A stock take of knowledge on soil amelioration tools

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Key messages

Yield improvement was the key benefit from soil amelioration reported in the research literature and farmer interviews.

There was a divergence in the research findings and in-paddock experience of farmers for crop vigour, ability to increase season length and crop establishment.

The key knowledge gaps identified were the effect of soil amelioration tools on crop diseases, in-paddock nutrition and herbicide application and variability in tool cost.

The findings support grower understanding and adoption of soil amelioration tools, identify knowledge gaps and provide recommendations for future research.

Aims

The aim of this study was to review the current research literature and collect farmer's views on the benefits, costs and risks of different soil amelioration tools for Western Australian grain growers.

Method

A combination of literature review and interviews with farmers were used to determine the current knowledge on soil amelioration tools and the drivers of their use by farmers.

The soil amelioration actions within the scope of this study are deep ripping and soil mixing. Deep ripping variations included deep ripping (30-45cm), deep ripping with inclusion and very deep ripping (45-70cm). The soil mixing variations included deep mixing (spader and offset disc), soil inversion (mouldboard, square, modified one-way plough), clay spreading with incorporation and clay delving with incorporation.

Trials and on-farm practices on all soil types, excluding clay, within the Western Australian agricultural soil zones are included.

Analysis framework

We used the framework by Kuehne et al. (2017), that underpins the ADOPT decision support tool, as a guide to collating the information available from the literature, farmer views and experiences. The framework maps out the population specific influences on the ability to learn about the practice, learnability characteristics of the practice, relative advantages of the practice and relative advantage for the population as influences on farm practice adoption.

Literature review

The literature was collected between April and June 2018 in Google Scholar, DPIRD Research Library, GRDC Research Library and Online Farm Trials. The following search terms were used: "soil amelioration" with "Western Australia" and "deep ripping" or "soil mixing"; "deep ripping inclusion" or "mouldboard plough" or "mouldboard" or "spader" or "grizzly" or "heliripper" or "tilco" or "terraland" or "plozza plow" or "clay delve" or "clay spreading" or "clay incorporation" with "Western Australia".

Each article matching the search terms was assessed as either a peer reviewed journal article, peer reviewed report or conference paper or not peer reviewed. Research articles that had not undergone peer review were excluded from the analysis.

Articles were selected if they met all of the following criteria: included one or more of the deep ripping and soil mixing actions, covered one or more of the target soil types, located in the Western region, research conducted post 2009, and research included a control site. 30 articles were reviewed.

The biophysical, economic and management outcomes reported in each article were listed in an Excel spreadsheet. The outcomes were segregated, where possible, according to the soil amelioration tool used. In some cases, outcomes were common or generalised across tools.

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An expert working group categorised the outcomes according to the segments (influences) in the ADOPT framework, with the distinction made between positive and negative outcomes, for example profit benefit in years used and profit reduction in years used.

Farmer interviews

We used a combination of purposive and self-selection sampling to recruit farmers to interview. Farmers were selected across the range of soil amelioration tools, soil types and rainfall zone.

Farmers were recruited from soil landscape regions that have a known moderate to high adoption of soil amelioration tools: Mid West, West Midlands, South Coast, Central Northern Wheatbelt, Mullewa to Morawa, East Moora to Kojonup and Salmon Gums Mallee (see DPIRD AgSoil Zones, www.agric.wa.gov.au/mysoil).

Data was collected in-person and via phone from 10 farmers. The interview questions capture the farmers experience and perception specific to the practices they have implemented. All respondents had implemented more than one soil amelioration tools. The questions used a combination of open-ended and Likert scale response options. The research was approved by UWA human ethics.

Results

The following section provides a review of the knowledge available to farmers in the published and grey literature and from farmer interviews on the soil amelioration tools.

Farmer interview summary statistics

The interviews were conducted in person and via phone from August to October 2018. Of the 10 farmers interviewed, four farmed in the Mid West, two in East Moora to Kojonup, two in the South Coast, one in Central Northern Wheatbelt, one in Salmon Gums to Mallee and one in West Midlands. The median growing-season rainfall across the 10 interviewees was 280 millimetres.

