Identification of land with a risk of acidification
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EXECUTIVE SUMMARY

Soil acidification is a key soil condition indicator and one of four central to the Caring for Our Country Program targets for sustainable land management. Soil acidification results where there is a combination of agricultural land management practices that add significant amounts of acidity to the soil and where the soil has a low resistance to pH change. Soil acidification needs to be urgently addressed where current soil pH levels are already low. Soil acidification can be ameliorated by liming, but the effectiveness of liming is reduced where deeper soil layers have become acidic. However, if acidification is left to progress to the point where mineral dissolution is initiated, the damage caused by acidification may be irreversible.

This report maps areas across Australia where a high risk of acidification exists and where there is a priority for land management intervention. The map was created from an expert assessment process using the best available national data. The assessment followed the process outlined below.

Step 1. Identify the acidifying potential of land management practices – measured as the cumulative proton input

Cumulative Proton Input = Area weighted Net Acid Addition Rate (NAAR) x years cleared – where

- Area weighted NAAR = Σ(Land use NAAR x land use area) / (developed area) in kmol H+ / developed ha/year; and

- Years cleared is an index for the time since clearing and imposition of the land use

Step 2. Identify the vulnerability of soils to change pH – measured as an index of soil pH buffering capacity

Step 3. Combine the Cumulative Proton Input with the soil pH buffering capacity.

This constitutes the Acidification Risk acting in each area.

Step 4. Determine the urgency for action - combine Acidification Risk with an estimate of current soil pH.

Areas with a high overall index will be priority areas for investment in managing acidity.

The process and the final map were endorsed both by the scientific group drawn from each State and the Northern Territory and by the representatives of the National Committee on Soil and Terrain.

The final map is reproduced below; it has been forwarded to the Caring for Our Country Program as input to the 2010-2011 Business Plan.
Acidification - priority areas

Priority for action
- Low
- Moderate
- High
1. **INTRODUCTION**

This report identifies areas of land within Australia with hazards and risks of soil acidification and where there are potential opportunities for improved management outcomes. It updates the assessment developed for the 2009 – 10 Caring for Our Country Business Plan (Baldock et al. 2008) and outlines the methods used. The focus was on areas where soil acidification processes have been accelerated by current and past agricultural practices. This assessment was undertaken as input to the 2010 – 2011 Caring for Our Country Business Plan.

Soil acidification is a major limitation to agricultural production in Australia. Its impact will grow if existing acidification is not addressed and action is not taken to prevent further acidification. The National Land and Water Resources Audit estimated that some 50 million ha of agricultural land, occupying approximately 50% of current agricultural land, had a surface soil pH (in CaCl2) below the optimal value of pH 5.5 (Dolling et al 2001). Of this acidified area, 25-50% (13-25 million ha) had a surface soil pH less than 4.8. While surface soil pH can be ameliorated with applications of lime, if acidity moves down the soil profile or is generated in the deeper layers, it is much more difficult to correct. Consequently, the national Caring for Our Country Program has the management of soil acidification as a key outcome within the targets for improved land management (http://www.nrm.gov.au/publications/factsheets/pubs/15-improving-land-management-practices.pdf).

Prolonged acidification may be difficult to reverse. As pH decreases, the vulnerability to nutrient loss increases especially for cations such as Ca, Mg and K and under high leaching conditions. This arises due to a reduction in cation exchange capacity and cation (nutrient) displacement by aluminium. In addition to these direct effects on nutrients and their availability, dissolution of clay-sized minerals, such as Fe and Al oxides, may occur at pH levels at or below 4.3. Leaching of these dissolved minerals will lead to permanent loss of clay as well as any associated nutrients, cation exchange capacity, or pH buffer capacity. This constitutes a permanent decline in soil capacity. So while it is possible to reverse short term soil acidity through the application of lime, it is not always possible to reverse all of the detrimental effects if a high degree of acidification has been allowed to occur or if the decline occurs in deeper layers beyond the reach of lime.

The national priorities are clear – prevention is the driving need allied with improvement of existing acidified areas. This analysis has been designed to support priorities in the Caring for Our Country Program to address these needs.

A high priority for investment will occur where there is a combination of three factors:

1. the dominant agricultural practice (current or past) is highly acidifying;
2. the soil has a low capacity to buffer itself against pH decline; and

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1 Note - severe acidification of acid sulfate soils which results from oxidation of iron sulfides (Dent 1986) occurs through a distinct and different land management process and is not included in this assessment.
The first point constitutes the acidification potential arising from land management and a combination of the first two constitutes the risk of change in soil pH. Areas with low current pH and high acidification risk have the highest priority for action.

