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Trialing environmental performance indicators for arable soils on the Canterbury Plains

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Signposts for sustainability

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1 EXECUTIVE SUMMARY

- ? The project 'Trialing environmental performance indicators for arable soils on the Canterbury Plains' was jointly funded by the Canterbury Regional Council and the Ministry for the Environment. Crop & Food Research was contracted as the research provider.
- ? Soil samples were taken from 30 different paddocks across the Canterbury Plains. Three or four paddocks were sampled from each of eight soil types on the basis of their cropping history. Each paddock was assigned a cropping index number (a soil pressure indicator) based on the number of consecutive arable crops grown.
- ? Paddocks were chosen from the 120 paddocks that were originally sampled by Crop & Food Research in 1992/93, supplemented by additional paddocks on other soil types.
- ? Soil state indicators measured were organic carbon, microbial biomass carbon, anaerobically mineralisable nitrogen, aggregate size distribution, aggregate stability, cadmium and DDE.
- ? With the exception of cadmium and DDE, all indicators showed a similar trend of declining soil quality with increasing cropping index number (i.e. increasing soil pressure).
- ? Cadmium and DDE showed no obvious trend with cropping index number, but are an indication of soil contamination.
- ? There were few statistically significant relationships between soil state indicators and cropping index numbers. This was largely because of the high variability of many of the indicators, both within and between paddocks.
- ? The cropping index number is a very simple soil pressure indicator. The measured soil state indicators were not very well related to the cropping index number in its current form.
- ? The cropping index number may be a more useful soil pressure indicator if soil and crop management practices are included as well as cropping history.

- ? No clear trends are apparent in changes in soil state indicators between 1992 and 1998. This is partly due to changes in laboratory methods, time of sampling and soil variability.
- ? Of the soil state indicators measured in this project, aggregate stability appears to be the most promising for arable soils in Canterbury.
- ? Different sampling strategies are recommended in future work for improving the statistical relationships between cropping index number and soil state indicators.

2 TRIALING PERFORMANCE INDICATORS

2.1 Background

The project ‘Trialing environmental performance indicators for arable soils on the Canterbury Plains’ is a project jointly funded by the Canterbury Regional Council and the Ministry for the Environment. Crop & Food Research was contracted by the Canterbury Regional Council as the research provider.

The aims of this project were to:

- ? test the flexibility of recommendations for land from ? Chapter 4, Proposed land indicators? in *Environmental Performance Indicators (EPI Programme), Proposals for air, fresh water and land* (Ministry for the Environment 1997),
- ? test indicators selected by Canterbury Regional Council relevant to arable land,
- ? provide a practical example of the implementation of environmental performance indicators for soil intactness and soil health,
- ? provide a basis for regional and national State of the Environment monitoring and reporting, and
- ? become part of Canterbury Regional Council’s regional land monitoring programme.

The Stage 1 environmental performance indicators for land proposed by the Ministry for the Environment are presented in Table 1.

Table 1: Proposed Stage 1 indicators for land.

Soil intactness	Soil health
? Land use relative to land capability	? Land use relative to land capability
? Land use	? Soil acidity
? Land cover	? Organic carbon
? Extent and frequency of slipping	? Soil compaction
? Extent and frequency of water and surface erosion	? Nutrient budgets
	? Soil nutrient status
	? Fertiliser use

Only one of the proposed indicators for soil health (organic carbon) is included in the soil variables contracted for investigation in this project. This means that only limited testing of the proposed indicators can be made. This project will look mainly at the usefulness of the other measured variables as potential indicators, as the other proposed indicators were not considered relevant for arable soil quality monitoring.

Heavy metal concentrations (e.g. Cadmium) and pesticide concentrations (e.g. DDE) are potential stage 2 indicators for land contamination.

2.2 Selection criteria for 1992/93 sites

In 1992/93, staff from Crop & Food Research measured a number of soil quality parameters from 120 paddocks, located on 32 commercial mixed cropping farms, covering a range of important agricultural soil types across the Canterbury Plains. The farms were selected to represent the various types of mixed cropping farms found on the Canterbury Plains in terms of their location and soil type and land use history.

For each farm, paddocks were chosen with a range of cropping histories (varying periods of pasture or arable management) to allow a comparison of matched sites. A cropping index number was assigned to each paddock.

2.2.1 *Cropping index number*

The cropping index number concept was initially proposed by Haynes et al. (1991) and modified by Haynes et al. (1995) and Fraser et al. (1996). The cropping index is a simple eight point scale that is based on the cropping history of a particular paddock in the past 10 years (Table 2). The number assigned is based on the number of consecutive years that a paddock has been under arable or pastoral use immediately prior to sampling.

Table 2: Cropping index number definitions.

Cropping index number	Cropping history
1	>9 years pasture
2	6-9 years pasture
3	3-6 years pasture
4	0-3 years pasture
5	0-3 years arable
6	3-6 years arable
7	6-9 years arable
8	>9 years arable

In this system, pasture includes both grazed ryegrass/white clover pastures and seed crops of ryegrass and/or white clover.

Previous studies (Haynes et al. 1991; Haynes et al. 1995; Fraser et al. 1996) have shown that statistically significant relationships exist between cropping index number (a pressure variable) and a range of soil properties (state variables) for a number of soil types. Significant relationships have been established between cropping index number and, amongst others, microbial biomass carbon and aggregate stability. These soil properties have been proposed as suitable indicators of soil health (Cameron et al. 1997; Sparling & Schipper 1998).

Previous research in New Zealand has shown that many soil properties deteriorate with increasing time under arable cropping and improve with increasing time under pastures (Francis & Kemp 1990; Haynes & Francis 1990; Francis & Knight 1993; Haynes & Francis 1993; Francis et al. 1994; Francis et al. 1997). Cropping index number may, therefore, be a simple but useful pressure indicator of land use. In its current form, the cropping index number implicitly assumes that soil conditions (or soil health) improve with increasing time under pasture. Contrasting pastoral management practices are not considered and no account is made for varying land use pressures (e.g. varying stocking rate) under pastoral management.

Similarly, under cropping no consideration is made for different management practices (e.g. cultivation type, cropping intensity, fertiliser rates, irrigation, residue management, etc.). Nevertheless, past research results show that cropping index number can be a useful measure of land use pressure.

2.3 Selection criteria for 1998 sites

Because of budgetary constraints, only 30 sites were analysed in this 1998 project. Criteria for site selection were established after discussion with staff from the Canterbury Regional Council in March 1998. The criteria were:

- ? samples were to be taken from eight soil types included in the original 1992/93 survey,
- ? the cropping index numbers of the sampled paddocks had to cover the range 4-8,
- ? there had to be at least one common cropping index number for all soil types,
- ? where possible, samples were to be taken from the same paddocks used in the original survey,
- ? where specific soil type/cropping index number combinations did not exist, new paddocks were to be sampled. Where possible, these new paddocks were to be from farms involved in other ? Landcare? groups.

All farmers from the original 1992/93 survey were telephoned, and cropping histories were updated for their relevant paddocks. From this information a proposed sampling strategy was developed and sent to the Canterbury Regional Council for comment. Paddocks that were sampled in 1992/93 and 1998 are presented in Appendices I and II.

2.4 Soil sampling

Four sampling positions were randomly selected in each paddock, away from fence-lines, gates, etc. At each sampling position soil was carefully removed with a spade from a pit 25 cm x 25 cm in area, to a depth of 15 cm.

This sampling strategy contrasted with that used by Sparling & Schipper (1998). It was adopted, following discussion with Canterbury Regional Council staff, because the aggregate size distribution analysis requires a large, relatively undisturbed sample of soil. At each location a percussion auger (5.6 cm in diameter x 15 cm deep) was used to collect a sample for bulk density determination.

After discussion with staff from the Canterbury Regional Council, the depth of soil sampling was set at 15 cm. This depth of sampling was chosen as it is the depth of cultivation commonly used in Canterbury. Large amounts of historical data (especially that collected by farmers) have also been measured at 15 cm sampling depth.

All samples were stored at 4°C until ready for processing. Individual soil pit samples were carefully mixed to avoid breaking aggregates and then subsamples were randomly removed for aggregate size distribution and DDE analysis. From another subsample, 2-4 mm diameter aggregates were removed by dry sieving and were air-dried at 30°C for aggregate stability determination. Aggregates <2 mm diameter were also collected and stored at 4°C for microbial biomass carbon and anaerobically mineralisable nitrogen analysis. Other samples of aggregates <2 mm diameter were air-dried for organic carbon analysis and finely-ground for cadmium analysis.

2.5 Analytical methods

Standard analytical methods were used for all the indicators measured. Where appropriate, methods followed were those used by Sparling & Schipper (1998).

2.5.1 *Organic carbon*

Organic carbon was determined on single 0.4 g soil samples by an automated dry combustion (or Dumas) method using a LECO CNS-2000 machine operating at 1050° C (McGill & Figueiredo 1993).

2.5.2 *Microbial biomass carbon*

Microbial biomass carbon was determined by the fumigation-extraction method (Vance et al. 1987). In this method, soil was pre-incubated for 7 days at a moisture potential of about -5 kPa at 25° C, before fumigation with chloroform for 24 h. Both fumigated and non-fumigated soil (50 g field moist) was extracted with 0.5 M K₂SO₄ (200 cm³) before the soluble organic carbon content of the extract was determined by wet oxidation. Microbial biomass carbon content was determined using a k_{ec} factor of 0.35 to compensate for incomplete extraction (Sparling & West 1988; Tate et al. 1988).

2.5.3 *Anaerobically mineralisable nitrogen*

Anaerobically mineralisable nitrogen was determined following incubation of soil under waterlogged conditions at 40° C for seven days (Keeney 1982). In this method, 5 g of soil was extracted with 50 cm³ of 2 M KCl. Nitrogen in the extracts was measured using an auto analyser technique.

