Impact of soil inversion, soil dilution and claying on non-wetting sandplain soils

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KEY MESSAGES

Soil compaction in deep sandy-textured soils is a substantial constraint to productivity in medium to high rainfall areas and significant benefits can be obtained from removing this compaction, provided other constraints such as subsoil acidity are not present.

Productivity benefits from inversion ploughing using a mouldboard plough were similar to those achieved by deep ripping in these trials suggesting that much of the initial impact of these tools is a result of compaction removal.

Mouldboard ploughing provides many other benefits including improved weed control and amelioration of soil water repellence that were not achieved by deep ripping.

Cultivation using mouldboard ploughs and rotary spaders fundamentally changes many soil properties and provides an opportunity to incorporate amendments (e.g. lime and clay), reduce compaction, increase soil pH and redistribute organic carbon through more of the soil profile. The long term impact of these changes is still to be assessed.

Crop establishment on soft soil as a result of deep cultivation can be difficult and soils need to be packed with reasonably heavy rollers or soil packers after mouldboard ploughing.

AIMS

To assess the impact on soil properties, weed control and crop productivity from one-off soil inversion using a mouldboard plough or soil mixing using a rotary spader.

BACKGROUND

Over the past three years growers and researchers in the northern agricultural region (NAR) have been examining the agronomic and productivity benefits derived from one-off inversion of sandplain soils using mouldboard ploughs (Newman and Davies, 2009). While initially touted as a highly effective means of reducing herbicide resistant weed seed banks the additional possibilities of managing non-wetting topsoil, subsoil acidity and soil compaction with a single-operation has increased grower interest in the technology (Newman and Davies, 2009). In 2009 growers started to experiment with the use of rotary spaders which combine a degree of soil inversion with soil mixing and have been used to incorporate surface spread clay subsoil for ameliorating soil water repellence in South Australia and in the Esperance region (D Hall pers. comm.).Several experiments were established on deep yellow sand at Binnu and pale deep sand at Badgingarra to assess the impact of mouldboard ploughing and rotary spading on agronomic and soil properties and their interaction with claying.

METHOD

Two research trials were established in 2009 in collaboration with the Northern Agri and West Midlands grower groups. In both trials a three-furrow Kvernerland mouldboard plough and an Imants 37 series rotary spader were used with both machines having a working depth of 25–30 cm. Clay rich-subsoil was spread at both sites using multi-spreaders which provided a relatively even spread of the clay compared to carry graders. Soil penetration resistance was measured with a Rimik CP40 cone penetrometer when the soil was at field capacity in both trials. Soils were sampled during the growing season to depths of 40 cm and subject to detailed chemical analyses. Additional soil measurements made at both sites during the season included bulk density and topsoil (0–5 cm) sampling for assessment of water repellence using the water droplet penetration test (WDPT) and molarity of ethanol droplet test.

Binnu – Northern Agri Group

Subsoil was spread at rates of 80, 125 and 250 t/ha on 29 April then incorporated to a depth of 15–20 cm with a rotary spader on the 11 June just prior to seeding. Mouldboard ploughing was done on the 27 March and the deep ripping treatments were applied on 11 June, just prior to seeding. The site was seeded 11 June to Bonnie Rock wheat using a DBS seeder with knife points and press wheels.

Badgingarra Research Station – West Midlands Group

Soil amendments were applied on the 8 April, treatments included a nil amendment (control), surface application of 3 t/ha limesand, and application of clay-rich subsoil at rate of 150 t/ha which was only lightly incorporated with one pass of offset discs. Cultivation treatments were applied across the soil amendment strips in a criss-cross design on 21 April and included an untreated (control); offset discs; rotary hoe; deep ripper; rotary spader; and mouldboard plough. The rotary hoe and offset discs worked to depth of about 15 cm and the deep ripper to a depth of 30 cm. Because the soil was dry at this time the sandy soil had insufficient cohesion between the sand particles to achieve complete sol inversion so an additional mouldboard plough treatment was applied when the soil was wet, just prior to seeding on 28 May and due to the moist conditions was able to work at a depth of 30–35 cm. Mouldboard plough and deep ripped plots were rolled with a light roller prior to seeding in an attempt to firm the seedbed for sowing. Each plot was sown to Calingiri wheat with a combine on 28 May 2009 at 90 kg/ha with Agstar Extra at 80 kg/ha.

