Provisional Targets for Soil Quality Indicators in New Zealand

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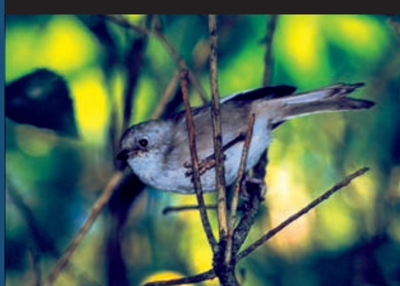

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Introduction

To judge the quality of a soil for production and environmental goals, the physical, chemical and biological properties of the soil need to be compared against the desirable condition for that land use. Ideally, a response curve is needed that shows the relationship between a quantitative soil characteristic and the quality ranking. Currently, soil quality response curves are poorly defined and there are no internationally agreed standards. This report explains how response curves were obtained for a number of key soil properties used for soil quality assessment in New Zealand, and presents the curves in graphical and numeric form.

Background

Soil quality indicators

Indicators are only of use if they attract your attention and tell you something you need to know. We require indicators of soil quality so we can identify what land-management actions adversely affect soils and which actions are beneficial. A large number of soil properties have been proposed as indicators of soil quality, but to be an effective and quantitative indicator, the property needs to have an interpretive framework. We need to know whether a particular value is a desirable, and what to do about it if it is not. To complicate matters, values that may be satisfactory for one land use may be unacceptable for another. Further, because of their differing pedogenesis, soils have different characteristics, and a target that is attainable and suitable for one soil may not be appropriate for another.

The setting of targets for soil quality characteristics has proved contentious, with a divergence of opinion about what constitutes good soil quality (e.g. see Sojka & Upchurch (1999) for an alternative view on soil quality). There are no internationally agreed standards, and there is even disagreement about such broad categories as 'more is better'; or 'less is better' (Sojka & Upchurch 1999). This disparity arises because the question 'soil quality for what?' needs first to be defined, and in some instances, the goals of different land-users may differ. Soil quality for crop production, requiring high nutrient availability for crop growth, may be in conflict with the aim of soil quality for environmental protection, where low concentrations of soil nutrient are usually desirable to maintain water quality and avoid eutrophication.

Interpretive frameworks

There is little point in advocating a soil property as an indicator of soil quality unless we can provide for its interpretation. Demonstrating a *difference* between soils does not necessarily mean one is better quality than the other. The rate of change in soil properties through time has been suggested as an indicator of quality (Larson & Pierce 1994), but to initiate a management response we still need to define 'trigger points' that show when we have reached a critical level.

It is also unwise to rely solely on statistical averages as a desirable target. Statistics only tell us how a given sample compares with a population. It does not necessarily define a *desirable* target. If you want to be the 'A team' then it will not help to compare yourself against the 'C team'. Further, if you are already in the A team, then using such statistical approaches as the upper or lower quartile as a target range, automatically means one-quarter of the samples will miss the target range, even though they may be of perfectly adequate quality.

Soil quality targets for New Zealand

Target ranges can be defined from experimental data, statistical metrics, and simulation modelling (Arshad & Martin 2002; Sparling et al. 2003). A further approach is to use a panel of experts. This is useful where knowledge is incomplete, because it allows information from the other three approaches (if available) to be synthesised with personal experience, anecdotal evidence, and best guesses based on an understanding of soil processes and relationships. We applied all available approaches to derive target values for a set of New Zealand soil quality indicators.

Objectives

We held two workshops to establish target values for an agreed set of soil properties. The seven key properties were: a measure of soil acidity (soil pH); two measures of compaction (bulk density and macroporosity); a measure of soil P fertility (Olsen P); and three measures of soil organic matter (total C, total N and mineralisable N). Response curves were also derived for the additional soil quality measures of potential rooting depth, earthworm numbers, C:N ratio, aggregate stability, depth of topsoil, and C and N balances.

Methods

Expert workshop structure

A workshop of 24 New Zealand soil scientists was held following the general methodology of Smith (1990); the difference was that we convened the group at an intensive 2-day workshop rather than using anonymous postal questionnaires. This meant there was group visual contact and interaction throughout. Gustafson et al. (1973) noted this interaction could increase overconfidence in the output. A neutral facilitator was used to maintain positive group interaction.

Once the necessary definitions, soil properties, and categories of soil and land use had been agreed among the group, each individual then drafted response curves relating soil quality status to soil property value for each soil and land-use category. The individual scientists were encouraged to drawn non-linear curves as, in common with Andrews et al. (2002), we believed a non-linear scoring method would be more representative of system function than a simple linear function based on the range of observed values (e.g. Liebig et al. 2001). Curves from each individual were then overlaid with those of the other scientists, discussed, and then modified if individuals agreed. The participating scientists were asked to complete an anonymous questionnaire at the end of the workshop to find their ranking of the usefulness of the exercise and their confidence in the outputs.

Environmental and production criteria

The workshop definition of soil quality was that used by the Soil Science Society of America (1995): 'The capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.'

Response curves were constructed using two sets of criteria to assess the soil quality status. One set of curves was based on production considerations, the second set on environmental considerations. Production criteria were agricultural productivity (plant dry matter, milk solids, logs for export), maximum economic yield, sustainable production, farm profitability, and impact on the rural economy. These were generally considered within a short-term time frame (< 5 years). Environmental criteria (including off-site impacts) were risks to air quality (including carbon sequestration); risk to water quality (surface and ground); loss of habitat, amenity, and access; loss of diversity of indigenous species; invasions by weeds and pests; and contaminant accumulation. These were generally considered over a longer time frame (25 years).

No specific values for productivity, profitability, or other criteria were specified; panel members were allowed to define their own values.

Aggregation and land-use classes

Curves were specific for each soil property, land use, and soil order (Hewitt 1998), although in most cases the group agreed that similar soil orders could be grouped. For several indicators, all the soils were grouped together. Broad land-use classes of pasture, cropping, horticulture, and forestry (exotic and indigenous) were adopted. We initially had more land-use classes, but during preliminary discussion the group agreed the two proposed classes of intensive and extensive pasture could be combined. This was because, once defined, the target criteria for the two classes were the same: attributes that make for a high quality pasture under intensive use were also applicable to extensive pastures. A single cropping and horticultural class was used. This was a great oversimplification, but in preliminary discussions it became clear that to classify accurately all the diverse horticultural and cropping land uses would need an impractically large number of classes. The reverse strategy was adopted with the aggregation of cropping and horticulture classes, but with the recognition that target ranges would be very broad and generalised.

Post-workshop

After the workshop, each curve was digitised and amalgamated with the rest of the group, and means and errors were calculated. A six-member subgroup of the original panel reviewed the conclusions of the workshop to resolve anomalies. These mainly consisted of editing the response curves to remove extreme outlier points, smoothing the amalgamated response curves, and aggregating soil and land-use categories where the curves were similar. Only the edited curves are presented here; the unedited data and response curves are available in Landcare Research Contract Report LC9900/118 (Sparling & Tarbotton 2000) and on CD as Corel WordPerfect and Quattro and Microsoft Excel files.

Combining curves

The production and environmental response curves for each combination of indicator, soil type, and land use were merged into a single response curve. Where the production and environmental response curves showed different trajectories, we took the more limiting (conservative) of the two responses. The curves reproduced here are the ones used in the Landcare Research web-based soil quality assessment tool Sindi (see below).

Target ranges

The editorial group defined four soil-quality categories: significant (adverse) impact; potential impact (and therefore of concern); within the target range; and above target range. The group focused on defining boundary points or thresholds along the response curves for each soil-quality category. In addition, upper and lower limits were defined for a target range. The acceptable range in a soil property was defined as the limit between the 'no significant impact' value, and the 'above target range' value. These are shown in heavy type in the tables, and are specific for land uses and soil orders. The target ranges can be used to identify outlier values for 'by exception' reporting (see below).

Soil quality reporting

The interpreted response graphs can be used to assess the soil quality of a single site. Each measured value is compared with the appropriate graph or table, providing a quick evaluation of which indicators (if any) are in the significant (adverse) impact or potential impact categories. This comparison can be done manually or by using a web-based tool (http://sindi.landcareresearch.co.nz) that also aggregates the results into four soil-quality indices: physical quality, organic resources, fertility and acidity.

Multiple sites can also be assessed using the 'by exception' approach, and large data sets can be summarised regionally or nationally. In this approach, the number of times that indicators do not meet the specified target threshold or range is reported as a single number or proportion. The reporting method can also highlight all samples in a region with at least one unsatisfactory indicator (or aggregated soil quality index), and provide summary data of the total number of acceptable measurements by region, land use, or soil type, as desired. A data set may be biased if it has not been randomly sampled, and commonly, land uses and soils are over- or under-represented in data sets compared with their area distribution on a regional or national basis. In that instance the bias in the data set should be corrected by applying a weighting factor based on the actual area of each soil or land use.

Sources of information

Multiple sources of information were used to define the category thresholds (for soil fertility and macroporosity reference details see Results). For soil fertility properties the yield response curves were used, as these were reasonably well defined (e.g. Cornforth & Sinclair 1984; During 1984; Clarke et al. 1986; Roberts & Morton 1999 – see Results). Long-term pasture sites were used as the 'optimum' target range for organic matter content, because the total C content of New Zealand pasture topsoils has been found to be similar to long-term indigenous forest sites (Sparling & Schipper 2002). Thresholds for organic resources (total C and N, mineralisable N) were obtained from interquartile ranges of long-term pasture sites, grouped by soil order, using data from the New Zealand National Soils Database (NSD) and the 500 Soils Project (Sparling et al. 2003). Soil bulk density thresholds were defined from quartile values from the NSD and 500 Soils Project, and macroporosity targets from published information on effects of soil compaction on pasture production (Drewry et al. 2000, 2001, 2002; Drewry & Paton 2000; Singleton & Addison 1999; Singleton et al. 2000 – see Results). There was little published information on soil quality targets for environmental criteria, so thresholds were set according to the expert opinion of the panel. For soil fertility characteristics, this generally involved assuming a negative environmental impact once the plateau phase on the yield response curve had been reached. Citations are provided in full after each indicator section of the results.

Data presentation

The rest of this publication presents the response curves for the 7 key indicators that form the recommended minimum data set: soil pH, Olsen P, total C, total N, mineralisable N, macroporosity and bulk density (Hill et al. 2003). Additional graphs showing the combined curves for production and environmental criteria are also presented, and a Table showing the numeric values and suggested target ranges. Data for the additional indicators: aggregate stability, earthworm numbers, topsoil depth, total rooting depth, C:N ratio, C balance and N balance are also presented in the Appendix, but with the exception of aggregate stability, no combined curves or target ranges have yet been defined for those properties.

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Results

Each soil property is presented in its own numbered section, following.

1. Response curves for total carbon (C)

What is total C?

Total C measures the amount of carbon in soil. This includes carbonates and soil organic matter C, but New Zealand soils typically contain very little carbonate, so total C is a good measure of organic matter C. Organic matter is important for soil quality because it helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth. Once depleted, organic matter takes many years to replace, and its careful conservation is recommended by most soil scientists.

How was it measured?

Total C is now usually measured by high temperature combustion methods, where the total C is measured as carbon dioxide after catalytic oxidation.

Response curves

Soils differ in the amounts of organic matter they contain depending on their mineralogy, climate and land use. The Semiarid, Pumice and Recent soils formed one distinct group, and Allophanic Soils another distinct group, sufficiently different to warrant their own specific response curves. As the organic soil order, by definition, contains more than 16% C, C content is not a useful measure of soil quality for that order. The response curves fitted the 'more is better' model. Total C targets for soil quality for environmental protection were higher than those for production (Figs 1.1, 1.2). The target for the Semiarid soil order was lower than for other orders, recognising that organic matter content in that soil type and environment rarely attains the levels of other soil orders. Conversely, total C content for the Allophanic Soils is higher than for the others because the high contents of allophanic clays and hydroxy-aluminium compounds tend to stabilise larger amounts of organic C in those soils.

There were no upper limits defined ('more is better'), but the desirable lowest level was 3% for Allophanic Soils, 2% for Semiarid, Pumice and Recent soils, and 2.5% for all other orders except the Organic Soils (Table 1.1).