The key hazard factor is the acidification rate of land uses expressed as the Net Annual Acidification Rate or NAAR in kmol H⁺/ha/yr and the length of time over which these processes have been operating. In combination, NAAR and time provide a measure of the cumulative proton input. The risk of NAAR leading to acidification is modified by the pH buffering capacity of the soil. It is possible to model accurately the extent of the risk and therefore the relative priority for action where appropriate measured data are available. This is unevenly available for Australia. The approach described below uses an analogue of a formal modelling approach (using an explicit logic trail with the best available national data) with expert overview and advice. The approach is described along with the interim and final data products.

This analysis was supported by the Australian Collaborative Land Evaluation Program which is jointly funded by the Australian Government and CSIRO and is supported by each state / territory agency responsible for land resource information.

1.1 LIMITATIONS OF SCALE AND THE NATIONAL APPROACH

It is important to note that this is a national assessment. It therefore involves the inevitable level of generalisation which occurs when the accent is on the use of consistent national data rather than the best finer scale data. The latter are available – but only for some regions. All states have areas with finer data; no state has complete coverage with finer data although the “agricultural” areas of South Australia and Western Australia have consistent mapping covering these lands. To illustrate the detail which is possible with good land resource data and which is essential for the on-ground management of this issue, Figure 1 shows the detailed hazard assessment of South Australia’s agricultural lands undertaken by the South Australian Government. While this broadly agrees with the national assessment outlined below, the regional detail is crucial. It is recommended that in pursuing projects for better management of acidification, land managers and NRM Regions approach their local NRM agency for access to the best fine scale data for their region.

For many regions, the level of land resource data needed for assessment at land management scales is not available in many regions – and is clearly needed.

The national assessment has used new data which have been recently captured and integrated into the national soil system (the Australian Soil Resource Information System or ASRIS); the system has substantially improved data sets since the assessments in 2008 and from those provided to the National Land and Water Resources Audit (2001). This does not address the key need for increased investment in soil survey data – which has declined substantially over the last decade. The gaps in information required for the fine scale study that this issue requires...
will not be resolved without an investment in the collection of soils data in the many regions where they are lacking or inadequate.

Figure 1 An extract from the acidity assessment of southern South Australia which illustrates both the detail possible with comprehensive land resource data and the importance in using it for investment within regions (Maschmedt 2002).
2. METHODS

2.1 ASSESSMENT PROCESS

The assessment process followed an explicit logic trail – endorsed by representatives of soil agencies from each state and the Northern Territory – and the expression of which was followed in a workshop in Canberra in June 2009. The subsequent results were distributed for comment and amendment, where necessary, amongst these representatives and members of the National Committee on Soil and Terrain.

The assessment was based around layers of evidence of the potential cumulative input of acidity (protons) into the soil, the resistance of a soil to pH change (the soil buffering capacity) and available information on likely pH. The assessment was done on 5km pixels for the continent as a whole in the Multi-Criteria Analysis Shell (MCAS) designed and made available by the Bureau of Rural Sciences. The steps followed in the analysis were:

Step 1. Identify the acidifying potential of land management practices – measured as the cumulative proton input

Cumulative Proton Input = Area weighted Net Acid Addition Rate (NAAR) x years cleared – where

- Area weighted NAAR = \( \sum (\text{Land use NAAR } \times \text{ land use area}) / (\text{developed area}) \) in kmol H+/ developed ha/year; and

- Years cleared is an index for the time since clearing and imposition of the land use

Step 2. Identify the vulnerability of soils to change pH – measured as an index of soil pH buffering capacity

Step 3. Combine the Cumulative Proton Input with the soil pH buffering capacity.

This constitutes the Acidification Risk acting in each area.

Step 4. Determine the urgency for action - combine Acidification Risk with an estimate of current soil pH.

Areas with a high overall index are priority areas for investment in managing acidity.

To populate this logic framework, spatial layers were acquired for the required input data from the Australian Soil Resource Information System (ASRIS), the Digital Atlas of Australian Soils (http://www.asris.csiro.au/index_other.html) and from Bureau of Rural Sciences collated data within MCAS (http://adl.brs.gov.au/mcass/index.html). MCAS was used for spatial decision support; it allowed the derivation, classification and manipulation of data layers to provide estimates for the steps in the assessment process. As importantly, it provided a capacity to
display and interact with the spatial data and the combinations used in capturing and applying the assessment logic. Thus, an expert overview was possible over each stage of the process.