The median cropped area was 5,000 hectares. All interviewees grew wheat and canola, eight grew lupins, seven grew barley and five grew a variety of other crops, such as oats, faba beans and field peas.

Nine interviewees had used deep ripping (30-45cm), six had used deep mixing, five had used very deep ripping (45-70cm), two had used soil inversion, two had used clay spreading and incorporation, two had used clay delving and incorporation and one had used deep ripping with inclusion.

The area treated was on average the highest for deep ripping (over 4,700 hectares and this was an underestimation given some farmers commented that they had deep ripped their farm multiple times). Area treated for clay spreading and incorporation and clay delving and incorporation were significantly lower (between 90 and 500 hectares).

We asked each interviewee to rate a list of soil constraints to their crop production. Soil compaction was the top constraint, followed by water repellence, acidity and sodicity. Some interviewees listed the additional constraints organic matter, water logging, shallow soils, organic carbon, Rhizoctonia and Boron toxicity.

Ability to learn about the practice

The literature review yielded no knowledge on whether the ability to learn about the amelioration practice (through demonstration trials, advisory support etc.) was an important characteristic or available to farmers in the adoption decision.

Farmer perception on the importance of advisory support, group involvement, relevant existing skills and knowledge and practice awareness in their decision to adopt each soil amelioration tool was collected. The majority of participants rated advisory support as: not important in deep ripping adoption; slightly important for deep ripping with inclusion; not important for very deep ripping; slightly important for deep mixing; not important and neutral for soil inversion; moderately important for clay spreading and incorporation; and not important and slightly important for clay delving and incorporation.

Practice awareness was perceived as very important in the adoption of all tools, except clay delving, by the farmers we interviewed.

The majority of participants rated existing skills and knowledge as: not important for deep ripping; neutral for deep ripping with inclusion; very important for very deep ripping; moderately important for deep mixing and soil inversion; very important and neutral for clay spreading and incorporation; and slightly important and neutral for clay delving and incorporation.

Learnability characteristics of the practice

Parker et al (2017) and Davies et al (2017) comment on the large variation in trial conditions (e.g. soil type, other farm operations) impacting the trialling ease of paddock-scale deep ripping. Betti et al (2018) note seasonal variation affected trial results for a range of amelioration practices.

Simulation modelling studies by Farre et al (2015) found there to be yield response variability across soil types using different tools to alleviate constraints to root growth.

We collected farmer views on the influence of trialling ease and practice complexity in their motivation to adopt soil amelioration tools. The majority of respondents rated trialling ease as: very important for deep ripping, deep ripping with inclusion, very deep ripping, deep mixing and clay spreading and incorporation; slightly important for soil inversion; not important and very important for clay delving and incorporation.

Nearly all respondents rated each tool as not difficult to evaluate the effect on their production system, indicating that crop responses and other production outcomes could be readily observed.

Relative advantage of the practice

Farmer views on whether their adoption decision was motivated by the practice's contribution to profit, environment and risk were captured. All three factors were rated highly in the decision to use each soil amelioration tool.

A number of profit benefits in years used and the profit reduction in years used were reported in the literature and these are summarised, by soil amelioration tool, in Table 1.

The farmers listed yield increase as a profit benefit in years used for all soil amelioration tools except clay delving. Incorporation of inputs (e.g. lime) was listed as a profit benefit for deep ripping with inclusion, very deep ripping, deep mixing and soil inversion. Improved weed control, through increased crop competition (deep ripping with inclusion) and improved effectiveness of chemicals (soil inversion), was listed as a profit benefit and environmental benefit for deep ripping with inclusion, soil mixing, soil inversion and claying delving and incorporation. Removal of a soil compaction constraint was listed as a profit benefit and environmental benefit for deep ripping, very deep ripping, deep mixing and soil inversion. Removal of non-wetting soil constraints was listed for deep ripping, deep mixing, soil inversion, clay spreading and incorporation and clay delving and incorporation.

