forestry. Soil properties such as total C and N do not show strong seasonal change, but we still recommend samples be collected at standard times.

For comparisons between different land uses and soils we advise sampling at comparable times of the year. Spring is our preferred option for pastures, indigenous, and plantation forests. Samples should not be collected when soils are under moisture deficit (excessively dry), frozen, or waterlogged. For cropping soils, the preferred collection time is after all harvesting operations have been completed, but before soil preparation for the following crop. Some soil properties in the monitoring set are responsive to short-term management effects. Allowances need to be made if the site has recently received lime or fertiliser, or trampled by stock, otherwise the values obtained for pH, exchangeable cations, Olsen P, bulk density and porosity will not be representative of the “normal” soil condition. Unless it is wished to study short-term trends specifically, then a recovery or “settling down” period of several weeks should be allowed. If such a delay is not practical, then the site condition should be noted in the field records and the analytical results interpreted with caution.

Main points

- ☐ A combination of land use and Soil Order explained half to two-thirds of total variation.
- ☐ Macroporosity and Olsen P were the most variable soil properties, and pH and bulk density were the least variable.
- ☐ Sites under indigenous vegetation were about twice as variable as sites under pasture and sites under cropping are likely to be less variable than sites under pasture.
- ☐ Additional land management information should be gathered and include management history for the past 10 years, and preferably much longer, fertilizer use, stocking rates, any major events (flooding, landslips, etc.), cultivation methods, and any exceptional climatic patterns (drought, wet spring weather, etc.).
- ☐ To follow trends through time, sites should be sampled at the same time of the year. Spring is preferred for pastures and forested sites.
- ☐ After harvest, but before soil preparation for the next crop, is the preferred sampling time for horticulture and cropping.
- ☐ Sampling should be avoided around times of major soil disturbance (tillage, fertiliser application, stock trampling) and when soils are dry and hard.
- ☐ Laboratory errors are a comparatively small part (<6%) of total variability.

3.7 State and trend

The 500 Soils Project has provided soil quality data from “one-off” samples at “point” locations in the participating regions. In only one instance has a site been resampled to follow trends through time (a farm under transition from drystock to dairy farming in Waikato). This is because, within the 3-year duration of the project, it was deemed more important to establish baselines and a network of sites that could be subsequently revisited. Consequently, the data provides information on *state* at the time of sampling, and, without further resampling, cannot provide information on trend and rates of change. Other soil quality monitoring programmes, such as Arable SQMS developed by Crop & Food research, have shown the benefits of repeated sampling over time. The resulting trends and rates of change in soil properties provide useful information on the effects of management practice on soil quality.

Attempts to relocate sites previously sampled by DSIR from archive records, and to compare present day characteristics against the archive records have been only partially successful. This is largely because the original locations were not precisely defined, land use in the intervening years is not known and the original samples were not collected for soil quality analyses, but for soil survey and general characteristics.

Although the state data cannot provide information on rates of change they do provide very strong information on patterns of soil properties under different land uses and, by comparison against similar soils and landscapes, overall trends can be deduced.

For the most effective resampling programme, those soils that show rapid change should be sampled more frequently than that showing little change. Soils showing rapid change are likely to be those that are undergoing a transition in land use (e.g. forest harvesting, pastures converted to horticulture, land restoration sites). Soils that have been under long-term unchanged land use (e.g. long-term permanent pastures, indigenous forest sites) are likely to be in equilibrium and will not show change through time while management remains constant. There is little point in frequent sampling of sites in equilibrium that do not change. For regional council monitoring, changes may need to be followed over periods of relevance for intergenerational equity (to meet the foreseeable needs of future generations as stated in RMA 1991) and so would need to be resampled at least every 20–25 years.

A further consideration is that some sites may have a change in land use prior to resampling. Estimates of between 10 and 25 percent have been experienced (Malcolm Todd, pers comm. 2002). This may alter the balance of samples per soil/land use combination. As a result new sites may have to be located and integrated into the sampling programme.

Main points

- ☐ Rates of change on individual sites are best determined by repeated sampling at some point in the future.
- ☐ To establish rates on change on rapidly changing sites, a resampling at 1-to-3 year intervals should be considered. Stable sites can be resampled on a 5–10 year basis or on an even longer cycle if there is no cause for concern and the sites appear stable (e.g. indigenous vegetation sites).

