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Paul Blackwell

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Improving sustainable production from water repellent sands

Water ponding on a water repellent soil at Geraldton.

By Paul Blackwell
Research Officer, Geraldton

The agricultural management of water repellent (non-wetting) sands is difficult, and production from them is mostly low. However, there are ways to make them more productive.

Furrow sowing and the incorporation of dispersive clay are two likely methods to make these soils easier to manage, more productive and more profitable than they are now.

Water repellency affects about 5 million hectares of agricultural land in Western Australia, South Australia and Victoria. These soils are unevenly wet by autumn rains and characteristic dry patches appear in their topsoil, often in spite of enough rain to completely wet non-repellent sands.

Water repellent sands are typically grey, pale yellow or red sands and usually have less than 5 per cent clay. Deeper yellow sands (loamy sands of the Western Australian sandplain) have about 10 per cent clay and are rarely water-repellent. However, there are exceptions. Some clay soils, such as on the Mallett Hills of the Great Southern, are water repellent.

This article discusses several aspects of our research on water repellent sands. In addition, some of the costs and benefits of alternative management strategies are outlined.

Causes of water repellency
Water repellency is usually caused by hydrophobic (non-wetting) and waxy materials coating the surfaces of individual soil particles such as sand grains and clay micro-aggregates. These substances probably result from the decomposition and degradation of certain plants. The waxy materials consist of organic substances such as long chain hydrocarbons, fatty acids and alkanes.

Fungal hyphae, usually found in undisturbed soils such as lawns, are another cause of water repellency.

Non-wetting organic matter is more effective in causing water repellency in sandy soils than clayey soils because sand particles have a smaller surface area for the same weight of soil than do clays. Sand has a surface area of about 0.1-0.2 sq m per gram whereas clays can have a surface area of 20-200 sq m per gram. Thus, the weight of non-wetting material that covers all the sand surfaces will cover less than 1 per cent of the clay surfaces.

Water repellency is often associated with some types of native vegetation, for example, blackbutt. The natural association between native vegetation and water repellency is probably an important mechanism in the selection of plants in sandplain ecosystems. The repellency may improve water conservation by channelling rainfall towards some plants, restricting germination of competitive plants, and reducing evaporation by a partial dry layer at the surface.

The severity of water repellency varies according to the crop and pasture rotation. It is commonly associated with longer periods of leguminous pasture and sometimes legume crops.

Climate also seems to have an effect. Along the State's south coast, for example, water repellency seems to be more of a problem under a wheat-lupin rotation than under the same rotation in northern areas (see Table 1). More research is needed to clarify the effects of rotation history and stubble management on water repellency of farmed soils.

Contributors
Dan Carter, Research Officer, Albany; Bill Crabtree, Adviser, Esperance; Grant Morrow, Technician, Geraldton; Doug McGhie, Private Consultant, Perth; Ted Spadek, Chemistry Centre of Western Australia

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Effects on agricultural production

Water repellency causes poor plant water use and production by restricting the supply of water and nutrients to crops and pastures.

Symptoms of water repellency are:

- Poor establishment of crops and pasture, owing to the restricted wetting of the soil by autumn rains. Ironically, summer rains wet these soils better than autumn rains because repellency diminishes as soil temperature rises. However, water can still run off these soils during heavy summer rains.
- Poor plant water use and production because of extra evaporation from water ponded on the surface and excessive drainage to the water-table in locally wet pathways.
- Poor weed control. Weed seeds germinate unevenly over the lengthy period it takes for these soils to completely wet. Weeds that germinate late miss earlier applications of herbicide.
- Water and wind erosion. Erosion is more likely because repellent sands have increased run-off, as well as loose surface soil and inadequate plant cover for protection against wind erosion. Severe water erosion has been a problem on these sands in the West Midlands and on the south coast in recent years.
- Poor use of nutrients. Fertiliser, like water, is unevenly available to plants because it can become 'locked up' in the dry soil.

Uses of these sands

Crop and animal production are often low on water repellent sands. Water repellency on duplex soils is less of a problem than on deep sands except where clay can encourage waterlogging. Once these duplex soils are wet, the water stored in the clayey subsoil is available to plant roots.

