Lime incorporation into acidic sandplain soils in the West Midlands and beyond!

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Purpose:	To improve understanding of the range of tillage implements and techniques available to incorporate lime into acidic soils, their respective costs and benefits.
Locations:	Dandaragan, Badgingarra and Mingenew
Soil Types:	Deep sands, sandy earths and sandy gravels
Growing Season Rainfall (April- October 2014): 407mm Badgingarra; 498mm Dandaragan; 226mm Mingenew (Casuarinas)	

BACKGROUND SUMMARY

Surface applied lime can take many years to ameliorate subsoil acidity. Ongoing acidification has resulted in lower subsoil pH's and the depth of the acidic layer is increasing. This has generated renewed interest in one-off lime incorporation using strategic tillage to reduce the time required to ameliorate the subsoil acidity and to get a more rapid return on investment from applying lime. Effective amelioration of subsoil acidity requires the creation of continuous pathways of pH corrected soil from the soil surface through the acidic subsoil layer.

TRIAL DESIGN

West Midlands

In the past few years a number of research and demonstration sites have been established in the West Midlands to assess the efficacy of a range of lime incorporation techniques (Table 1). The sites were established on sandplain soils in cropping and pasture paddocks which had subsoil acidity.

Efficacy of lime incorporation at these sites has primarily been visually assessed through the use of universal pH indicator on soil pit faces or in some cases by soil sampling and measuring the soil pH. In this paper grain and pasture productivity will not be reported or used as an indicator of successful lime incorporation as these responses tend to be confounded by cultivation effects and responses can take some years to develop depending on the starting pH and soil variation.

Short-term Results

For most of the sites' responses have tended to be confounded by the short term impact of cultivation. In some cases difficulties with seeding depth, wind damage and late seeding can reduce the likelihood of a short-term response to the treatments. Immediate, first year responses to lime can occur and an example of this is shown for site 3 (Table 1; Figs. 1 and 2) near Badgingarra which was established in 2013 on sandy gravel and sown to barley that year before going back to pasture in 2014. Incorporation treatments included offset discs or combination of offsets and deep ripping in addition to the untreated control while lime was applied at rates of 0 and 3 t/ha.

Long-term Results
In addition to these more recent trials a soil inversion and lime incorporation replicated plot trial was established in 2007 on deep yellow sandy earth, in a cropping paddock near Mingenew. The site is affected subsoil acidity, mild water repellence and a weed burden consisting mainly of wild radish and ryegrass. One-off soil inversion was achieved using a 3-furrow Kvernerland mouldboard plough (MBP). Limesand sourced from Dongara was applied to selected treatments at a rate of 2 t/ha.

Treatments applied in 2007 were as follows:
1. Untreated control
2. 2 t/ha surface applied lime
3. Mouldboard plough (no lime)
4. 1 t/ha lime then Mouldboard plough then another 1 t/ha lime
5. Mouldboard plough then 2 t/ha lime
6. 2 t/ha lime then Mouldboard plough

The site was sown to cover crop of barley in 2007. In 2008 the site was sown to canola using the DAFWA coneseeder. From 2009-2014 the site has been sown across using the growers seeder. From 2007-2009 and 2013-2014 the plots were harvested individually with a plot header and samples collected for grain quality. In 2010-2012 (between projects) bulk yields of ploughed and unploughed blocks were harvested by the grower, so detailed treatment effects could not be assessed. In 2014 the entire site was deep ripped by the grower to depth of 30-35 cm. Hand harvest samples were taken at crop maturity in 2014 and assessed for shoot biomass, yield components and ryegrass biomass. Soil sampling to measure soil pH and other properties was undertaken after harvest from the same locations the hand harvest samples had been taken. Crop rotations and growing season rainfall (April-October) over the 8 seasons the experiment has been running are shown in Table 3.

