Managing subsoil acidity – project overview

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Key findings

- Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia.
- More aggressive methods, such as deep ripping in conjunction with lime or other amendments, are being tested to achieve rapid changes to pH at depth.
- A long-term field experiment was established to study changes in the chemical, physical and biological properties of soil under vigorous soil amelioration techniques.

Introduction

Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia (Pinkerton & Simpson 1986; Scott et al. 1997). Approximately 50% of Australia's agriculture zone (~50 million hectares) has a surface soil pH <5.5 in calcium chloride (pH_{Ca}); half of this area also has subsoil acidity (Dolling et al. 2001).

Soil acidification is accelerated by:

- nitrate leaching under certain crop rotations
- using ammonium-based fertilisers
- regular removal of plant products, such as grain or hay.

The major constraint to plant production on acid soils is aluminium (Al) toxicity, which inhibits root growth even at very low concentrations. Smaller root systems limit nutrient and water uptake and increase the plants' vulnerability to periodic droughts.

Applying lime to the surface 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 15–20 cm by maintaining an average 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 years of data from a long-term liming experiment (known as MASTER) near Wagga Wagga, NSW. 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 deep ripping in conjunction with lime or other amendments, are required to deliver soil amendments to the subsoil directly and achieve more rapid changes to pH at depth.

It has been reported that organic amendments could be used to improve the subsoil acidity, because the decarboxylation reactions can potentially 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.

This project investigates placing lime deep into the subsoil where it is most needed, with or without organic amendments to achieve more rapid changes to pH at depth. Novel amendments, such as magnesium silicate, reactive phosphate rock, and calcium nitrate, are being tested in different soils with different crop species in both controlled environments and under field conditions.

The aim of the project is to manage subsoil acidity through innovative amelioration methods that increase productivity, profitability and sustainability on farms. Specifically the objectives of the project are to:

- conduct a scoping study to highlight the range of potential traits and mechanisms that might improve wheat, canola and pulse performance in acid soils where Al toxicity limits production

- assess and develop innovative techniques to improve efficacy of liming, such as the deep placement of lime with inorganic or organic amendments
- develop and use novel materials, such as magnesium silicate, reactive phosphate rock and calcium nitrate as alternatives to lime for ameliorating subsoil acidity
- assess the economic impact for the proposed treatments which prevent or ameliorate subsoil acidification by considering their costs, yield benefits and residual values.

Methodology

This project brings 10 scientists from four research organisations: the NSW Department of Primary Industries, La Trobe University, Charles Sturt University and CSIRO in partnership with four leading grower groups (Farmlink Research, Holbrook Landcare Network, Riverine Plains and Southern Farming Systems) in the main grain production regions of south-eastern Australia where acid soils are prevalent. The project consists of six components as shown in the program logic framework (Figure 1), each described in more detail below.

Scoping study

Dr Peter Ryan completed the scoping study, 'Genetic potential for yield improvements in Australia's major grain crops on acid soils'. The review provided an overview of current knowledge of acid soil tolerance in the major winter crops species: wheat, canola and pulses. The review listed known mechanisms and genes controlling Al and manganese (Mn) tolerance and proposed strategies for improving tolerance in certain species. The review also identified knowledge gaps, which would provide guidelines for future research. Contact Dr Peter Ryan at peter.ryan@csiro.au for more details on the scoping study.

Laboratory/glasshouse experiments

A series of laboratory incubation studies and soil column experiments have been or are to be conducted under controlled conditions. The overall objectives are to:

- compare the effectiveness of a range of inorganic and organic amendments and their combinations to ameliorate soil acidity
- optimise the application rates and application depth in soil profiles to identify the most effective amendment treatments.

The best amendment treatments will be applied at optimum rates to various soil depths to validate the effectiveness under field conditions. The organic amendments tested so far in laboratory/glasshouse experiments include poultry litter, poultry manure, mature dairy compost, sheep manure, biochar, biosolids, lucerne pellets, and crop residues from field peas, vetch, oats and wheat. The inorganic amendments used are lime, dolomite, magnesium silicate, gypsum, calcium nitrate and reactive phosphate rock. A couple of experiments investigated the effectiveness of combinations of lime or magnesium silicate with lucerne pellets, respectively. In those column experiments, the selected amendments were placed at different depths or combinations of depths to mimic the situations in the field where lime is surface, subsurface or to the whole soil profile.

