The need for a long-term field experiment to manage subsoil acidity

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Abstract

Many of the important questions facing farming systems in the world today, such as soil acidity, require long-term studies to provide meaningful information and answers. Managing subsoil acidity is a research topic that lends itself to long term experimentation. Methods known to ameliorate acidity in the subsoil take decades due to slow biochemical processes, so extended periods of time are required to monitor results. Furthermore, soil pH is a fundamental driver of soil biological and chemical processes, and so impacts upon crops and upon the soil environment can be complex requiring additional time for monitoring in order to fully understand the processes. In late 2014, a multidisciplinary team was formed, including agronomists, soil chemists, soil physicists, economists, system modellers and farm advisers as well as leading farmers. In early 2015, a long-term field experiment was established at Dirnaseer, west of Cootamundra, NSW to *a*) manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability; and *b*) to study soil processes, such as the changes of soil chemical, physical and biological properties under vigorous soil amelioration techniques over the longer term. The current paper discusses the principles of setting up a long-term experiment and develops a framework of designing a long-term experiment to manage subsoil acidity in the high rainfall cropping region of southern Australia.

Keywords

Soil pH, aluminium, lime, organic amendment, crop rotation, experimental design.

Introduction

Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia. Approximately 50 per cent of Australia's agriculture zone (~50 M ha) has a surface soil pH (in $CaCl_2$, pH_{Ca} hereafter) below optimal levels ($pH_{Ca} < 5.5$) and half of this area also has subsoil acidity (Dolling et al. 2001). The surface application of lime (calcium carbonate) is a common practice used to combat soil acidity. However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular application which is inefficient and expensive. Li et al. (2010) reported that pH increased at 0.044 pH units per year at 15-20cm by maintaining a pH_{Ca} of 5.5 at 0-10 cm with lime, indicating that it would take approximately 23 years to raise the subsurface soil pH by one unit based on 20-year data from a long-term liming experiment (known as MASTER) near Wagga Wagga, NSW. Indeed, at the current commercial recommended rate of 2.5 t/ha every 6-10 years, most of the alkalinity added is consumed in the topsoil with very little remaining to counteract subsoil acidification. Thus more aggressive methods, such as the deep ripping with lime or other amendments, are required to deliver soil amendments to the subsoil directly, which would achieve more rapid changes to pH at depth.

Long-term experiments are probably the most difficult type of experiments to design correctly. The prerequisites for setting up a long-term experiment are secured land, continuous funding and dedicated scientists. A number of principles must be considered carefully when establishing a long-term experiment: *a*) the site must be representative of large areas of an agronomic zone; *b*) the treatments should be simple, but focusing on the big questions; *c*) the plots should be large enough to allow subsequent modification of the experiment if this becomes necessary; *d*) crop rotations should be considered to minimise the risk of build-up of weeds, pests and diseases, wherever possible; *e*) a clearly defined experimental protocol should be developed to ensure data collected is scientifically sound and statistically valid, but with flexibility to allow tactical changes; *f*) soil samples, and possibly plant samples, should be archived to provide better answer to the original questions when new, perhaps more accurate analytical techniques are developed, or answer new research questions that were not considered in the original design.

In late 2014, a multidisciplinary team was formed, including agronomists, soil chemists, soil physics, economists, system modellers and farm advisers as well as leading farmers. In early 2015, a long-term field experiment was chosen and established at Dirnaseer, west of Cootamundra, NSW. The objectives were to *a*) to manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability, and *b*) to study soil processes, such as the changes of soil chemical, physical and biological properties under vigorous soil amelioration techniques to date over the longer term. The current paper discusses the principles of setting up a long-term experiment and develops a framework of designing a long-term experiment to manage subsoil acidity in the high rainfall cropping region of southern Australia.

Site selection

There are several rigorous criteria for the site selection. First, the site must be secured for long-term use and a co-operative collaborator is essential. Second, the site must be acidic to depth in high rainfall zone (> 550 mm), representative of large areas in the region. We were targeting pH_{Ca} 4.0-4.5 at 0-10 cm, pH_{Ca} < 4.3 and exchangeable aluminium (Al) > 20% at 10-20 cm, pH_{Ca} < 4.5 and exchangeable Al > 10% at 20-30 cm. Third, the site must be flat, uniform and big enough (8-10 ha) to accommodate necessary treatments. A sufficiently uniform site can be challenging in acid soil research, given the spatial and temporal variability which is known to exist in acid soil environments (Conyers et al. 1997).