2.5.4 *Aggregate size distribution*

Aggregate size distribution was determined using a dry-sieve method (White 1993). Samples of field moist soil (approx. 1 kg) were dried overnight at 30° C and then shaken on a nest of eight sieves for 10 minutes. The diameters of the sieves used were 19.0, 13.2, 9.5, 4.0, 2.0, 1.0, 0.5 and 0.25 mm.

The soil remaining on each sieve was weighed and the aggregate size distribution expressed as a mean weight diameter (MWD):

$$\text{MWD} = \sum_{i=1}^n x_i w_i$$

Where: X_i = mean diameter of adjacent sieves

W_i = proportion of total sample retained on sieve

In this analysis, the upper size limit for aggregates was determined by measuring the diameter of the largest aggregate remaining on the largest (19.0 mm diameter) sieve.

2.5.5 Aggregate stability

Aggregate stability was determined using a wet-sieving method (Kemper & Roseneau 1986). Samples of air-dried soil (50 g) 2-4 mm in diameter were sieved underwater for 20 minutes on nest of sieves (2.0, 1.0 and 0.5 mm diameter). The soil remaining on each sieve was weighed after oven drying at 105° C. The aggregate stability was expressed as a mean weight diameter (see Section 2.5.4).

2.5.6 Cadmium

Cadmium analyses were subcontracted to Soil Fertility Services in Hamilton. Soil samples were digested in perchloric and nitric acid (Gorsuch 1959). Cadmium was determined in the digest by atomic absorption spectrophotometry using a graphite furnace, with a detection limit of 0.01 µg Cd/g soil.

2.5.7 DDE

DDE analyses were subcontracted to the Plant Protection Research Unit, Lincoln Ventures. DDE analyses were performed using a Varian 3400 gas chromatograph based on the PPRU/SOP 4.04 method, with a detection limit of 0.01 µg DDE/g soil.

2.5.8 Bulk density

Soil collected using the percussion auger (volume of 369 cm³) was oven-dried (105° C) overnight and weighed. Soil bulk density was calculated from the soil weight and auger volume. Bulk density was not included in this project as an indicator, but was used to express collected data on a volumetric basis where appropriate.

2.5.9 Statistical and graphical analyses

Box-and-whisker plots contain data averaged over all soil types for each cropping index number. These plots show median values, upper and lower quartiles, median values 1.5 times the interquartile range (i.e. the whiskers) and outlying data points.

In this study, formal statistical analyses cannot separate the farmer and soil effect as there was only one farmer sampled for each cropping index number and soil type combination. However, past work with greater numbers of paddocks per soil type and per cropping index has shown a consistent trend in soil indicator values with cropping index number across soil types (Haynes et al. 1991). Therefore, much of the inconsistency in cropping index number pattern can be attributed to farmer to farmer differences. This is apparent for the Wakanui soil in Figure 2, for example, where organic carbon decreases with cropping index number within both farms, but increases with cropping index number between Farmer 1 and Farmer 2.

Thus, approximate and conservative tests of patterns in cropping index numbers can be made by assuming soil to soil differences are predominantly composed of farmer to farmer differences. These tests (presented in Table 5) are made by comparing between cropping index numbers using paddock to paddock variability not adjusted for soil type. The LSDs for these comparisons are artificially large because soil type differences could be masking any cropping index number and/or soil type/cropping index number interactions (The LSDs in Table 5 are means of the LSDs for all possible comparisons).

An alternative approach would be to use within paddock variability. However, although multiple samples were taken from each paddock, they are not true replicates as only one paddock was sampled for each combination of soil type and cropping index number. As such, no formal statistics comparing cropping index number and/or soil type apply. Using within paddock variability would give excessively optimistic tests as experience indicates that between paddock variability is greater than within paddock variability. This was reflected in the much greater between field than within field variability found in the analyses described above. Because of this, it is not possible to obtain a formal statistical comparison between soil types.

3 RESULTS

3.1 Sites sampled

The list of sampled sites is presented in Table 3. The cropping history for each sampled site is presented in Appendix III.

Table 3: Soil types sampled, their locality, farmer paddock label and cropping index numbers in 1998 and 1992/93.

Soil type	Locality	Farmer paddock label	1998 cropping index number	1992/93 cropping index number
Templeton silt loam	Dunsandel	2	4	5
Templeton silt loam	Dunsandel	10	5	4
Templeton silt loam	Dorie	Jb	6	2
Templeton silt loam	Dorie	J2	7	-
Wakanui silt loam	Leeston	Wf	4	-
Wakanui silt loam	Leeston	We	5	-
Wakanui silt loam	Lincoln	SFT	6	-
Wakanui silt loam	Lincoln	RC	8	-
Mayfield silt loam	Lyndhurst	8	6	5
Mayfield silt loam	Lyndhurst	9	7	5
Mayfield silt loam	Lyndhurst	10	8	6
Mayfield silt loam	Methven	F	5	-
Barrhill fine sandy loam	Barrhill	B	4	6
Barrhill fine sandy loam	Barrhill	Y	8	6
Barrhill fine sandy loam	Mitcham	Y	5	4
Barrhill fine sandy loam	Mitcham	A	6	5
Hatfield silt loam	Courtenay	P1	5	4
Hatfield silt loam	Kirwee	J	7	6
Hatfield silt loam	Kirwee	Q	8	8
Lismore silt loam	Aylesbury	A	4	8
Lismore silt loam	Aylesbury	P	8	8
Lismore silt loam	Charing Cross	C	5	-
Lismore silt loam	Charing Cross	G	6	3
Highbank silt loam	Highbank	HH	4	4
Highbank silt loam	Highbank	U	5	5
Highbank silt loam	Highbank	E	6	3
Highbank silt loam	Highbank	CA	7	5
Lyndhurst silt loam	Annat	4845	5	6
Lyndhurst silt loam	Annat	J	8	6
Lyndhurst silt loam	Waddington	EE	6	3

3.2 Within site variability

The within site variability of the indicators over all soil types and cropping index numbers was calculated as the coefficient of variation (CV%):

$$\text{CV\%} = \frac{\text{standard deviation} \times 100\%}{\text{mean}}$$

where the standard deviation is for samples within a paddock (Table 4). The coefficients of variation for the indicators ranged from 5.4% to 44.0%.

Sparling & Schipper (1998) consider soil parameters with CVs of less than 15% to be sufficiently accurate to obtain reliable measurements of most soils. From Table 4, it is clear that only organic carbon, cadmium, aggregate stability and bulk density have CVs less than 15%. The CVs associated with biochemical indicators were higher than those reported by Sparling & Schipper (1998) for mainly uncultivated soils, possibly because of the heterogeneous conditions that exist in cultivated soils. There was high variability associated with measurements of DDE (34.3%) and aggregate size distribution (44.0%). In general, the usefulness of any soil parameter as an indicator of soil health or soil quality declines as its variability increases.

Table 4: Coefficients of variation for measured soil indicators in 1998 and 1992 over all soil types and cropping index numbers.

Soil indicator	CV%	
	1998	1992
Organic carbon	5.4	5.8
Microbial biomass carbon	20.6	16.3
Anaerobically mineralisable nitrogen	32.2	
Aggregate size distribution	44.0	
Aggregate stability	14.7	
Cadmium	11.2	
DDE	34.9	
Bulk density	8.2	

3.3 Performance indicators

All experimental results are presented in Appendix IV. Results for all the measured indicators are presented in a similar fashion.

3.3.1 Organic carbon

Organic carbon contents measured over all soil types showed a trend towards greatest values in soil with a cropping index number of 4 and least values in soil with cropping index numbers of 7 and 8. However, analysis of variance of the data (as described in 2.5.9, Table 5) shows there is no significant difference in organic carbon content between soils with different cropping index numbers.

The reason why there is no significant relationship between cropping index number and organic carbon content is apparent in Figure 1. This box-and-whisker plot shows the high variability of organic carbon contents in soils with the same cropping index number. Due to the variability of the results, no simple trend is apparent for the effect of cropping index number on organic carbon content.

Table 5: Mean and LSD values for soil indicators classified by cropping index number.

Indicator	Cropping index number					Mean LSD (df=25)
	4	5	6	7	8	
Organic carbon (mg/cm ³)	33.5	31.6	32.0	29.0	30.1	5.02
Microbial biomass carbon (? g/cm ³)	531	433	489	425	426	170.8
Anaerobically mineralisable nitrogen (? g/cm ³)	44.2	36.0	37.5	28.9	31.3	13.68
Aggregate size distribution (mm)	12.8	11.6	10.6	9.9	9.7	6.4
Aggregate stability (MWD; mm)	2.06	1.80	1.84	1.50	1.53	0.694
Cadmium (? g/g)	0.15	0.14	0.14	0.16	0.14	0.054
DDE (? g/g)	0.30	0.17	0.10	0.19	0.12	0.130
Number of paddocks	5	8	7	3	7	