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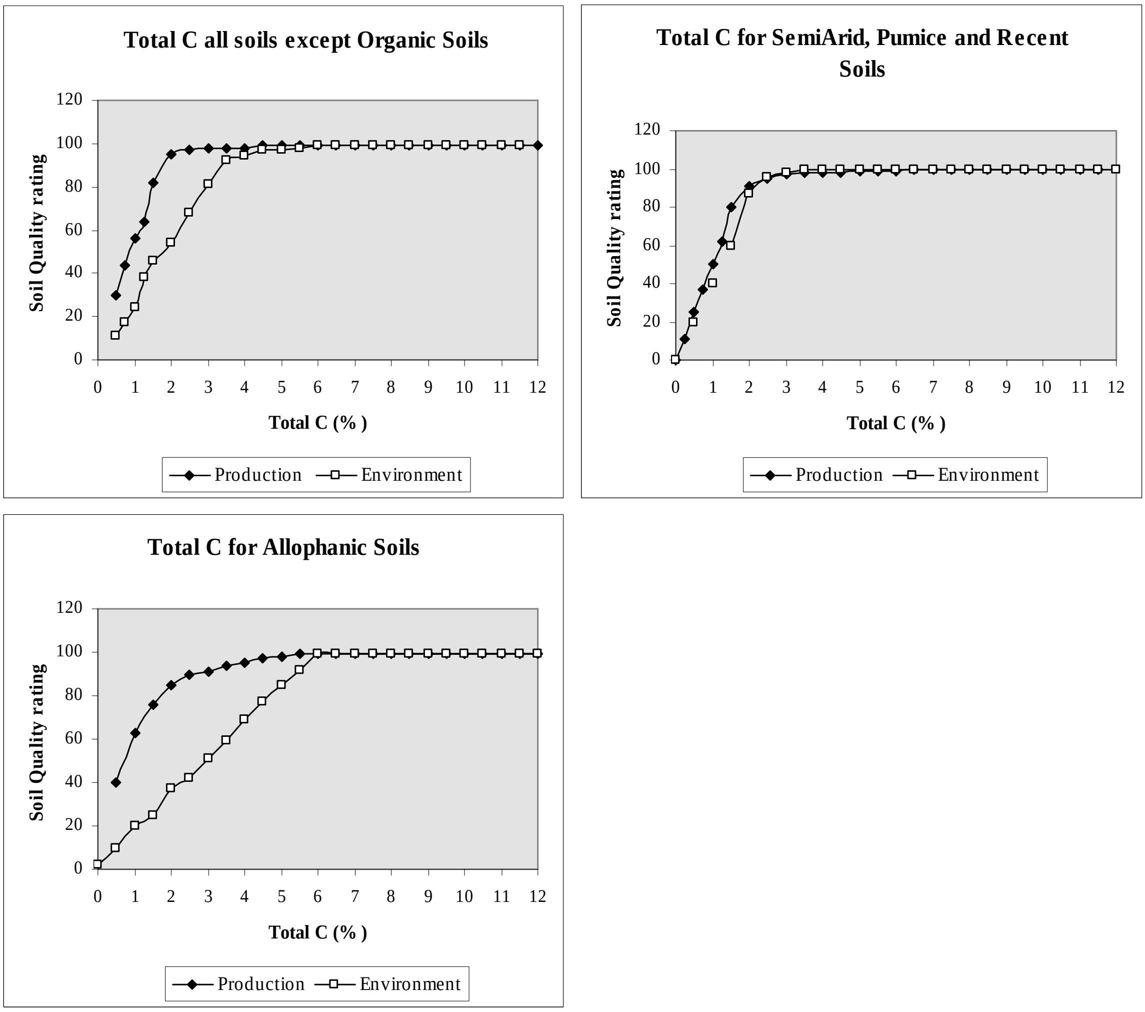

Fig. 1.1 Soil quality response curves for total C.

Notes: No curve is presented for Organic (peat) Soils. These soils by definition have an organic C content >16% and organic C is not a useful measure of their quality.

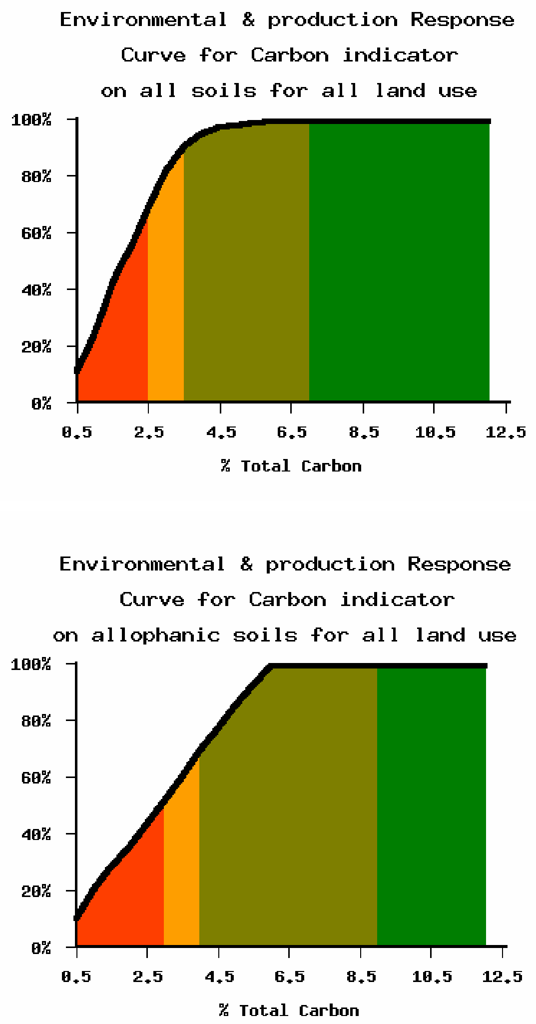

Fig. 1.2 Combined soil quality response curves for total C.

Table 1.1 Provisional quality classes and target ranges for total C

Allophanic	0.5	**3**	4	9	12
Semiarid, Pumice & Recent	0	**2**	3	5	12
All other soil orders except Organic	0.5	**2.5**	3.5	7	12
Organic	Exclusion				
	Very depleted	Depleted	Normal	Ample	

Notes: Applicable to all land uses. Organic Soils by definition must have >15% total C content, hence C content is not a quality indicator for that order and is defined as an 'exclusion'. Target ranges for cropping and horticulture are also poorly defined.

2. Response curve for total nitrogen (N)

What is total N?

As the name implies, the total N content of a soil is a measure of the total amount of all forms of nitrogen in soil. Typically, in topsoils, organic matter N makes up more than 90% of the total N. N is an essential major nutrient for plants and animals, and the store of organic matter N is an important measure of soil fertility. Organic N needs to be mineralised to inorganic forms (ammonium and nitrate) by soil micro-organisms before it can be used by plants. Total N tends to accumulate under clover–ryegrass pastures, which can be of benefit for pasture production. C:N ratios run in the pattern pastures>crops<plantations<indigenous vegetation. However, very high total N contents under pastures are becoming of concern for environmental goals because of the potential to contribute to nitrate levels in soil, and to increase leaching losses and eutrophication.

How was it measured?

Total N is measured as gaseous N after catalytic high temperature combustion. Some laboratories still use the long-established Kjeldahl digestion method, which involves heating soil in concentrated acid to convert all N to ammonium forms. Ammonium is then measured colorimetrically, or by steam distillation and titration.

Response curves

The response curves showed two distinct patterns depending on whether they were for production or environmental criteria. Production curves followed the ‘more is better’ pattern; those for environmental goals followed the ‘less is better’ pattern (Figs 2.1, 2.2). Curves were only produced for pastures and for forestry land uses, there being insufficient data to specify curves for cropping and horticulture. In general, low total N contents were considered very undesirable for production (Figs 2.1, 2.2).

Target ranges were set at 0.25–0.70% for pastures and 0.10–0.70% for forestry. Those ranges recognise that forest plantations are often sited on soils with low levels of organic matter (Table 2.1).

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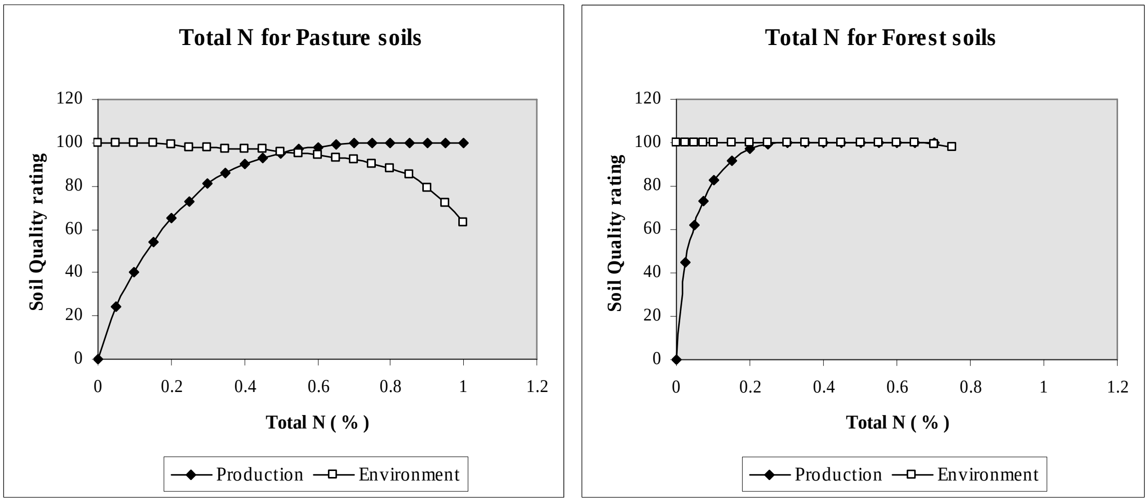

Fig. 2.1 Soil quality response curves for total N.

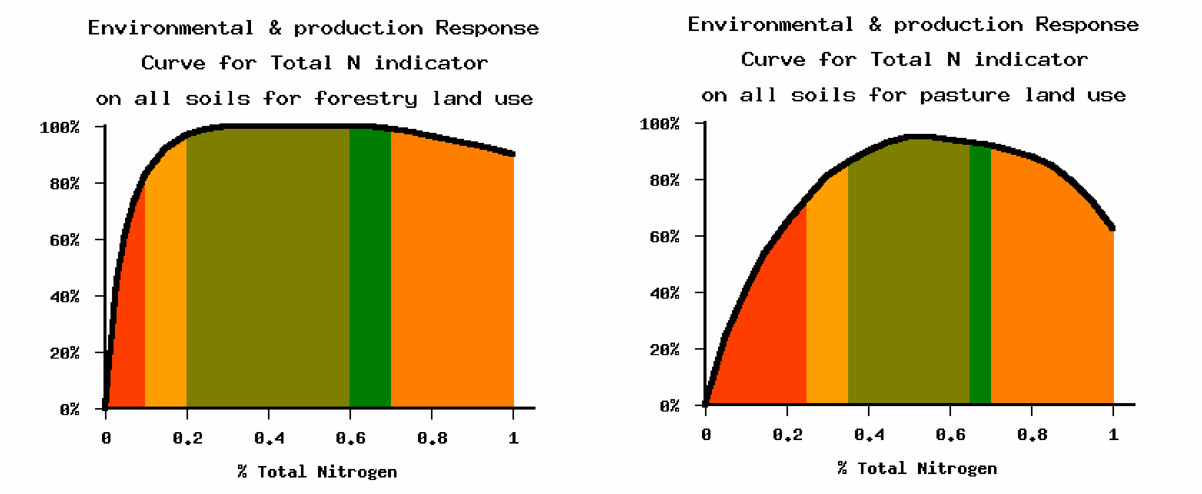

Fig. 2.2 Combined soil quality response curves for total N.

Table 2.1 Provisional quality classes and target ranges for total N

Pasture	0	**0.25**	0.35	0.65	**0.7**	1.0
Forestry	0	**0.10**	0.2	0.6	**0.7**	1.0
Cropping & horticulture	exclusion					
	Very depleted	Depleted	Adequate	Ample	High	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are not specified as target values will depend on the specific crop grown.

3. Response curves for anaerobically mineralised nitrogen

What is anaerobically mineralised nitrogen?

Anaerobically mineralised nitrogen (AMN) is a laboratory measure of the amount of nitrogen that can be supplied to plants through the decomposition of soil organic matter. It is a useful measure of soil organic matter quality in terms of its ability to store nitrogen useful to plants. The amount of AMN has also been found to correspond with the amount of soil microbial biomass (Hart et al. 1986; Myrold 1987).

How was it measured?

AMN is estimated in the laboratory using the anaerobic incubation method. Sieved, moist soil is incubated under waterlogged conditions (5 g equivalent dry weight soil with 10 ml water) for 7 days at 40°C. The increase in ammonium-N extracted in 2 M KCl over the 7 days gives a measure of potentially mineralisable N.

Response curves

The response curves generally fell into the category of 'more is better' for production purposes, but 'optimal range' to meet environmental criteria. Separate curves were therefore constructed for environmental and production targets, and different curves were required for pasture, forestry and horticultural land uses (Fig. 3.1). The curves were considered applicable to all soil orders. The combined curves had a flat humpback shape (Fig. 3.2). The target range for pasture was 50–250 µgN/g, for forestry 20–175 µgN/g, and for cropping and horticulture 20–200 µgN/g (Table 3.1). These targets recognise the generally greater organic N contents of pastures. The main risk to the environment from high AMN was the increased chance of nitrate leaching and eutrophication of receiving waters.

