Designing a soil pH monitoring network for the Western Australian wheatbelt

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Abstract

Soil acidification is recognised as becoming the major land degradation issue in Australia in the coming decades. It happens slowly, within a complex mosaic of variable soils and agricultural management, and it can take decades for related environmental consequences to become apparent. Monitoring efforts are needed to quantify the changes occurring and inform policy and management. We discuss the design of a soil pH monitoring network for south-western Western Australia. We describe the important criteria used in designing the network, present the methodology developed and site selection process, and highlight some of the challenges of carrying out a long term soil monitoring programme.

Key Words

Sampling design, monitoring, soil pH, acidification.

Introduction

The negative impacts of 60 years of intensive agricultural practices on soil condition are beginning to show in Western Australia, as in other parts of the world. At the same time, regional and global demand for food production is increasing, and climatic constraints on agriculture are predicted to increase (Hennessy *et al.* 2007; FAO 2009). Acidification of agricultural land in Australia is considered a larger risk to sustainable production than salinity (Government of Western Australia 2007), and declines in soil pH are expensive and difficult to reverse, making detection of the problem and proactive management paramount. Natural resource managers in Western Australia require a purposively designed soil pH monitoring network to identify areas at higher risk of soil acidification and to detect changes in soil pH through time. This monitoring network, in conjunction with field experimental work and acidification modelling, will identify trends and help shape state natural resource management policy and regional extension programmes, as well as directly inform industry and land managers.

The wheatbelt in southwestern Australia includes approximately 13 Mha under dryland agriculture, two-thirds of which are at risk of acidification (Government of Western Australia 2007). Key regional impacts of soil acidity include: lower plant yields and related profits, fewer suitable planting options, irreversible degradation of clays and colloids in the soil, further reducing fertility; accelerated erosion related to lower density groundcover; and worst case scenario, severe erosion preventing future agricultural production (NLWRA 2001). The processes that decrease soil pH in agricultural systems are removal of base cations from the soil system (generally through plant uptake and removal of vegetation, or leaching), and application of ammonium-based nitrogen fertiliser at rates in excess of plant requirements. Liming causes soil pH to increase, though its effectiveness varies with soil texture, type of lime, and amount applied. This combination of variable loss and gain complicates detection of long term trends in soil pH. Here we describe the design of a soil monitoring network to characterise the current status and future trends in soil pH for the wheatbelt of south western Western Australia.

Design criteria

To provide the most flexible framework for assessing soil condition, a monitoring network must be both as general and as representative of natural and human-affected conditions as possible but still meet the funders budgetary constraints. Careful planning is required to ensure that a relatively small sample of sites selected to form the network allows estimation of the general spatial and temporal trends in soil pH. A number of decisions are required to define the focus, required outputs and reliability of the monitoring programme.

The goal is to estimate the change in pH (ΔpH) over the wheatbelt as a whole, and within the wheatbelt with as much spatial detail relevant to regional planning as possible. Design-based inference was chosen so that an *unbiased* estimate of the mean ΔpH (not pH itself) across the whole wheat belt could be obtained. Using

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design-based methods also ensures the estimates of ΔpH made using the network will be adequate for regulatory practices, if required in the future (de Gruijter *et al.* 2006).

The processes causing soil acidification are slow, and the high spatial and seasonal variability in pH can make detection of trends difficult. Change is undetectable in less than five years even in the most severe cases of degradation, and can be more consistently determined over a ten year period (McKenzie and Dixon, 2006). This long term degradation process requires an equally long-term monitoring programme. The planned duration for the monitoring network is 20 years, and sampling will occur once every five years. The same sites will be sampled through time, helping to minimise the spatial variability between time pairs which can often confound interpretation of trends (McKenzie *et al.* 2002).