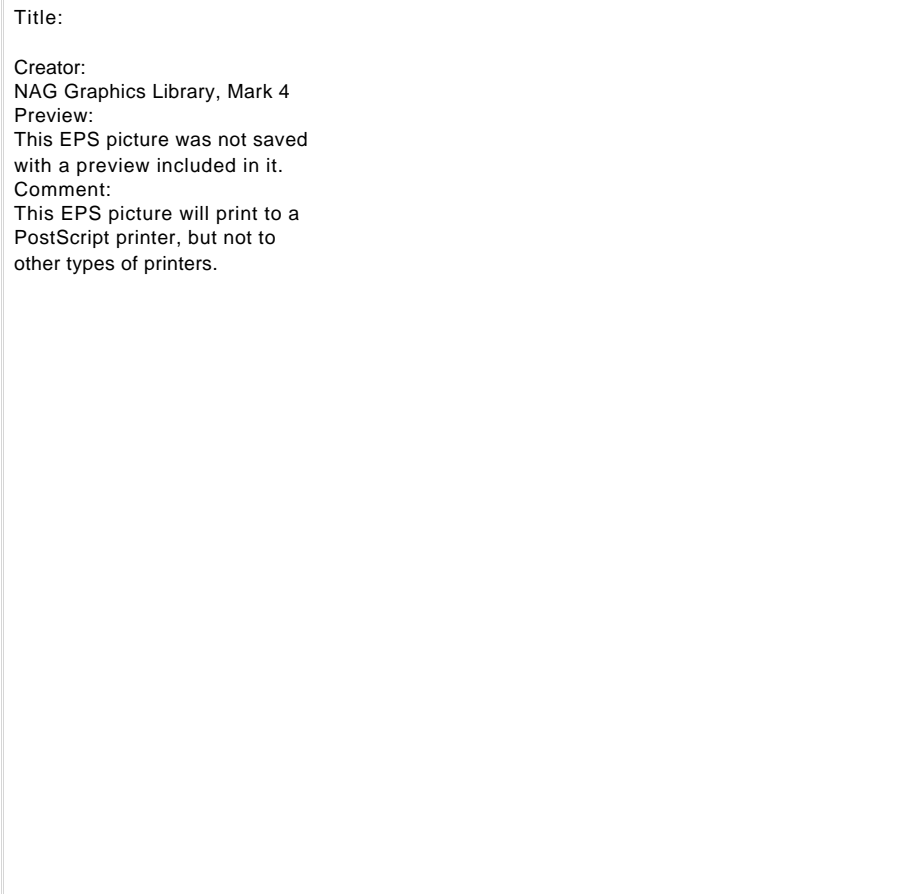


Figure 1: Box-and-whisker plots showing the effect of cropping index number on organic carbon content, averaged over all soil types. Horizontal lines within the boxes represent the median values, the ends of the boxes represent the upper and lower quartiles and the whiskers represent either the median values ± 1.5 times the interquartile range, or the limit of the data spread.

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Figure 2: Effect of cropping index number on organic carbon content classified by farmer and soil type. For each soil type, different symbols represent different farmers. The data plotted at each cropping index number are for the four replicate samples taken from each paddock.

In Figure 1, results for each cropping index number are meaned over all farmers and soil types. In this project it is not possible to statistically separate the farmer and soil effects (see Section 2.5.9).

In Figure 2, the effect of cropping index number on organic carbon content is classified by farmer and soil type. For each soil type, different farmers are represented by different symbols. Figure 2 helps to explain why no simple trend is apparent in organic carbon content due to cropping index number. In the Wakanui soil, for example, for both Farmers 1 and 2, organic carbon content declines with increasing cropping index number. However, there is an inconsistency in organic carbon contents between Farmers (i.e. there is an increase in organic carbon content between cropping index numbers 5 and 6). We suggest that this increase may be a reflection of different soil and crop management practices on the two farms. This is a result of the simple nature of the cropping index number and is discussed in Section 4.2. For many of the soil types, similar patterns are apparent for individual farmers; organic carbon contents decline with increasing cropping index numbers.

3.3.2 *Microbial biomass carbon*

Microbial biomass carbon contents meaned over soil type showed a similar trend to organic carbon contents (Table 5). Mean microbial biomass carbon contents were greatest in soil with a cropping index number of 4 and least in soil with cropping index numbers of 7 and 8. These values are similar to those found in the previous study (Fraser et al. 1996). However, analysis of variance of the data shows there is no significant difference in the microbial biomass carbon content of soils with different cropping index numbers (Table 5). This is due to the high within paddock variability (Table 4) and soil type/soil management/farmer effects associated with microbial biomass carbon measurements.

The effect of cropping index number on microbial biomass C for individual farms and soil types is shown in Figure 4. On this basis there do not appear to be any clear trends. On some farms, microbial biomass increased as cropping index increased, but on other farms there was a decrease. For example, on the Barrhill soil, microbial biomass increased on Farm 1 between cropping index 5 and 6. However, on Farm 2, the microbial biomass C decreased between cropping index 4 and 8. The measure of soil microbial biomass C reflects the size of the microbiological population and the rapidly cycling soil organic matter. It is sensitive to changes in soil and crop management (Fraser et al., 1996) which may influence its activity more than simply cropping history.

3.3.3 *Anaerobically mineralisable nitrogen*

Anaerobically mineralisable nitrogen contents meaned over soil type were all $< 80 \text{ g N/cm}^3$ (Table 5), which is similar to the range for cropping soils reported by Sparling & Schipper (1998). Anaerobically mineralisable nitrogen contents were greatest in soil with a cropping index number of 4 and smallest in soil with cropping index numbers of 7 and 8 (Table 5).

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Figure 3: Box-and-whisker plots showing the effect of cropping index number on microbial biomass carbon content averaged over all soil types. See legend in Figure 1 for further detail.

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Figure 4: Effect of cropping index number on microbial biomass carbon content classified by farmer and soil type. See legend in Figure 2 for further details.

The difference between soil with a cropping index number of 4 and soil with a cropping index number of 7 was statistically significant ($P < 0.05$). Such a trend is expected as anaerobically mineralisable nitrogen is a measure of the amount of soil organic nitrogen that has the potential to be mineralised to a plant available form. It is related to both soil organic matter quantity and quality and so is higher under pasture than with arable land use (Sparling & Schipper 1998). None-the-less, this indicator has a high variability, as shown by the high CV (CV = 32%, Table 4), and the box-and-whisker plot (Fig. 5).

On the individual farms there is no clear trend between anaerobically mineralisable nitrogen and cropping index number (Fig. 6). Using the Wakanui soil as an example, on farm 2 the anaerobically mineralisable nitrogen decreased from cropping index 4 to 5, but on farm 1 it was similar between cropping index 6 and 8. As for the measurements of microbial biomass carbon, there is a high variability associated with the measurement of anaerobically mineralisable nitrogen that may be affected more by short-term changes in crop and soil management than by cropping history.



Figure 5: Box-and-whisker plots showing the effect of cropping index number on anaerobically mineralisable nitrogen averaged over all soil types. See legend in Figure 1 for further details.

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Figure 6: Effect of cropping index number on anaerobically mineralisable nitrogen classified by farmer and soil type. See legend in Figure 2 for further details.

3.3.4 *Aggregate size distribution*

Aggregate size distribution meaned over soil type ranged from 12.8 mm for soil with a cropping index of 4 to 9.7 mm for soil with a cropping index 8 (Table 5). This shows that as length of time under cropping increased, particle size becomes smaller and the potential for soil loss by erosion increases. However, there was no significant relationship between cropping index number and aggregate size distribution (Table 5). Indeed, the box-and-whisker plots show that there was a very large range of sizes for each cropping index number (Fig. 7). The within site variability for this indicator was higher than for any other indicator (CV = 44%; Table 4) and the between site variability (i.e. LSD relative to means, see Table 5) was also large, so the trend in Table 5 was not significant. Figure 8 also shows the large range in aggregate size distribution between replicates collected from the same field.

The data in Figure 8 allow us to compare the effect of cropping index number on aggregate size distribution for each farm and soil type. Overall, no clear trends are evident, except that there is a large variability between farms. For example, comparing the aggregate size distribution at cropping index 6 with cropping index 8 shows an increase for Farmer 1 on the Templeton soil and a decrease for Farmer 1 on the Wakanui soil. The method of cultivation and the time elapsed since the last cultivation are likely to influence aggregate size distribution and may help to explain the variability between farms. Cultivation effects are not accounted for in the cropping index number used in this study.

3.3.5 *Aggregate stability*

Aggregate stability is a measure of how stable soil aggregates are when they are shaken in water. Soils with good structural stability generally have an aggregate stability value of 2-3 mm, while soils with poor stability have a value <1.5 mm (Haynes & Francis 1990). In this study, mean aggregate stability values were greatest for soil with a cropping index number of 4 and least for soil with cropping index numbers of 7 and 8 (Table 5).

Such a trend is expected as aggregate stability increases under pasture due to the production of carbohydrates, which bind soil particles into stable aggregates, by the large population of soil micro-organisms (Haynes et al. 1991). As the length of time under arable cropping increases, the organic matter returns to the soil and the production of binding carbohydrates by the soil micro-organisms decreases. In turn, the decline in binding carbohydrate production results in a decline in aggregate stability. There was a large variability in aggregate stability values as individual values ranged from about 0.5 to 2.7 mm (Fig. 9).

The effect of cropping index number on aggregate stability, classified by farmer and soil type, is shown in Figure 10. For most farms there is a clear downward trend in aggregate stability as cropping index increases. Notable exceptions to this trend are the Lismore soil Farmer 1 and Wakanui soil Farmer 1. On these farms there may be other factors influencing aggregate stability (e.g. cultivation method, crop residue management) rather than cropping history alone.



Figure 7: Box-and-whisker plots showing the effect of cropping index number on aggregate size distribution, averaged over all soil types. See legend in Figure 1 for further details.