RESULTS AND DISCUSSION

The clay content of the subsoils used for claying the trials ranged from 26–31 per cent clay (Table 1). The subsoil spread at Binnu was strongly alkaline, moderately saline and contained much higher levels of potassium, sulphur and boron compared with the Badgingarra subsoil (Table 1). This demonstrates the large variability in the properties of subsoils used for claying. Ideally subsoils should be tested prior to spreading.

Table 1. **Analyses of spread subsoil (clay)**

Site	pH_{Ca}	pH_w	mg/kg				EC mS/m	Particle size %		
			K	S	P	B		Sand	Silt	Clay
Binnu	8.5	9.1	400	147	5	9	99	69	5	26
Badgingarra	5.8	6.4	54	20	2	1	20	64	5	31

Binnu – Northern Agri Group

The topsoil at this site was only slightly repellent with a laboratory measured water droplet penetration time of 7 seconds. Despite this the grower and the sparse nature of the previous seasons canola stubble affirmed that establishment at the site was poor. Many growers in this area report that their yellow deep sand and sandy earth soils are becoming increasingly water repellent which is being reflected in poorer crop establishment. Clay content of the sandy topsoil was 3.5 per cent and this was increased by the addition of the subsoil to between 5.2–5.8 per cent (Table 2). In many yellow sandy earths, of this type, clay content can gradually increase with depth and this is reflected in the fact that soil inversion using the mouldboard plough increased the clay content of the inverted topsoil to 5.5 per cent. Rotary spading which does some degree of inversion and mixing increased the topsoil clay content to 4.2 per cent (Table 2). Soil pH at the site was reasonable, with only a maintenance dressing of lime required, but addition of the strongly alkaline subsoil which was then incorporated increased the pH of the top 20 cm and in the case of the high rate of clay also increased the pH in the 20–30 cm layer (Table 2). Soil strength was measured using a cone penetrometer when the soil was at field capacity. Undoubtedly one of the consequences of mouldboard ploughing and rotary spading is the loosening of compact soil. In this trial the control soil had a penetration resistance of 1.8 MPa at 20 cm which is a sufficient strength (> 1.5 MPa) to slow root growth but at 30 cm the strength was as high as 2.7 MPa which would severely reduce root growth (Table 2). By comparison deep ripping, mouldboard ploughing and rotary spading reduced the soil strength to levels which would not restrict root growth to a depth of at least 30 cm (Table 2).

One concern often raised when cultivation is used is that organic carbon will be lost as a result of the soil disturbance. Certainly cultivation can encourage microbial breakdown of soil organic matter however, the extent of this can be greatly overemphasised when only the top 10 cm of soil is considered. The biggest change as a result of cultivation is a change in the distribution of the organic carbon in the soil. In both the Binnu and Badgingarra experiments, and in others (Angers and Eriksen-Hamel 2008; Blanco-Canqui and Lal 2008; Christopher et al. 2009), cultivation has not greatly reduced the total amount of organic carbon present in the soil if it is measured over the depth of working, in this case 30 cm (Tables 2 and 4).

Table 2 **Soil pH_{Ca}, mass of organic carbon, clay per cent and penetration resistance for various soil amendment treatments applied to a deep yellow sand at Binnu in 2009.**

Treatment	Soil pH_{Ca}			Mass Organic Carbon (t/ha)				Clay %	Resistance (MPa)	
	0–10	10–20	20–30	0–10	10–20	20–30	Total 0–30	0–10	@20 cm	@30 cm
Control	5.1	4.9	5.0	7.6	4.0	1.6	13.1	3.5	1.8	2.7
Clay 80 t	7.2	5.7	5.3	–	–	–	–	5.2	1.0	2.3
Clay 125 t	6.4	5.6	5.0	–	–	–	–	5.5	1.1	2.1
Clay 250 t	7.5	7.1	5.9	–	–	–	–	5.8	1.0	2.6
Deep rip	5.4	5.2	5.3	–	–	–	–	3.9	0.6	1.0
Mouldboard	5.1	5.3	5.1	3.6	6.1	3.5	13.2	5.5	0.4	1.1
Spader	5.2	4.9	4.8	4.0	3.3	3.4	10.7	4.2	0.6	1.5