The final set of design criteria were:

- *Target population*: soils vulnerable to acidification (low buffering capacity) under rotational cropping, in the low rainfall region (< 500 mm/yr)
- *Target quantity*: the mean change in pH over the sampling interval
- *Reporting units*: the region as a whole, and mapped soil-landscape zones which reflect physiographic and cropping system differences in the region and help to partition variability in soil pH plus provide broad-scale spatial patterns in results
- *Quality measure*: High confidence (>95%) for the region as a whole of detecting a 0.2 pH unit change from the mean, and moderate confidence (70-90%) of detecting a 0.3 pH unit change within the subregions (26 soil landscape zones)
- *Logistics*: Must keep costs and labour requirements as constant as possible throughout the life of the survey (e.g. spread out timing of sampling); fix total sites for affordability
- *Flexibility*: Design network for acidification only, but allow flexibility to augment the system to monitor additional processes in the future; ability to adjust network in reaction to ongoing findings

Calculation of the number of sites needed

The sites need to be randomly selected (probability sampling) as we are using design-based inference (de Gruijter *et al.* 2006). The following equation, based on standard statistical sampling theory, was used to estimate the number of samples (n) required to detect the specified minimum detectable pH change (y) at a certain confidence level (100*(1- α)%) (Saby *et al.* 2008, equation 5):

$$n > \frac{2z_\alpha^2 s^2}{y^2} \qquad (1)$$

where z_α is the value of the standardized Normal distribution at probability α, and s^2 is an estimate of the variance of pH. This equation assumes that the soil is sampled from the same site on subsequent monitoring visits, the variability of pH does not change over time and that the correlation between two sampling times is small. Best current estimates of soil pH and its variability were used as very little reliable information was available on ΔpH and its variability in the region. Soils with low buffering capacity were targeted; within these soil types, the current estimate of pH gives an indication of those soils that are at greatest risk of falling below the recommended pH levels for cropping.

Table 1. Summary for the 0-10cm layer of pH variability and estimated number of monitoring sites required per reporting unit to detect changes of: 0.2 pH units with 95% confidence (N1), and 0.3 pH units with 85% confidence (N2). A subset of soil landscape zones (8 of 26) shows how N changes with pH variance.

Reporting Unit	Count	Mean	Variance	N1	N2
Wheatbelt	42585	5.18	0.449	86	37
Zones					
253	4008	5.00	0.126	24	6
243	719	5.02	0.220	42	10
220	227	5.66	0.273	52	13
256	7989	5.15	0.319	61	15
258	12111	5.19	0.417	80	19
250	985	5.27	0.689	132	32
221	87	6.41	0.955	183	44
246	2668	6.01	1.191	229	55
Total for 8 of the 26 zones:				803	194

A commercial pH dataset (Precision Soil Tech (Perth WA) unpublished data) was used to characterise current pH status. Samples were collected between 2006 and 2008 and consist of 10 cores at 0-10, 10-20, and 20-30 -cm depths sampled in an 8-m arc, bulked, mixed and subsampled by layer (Gazey *et al.* 2007). The sample count, mean, and variance for each reporting unit are shown in Table 1, along with the estimated number of sample sites required for different levels of detection (see caption). The funding available dictated approximately 400 sites in total could be sampled; the programme goals were met with this total by distributing the sites across soil landscape zones using a detectable change of 0.3 pH units, and 85% confidence. The 400 sites will permit estimation of a 0.2 pH unit change for the wheatbelt as a whole with 99.9% confidence.

Selection of monitoring sites

Once the number of sites was determined by reporting unit, the highest resolution soil map unit polygons (Schoknecht *et al.* 2004) were randomly selected for sampling, weighted toward polygons with larger areas of vulnerable soils (probabilities proportional to size: de Gruijter *et al*. 2006). Areas outside the target population were masked out (e.g. urban areas, remnant vegetation, saline areas, water bodies). The masked, selected polygons were overlain with property boundaries. If only one sample was required per polygon, then the property with the largest target area was selected. If more samples were allocated to the polygon, or the first property owner refused access, then the property with the next largest area was selected, and so on. A list of property identifiers and percent coverage of vulnerable soil types in the map unit polygon was prepared for the field surveyors. The exact location of the site is determined in the field.

