Amending sodic soils using sub-soil manure: economic analysis of crop trials in the high rainfall zone of Victoria

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Abstract

In this paper the question is answered about how profitable it was to incorporate 10 and 20 tonnes of poultry litter (manure) per ha to amend sodic sub-soil used for high rainfall cropping on two farms in south western Victoria over the four years 2009 to 2012. The subsequent four crop yield responses were measured in plots from replicated field trials on the two farms, and the costs and benefits analysed. The costs of growing crops using sub-soil manure were high. Incorporating the full rate of 20 tonnes of manure cost $1244 and $1345/ha at the two farms, with the difference resulting from the distance the manure was transported. Applying half the rate of manure at 10 tonnes/ha greatly reduced the cost of the sub-soil treatment. Despite the high costs, the practice was profitable at both sites, because significant increases in crop yields were achieved in each crop over the four years from 2009 to 2012. Incorporating 20 t/ha of manure in the sub-soil resulted in an extra annual net return of $419 or $546/ha, in present value equivalent terms at 8% nominal discount rate, above the return from conventional cropping each year for the four years. This extra net return represents a return to the extra capital invested above a cost of capital of 8% nominal per annum. Cumulative net cash flows were from $1800-$2400/ha over the four years. Incorporating 10 t/ha of manure in the sub-soil resulted in an extra annual net return of $309 to $336/ha above the conventional cropping for each year for the four years. Cumulative net cash flows were $1300-$1400/ha.

Keywords: sodic soil, sub-soil manure, cropping systems, economic analysis

Introduction

Sodicity reduces the productivity of soils used for cropping (Rengasamy and Sumner 1998). The physical structure of sodic soil is affected by the sodium (Na+) ions in the soil causing clay particles to disperse. The clay dispersion blocks soil pores and creates a hostile, anoxic environment for root growth in wet soil, as air is unable to diffuse to respiring roots. The dispersed clay also reduces water infiltration and water conductivity in the soil (Oster and Jayawardane 1998). Plants do not thrive.

The aim of management of sodic soils is to increase pore space in the soil. Flocculating the dispersed clay particles into small aggregates using calcium (Ca2+) ions from gypsum can achieve this. Gypsum applications are indeed the practice of choice for sodic surface soils, by broadcasting it over the soil surface (Sims and Rooney 1965; Ford et al. 1993). It is much more difficult to ameliorate sodic sub-soils with gypsum as it cannot be distributed evenly through the sub-soil. Shaw et al. (1998) stated that the only low-cost way was to increase organic matter in the soil with plant roots (Nelson and Oades 1998).

Growing crops using sub-soil manure is a new technology that has been developed to improve sodic sub-soils by overcoming the constraints to crop growth on the dense, sodic clay in the sub-soil. MacEwan et al. (2010) reports that these dense clay subsoils are widespread in cropping soils across the Victorian high rainfall zone (HRZ), and also occur across much of Australia's cropping soils (Rengasamy 2002). The practice involves incorporating high rates of organic manure such as poultry litter (up to 20 t/ha fresh weight) in rip-lines 80 cm apart, in the upper layers of dense clay sub-soils at depths of around 30-40 cm. The result is biological aggregation of the sodic clay in the B horizon of these soils.

Trials of crops with sub-soil manure were started in 2005. The aim was to determine whether sub-soil manure would increase grain yield above the yields from conventional cropping at a range of sites across the Victorian HRZ. Using sub-soil manure achieved rain-fed wheat yields up to 12 t/ha in soil with sodic sub-soils; the control yielded around 7 t/ha (Gill et al. 2008). Cropping with sub-soil manure over the next seven growing seasons at sites across the HRZ increased cereal yields 60% above the yields of cereals grown conventionally, when averaged over 11 site x season combinations (Sale et al. 2013). In 2012 there was a dry finish to the season. The wheat crops at three sites yielded over 9 t/ha on land treated with sub-soil-manure, while conventional crops yielded around 5 t/ha. At two sites the 2012 crop represented the fourth consecutive crop on the land with sub-soil-manure.

