Summary

Water repellent soils constrain agricultural production in southern and south western Australia, affecting 10 million hectares of arable land.

This project:
1. Delivered to GRDC a review on management options for water repellent soils, which was also published in a peer reviewed journal;

and demonstrated that:
2. Under no-till and stubble retention, root pathways are preserved and allow water to bypass repellent surface layers and wet-up the profile from underneath, benefiting crop performance.

3. Seeding near the previous years' row improves crop emergence due to higher soil water content in the row.

4. Disturbing dry soils (dry seeding) worsens the expression of repellency due to changes in soil structure.

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   b) Seeding near the previous years' row improves crop emergence due to higher soil water contents in the row.

   c) Disturbing dry soils (dry seeding) worsens the expression of repellency due to changes in soil structure.
Significant advances have been made in developing and assessing strategies to mitigate (reduce the symptoms of) and ameliorate (alter the soil-surface properties of) water repellent soils in agricultural systems. This project focused on mitigation practices, but was closely integrated with another concurrent project on non-wetting soils (project DAW00204), which addressed amelioration. Growers are becoming increasingly aware of these strategies through targeted extension activities, but there is still more work to be done. Growers need to find a balance between (a) using expensive amelioration strategies to improve yield greatly over a small area, and/or (b) using lower cost and lower risk mitigation strategies to achieve smaller yield increases over a greater land area.

In this project, the focus was on no-till/stubble retention practices, which are classed as mitigation strategies because they do not substantially change the surface properties of the soil. In fact, stubble retention and no-tillage concentrates soil organic matter (SOM) and associated repellency near the soil surface. However, maintenance of root pathways is the key to achieving water infiltration into more wettable layers below, allowing the profile to wet-up from underneath. This research indicates that benefits from the conversion to no-till/stubble retention from other practices, such as cultivation and/or stubble removal, can be slow to develop (more than four years), particularly if burning or cultivation has been practised for a number of years. It takes time to rebuild SOM (and associated water holding capacity) and surface residues, which protect soils from extreme temperatures and reduce soil water evaporation. Word of mouth has indicated that grain growers on the south coast of Western Australia (WA) and in the Stirlings to Coast region are adopting or have adopted no-till/stubble retention practices (including zero-till) and are successfully managing their water repellent sands to grow excellent crops.

Better utilisation of the no-till/stubble retention system is possible with on-row or near-row seeding in order to capture the water channelled down root pathways. This research indicated that seeding on-row greatly increased crop emergence, due to increased soil water content, and reduced repellency in the rows. But in experiments, this benefit did not carry through to harvest. However, some growers involved in the research reported significant anecdotal yield benefits with on-row seeding. Growers who have recognised the benefits of seeding on-row are experimenting with new equipment (e.g. iTill and others) and adoption by others has occurred.
A number of grain growers have observed that when they sow into dry non-wetting soils, wetting-up is often slow and crops establish poorly. Laboratory experiments confirmed that disturbance of water repellent soils, when they are dry, greatly increases the expression of repellency, and through a collaboration with the University of South Australia (UniSA) it has been confirmed that this is due to changes in the structural behaviour of soils under dry disturbance and, in particular, a loss of porosity in soil. Growers should try to avoid dry seeding their water repellent paddocks and leave them until late in their seeding program when rainfall breaks are more likely.

Recommendations

1. The mitigation strategy - no-till/stubble retention - is an effective way to manage soil water repellency and grow excellent crops. The key messages are to:
   a) Retain remnant root systems from previous crops to provide pathways for water into the more wettable soil layers below and allow the profile to wet up from underneath.
   b) Allow time for
      i. An extensive root pathway to develop.
      ii. Building SOM (which contributes to soil water holding capacity).
      iii. Building surface crop residues which protect soils from extreme temperatures and reduce soil water evaporation.
   Research that is underway suggests this could take more than four years in extreme cases where significant soil disturbance and losses of organic matter and surface residues have occurred.