Table 1. Lime incorporation trials established in 2007-14 and tillage implements used for the purpose of this overview

Site	Location	Soil type	Trial type	Start Year	Incorporation implements tested	Funder
1	Mingenew	Yellow sandy earth	Replicated	2007	Mouldboard plough	GRDC
2	Dandaragan	Deep yellow sand	Replicated	2013	Mouldboard, Spader, Deep Ripping, Scarifier, Offsets, One-way Plough, Deep rip + Spader	GRDC
3	Badgingarra	Pale sandy gravel	Demo	2013	Offsets, Offsets + Deep Ripping	GRDC
4	Dandaragan	Deep yellow sand	Replicated	2014	Shallow leading tine ripper, Modified ripping (3 methods), Grizzly deep digger	COGGO
5	Dandaragan	Deep yellow sand	Demo	2014	Deep ripper, Grizzly deep digger, Grizzly offsets, Spader, Modified blade plough	COGGO

RESULTS and DISCUSSION

The efficacy with which various implements can incorporate surface applied lime can depend on numerous factors including:

- Soil type, in particular clay content can affect soil cohesion, fracturing and flow.
- Soil moisture conditions – in sandplain soils moisture can help the sand maintain its form (greater cohesion) allowing slots to remain open for longer but may reduce fracturing and soil flow. Wetter soils are softer so this can improve the penetration of soil by implements and reduce the draft. Dry surface sand flows (less cohesion) which can be an advantage for moving limed topsoil behind soil openers.
- Implement type – variations between machinery brands such as width of tines, curved or laid-back tines which may promote a lifting (delving) action; curvature (dish depth) of discs are just some examples.
- Implement setup and use – for disc ploughs and mouldboard ploughs setup greatly influences the incorporation result. Having ploughs more open will increase the work rate and the space between plough shares available for soil to move but may limit the working depth.
- Speed of operation – higher speeds can sometimes encourage more soil throw and mixing but may require a shallower working depth.

Table 2. Details of tillage implements and a summary of their efficacy when assessed for lime incorporation

Incorporation implement (approx. cost range $/ha)	Overview of tillage by implement	Typical working depth (cm)	Depth of lime incorporation achieved (cm)	Lateral spread of lime and incorporation efficacy
Deep ripping ($45-55/ha)	Narrow strong deep working tines used to break out subsoil compaction	30-40	10-15, variable	Limed topsoil tends to be mixed in the surface layer where the tine passes through but the slot behind the tine closes rapidly so there is little opportunity for limed topsoil to fall deeper into the subsoil
Shallow-leading tine ripping ($40-50/ha)	Ripping with shallow leading tines allowing deeper break out by deeper working, trailing tines	40-50	10-15	Limed topsoil can be incorporated better due to multiple tines disturbing the soil in the one pass, although incorporation is still limited as tines are narrow and slots close rapidly behind the tines
Ripper with wings ($45-55/ha)	Wings mounted on ripper tines that operate below the soil surface when ripping which creates greater soil disturbance as they tend to lift subsurface soil	30-40	20-25	Limed topsoil can flow into the space opened up via the lifting (delving) action of the wings. Lateral incorporation is improved with 'tongues' of topsoil up to 8 cm wide on either side of the ripping tine where the wings had passed.

Ripper with 'Horwood' opener ($45-55/ha)	Plates extend behind the ripping tine to hold open the soil slot longer operating just below the topsoil	30-40	20-26	Holding the slot open for longer below the soil surface allows limed topsoil to drop into the subsoil. A continuous seam of limed topsoil was achieved but the slot narrowed to 1-2 cm at depth.
Ripper with 'Railway Fishplate' opener ($50-60/ha)	Plates bolted onto the side of the ripper tines effectively increased the tine width and the degree of disturbance	30-40	19-23	More disturbance resulted in more mixing. Width of mixing was increased up to 14 cm in some instances but this was variable.
'Deep digger' (estimated $60-70/ha)	Large wide curved tines in a V-shaped arrangement capable of ripping deeper than standard deep rippers	40-60	23-25	Wider tines and some delving action allow some topsoil flow around and behind the tines but overall incorporation is fairly minimal for cost. Modifications needed for better incorporation.
Offsets ($40/ha)	Standard offset (two-way) discs that cultivate the topsoil	10-15	10-15	Very little limed topsoil is incorporated into the subsoil layers due to inadequate working depth. Mixing will still improve the reaction of the lime in the topsoil which may then allow for faster lime movement into the subsoil.
Large offsets ($50-60/ha)	Large offset (two-way) discs, typically greater than 70cm in diameter, that can cultivate deeper than standard offsets	24-25	24-25	Limed topsoil is effectively incorporated to the working depth. Some layering occurs on an angle from the surface but generally the mixing is good. Visually it appears about two-thirds to three-quarters of the profile is treated to the working depth. The incorporation depth can be less if hardpans or gravel prevent disc penetration.
One-way plough ($30-40/ha)	Discs throw the soil one-way, can achieve partial turning of the soil but mixing occurs as soil tumbles off the disc.	15-25	15-25	Limed topsoil is partially mixed and layered on an angle from the surface as a result of the cultivation process. Despite partial inversion and layering continuous pathways of limed topsoil are still available for root growth. About half to two-thirds of the topsoil is buried. Can