The key result was the increase in the plant available water capacity in the soil with the sub-soil-manure: an extra 78 mm of plant-available water in the 40-100 mm sub-soil layer, compared to the control. The high efficiency with which a wheat crop uses sub-soil water (Kirkegaard et al. 2007) explains these large increases in crop yields with sub-soil manure.

Hitherto, the high initial costs relative to conventional cropping methods has *prima facie* created the impression that, despite anticipated increases in crop yields (Shaw et al. 1998), innovations to modify sub-soil are likely to be unprofitable. However, the merit of an innovation depends on all costs and benefits over a run of seasonal and price conditions. Evaluation requires complete economic financial and risk analysis.

Economic Analysis

Technical and financial detail

The approach taken in this economic analysis was to analyse thoroughly the inputs and outputs and costs and income at two sub-soil manure trial sites, Penshurst and Derrinallum in the high rainfall region of Western Victoria where sub-soil manure at 20t manure/ha and 10t manure/ha was used in 2009. The costs and benefits of achieving the actual grain yield responses were measured at the two field sites over four consecutive crops. The comparison is between what happened over four years of cropping trials on these two grain farms when sub-soil manure was used in 2009, compared with what happened with the usual cropping practices over the same time on the same farms. The question is, if the trial results per hectare for the control crops and for the sub-soil manure crops were to be achieved on a wider scale across the farm, would the farm business have been better off cropping using sub-soil manure or by using the conventional cropping methods?

Two analyses were carried out for each site. The first trial involved sub-soil manure at 20 tonnes of manure (fresh weight basis with 18% moisture) which was incorporated at the two sites in 2009. The second trial involved 10 tonnes of manure being incorporated in the sub-soil at the two sites in 2009.

The cost of incorporating the manure into the top layers of the clay sub-soil is difficult to determine. In this case the costs used were for a custom-made implement that has been developed and used to incorporate around 18-20 t/ha of manure into the sub-soil on 50 ha at a farm at Ballan, in south west Victoria. The analysis uses assumptions based on the costs of using this implement, as well as the actual purchase cost, the transport and handling costs of the manure (adjusted for the farm location), and the costs for placing the manure at a depth of 30-40 cm at the Ballan farm.

<u>Sub-soil manure at 20 tonnes of manure/ha</u>

Costs of machinery

The assumption is that both large grain farms have a 300 HP tractor that normally works for 1500 hours/year. It will now be used for an additional 500 hours/year working up land and placing sub-soil manure. The tractor initially cost $250,000 and after 10 years will have a salvage value of $87,500 in nominal dollars. The sub-soil manure implement at Ballan, which cost $170,000 to construct, has a salvage value of $59,500 in nominal dollars after eight years. The implement work rate is slow, at 0.5 ha/hour. Speed is low because of the need to place such a high rate of manure at depth per unit area. Under these assumptions, the machinery will modify 250 ha per year. The assumption is that the farmers will apply sub-soil manure to 125 ha of their own land each year, and contract their machinery to other farmers to undertake a further 125 ha of sub-soil manure work during the year. The cost of owning the large tractor, after allowing for depreciation, interest on capital, insurance and shedding is $23.97/hour or $47.95 per treated ha. The operating costs of the tractor are $111/ hour or $222/treated ha. The total cost of owning and operating the implement, allowing for depreciation, interest on capital, repairs and maintenance (at 8% of the purchase price per year) that are allocated to the sub-soil manure activity comes to $60.29/ hour or $120.57 per treated hectare. The labour cost to operate the tractor and sub-soiling implement is $25/ hour or $50 per treated ha. The machinery costs are provided in Table 1.