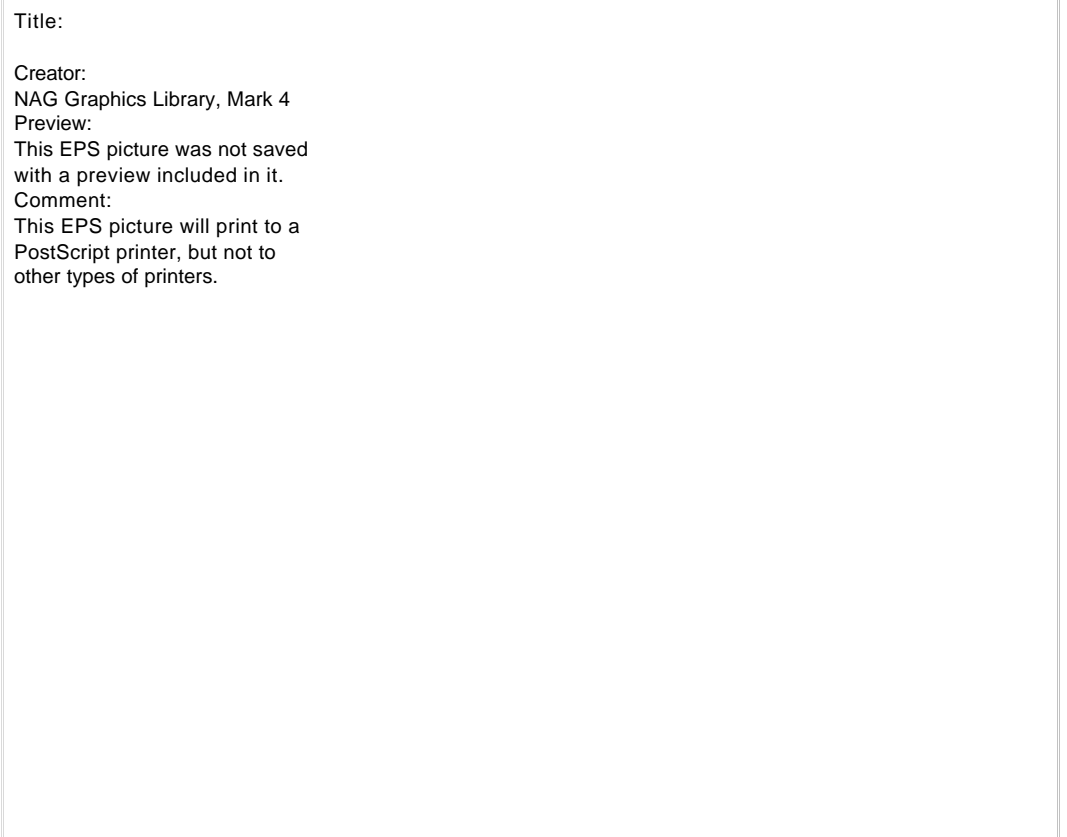


Figure 8: Effect of cropping index number on aggregate size distribution classified by farmer and soil type. See legend in Figure 2 for further details.

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Figure 9: Box-and-whisker plots showing the effect of cropping index number on aggregate stability, averaged over all soil types. See legend in Figure 1 for further details.

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Figure 10: Effect of cropping index number on aggregate stability, classified by farmer and soil type. See legend in Figure 2 for further details.

3.3.6 Cadmium

Mean cadmium values ranged from 0.14 to 0.16 $\mu\text{g Cd/g}$ (Table 5). There does not appear to be any trend between cadmium and cropping number index (Fig. 11, Table 5). As an indicator, cadmium is not particularly variable so replication of each site had a relatively low coefficient of variation (CV = 11.2%; Table 4). However, there was quite a lot of variability between some farms as shown in Figures 11 and 12. For example, there is a large difference in cadmium content between Farmer 1 and 2 on the Templeton and Mayfield soils. Total variability in cadmium content decreases with increasing cropping index number.

In New Zealand, the cadmium content of the soil is strongly influenced by the amount of phosphorus fertiliser applied, particularly superphosphate. Historically, the superphosphate manufactured in New Zealand had a high cadmium content and the cadmium has accumulated in agricultural soils over time (Williams 1992; Roberts et al. 1996). The range in cadmium content between farmers shown in Figure 12 probably reflects fertiliser history rather than cropping history.

There is little published information on soil cadmium levels with which to compare these values. Roberts et al. (1996) measured the cadmium concentration in the 0-75 mm depth of pastoral soils throughout New Zealand. They found that values ranged from 0.12-0.22 $\mu\text{g Cd/g}$ in the soils that were similar to those in our study (alluvial, yellow grey and yellow brown earths) to 0.70 $\mu\text{g Cd/g}$ in yellow brown loams. The mean value across New Zealand soils was 0.44 $\mu\text{g Cd/g}$. Our values appear to be at the low end of this range but we sampled the soil to a depth of 150 mm and there is likely to be a dilution of the surface applied cadmium by mixing through the plough layer during cultivation (Roberts et al. 1994). None-the-less, cadmium contents measured in this project were low compared to other countries where studies have been published (Roberts et al. 1994).

3.3.7 DDE

Application of the organochlorine insecticide DDT to control grass grub and porina during 1940-70 resulted in the build up of residues (mainly DDE) in the soil which are still present today (Roberts et al. 1996). Mean DDE contents were significantly greatest ($P < 0.05$) in soil with cropping index number 4 and least in soil with cropping index number 6 (Table 5). The variability of the DDE contents is shown in Figure 13. These values are lower than those measured by Boul et al. (1994) in long-term pasture from the Winchmore Irrigation Research Station. DDE concentration is relatively constant over 150 mm depth (Boul et al. 1994), so it is likely that the lower DDE concentrations in cropping soil is a result of lower amounts of DDT applications than in long-term pastoral soils.

The pattern of DDE varied between farms and between paddocks on farms with no obvious relationship to cropping index number (Fig. 14). For example, on the Highbank soil DDE decreased on farm 2 between cropping index 4 and 5, but increased on farm 1 between cropping index 6 and 7. This lack of a consistent trend is not surprising as the DDE content of the soil is strongly influenced by DDT use during the 1940-70 period (Roberts et al. 1996) rather than crop history over the last 10 years.

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Figure 11: Box-and-whisker plots showing the effect of cropping index number on cadmium content, averaged over all soil types. See legend in Figure 1 for further details.

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Figure 12: Effect of cropping index number on cadmium content, classified by farmer and soil type. See legend in Figure 1 for further details.



Figure 13: Box-and-whisker plots showing the effect of cropping index number on DDE content, averaged over all soil types. See legend in Figure 1 for further details.

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Figure 14: Effect of cropping index number on DDE content, classified by farmer and soil type. See legend in Figure 2 for further details.

3.4 Comparison of 1992 and 1998 indicators

Of the indicators measured in 1998, only organic carbon and microbial biomass carbon were measured in 1992. Box-and-whisker plots for organic carbon for the paddocks measured in 1992 and 1998 are shown in Figure 15. As bulk density data for 1992 are not available, data in Figure 15 are presented on a gravimetric basis. This contrasts with Figure 1 where organic carbon is presented on a volumetric basis. Although samples were taken from the same paddocks in 1992 and 1998, the sampling sites within each paddock were not marked in 1992. Consequently, soil variability within the sampled paddocks may explain some of the differences in results between sampling occasions. In addition, in 1992 samples were collected in the spring, whereas in 1998 samples were collected in the autumn of a year with a severe drought. This difference in timing of sample collection is unlikely to be important for organic carbon results, but may be significant for microbial biomass carbon results.

It is also important to note that in 1992 organic carbon content was measured by a wet oxidation (Walkley-Black) method, whereas in 1998 it was measured by an automated dry combustion (Dumas) method. The use of two different laboratory methods could have resulted in small, but consistent differences between the two sampling occasions. This effect could be checked by re-analysing the archived 1992 soil samples using the automated dry combustion method. In 1992 there appears to be little correlation between cropping index number and organic carbon. As discussed in Section 3.3.1 there was no statistical difference between organic carbon values in 1998 either, although there is a trend towards lower organic carbon as cropping index increases.

In Figure 16, the organic carbon data for both years are presented on a soil type and individual farmer basis. Despite the differences in laboratory methods used in each year, this figure shows that changes in organic matter content have varied between farmers regardless of soil type and cropping index. While changes have occurred in many fields the change does not appear to be related to cropping history but to other factors. These factors are likely to include soil variability and sampling time effects (see above), as well as cultivation techniques, crop residue management and crop yields.

Box-and-whisker plots for microbial biomass carbon are presented in Figure 17 for 1992 and 1998. Median values for each cropping number index are similar in both years. As for 1998 (Section 3.3.2) there does not appear to be a clear trend between cropping index number and microbial biomass carbon in 1992.

A comparison of the changes in microbial biomass carbon for individual farms between 1992 and 1998 is shown in Figure 18. While microbial biomass carbon values have increased on some fields, on others they have decreased. Such changes are not related to changes in cropping index number between 1992 and 1998. Instead the changes are likely to be influenced by short-term changes in crop and soil management (see Section 3.3.2).



Figure 15: Box-and-whisker plots showing the effect of cropping index number on organic carbon content, averaged over all soil types for paddocks sampled in both 1992 and 1998. See legend in Figure 1 for further details.