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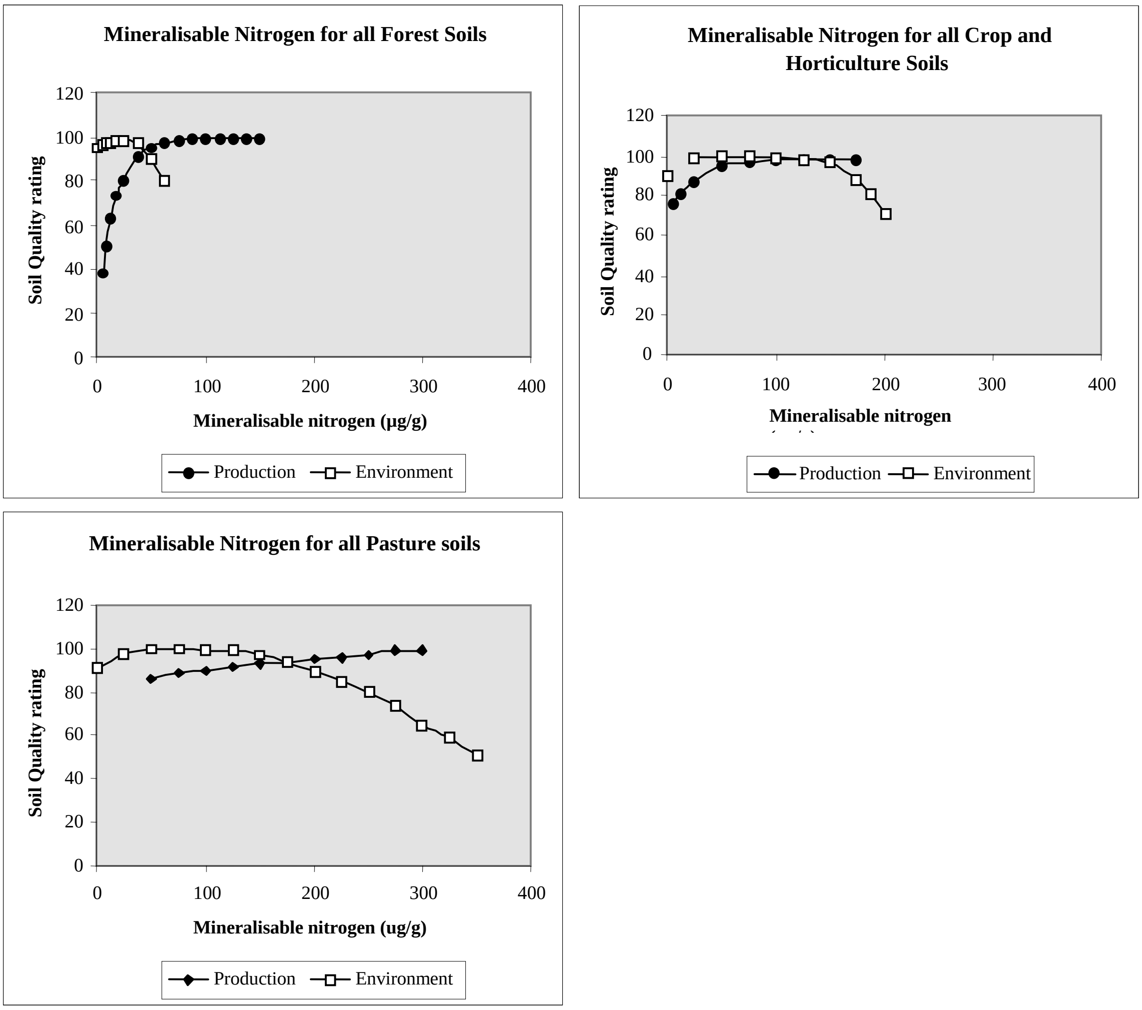

Fig. 3.1 Soil quality response curves for anaerobically mineralisable N.

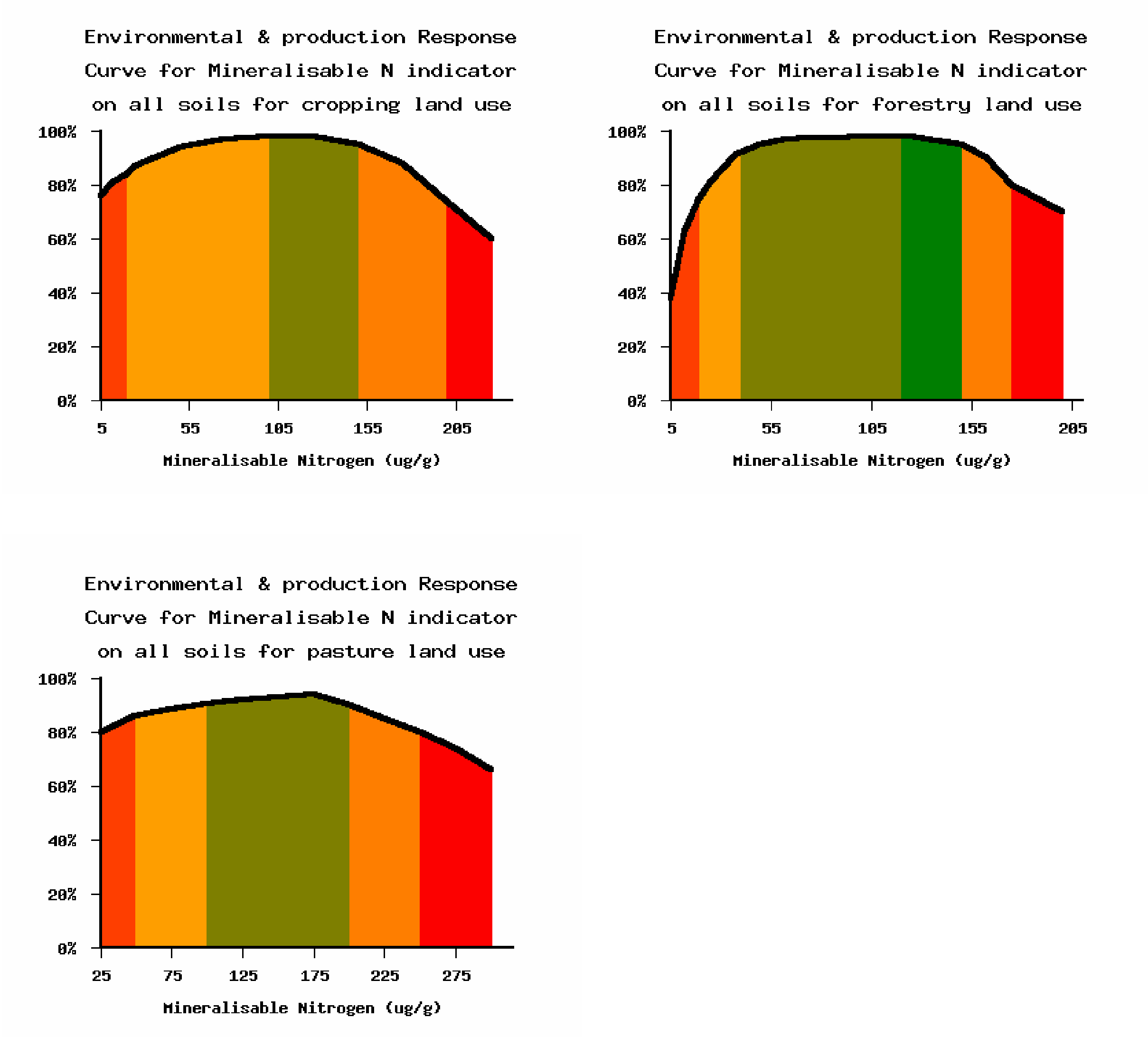

Fig. 3.2 Combined soil quality response curves for anaerobically mineralisable N.

Table 3.1 Provisional quality classes and target ranges for anaerobically mineralisable N

Pasture	25	**50**	100	200	200	**250**	300
Forestry	5	**20**	40	120	150	**175**	200
Cropping & horticulture	5	**20**	100	150	150	**200**	225

Very low	Low	Adequate	Ample	High	Excessive

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are poorly defined.

4. Response curves for soil pH

What is pH?

The pH scale measures the acidity or alkalinity of a substance. The acidity depends on the number of H^+ ions in solution. Most plants and soil animals have an optimum pH range for growth, and the pH of soil affects which species will grow best. Most forest soils in New Zealand are acidic, and indigenous forest species are generally tolerant of acid conditions. Introduced exotic pasture and crop species require a more alkaline soil. Excess soil acidity is normally corrected by topdressing with lime (ground limestone) to raise the pH.

How was it measured?

Soil pH is usually measured by glass electrode in a slurry of 1 part by weight of soil to 2.5 parts water. The units are expressed on a logarithmic scale that runs from 0 to 14, with neutrality at pH 7. Most New Zealand mineral soils fall within a pH range of 5–8. Some unmodified peats may have pH around 3–4.

Response curves

Separate curves were required for mineral and organic (peat) soils. In general, Organic Soils had a lower pH optimum. Response curves were also different for pastures, for crops and horticulture, for forestry and for indigenous vegetation. For each land-use category, separate pH curves were required to depict soil quality for production purposes and soil quality for the environment. In general, the pH response curves for production goals showed a marked 'optimum range', but this was less marked for environmental goals (Fig. 4.1). The combined curves showing soil pH for pastures for both production and environmental goals showed a marked 'humpback' with pH optimum around 5.5–6.3 (Fig. 4.2). The target ranges for pastures were set at 5–6.6 for mineral soils and 4.5–7 for organic soils. Different crops have differing pH needs, and the pH range for this land use was set wider, at 5–7.6 on mineral soils and 4.5–7.6 on organic soils. The pH targets for forestry land use were set at a lower pH (3.5–7.6), reflecting the greater tolerance of acidity of forest species (Table 4.1). No limits were set for forestry on organic soils, as this was not considered a practical land-use combination.

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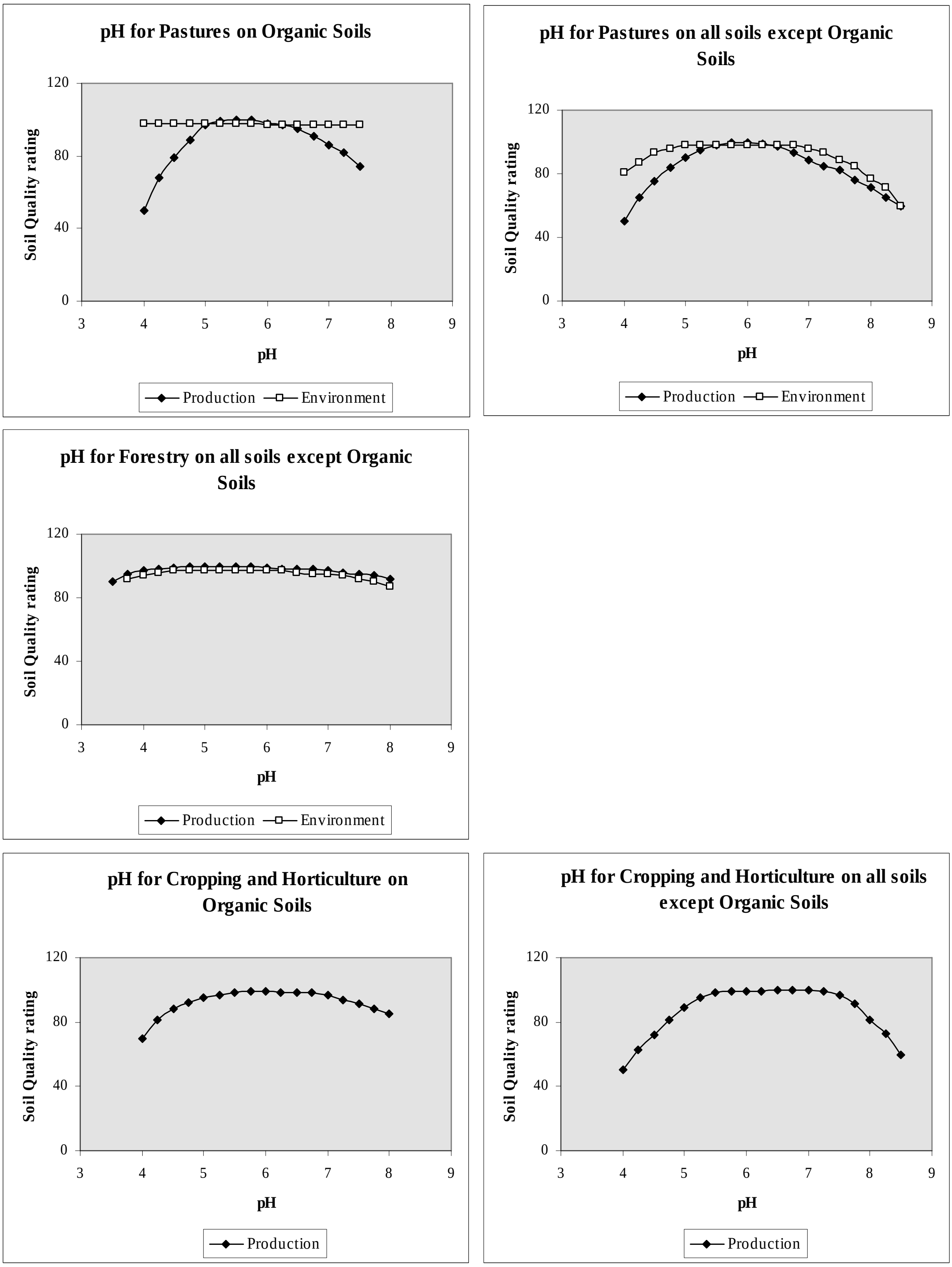

Fig. 4.1 Soil quality response curves for soil pH.