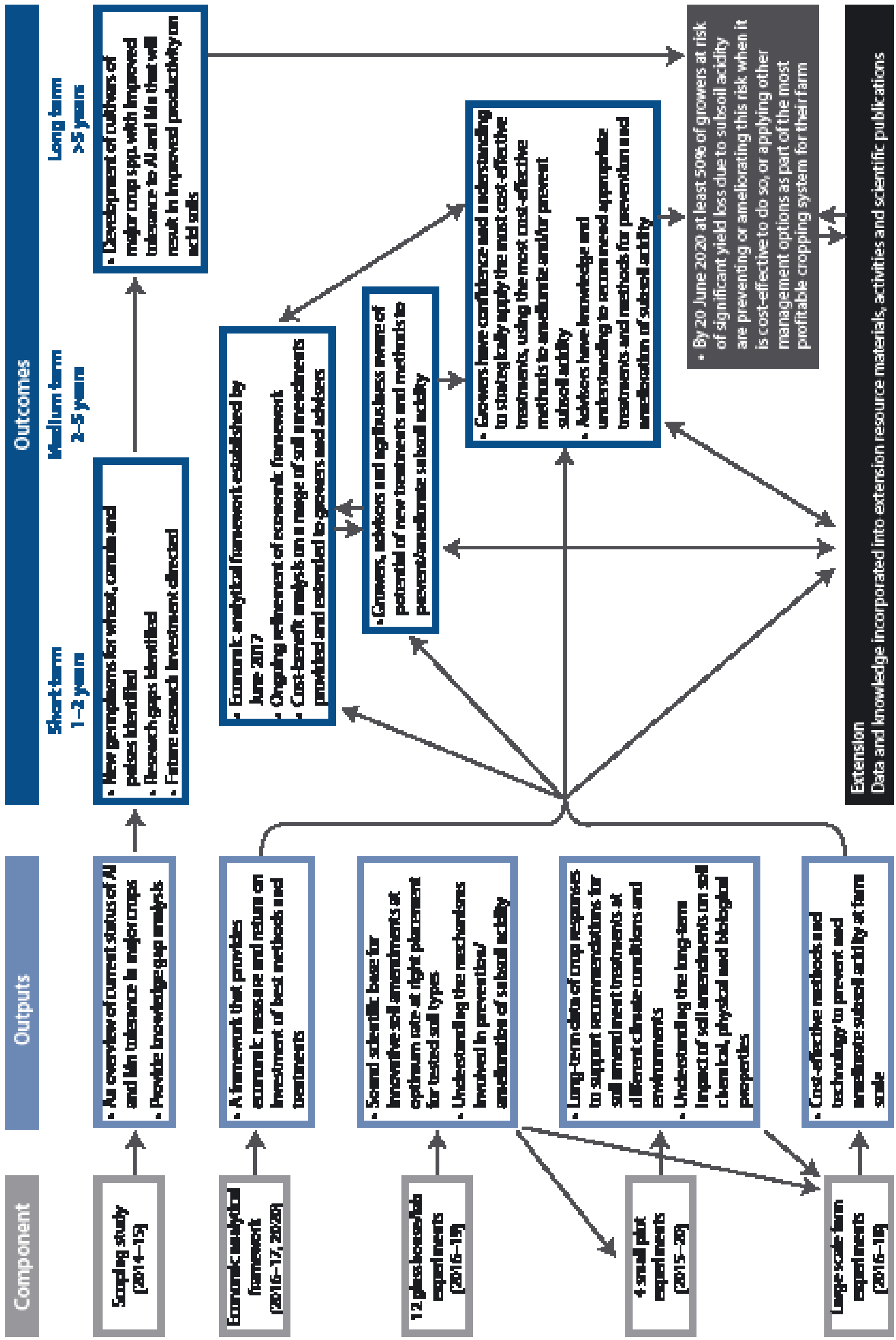

Figure 1. Program logic frame work for 'Innovative approaches to managing subsoil acidity in the southern grain region'.

Small plot experiments

Four small plot experiments have been, or are to be, established across southern NSW and northern Victoria. The changes in soil chemical, physical and biological properties, and crop responses to soil amendments are being monitored. One of the field sites was established in 2016 as a long-term experiment. There were six treatments with two major contrasts:

- surface liming vs deep liming
- deep placement of lime vs deep placement of organic amendment (Table 1).

Treatments 2–5 are regarded as core treatments included in all field experiments, which will enable a multi-site analysis.

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

* Core treatments, included in all field experiments.