2. On or near-row seeding may better capture the benefits of remnant root systems as pathways for water entry into soil and provide greater access to water for an emerging plant than seeding between rows, particularly in a dry start to the season. Research indicates that soil in crop rows stays wetter for longer and is less repellent than in the inter-row. Growers need to sow on the row to an accuracy of 2cm and this requires the use of recent advances in tractor guidance systems, combined with an independent system for seeder guidance. Seeding on the previous year's row requires careful consideration of rotations to avoid consecutive crops with similar disease susceptibility. Further research is needed to properly evaluate this risk.

3. Dry seeding into water repellent soils should be avoided if possible. Disturbance of water repellent soils when they are dry greatly increases the expression of repellency, due in part to changes in soil structure and loss of soil porosity. Based on this, it is recommended that paddocks with water repellent soils be sown later in the seeding program when break-of-season rains are more likely to have occurred. Further research is underway to determine if on-row seeding mitigates the negative effects of dry seeding.

4. A review of 'Management options for water-repellent soils in Australian dryland agriculture', prepared jointly by CSIRO and the Department of Agriculture and Food WA (DAFWA) - and delivered to GRDC - provides a comprehensive evaluation of management options available to growers to mitigate, ameliorate or avoid soil water repellency. Growers need to develop a balance for their farming enterprise between: (a) using expensive amelioration strategies to improve yield greatly over a small area; and/or (b) using lower cost and lower risk mitigation strategies to achieve smaller yield increases over a greater land area.

Outcomes

The main outcome from the research is the availability to growers of a suite of practices to manage soil water repellency and maximise grain yields.

The benefits of this work have been, and will continue to be, delivered to growers, agribusiness and researchers in Western and Southern GRDC Regions, but also have relevance internationally where water repellent soils limit agricultural production.

Practices that increase water infiltration into water repellent soils are expected to have the following benefits:

1. Economic benefits: No-tillage/stubble retention is a mitigation strategy with relatively low cost if growers are already using this system for other purposes. Adoption of no-tillage/stubble retention practices predominantly incurs a one-off capital cost. The benefits are increased grain or pasture production, but other benefits may include improved timeliness of operations, reduced erosion and improved soil carbon content.

2. Environmental benefits: No-tillage systems were initially adopted to reduce soil erosion, particularly on fragile sandy soils which also tend to be repellent. More even crop and pasture establishment protects surface soils and maintains SOM,
contributing to soil quality.

3. Social benefits: There is a reduced risk of investment for growers, greater certainty of a crop and improved profitability, all of which directly benefit farming families and flow on to rural communities.

**Achievements/Benefits**

Further details in Attachment 1.

**Background and Rationale**

Water repellent soils are a major constraint to agricultural production in southern and south-western Australia, affecting up to 10 million ha of arable soils. The main symptom is dry patches of surface soil, even after substantial rainfall, directly affecting agricultural production through uneven crop and pasture germination and reduced nutrient availability. Staggered weed germination impedes effective weed control and delayed crop and pasture germination increases the risk of wind erosion. Water repellency commonly occurs on sandy or sandy duplex soils and is caused by waxy compounds derived from the breakdown of organic matter, mostly of plant origin.

Management strategies for water repellency fall into three categories of: 1) amelioration, where the properties of surface soils are changed and water repellency is decreased; 2) mitigation, where repellency is managed to allow crop and pasture production; and 3) avoidance, where severely affected areas are removed from crop production and sown to perennial forage. This project has focused on mitigation strategies and, in particular, the use of no-till and stubble retention, on-row seeding and stimulating natural microbial degradation of waxy compounds.

The project was closely integrated with another concurrent project on non-wetting soils (project DAW00204) in which amelioration options were developed and evaluated. Beginning in July 2014, an integrated project (project DAW244) is continuing the research and extension that started in projects CSP00139 and DAW00204.