Table 1. Costs for 20t/ha sub-soil manure at the Penshurst and Derrinallum sites in 2009

Costs of incorporating manure	Penshurst	Derrinallum
Manure – purchase ($/ha)	320	320
Manure – freight ($/ha)	435	334
Manure – handling ($/ha)	100	100
Manure – labour ($/ha)	50	50
Manure - TOTAL	905	804
Incorporation - machinery ($/ha)	168	168
Incorporation – operating ($/ha)	222	222
Incorporation – labour ($/ha)	50	50
Incorporation – TOTAL	440	440
TOTAL	$1345 /ha	$1244 /ha

Costs of the manure

The costs of supplying the manure to the sub-soil implement are provided in Table 1. These are based on a purchase price of the manure of $9/m^3$ which is $18/t assuming there are $2m^3/t$. The freight costs for the manure are based on the rate of $0.083 /t/km with the manure being supplied from Bendigo. The distances are 201 km to Derrinallum and 262 km to Penshurst. The handling costs involve $80 per treated ha to screen the litter and a further $20 per treated ha to load the implement with manure. An extra labour unit at $25/hour or $50 per treated ha is required to keep loading the sub-soiling implement with manure.

Costs of handling the extra grain

The cost of harvesting the higher grain yields was an extra $15/t in 2012. The costs in earlier years were slightly lower as inflation over the four years was 3% per annum. The cost of handling the extra grain was $12/t in 2012 and slightly lower in earlier years.

Returns from the extra grain produced

The increases in grain yield at the two sites from 2009 to 2012, resulting from incorporating 20 tonnes of manure in the sub-soil in the autumn of 2009, are shown in Table 2. The actual prices that were received for crops at the Penshurst site were $190/t of wheat in 2009, $500/t for canola in 2010, $220/t for wheat in 2011, and $550/t for canola in 2012. The prices received at the Derrinallum farm were $218/t for wheat in 2009 (with an extra $55/ha for the higher wheat grade for the extra 4.5 tonnes of the crop in year 1). There was a crop failure for the canola in 2010 because of extreme water-logging in the paddock. The price for the wheat in 2011 was $220/t, and $265/t in 2012.

Savings in reduced annual fertiliser inputs

A saving was assumed for the cost of fertiliser inputs for each of the first three years as a result of the high nutrient load contained in the manure. It was observed that the manure in 2009 supplied superior nutrition for the crops. There were higher nitrogen (N) uptake rates and grain protein concentrations in wheat grown in the sub-soil-manure plots, compared to conventional crops. These benefits persisted for three years (Table 3). This meant that expenditure on fertiliser could be avoided for three years on the sub-soil-manure land. The average fertilizer rates for the two farms were 150 kg/ha of urea, and 80 kg of mono-ammonium phosphate (MAP)/ha annually. In addition the Penshurst farm applied around 35 kg/ha of muriate of potash (KCl) per year. The costs of the fertilisers applied to the conventionally grown crops were determined from actual prices obtained from local suppliers in the autumn of each year. The urea prices were $808, $489 and $645 per tonne in the autumn of 2009, 2010 and 2011 respectively, while the MAP prices were $1463, $825 and $880 per tonne respectively, for the same period.

Table 2. Yield increases, and extra costs and benefits from 20t sub-soil manure per hectare at the Penshurst and Derrinallum sites

Yield increases costs and benefits	Penshurst				Derrinallum			
	2009 Wheat	2010 Canola	2011 Wheat	2012 Canola	2009 Wheat	2010 Canola	2011 Wheat	2012 Wheat
Yield increase (t/ha)	2.8	1.2	4.5	2.0	4.8	0.0	2.4	4.1
Extra costs ($/ha)	1398	27	67	39	1310	0	43	64
Extra benefits ($/ha)	830	789	1184	1100	1359	66	715	1086
NET BENEFIT ($/ha)	-568	764	1201	1061	49	66	672	1022
Cumulative NCF	-568	196	1331	2392	49	115	787	1810

Table 3. Grain protein concentrations (%) for commercial and sub-soil-manured wheat crops grown at Penshurst and Derrinallum in 2009 and 2011

Crop treatment	Penshurst		Derrinallum	
	2009	2011	2009	2011
Commercial crop	13.3 %	9.3 %	11.5 %	10.3 %
Sub-soil-manured crop	15.8 %	10.7 %	12.9 %	11.6 %
LSD (P=0.05)	1.5 %	1.3 %	1.0 %	1.6 %