3.8 Replication

In general, the level of replication has provided adequate precision. However, two different approaches have been used depending on the needs of the region. In Canterbury a replicated design was used, with three plot samples to allow within treatment variability to be calculated. This makes for valid statistical comparisons between treatments, but greatly curtails the number of soil and land uses that can be investigated. The alternative and more widely used approach was to take a single sample (actually a short transect) from the land use under consideration, and to use other transects on the same land use (but in other locations) as the replicates. This latter method allows different land uses to be compared on a broad scale, and for a wider-ranging survey to be completed. The disadvantage is that it provides no information about differences resulting from contrasting management on the same land use.

Both approaches are valid. Councils should consider whether they require the detailed information about small differences in management within a single land use (e.g. different types of cultivation and residue retention in arable farming), or whether information on a broader scale (e.g. dairy farming versus drystock farming) is the purpose of the monitoring.

Main points

- ☐ With a replicated design there is a trade-off between understanding within treatment variability and the number of soil and land uses that can be investigated.
- ☐ A single plot (sample) representation allows different land uses to be compared on a broad scale, and for a wider-ranging survey to be completed.
- ☐ The latter approach is preferred for a national monitoring programme.

3.9 Regional and National requirements

Data for the 500 Soils Project has been collected on a regional basis using targeted and selective sampling. Targeted sampling is justified at the regional level because it represents efficient use of resources for monitoring, and can be justified to councillors and ratepayers. However, there are deficiencies when combining the regional data into a national overview. Some regions are not represented at all (e.g. Otago and Southland) and the intensity of sampling has differed in participating regions.

Main points

- ☐ Regionally there is bias in the sampling because of the requirement for targeted sampling.
- ☐ Nationally some regions are not represented and the intensity of sampling has differed in participating regions.

3.10 From point samples to area

The bias in the point samples of the 500 Soils dataset has already been stressed. To extrapolate from the point samples to an area basis, we need to assume the sampled site was representative of that soil and land-use combination over a larger area. In many cases, we can only infer this from the general form of the landscape, vegetation cover, and land use. Intensive point sampling is needed to establish the variability across the landscape. Such intensity of sampling was not feasible within the present project, and indeed may well be a waste of resources where a particular soil and land use may be extensive, but at little risk of poor quality. However, for accuracy, and if it is wished to extrapolate from point to area depiction, then the number of samples should reflect the extent of occurrence of that soil-type land use in the landscape. This argument also applies where the number of exceedances differs markedly between soils and land uses. A high incidence on one particular land use combination may bias the whole sample if that particular land use comprises only a small proportion of the total land area. To avoid this bias, the distribution of sampling points should ideally reflect the frequency of the land use but, as discussed earlier, such a sampling routine may entail the collection of impractical large numbers of samples.

It is anticipated that regions will use targeted or selective sampling strategies, and to avoid bias within data sets, we suggest any sites showing exceedance should be weighted according to area. Such an approach was used by Brejda *et al.* (2000a, b) and Wander and Bollero (1999). A method is described to calculate the weighting factors in the 1999–2000 report (Sparling et al., 2001). The suggested method is reproduced below.

A weighting factor for each soil and land-use combination can be applied if it is assumed that the sites sampled were representative of the total area of that particular combination. Weighting factor (W) = C/T. Where: C = the area of land under that soil type and land use combination. T = Total area of the landscape under consideration.

Hypothetical example: there are 8000 ha of dairy pasture under soil A, from a region with a total rural land area of 200 000 ha. You have sampled 4 sites under dairy on the A soil, and 16 under other soils and land uses. Suppose one of the A sites is identified as having poor quality. This means that 1 in 4 of the sites sampled from A soil under dairying were poor quality, and 1 in 20 of all the sites sampled (5% of sites). However, regionally the A combination is only 8000/200 000, or 0.4 of the total. The true proportion is therefore: (1 x 0.4)/20 = 0.02 or 2% of the regional area.

Multiple samples: Suppose that in addition to the A example you had a further site on a different soil that exceeded a quality test. Let's call this soil B and there are 2000 ha of it. We now have two sites that exceed the quality criteria out of 20 sampled (i.e. 10% of the sites sampled). We should correct for the relative areas sampled. The weighting factor for B soil is 2000/200 000 = 0.01. The correct exceedance is therefore [(1 x 0.4) + (1 x 0.01)]/20 = 0.0205 or 2.05% of the regional area (not 10% as obtained by number of sites affected).