Agricultural practices on water repellent sands range from permanent annual pasture, delayed crop sowing, and sowing in the rain, to the use of adapted vegetation such as perennial pasture, WA blue lupins, fodder shrubs or trees.

Crop production from water repellent sands in the West Midlands is often less than 0.5 t/ha. Sowing late, after the break of season, results in small yields, because the slow development of the crop leads to drought stress in spring, when grain is forming. Sheep carrying capacity of brome grass pastures on these soils in the West Midlands is often little more than two dry sheep equivalents per hectare.

On the south coast water repellency problems may be less than in the West Midlands because it rains more often and the growing season is longer. However, the south coast has lower autumn temperatures and more severe repellency than the West Midlands. Cultivating these south coastal sands can create considerable difficulties.

Rotary hoeing and deep ploughing have little effect on either crop establishment, yield or pasture growth. These practices are not recommended on large areas because they also increase seeding costs. Soil disturbance and loss of surface cover increase the risks of wind erosion.

Low plant production on water repellent sandplain soils means only small amounts of rainfall are used and groundwaters rise, increasing the likelihood of waterlogging and salinity in the lower parts of the landscape.

The choices for agricultural use of water repellent soils depends on the proportion of the farm affected, the farm enterprise mixture, and the landowner's attitude and management skills.

Better management of repellent sands

There are four current principles on which to base better management of water repellent sands. These are shown in Figure 1.

- Increase the 'wetting power' of rain. This can be achieved by increasing water pressure at the surface, for example, the base of water-filled depressions or furrows, or by reducing surface tension of water by treating the soil with surfactants.
Wide furrow sowing

Wide furrows are usually spaced more than about 200 mm apart. Such row spacing encourages more water harvesting and easier sowing into moisture than furrows spaced the normal 170 mm apart.

Furrow sowing and the incorporation of dispersive clay (claying) to correct repellency have been compared in Department of Agriculture experiments since 1990 at Geraldton, Badgingarra, Albany and Esperance. These methods can improve plant water use and, hence, crop and pasture production.

Research and development
In the following sections we report, in more detail, Western Australian and South Australian research and development on furrow sowing, incorporation of clay and the potential for microbes to breakdown non-wetting waxes in water repellent soils.

Lime sand
Some farmers on the south coast have added lime sand to improve water infiltration of some repellent sands. Subsequent research has shown the lime sand alters soil structure rather than repellency. The effect has generally been inconsistent and is confined mainly to duplex soils with water repellent sand over clay or gravel. The high rates of application (2.5-5.0 t/ha) can cause nutritional problems in some plants.

Surfactants
Application of surfactants and water absorbing gels has also been studied. While these substances reduce the effect of repellency and sometimes increase plant growth and yield, they are not economical for large-scale operations.

Banded applications of wetting agent are more economical. When applied to the bottom of the furrow they have produced increases in crop, pasture and fodder shrub establishment, and early plant growth. Research is continuing on this technique as a possible component of furrow sowing.

Cover the waxy 'skins' on sand particles with a microscopically thin layer of clay. Incorporation of dispersive clay in the surface layer of water repellent soil allows it to wet normally after a period of time.

Earlier attempts at removing the water repellent 'skin' were unsuccessful. Rotary tillage, for example, does not remove this repellent 'skin'. CSIRO is now studying whether microbes can remove this waxy layer.

Avoid or remove the non-wetting surface soil.

Deep furrows help avoid or remove the non-wetting surface soil and can allow seed to be sown below the original topsoil and in moist soil. This is called 'sowing into moisture'. Furrow sowing on wide rows (more than 200 mm) can allow this. Removal of non-wetting soils by deep or inversion cultivation may provide a temporary respite, but the risk of wind erosion is increased.

Minimise drying. Where it rains frequently on water-repellent sands, for example along the south coast, cultivation will accelerate drying and exacerbate the problem. Stubble retention and no till drills can minimise drying. Such practices are reported to be successful on the south coast.

Minimise drying.

Figure 1. Illustration of the principles of better management of non-wetting sands.