During September 2014 to February 2015, the project team screened nearly 100 paddocks in southern NSW by taking 3-5 soil cores at 0-10, 10-20 and 20-30 cm from Culcairn and Henty in the south to Cootamundra and Binalong in the north. The initial screening was based upon prior knowledge of acid soil distribution from a soils database created as a result of the Acid Soil Action research in 1997-2003 (Scott et al. 2007), as well as recommendations from private and public agronomists and farm advisers in the region. Additional soil samples based on EM28 survey map were taken from the most promising sites to confirm their suitability. The site chosen, in general, met the selection criteria (Figure 1). The 10-30 cm zone was acidic with levels of exchangeable Al likely to be toxic to crops, but surface applied lime is not likely to reach this depth in the short term.

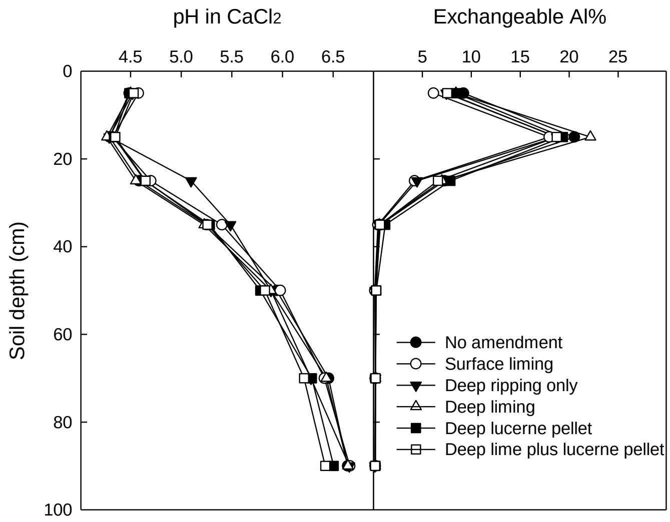

Figure 1. Soil profile at the long-term site at Dirnaseer, west of Cootamundra, NSW

Treatment selection

Long-term experiments should contain a small number of treatments that focus upon the key issues (Johnston 1997). In this experiment, there are 6 treatments with two major contrasts: a) surface liming vs deep liming; and b) deep liming vs deep organic amendment (Table 1). Treatment 1 (Control) is a nil-amendment treatment, representing the 'do nothing' approach as a control. Treatment 2 (Surface liming) is common practice when soil becomes acidic. Our lime rate was calculated to achieve an average pH_{Ca} of 5.5 at 0-10 cm over 8 years, at which point the site is likely to be re-limed. The assumption is that pH_{Ca}5.5 is high enough to neutralise new acid added by production system in the surface 0-10 cm and to allow excess alkalinity to move down the profile over time, and is the present best-practice recommendation (Li et al. 2001; 2010). Treatment 3 (Deep ripping only) is included to quantify the ripping effect. For Treatment 4 (Deep liming), we aimed to place the lime at two depths in the acidic 10-30 cm zone of the soil profile using a 3-D Ripping Machine (designed and fabricated by NSW Department of Primary Industries, Li 2016). The target pH is above 5.0 throughout the whole soil profile, which should eliminate pH restrictions to plant growth for most crops. Treatments 5 and 6 are to use organic amendment (e.g. lucerne pellets) to increase soil pH while supplying additional nutrients such as N, P, K. It has been reported that organic amendments could be used to improve the subsoil acidity because the decarboxylation reactions that they promote have the potential to increase soil pH, decrease Al toxicity and generally improve conditions for root growth (Tang et al. 2013). This has not previously been tested in a field environment in the target region.

Table 1. Soil amendment and treatment description at the long-term site.