The weighting factors also enable the correct apportioning of sample sites for point to area extrapolation. If 20 sites are sampled, then 20 x 0.4 = 8 of them should be on the A soil, and 20 x 0.01 = 0.2 (i.e., none) on B. If 100 sites were sampled, 40 should be on A soil and 1 on the B soil.

Main points

- ☐ Intensive point sampling needed to establish the variability across the landscape, and validate spatial extrapolation of point data, is beyond the scope of a broad national monitoring programme.

3.11 National data sets

Even though the soils may be mapped as the same type, and be under similar land use, many soil quality characteristics are greatly modified by land management under the direct control of the individual farmer. Landcare Research and AgResearch are currently collecting information of soil fertility (Olsen P, pH, cations) and landscape characteristics (soil, slope, aspect, climate) to obtain regional distribution and variation in those soil properties. Such information will be useful to gauge the representitiveness of the 500 Soils data set. If the soils in the 500 Soils data set fall within the expected distribution, then greater confidence can be applied to extrapolating area information from point data.

Landcare Research is working on mapping the locations of the 500 Soils sampling points, and will examine these to see how well each of the various land-use and soil-order combinations are represented. Further categories (such as IPCC soil and climate classes) could also be examined. The intention will be to obtain sufficient samples in each class or combinations of classes to get robust representation. More likely, some classes will not be represented in the current data set, which will assist with prioritisation of any future sampling.

Main points

- ☐ Information of soil fertility (Olsen P, pH, cations) and landscape characteristics (soil, slope, aspect, climate) is being collated by Landcare Research and AgResearch and will be useful to gauge the representitiveness of the 500 Soils data set.
- ☐ Landcare Research is mapping the locations of the 500 Soils sampling points to see how well each of the various land-use and soil-order combinations are represented.
- ☐ The locations of all of the 500 Soils sampling points have been located on a GIS layer to provide an indication of the spatial distribution of the current dataset regionally and nationally.

3.12 Matched sites

For land-use comparisons it is useful to have paired sites, as used in the earlier project 5001. However, the reality is that exactly matched sites, differing only in land use, are difficult to locate, and may not be representative of overall farming practice. The majority in the 500 Soils dataset were matched only in that some subsets were on the same soils. The matched sites approach is no longer essential because there now exists a much stronger interpretative framework for each of the soil quality characteristics, specific to land use and soil groupings. Consequently, there does not need to be an alternative land use or soil for comparison.

Main points

- ☐ The matched sites approach is no longer essential because a much stronger interpretative framework for each of the soil quality characteristics, specific to land use and soil groupings has been established.

3.13 Critical limits and target values

3.13.1 Provisional production and environmental target values

The basis for the interpretative framework was derived during two expert panel workshops, sponsored by MfE (Sparling & Tarbotton, 2000). Production and environmental target values were defined for the various soil properties (Tables 21 and 22).

Table 21: Provisional target values or ranges proposed for soil chemical properties to assess soil quality using production or environmental criteria

Soil property	Soil orders	Land use categories	Target value or range for production criteria	Target value or range for environmental criteria
Soil pH	All soil orders except Organic	Pastures	6.0	5.0–7.0
		Cropping and Horticulture	6.0	5.0–7.0
		Forestry	4–6.5	4.2–6.5
		Indigenous	4.5–6.0	4.0–6.5
	Organic	Pastures	5.3–6.4	4.0–6.5
		Cropping and Horticulture	5.0–7.5	4.0–6.5
		Forestry	4.0–7.5	ND
		Indigenous	ND	ND
Organic C (% w/w)	Allophanic and Oxidic	All land uses	>2	>5
	Semiarid, Recent and Pallic		>5	>3
	All other soil orders		>1	>3.5
Olsen P (:µg/cm^3)	Recent	Pasture	>40	40–75
		Cropping and Horticulture	>90	35–70
	Organic and Pumice	Pasture	>40	35–65
		Cropping and Horticulture	>90	ND
	All other soil orders	Pasture	>40	20–80
		Cropping and Horticulture	>50	ND

ND = Not determined

Table 22: Provisional target values or ranges proposed for soil biological and physical properties to assess soil quality using production or environmental criteria

Soil quality attribute	Soil Orders	Land use categories	Target value or range for production criteria	Target value or range for environmental criteria
Mineralisable N (:g/cm^3)	All Soil Orders	Pasture	>70	0–150
		Cropping and Horticulture	>70	0–120
		Pines	>50	50–170
		Indigenous	ND	ND
Bulk density (Mg/m^3)	All Soil Orders	All land uses	0.8–1.1	0.8–1.1
Aggregate stability (mean wt diam)	Recent	Cropping and horticulture	>2mm	>1.5 mm
	All others	All others	ND	ND
Macroporosity (%v/v)	All Soil Orders	Pastures	10–15%	10–15%
		Cropping and horticulture	8–17%	8–17%
		Pines	8–17%	8–17%

ND = Not determined

The target values derived from the workshops provide a useful basis for setting target values but further fine-tuning will occur as the targets are more widely applied and discussed.