Crop establishment was similar for all of the treatments (Table 3). The site received 9 mm of rain on the day the crop was sown and had received over 40 mm of rain several weeks prior to seeding (DAFWA Binnu weather station and grower data). During tillering substantially improved crop performance was seen in parts of the trial, which turned out to be due to prescence of a deep subsoil clay layer at 1 metre. The prescence or absence of this deep subsoil clay layer was included as a covariate in the analyses of all the harvest data and means shown have been adjusted for this affect (Table 3). Mouldboard ploughing and deep ripping increased shoot biomass by 50 per cent (1.6–1.7 t/ha increase; Table 3). Head number was increased by 19 per cent for rotary spading and by 24 per cent for mouldboard ploughing and deep ripping, an increase of over 50 heads/m^2 (Table 3).

Table 3 **Plant density, shoot, head and grain dry weight (DW), head number and machine harvest grain yield for Bonnie Rock wheat grown at Binnu in 2009.**

Treatment	Plant No./m^2	Hand harvest plant cuts				Machine harvest grain yield (t/ha)
		Shoot DW (t/ha)	Head DW (t/ha)	Head No./m^2	Grain DW (t/ha)	
Control	134	3.4	2.2	243	1.6	1.4
Clay 80 t	137	3.6	2.6	257	1.9	1.4
Clay 125 t	143	4.4	2.9	268	2.1	1.6
Clay 250 t	146	3.6	2.6	266	1.9	1.6
Deep rip	148	5.1	3.4	306	2.5	1.9
Mouldboard	140	5.0	3.2	302	2.5	1.9
Spader	145	4.3	2.8	290	2.1	1.9
l.s.d. (P < 0.10)	*ns*	*1.1*	*0.7*	*43*	*0.5*	*0.3*

The trends in grain dry weight, measured from hand cuts, and machine grain yield were similar to those measured for whole shoot dry weight. Mouldboard ploughing, deep ripping and rotary spading increased grain yield by 36 per cent, an increase of 0.5 t/ha in machine harvest yield (Table 3).

Weed control at the site was excellent across all the treatments so it was not possible to measure any differences in weed control between the treatments.

Badgingarra Research Station – West Midlands Group

The soil at the Badgingarra site was highly water repellent. Water droplet penetration times (WDPT) for untreated soil collected in summer prior to treatment application exceeded 420 seconds (seven minutes) while the WDPT of post-treatment samples collected during winter averaged 320 seconds (Table 4). Cultivation alone decreased the WDPT with the extent of the reduction correlating with the degree of soil disturbance. Soil inversion is the highest level of 'disturbance' where the topsoil is essentially removed and replaced with a different soil (i.e. the subsoil) whereas the other treatments involve varying degrees of mixing (dilution) of the topsoil. Given this the rotary spader and mouldboard plough gave the biggest reductions in WDPT with the mouldboard plough effectively removing water repellence (Table 4). Addition of clay also effectively removed water repellence regardless of the level of cultivation (Table 4). It should be noted that the procedure for collecting the samples, drying them, sieving them to remove stubble and gravel then conducting the WDPT test under standard laboratory conditions does effectively mix the clay through the sample and may not accurately reflect the situation in the field given the variable effectiveness of clay incorporation achieved. Similar issues affect the measurement of the clay per cent in the top 10 cm, with applied subsoils in the control, deep ripped and offset disc treatments being concentrated near the soil surface and not mixed through the top 15 cm as occurs with the rotary hoe or through the top 25–30 cm with the spader. Interestingly clay content of the untreated topsoil was greater than the 3 per cent at which water repellence is often not a problem in sandy textured topsoils (Table 4) however the soil at this site was clearly highly repellent. Claying did increase the clay content of the top 10 cm by 0.5 per cent or more for most of the treatments (Table 4). Clearly inverting the clayed topsoil with a mouldboard plough is not a sensible approach with the benefit of the clay for ameliorating water repellence being completely lost!