For all tools, except deep ripping with inclusion, the high implementation cost of the operation and that it is time consuming were listed as a profit reduction in years used. A high cost of machinery wear was listed for very deep ripping, soil mixing, soil inversion and clay spreading and incorporation. For very deep ripping and soil mixing the reduced efficiency of other farm operations was listed.

Table 1 Profit benefits in years used and profit reduction in years used reported in the literature, by soil amelioration tool.

Profit benefit		**Profit reduction**	
Effect	Tool	Effect	Tool
Removal of soil compaction	DR, DM, SI, CS+I, CD+I	Surface crusting	DM, SI, CS+I
Ability to incorporate other inputs(e.g. lime;	DM, SI	Poor crop establishment	DR, DM, SI, CS+I, CD+I
Reduced non wetting	DR, DM, SI, CS+I, CD+I	Time lag for benefits to occur	CS+I, CD+I
Increased root depth	DR, VDR, DM, SI, CD+I	Impact of the growing season weather on yield response	DR, DM, SI, CS+I
Redistribution of organic matter in the soil profile	DM, SI	Uneven sowing depth	DM, SI, CD+I
Improved weed control	DR, DM, SI, CS+I	Reduced soil water availability	SI
Improved effectiveness of chemicals	DM, SI	Damage to machine from paddock rocks	DM
Higher crop biomass	DR, SI, CS+I	Reduced crop root growth	DM, SI, CS+I
Reduce chance of frost damage	DM, CS+I, CD+I	Increased germination of grass weeds	DM
Change in nutrition availability	DR, DR+I, VDR, DM, SI, CS+I, CD+I	Sandblasting the established crop	DM, SI
Improved crop establishment	DM, SI, CS+I	Time consuming operation	DM, SI, CS+I
Change in amount and distribution of organic carbon	CS+I	Reduced crop yield	DR, DR+I, DM, SI, CS+I, CD+I

Increased yield	DR, DR+I, VDR, DM, SI, CS+I, CD+I	Variable yield response across soil type	DR, DR+I, VDR, DM, SI, CS+I
Increased number of tillers	DM	Less available phosphorous and potassium	DM, SI
Increased number of grain heads	DR, DM, SI	Increased weed biomass	DM
Increased grain size	DR, DR+I	Less grain per head	DR+I
Increased oil content in canola	DR	No effect on yield	DR, DM, SI, CS+I
Larger benefits in more constrained soils	DM	Decreased plant density	DM, SI
Improved drainage in waterlogged sites	DR, DR+I, VDR	Delayed sowing	SI
Improved crop access to soil nutrients	SI	Increase in soil toxicity	CS+I, CD+I
Reduction in leaf diseases	SI	No improvement in crop establishment	DR, DM, CD+I
Short-term return on investment	DR, DR+I, VDR	No improvement in non-wetting	DR, DR+I, VDR, CD+I
Improved crop access to soil moisture	DR, DR+I, VDR, SI	Other crop operations reduce the success of the tool	DR, DR+I
Impact of the growing season weather on yield response	DM	Less nutrients available from increased soil pH	DR+I
Increased soil water holding capacity	DM, SI	Change in organic carbon in soil	DM, SI

Soil amelioration tools: deep ripping (DR); deep ripping with inclusion (DR+I); very deep ripping (VDR); deep mixing (DM; soil inversion (SI); clay spreading and incorporation (CS+I); clay delving and incorporation (CD+I).

Longevity of benefits, an increase in soil pH over time through lime incorporation and an increase in yield over time were reported in the literature as a profit benefit in future. Re-compaction of soils, surface crusting, short term yield increase, no improvement in non-wetting, decrease in nutrient availability and loss of soil organic matter were reported in the literature as a profit reduction in future. Some farmers interviewed reported a decreased workability of paddocks (e.g. rocks) for very deep ripping as a profit reduction in future.

The environmental costs and benefits from soil amelioration tools reported in the research literature are summarised in Table 2. Farmers listed improved weed control as an environmental benefit for all tools except deep ripping and very deep ripping. Wind erosion was listed as an environmental cost for all soil amelioration tools except clay spreading and incorporation.