3.13.2 Number of occasions not meeting quality target

The number of times a quality attribute is in exceedance of a particular limit is frequently used in water and air quality monitoring. The fewer the number of instances, and the smaller the magnitude of exceedance, the better the quality rating. The same general approach can be used with soils, but because the number of samples is so much less, and they are not resampled frequently and also come from a single point rather than an integrated area, the overall assessment can be strongly biased by a small number of samples. Care is therefore needed when extrapolating from small data sets, where a single sample in exceedance may represent 10% of the set. It does not follow that 10% of the region's soils are therefore of poor quality. Further samples need to be collected, and the suspect site resampled to confirm the original observations. None-the-less the number of sites showing any exceedance is a guide as to where problems exist and where resources need to be targeted. As the number of monitored sites increases, and by integration across regions, an overall national report can be obtained.

Smith (1990) applied a rule of minimands to water quality monitoring. In that approach, the sample must meet a certain standard in all its measured attributes. A failure to meet the standard on any single characteristic meant that the sample was graded at that score. The analogy is the same as awarding a motor vehicle a warrant of fitness: it does not matter how good the tyres are, if the brakes are less than standard, the vehicle will fail the test. Similarly for soils, the quality rating is made up of a number of components – the chemical, physical and biological status of the soil. An exceedance in any category should be a cause for concern, and a high quality rating in, for example, physical characteristics should not counter a low rating in biology and chemical quality. This ranking method is known as the *minimum determinand*, and provides a conservative way to assess a sample. It is *conservative* because there is no risk of the sample being classified as good quality despite one of its characteristics failing to meet the standard specified (Smith 1990).

The masking of a poor result by good ones is known as eclipsing and is one of the problems in reducing the quality rating to a single index although this is often attempted for ease of communication. Landcare Research is currently trialing a diamond-shaped visual depiction of quality using the four factor grouping from the PCA.

Main points

- ☐ The findings of the MfE workshops on soil quality are recommended as a basis for defining target values for soil properties.
- ☐ Further work is required to validate target values, critical limits and optimum ranges.

3.14 Other sampling depths

The standard sampling depth used in this study for bulked cores was 0–10 cm, taken with a standard tube auger. The sampling depth is the same as used for the surface soil of the IPCC Soil Carbon Monitoring Programmes, but differs from the depth used by soil fertility testing services (0–7.5 cm). Soil physics samples were taken 0–10 cm with a spade for soil aggregate stability tests, and intact cores 0–7.5 cm for bulk density and macroporosity. Sampling depth is important because some characteristics such as organic matter and Olsen P tend to be highly concentrated in the upper regions of soil. Including an extra depth of soil can “dilute” the concentration. On the whole, there seems no strong reason to change the current depth regime, particularly as conversion factors have been derived to convert between 10 cm and 7.5 cm cores for soil fertility testing (Sparling & Roberts 2001a, b).

Other sampling depths may be useful on specific occasions. In particular, some authors consider soil condition below 10 cm depth to be of relevance for the growth of some crops and advocate sampling down to 20 cm depth or beyond (e.g., Sojka *et al*., 1997). While desirable, the practicalities of such sampling on a broad scale study need to be considered. It is suggested that in many cases an examination of the soil profile and identification of limiting horizons may be adequate in the first instance.

For some forest sites the litter and FH material comprises a considerable organic resource. The convention is that this “forest floor” material is not mineral soil, and may be separated before sampling the mineral soil. However, the litter and FH material is a substantial “soil” resource and the depth of organic horizon is itself a useful indication of forest health. It may also be appropriate to analyse this forest floor layer in addition to the mineral soil. If forest floor material is to be collected, then that needs to be done by area using sample quadrats rather than cores. Quadrat sampling is not recommended for routine soil quality sampling on normal mineral soils.