Table 4 **Mass of organic carbon, clay per cent, water droplet penetration time (WDPT) and penetration resistance for various soil amendment treatments applied to a pale deep sand at Badgingarra in 2009.**

Cultivation	Amendment	Mass Organic Carbon (t/ha)				Clay %	WDPT	Resistance (MPa)	
		0–10	10–20	20–30	Total 0–30	0–10	seconds	@20 cm	@30 cm
Nil	Nil	12.8	5.6	3.1	21.5	3.7	320	2.8	4.0
	Clay	11.1	5.5	2.4	19.0	4.2	1	–	–
Offset Discs	Nil	11.5	5.8	3.6	20.9	3.4	190	2.3	3.7
	Clay	13.3	5.5	3.3	22.1	4.2	1	–	–
Rotary Hoe	Nil	13.5	5.0	1.9	20.4	3.9	75	2.3	3.7
	Clay	13.1	4.7	2.4	20.2	3.9	4	–	–
Deep Ripped	Nil	–	–	–	–	3.4	155	0.5	1.4
	Clay	–	–	–	–	4.9	1	–	–
Rotary Spader	Nil	7.3	8.6	3.7	19.6	2.9	11	1.3	3.1
	Clay	10.2	8.6	3.7	22.5	3.4	4	–	–
Mouldboard (wet)	Nil	5.1	10.8	9.7	25.6	2.7	1	0.6	0.9
	Clay	4.0	8.5	8.4	20.9	2.4	1	–	–

Similar to the Binnu site one impact of the spader and mouldboard plough is to loosen compacted soil to the depth of working although soil strength at the Badgingarra site was considerably higher than those measured at the Binnu site with resistance of 4 MPa at 30 cm (Table 4). This high soil strength was reduced considerably by the mouldboard plough and the deep ripper (measured on the rip line). Similar to the Binnu experiment the various cultivation treatments in the Badgingarra trial did not result in any net loss in the total mass of organic carbon when measured over the top 30 cm (Table 4). Distribution of organic carbon in the soil profile can be markedly altered. For example, mouldboard ploughing reduced the mass of organic carbon in the top 10 cm by 60 per cent but in the 10–20 cm the mass of organic carbon in the inverted soil is increased by 52 per cent and is more than doubled at 20–30 cm (Table 4) with little or no change to the total organic carbon over the depth of working.

Crop establishment varied markedly with cultivation treatment. Shallow cultivation using offset discs and the rotary hoe reduced crop establishment but addition of clay to the rotary hoe treatment improved crop establishment by 49 plants/m^2 (Table 5). Visually the rotary hoe treatment appeared to do the best job of mixing the clay through the topsoil. There was some evidence of furrow infill for some of the shallow cultivation treatments. Deep ripping and mouldboard ploughing (dry) also reduced establishment but less so than the shallow cultivation treatments (Table 5). Establishment on the mouldboard plough (wet) treatments was poor (Table 5) and very patchy and for this reason the machine harvest yields for this treatment are not reliable. Despite trying to adjust the seeding depth for these very soft plots which had just been ploughed seed placement was still too deep and there was also evidence of furrow infill. Furthermore there was evidence of crusting of the soil surface from the inverted subsoil which may have prevented emergence of deeply sown seedlings. This crusting was not evident where the soil had been mouldboard ploughed earlier on 21 April and this treatment which had time to settle and provide a firmer seed bed for crop establishment. Best establishment was achieved with the rotary spader which has a powered soil-packer at the back of the machine which effectively firms the soil surface after spading (Table 5).