This Final Report for project CSP00139 includes findings from: (1) a seven-year field experiment at Munglinup, WA, and two sets of four-year experiments at Munglinup and Hopetoun, WA, into the impact of zero/no-tillage and stubble management on soil water repellency and soil water infiltration; (2) two field trials at Calingiri, WA, on seed placement; (3) two field trials at Pingrup, WA, on seed placement, surfactants and dry versus wet sowing; (4) four-years of measurements at a trial on Eyre Peninsula, SA (Vanilla), to test the impact of stubble and tillage practices on water infiltration on sandy soils in the Southern Region; (5) investigation of spatial variation in repellency at the plant scale and, in particular, understanding the impacts of dry seeding on the expression of repellency. The report also includes delivery to GRDC of a critical review into management options for water repellent soils and publication in a peer-reviewed journal, and other extension activities.

**Major achievements:**

1. Impact of stubble and tillage management practices on soil carbon, repellency and soil water content:

   Crop residues are sources of waxes that can cause repellency and therefore their retention would be expected to reduce water infiltration. However, growers on the south coast of WA have developed no-till systems with improved water infiltration and claim that water repellency ‘disappears’ under no-till with stubble retention.

   To validate these claims, three field sites on the south coast of WA were set up in 2008 (within Exploratory Practices projects CSP0098 and CSP00117) and continued in CSP00139. At two sites (one at Hopetoun) and one at Munglinup, stubble was managed by burning. At a third site also at Munglinup, stubble was managed by intensive short-term grazing. At all three sites, the treatments were: a) No-till/Stubble retained, b) Cultivated/Stubble retained, c) No-till/Stubble burned or grazed, and d) Cultivated/Stubble burned or grazed. Burning, grazing and cultivation were done immediately prior to seeding and crops were managed according to normal grower practice. Soil water content, water repellency, organic carbon, plant emergence and grain yield were measured.

   At all sites, soil carbon was highest in the no-till/stubble retained treatments and least in the cultivated/stubble removed treatments. Soil water repellency mirrored these patterns. That is, soil water repellency was worse under no-till and stubble retention than under other stubble/tillage treatments. Despite this, soil water contents were highest under no-till/stubble retention, indicating that in the field, mechanisms other than soil water repellency are important in water entry to soil. Blue dye tracers demonstrated that root pathways, preserved under no-till systems, allow water to bypass repellent surface layers and wet-up the profile from underneath. There was a direct benefit of no-till/stubble retention on plant emergence and in some years, this translated to benefits in grain yield. The impact of soil disturbance was observed when looking at the rate of infiltration following rainfall. In the inter-row spaces, rain was much less effective in wetting-up the soil than in the row for up...
to 11 months after soil tillage.

In 2012, two of the field trials (Hopetoun and Munglinup grazed) were discontinued. At the remaining site, burning and cultivation treatments were halted and all treatments were restored to no-till and stubble retention. This was to allow monitoring of the rate of recovery of infiltration patterns after four years of burning and/or cultivation. In March 2013, two seasons since the return to no-till/stubble retention, there was no evidence of recovery and soil carbon contents were similar to those in previous years. Water repellency mirrored the patterns of soil carbon, but showed an annual cyclical pattern due to breakdown of repellency during the wetter months and diffusion of new waxes onto sandy surfaces in warmer months later in the year. Soil water contents remained consistently higher where stubble was retained, compared to plots previously burnt, particularly during the growing season but also during the drier months. A similar pattern for soil carbon, water repellency and soil water contents occurred in 2014. These treatment differences in soil water contents translated to significantly higher yields of canola in 2014 where stubble had always been retained, compared with previously burnt treatments.

From 2008-2012, surface crop residue cover was recorded in all treatments. Image analysis and comparisons with soil water contents indicated that where residue cover had been reduced by stubble burning and cultivation, minimum soil water contents in summer were up to 2% less than in soil with up to 90% cover under no-till. Surface residue cover in no-till treatments represented material built up over a number of years. This may explain, in part, the slow return to infiltration patterns observed after restoration of no-till and stubble retention following four years of stubble removal and/or cultivation.

The findings of this trial highlight the importance of retaining root pathways (past and present) for water infiltration. This offers a management opportunity for growers where alternative and sometimes more aggressive practices are not possible. Several growers on the south coast of WA are successfully managing their water repellent soils with no-tillage and stubble retention to grow excellent crops. Furthermore, the findings of the trial at Munglinup in a recovery phase have implications for strategies that reduce SOM in water repellent soils and demonstrate that building new organic matter is slow and affects soil water and crop performance.