				bring acidic subsoil to the surface so more surface lime may be required post-ploughing.
Modified blade plough ($40-50/ha)	Lifting plates attached to back of the blades lifts soil up to then roll off the back and sides of the plates	21-23	20-23	Effective in mixing limed topsoil to the working depth in reasonably wide seams, 10-15 cm wide, spaced about 15 cm apart.
Rotary spader ($120-150/ha)	Rotating spades bury some topsoil while lifting up some subsoil. About two-thirds of the topsoil is buried below 10 cm. Soil tends to take on marbled appearance.	28-35	28-35	Very effective at mixing limed topsoil into the subsoil. Does lift some acidic subsoil to the surface so additional lime may be required in subsequent years. Because spades are offset and overlapping lime is incorporated through the entire profile to the working depth, although pockets of acidic subsoil may remain.
Mouldboard plough ($100-150/ha)	Curved mouldboard shares lift, roll and invert the soil aided by skimmers which scalp the topsoil into the base of the furrow. Square ploughs achieve similar results.	28-35	28-35	Inversion buries limed topsoil in a layer and can bring a thick layer of acidic subsoil to the surface that needs treating with more surface-applied lime. Continuous ameliorated pathways are not always present if inversion has been effective.

The relatively high cost implements, such as rotary spaders, mouldboard and 'TopDown' ploughs and large offsets are more effective at getting large amounts of limed topsoil to depth but with a higher capital and operating cost (Table 2). Modified deep rippers and one-way ploughs (Table 2) tend to be cheaper and can provide seams of limed topsoil to depth for much lower cost. Productivity responses may not be as large when only part of the acidic soil profile has been fixed, though this depends on spacing of the ameliorated seams.

The cost of one-off tillage to incorporate lime can vary significantly ranging from about $30/ha if using a second-hand one way disc plough through to $150/ha or more if using a rotary spader, excluding the cost of lime. For growers already deep ripping to remove subsoil compaction trying to create seams of limed topsoil through the addition of simple openers may be a cost-effective way of starting to address the problem although several years of deep ripping may be needed to create sufficient pathways to benefit the entire crop. Large offset discs or one-way ploughs are also likely to be cheaper and yet quite effective provided they can achieve good soil penetration and working depth. Rotary spaders are the most effective at incorporating lime throughout the whole profile to the working depth but the slow work rate, high cost and applicability due to soil type (e.g. rocks and roots) limits their use.

Short-term crop yield responses to lime incorporation can occur but are often overwhelmed by responses to the tillage. The short-term impacts of lime incorporation on soil pH and barley grain yield for Site 3 (Table 1) are shown in Figures 1 and 2. Incorporation increased soil pH in sandy gravel at 20-30cm (Figure. 1) whereas in the no-till control there was no short-term pH increase at this depth.