Large-scale on-farm experiments

Eight large-scale on-farm experiments have been, or are to be, established over four years, conducted by the four grower groups: Farmlink Research, Holbrook Landcare Network, Riverine Plains and Southern Farming Systems. Each site will be in place for at least three years to monitor crop response to soil amendments. Four core treatments described in small plot experiments are arranged in a randomised complete block design with three replicates. Plot size is 10 m × 100 m.

All soil amendments are to be implemented by a 3-D (dual depth delivery) Ripping Machine (Li & Burns 2016). The custom-built machine, designed and fabricated by Adam and Richard Lowrie, NSW Department of Primary Industries, can deliver inorganic and organic amendments, or combinations of products, at two depths (10–20 cm and 20–30 cm). The machine can also deliver liquid nutrients/fertilisers at depth. The 3-D Ripping Machine produces an even, firm seedbed that is suitable for sowing immediately after the amendments are in place (Figure 2).

Figure 2. 3-D Ripping Machine, designed and fabricated by NSW Department of Primary Industries staff. (Photo by Guangdi Li)

Economic analytical framework

An economic model will be developed to undertake a short- and long-term financial analysis on data from both small plot experiments and large-scale field experiments. The economic model will evaluate the financial implications and the productivity and profitability changes resulting from the subsoil acidity amelioration. Enterprise gross margins for the specific crops will be developed and compared at the early stages of the economic evaluation, but a long-term financial analysis will be conducted at the end of the project period.

Extension and communication

Extension is an essential part of the project and plays an important role in grower adoption. Farmers, private and public advisers and consultants continue to be engaged through project planning meetings, workshops, field days and regional updates to ensure that the research outputs are delivered to end-users. The research findings will be available to the wider scientific community at relevant conferences and in appropriate scientific journals. Contact Helen Burns at helen.burns@dpi.nsw.gov.au for information related to extension and communication activities.

Principles and design of long-term field experiment

Long-term experiments are probably the most difficult type of experiments to design. The prerequisites for setting up a long-term experiment are the secured tenure of land, continuous funding and dedicated scientists. A number of principles must be carefully considered when establishing a long-term experiment:

- the site must be representative of large areas
- the treatments should be simple, but focused on the big questions
- the plots should be large enough to allow detailed sampling and subsequent modification if necessary
- crop rotations should be considered to minimise the risk of weed, pest and disease build-up wherever possible
- a clearly-defined experimental protocol should be developed to ensure data collected is scientifically sound and statistically valid, but with the flexibility to allow tactical changes
- soil samples, and possibly plant samples, should be archived to enable future analysis when new, perhaps more accurate, analytical techniques are developed, or answer new research questions that were not considered in the original design.

Site selection

There are several rigorous selection criteria applied when selecting a long-term field site. The site must be:

- secured for long-term use and a cooperative collaborator is essential
- located in the high rainfall cropping zone (>550 mm), representative of large areas in the region
- acidic to depth. 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
- flat, uniform and big enough (8–10 ha) to accommodate the necessary treatments.

From September 2014 to February 2015, the project team screened about 100 paddocks in southern NSW from Culcairn and Henty in the south to Cootamundra and Binalong in the north, by taking 3–5 soil cores at 0–10, 10–20 and 20–30 cm depths. 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 Program NSW Government 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 EM38 survey maps were taken from the most promising sites to confirm their suitability and avoid excessive spatial variability. In early 2015, a long-term field experiment site was chosen and established at Dirnaseer, west of Cootamundra, NSW. The soil at 10–30 cm depth 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–medium term (Figure 3).