The trial is continuing within the new project (project DAW00244) to further monitor recovery.

2. Seed placement, surfactants and dry versus wet sowing:

The findings that water pathways form down old root channels suggest that seeding near the previous year’s row (on-row seeding) should benefit new crops through greater access to water, particularly early in the season.

Calingiri, WA - seed placement trial:

At Calingiri, differences in crop performance were observed between on-row and inter-row sown crops and in 2012, two field trials were set up to test this. Plots established using on-row seeding were generally less severely repellent. For example, Molarity of Ethanol Droplet (MED) values in the crop rows were 2.8 and 2.9 in August of 2012 and 2013, respectively, compared with MED values in the crop rows of inter-row sown plots of 3.3 and 3.3. Measurements of soil water content and soil water repellency throughout the 2013 season indicated that there was up to 4% v/v more water in the row than the inter-row and this was coupled with a gradual decrease in repellency. In 2012, crop emergence was significantly greater (147 versus 79 plants per square metre) in the on-row sown treatment, but there was no significant difference in 2013 (86 versus 80 plants per square metre). In neither year were there any benefits in grain yields of wheat (2012) or barley (2013), despite growers’ anecdotal evidence to the contrary in previous years. Despite the lack of positive yield responses, changes in MED values and crop emergence suggest that on-row seeding may be a viable tool for long-term management of crop production in water repellent soils.

Pingrup, WA - seed placement, surfactants, dry vs wet sowing trial:

At Pingrup, WA, a grower has been experimenting with on-row seeding and has developed a seeding system (called iTILL) that allows precise placement of the seed in the row or inter-row. This provided an opportunity to accurately evaluate seed placement, in combination with other variables, such as the use of banded surfactants and dry seeding practices. Dry seeding in non-wetting soils can pose significant problems with wetting-up of soil.

Two trials were set up in 2013 to determine if on-row seeding mitigated this. Site A (Centre Range): On-row versus inter-row sown, with and without surfactant. Site B (Purgatory): As for trial A, but with an additional factor (wet versus dry sowing). At both sites, barley was grown in 2013 and in 2014, oats were sown at Site A and barley at site B. In both 2013 and 2014, there were wet starts to the season and no proper assessment of wet versus dry sowing was possible.

In the second year of the trial at site A, soil carbon percentage was lower in the furrow (row) than the ridge (inter-row) and soil
water repellency measures mirrored this, although the intensity of repellency varied seasonally. Soil water contents at Site A were highest in the furrow sown on last year's row. It is hypothesised that the wetter furrows promoted microbial decomposition of waxes and that this resulted in reductions in soil water repellency. In 2015, populations of wax-degrading communities were being measured to confirm this. Preliminary results in March 2015 indicated that numbers of wax-degrading bacteria in the furrow were 10-fold higher than in the ridge, but further measurements are needed to validate this and measure seasonal changes. Application of surfactant (Precision Wetter, Chemsol Australia) increased crop emergence compared with treatments without surfactant in both 2013 and 2014. On-row sowing also increased emergence in 2013. In 2015, site A was expanded to include dry versus wet seeding treatments.

At site B, the differences in repellency in the furrows and ridges were similar to site A. However, the application of surfactant had almost no impact on soil water repellency and little impact on soil water content, except in June and August (2014), where the combination of surfactant and on-row sowing increased soil water content slightly. Otherwise, the site was highly variable. The site was abandoned at the end of 2014 due to difficulty in applying the iTill system because the stubble rows had been storm damaged.

Overall, the findings at Pingrup concur with the Calingiri trials and show that seeding on-row can benefit crop emergence. Further measurements are needed to establish the impacts of surfactants and dry-seeding in a season with a drier start than the past two years. Site A at Pingrup is being continued in 2015 as part of project DAW00244.