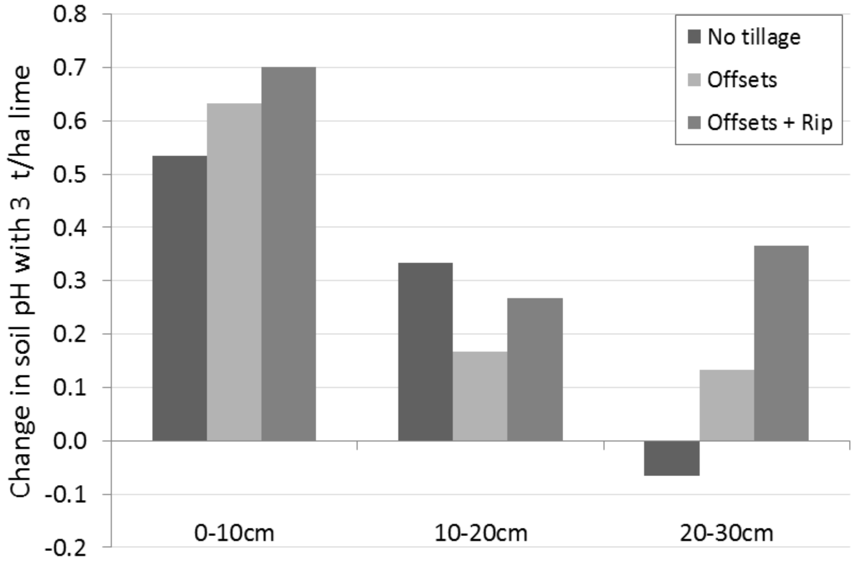

Figure 1. Impact of lime application and tillage methods on the change in soil pH ($CaCl_2$) after application of 3 t/ha limesand at 0-10, 10-20, and 20-30cm for sandy gravel at Badgingarra in 2013

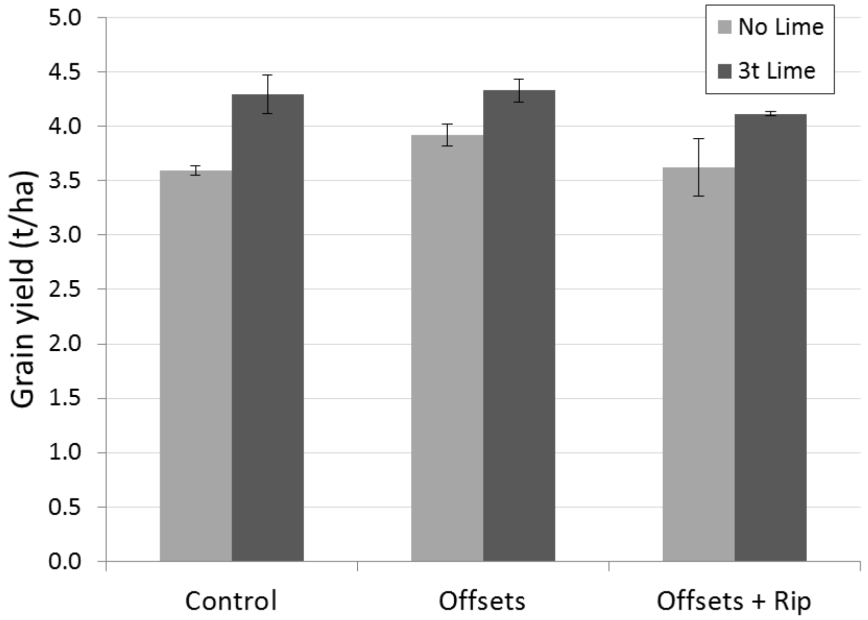

Figure 2. Impact of lime application and tillage methods on barley grain yield on sandy gravel at Badgingarra in 2013

In this experiment there is yield response to one-off cultivation for the offset discs with an increase over the uncultivated control of 330 kg/ha (Figure 2). Application of lime increased yield much more, by 700 kg/ha with no incorporation and there was no additional benefit of incorporation in this instance (Figure 2).

Soil pH, two seasons after the lime was applied shows that the increase in topsoil pH for any of the liming treatments has taken the pH above the topsoil target of 5.5 (Table 3). In the limed treatments there has been an increase in the pH of the 10-20 cm layer, irrespective of incorporation but none of the treatments show an increase in pH for the 20-30 cm layer (Table 3). The findings indicate that application of sufficient lime to the surface of a sandy soil in a relatively high rainfall environment such as Badgingarra can result in an increase in the pH of the subsurface layer within several years, although there is still no improvement below 20 cm.

Table 3. Soil pH ($CaCl_2$) measured in January 2015 for sandy gravel where lime was applied at a rate of 3t/ha in 2013 and either not incorporated (Control) or incorporated with offset discs or a combination of offset discs and deep ripping

Depth (cm)	Control	Control+Lime	Offsets	Lime+Offsets	Offsets+Rip	Lime+Offsets+Rip
0-10	4.8	6.2	4.9	5.7	4.8	6.0
10-20	4.8	5.4	5.0	5.2	4.9	5.4
20-30	4.8	4.9	4.8	4.8	4.8	4.8

Long-term Responses

In this experiment lime and mouldboard ploughing treatments were applied, once only, in 2007. In 2013, the seventh season after treatments were applied, wheat yields were increased by an average 300 kg/ha due to mouldboard ploughing with an additional 200 kg/ha yield increase where lime was applied in conjunction with the ploughing. Lime application strategy whether applied before or after ploughing or split between the two in conjunction with ploughing did not significantly impact on the yield outcome.