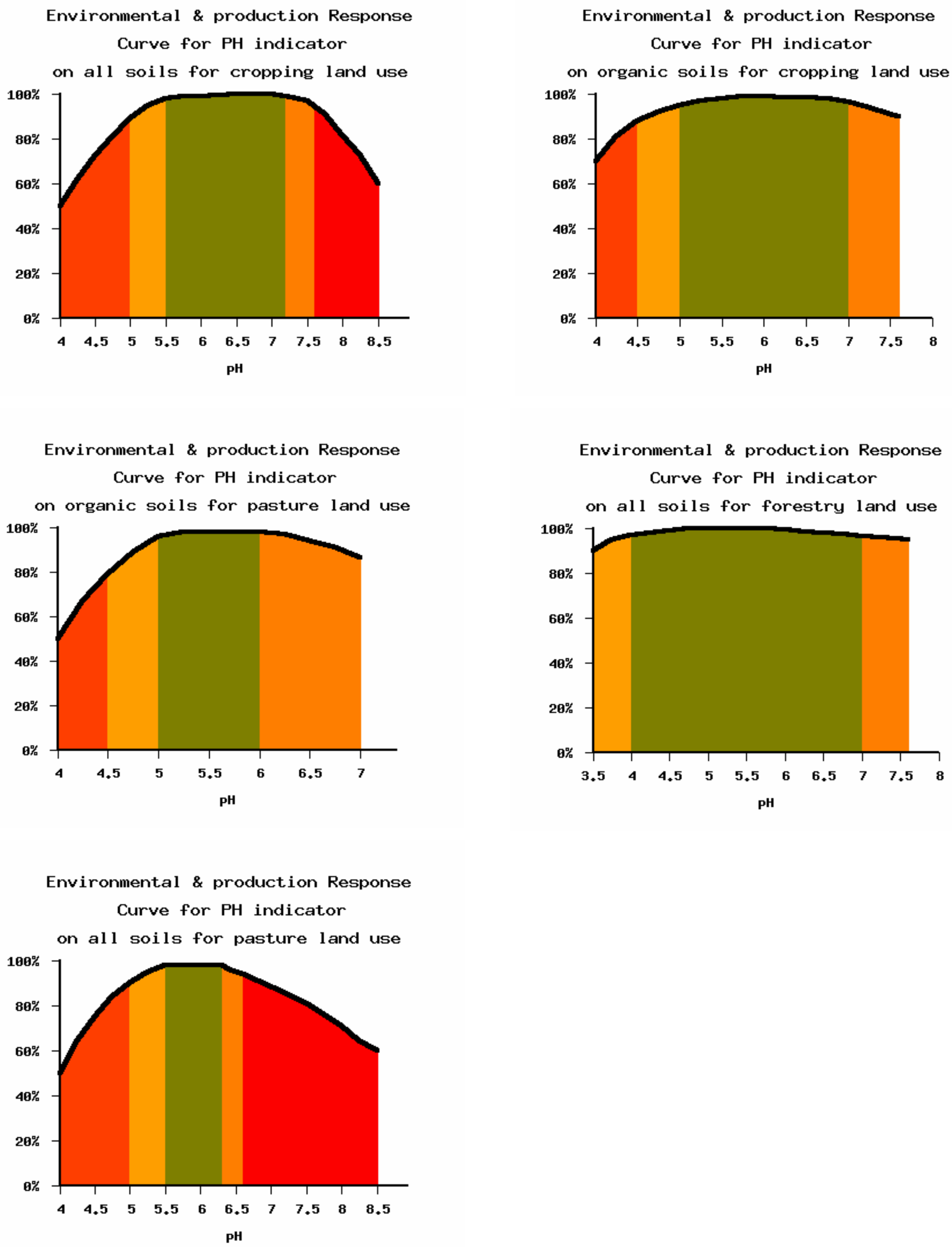

Fig. 4.2 Combined soil quality response curves for soil pH.

Table 4.1 Provisional quality classes and target ranges for soil pH

Pastures on all soils except Organic	4	**5**	5.5	6.3	**6.6**	8.5
Pastures on Organic Soils	4	**4.5**	5	6	**7.0**	
Cropping & horticulture on all soils except Organic	4	**5**	5.5	7.2	**7.6**	8.5
Cropping & horticulture on Organic Soils	4	**4.5**	5	7	**7.6**	
Forestry on all soils except Organic		**3.5**	4	7	**7.6**	
Forestry on Organic Soils	exclusion					
	Very acid	Slightly acid	Optimal	Sub-optimal	Very alkaline	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are general averages and target values will depend on the specific crop grown. Exclusion is given for forestry on organic soils, as this combination is unlikely in real life because of windthrow.

5. Response curves for Olsen phosphate (P)

What is Olsen P?

Phosphorus (P) is one of the three major nutrients required by plants and animals. P occurs in many different forms in soil, but it is only the phosphate form that is taken up by plants. There is very little phosphate in soil solution; most 'available' phosphate is adsorbed onto clays and organic matter. The Olsen extractant tries to mimic the ability of a plant to remove solution and absorbed phosphates from soil, and hence get a measure of the P status for plant nutrition. Olsen P has been measured in many agronomic tests for crop production, and is used to calculate rates of P fertiliser application.

How was it measured?

Soil is extracted with a solution of 0.5 M $NaHCO_3$ (sodium bicarbonate) at pH 6.5, and a soil: solution ratio of 1:20. P concentration in the extract is measured by the phospho-molybdenum blue reaction.

Response curves

Separate curves are required for Allophanic, Pumice and Organic soils. These correspond to the Volcanic, Pumice and Peat soil categories used by MAF and AgResearch. The other soil orders are combined and approximate to the 'sedimentary' soil category used by MAF and AgResearch. P requirements differ for different land uses and for environmental and production goals (Figs 5.1, 5.2)

Target ranges for pastures were 15–100 µgP/cm^3, although the shape of the response curves differed between these ranges. The lower limit for cropping and horticulture on sedimentary and Allophanic soils was 20 µgP/cm^3, and 25 µgP/cm^3 on Pumice and Organic soils. The lower limit for forestry on all soil orders was 5 µgP/cm^3; the upper limit for all land uses and soil categories was 100 µgP/cm^3 (Table 5.1)

Sources of information

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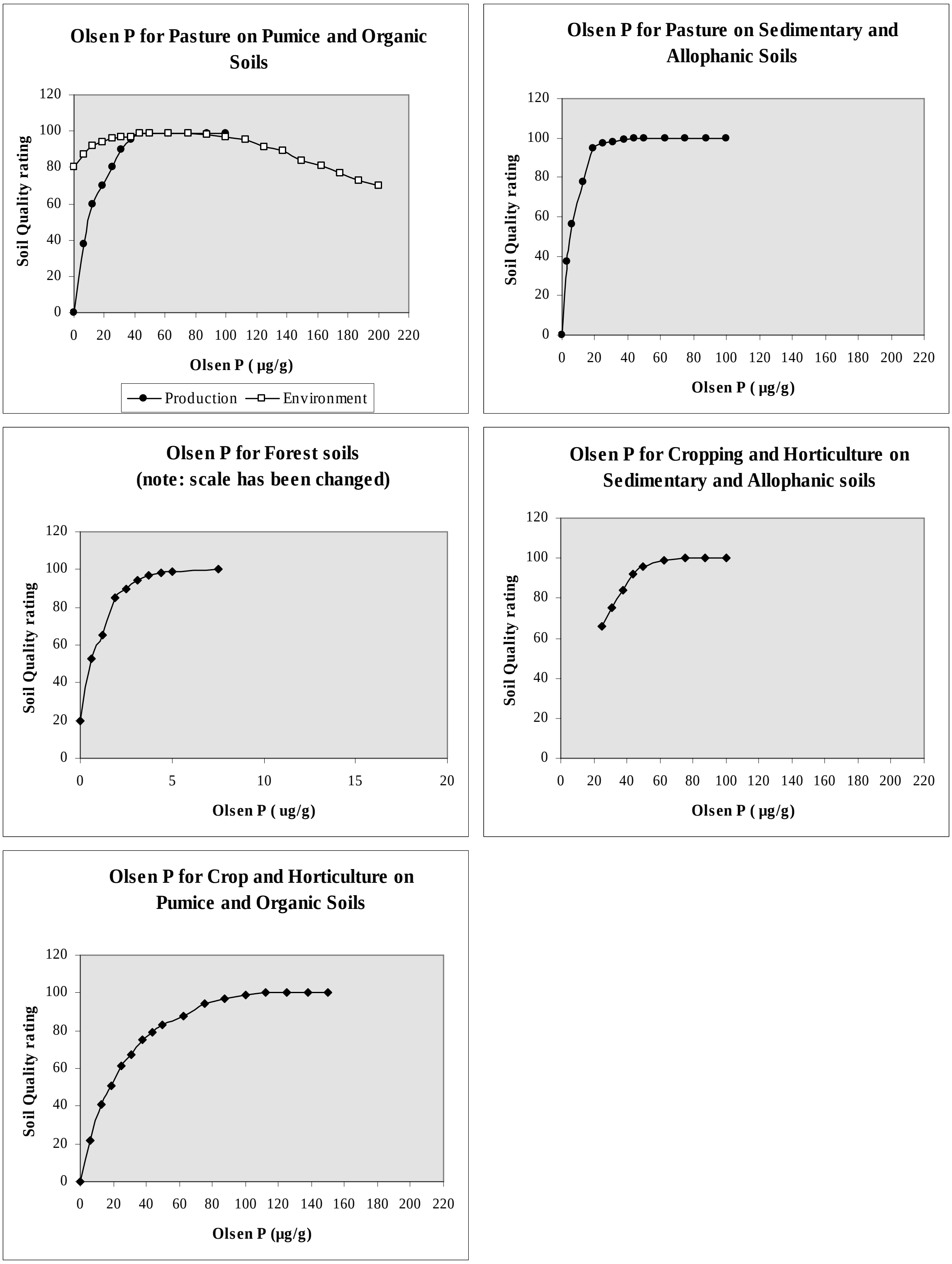

Fig. 5.1 Soil quality response curves for Olsen P.

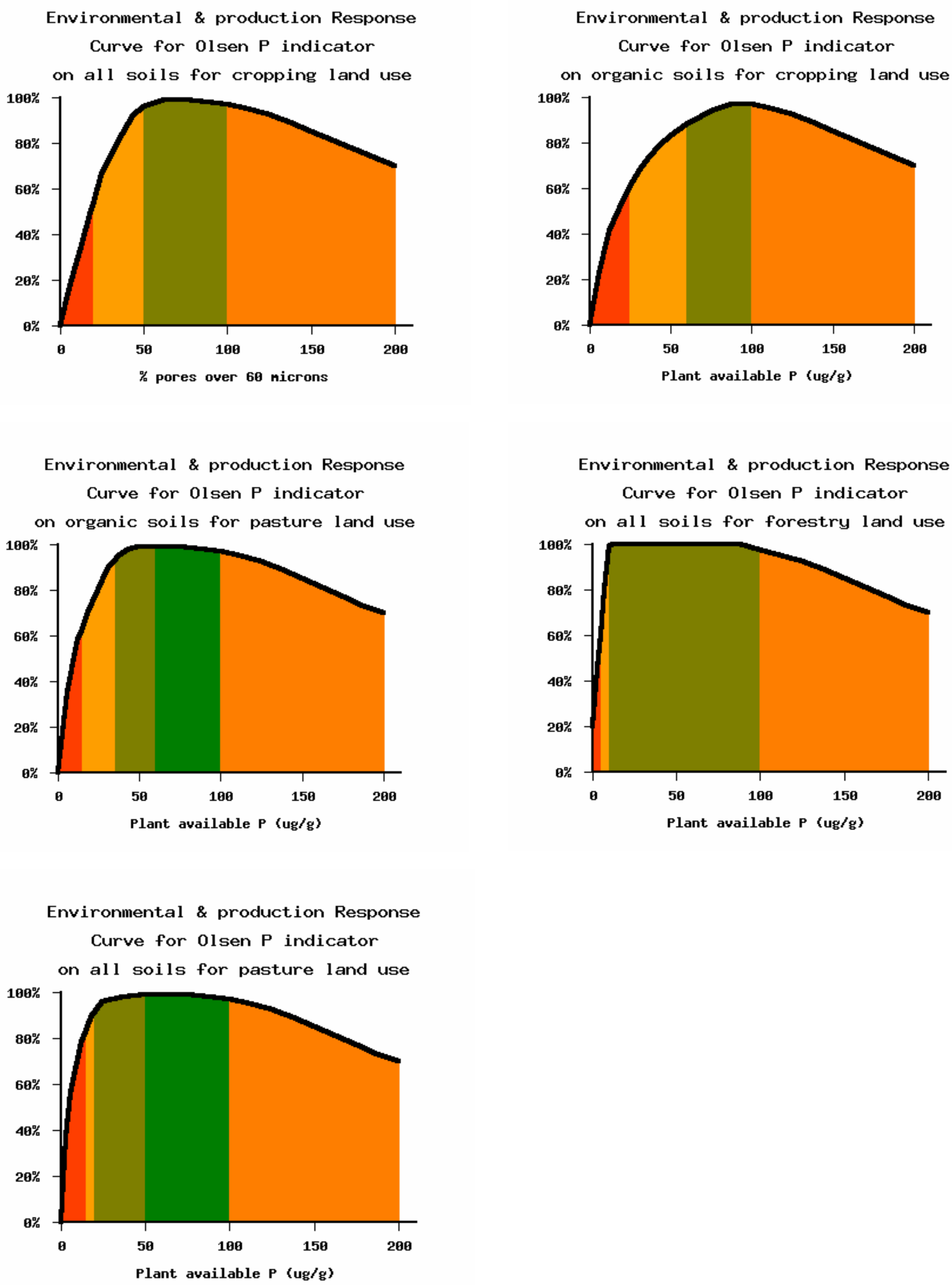

Fig. 5.2 Combined soil quality response curves for Olsen P.

Table 5.1 Provisional quality classes and target ranges for Olsen P

Pasture on Sedimentary & Allophanic soils	0	**15**	20	50	**100**	200
Pasture on Pumice & Organic soils	0	**15**	35	60	**100**	200
Cropping and horticulture on Sedimentary & Allophanic soils	0	**20**	50	100	**100**	200
Cropping and horticulture on Pumice & Organic soils	0	**25**	60	100	**100**	200
Forestry on all soil orders	0	**5**	10	100	**100**	200
	Very low	Low	Adequate	Ample	High	

Notes: Sedimentary soil (AgResearch classification system) includes all other soil orders except Allophanic (volcanic ash), Pumice, and Organic.

6. Response curves for bulk density

What is bulk density?