Main points

- ☐ A number of authors consider the soil condition below 10 cm , especially for cropping to be important. The practicalities of sampling below 10 cm on a broad scale study need to be considered.
- ☐ In many cases an examination of the soil profile and identification of limiting horizons may be adequate in the first instance.
- ☐ Forest litter and the depth of the organic horizon are useful indicators of forest health and may warrant sampling. If sampled a sample quadrats method rather than cores should be used.

3.15 Modelling

Where similar soils and land uses are known to occur, and where these can be matched to climates zones, ecological domains or soil/climate maps (as used by IPCC for soil C mapping), then the likely soil quality composition in those non-sampled areas can be deduced by spatial modelling. Spatial modelling was not a component of the 500 Soils Project but this aspect warrants further investigation for reporting at a national scale.

Main points

- ☐ For national reporting, spatial modelling of soil quality characteristics should be investigated to derive soil quality status in non-sampled areas.

3.16 Cost estimates

Costing have been estimated from the actual costs of the 500 Soils Project. The estimates provide an average, indicative cost, as costs will vary between Regions. The cost estimates are broken into site selection, fieldwork, laboratory analyses and reporting (Table 23).

Table 23: Breakdown of costs for soil quality monitoring (based on the 500 Soils Project actual costs)

Item	Activity	Cost per site	Total for 15 sites ($)	Total for 15 sites (%)
Site selection	Identify potential sites and contact land owners for access	**$60** (based on 1.5 days @ $75 for 15 sites	$900	5
Field work – travel	Travel to site	**$75** (based on 1,500 km @ 70c/km for 15 sites).	$1,125	7
Field work – on-site activities	Complete field description, soil profile, collect samples for chemical, physical and aggregate stability analyses	**$300** (based on sampling 3.5 sites per day, 2 fieldworkers @$75/h each	$4,500	25
Reporting - site and soil information	Complete report based on field notes, check rainfall data etc	**$75** (based on 1 h per site at $75)	$1,125	7
Send soils to analytical laboratory	Package and dispatch soils to receiving laboratory	**$20** (based on 3 h @ $75/h, plus $65 courier costs for 15 sites)	$300	2
Laboratory analyses	Option A: Prepare soils and complete analyses for soil quality indicators. Recommended indicators are: total C and N, pH, Olsen P, mineralisable N, bulk density and macroporosity. Aggregate stability useful for arable sites	**$425** (Based on $95 per bulked sample for 5 chemical characteristics, $210 for 3 replicates for 2 physical characteristics, and $120 for 3 replicate aggregate stability measures)	$6,375	37
	Option B: Analyses for bulk density, pH and total C only	**($55)** per site	($825)	(8)
Reporting – record laboratory data	Data input and manipulations	**$40** (based on 8 h @ $75/h for 15 sites)	$600	3
Reporting – interpretive report	Compile data, record methods, complete statistical analyses, compare sites, determine trends, identify sites exceeding recommended limits, make recommendations for future monitoring	**$160** (based on 32 h @ $75/h for 15 sites)	$2,400	14
		TOTAL ($1155 per site)	**$17325**	**100**

The allocation of costs is greatest for laboratory analysis (37%), decreasing for field work (34%), reporting (24%) and site selection (5%) respectively. Comparatively, analysis costs make up a major proportion of the total costs. The lower laboratory analyses option (see Option B in Table 23) is $5550 less than option for 15 sites or $370 less per site. At $785 per sample site this would provide 7 extra sites for the same cost. Using Option B (see 22) analysis costs are estimated at 8% of the total cost per site. However, the data provided is compromised, not as scientifically robust and there is a real chance that soil quality issues may not be identified (e.g. nutrient depletion, nutrient saturation and biological activity change).

The “500 Soils” indicators incorporate the MfE indicators and are supported scientifically. They fit into the national framework for assessing soil quality allowing comparison of soil quality data with findings from adjoining regions. Although there is a cost difference of about $370 per site, the value and “usability” gained from adopting the “500 Soils” indicators is greater because the data set is more flexible, comprehensive and scientifically defensible.

Main points

- Based on the 500 Soils Project the estimated cost per site is $1155.
- Analysis of MfE SQ indicators (pH, bulk density and total C) instead of the 500 Soils indicators reduces the cost per site to $785.
- The value and “usability” gained from adopting the “500 Soils” indicators is greater because the data set is more flexible, comprehensive and scientifically defensible.