The compilation processes used for deriving each index are described in conjunction with the resulting map of the index in Section 3. Spatial data layers were typically divided into classes that were assigned a relative score. To derive the indices the scores were either added (where layers provided independent evidence) or multiplied (where layers provided a modification of a value).
3. RESULTS

Land use intensity:

The BRS native vegetation layer was used to identify cleared areas. This was overlain with BRS national catchment scale landuse data to identify areas of cropping and intensive agriculture (horticulture). The layer was classified to:

1) non-cleared/grazing native pasture,
2) pasture,
3) cropping, and
4) intensive agriculture (Figure 2).

Net Acid Addition Rate (NAAR)

Net Acid Addition Rate (NAAR) is a measure of the amount of net acidity added to soil by land management systems. The various components are complex but the major influences are the change in organic matter in the soil, the export of organic matter (product), the addition of inorganic nitrogen fertilisers (potential acidification from ammonium based fertiliser and alkalisation from nitrate based fertiliser), the addition of lime, and the leaching loses of nitrate.

Figure 2 Land use intensity derived from BRS catchment scale land use data

Figure 3 Draft NAAR data (Mike Webb (2009 pers comm) (1) and the NAAR land use layer (2). The NAAR Land use data was created as a two way layer from land use intensity (Figure 2) and the NAAR data.
Identification of land with a risk of acidification (Baldock et al 2009). NAAR is measured in kmol H+/ha/yr. A national estimate has been newly collated by Mike Webb as part of the NHT funded soil monitoring project (Baldock et al 2009). Due to limitations in national land use management practice information, the mapping is averaged across statistical local areas. For this analysis, the values were applied (using GIS overlay approaches within MCAS) to the mapped land use in the land use intensity map (Figure 2) – thus producing a finer representation of NAAR applied to intensive land uses (Figure 3).

**Cumulative Proton Index – Acidification from land management over time**

Acid addition accumulates over time. Combining NAAR with the time since clearing allows an estimate of the total acid input to an area. To achieve this, a clearing date was estimated for Australia based on NRM regions – in broad categories and with input from each state agency representative. This was applied to the NAAR land use layer to increase proton inputs in areas with longer clearing/land use history and higher NAAR landuse. The final ‘cumulative proton input index’ map has 10 classes - 1 low, 10 high (Figure 4).
3.1 ACIDIFICATION RISK

Acidification risk is defined in this analysis as a combination of the duration and intensity of acid (proton) addition (Figure 4) and the resistance of a soil to pH change – the soil buffering capacity.

3.1.1 SOIL BUFFERING CAPACITY

There is as yet no satisfactory national map of soil buffering capacity. For the purpose of this exercise, an index was derived from the Atlas of Australian Soils and the mapping of soil reaction trend modified by texture and the presence or absence of calcium carbonate. High buffering capacity soils are class 1 with a lower risk of acidification; low buffering capacity soils are class 8 with least resistance to pH change (Figure 5).

Figure 5 Soil buffering capacity to pH change derived from Atlas of Australian Soils (T. Griffin pers. comm.)
3.1.2 DERIVING THE ACIDIFICATION RISK

The overall acidification risk map was created by multiplying the ‘cumulative proton input index’ with the classification of soil buffering capacity derived from the Atlas of Australian Soils (Figure 6).

![Figure 6: Interim soil acidification risk assessment - prior to current pH adjustment](image)

3.2 IDENTIFYING PRIORITY AREAS

Where soil pH is close to levels of concern (pH 4.8 – 5.5), there is greater urgency for action. Consequently, the risk was compared with current pH data – to the extent they are known – to establish high priority areas.
3.2.1 CURRENT PH

‘Current pH’ was estimated from the latest ASRIS pH values and Atlas of Australian Soils mapping in similar classes of pH values. This allowed a combination of ASRIS and Atlas mapping into one national coverage – thus “gap-filling” the areas not covered by newer ASRIS data (Figure 7).