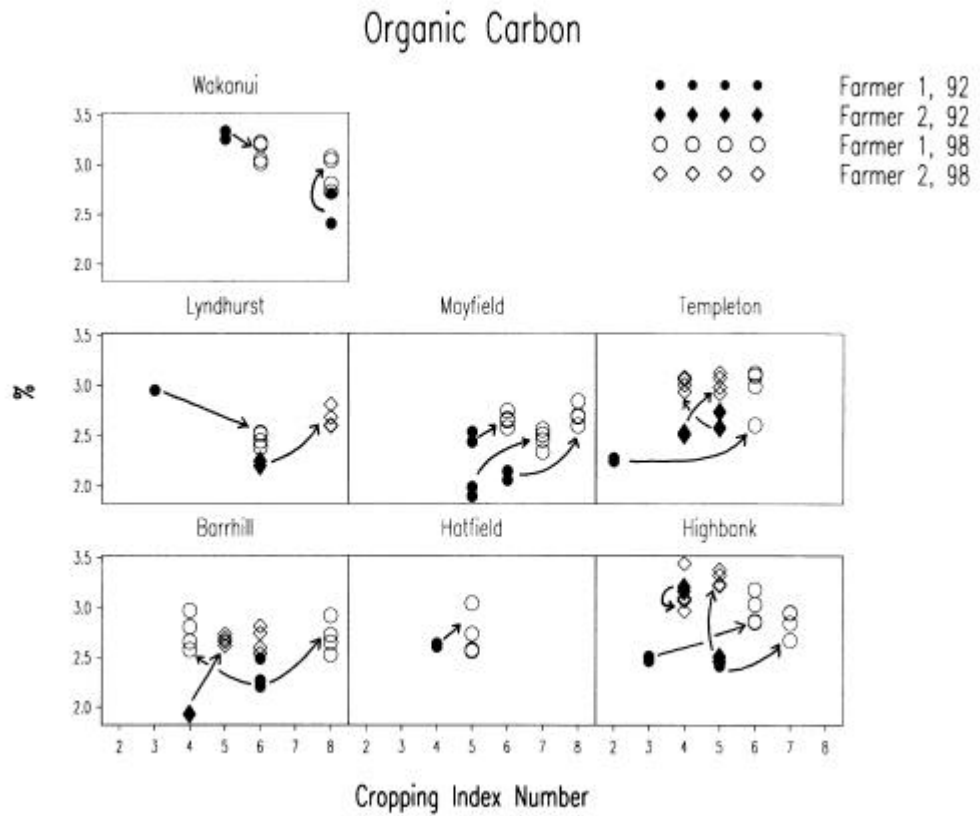


Figure 16: Effect of cropping index number on organic carbon content for all paddocks sampled in both 1992 and 1998, classified by farmer and soil type. Arrows indicate changes between 1992 and 1998. See legend in Figure 2 for further details.

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Figure 17: Box-and-whisker plots showing the effect of a cropping index number on microbial biomass carbon content, averaged over all soil types for paddocks sampled in both 1992 and 1998. See legend in Figure 1 for further details.

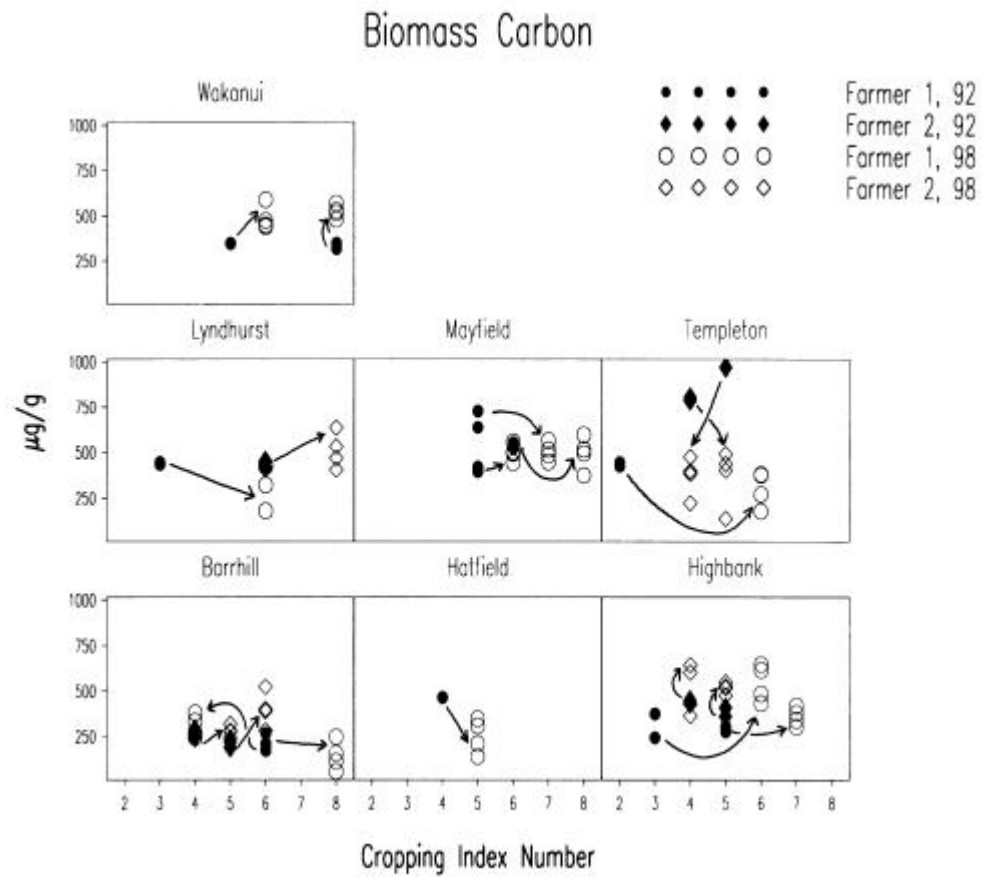


Figure 18: Effect of cropping index number on microbial biomass carbon content for all paddocks sampled in both 1992 and 1998, classified by farmer and sil type. Arrows indicate changes between 1992 and 1998. See legend in Figure 2 for further details.

4 USEFULNESS OF TRIALED ENVIRONMENTAL PERFORMANCE INDICATORS

4.1 To determine trends in soil health under arable land use

Little research has been reported for New Zealand on the effect of land use on soil health. Nevertheless, previous work has reported significant effects of land use on soil quality when very large ranges in land use are studied. Differences have been reported between long-term cropped and long-term arable soils (Haynes et al 1995; Fraser et al 1996) and between forest and pastoral sites (Sparling & Schipper, 1998). In contrast, this study covered a relatively narrow range of land uses, with a limited number of paddocks.

The results obtained in this study were generally in good agreement with those reported by Sparling & Schipper (1998) even though slightly different sampling techniques were used. The sampling technique used in this study was used in order to obtain samples for aggregate size distribution analysis, but appeared to result in higher CVs than in the Sparling & Schipper (1998) study.

With the exception of cadmium and DDE contents, all the indicators trialed showed similar trends of reduced values with increasing cropping index number. In this study, we attempted to statistically analyse the effect of cropping index number on soil quality indicators. As presented in Section 3, there were very few statistically significant differences in soil indicators between cropping history numbers. One of the reasons for this is the high variability in soil indicators both within fields (Table 4) and between fields (see Box-and-whisker plots). As discussed in Section 2.5.9, because we could not separate the soil type and farmer differences, we used very conservative LSDs for comparing between cropping index numbers.

In future studies we would recommend different sampling strategies where soil type and farmer differences could be statistically separated. This would involve sampling more than one farmer at each cropping index number/soil type combination and taking more samples (spanning a range of cropping index numbers) from each farm.

With the exception of cadmium and DDE, all indicators showed potential for use as soil quality indicators. However, revised sampling strategies are needed in order to obtain significant relationships between land use (or cropping index number) and soil quality. However, cadmium and DDE are useful indicators of soil contamination.

4.1.1 *Organic carbon*

Organic carbon is a measure of organic matter in the soil. Since soil organic matter is important for many aspects of soil quality (formation and stabilisation of soil structure, source of plant nutrients, water holding capacity etc.), it would seem to be a good indicator (Cameron et al. 1997). Other studies have shown that organic carbon is strongly influenced by land use (Haynes et al. 1991; Sparling & Schipper 1998) but it did not appear to be influenced by the narrow range of land uses in this study. Under continuous arable cropping there may be short term changes in some forms of soil organic matter which the total organic carbon test is not sensitive enough to detect.

4.1.2 *Microbial biomass carbon*

We hoped that the microbial biomass carbon would provide a more sensitive measure of short term changes in organic matter content. Indeed, there was a greater relative decline in microbial biomass carbon than in organic carbon as cropping index number increased. However, the greater variability in microbial biomass than organic carbon measurements in this study reduced the value of the microbial biomass carbon indicator.

4.1.3 *Anaerobically mineralisable nitrogen*

As for microbial biomass carbon, we had hoped that anaerobically mineralisable nitrogen would be a sensitive measure of short-term changes in soil organic matter quantity and quality. Anaerobically mineralisable nitrogen showed greater changes in relation to cropping index number than microbial biomass carbon, but it was also more variable. There was no simple correlation between microbial biomass carbon and anaerobically mineralisable nitrogen data.

4.1.4 *Aggregate size distribution*

Aggregate size distribution showed a consistent trend with cropping index number. However, the very large variability associated with this indicator suggests it may be of limited value in determining the quality trends.

4.1.5 *Aggregate stability*

Aggregate stability appears to be a promising indicator for arable land. A previous study showed that there is a correlation between aggregate stability and cropping index number on a range of soils (Haynes et al. 1991). This trend was also apparent in this study although it was not statistically significant. It is likely that this relationship was impaired by a lack of replication.

4.1.6 *Cadmium*

Despite the low variability, soil cadmium content is very dependent on the use of phosphate fertilisers. Currently, phosphorus is not a limitation to arable crop production and so the rates of phosphate fertiliser applied to the main arable crops are relatively low. Furthermore, the fertiliser companies have undertaken to reduce the cadmium content of fertiliser.

So, in the future, the rate of accumulation of cadmium in soils used for arable crops is likely to be low. Overall, cadmium content appears to be a rather insensitive indicator of soil quality. Nevertheless, cadmium is an important indicator of soil contamination trends.

4.1.7 DDE

DDE content showed no consistent trend with cropping index number. As discussed in Section 3.3.7, this is not surprising as DDE content is largely a reflection of DDT use during 1940-70. Measuring DDE could be useful for measuring trends in DDE concentrations, especially with improved sampling protocols.