Surface lime application did not significantly increase wheat yield in 2013 (data not shown). In addition to the increase in yield mouldboard ploughing also significantly increased grain protein by 1% or more, reduced screenings for all but one of the mouldboard treatments.

In 2014 a more acid soil sensitive Fleet barley crop was grown. Barley yields were increased by around 300 kg/ha for both surface liming and mouldboard ploughing without additional lime (Figure 3). In combination mouldboard ploughing and lime increased barley yield around 1 t/ha in 2014 (Figure 3) and like the previous year’s wheat crop the order with which the lime as applied in relation to ploughing was not significant at this site.

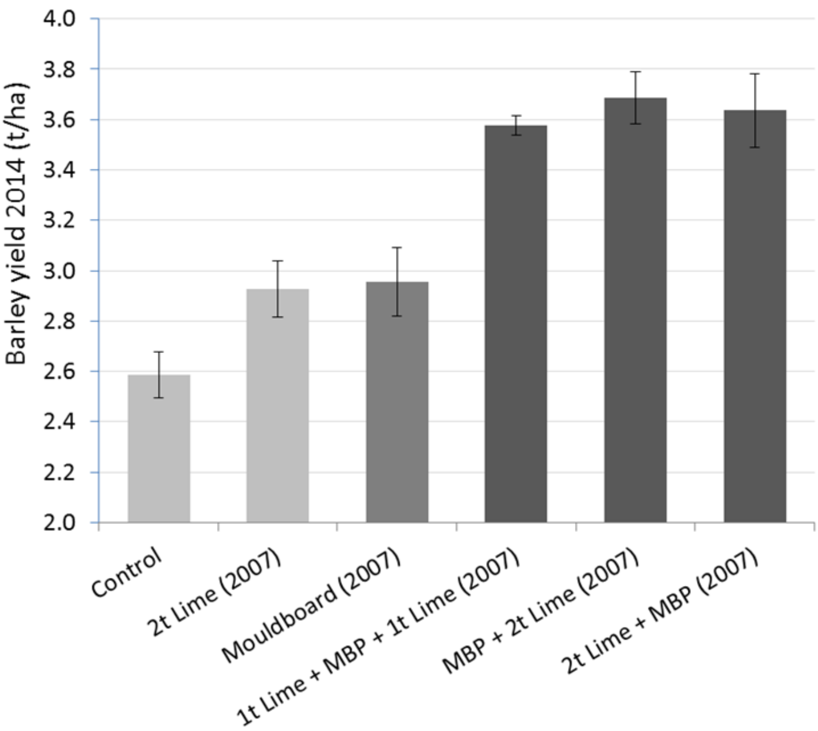

Figure 3. Impact of lime application and mouldboard ploughing in 2007 on barley grain yield in 2014

In 2014 ryegrass biomass was measured in each treatment as visual differences in ryegrass density across the treatments were evident. Ryegrass shoot biomass was highest in the untreated control at just over 500 kg/ha (Figure 4). Mouldboard ploughing on its own had 36% lower ryegrass biomass but the impact of surface liming was even greater with a 54% reduction in ryegrass biomass (Figure 4). The combination of mouldboard ploughing with lime further reduced ryegrass biomass by up to 75%, with a trend towards lower biomass where some lime had been applied after mouldboard ploughing (Figure 4). Overall the average ryegrass biomass of the limed treatments was 180 kg /ha compared to 460 kg/ha of ryegrass for the un-limed treatments. By comparison the average whole shoot biomass of the barley was 8.0 t/ha for all of the limed treatments and 5.9 t/ha of barley biomass for the un-limed treatments, highlighting the importance of the crop competition.