Figure 2. Simplified section of furrow sowing, water harvesting and dry zones in ridges of soil.
In a furrowed seedbed on non-wetting soils the ridges will only wet to a few millimetres depth during autumn rains and then shed water to adjacent furrows (see Figure 2). This ‘water harvesting’ can increase opportunities for early crop and pasture establishment if seeds are sown in the furrow. It effectively increases the amount of rainfall reaching the seed, increasing the likelihood of successful establishment, even on small autumn showers. Wider furrows harvest more water than narrow furrows.

A major advantage of furrow sowing on widely spaced rows for all soils is the ability to seed in moist soil below about 75 mm (3 inches) deep. This ‘sowing into moisture’ is helped by the bottom of the furrow being lower than the original soil surface. For furrows 50 mm deep (from the original surface) seed can be sown 20-30 mm below the furrow bottom, close to or in the wet soil. Seedlings can easily emerge through 20-30 mm of soil in the furrow.

This robustness of the furrow seeding technique allows farmers to start seeding sooner and finish later than usual. Wide row seeders have greater stubble handling abilities than seeders with conventionally spaced rows, and thus facilitate stubble retention for protection against wind erosion.

Detailed soil studies at Geraldton have shown that in autumn soil below a furrow experiences less extreme temperatures than soil below a level surface. There is also less evaporation from a furrow’s dry zones and ridges compared with that from a level surface. These changes improve conditions for early plant establishment and growth compared with those from conventional level sowing methods.

Tie banks to minimise run-off along the furrow, presswheels to help form the furrow and firm the sand around the sown seed, and banded wetting agent to increase water entry at the bottom of the furrow, all provide complementary increases in plant establishment, growth and, often, yield. Tie banks are small cross-banks in the furrow at right angles to the ridges. They are often formed by presswheels or rollers with gaps in their circumference.

The main problems with furrow sowing are the risk of wind erosion and difficulties with weed control, as well as early season ‘droughting’ for young plants.
An important question is: How does furrow sowing compare with the use of recent designs of no till drills for cropping water repellent sands? This new design of disc coulter and sweeps (a ‘furrowing coulter’), and wetting agents, are being studied in experiments to minimise burial of stubble or pasture, and to manipulate sand into ridges. Further technical details of equipment for furrow sowing can be found in The Seeding Edge produced by the Kondinin Group.

Innovative farmers such as Fred, Edward and Glen Rogers in the northern wheatbelt (See ‘Wide furrow sowing at Flora Downs, Moora’) and others in the northern and south coast agricultural areas, are using the furrow sowing technique successfully. They use simple, low cost furrow sowing with a modified combine and grow 1.5-2 t/ha of oats, barley or lupins. Modified cultittrash seeders also allow furrow sowing into cereal and blue lupin stubbles.

Research into furrow sowing with members of the Irwin Landcare Group in 1992 resulted in profitable increases in lupin yields of 800 kg/ha for wide-furrow sown crops (using modified equipment) over those sown into a level seedbed at wide and narrow row spacings (see Figure 4). In experiments with early furrow seeding into dry soil with 350 mm (14 inch) row spacing, cereal and lupin yields have doubled, up to 2-3 t/ha of wheat or lupins. Presswheels to firm the furrow bottom also provided a worthwhile improvement in yield (see Figure 3).

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Fred, Edward and Glen Rogers have been developing their own furrow sowing method since about 1989. This is their method. They sow the crop in wide (350 mm) furrows with a modified International 511 combine (see photo). The modifications involve raising the covering tines at the back of the seeder, directing all seed through the back row of sowing tines (350 mm spacing), and increasing the size of the wings on the back row of sowing points.

The crop is sown while the topsoil is dry in a one-pass operation in late April, preferably after a weed germination from summer rains. Seed is placed close to subsoil moisture. Fertiliser is often top-dressed after seeding. The puddock is sown on the contour to prevent water running downslope in the furrows during the first rains. Crops are germinating and establishing on as little as 5-10 mm of rain.

Yields of oats and barley have increased to about 1.5 t/ha using furrow sowing. Direct drilled crops of oats on a level dry surface have yielded 0.7 t/ha in trials.

Research is now investigating furrow sowing techniques in more detail, including effects of row spacing and presswheel pressure.