Sub-soil manure at 10 tonnes of manure/ha

Costs of machinery

The fixed and operating costs per hour for the machinery that were used for the full rate of sub-soil manuring also apply to the 10 tonne analysis, except that the travel speed of the tractor plus the implement increases because of the lower rate of manure application per unit area. This will nearly halve the per hectare costs of operating the tractor and the sub-soil implement. The faster operating speed for the sub-soiling implement will mean that the annual repairs and maintenance cost will increase from 5 to 7.5 % of the cost of the implement. Further, if the more rapid rate of operation made it possible to double the number of hectares treated each year, then the fixed costs per hectare of depreciation, interest on capital, insurance and shedding for the tractor would be halved also. The machinery costs for this analysis are provided in Table 4.

Costs of the manure

The costs of supplying the manure to the sub-soil implement were halved in this analysis. This will apply to the purchase cost, the freight, the handling on farm, and the labour costs; all of these costs will be half those for 20 t/ha of sub-soil manure.

Table 4. Costs for 10t/ha of sub-soil manure at the Penshurst and Derrinallum sites in 2009

Costs of incorporating manure	Penshurst	Derrinallum
Manure – purchase ($/ha)	160	160
Manure – freight ($/ha)	217	167
Manure – handling ($/ha)	50	50
Manure – labour ($/ha)	25	25
Manure - TOTAL	452	402
Incorporation - machinery ($/ha)	93	93
Incorporation – operating ($/ha)	111	111
Incorporation – labour ($/ha)	25	25
Incorporation – TOTAL	229	229
TOTAL	$681 /ha	$631 /ha

Costs of handling the extra grain

The costs per tonne of harvesting and handling the extra grain that resulted from incorporating 10 t/ha of manure in the sub-soil in 2009 is the same as for the 20t/ha of sub-soil manure.

Returns from the extra grain produced

The grain yield increases that resulted from incorporating 10 tonnes of manure in the sub-soil per ha in 2009 are shown in Table 5. These were the actual yield responses that were measured at these sites for the four successive years. The actual prices that were received for the crops at Penshurst and Derrinallum are the same as those used in the analysis for the 20t/ha rate of sub-soil manure trial.

Table 5. Yield increases and extra costs and benefits from 10t sub-soil manure per hectare at the Penshurst and Derrinallum sites in 2009

Yield increases Costs and benefits	Penshurst				Derrinallum			
	2009 Wheat	2010 Canola	2011 Wheat	2012 Canola	2009 Wheat	2010 Canola	2011 Wheat	2012 Canola
Yield increase (t/ha)	2.0	0.6	3.6	0.6	2.7	0.0	1.9	2.5
Extra Costs ($/ha)	717	7	43	22	674	0	38	45
Extra Benefits ($/ha)	678	398	814	330	902	66	418	662
NET BENEFIT ($/ha)	-395	377	757	308	228	66	381	617
Cumulative NCF	39	338	1095	1403	228	294	675	1292

Savings in reduced fertiliser inputs

A reduced saving in the cost of fertiliser inputs occurred with the 10t/ha of sub-soil manure compared to the 20t/ha case, as the saving in fertilizer only lasted for two years. The savings were equivalent to the application rates for the commercial crop, which involved 150 kg of urea/ha and 80 kg of MAP per ha per year. There were also 17 kg potassium (K) applied at the Penshurst site. The savings in 2009 and 2010 were similar to those used in the analysis for the 20t/ha sub-soil manure trial.