Bulk density gives a measure of how densely a soil is packed. Soils typically have about half of their volume comprised of voids (pore spaces). If these voids are lost through compaction, bulk density increases. The voids hold water and air and also allow water and air to move through soil. Compacted soils have poor aeration, are slow draining, and roots find it difficult to grow and push through such soil. Bulk density is influenced by the amount of organic matter in soils, their texture, constituent minerals and porosity. Soils with very low bulk density are open textured and porous but may be so loose they are susceptible to erosion, dry out quickly, and roots find it difficult to get purchase and absorb water and nutrients.

How was it measured?

Intact cores or soil blocks are needed to measure bulk density, so bulk density measurements can be conveniently combined with moisture release characteristics to measure porosity and available water. A known volume of soil is dried at 105°C, and weighed. Bulk density is the mass per unit volume, usually expressed in SI units as Mg/m^3. Equivalent units are g/cm^3 or $tonnes/m^3$.

Response curves

The bulk density response curves followed the 'optimum range' pattern Separate curves were required for (1) Semiarid, Pallic and Recent soils, (2) Allophanic Soils, (3) Organic Soils, (4) Pumice and Podzol soils, (5) All other soil orders. A single curve was considered adequate to meet both production and environmental soil quality goals. The four separate curves reflect the differing organic matter contents and mineralogy of the soil orders. High bulk density was considered less desirable than low bulk density (Figs 6.1, 6.2).

Insufficient data were available to differentiate between land-use categories, and the curves are applicable to all uses. Because of this lack of knowledge, the target ranges are broad (Table 6.1). Target ranges for the lower-density Allophanic Soils were set at 0.5–1.3 Mg/m^3 and those for Organic Soils at 0.2–1.0 Mg/m^3. Desirable ranges for the Semiarid, Pallic and Recent soils were 0.7–1.4 Mg/m^3, and for all other orders 0.6–1.4 Mg/m^3.

Sources of information

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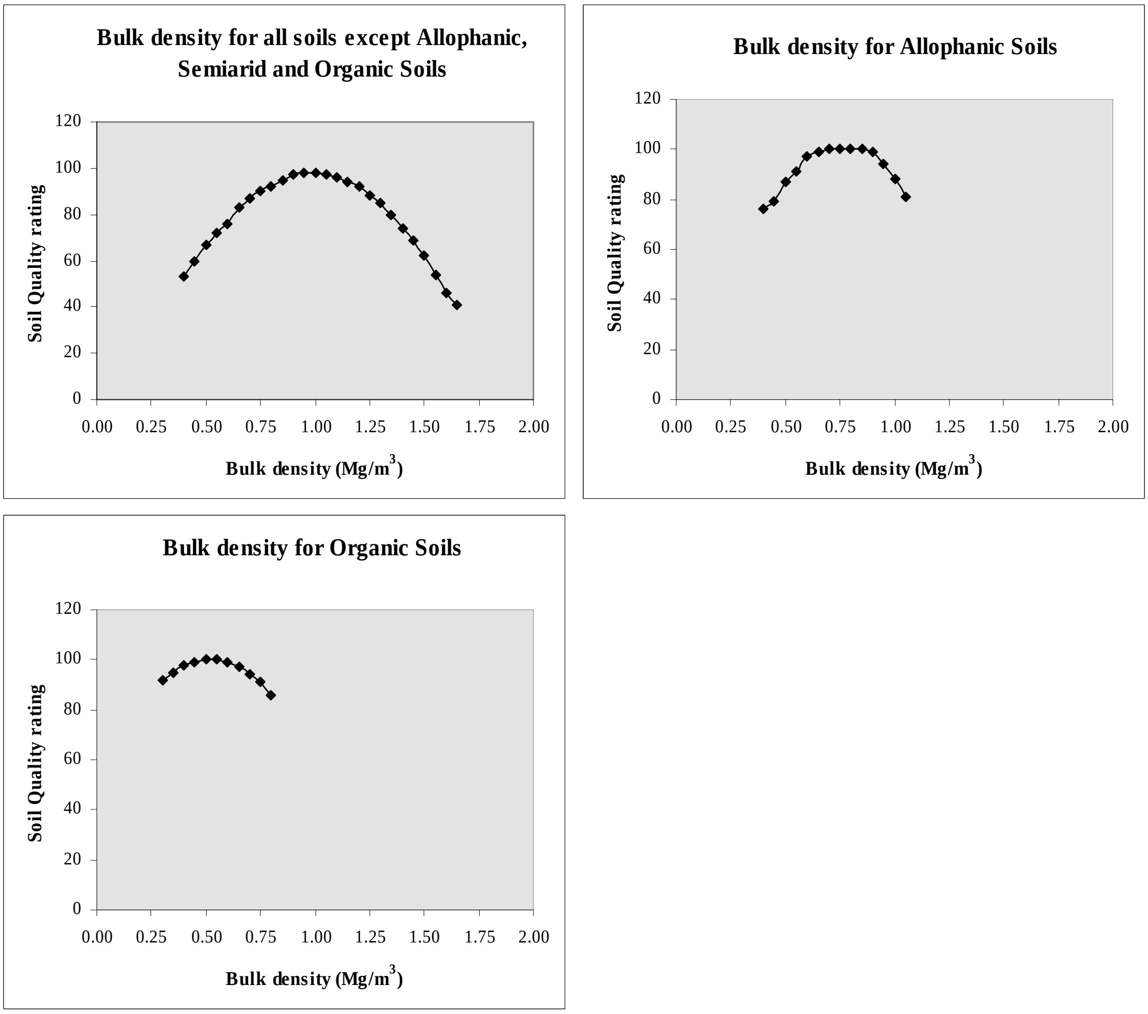

Fig. 6.1 Soil quality response curves for bulk density.

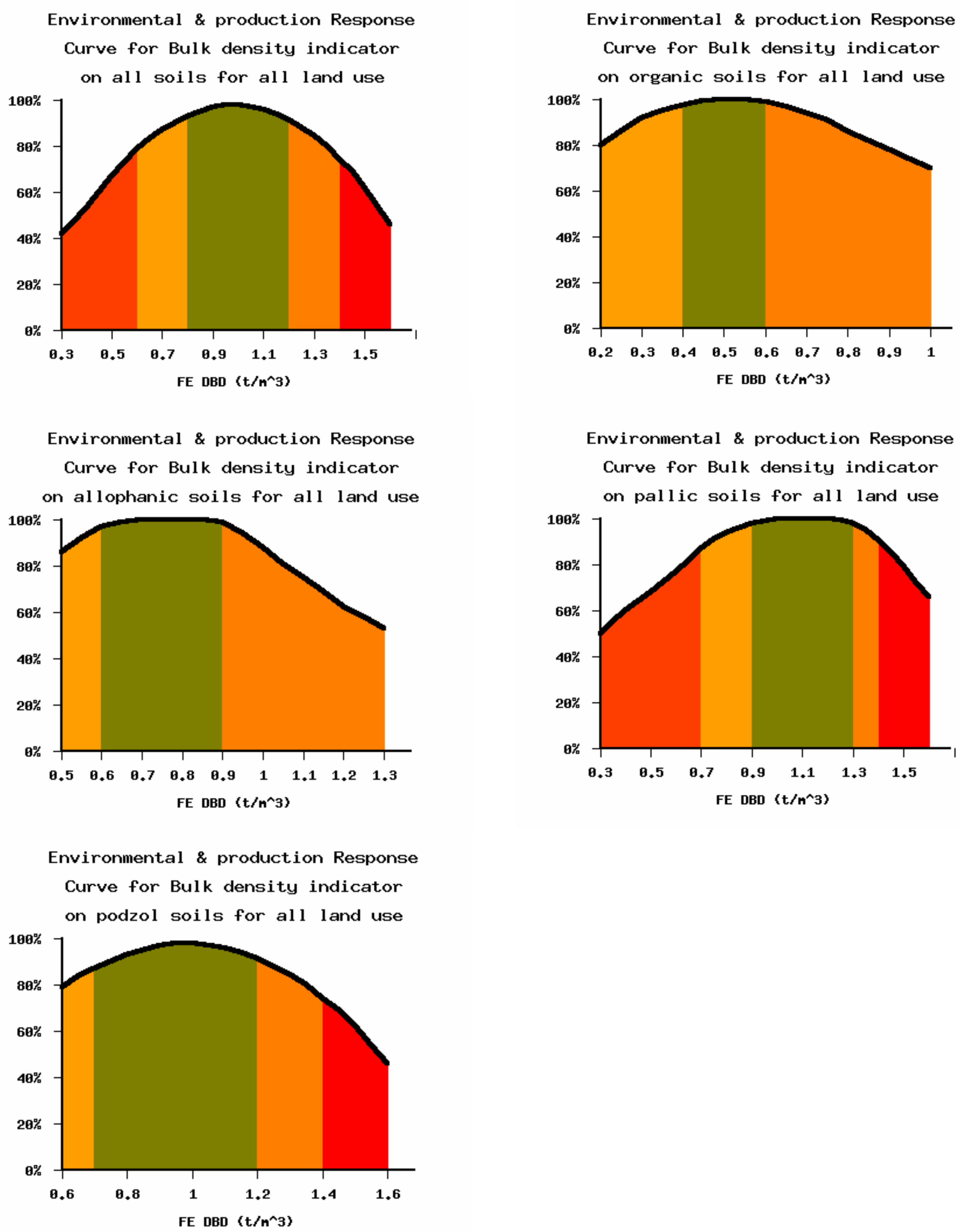

Fig. 6.2 Combined soil quality response curves for bulk density.

Table 6.1 Provisional quality classes and target ranges for bulk density

Semiarid, Pallic & Recent soils	0.3	**0.7**	0.9	1.3	**1.4**	1.6
Allophanic Soils		**0.5**	0.6	0.9	**1.3**	
Organic Soils		**0.2**	0.4	0.6	**1.0**	
Pumice & Podzol soils		**0.6**	0.7	1.2	**1.4**	1.6
All other soils	0.3	**0.6**	0.8	1.2	**1.4**	1.6
	Very loose	Loose	Adequate	Compact	Very compact	

Notes: Applicable to all land uses. Target ranges for cropping and horticulture are poorly defined.

7. Response curves for macroporosity

What is macroporosity?

Macroporosity is a measure of the number of large pores in soil. Large pores are defined as those with a diameter greater than 60 µm. Macropores are important for air penetration into soil, and are the first pores to be lost when soils are compacted. Low macroporosity reduces soil aeration, resulting in less clover growth and N-fixation and decreased pasture yields.

How was it measured?

A series of measures based on the moisture release characteristics, particle and bulk density are needed to calculated macroporosity. Moisture release characteristics are obtained from drainage on pressure plates at specific tensions (−5, −10, −100 and −1500 kPa; Gradwell & Birrell 1979). The proportion of macropores is calculated from the total porosity and moisture retention data: $S_m = S_t - \theta$ where S_m is macroporosity, and θ is the volumetric water content at −10 kPa tension (Klute 1986). The total porosity is calculated from the formula: $S_t = 100[1 - (p_b/p_p)]$ (Klute 1986), where S_t is total porosity, p_p is the particle density and p_b is the dry bulk density. The dry bulk density is obtained from the mass of an intact soil core of known volume dried at 105°C (Gradwell & Birrell 1979). The weight of the oven-dry soil, expressed per unit volume, gives the bulk density. The particle density is measured by the pipette method as described by Claydon (1989) and used to calculate total porosity as explained above. Porosity is expressed as the proportion of pores per unit volume of soil (v/v%).

Response curves

This soil quality characteristic fell in the category of 'optimal range'. A single response curve was considered adequate for all soil orders and for pasture, horticulture and cropping soils, but a different curve was obtained for forestry land use (Fig. 7.1). These two curves were also considered adequate to cover both production and environmental criteria (Fig. 7.2). Low macroporosity was undesirable because of poor aeration, while high microporosity implied the soil was very loose, leading to susceptibility to erosion and poor water capillarity. Macroporosity in the range 8–30% was considered acceptable, with sharp declines in soil quality outside that range (Figs 7.1, 7.2). Target ranges for pastures, horticulture and cropping soils were therefore defined as 6–30%, and for forestry as 8–30% (Table 7.1).

Sources of information

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Drewry JJ, Littlejohn RP, Paton RJ 2000. A survey of soil physical properties on sheep and dairy farms in southern New Zealand. New Zealand Journal of Agricultural Research 43: 251–258.

Drewry JJ, Cameron KC, Buchan GD 2001. Effect of simulated dairy cow treading on soil physical properties and ryegrass pasture yield. New Zealand Journal of Agricultural Research 44: 181–190.

Drewry JJ, Littlejohn RP, Paton RJ, Singleton PL, Boyes M, Judge A, Monaghan RM, Smith LC 2002. Dairy pasture yield responses to macroporosity and soil physical properties, and variability of large and small samples. In: Currie LD, Loganathan P eds Dairy farm soil management. Occasional Report No. 15. Palmerston North, Fertilizer and Lime Research Centre, Massey University. Pp. 61–78.