Within site sampling

The soil monitoring site is defined as a plot of land 25 x 25 m, following recommendations in McKenzie et al (2002). The within site sampling method is as follows: The south-west corner of each site is georeferenced with a standard GPS, and the sampling grid is laid out from there. Each grid cell is 5x5m (= 25 sampling cells). Each grid cell is sampled at four depth intervals, 0-5, 5-10, 10-20 and 20-30. Total number of samples per site = observations x depths = 25 x 4 = 100. The samples will be bulked by depth, split for laboratory analysis, and the remainder archived. The site and the soil profile will be described according to MacDonald *et al.* (2009) and the soil classified according to the WA classification and the Australian Soil Classification. Sampling will be done during the dry summer season when pH is most stable, and to reduce the seasonal signal year to year (Conyers 1997). In addition to pH, soil carbon and bulk density will be measured at least for the first 5 years of the programme. The soils targeted as vulnerable to acidification are unlikely to be those most vulnerable to changes in soil carbon, nevertheless they will contribute to a more complete assessment of current soil carbon status in WA.

Sampling strategy

The number of sites (approximately 400) and time interval for sampling (5 years) were determined, but sampling all sites in a season then waiting 5 years to repeat the exercise was considered too difficult to maintain continuity of funding and skilled personnel. Instead, a rotational sampling programme was planned in which the same sites are resampled at the same time interval, but a subset of the sites are visited each year. The selected sites were divided into five panels, and each year one panel will be monitored, with a repeat visit in 5 years time. Having some sites sampled in consecutive years (“partially augmenting” the sample) connects the panels as for an experimental design, and increases the power for trend detection. In fact, nearly equivalent trend detection results are obtained with fewer repeat visits to sites using this type of partially augmented rather than an “always revisit” plan (Urquhart and Kincaid 1999). The design as a whole is a 5-year period partially augmented serially alternating rotational pattern (Urquhart and Kincaid 1999; de Gruijter *et al.* 2006).

Will the number of sites really be adequate?

Generally speaking, more sites improve the precision of estimation, but the number of sites in the network must be balanced with affordability. Whether or not a smaller network would have been adequate was of real concern, particularly when ten years of data must be collected before the first results on ΔpH are available. We deliberately over estimated the number of sites required in the following ways:

- Data used to calculate number of sites: Used all currently available pH data even though we were only interested in data for vulnerable soils, so the variance was likely higher than that of the target population. Lower variance means fewer sites actually needed to meet quality criteria.
- Equation used to calculate sites: Equation 1 assumes no correlation between sampling times, whereas

we would realistically expect a positive correlation, reducing the estimate of s^2 thus reducing the number of samples required. This was shown to be true for a small catchment within the wheatbelt with appropriate data where the correlation over 7 years was approximately 0.3.

- Distribution of change: The number of sites required were calculated for a two-tailed distribution, but primary interest is in detecting negative trends (lower tail only), which would reduce sample requirements.
- Minimum of ten samples: All reporting units were assigned a minimum of 10 sites to assist in assessing the variability in ΔpH once two sampling rotations are completed.

After each sampling season, the variability in pH for every reporting unit will be recalculated; if after the first full sampling (5 years) the variability is different from that calculated from the existing database, then sites will be added or eliminated from the programme without negative impacts on the survey results.

Conclusion

We have illustrated the steps involved in designing a long-term, spatially extensive monitoring programme to assess changes in soil pH in Western Australia. The network design chosen was the most efficient scheme to answer specific questions about particular reporting units within the practical limitations set out. However this design was based on a target population of soils vulnerable to acidification which will limit its ability to answer future questions on other soil properties or soil functions. As this network was designed using design-based methods it will be flexible enough to extend the target population to all soils and add sites to the network to address future unforseen questions if funding becomes available.

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