Economic and financial analysis

Discounted cash flow analysis was used to estimate the return to capital and addition to wealth of growing crops using sub-soil manure. The measures used were the Modified Internal Rate of Return (MIRR), the Net Present Value (NPV), which indicates addition to wealth after the opportunity or actual interest cost of the capital invested, and the nominal Net Cash Flow, which indicates the financing requirements and time to recoup cash outlays. The NPV of the net benefits of the investment (extra yield, extra income minus extra costs) is expressed as a equal annual sum for the four years of the trial, known as an annuity, also at 8% per annum nominal. The annuity is the net benefits of the crop grown using sub-soil manure each year for the four years of the trial expressed as an equal sum each year of the trial, above the yield, income and cost performance of the conventional crop. The analysis is 'after the event' so the economic and financial analysis is conducted using the actual costs and income of the years in which they were incurred and an interest cost of 8% per annum nominal, as if the crops were grown using overdraft finance. An alternative interpretation would be that the investor used capital that could have been used in another way that would earn 8% per annum. All results were before tax implications were considered.

Sensitivity testing

Sensitivity testing was conducted. The breakeven extra yield from the wheat and canola crops grown in the rotation that would have been required to earn the 8% per annum interest cost was estimated. Next, the effect on the returns from the investment if fertilizer and machinery costs were double the actual rates was tested. The final sensitivity test was to apply a higher discount rate to calculate the economic criteria. A discount rate of 20% was tested, which would be realistic for the situation 'before the event' where a farmer was contemplating taking the risk and adopting the innovation of using sub-soil manure.

Results and Discussion

Sub-soil manure using 20 tonnes of manure per hectare

The criteria for judging the economic performance of this intervention in cropping soils in the high rainfall region was the extra net return above conventional cropping and above the cost of the capital of 8% nominal per annum. The annual net benefit is expressed as the annuity equivalent of the net present value (the four year lump sum addition to wealth) from the investment at 8% discount rate. The financial criterion was the size of, and time to, positive cumulative nominal net cash flow.

The costs of cropping with 20t/ha sub-soil manure were high compared with conventional cropping. For these two farms in western Victoria, around two-thirds of the total cost was for the manure and the remainder was for mechanically incorporating the manure. The Penshurst farm, which was 60 km further from the source of the manure, needed to pay an extra $100 per ha in freight. This highlights the critical importance of the cost of transporting bulky inputs such as manure over long distances as a determinant of profit.

The slow delivery rate of manure to each of the six rip-lines created by the sub-soil machine meant that the tractor had to proceed extremely slowly so that the required manure rate could be incorporated into the upper clay layers. The benefit from faster travel speed reducing the cost of incorporating the manure into the sub-soil is evident when less manure is deposited, shown in Table 4. Improving the design of the sub-soil implement is an important area for further work.

The yield increases from using sub-soil manure, and their continuation over time, were significant (Table 2). Despite the high initial cost, the large increases in grain yield meant that a positive cumulative net cash flow of the program was reached with the second crop at Penshurst, and with the first crop at Derrinallum. The dry finishes to the crops at Penshurst in 2011 and 2012, and at Derrinallum in 2012, were associated with a net benefit of over $1,000 per ha above conventional cropping in these years at both farms (Table 2). The rainfall patterns during the year will affect the profit of cropping with sub-soil manure.

The extra crop yield achieved in the Penshurst and Derrinallum trials with sub-soil manure, and their continuation over time produced results that would have made these farm businesses significantly better off, in both financial (cash flow) and economic (profit, wealth) criteria, from the land that was amended with sub-soil manure, compared with cropping the land conventionally. At Penshurst there was the equivalent in present value terms (an annuity at 8% nominal discount rate) of an extra $546 per ha per year increase in wealth for the four years (Table 6), above the conventional way of using the land and capital. This annuity of annual net benefit was less at Derrinallum because of the crop failure in the second year after the sub-soil intervention, though still substantial.

The performance of the crops with sub-soil manure is also shown as the extra annual nominal net cash flow and extra cumulative net cash flow, as shown in Table 6. The sub-soil manure crop at Derrinallum had a positive extra net cash flow from the first year, and at Penshurst, the first year extra net cash flow was negative $568. This difference in year one is because the Derrinallum crop had markedly higher extra yield with higher protein than was achieved at Penshurst, thus was worth more. The extra cumulative net cash flow for the sub-soil manure crops at both sites over the four years were $2392 at Penshurst and $1810 at Derrinallum (Table 2).