Table 2 Environmental costs and benefits reported in the literature, by soil amelioration tool.

Environmental benefit		**Environmental cost**	
Effect	Tool	Effect	Tool
Reduced wind erosion relative to other practices	CS+I	Re-compaction of soil	DR+I, SI
Removal of soil compaction	DR, DM, SI, CS+I, CD+I	Surface crusting	DM, SI, CS+I
Increase soil pH over time through lime incorporation	DM, SI	Poor crop establishment	DR, DM, SI, CS+I, CD+I
Reduced non-wetting	DR, DM, SI, CS+I, CD+I	Short term wind erosion	DM, SI
Improved weed control	DR, DM, SI, CS+I	Loss of soil organic matter	DM
Improved crop establishment	DM, SI, CS+I	Decreased plant density	DM, SI
Change in amount and distribution of organic carbon	CS+I	Delayed sowing	SI
Increased time to herbicide resistance	SI	No improvement in non-wetting	DR, DR+I, VDR, CD+I
Increased N uptake	DM, SI	Change in organic carbon in soil	DM, SI
Improved effectiveness of chemicals	DM, SI	Increase in grass weed germination	DM, SI

Soil amelioration tools: deep ripping (DR); deep ripping with inclusion (DR+I); very deep ripping (VDR); deep mixing (DM; soil inversion (SI); clay spreading and incorporation (CS+I); clay delving and incorporation (CD+I).

Reduction in production risk as a result of soil amelioration arises predominantly from improved access to subsoil moisture via improved root growth and/or an increase in plant available soil water holding capacity (Table 3). Combined, these risks were listed for all of the amelioration tools, except clay spreading and incorporation. This contrasted with reports of increased production risk from reduced root growth deeper in the subsoil below plough and clay incorporation depths (deep mixing, soil inversion, clay spreading and incorporation), reduced water availability including later in the season (soil inversion, soil mixing). Similarly, improved establishment (deep mixing, soil inversion, clay spreading and incorporation; clay delving and incorporation) and increased crop vigour in a dry season (very deep ripping) to improve production risk was in contrast to reports of poor crop establishment (deep ripping, deep mixing, soil inversion, clay spreading and incorporation, clay delving and incorporation), uneven sowing depth (deep mixing, soil inversion) and reduced vigour in a dry season (deep mixing, clay spreading and incorporation). Decreased production risk through reduced frost damage was reported for deep mixing, clay spreading and incorporation and clay delving and incorporation. Short-term wind erosion and sandblasting of young crops were associated with deep mixing and soil inversion, increasing the production risk.

Table 3 Production risk decrease or increase reported in the literature, by soil amelioration tool.

Production risk reduction		Production risk increase	
Effect	Tool	Effect	Tool
Increased rooting depth	DR, VDR, DM, SI, CD+I	Poor crop establishment	DR, DM. SI, CS+I, CD+I
Reduced frost damage	DM, CS+I, CD+I	Short-term wind erosion	DM, SI
Improved crop establishment	DM, SI, CS+I, CD+I	Reduced crop vigour in dry season	DM, CS+I
Better access to subsoil moisture	DR, DR+I, VDR, SI	Increased soil evaporation	DM, SI, CS+I
Increased soil water holding capacity	DM, SI	Impact of growing season weather on yield response	DR, DM, SI
Reduced risk of yield loss in extreme climatic conditions	VDR	Uneven sowing depth	DM, SI
Improved crop vigour in dry season	VDR, CD+I	Reduced soil water availability	SI
		Reduced root growth (below plough or clay incorporation depth)	DM, SI, CS+I
		Sandblasting of established crop	DM, SI
		Less soil water available late in season	DM

Soil amelioration tools: deep ripping (DR); deep ripping with inclusion (DR+I); very deep ripping (VDR); deep mixing (DM; soil inversion (SI); clay spreading and incorporation (CS+I); clay delving and incorporation (CD+I).