Table 5 **Plant density, shoot dry weight, head number and machine harvest grain yield for Calingiri wheat grown at Badgingarra, 2009.**

	No. Plants/m^2		Hand harvest cuts			Machine harvest grain yield (t/ha)
	Nil	Clay	Shoot DW (t/ha)	Head DW (t/ha)	Head No./m^2	
Nil	127	116	6.2	3.6	301	2.0
Offset Discs	68	94	7.0	4.0	309	2.1
Rotary Hoe	77	126	6.2	3.5	294	2.1
Deep Rip	101	84	7.3	4.3	320	2.4
Spader	140	141	6.7	4.0	302	2.2
Mouldboard (dry)	100	96	8.1	4.8	334	2.4
Mouldboard (wet)	66	42	8.0	4.9	330	–
l.s.d. (P < 0.10)	*33*		*1.2*	*0.8*	*28*	*0.4*

There was no significant interaction between clay addition and cultivation on crop harvest data so data presented (Table 5) shows the impact of the cultivation treatments only. Mouldboard ploughing increased shoot dry weight by 30 per cent (1.8 t/ha; Table 5). The increases in shoot dry weight as result of deep ripping (17 per cent, 1.1 t/ha), offset discs (13 per cent, 0.8 t/ha) and the rotary spader (8 per cent, 0.5 t/ha) were not significant (Table 5). Similar effects were seen for head dry weight. There was no significant increase in head number with cultivation although the trends were similar to those seen for head dry weight with the mouldboard plough treatment having the highest number of heads an 11 per cent increase over the control. Similarly there was no significant grain yield response to cultivation in 2009. Grain yield for the offset discs, rotary hoe and spader treatments were similar to the control with more substantial trends toward higher yield for the deep ripping and the mouldboard plough treatments which had average yields of 2.4 t/ha compared with 2 t/ha for the control (Table 5). Gross soil disturbance treatments such as these can induce increased variability in the early years of these research trials but hopefully this variability may decline as disturbed soils settle in future seasons.

Wild radish control at the site ranged from 30 per cent for the offset discs, 45 per cent for the deep ripper and rotary hoe, 65 per cent for the spader and 100 per cent for the mouldboard plough (wet) without the addition of clay (data not shown). This is in-line with other high levels of weed control measured in other mouldboard plough trials and demonstration sites (Newman 2010).

CONCLUSION

Both of these experiments clearly demonstrated that removing subsoil compaction, whether through the use of a deep ripper or a mouldboard plough, could result in significant improvements in crop productivity in the absence of other subsoil constraints such as acidity. The results demonstrate that much of the productivity benefit from mouldboard ploughing may be derived from a soil loosening, deep ripping effect. Mouldboard ploughing however does have a number of agronomic advantages and is capable of substantially altering the soil profile beyond what a deep ripper is capable of. In particular mouldboard ploughing can almost completely control weeds by burying weed seed as demonstrated in the Badgingarra trial as well as numerous others (Newman 2010). Soil inversion can also remove water repellence, bring up subsoil with higher clay content in some soil types, and provide an opportunity to alter the subsoil pH.

These trials have also demonstrated how inversion tillage changes the distribution of carbon in the soil profile substantially increasing the amount of organic carbon in the 10–20 and 20–30 cm layers. Given that management of these soils will now revert back to a stubble retention and minimum tillage system for at least 10 years, it is tempting to speculate on whether the organic carbon in the topsoils of these inverted profiles can be increased and the total organic carbon stored in the top 30 cm of the soil increased.

These were the first trials where a rotary spader and mouldboard plough were compared. The spader can also reduce the soil strength, change the distribution of organic matter, reduce water repellence and weed populations and may increase crop productivity. However, compared to the complete soil inversion caused by the plough the impact of the spader on these soil and agronomic properties is not as large. For incorporating clay and lime however the spader does have an advantage because the mouldboard plough completely buries these amendments rather than mixing them through the soil. Even with the spader care will need to be taken not to bury the clay subsoil so deep that the effect of the clay in ameliorating topsoil water repellence is lost. The next generation of spaders that growers are purchasing can work deeper than the spader used in these trials and this may provide a greater advantage in regards to soil loosening, weed control and removal of water repellent topsoil. The fate of buried water repellent topsoil over time remains a particularly important question with the trial at Badgingarra providing a good opportunity to assess this.