Sub-soil manure using 10 tonnes of manure per hectare

Reducing the manure incorporated into the upper layers of the sub-soil from 20t/ha to 10 t/ha reduced the cost of the sub-soil treatment (Tables 1, 4). At Penshurst the cost fell from $1345 to $681/ha, and the fall was similar at Derrinallum. The manure costs were lower as the lower rate of application doubled the land that could be treated per hour, almost halving the cost of incorporating the manure. Any opportunity to reduce the amount of organic amendment that is incorporated in the sub-soil, and still deliver similar profitable outcomes, would be advantageous.

The yield increases with 10t/ha of manure incorporated were less than the yield increases with 20t/ha manure (Tables 2, 5). The reductions in yields differed between wheat and canola. For example, the average yield increase for wheat fell from 2.7 t/ha with 20 t/ha of manure to 1.8 t/ha with 10 t/ha of manure whereas the average canola yield increase of 1.6 t/ha with 20 t/ha of manure fell to 0.6 t/ha with 10 t/ha of manure at Penshurst.

Despite the lower yield increases with the lower rate of manure incorporation, the practice was still profitable (Table 7), though less profitable than applying 20 tonnes of manure. The Net Present Value of the investment over the four years at 8% per annum discount rate, still exceeded $1000/ha over the four years, and the associated annuity was worth more than $300 /ha in net benefit each year above alternative uses of the land and capital. The extra cumulative net cash flow was $1403 at Penshurst and $1292 at Derrinallum (Table 5).

Table 6. Economic results from using 20t/ha sub-soil manure at Penshurst and Derrinallum based on the extra costs and returns from the four successive crops between 2009 and 2012

Economic performance	Penshurst	Derrinallum
NPV /ha[1]	$1810	$1387
Annuity /ha[2]	$546	$419
MIRR[3]	76 %	N/A

Table 7. Economic results from using 10t/ha sub-soil manure at Penshurst and Derrinallum based on the extra costs and returns from the four successive crops between 2009 and 2012

Economic performance	Penshurst	Derrinallum
NPV	$1114 /ha	$1024 /ha
Annuity	$336 /ha	$309 /ha
MIRR	239 %	N/A

Sensitivity analysis

For the Penshurst site the breakeven extra yield – the extra annual wheat and canola crop yields over the four years at which the investment earns the cost of capital of 8% per annum – was 30% of the actual extra yields achieved each year, or an average over the four years of 0.8t/ha extra yield. The actual average extra yield over the four years of wheat and canola at Penshurst was 2.65t/ha. At the Derrinallum site, the breakeven extra yield required was 0.36 of the actual extra yields achieved each year, or an average four year extra yield of 1.03t/ha. The actual average extra yield was 2.82 t/ha.

A 20% per annum nominal required rate of return on capital was applied instead of the 8% per annum nominal cost of capital. Sub-soil manure cropping still outperformed conventional cropping; the annual advantage (annuity) per hectare for the Penshurst site was $473/ha and at Derrinallum it was $374/ha.

Doubling the costs of obtaining and applying the manure and doubling the costs of owning and operating the machinery reduced the size of the advantage of sub-soil manure cropping over conventional cropping, but did not eliminate the advantage. The annual advantage/ha at Penshurst fell to $198/ha and to $98/ha at Derrinallum. The higher manure and machinery costs reduced the MIRR at Penshurst from 76% to 19% nominal, and to 18% nominal at Derrinallum.

1 NPV is the total addition to wealth per ha (in 2009 $s) over the four years from sub-soil manuring in 2009,above other uses of capital that would earn 8% nominal per annum

2 The Annuity is the extra annual addition to wealth per ha (in 2009 $s) from sub-soil manuring in 2009, over and above other uses of capital that would earn 8% nominal p.a

3 The MIRR is percentage annual return over the four years on the extra capital that was invested in sub-soil manure in 2009. This is only possible if there is negative benefit in year 1.