4 Summary of main points

Soil indicators

- A set of 7 soil quality properties (total C, total N, mineralisable N, pH, Olsen P, bulk density and macroporosity) validated in this work by PCA, should form part of any soil quality monitoring programme.
- Additional soil properties (QuickTest exchangeable cations Ca, Mg and K) should be measured where soil nutrient status is of importance, and for nutrient budgets.
- Aggregate stability should be measured on tilled (cropping) soils, but is not necessary for pastures or forestry.
- A basic soil profile description including horizon depths colour and texture, combined with potential rooting depth and depth and character of any limiting layer are recommended.
- Classification to Soil Suborder level (Hewitt 1998) is required for stratification purposes.
- Identification of soil series and type where possible, are useful for spatial extrapolation to unsampled with the same land use and soils.
- Soil quality monitoring should address the seven main soil management issues identified by the NLMF (structural decline, nutrient depletion, carbon depletion, nutrient saturation, biological activity change, pH change and contaminants as required).

Stratification

- Both Soil Order (Hewitt 1998) and land use type are useful criteria for explaining the variability of the soil properties used to measure soil quality.
- Soil and land use criteria should be “multi-level” to facilitate classification at national, regional and sub-regional levels.
- Soil and land use criteria should, where possible, coincide with present spatial database classifications (e.g. LCDB) or be flexible to coincide with future soil and land use classifications if required.
- The AgResearch soil grouping and LENZ classification are not recommended as alternative criteria for stratification. However, they may provide a useful way of comparing other monitoring data to the soil quality data collected in this study.
- The Soil Order and land use type stratification criteria are recommended for national reporting.
- A more detailed stratification may be more appropriate for regional level reporting but may require a greater number of samples.

Sample distribution and size

- The 500 Soils Project sampling has targeted intensive land uses and soils capable of supporting intensive land use.
- A sample size of 516 samples is sufficient (with CI95% and +/- 20% of the mean) if the data is stratified using six land use types (6 LUT); cropping and horticulture, pasture, exotic forest, shrubland/scrub, indigenous forest and tussock.
- A sample size of 616 samples is sufficient (with CI95% and +/- 20% of the mean) if the data is stratified using the 8 LUT stratification. Increasing the sample size from around 500 to 616 is a viable option and the stratification does provide additional land use type strata, useful for reporting and identifying specific soil quality issues.
- A sample size of 500 is not statistically sufficient for the use of the 88 LUT/SO because the required sample size is a magnitude greater than required for either the 6 LUT stratification or the 8 LUT stratification.
- The preferable stratification option is to use either the 6 LUT or the 8 LUT stratification, with sampling weighted by the dominance of Soil Order to ensure the sampling incorporates a “soil effect”. Weighting is best achieved using the proportions provided in Table 10.

Sources of Variability

- A combination of land use and Soil Order explained half to two-thirds of total variation.
- Macroporosity and Olsen P were the most variable soil properties, and pH and bulk density were the least variable.
- Sites under indigenous vegetation were about twice as variable as sites under pasture and sites under cropping are likely to be less variable than sites under pasture.
- Additional land management information should be gathered and include management history for the past 10 years, and preferably much longer, fertilizer use, stocking rates, any major events

(flooding, landslides, etc.), cultivation methods, and any exceptional climatic patterns (drought, wet spring weather, etc.).

- ☐ To follow trends through time, sites should be sampled at the same time of the year. Spring is preferred for pastures and forested sites.
- ☐ After harvest, but before soil preparation for the next crop, is the preferred sampling time for horticulture and cropping.
- ☐ Sampling should be avoided around times of major soil disturbance (tillage, fertiliser application, stock trampling) and when soils are dry and hard.
- ☐ Laboratory errors are a comparatively small part (<6%) of total variability.

State and trend

- ☐ Rates of change on individual sites are best determined by repeated sampling at some point in the future.
- ☐ To establish rates on change on rapidly changing sites, a resampling at 1 to 3 year intervals should be considered. Stable sites can be resampled on a 5 to 10 year basis or on an even longer cycle if there is no cause for concern and the sites appear stable (e.g. indigenous vegetation sites).

Replication

- ☐ With a replicated design there is a trade-off between understanding within treatment variability and the number of soil and land uses that can be investigated.
- ☐ A replicated plot (sample) design allows greater understanding of within treatment variability.
- ☐ A single plot (sample) representation allows different land uses to be compared on a broad scale, and for a wider-ranging survey to be completed.
- ☐ The single sample representation approach is preferred for a national monitoring programme.
- ☐ Regionally there is bias in the sampling because of the requirement for targeted sampling.
- ☐ Nationally some regions are not represented and the intensity of sampling has differed in participating regions.