![Figure 7 Components for classifying current pH – (1) ASRIS pH values; (2) Atlas pH values; (3) combined pH values and pH in four classes allocated so that areas of ‘current’ low pH have a high class value (blue) when added to the cumulative proton input](image)

3.2.2 ACIDIFICATION PRIORITY INVESTMENT AREAS

The final priority map was produced by a combination of cumulative proton input, soil buffering capacity and the estimate of current pH ie. the priority for action is greatest where the effect of acid addition in management systems, soil vulnerability and current soil pH status
coincide. The final map divides these combinations into three classes; identifying a high, moderate and low need to invest in managing or ameliorating acidity (Figure 8). The class limits were iteratively defined through a region by region inspection of the component layers and the final compilation by the assembled experts and state representatives. Versions of the map were then circulated for wider comment. There was general agreement across relevant agencies that the assessment reflected investment priorities within the limits of a national assessment.

![Acidification priority areas](image)

Figure 8 Acidification priority areas in Australia

4. DISCUSSION

4.1 COMPARISON WITH 2008 ANALYSIS

The analysis described in this report is the second advisory assessment on soil acidification for Caring for Our Country business planning from the national soil science community – coordinated through the National Committee on Soil and Terrain. The earlier advice (Balodock et al. 2008) produced a priority rating of NRM regions with a single index for each region. In the 2009 assessment, the logic of the analysis used in 2008 remains and broadly similar
priorities were identified. Nevertheless, there are important differences which have achieved an improved assessment.

- This analysis has aimed for and achieved a much finer scale analysis – identifying high priority areas on a 5km grid. The end result identifies priorities within more regions and provides a significantly improved spatial distribution of acidification risk and priority;

- Substantially improved datasets were available in 2009. In particular, the new NAAR spatial coverage provided by Mike Webb as part of the Baldock et al. (2009) report is markedly more accurate in terms of the values and their spatial variation. New soils data in the Australian Soil Resource Information System has become available as a result of the NHT funded National Soils Data Provision project and better use was made of catchment scale land use data now available through the Australian Collaborative Land Use Mapping Program.

- A more effective national collaboration in running and iteratively improving the analysis was possible with the use of the Multi-Criteria Analysis Shell (MCAS) developed by the Bureau of Rural Sciences. The logic of the analysis was independent of MCAS but the capacity of the system to display spatial datasets, including data derived elsewhere and to explore visually in a workshop situation data quality, data interactions and provisional results allowed immediate iteration of the components of the analysis. Although, an identical result could have been achieved with standard GIS software, MCAS provided an immediacy and ease of use which substantially improved the process of integrating an expert overview into the assessment.

- More detailed advice on current pH in both South and Western Australia was available for this analysis and, with the change in spatial definition, was more easily assimilated into the analysis (DWLBC, 2007a; DWLBC, 2007b; Gazey and Andrew, 2008; Gazey and Andrew, 2009; Hall, 2008; Hall et al., 2008; and Maschmedt, 2002). Consequently, better assessments of Western Australian and South Australian priorities have been possible.

4.2 IMPROVING THE ANALYSIS

It is relatively simple to quantitatively establish trends in acidification given satisfactory component datasets – at least in surface soils. Many of these components are not available in an appropriate quantitative form across Australia or even across those managed landscapes where acidification needs management. A complete satisfactory analysis would require the following spatial datasets at a grid resolution of 100m or smaller:

- Land management practices specified in terms of nutrient input and product off-take;

- Calculated NAAR based on the land management data;

- Land management history;
• Soil pH buffering capacity (or the components of a pedotransfer function to estimate it – detailed in Baldock 2009); and

• Recent measurements of current pH in the surface and subsurface.

In the absence of these data, the index approach described in this report provides a useful estimate of how risk varies across the Australian landscape. With current programs, some progress will be made in acquiring these data but it is unlikely that a comprehensive quantitative analysis will be possible for some time.

Following the workshop which involved the scientists listed as authors of this document and who represented each state and the Northern Territory, the analytical steps and the resultant maps were circulated within the group and to a wider set of representatives of the National Committee on Soil and Terrain. There were few requests for change (and no substantive changes) and general agreement that the analysis had covered the expected risk variation across Australia.
5. CONCLUSIONS

A group of scientists with expertise in soil acidification and representative of the major jurisdictions responsible for soil information in Australia developed and implemented a process to map the variation in the risk of soil acidification and those areas where acidification management is most urgent. The process was seen as the best approach to a national assessment possible with existing data. The resulting map and a description of the process were circulated both within the assessment group and to the membership of the National Committee on Soil and Terrain. The map has been endorsed by that community as input to the Caring for Our Country 2010-2011 Business Plan. The final map (Figure 8) has been forwarded to the Caring for Our Country Program for inclusion in the planning process.
REFERENCES


CSIRO and the Flagships program

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