A new design of disc coulter and sweeps (a ‘furrowing coulter’), and wetting agents, are being studied in experiments to minimise burial of stubble or pasture, and to manipulate sand into ridges. Further technical details of equipment for furrow sowing can be found in The Seeding Edge produced by the Kondinin Group.

Methods of modifying cultittrash seeders for wide-furrow sowing are now a high priority. These machines can penetrate stubble and pasture and are readily available.

An important question is: How does furrow sowing compare with the use of recent designs of no till drills for cropping water repellent sands? This
Furrowing coulters can sow into a heavy crop stubble without becoming blocked and form a furrow at the same time.

Mr Obst started to apply clay to his water repellent sandhills in 1970. Now, he grows enough clover to carry six dry sheep equivalents per hectare.

During a national workshop on water repellent sands in 1990, farmers visited Clem Obst's farm. The visit and workshop encouraged other scientists to experiment with dispersive clay in Western Australia.

The main problems with spreading clay this way are cost and convenience. It costs about $2 per tonne where the clay is shallow and near the place of application and contractors cart and spread it.

After the clay is applied in summer and incorporated mechanically into the soil, rain is needed to induce dispersion and to allow a microscopically thin clay layer to form over the sand grains. About a season later, crop yields and early autumn pasture production have approximately doubled.

In Western Australian experiments, yields of up to 2 t/ha of lupins or wheat in the northern agricultural region and 3.5 t/ha barley on the South coast have been measured (see Figure 5).

Improved weed control through earlier spraying with herbicides as a result of adding clay is considered to be very important in these effects.
Integrated systems using shelterbelts of fodder shrubs and trees should further reduce risks of wind erosion for dry furrow sowing, as well as provide other benefits of better water use and improved stock feed.

Progress in achieving land conservation objectives should also flow from the adoption of furrow sowing and application of clay. Plant water use should increase and the risk of wind erosion should decrease.

Conclusion

There are cost-effective ways of managing troublesome water repellent sands. Profitable and safe cropping is possible if new methods are used carefully. Furrow sowing turns water repellency into an advantage, rather than a problem. It allows crops to be established earlier than usual and more reliably. The application of dispersive clay may prove to be sufficient for appropriate cereals, and in areas with longer growing seasons.

Costs and benefits

A simplified cost-benefit analysis has been made for one paddock for four improved methods or present methods of managing non-wetting sands. Yields are based on 60 per cent of trial yields and the costs use MIDAS model estimates of most operations (see Tables 2 and 3) Capital costs are estimated from costs of commercial spreading of gravel and modifications to seeders. The results for cumulative finance for a 500 ha paddock are shown in Figure 6.

Wide furrow sowing gave the largest short term benefits, but other effects, such as the development of herbicide resistance, have not been included.

Claying by a delving tyne was most economical over a ten-year period, especially for inexpensive modifications to farm machinery. If a contractor spreads clay, it could take four to five years to cover costs or be as profitable as present farmer methods. Profits from furrow sowing could be used to finance claying.

It is also important to consider the differences in sowing strategy offered by these methods. Opportunities for early establishment in warm conditions by dry furrow sowing can be very suited to legume crops. Later establishment, after application of dispersive clay, may prove to be sufficient for appropriate cereals, and in areas with longer growing seasons.

Microbial degradation

Wax-degrading bacteria may be able to improve water repellent sands by removing non-wetting substances from the surfaces of soil particles.

In Perth, CSIRO scientist Dr Margaret Roper is studying how wax-degrading bacteria can improve the wettability of repellent sands. Soils contain a wide range of wax-degrading bacteria and natural enrichment of these bacteria may occur.

Soils enriched with waxes, fats and oils, as well as sewage sludge and organically farmed soils, have been sampled. Bacterial growth on wool wax, which contains a wide range of lipids, has been used to select suitable bacteria. More than 50 wax-degrading bacteria have been isolated. Their ability to reduce water repellence in soils is being assessed under different moisture and temperature conditions. The bacteria will be further evaluated for use in the field.

CSIRO scientist Margaret Roper has isolated about 50 wax-degrading bacteria to see if they will improve water repellent sands. Bacterial activity shows up as dark staining along the white stripes of wool wax.