In the farmer interviews, seasonal effects were considered a prominent risk. For example, farmers listed decreased workability of paddocks in wet seasons as a risk with deep ripping, very deep ripping and clay delving, and decreased crop vigour in a dry season for deep ripping, deep ripping with inclusion, deep mixing and clay spreading and incorporation. Poor crop establishment was listed as a risk for deep ripping, deep ripping with inclusion, very deep ripping and deep mixing. Decreased accuracy of seed placement was listed as a risk for deep ripping, deep mixing, soil inversion and clay delving and incorporation. Wind erosion was listed as a risk for all soil amelioration tools except clay spreading and incorporation.

The ease and convenience effect of the soil amelioration tools, both positive and negative, reported in the literature were: ability to incorporate other soil amendments (deep mixing, soil inversion), uneven sowing depth (deep mixing, soil inversion) and decreased workability of paddocks (deep mixing, soil inversion).

Farmers gave conflicting views on the ease and convenience: a decrease and increase workability of paddocks was listed for deep ripping, very deep ripping and soil mixing. For clay delving, only a decreased workability of paddocks was listed. A high management cost (e.g. logistics) was listed by farmers for deep mixing and deep ripping with inclusion. Incorporation of inputs (e.g. lime) was considered an ease and convenience for deep ripping with inclusion, very deep ripping, deep mixing and soil inversion.

In the literature, a reported variation in organic carbon present in the soil with deep mixing and soil inversion is evidence of the time lag for environmental costs and benefits. For example, Davies et al. (2018) found that for inverted soil the total organic carbon in the topsoil remains low after 8 years of continuous cropping and stubble input at a Goomalling research site. Higher organic carbon levels were found buried deeper in the soil profile after ploughing over this time.

The increased time to herbicide resistance for soil inversion was reported in the literature (e.g. Renton and Flower, 2015) and by farmers as an environmental benefit.

Davies (2013a), Betti (2018), Davies (2013b), Davies (2017), Ward (2018) and Davies (2013c) report on the relative upfront costs of soil mixing and soil inversion tools. Significant variation in the ratings of the upfront cost of each soil amelioration tool was reported by the farmers. For deep ripping and very deep ripping the majority of farmers reported a moderate upfront cost; deep ripping with inclusion was rated as some upfront cost; deep mixing and soil inversion was a large upfront cost; clay spreading and incorporation was listed as a moderate and large upfront cost; and clay delving and incorporation was listed as a small and large upfront cost.

The variable cost (machinery depreciation, fuel, labour, maintenance) also varied substantially by the farmers interviewed. The two estimates for soil inversion were close, approximately $70 per hectare. Deep ripping ranged from $25 to $150 per hectare, deep ripping with inclusion was $30 per hectare, very deep ripping ranged from $36 to $220 per hectare, deep mixing ranged from $15 per hectare (offset discs) to $150 per hectare for a spader. Clay spreading and incorporation and clay delving were by far the most expensive tools to operate, approximately $300 to $400 per hectare.

Conclusion

Both the literature, often written by researchers, and experienced growers noted multiple benefits and risks in the use of soil amelioration tools. While many risks associated with the amelioration tools were noted, both the literature and growers indicated that these risks varied across farming systems and tools. Grower experience and published research indicate that there is a positive return on investment from soil amelioration, typically becoming profitable within 1-3 years of the amelioration event (Petersen et al 2018; Davies et al 2018). This research demonstrates that the magnitude of the return varies by tool, due to capital and variable costs, combination of constraints overcome and effective management of associated risks.

The key adoption factors for soil amelioration practices from the farmers were being aware of the practice, profit advantage and motivation, environmental outcomes and risk reduction. Having advisory support was not particularly important in the farmer's adoption of the soil amelioration practices. Key factors that might limit adoption are cost, and environmental and production risk. The findings support grower understanding and adoption of soil amelioration tools, identify knowledge gaps and provide recommendations for future research.

Key words

Soil amelioration; grower adoption; risk; grower profitability

Acknowledgments

We are grateful to the farmers who agreed to be interviewed for this study, their insights were invaluable to the research. Funding for this work was provided by GRDC and UWA through DAW00244 Soil Water Repellence project part of GRDC's Soil Constraints West group of projects.

GRDC Project Number: DAW00244

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