4.2 To predict land use ? pressures? on soil ?states?

In this study an attempt was made to link the ? pressure? indicator of cropping index number with various soil state indicators. As outlined in the results (Sections 3.3.1 to 3.3.7) this link was limited by the usefulness of cropping index number to reflect soil and crop management practices that affect soil indicators, particularly organic carbon and aggregate stability. The cropping index number relates to the number of consecutive years that a paddock has been under arable crops or pasture. This system is very simple and works well when a large range of cropping index numbers is studied.

However, when considering a relatively narrow range of land uses (i.e. different lengths of arable cropping), it appears that the simple cropping index number concept is not sensitive enough as a pressure indicator. In its current form, the cropping index number is purely based on the number of continuous years that arable crops have been grown. It may well be that for the cropping index number to be a useful pressure indicator it needs to include details of soil and crop management practices. For example, conventional cultivation is detrimental to soil aggregate stability but direct drilling has a less drastic effect. So soil in a paddock where arable crops have been grown continuously by conventional cultivation can have a lower aggregate stability than soil in a paddock where arable crops have been grown by direct drilling (Francis et al. 1987). Similarly, management of crop residues (burning versus incorporation) may affect soil state indicators, as may other management practices like fertiliser and irrigation.

We recommend that future research focuses on developing a more sophisticated pressure indicator (or index) that incorporates dominant management variables (e.g. cultivation method, fertiliser and irrigation inputs, residue management) in addition to cropping history.

4.3 To link pressure and state indicators of the EPI programme

The EPI stage 1 indicators for soil health include land use as a pressure indicator. Of the stage 1 state indicators proposed by the EPI programme, only organic carbon was measured in this study. Cadmium and DDE indicators in the study are relevant to the EPI stage 2 land indicators proposed for land contamination.

Where land use covers a diverse range such as forestry, native bush, pasture and cropping then there is likely to be a correlation between land use and organic carbon. However, in this study we considered only arable cropping. Our pressure indicator was number of years with consecutive crops grown. As outlined in Sections 4.1 and 4.2, this does not appear to be sensitive enough to relate to the state indicators measured in this study.

4.4 In other arable land areas in New Zealand

Canterbury is the dominant arable farming region in New Zealand providing 64% of the total land area in arable production (Williams 1998). Other major areas are Southland and Manawatu. Crop rotations vary between the regions with the greatest diversity found in Canterbury. Some Canterbury farms still practise mixed cropping systems where arable crops are grown for three to five years followed by a grazed grass/clover pasture for two to five years.

However, due to increased pressure to intensify crop production the restorative pasture phase is becoming shorter and may be limited to a one-year grass seed crop on continuous arable production farms. The cropping index number was developed for Canterbury rotations. In other regions, due to different crop rotations, this index may not be applicable.

In other arable regions, the major issues affecting soil quality are likely to be similar to Canterbury, e.g. maintaining soil organic matter levels and good soil structure. However, these issues are likely to be influenced by regional differences in soil type and soil mineralogy. As noted by Sparling & Schipper (1998), some soils are able to retain good soil structure at very low organic matter levels due to their mineralogy. The impact of this on soil quality indicators and their interpretation is unknown.

5 OTHER SOIL HEALTH INDICATORS FOR ARABLE LAND

The seven indicators trialed in this study were based on the soil quality monitoring study of Sparling & Schipper (1998), local research on the Canterbury Plains and Canterbury Regional Council staff preferences. Particular emphasis was on choosing indicators which are relevant to arable land rather than other land uses.

Of the indicators not chosen in this project, the number of earthworms present per m² soil has good potential. They were not included in this study due to the timing of the project. Earthworm populations vary between the seasons. They are lowest in the summer and highest in spring (Fraser & Piercy 1996). Soil samples in our study were collected in late March/April 1998 when earthworm numbers were still low from the summer drought and so it was not worthwhile including earthworms as an indicator.

However, research on the Canterbury Plains shows that earthworms are a good indicator (Haynes et al. 1995; Fraser et al. 1996). They are strongly correlated to soil microbial populations and so provide information on soil biological health. In addition, we understand how earthworms are affected by farm management practices and the number in the soil is correlated with cropping index number. We suggest that earthworm population is considered as a potential indicator for arable land.

MAF Policy is currently funding a project carried out by Crop & Food Research and Lincoln University which is developing a soil quality monitoring system (SQMS) for the arable industry. The aim of the project is to develop simple, robust measures of soil quality which can be carried out by farmers and consultants. End users are encouraged to carry out the measurements regularly and monitor the results to look for trends. Information is provided on how changes to management can be carried out to ensure that the indicators are kept within a desirable range. As samples are taken from the same paddock each year, this approach overcomes some of the difficulties described in this report that are associated with farmer-to-farmer variability. However, it is unclear how this information that is collected by the farmer could be used by the Canterbury Regional Council in its environmental performance indicator reporting.

The monitoring system includes guidelines for establishing a monitoring programme, instructions on how to carry out the soil quality indicator measurements, guidelines for interpreting the indicator results and recommendations for reversing trends of soil quality decline where they occur. Seven indicators of soil biological, chemical and physical quality are included in the SQMS. Each was selected to address one or more production and/or environment oriented issues of sustainability. Bulk density and penetration resistance are indicators of surface and subsoil compaction, respectively.

These reflect the soil's susceptibility to water logging and surface runoff and potential to impair root growth. Results of standard chemical fertility testing (i.e. SFS Quick test) provide measures of nutrient availability that reflect the over or under supply of nutrients for crop production.

Earthworm populations are an indicator of biological health that reflect the soil's capacity to cycle nutrients and the effects of chemical contamination. Water holding capacity reflects the soil's capacity to store and supply water for plant production. A visual assessment of the soil profile provides information on rooting depth, density and porosity that reflect the water infiltration and drainage capacity of soil. Finally, a structural stability test (that closely correlates with the aggregate stability method used in this report) indicates the soil's capacity to resist structural breakdown and, therefore, its susceptibility to surface capping and erosion by wind or water.

Many of these measurements used in the SQMS are similar to the laboratory measurements in our study and Sparling & Schipper's (1998) study, but have been simplified so they can be used in the field.

Currently the project involves trialing the monitoring system with four arable groups in Canterbury. These groups are the Methven Arable Landcare Group, Waikaakahi Resource Care Group, Geraldine Farmer Discussion Group and Darfield Arable Farmers Group. At present, interested farmers have been identified and paddocks with suitable cropping histories for monitoring have been selected. The system will be trialed on a few paddocks in July 1998, but most monitoring will start in September 1998. There are also plans to trial it with arable farmers in other regions. It has the potential to be used as a simple monitoring tool by the arable industry.

6 RECOMMENDATIONS

- ? Evaluation of soil quality indicators in this study was limited by the lack of replication in the field sampling. Further evaluation should consider more replication of the cropping index number on farms of the same soil types and/or a greater range of paddocks with different cropping index numbers on the same farm.
- ? Of the indicators trialed, aggregate stability appears to be the most promising for arable land. Organic carbon is an important indicator, but for longer term monitoring rather than short term. Cadmium and DDE are useful indicators for soil contamination.
- ? The pressure indicator cropping index number, as used in the study, was not well linked to the soil state indicators. Better correlations may be achieved if the index included soil and crop management practices like tillage method and crop residue management.
- ? The state indicators need to be trialed in other arable regions, particularly those with different soil types and mineralogy to Canterbury, before recommendations on potential soil quality indicators can be made in these regions.
- ? Other potential soil indicators for arable land are earthworm population numbers and the Soil Quality Monitoring System being developed by Crop & Food Research and Lincoln University.
- ? Once suitable indicators for soil quality have been identified it will be important to develop sampling protocols for these indicators.
- ? Repeat organic carbon analyses of the archived 1992 samples, so that differences in laboratory analytical methods are removed between the 1992 and 1998 sampling events.

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9 APPENDICES

Appendix I Numbers of paddocks sampled in 1992/93, classified by soil type and cropping index number.

Soil type	Cropping index number								Total
	1	2	3	4	5	6	7	8	
<i>Soils of the low terraces - subhumid climate</i>									
Templeton	3	1	4	3	4	4	1	5	25
Eyre		1		1			2		4
Wakanui	1								1
Temuka		3	1	4	1	3			12
Waterton	2								2
<i>Soils of the low terraces - humid climate</i>									
Mayfield				1	2	2			5
<i>Soils of the high terraces - subhumid climate</i>									
Barrhill	1			3	2	3			9
Hatfield		1		1		4		2	8
Lismore	11	2	1	4	2	3		4	27
<i>Soils of the high terraces - humid climate</i>									
Highbank			3	2	4	2		1	12
Lyndhurst	2		2	3	1	3	2	2	15
TOTAL	20	8	11	22	16	24	5	14	120

Appendix II Sampling strategy in 1998. Paddocks for sampling are marked x.

Soil type	Cropping index number								Total	
	1	2	3	4	5	6	7	8		
<i>Soils of the low terraces - subhumid climate</i>										
Templeton				x	x	x	x			4
Wakanui				(x) ^a	(x)	(x)			(x)	4
<i>Soils of the low terraces - humid climate</i>										
Mayfield					(x)	x	x	x		4
<i>Soils of the high terraces - subhumid climate</i>										
Barrhill				x	x	x			x	4
Hatfield					x		x	x		3
Lismore				x	(x)	x			x	4
<i>Soils of the high terraces - humid climate</i>										
Highbank				x	x	x	x			4
Lyndhurst					x	x			x	3
TOTAL				5	8	7	4	6		30
^a Indicates	paddock	was	not	part	of	the	1992/93	survey.		