From point samples to area

- ☐ Intensive point sampling needed to establish the variability across the landscape, and validate spatial extrapolation of point data, is beyond the scope of a broad national monitoring programme.

National data sets

- ☐ Information of soil fertility (Olsen P, pH, cations) and landscape characteristics (soil, slope, aspect, climate) is being collated by Landcare Research and AgResearch and will be useful to gauge the representitiveness of the 500 Soils data set.
- ☐ Landcare Research is mapping the locations of the 500 Soils sampling points to see how well each of the various land-use and soil-order combinations are represented.
- ☐ The locations of all of the 500 Soils sampling points have been located on a GIS layer to provide an indication of the spatial distribution of the current dataset regionally and nationally.

Matched sites

- ☐ The matched sites approach is no longer essential because a much stronger interpretative framework for each of the soil quality characteristics, specific to land use and soil groupings has been established.

Critical limits and target values

- ☐ The findings of the MfE workshops on soil quality are recommended as a basis for defining target values for soil properties.
- ☐ Further work is required to validate target values, refine the critical limits for both environment and production, possibly combining these to provide a single set of critical limits.

Other sampling depths

- ☐ A number of authors consider the soil condition below 10 cm , especially for cropping to be important. The practicalities of sampling below 10 cm on a broad scale study need to be considered.
- ☐ In many cases an examination of the soil profile and identification of limiting horizons may be adequate in the first instance.
- ☐ Forest litter thickness and the depth of the organic horizon are useful indicators of forest health and may warrant sampling. If sampled a sample quadrats method rather than cores should be used.

Modelling

- ☐ For national reporting, spatial modelling of soil quality characteristics should be investigated to derive soil quality status in non-sampled areas and predict the long-term effect of management practices on soil quality. Developing indices would assist sampling design by ensuring a representative coverage of management practices for a given land use are included in the NSQMP.

Cost estimates

- Based on the 500 Soils Project the estimated cost per site is $1155.
- Analysis of MfE SQ indicators (pH, bulk density and total C) instead of the 500 Soils indicators reduces the cost per site to $785.
- The value and “usability” gained from adopting the “500 Soils” soil quality indicators is greater than using a reduced set of soil quality indicators.

5 Recommendations for a national soil quality monitoring programme

The review sub-committee recommend that:

- The 500 Soils Project provides suitable methods and scientifically based criteria for an ongoing nation-wide but regionally based SQM programme.
- Although the review analyses indicate a combination of soil order and land use type provides the most useful stratification the sample requirements for stratification by land use type/soil order combinations is prohibitive (a magnitude greater than stratification using land use type and soil order weighting) and renders this approach impracticable
- The current data set is sufficient for reporting by six land use types but the finalising of land use types requires further attention.
- For each land use type the sampling should be weighted according to the area each Soil Order occupies nationally to provide a more accurate representation of Soil Order and land use type combinations.
- Sampling and analysis methods need to be standardised and documented to an agreed level of detail. To facilitate this nationally agreed guidelines should be developed.
- A national (but regionally accessible) centralised data management system, potentially including spatial data (GIS based) is required.
- A MfE (central government) co-ordinated approach is required to ensure continuous resource support and incentives for long term Regional Authority commitment to a national soil quality monitoring programme. Priorities should be to achieve full commitment to a soil quality monitoring programme from all Regional Authorities and move toward nationally agreed and adopted soil quality methodologies and outputs within a set timeframe.

6 References

Beare, M.H.,Williams, P.H., Cameron, K.C. 1999. On-farm monitoring of soil quality for sustainable crop production. In Best Management Pracrices for Production. (Eds L.D. Curirie, M.J. Hedley, D.J. Horne & P. Loganathan). Occasional report No. 12, Fertilizer and lime Research Centre,81–90. Palmerston North, Massey University.

Brejda, J.J., Moorman, T.B., Karlen, D.L., Dao, T.H. 2000a. Identification of regional soil quality factors and indicators: I. Central and southern high plains. *Soil Science Society of America Journal* 64, 2115–2124.

Brejda, J.J., Karlen, D.L., Smith, J.L., Allan, D.L. 2000b. Identification of regional soil quality factors and indicators: II. Northern Mississippi Loess Hills and Palouse Prairie. *Soil Science Society of America Journal* 64, 2125–2135.