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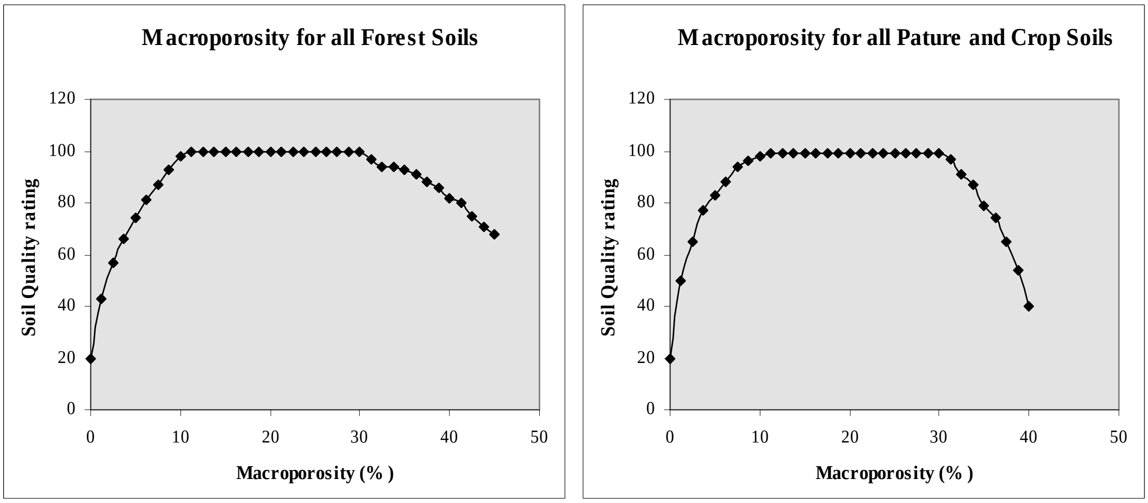


Fig. 7.1 Soil quality response curves for macroporosity.

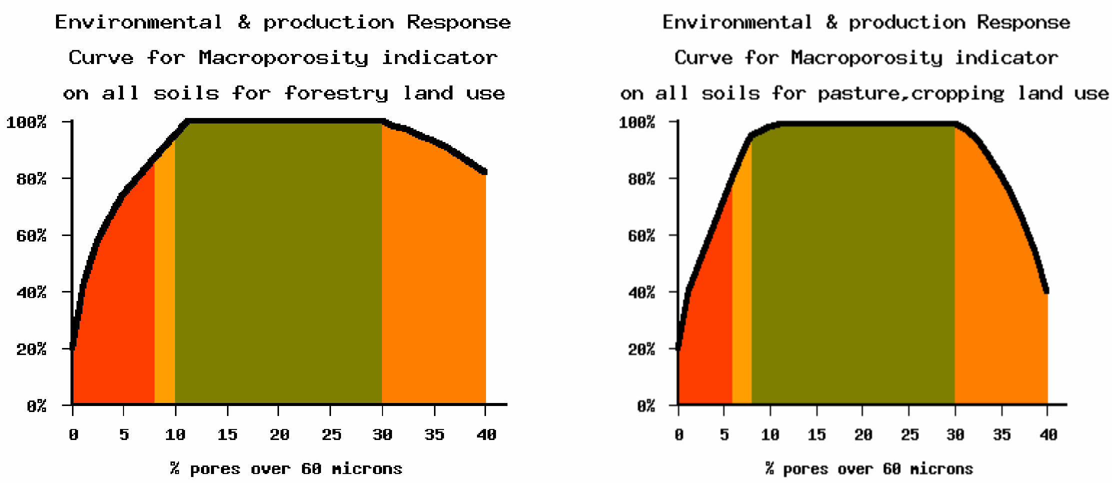


Fig. 7.2 Combined soil quality response curves for macroporosity.

Table 7.1 Provisional quality classes and target ranges for macroporosity

Pasture, cropping & horticulture	0	**6**	8	**30**	40
Forestry	0	**8**	10	**30**	40
	Very low	Low	Adequate	High	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are poorly defined, and almost nothing is known about indigenous forest species.

Appendix

Additional soil quality indicators

Several additional indicators not currently part of the recommended minimum data set were also considered by the expert groups. The response curves for these additional indicators, plus comments, are supplied here. In most cases target values have not been specified as these were not considered by the group that completed that stage of the study.

A target of >2 mm as a lower limit for the aggregate stability test has been suggested by Crop and Food Research as appropriate for cropping soils in Canterbury.

Rooting depth

A rooting depth in excess of 70 cm was considered necessary for optimum soil quality for production (Fig. 8.1). A rooting depth of at least 50 cm was defined for optimum soil quality for environmental criteria. The reason for the greater soil depth needed for production presumably reflects the greater demand on soil nutrients and water supply when the soil is used for shorter-term production goals.

Workshop notes

Rooting depth and topsoil depth might be simple soil characteristics that can provide a useful soil quality measure. Shallow rooting depth tends to lead to decreased production. There are various reasons for this, including decreased water storage, fewer nutrients, and windthrow. Forest harvesting on shallow soil leads to soil erosion and runoff.

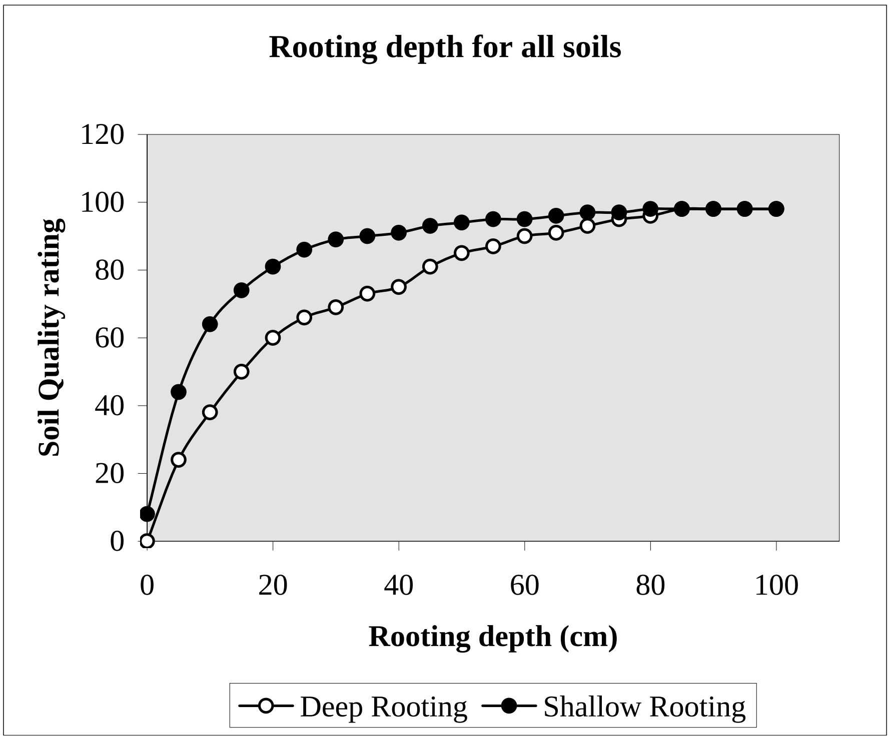


Fig. 8.1 Soil quality responses curve for rooting depth.

Note: Deep rooting under production has the same values as environment.

Earthworms

Earthworms, being large macrofauna, are readily visible in soil (when present) and provide good instant feedback without the necessity of laboratory tests. They are therefore useful for on-farm self-monitoring schemes. Sampling equipment is simple (spade, plastic sheet and pottles). Most earthworms in pastures and cropping land in New Zealand are introduced European Oligochaete species; such worms are not common in native ecosystems or forest plantations, and soil quality criteria using Oligochaete earthworms for these ecosystems are not defined.

Earthworm numbers in excess of 700/m^2 were considered to reflect optimal soil quality for pasture production (Fig. 8.2). Optimal numbers under pasture when environmental criteria were considered were also >700/m^2, but numbers in excess of 1200/m^2 were considered detrimental. The reason for the decrease in quality rating for environmental criteria at high numbers of earthworms reflected the risk of increased leaching and bypass flow through macropores because of the large numbers of earthworm channels.

Under cropping and horticulture, earthworm numbers in excess of 500/m^2 provided a high soil quality ranking. When environmental criteria were considered, numbers in excess of 100/m^2 were considered adequate for a high soil quality ranking, but that soil quality declined if numbers were in excess of 1300/m^2. The soil system will only sustain a certain worm population (there is a maximum limit). Time of sampling is important, as there is a big seasonal fluctuation in numbers of worms. The best time for sampling is in winter/spring.

Workshop notes

Pasture: Production factors

When numbers fall below 400–600 m^2, this is related to a small decrease in intensive pasture production.

Pasture: Environmental quality

Earthworms aid infiltration. There are also possible effects of earthworms and their burrows on leaching, biodiversity, and soil chemistry.

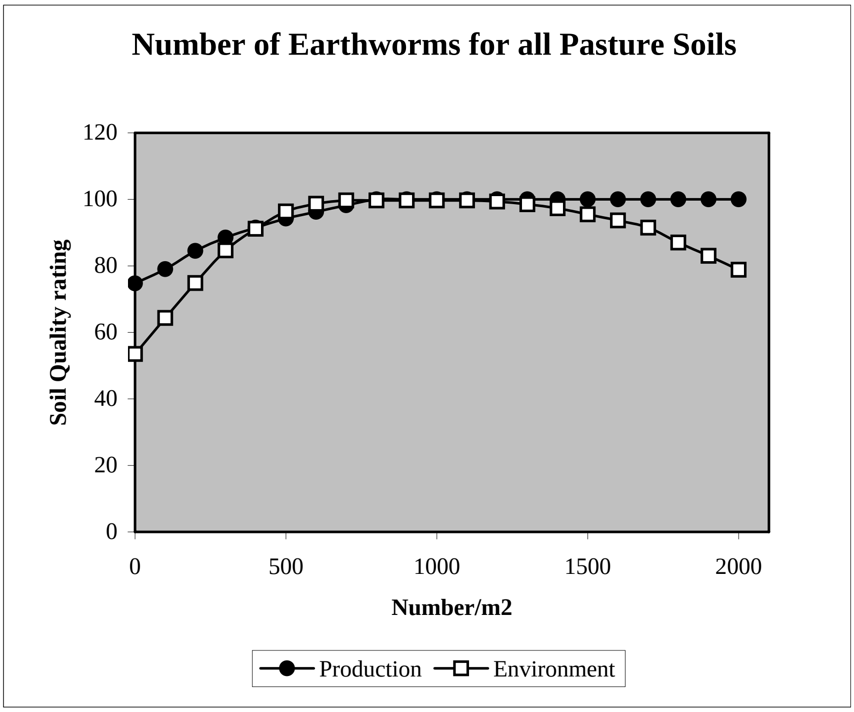
Cropping: Production factors

Probably will not get more than 900 earthworms/m^2 under cropping, because of soil disturbance and decreased organic matter return to the soil. There is general agreement that a low number of worms is linked to decreased production. But – more earthworms are not necessarily better.

Organic soils need to be considered in a separate category.

Other ecosystems

There are insufficient data about earthworms in pine plantations and indigenous ecosystems for worms to be used as indicators.



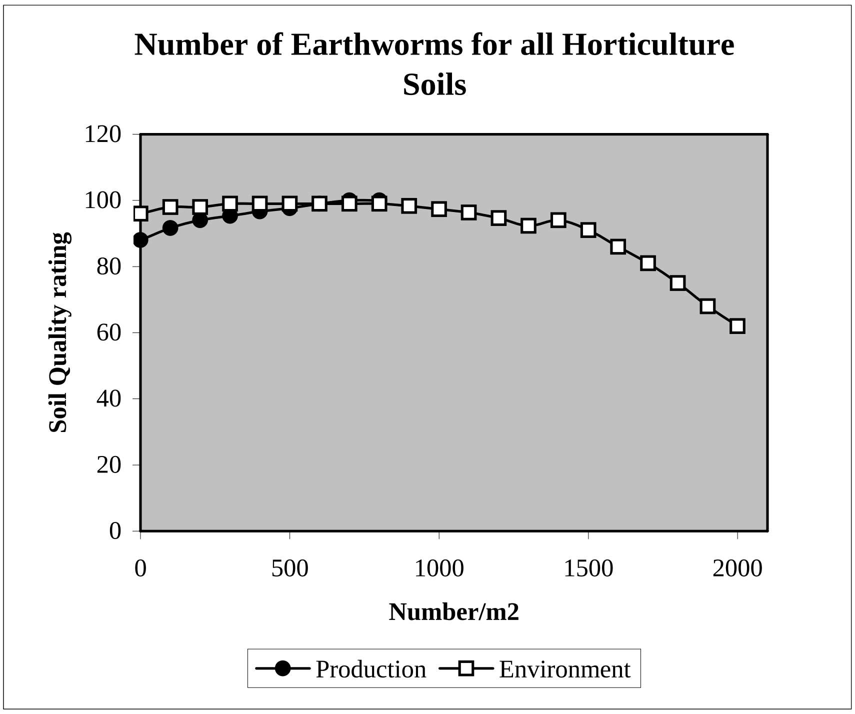


Fig. 8.2 Soil quality response curves for earthworm numbers.

C:N ratio

The C:N ratio provides a measure of organic matter quality, particularly in its ability to supply nitrates and ammonium through mineralisation.

The ratio applies to all soils and all land uses, but its interpretation depends on land use. Response curves were constructed for pastures, cropping & horticulture, and for forestry, applicable to all soil types. Overall, the curves follow the 'optimal range' pattern. For an optimum soil-quality rating for pastures, the C:N ratio needed to be in the range 8–12. For cropping & horticulture, the optimal range was considered to be 8–20, again reflecting the lesser dependence on N from organic sources. For forestry, a ratio less than 15 was considered optimal. In reality, it is unlikely a soil would have a C:N ratio of less than 8.

For environmental criteria, a single curve was obtained for all soils and land uses (Fig. 8.3). A C:N ratio of 7–30 was considered optimal. The lower soil quality ranking at <7 reflected the possible risk of excess N mineralisation and N leaching, while values <30 possibly reflected N limitation and poor ecosystem health.