Appendix III Cropping history for each sampled site

Soil type	Locality	Paddock number	1998 Cropping index	Crop sown									
				? 97	? 96	? 95	? 94	? 93	? 92	? 91	? 90	? 89	? 88
Templeton	Dunsandel	2	4	pasture	ryegrass	Barley	barley	peas	wheat	pasture	pasture		
Templeton	Dunsandel	10	5	barley	barley	Wheat	clover	clover	pasture	barley	peas	wheat	
Templeton	Dorie	Jb	6	wheat	clover	peas	turnips	lucerne	lucerne	lucerne	lucerne	lucerne	lucerne
Templeton	Dorie	J2	7	wheat	clover	barley	maize	clover	peas	primrose	wheat	pasture	pasture
Wakanui	Leeston	Wf	4	clover	ryegrass	wheat	beans	peas	clover	ryegrass	wheat	beans	peas
Wakanui	Leeston	We	5	barley	beans	peas	clover	ryegrass	wheat	beans	squash	clover	ryegrass
Wakanui	Lincoln	SFT	6	oats	oats	barley	barley	wheat	wheat	grass	grass	grass	grass
Wakanui	Lincoln	RC	8	wheat	wheat	wheat	barley	barley	barley	barley	barley	barley	linseed
Mayfield	Lyndhurst	8	6	ryegrass	wheat	wheat	ryegrass	wheat	lentils	fescue	fescue	barley	wheat
Mayfield	Lyndhurst	9	7	ryegrass	wheat	wheat	clover	wheat	peas	primrose	fescue	fescue	fescue
Mayfield	Lyndhurst	10	8	ryegrass	wheat	wheat	peas	wheat	ryegrass	wheat	clover	barley	barley
Mayfield	Methven	F	5	wheat	wheat	ryegrass	ryegrass	ryegrass					
Barrhill	Barrhill	B	4	clover	ryegrass	wheat	carrots	carrots	wheat	potatoes	grass	barley	lentils
Barrhill	Barrhill	Y	8	linseed	wheat	clover	peas	ryegrass	wheat	clover	wheat	clover	barley
Barrhill	Mitcham	Y	5	wheat	peas	wheat	clover	pasture	pasture	wheat	peas	ryegrass	barley
Barrhill	Mitcham	A	6	wheat	peas	wheat	clover	barley	pasture	pasture	wheat	peas	rape
Hatfield	Courtenay	P1	5	turnips	ryegrass	clover	pasture	pasture	clover	peas			
Hatfield	Kirwee	J	7	wheat	potatoes	turnips	barley	ryecorn	peas	wheat	potatoes	clover	clover
Hatfield	Kirwee	Q	8	barley	potatoes	peas	ryegrass	wheat	onions	onions	beans	wheat	beans

Soil type	Locality	Paddock number	1998 Cropping index	Crop sown										
				? 97	? 96	? 95	? 94	? 93	? 92	? 91	? 90	? 89	? 88	
Lismore	Aylesbury	A	4	ryegrass	barley	barley	barley	barley	barley	barley	barley	peas	barley	barley
Lismore	Aylesbury	P	8	barley	barley	barley	barley	barley	barley	barley	primrose	barley	barley	barley
Lismore	Charing Cross	C	5	wheat	ryegrass	wheat	clover	clover	peas	clover	clover			
Lismore	Charing Cross	G	6	peas	barley	barley	primrose	clover	clover	peas	wheat			
Highbank	Highbank	HH	4	grass	barley	wheat	peas	wheat	clover	pasture				
Highbank	Highbank	U	5	linseed	ryegrass	ryegrass	wheat	peas	barley	pasture	pasture	pasture	pasture	pasture
Highbank	Highbank	E	6	clover	peas	ryegrass	wheat	wheat	fescue	fescue	fescue	fescue	fescue	fescue
Highbank	Highbank	CA	7	barley	wheat	clover	peas	ryegrass	wheat	potatoes	ryegrass	ryegrass	ryegrass	ryegrass
Lyndhurst	Annat	4845	5	peas	wheat	pasture	ryegrass	barley	barley	peas	wheat	pasture	pasture	pasture
Lyndhurst	Annat	J	8	peas	ryegrass	wheat	peas	barley	wheat	potatoes	ryegrass	barley	barley	peas
Lyndhurst	Waddington	EE	6	barley	peas	barley	potatoes	grass	grass	grass	grass	grass	grass	grass

Appendix IV: Experimental data for all paddocks sampled in 1998

Soil type	Locality	Paddock Number	1998 Cropping Index	Organic Carbon (mg/cm ³)	Microbial Biomass Carbon (:g/cm ³)	Anaerobically Mineralizable Nitrogen (:g/cm ³)	Aggregate Size Distribution (mm)	Aggregate Stability (MWD; mm)	Cadmium (:g/g)	DDE (:g/g)
Templeton silt loam	Dunsandel	2	4	36.98	274	25.79	20.78	1.52	0.20	0.32
Templeton silt loam	Dunsandel	2	4	37.90	585	31.50	14.24	1.84	0.22	0.37
Templeton silt loam	Dunsandel	2	4	36.14	490	47.53	6.89	2.45	0.24	0.56
Templeton silt loam	Dunsandel	2	4	37.67	472	43.97	16.25	1.47	0.27	0.40
Templeton silt loam	Dunsandel	10	5	33.97	510	26.20	27.32	1.03	0.25	0.13
Templeton silt loam	Dunsandel	10	5	34.70	470	34.51	26.27	1.74	0.25	0.23
Templeton silt loam	Dunsandel	10	5	35.80	159	34.40	13.81	1.85	0.24	0.14
Templeton silt loam	Dunsandel	10	5	36.39	573	37.77	12.81	1.76	0.25	0.15
Templeton silt loam	Dorie	Jb	6	36.54	467	32.60	5.88	2.40	0.10	0.33
Templeton silt loam	Dorie	Jb	6	31.81	217	34.43	11.68	2.02	0.10	0.28
Templeton silt loam	Dorie	Jb	6	38.12	460	44.36	5.04	2.16	0.10	0.36
Templeton silt loam	Dorie	Jb	6	37.83	332	32.85	8.99	2.64	0.08	0.11
Templeton silt loam	Dorie	J2	8	33.47	446	30.44	6.32	1.36	0.11	*
Templeton silt loam	Dorie	J2	8	32.62	334	23.61	14.14	1.26	0.13	0.01
Templeton silt loam	Dorie	J2	8	31.80	482	34.02	11.66	1.01	0.13	*
Templeton silt loam	Dorie	J2	8	35.29	437	38.99	6.54	1.44	0.12	*
Wakanui silt loam	Leeston	Wf	4	31.34	779	69.41	23.13	1.26	0.13	0.35
Wakanui silt loam	Leeston	Wf	4	31.21	785	70.65	26.78	1.30	0.12	0.36
Wakanui silt loam	Leeston	Wf	4	31.24	944	73.51	31.08	1.00	0.14	0.35
Wakanui silt loam	Leeston	Wf	4	26.89	651	50.08	12.96	1.41	0.12	0.33
Wakanui silt loam	Leeston	We	5	27.00	520	66.06	13.50	0.53	0.13	0.28
Wakanui silt loam	Leeston	We	5	27.21	451	29.99	26.78	0.79	0.14	0.26
Wakanui silt loam	Leeston	We	5	23.33	532	27.60	29.51	0.57	0.14	0.26
Wakanui silt loam	Leeston	We	5	27.21	544	32.06	7.39	0.79	0.13	0.24
Wakanui silt loam	Lincoln	SFT	6	32.44	468	25.88	11.58	0.95	0.15	0.02
Wakanui silt loam	Lincoln	SFT	6	32.06	504	25.34	16.84	0.77	0.14	0.03
Wakanui silt loam	Lincoln	SFT	6	34.06	478	27.26	12.57	0.71	0.20	0.03
Wakanui silt loam	Lincoln	SFT	6	34.27	627	27.95	10.99	0.77	0.22	0.03
Wakanui silt loam	Lincoln	RCT	8	29.06	549	28.30	10.19	0.94	0.17	0.06
Wakanui silt loam	Lincoln	RCT	8	31.86	590	28.71	14.02	1.15	0.18	0.01
Wakanui silt loam	Lincoln	RCT	8	31.50	534	25.50	7.24	0.92	0.10	0.03
Wakanui silt loam	Lincoln	RCT	8	28.24	497	28.64	7.57	1.01	0.17	0.04