Conclusions

The profit of using sub-soil manure on two farms in the HRZ of south western Victoria in 2009 was evaluated. Additional crop yields from incorporating 10t/ha and 20t/ha of poultry manure per ha in the sub-soil were measured in plots from replicated field trials on the two farms, and the results analysed.

Incorporating the 20 tonnes of manure cost $1244 and $1345/ha at the two farms. This cost is high relative to conventional cropping in this region. Applying manure at 10 tonnes/ha reduced the cost of the sub-soil treatment. The increases in grain yield each year over four years, plus savings on fertiliser use, produced significant economic benefits. In practice, the benefits of the initial sub-soil manure could extend for up to 10 years (it is too soon to know).

The analysis shows that 20t/ha and 10t/ha manure sub-soil amendment in 2009 grew crops that were substantially more profitable and had greater net cash flows than the conventional crops in the four year trial. Incorporating 20 t/ha of manure in the sub-soil gave the equivalent of an extra annual net return of $419 or $546/ha above the return from conventional cropping each year for the four years. This extra net return represents a return to the extra capital invested after meeting 8% nominal cost of capital per annum. These extra net returns represented high percentage rates of return on capital, well above alternative investments. The extra cumulative net cash flow over the four years was $1800 to $2400. Incorporating 10 t/ha of manure in the sub-soil was also beneficial, producing an extra annual net return of $309 to $336/ha above the conventional cropping for each year for the four years with cumulative extra net cash flows of $1300 to $1400. The investment in soil modification promptly returned to positive cumulative net cash flow. A hidden advantage often not considered when only the initial costs of incorporating the sub-soil manure are considered is the saving made possible in annual fertilizer costs per hectare for a couple of years at least following the initial sub-soil manure placement.

These conclusions about the likely superiority of cropping sodic soils using sub-soil manure over conventional cropping methods are robust for the paddocks of the high rainfall area of the trial. The extra yield required to cover the 8% cost of capital was around a third of the actual extra yields achieved. Further, doubling the costs of manure and machinery, and requiring a rate of return on capital of 20% per annum, showed the crops with sub-soil manure outperformed the conventional crops. The sub-soil manure method of modifying soil condition has been evaluated here for four years of actual crop-growing experience; and looks attractive for these paddocks in this high rainfall cropping region. The soil modifying effects will last longer than this, and if the yield effects were maintained, this would further improve the economic and financial performance and strengthen the case for the conclusion drawn here.

These results will likely increase interest in using sub-soil manure in cropping the HRZ of Victoria and will likely lead to increased adoption in this region. If these types of results are achievable on wider regional scales it would suggest sub-soil manure could have potential world-wide in similar soil and rainfall environments to tackle the vexed issue of crop performances being constrained less by rainfall and more by sub-soil sodicity. This constraint was eliminated in this trial in six months with sub-soil manuring as it transformed the physical properties of the sub-soil, and the effect has lasted for some years, though it is not yet known for how long it will persist.

There is one main proviso regarding these results, and several major constraints to widespread adoption of manure cropping with sub-soil manure to amend sodic sub-soil. First, these results were achieved under soil and rainfall conditions found in a high rainfall cropping zone and the applicability of sub-soil manuring to areas with lower rainfall and different soil profiles remains to be researched sufficiently to draw solid conclusions. In addition, the supply of poultry manure is small; it is bulky and costly to transport; and it is difficult and extremely slow to place it deep into soil. Research is underway to further improve all these limiting aspects of using sub-soil manure in practical cropping on sodic soils. It is likely that alternative nitrogenous organic matter will be developed for sub-soil manuring, removing the need to use animal manures. It is likely that deep placing the soil amendment will become faster to carry out, less-daunting logistically. Developments such as these should make it more economically rewarding than the methods used in the trials reported here. Crop residues fortified with nitrogen may be a possible alternative carbon source to place in sub-soil to aggregate the sodic clay. So too could be lucerne pellets. Such developments may enable grain farmers in good rainfall cropping regions world-wide to adopt this technology to improve the yield and profit of cropping on sodic sub-soils.

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