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KEY WORDS

water repellence, mouldboard plough, rotary spader, deep ripping, soil compaction, organic carbon

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Long-term effect of lime application on soil pH, crop yields and annual ryegrass competition

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KEY MESSAGES

Surface applications of agricultural lime to an acidic yellow earth at Kellerberrin in 1991 and 2000, reduced acidity in the soil profile to a depth of 40–50 cm with multiple benefits for the broadacre dryland farming system.

The ameliorated soil pH profile, meets the Wheatbelt Natural Resource Management 2025 resource targets (Avon Catchment Council 2005) designed to remove acidity as a constraint to productive agriculture. Amelioration of acidity in the soil profile has provided multiple benefits: increased productivity, increased crop competitiveness, reduced weed burden, reduced risk of soil erosion by wind due to increased biomass cover and potentially reduced off-site effects which result from decreased water use efficiency on soil profiles with low pH.

Current annual losses due to soil acidity for the WA wheatbelt are estimated at between $300–400 million or around 9 per cent of the total value of the crop. The treated soil profile in this trial returned a $174/ha benefit from increased wheat yield in 2008 and an estimated $300/ha benefit from increased barley grain yield in 2009.

AIM

To assess the long-term benefits to broadacre dryland farming that are possible by removing acidity as a soil constraint.

Soil and crop assessments were made in 2008 and 2009 on a large-scale long-term lime trial initiated in 1991. The trial was managed as part of the paddock by growers David and Alex Leake on their property located 17 km north of the WA wheatbelt town of Kellerberrin.

BACKGROUND

Low soil pH is a significant and widespread constraint to dryland agriculture in Australia (Dolling 2001) and world wide (Sumner and Noble 2003). It is particularly widespread in the Western Australian wheatbelt (Wilson et al. 2009) and has been exacerbated by dryland agricultural practices, especially because the use of agricultural lime has not been common-place. Current estimates indicate that; 78 per cent of topsoil (0–10 cm) is below the soil pH_{Ca} targets of 5.5, 25 per cent of the 10–20 cm and 18 per cent of the 20–30 cm layer is below the soil pH_{Ca} targets of 4.8 in the agricultural area of the Avon River Basin (ARB) (Andrew and Gazey 2010, Gazey and Andrew 2008). The ARB covers 8.3 million hectares or about 45 per cent of the WA wheatbelt. Similar proportions of acidic soils are expected to be present in the northern and southern wheatbelt regions (Gazey and Andrew 2009).

Western Australian farmers consistently highlight the upfront cost of applying agricultural lime as a significant barrier to treating soil acidity (Fisher 2009). A short-term view of returns on investment dominates decision making and this approach is unable to adequately account for either, the long-term losses which accrue from allowing the profile to continue to acidify, the increased costs to ameliorate the degraded soil or, the long-term gains in productivity and other benefits which result from eliminating this economically manageable constraint.

Quantification of the impact of soil acidity on agriculture has typically been carried out by applying either high rates of lime, more reactive types of lime or more vigorous incorporation of lime in an attempt to ‘simulate’ the gradual removal of the soil acidity constraint by surface applications and time. Each of these experimental approaches has potential to abruptly change more than just the acidity profile. For example, high rates of lime and more reactive lime may change the availability of nutrients and/or the level of microbial activity.

A better approach to determining the long-term benefits or implications of treating soil acidity is to follow the changes in long-term trials that span one or more decades. Conducting and managing such long-term trials is both expensive and resource intensive when carried out by state agriculture departments and reduced investment in these areas has made such work rare.

METHOD

Establishment and management

Limesand, neutralising value of 90 per cent sourced from mobile dunes near the coastal town of Lancelin in WA (340 km away from the farm) was surface applied in 1991 at rates of 1, 2.5 or 5 t/ha to plots 15 m wide and 100 m long using a multi-spreader, a nil lime treatment (control) plot was left untreated in each of three replicates. The soil type is a Tenosol, locally known as a yellow sandy earth (Schoknecht 2002). Lime from the same source was applied to the whole paddock including the trial area at 1 t/ha in 2000.

The starting pH of the trial area, based on soil test results taken around the same time, was 4.8 in the surface and 4.5 in the 10–20 cm layer. The soil pH deeper in the soil profile was not measured at the time but is assumed to increase to around 5, which is typical for the soil type.