Soil type	Locality	Paddock Number	1998 Cropping Index	Organic Carbon (mg/cm ³)	Microbial Biomass Carbon (:g/cm ³)	Anaerobically Mineralizable Nitrogen (:g/cm ³)	Aggregate Size Distribution (mm)	Aggregate Stability (MWD; mm)	Cadmium (:g/g)	DDE (:g/g)
Mayfield silt loam	Methven	F	5	25.99	415	25.03	5.53	1.55	0.11	0.04
Mayfield silt loam	Methven	F	5	32.12	574	43.97	5.46	1.80	0.12	0.04
Mayfield silt loam	Methven	F	5	29.65	569	38.08	17.28	1.63	0.13	0.04
Mayfield silt loam	Methven	F	5	30.67	639	47.52	5.51	1.71	0.12	0.03
Mayfield silt loam	Lyndhurst	8	6	31.68	532	42.26	5.41	1.70	0.21	0.02
Mayfield silt loam	Lyndhurst	8	6	31.87	602	43.15	13.82	1.70	0.20	0.02
Mayfield silt loam	Lyndhurst	8	6	32.86	668	46.68	21.82	1.86	0.21	0.01
Mayfield silt loam	Lyndhurst	8	6	30.83	591	36.71	18.76	1.66	0.19	0.01
Mayfield silt loam	Lyndhurst	9	7	25.65	620	38.52	16.91	1.31	0.16	0.04
Mayfield silt loam	Lyndhurst	9	7	27.52	566	49.46	10.65	1.60	0.17	0.04
Mayfield silt loam	Lyndhurst	9	7	28.07	492	44.92	15.07	1.49	0.20	0.07
Mayfield silt loam	Lyndhurst	9	7	26.94	534	35.56	13.78	1.59	0.18	0.07
Mayfield silt loam	Lyndhurst	10	8	31.17	543	43.56	20.96	1.58	0.20	0.28
Mayfield silt loam	Lyndhurst	10	8	29.46	567	28.51	14.91	1.50	0.19	0.24
Mayfield silt loam	Lyndhurst	10	8	29.59	411	34.64	20.29	1.60	0.19	0.09
Mayfield silt loam	Lyndhurst	10	8	28.51	655	45.53	28.83	1.38	0.18	0.10
Barrhill fine sandy loam	Barrhill	B	4	29.04	267	47.10	7.32	2.01	0.16	0.30
Barrhill fine sandy loam	Barrhill	B	4	28.14	365	37.60	10.71	2.20	0.14	0.27
Barrhill fine sandy loam	Barrhill	B	4	30.66	293	42.52	4.94	2.28	0.14	0.23
Barrhill fine sandy loam	Barrhill	B	4	32.45	416	47.92	15.75	2.73	0.16	0.34
Barrhill fine sandy loam	Mitcham	Y	5	27.15	293	32.37	12.31	2.39	0.10	0.43
Barrhill fine sandy loam	Mitcham	Y	5	28.32	287	39.93	3.77	2.41	0.10	0.33
Barrhill fine sandy loam	Mitcham	Y	5	27.56	330	32.32	4.72	2.53	0.09	0.35
Barrhill fine sandy loam	Mitcham	Y	5	27.87	250	28.95	6.77	2.14	0.10	0.31
Barrhill fine sandy loam	Mitcham	A	6	30.13	465	58.98	5.57	2.67	0.10	0.07
Barrhill fine sandy loam	Mitcham	A	6	29.44	328	49.13	7.87	2.18	0.09	0.08
Barrhill fine sandy loam	Mitcham	A	6	32.64	607	102.55	10.39	2.65	0.09	0.08
Barrhill fine sandy loam	Mitcham	A	6	31.81	451	61.24	12.47	2.54	0.09	0.09
Barrhill fine sandy loam	Barrhill	Y	8	30.74	131	14.02	3.19	2.47	0.11	0.11
Barrhill fine sandy loam	Barrhill	Y	8	29.30	182	16.57	4.13	1.97	0.11	0.13
Barrhill fine sandy loam	Barrhill	Y	8	33.87	66	27.35	2.86	2.29	0.13	0.27
Barrhill fine sandy loam	Barrhill	Y	8	31.74	289	23.39	4.07	2.09	0.13	0.21

Soil type	Locality	Paddock Number	1998 Cropping Index	Organic Carbon (mg/cm ³)	Microbial Biomass Carbon (:g/cm ³)	Anaerobically Mineralizable Nitrogen (:g/cm ³)	Aggregate Size Distribution (mm)	Aggregate Stability (MWD; mm)	Cadmium (:g/g)	DDE (:g/g)
Hatfield silt loam	Courtenay	P1	5	30.83	368	36.67	8.07	1.89	0.12	0.30
Hatfield silt loam	Courtenay	P1	5	30.63	166	34.81	5.11	2.48	0.12	0.30
Hatfield silt loam	Courtenay	P1	5	32.74	417	39.89	14.51	2.24	0.13	0.31
Hatfield silt loam	Courtenay	P1	5	36.40	252	58.88	10.25	2.14	0.12	0.28
Hatfield silt loam	Kirwee	J	7	23.21	298	58.31	9.26	1.61	0.12	0.16
Hatfield silt loam	Kirwee	J	7	23.01	265	13.22	7.48	0.78	0.12	0.16
Hatfield silt loam	Kirwee	J	7	24.46	345	15.30	8.84	1.37	0.13	0.14
Hatfield silt loam	Kirwee	J	7	26.13	184	18.82	8.63	1.05	0.14	0.18
Hatfield silt loam	Kirwee	Q	8	24.78	504	24.19	6.05	0.97	0.11	0.14
Hatfield silt loam	Kirwee	Q	8	25.45	439	21.64	8.11	1.00	0.13	0.15
Hatfield silt loam	Kirwee	Q	8	24.84	380	23.06	20.68	0.65	0.10	0.01
Hatfield silt loam	Kirwee	Q	8	23.37	337	19.66	7.50	0.77	0.11	0.01
Lismore silt loam	Aylesbury	A	4	38.41	524	49.45	6.85	2.52	0.11	0.27
Lismore silt loam	Aylesbury	A	4	30.73	533	27.60	4.78	1.98	0.06	0.19
Lismore silt loam	Aylesbury	A	4	35.96	485	49.98	8.29	2.30	0.07	0.15
Lismore silt loam	Aylesbury	A	4	32.89	463	40.52	8.29	2.38	0.10	0.15
Lismore silt loam	Charing Cross	C	5	27.77	347	33.54	14.35	1.59	0.12	0.01
Lismore silt loam	Charing Cross	C	5	24.69	398	19.17	21.34	1.54	0.10	0.01
Lismore silt loam	Charing Cross	C	5	23.91	376	18.99	6.36	1.01	0.10	0.01
Lismore silt loam	Charing Cross	C	5	24.23	199	23.50	7.92	1.14	0.11	0.01
Lismore silt loam	Charing Cross	G	6	27.65	523	24.32	10.57	1.55	0.10	0.04
Lismore silt loam	Charing Cross	G	6	29.15	386	41.89	9.65	1.86	0.12	0.04
Lismore silt loam	Charing Cross	G	6	28.11	416	32.27	10.35	1.54	0.10	0.07
Lismore silt loam	Charing Cross	G	6	28.72	446	29.88	11.02	1.71	0.10	0.06
Lismore silt loam	Aylesbury	P	8	29.43	250	21.12	5.11	2.39	0.09	0.12
Lismore silt loam	Aylesbury	P	8	29.46	187	21.84	3.56	2.49	0.09	0.11
Lismore silt loam	Aylesbury	P	8	30.85	285	20.90	4.90	1.92	0.11	0.11
Lismore silt loam	Aylesbury	P	8	29.32	387	85.24	5.35	1.69	0.12	0.06

Soil type	Locality	Paddock Number	1998 Cropping Index	Organic Carbon (mg/cm ³)	Microbial Biomass Carbon (:g/cm ³)	Anaerobically Mineralizable Nitrogen (:g/cm ³)	Aggregate Size Distribution (mm)	Aggregate Stability (MWD; mm)	Cadmium (:g/g)	DDE (:g/g)
Highbank silt loam	Highbank	HH	4	34.67	411	40.83	8.95	2.57	0.18	0.27
Highbank silt loam	Highbank	HH	4	38.87	483	28.53	13.85	2.63	0.17	0.24
Highbank silt loam	Highbank	HH	4	34.94	726	36.09	6.09	2.64	0.18	0.30
Highbank silt loam	Highbank	HH	4	33.52	680	24.08	8.11	2.58	0.18	0.25
Highbank silt loam	Highbank	U	5	40.14	625	33.84	4.86	2.49	0.17	0.11
Highbank silt loam	Highbank	U	5	38.45	615	40.13	5.19	2.44	0.13	0.13
Highbank silt loam	Highbank	U	5	38.28	652	62.99	13.53	2.45	0.15	0.23
Highbank silt loam	Highbank	U	5	39.53	564	37.93	6.65	2.37	0.13	0.21
Highbank silt loam	Highbank	E	6	35.32	754	35.82	10.32	2.04	0.16	0.13
Highbank silt loam	Highbank	E	6	33.23	717	39.13	20.84	2.25	0.16	0.11
Highbank silt loam	Highbank	E	6	37.04	504	38.55	10.35	2.60	0.11	0.14
Highbank silt loam	Highbank	E	6	33.36	565	26.11	5.42	2.41	0.15	0.13
Highbank silt loam	Highbank	CA	7	36.77	523	19.76	8.40	1.32	0.18	0.44
Highbank silt loam	Highbank	CA	7	36.84	474	20.07	8.91	1.69	0.18	0.56
Highbank silt loam	Highbank	CA	7	35.50	425	19.69	4.27	1.86	0.17	0.22
Highbank silt loam	Highbank	CA	7	33.37	378	13.46	6.23	2.31	0.12	0.20
Lyndhurst silt loam	Annat	4845	5	36.59	519	25.08	12.22	1.63	0.17	0.09
Lyndhurst silt loam	Annat	4845	5	38.98	489	40.85	9.62	2.20	0.16	0.12
Lyndhurst silt loam	Annat	4845	5	36.60	327	28.19	5.26	2.51	0.15	0.12
Lyndhurst silt loam	Annat	4845	5	37.35	417	41.70	5.52	2.22	0.18	0.07
Lyndhurst silt loam	Waddington	EE	6	29.24	209	25.07	6.82	1.12	0.15	0.13
Lyndhurst silt loam	Waddington	EE	6	29.38	374	17.64	6.02	2.14	0.15	0.13
Lyndhurst silt loam	Waddington	EE	6	28.42	504	15.55	6.01	1.56	0.13	0.11
Lyndhurst silt loam	Waddington	EE	6	27.72	491	31.40	9.05	1.23	0.12	0.11
Lyndhurst silt loam	Annat	J	8	33.53	636	65.81	12.34	2.05	0.17	0.21
Lyndhurst silt loam	Annat	J	8	32.01	559	39.70	5.07	2.02	0.17	0.22
Lyndhurst silt loam	Annat	J	8	30.97	759	28.91	11.28	1.56	0.15	0.29
Lyndhurst silt loam	Annat	J	8	31.08	484	32.67	5.51	1.42	0.18	0.27

* indicates value below detection limit