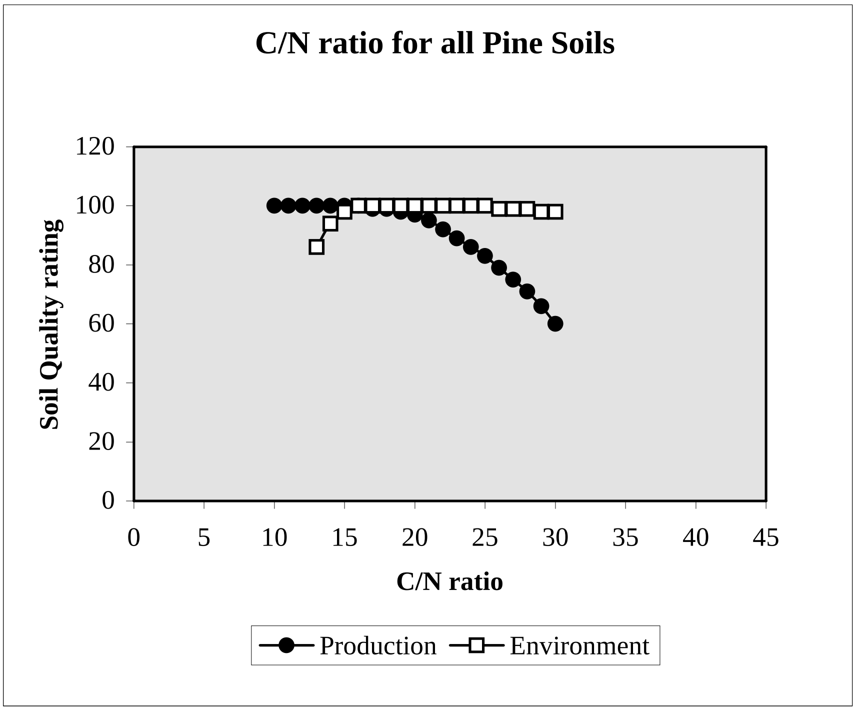
Workshop notes

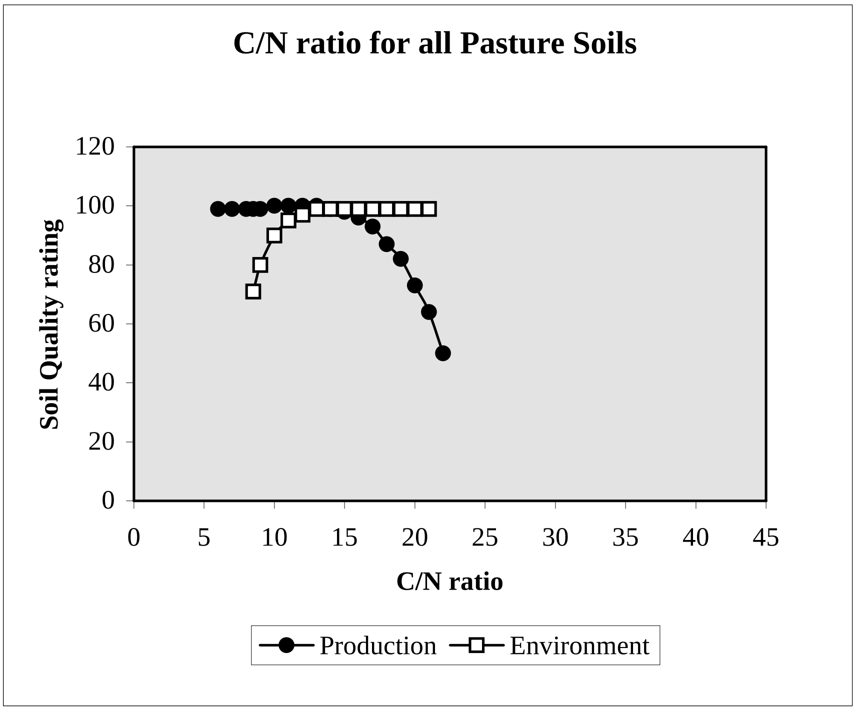
Production factors

A high C:N ratio may indicate possible N deficiency, but different land uses will vary in their expected responses. A maximum cut-off for C:N ratio should be 40; however, a high C:N ratio was not expected to adversely affect indigenous vegetation. The lower cut-off limit for C:N ratio for production purposes should be 5.

Environmental quality

Quality declines at low C:N ratio because of perceived risk of more N leaching.
Lower cut-off limit for C:N ratio should be 5, as for production factors.


C/N ratio for all Pine Soils
Soil Quality rating
120
100
80
60
40
20
0
0 5 10 15 20 25 30 35 40 45
C/N ratio
Production
Environment


C/N ratio for all Pasture Soils
Soil Quality rating
120
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0 5 10 15 20 25 30 35 40 45
C/N ratio
Production
Environment

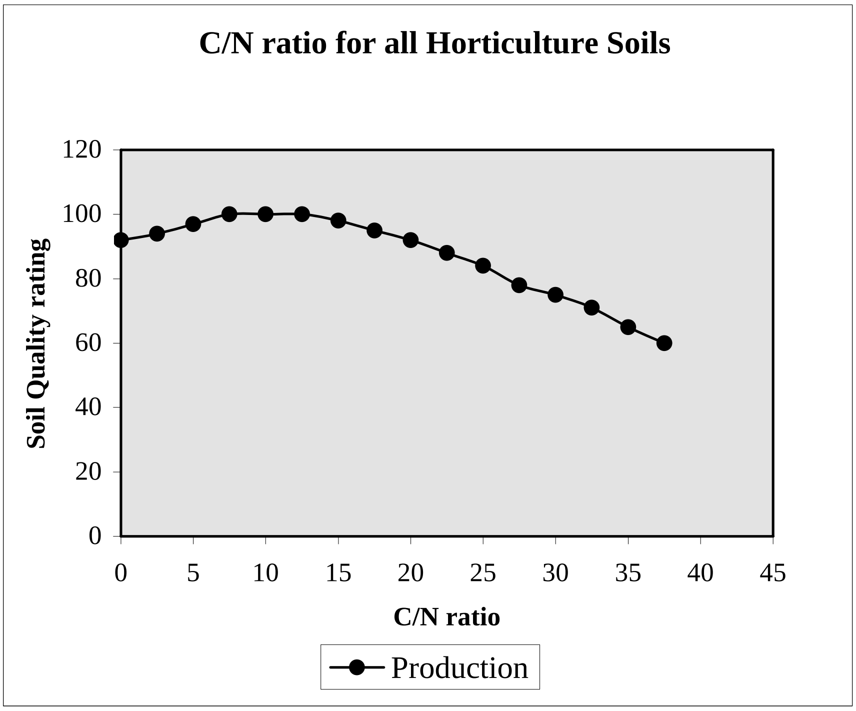


Fig. 8.3 Soil quality response curves for C:N ratio.

Aggregate stability

Soil quality rankings for aggregate stability were only constructed for cropping and horticulture on Recent Soils, there being insufficient knowledge or confidence to construct response curves for other soil orders and land uses. The curves followed the pattern that 'more is better'.

On those Recent Soils, an aggregate stability > 2 mm mean weight diameter was considered necessary for optimal soil quality. A similar limit of 2 mm was obtained for optimal soil quality when environmental criteria were considered. However, the group considered small mean weight diameters (< 1 mm) were more detrimental when considering environmental rather than production criteria. This reflected the poorer structural characteristics of soils with mean weight diameters < 2 mm.

Workshop notes

The scale should have a minimum value of 0.25 mm (mean weight diameter), a maximum of 3 mm. Although applicable to all soils, most current information relates to cropping systems. The response curves produced by the group generally tended to be similar, but differed at the point at which they considered production would be affected.

Production factors

There was general agreement that decreased aggregate stability is reflected in decreased production, or increased costs. Soil management can mask the affect of decreased stability, so loss of stability does not necessarily impact production.

Environmental quality

Loss of aggregate stability increases the risk to the environment, e.g. more erosion, more CO_2 production.

There were varied opinions about how much environmental risk is caused by a loss of stability. Concern if MWD < 1.5 mm.

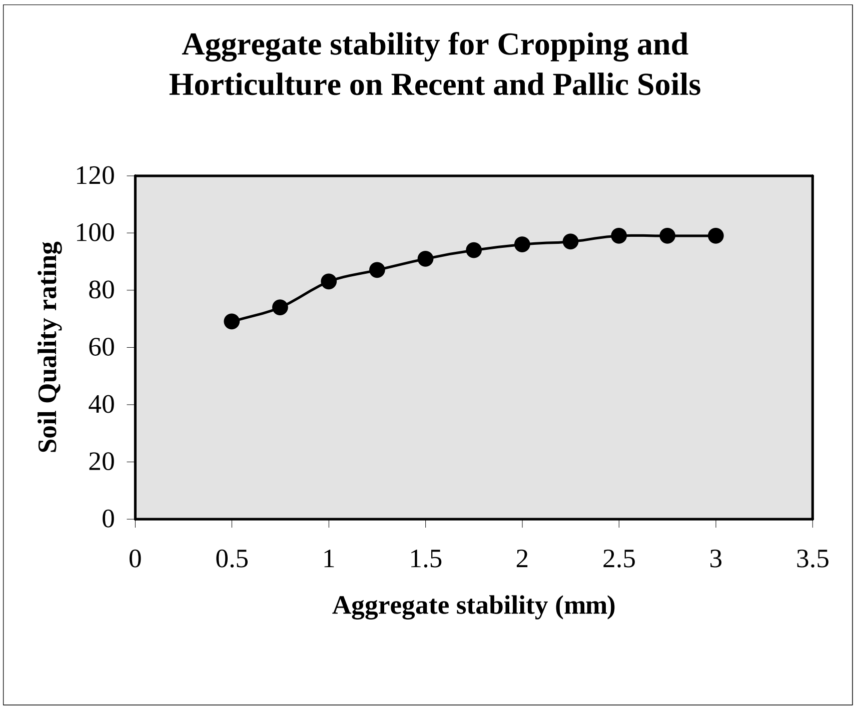


Fig. 8.4 Soil quality response curve for aggregate stability.

Topsoil depth

Topsoil depth generally reflects the depth of soil influenced by biological processes such as root extension and soil faunal burrows, and is normally synonymous with the depth of the A horizon. Topsoil characteristics are mostly favourable for plant production because topsoils have greater organic matter, are generally more porous and, in previously fertilised sites, contain much of the store of applied nutrients.

The curve (Fig. 8.5) follows the trend that 'more is better'. The findings apply to all soil orders. A minimum topsoil depth of 12 cm was considered necessary to obtain a high soil quality rating. The curves were very similar for both production and environmental criteria.

Workshop notes

There is a drop-off in production where topsoil is less than 10 cm. Soil depth is closely connected to topsoil loss and erosion. Two important factors are the amount of soil lost and the thinness of what remains; both factors are important for production and environmental quality.

A soil mass balance (inputs and losses) would allow monitoring of trends through time.

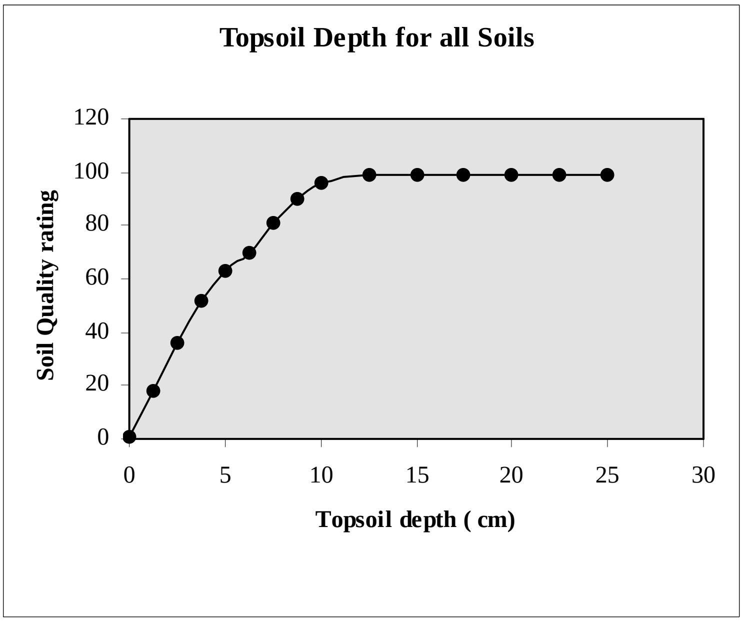


Fig. 8.5 Soil quality response curve for topsoil depth.

Carbon balance

A carbon balance could be an indicator of soil quality because this shows the net accumulation or loss of organic matter in the soil ecosystem. As well as organic matter content having implications for soil quality, soil organic C is an important pool in the global C balance. Loss or accumulation of C within the soil influences the net C emissions, and the balance could alter the liability for C taxes. Annual budgets were not considered useful soil quality indicators, but budgets over several years or decades could reveal informative trends. Consistent negative trends over several years would be considered detrimental to soil quality.

There were insufficient data to prepare response curves for individual soil orders, and single curves for each order are presented (Figs 8.6, 8.7, 8.8). Whatever the soil order, the acceptable zone for C balance for production was clearly shown. For all soils and land uses, the response curves indicated the annual budget should not exceed 250 kg/ha in either positive or negative sectors.

For environmental criteria, the response curves showed that any negative value was not considered acceptable and that within the C surplus there was no clear upper limit. In terms of C accumulation, 'more is better'.