Treatment	Depth (cm)	Target pH	Lime rate (t/ha)	Organic amendment rate (t/ha)*	Treatment description
1. Control	0-10	-	-	-	No amendment
	10-30	-	-	-	
2. Surface liming	0-10	5.5	3.8	-	Lime incorporated into 0-10 cm
	10-30	-	-	-	
3. Deep ripping only	0-10	5.0	2.5	-	Lime incorporated into 0-10 cm
	10-30	-	-	-	Deep ripping to 30 cm
4. Deep placement of lime	0-10	5.0	2.5	-	Lime incorporated into 0-10 cm
	10-30	5.0	3.0	-	Deep placement of lime at 10-30 cm
5. Deep placement of organic amendment	0-10	5.0	2.5	-	Lime incorporated into 0-10 cm
	10-30	5.0	-	15	Deep placement of organic amendment at 10-30 cm
6. Deep placement of lime and organic amendment	0-10	5.0	2.5	-	Lime incorporated into 0-10 cm
	10-30	-	3.0	15	Deep placement of lime and organic amendment at 10-30 cm

* Organic amendment: lucerne pellets.

Experimental design

There are 4 crops with 6 soil amendment treatments arranged in a fully phased design (Table 2). The crop sequence is in a 4-year rotation; as wheat (*Triticum aestivum*)-canola (*Brassica napus*)-barley (*Hordeum vulgare*)-pulse. Faba bean (*Vicia faba*) will be the first choice in the pulse phase due to its sensitivity to soil acidity, otherwise field peas (*Pisum sativum*) will be used in this phase if breaking autumn rains were late. Each crop will appear once in any given year to a) assess responses of different crops to different soil amendments; and b) compare underline underlying treatment effects taking account of seasonal variation. The experiment is designed to run for at least two crop rotation cycles (4-year a cycle), or one soil amendment cycle (8-year a cycle). The experiment may run for the second soil amendment cycle unless soil processes being monitored have reached equilibrium within the first amendment cycle.

Table 2. Crop rotation cycle and soil amendment cycle at each phase.

		Phase 1	Phase 2	Phase 3	Phase 4	Crop rotation cycle	Soil amendment cycle
Year 1	2016	**W1**	C2	B3	**P4**	Crop cycle 1	Soil amendments
Year 2	2017	C2	B3	**P4**	**W1**	starts in year 1	implemented in year 1
Year 3	2018	B3	**P4**	**W1**	C2		
Year 4	2019	**P4**	**W1**	C2	B3		
Year 5	2020	**W1**	C2	B3	P4	Crop cycle 2	
Year 6	2021	C2	B3	P4	**W1**	starts in year 5	
Year 7	2022	B3	P4	**W1**	C2		
Year 8	2023	P4	**W1**	C2	B3		
Year 9	2024	W1	C2	B3	**P4**	Crop cycle 3	Soil amendments
Year 10	2025	C2	B3	**P4**	**W1**	starts in year 9	re-applied in year 9
Year 11	2026	B3	**P4**	**W1**	C2		
Year 12	2027	**P4**	**W1**	C2	B3		
Year 13	2028	**W1**	C2	B3	P4	Crop cycle 4	
Year 14	2029	C2	B3	P4	**W1**	starts in year 13	
Year 15	2030	B3	P4	**W1**	C2		
Year 16	2031	P4	**W1**	C2	B3		

Crop code: W1, crop at phase 1 as wheat; C2, crop at phase 2 as canola; B3, crop at phase 3 as barley; P4, crop at phase 4 as pulse.

Experimental protocol and dataset

A comprehensive experimental protocol has been developed to ensure data collected are scientifically sound and statistically valid. Agreed sets of measurements have been clearly listed in the protocol to meet the minimum requirements by agronomists, soil chemists, soil physics, economists as well as system modellers. In addition, a detailed electronic field diary was created to keep field records, such as details of fertilisers applied, herbicides and insecticide applied, general observations of weeds, pests and diseases and any other factors considered relevant to future interpretation of the results. It is often the case that the scientist who writes up the long-term experiment is often not the scientist who ran the experiments (Leigh et al. 1994).

Archiving samples

All soil samples, possibly plant samples if necessary, will be archived for long-term storage. The value of a long-term experiment is greatly reduced if samples are not archived (Martin et al. 1998). Archived samples provide for two important contingencies. Firstly, samples can be reanalysed when new, perhaps more accurate analytical techniques are developed. Secondly, they allow researchers to examine historical questions that were not considered in the original design. Only if historical samples are available, can new analytical techniques be used to answer new questions or just to provide better answer to the original questions.

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