3. Impact of tillage and stubble management practices on water infiltration - validation of strategies to mitigate soil water repellency over a wider area of southern Australia.

Eyre Peninsula, SA (Wanilla)
This trial was set up in 2011 on a severely repellent deep sand at Wanilla, SA, on land previously grazed by sheep. There were two tillage treatments (no-till and cultivation) and threestubble treatments (retained, burned and grazed). The site was sown to wheat (2011), canola (2012), barley (2013) and lupins (2014). Patterns of water infiltration, water repellency, soil organic carbon, plant emergence and grain yield were measured at regular intervals at least five times during the year. During the trial, differences in soil carbon and soil water repellency developed, similar to the trials on the south coast of WA, although the responses were smaller. Soil carbon contents were significantly higher under stubble retention and no-till as was soil water repellency. However, soil water contents showed no treatment trends and there were no significant differences in crop yields, which were very low.

At the end of 2014, it was decided that this land was best suited to an ‘avoidance’ management strategy, where severely affected or poorly producing areas are removed from annual production and sown to perennial forage. The trial was discontinued.

A new trial location on the Eyre Peninsula (at Wharminda) was identified in early 2015, where crop performance is better but repellency is still an issue. This new trial is part of the Project DAW00244 and is testing on-row seeding, dry versus wet seeding, surfactants, claying, and local grower strategies.

This project delivered a critical review of non-wetting soils, incorporating a review of literature on Australian and international research outcomes, grower knowledge of management solutions and unpublished DAFWA reports.

It developed and delivered novel research solutions that enhance water infiltration into non-wetting soils at both the paddock and plant scale. It researched mechanisms and developed ameliorative strategies that can be applied to non-wetting soils across WA and SA.

The project determined changes in microscopic soil structure and strength of water repellent soil in response to soil disturbance under dry conditions and integrated findings with field studies to develop strategies to avoid increased expression of repellency following dry seeding of crops.

**Other research**

Further research into management options for water repellent soils is continuing in the new project ‘Delivering enhanced agronomic strategies for improved crop performance on water repellent soils in Western Australia’ (project DAW00244; 2014-2019), led by Dr Stephen Davies (of DAFWA) and Dr Phil Ward (CSIRO).
As part of this project, the following research opportunities will be addressed:

1. Continued evaluation of the recovery of water infiltration patterns after four years of burning and/or cultivation at a field site at Munglinup, WA. Results to date indicate recovery is slow. Information on the path to recovery will guide growers’ expectations after they adopt no-till/stubble retention practices, particularly in paddocks where soil structure and SOM have been compromised.

2. Further evaluation of on-row seeding in the field in combination with surfactants to determine the most effective mitigation strategies under different seasonal conditions to enhance crop productivity.

3. Increased understanding of effects of disturbance of dry water repellent soils in:
   a) Laboratory - understanding all mechanisms to assist with development ways to avoid the problem;
   b) Field - exploration of combinations of surfactants and/or on-row seeding to enable growers to dry seed earlier in their program should they need to.

4. Integration of mitigation strategies with amelioration approaches being evaluated by DAFWA. Amelioration is generally a one-off practice and, therefore, management practices that follow need to reduce the risk of re-development of expression of repellency. Researchers in the project will be working together on two long term field sites in WA, with multiple integrated management practices applied to address not only repellency directly but the impacts of management practices on plant nutrition and weed control, for example.

Crop diseases are not part of project DAW00244. However, on-row seeding may require careful management to avoid the transmission of crop diseases to following crops with similar disease susceptibility. Grain growers have traditionally sown their crops on the inter-row to avoid/reduce the risk of disease carry-over. However, there is little information about the relative risks of on-row and inter-row seeding in terms of disease, and further research is needed. Sowing on the old row may actually be beneficial. Research by Margaret McCully and others at CSIRO have shown that root channels of matured crop plants become colonised by actinobacteria. Some actinobacteria have been shown (by Franco et al, and Roper et al.) to suppress root and crown diseases and, therefore, new plant roots following these old root pathways may actually be protected from disease, but this needs to be evaluated.

Additional information