The long-term rotation in the paddock was 2–3 wheat crops and one lupin crop, all sown on 25 cm row spacings.

Soil pH measurement

The soil profile to 50 cm was sampled in October 2009 using a 5 cm diameter steel tube in 10 cm increments. A sample was taken from each of 4 locations in each plot and corresponds with 2009 crop biomass assessment. Soil pH was measured in one part soil to five parts 0.01 M $CaCl_2$ which is the standard for WA.

Crop assessment: 2008, 2009 grain yield; 2009 barley and weed biomass

Strips of crop were cut from within the large plots using a small plot harvester in 2008 and 2009, wheat and barley grain was weighed in the field and grain yield calculated.

One half-metre squared quadrat consisting of two 1 m rows and inter-rows from each of four locations in each plot was cut at ground level and collected in October 2009, corresponding to maximum biomass for the barley. Each sample was sorted into barley and weeds. Dry biomass was weighed after oven drying the samples at 60 °C for 72 hours.

RESULTS

Soil pH changes

Lime applied in 1991 (with an additional 1 t/ha across all treatments in 2000) increased the soil pH to a depth of 30–40 cm when applied at the highest rate of 5 t/ha. This soil pH profile meets the recommended targets and productivity will not be constrained by the effects of low pH soil. The 2.5 t/ha lime treatment has a soil pH profile that is intermediate between the unlimed and the highest lime treatment and subsurface acidity is at a level where it is expected to affect productivity. The soil pH profile for the unlimed treatment and the treatment that received the least amount of lime 18 years previously were not different from each other (Figure 1). In previous years the soil pH profile in the 1 t/ha treatment would have been better than that for the unlimed treatment (but has now re-acidified).

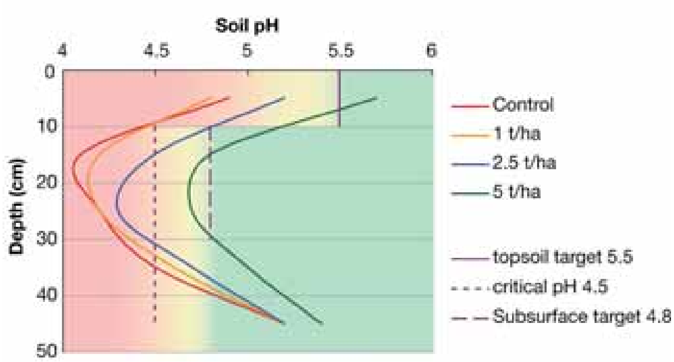

Figure 1. **Soil pH measured in 2009, 18 years after initial lime application.**

2008 grain yield and 2009 plant biomass and grain yield

Wheat grain yield in treatments receiving either 1 or 2.5 t/ha lime were not significantly different ($p < 0.05$) and produced about $100 per hectare more grain than the unlimed control. The treatment receiving 5 t/ha of lime was higher yielding again and produced about $175 per hectare more grain (Table 2). Treatment differences of at least this magnitude have been common during the life of the trial (D. Leake pers. comm.).

Table 2 **Wheat grain yield for lime treatments at Kellerberrin in 2008. Grain yields followed by the same letter are not significantly different ($p < 0.05$).**

1991 Lime treatment (t/ha)	Wheat grain (t/ha)		Relative to maximum (%)	Yield increase (kg grain/ha)	$ value of extra grain @ $300/t in 2008
0	2.92	a	83		
1.0	3.30	b	93	330	$ 99
2.5	3.20	b			
5.0	3.50	c	100	580	$174
l.s.d. (P = 0.05)	0.19				

A significant wheat grain increase was recorded in the 1 t/ha lime treatment in 2008 despite the soil pH profile being similar to the unlimed control. Although weed numbers were not assessed in 2008 it was observed that the unlimed treatment had the most weeds. It is likely that the wheat did better in the 1 t/ha treatment because there was less competition for water and nutrients from the weeds. In previous years when the soil pH profile was less acidic, the crops would have grown better, more effectively competing with the weeds compared to the unlimed treatment and there would have been less build-up of a weed seed bank.