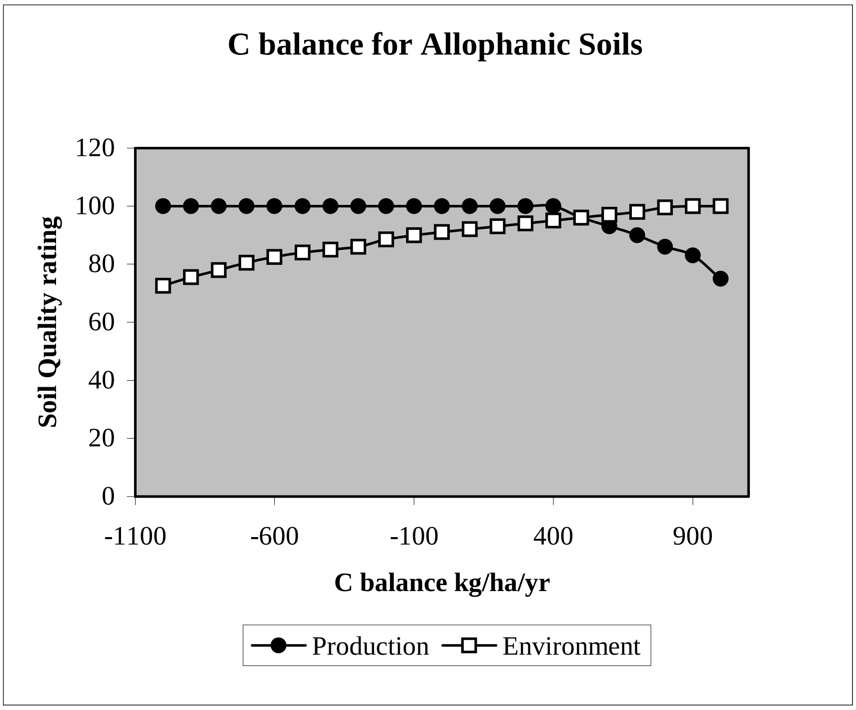
Workshop notes

Carbon balance was discussed in conjunction with organic C because soil storage of C is significant for greenhouse gas emissions.

Stand-alone annual budgets are not thought to be useful. An annual loss of C continuing for 10 years is/will be of more concern. Losing C every year (finally) results in production loss.

A large positive C balance has the potential to immobilise soil-available N, resulting in decreased production.

Need to have clear instructions whether to include greenhouse gases as a factor when assessing environmental risk.



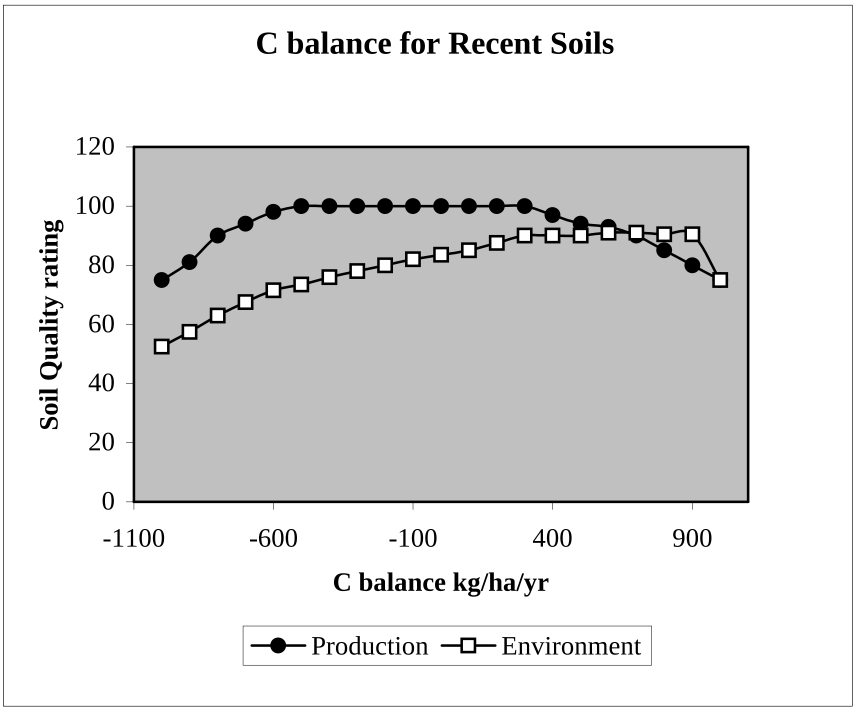


Fig. 8.6 Soil quality response curves for C balance for Allophanic and Recent soils.

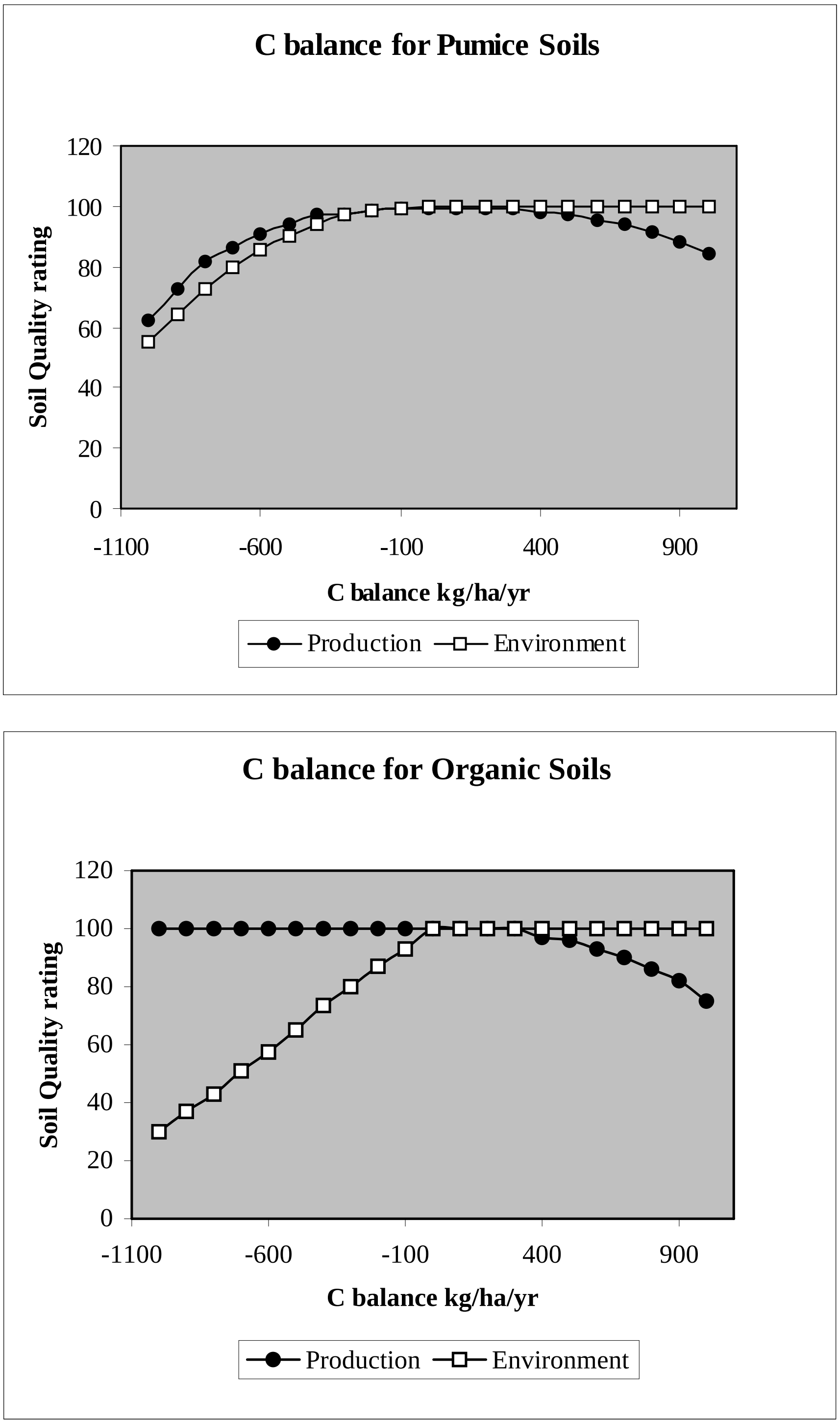


Fig. 8.7 Soil quality response curves for C balance for Pumice and Organic soils.

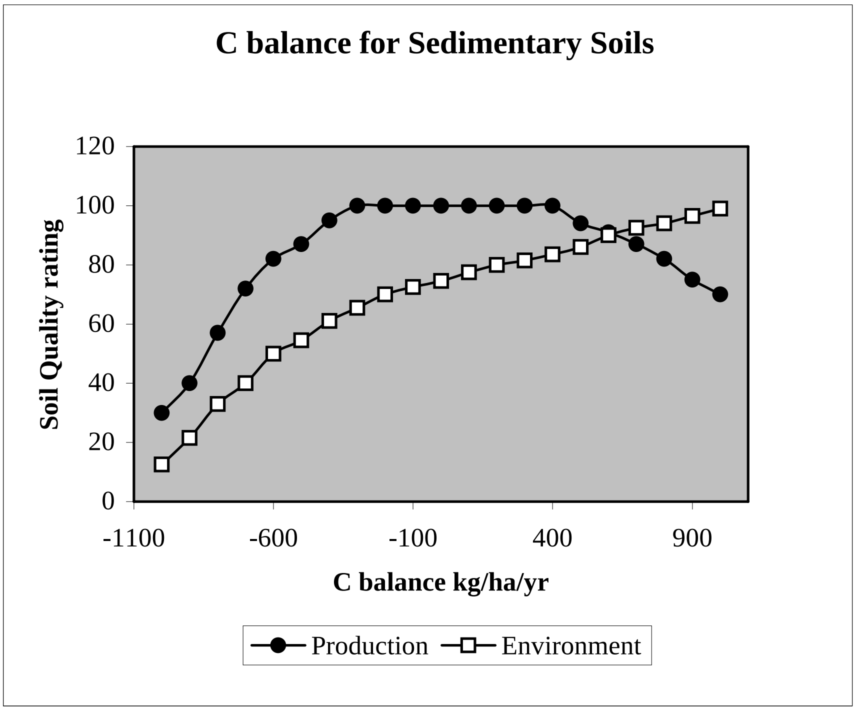


Fig. 8.8 Soil quality response curves for C balance for Sedimentary soils.

Nitrogen balance

Nitrogen balances are favoured by some European countries as a broad farm-scale soil quality indicator. A positive balance (more inputs than losses) could indicate the potential for N accumulation and a potential for N losses through N leaching. However, as observed by the Workshop group, a zero balance does not indicate that there are no losses, only that inputs and losses are in balance. A portion of the losses could have been through leaching, which would generally be considered detrimental to environmental quality.

The curves showed the 'optimum range' pattern, and were applicable to all soils and land uses. For production criteria it was considered that the annual N balance should be positive, with an optimum value of about 90 kgN/ha. For environmental criteria, a neutral or slightly negative annual balance (−50 kgN/ha) was favoured.

Workshop notes

Concerns

N balance should be annualised but interpreted over a 5- to 10-year period.
Weeds (undesirable plant species) are a risk factor at both ends of the scale.
A system in balance could still be leaking lots of N!

Production factors

Point of inflection is zero (inputs and outputs balance).
Interpretation is important, whether for that one year or as an ongoing balance.
At practical year-to-year basis you can operate in a negative state.
The amount of N in the system is an important factor when considering the balance.
The N balance for production is not a valid response curve.

Environmental quality

Legume-based systems are buffered, and contributions from legumes to the N budget will shift according to the amount of N in the system.
A negative N balance would indicate N 'mining'.
A positive N balance indicates greater risk of N leaching.

Cropping soils

A simple N balance is too difficult to interpret for it to be a useful indicator in cropping systems.
A positive N balance may indicate increased risk of N leaching.

The N balance can go negative for a number of reasons; might be 'mining' soil N.

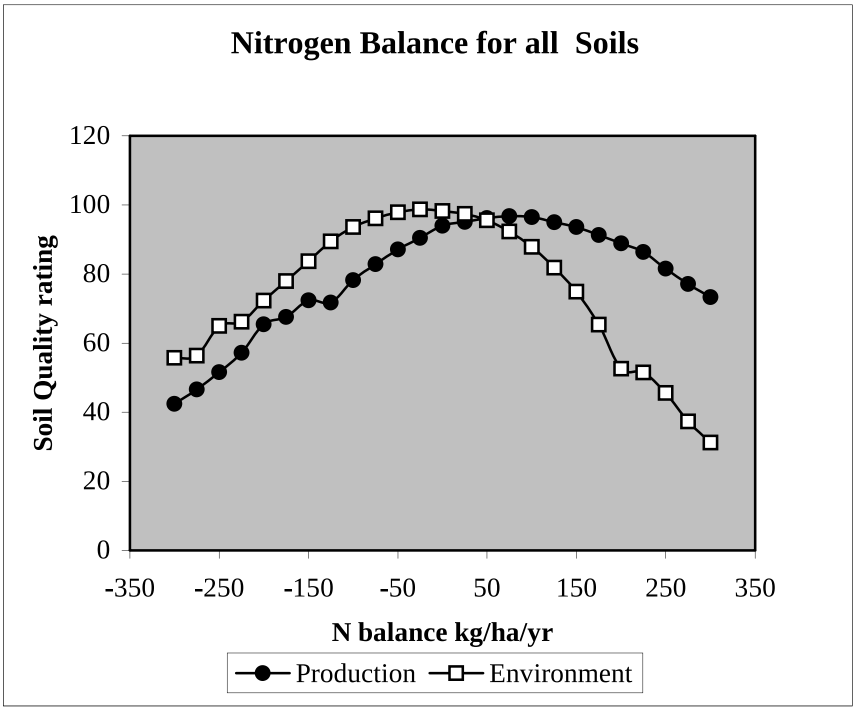


Fig. 8.9 Soil quality response curves for N balance.

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