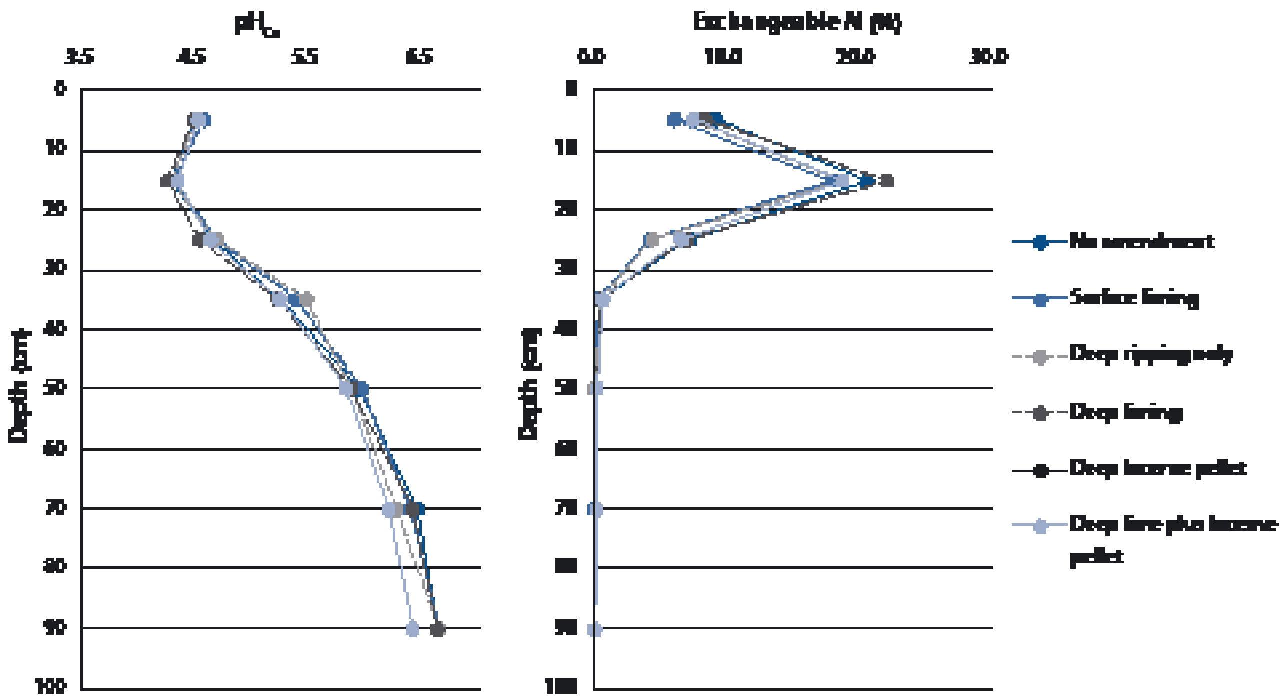

Figure 3. Soil pH and exchangeable Al profile at the long-term site at Dirnaseer, west of Cootamundra, NSW.

Treatment and experimental design

There were four crops with six soil-amendment treatments arranged in a fully phased design (Table 2). The crop sequence is in a 4-year rotation: wheat (*Triticum aestivum*); canola (*Brassica napus*); barley (*Hordeum vulgare*); pulse. Faba bean (*Vicia faba*) is the preferred pulse phase due to its sensitivity to soil acidity, but field peas (*Pisum sativum*) will be used in this phase if breaking autumn rains occur later than mid May. One of the features of the phased design is that each crop appears once in any given year to:

1. assess responses of different crops to different soil amendments
2. compare underlying treatment effects taking account of seasonal variation.

The experiment was designed for at least two 4-year crop rotation cycles, or one 8-year soil amendment cycle. The second soil amendment cycle will proceed unless soil processes being monitored have reached equilibrium within the first amendment cycle. See detailed treatments description in Li et al (2017) in this book.

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 starts in year 1	Soil amendments implemented in year 1
Year 2	2017	C2	B3	P4	W1		
Year 3	2018	B3	P4	W1	C2		
Year 4	2019	P4	W1	C2	B3		
Year 5	2020	W1	C2	B3	P4	Crop cycle 2 starts in year 5	
Year 6	2021	C2	B3	P4	W1		
Year 7	2022	B3	P4	W1	C2		
Year 8	2023	P4	W1	C2	B3		
Year 9	2024	W1	C2	B3	P4	Crop cycle 3 starts in year 9	Soil amendments re-applied in year 9
Year 10	2025	C2	B3	P4	W1		
Year 11	2026	B3	P4	W1	C2		
Year 12	2027	P4	W1	C2	B3		
Year 13	2028	W1	C2	B3	P4	Crop cycle 4 starts in year 13	
Year 14	2029	C2	B3	P4	W1		
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 that the data collected is 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 physicists, economists as well as system modellers. In addition, a detailed electronic field diary was created to keep field records, such as details of fertilisers, herbicides and insecticide applied, general observations of weeds, pests and diseases and any other factors considered relevant to future interpretation of the results. This is essential, as it is often the case that the scientist who writes up the long-term experiment is not the scientist who conducted the experiments (Leigh et al. 1994).

Archiving samples

All soil samples, and 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:

1. samples can be reanalysed when new, perhaps more accurate analytical techniques are developed
2. 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 answers to the original questions.

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