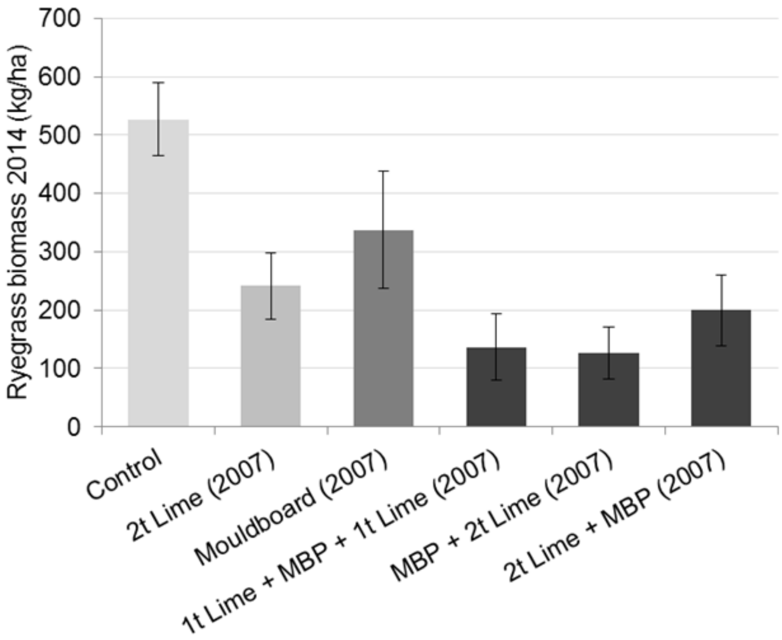

Figure 4. Impact of the lime application and mouldboard ploughing in 2007 on above-ground ryegrass biomass in 2014

FINANCIAL ANALYSIS OF RESULTS - *Long-term experiment*

Additional income benefits from the treatments have been determined over the course of the long-term experiment using September grain prices for each growing season (Table 4). This has not taken into account the cost of the amelioration treatments which is estimated at $150/ha for mouldboard ploughing and $50/ha for application of lime at 2 t/ha. Returns over the 8 seasons have more than covered these costs with returns from liming providing an additional $222/ha over the past 2 seasons alone (Table 4). Overall the additional income generated from the soil amelioration treatments has been over $600/ha over the course of the experiment.

Table 4. Crop type, growing season rainfall (GSR), yield changes and additional income benefits for 2007-2014 seasons following soil amelioration with a combination of mouldboard ploughing and lime applied once-only in 2007 (n.m. = not measured)

Year	GSR (mm) April-October	Crop type	Crop price $/t	MBP t/ha over NIL	Lime t/ha over MBP	MBP $/ha Benefit	Lime $/ha Benefit
2007	233	Barley	220	0.1	0	22	0
2008	313	Canola	625	-0.1	0	-63	0
2009	384	Wheat	250	0.6	0	150	0
2010	257	Lupin	200	0	n.m.	0	n.m.
2011	361	Wheat	310	0.4	n.m.	124	n.m.
2012	313	Lupin	250	-0.1	n.m.	-25	n.m.
2013	350	Wheat	330	0.3	0.2	99	66
2014	226	Barley	260	0.4	0.6	104	156
					Total $ returns	**412**	**222**

CONCLUSION

It is critically important to sample soil pH to depth prior to investing large sums in lime application and incorporation. Typically it has been found that on sandplain soils the yield benefit of one-off deep cultivation or deep ripping is large enough to cover the cost of the tillage in the first year so the subsequent productivity benefits associated with more rapidly fixing the soil pH by incorporating lime can be realised sooner. Other factors such as water repellence, herbicide resistant weeds, subsoil compaction, wind erosion risk and soil type will impact on the choice of incorporation implement used.

PEER REVIEW: Chad Reynolds, Wayne Parker; Glen Riethmuller (DAFWA)

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GRDC Project Numbers: LIE0008 Working together to deliver multiple benefit messages to growers through a whole systems approach to soil management; DAW00204 Developing agronomic strategies for water repellent soils in WA; DAW00236 Soil acidity is limiting grain yield.

COGGO Project: Developing and testing innovative, practical and reliable methods for incorporating lime into acidic sandplain subsoils – West Midlands Group

NACC Project 1412-05-01: Demonstrating innovative practices for the amelioration of sub surface Acidity to improve soil health – West Midlands Group

GRDC Project 04.07.2013 Western Agribusiness Trial Extension Network, “Deep incorporation of lime into acidic subsoils”.