The barley and weed biomass measured in 2009 (Figure 2) support the weed competition theory. Weed biomass decreased and barley biomass increased as the lime rate increased. Where soil acidity had been removed as a constraint to production (5 t/ha lime treatment) the total biomass increased by 1.6 times compared the unlimed acidic profile and the weed biomass was reduced to only three per cent of the total biomass.

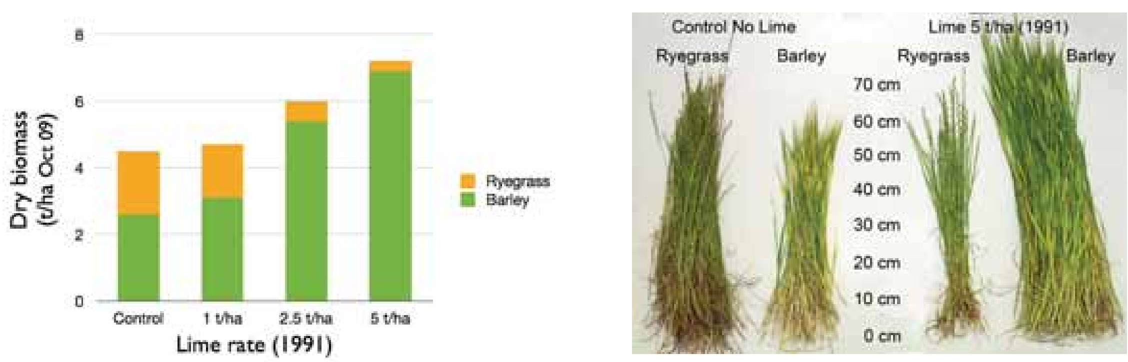

Figure 2. **Barley and ryegrass biomass from the long-term Kellerberrin lime trial in 2009. Note the barley plant size as well as total biomass differences (photo).**

Barley grain yield in 2009 increased almost linearly with the rate of lime application. Over three times the yield was recorded for the 5 t/ha lime treatment (non-limiting soil pH profile) compared to the unlimed acidic soil profile (Table 3)

Table 3. **Barley grain yield for lime treatments at Kellerberrin in 2009. Grain yields followed by the same letter are not significantly different (p < 0.05).**

1991 Lime treatment (t/ha)	Barley grain (t/ha)		Relative to maximum (%)	Yield increase (t grain/ha)	$ value of extra grain @ $200/t in 2009
0	0.70	a	32		
1.0	1.10	b	49	0.40	$ 80
2.5	1.76	c	79	1.06	$212
5.0	2.22	d	100	1.52	$304
l.s.d. (P = 0.05)	0.37				

CONCLUSION

Managing soil acidity can provide multiple benefits to the farming system and the environment. Soil pH is the keystone to many of the so-called 'soil health' issues. A soil free of constraints imposed by low pH can support a wider range of rotation choices, increased productivity (both grain and total shoot biomass), better weed control, improved nutrient availability and cycling by microbial activity. Reduced soil degradation resulting from further acidification and potentially decreased soil erosion from wind due to increased biomass cover are additional benefits.

Unfortunately, all too often, very few of these benefits are considered in an economic analysis of managing soil acidity when too much attention is directed towards 'what will be the short-term return on investment?'

There is a need to improve the economic analysis to include the value of soil-services to adequately account for i) the cost of degrading the soil resource, ii) the cost of 'borrowing' alkalinity from the resource (by continuing to farm without applying lime to replace the alkalinity used) and iii) the value of a maintained or recovered soil pH profile.

However, in a pure dollars and cents view, using 2010 prices a 5 t/ha lime application would cost $230 (lime costs approximately $8 per tonne, freight for 300 km approximately $30 and $8 for spreading). The ameliorated profile returned the grower $474 per hectare in 2008 and 2009 alone, not to mention the accrued benefits from the previous 17 years of the trial. DAFWA's recommendation is to apply the required lime in stages. For example, applying 2 t/ha plus 2 t/ha plus 1 t/ha in three applications over a number of years would give a similar result.

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soil acidity, pH, agricultural lime, weeds

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