Carter, M.R., Gregorich, E.G., Angers, D.A., Beare, M.H., Sparling, G.P., Wardle, D.A., Voroney, R.P. 1999. Interpretation of microbial biomass measurements for soil quality assessment in humid temperate regions. *Canadian Journal of Soil Science* 79 , 507-520.

Doran, J. W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A *Eds.* 1994. Defining Soil Quality for a Sustainable Environment. SSSA Special Publication Number 35, 244pp. Madison, Wisconsin, Soil Science Society of America, Inc.

Francis, G.S., Knight, T.L. 1993. Long-term effects of conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. *Soil and Tillage Research* 26, 193–210.

Francis, G.S., Tabley, F.J., White, K.M. 2001. Soil degradation under cropping and its influence on wheat yield on a weakly structured New Zealand silt loam. *Australian Journal of Soil Research* 39, 291–305.

Hewitt, A. E. 1998. New Zealand Soil Classification. *Landcare Research Science Series 1*. Lincoln, New Zealand, Manaaki Whenua Press.

Lee, R., Cornforth, I.S., Edmeades, D.C.,Watkinson, J.H. 1991. A comparative study of MAF (Ruakura) and DSIR Land Resources soil analyses results. *New Zealand Journal of Agricultural Research* 34, 227–233.

Schipper, L.A., Sparling, G.P. 2000. Performance of soil condition indicators across taxonomic groups and land uses. Soil Science Society of America Journal 64, 300–311.

Singleton, P.L., Boyes, M.,Addison, B. 2000. Effect of treading by dairy cattle on topsoil physical conditions for six contrasting soil types in Waikato and Northland, New Zealand, with implications for monitoring. *New Zealand Journal of Agricultural Research* 43, 559–567.

Smith D.G. 1990. A better water quality indexing system for rivers and streams. *Water Research* 24, 1237–1244.

Sojka, R.E., Horne, D.J., Ross, C.W.,Baker, C.J. 1997. Subsoiling and surface tillage effects on soil physical properties and forage oat stand and yield. *Soil & Tillage Research* 40, 125–144.

Sparling, G. P.,Roberts, A. H. C. 2001a: Interpretation of Taranaki region soil health data from the 500 Soils Project, 1998-2000. Landcare Research Contract Report LCR0001/080, Hamilton, Landcare Research.

Sparling, G. P., Roberts, A. H. C. 2001b: Interpretation of Environment B·O·P soil health data from the 500 Soils Project, 1998–2000. Landcare Research Contract Report LC0102/001, Hamilton, Landcare Research.

Sparling, G. S.; Tarbotton, I. 2000: Workshop on soil quality standards. 7-8 February 2000, Palmerston North. Final Report. Landcare Research Contract Report: LC9900/118. Hamilton, Landcare Research.

Sparling, G. S., Rijkse, W., Wilde, H., van der Weerden, T. J., Beare, M. H., Francis, G. S. 2000a. Implementing soil quality indicators for land: Research Report for 1998/1999. Landcare Research Contract Report: 9900/108, Hamilton, Landcare Research.

Sparling, G. P., Rijkse, W, Wilde, R. H., van der Weerden, T, Beare, M. H.,Francis, G. S. 2001. Implementing soil quality indicators for land. Research report for 1999/2000. Landcare Research Contract Report 0001/059, Hamilton, Landcare Research..

Sparling, G.P., Schipper, L.A., Hewitt, A.E., Degens, B.P. 2000b. Resistance to cropping pressure of two New Zealand soils with contrasting mineralogy. *Australian Journal of Soil Research* 38, 85–100.

Sparling, G.P., Shepherd, T.G., Schipper, L.A. 2000c. Topsoil characteristics of three contrasting New Zealand soils under four long-term land uses. *New Zealand Journal of Agricultural Research* 43, 569–583.

Tate, K.R., Speir, T.W., Ross, D.J., R.L., P., Whale, K.N.,Cowling, J.C. 1991a. Temporal variations in some plant and soil P pools in two pasture soils of widely different P fertility status. *Plant and Soil* 132, 219–232.

Tate, K.R., Ross, D.J., Ramsey, A.J.,Whale, K.N. 1991b. Microbial biomass and bacteria in two pasture soils: an assessment of measurement procedures, temporal variations, and the influence of P fertility status. *Plant and Soil* 132, 233–241.

Wander, M.M., Bollero, G.A. 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Science Society of America Journal* 63, 961–971.