Figure 5. Crop yields after different additives to overcome water repellency, 1992.

Figure 6. Financing improved methods for a 500 ha wheat-lupin rotation, West Midlands.
Table 2. Comparative effect of different management methods on crop production

<table>
<thead>
<tr>
<th>Period of growing season</th>
<th>Early autumn showers</th>
<th>Break of season</th>
<th>Late autumn/winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional methods</td>
<td>Sown late (yield penalty)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Claying</td>
<td>Sown at break soil wets easily (no yield penalty)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or microbial treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry furrow sowing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sown early</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establishment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>on small showers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and subsoil moisture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop well established by break of season (yield advantage, for appropriate varieties)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further reading

The Seeding Edge, published by the Kondinin Group.

Thanks

Thanks to staff from the Department of Agriculture’s research stations at Badgingarra and Esperance Downs and from offices at Albany, Esperance and Moora.

Paul Blackwell can be contacted on (099) 21 0555

Table 3. Costs and benefits of alternative systems for a wheat-lupin rotation in the West Midlands

<table>
<thead>
<tr>
<th>Sow on break (level, direct drilling)</th>
<th>Year one (wheat)</th>
<th>Year two (lupins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield t/ha</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Price $/t</td>
<td>132</td>
<td>157</td>
</tr>
<tr>
<td>Income $/ha</td>
<td>79</td>
<td>94</td>
</tr>
<tr>
<td>Costs $/ha</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Seeding</td>
<td>41 (superphosphate &amp; urea)*</td>
<td>25 (super)</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>21 (knockdown &amp; sulfonyl ureas) **</td>
<td>15 (knockdown &amp; simazine) **</td>
</tr>
<tr>
<td>Herbicide</td>
<td>20 **</td>
<td>20</td>
</tr>
<tr>
<td>Harvest</td>
<td>92</td>
<td>70</td>
</tr>
<tr>
<td>Sub-total</td>
<td>92</td>
<td>70</td>
</tr>
<tr>
<td>Interest (8% of costs)</td>
<td>7.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Net income $/ha</td>
<td>-20.4</td>
<td>18.4</td>
</tr>
<tr>
<td>Capital: no extra capital</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* 150 kg/ha of superphosphate at $167/t and 50 kg/ha urea at $320/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>** $10/ha operating and $10/ha depreciation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wide furrow sown (additional to level direct drilling)</th>
<th>Year one (wheat)</th>
<th>Year two (lupins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide</td>
<td>18</td>
<td>15 (grass selectives)</td>
</tr>
<tr>
<td>Sub total</td>
<td>110</td>
<td>85</td>
</tr>
<tr>
<td>Interest (8% of costs)</td>
<td>8.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Net income $/ha</td>
<td>39</td>
<td>96</td>
</tr>
<tr>
<td>Capital: $10/row for a 28-row seeder, $280</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clayed (additional to level direct drilling)</th>
<th>Year one (wheat)</th>
<th>Year two (lupins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield t/ha</td>
<td>0.6 (no effect in first year)</td>
<td>1.2</td>
</tr>
<tr>
<td>Price $/t</td>
<td>132</td>
<td>157</td>
</tr>
<tr>
<td>Income $/ha</td>
<td>79</td>
<td>188</td>
</tr>
<tr>
<td>Costs (extra cultivation in the first year)</td>
<td>10</td>
<td>7.5 (grass selectives)</td>
</tr>
<tr>
<td>Herbicide</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Sub total</td>
<td>111</td>
<td>77.5</td>
</tr>
<tr>
<td>Interest (8% of costs)</td>
<td>8.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Net income $/ha</td>
<td>-41</td>
<td>104</td>
</tr>
<tr>
<td>Capital</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lifting clay on a duplex soil; estimated $1000 to build a delving tine to lift clay and $50/ha for operating costs. Carting and spreading clay: Mobilisation of scraper: $3.5/km and 100 km round trip. Removal of overburden at $0.8/cubic metre and 0.5 m depth. Cutting, carting and spreading from 1.5 km, $2/t. Application rate of 100 t/ha. Furrow sowing modifications are $10 a row for wide rows on a 28-row seeder, plus an additional $500 a row for presswheels.