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Managing water-repellent soils

By D.A. McGhie, Plant Research Division

A study of water-repellent soils has led to some management recommendations.

Many farmers, particularly those with sandy soils, may have experienced problems with soils which do not easily wet. A water droplet placed on such a dry soil will ball up and remain on the surface for some time (Fig. 1). These soils are termed water-repellent and their effects may be seen in several ways:

• Patchy pastures. Some areas of water-repellent soil wet more easily than others and this may lead to a patchy germination (Fig. 2a). The dry zones may not wet with later rains and the bare areas may persist throughout the growing season. The effect is intensified in drier seasons and wet soil is most commonly found underlying small depressions (Fig. 2b).

• Reduced crop germination. Seeds placed under ridges are most likely to be placed in dry soil and cannot germinate. The head of water acting downwards in a furrow is usually enough to overcome the water repellence and a characteristic wetting pattern develops (Fig. 3).

• Erosion. Where water-repellent soils occur on steeply-sloping land, most rainfall runs off and erosion may result, affecting both the water-repellent soil and wettable areas lower in the landscape. An outstanding example of this is provided by the ‘mallet hills’ of the Great Southern area. These are stable before clearing because of the dense vegetation and thick litter layer covering the surface (Fig. 4). On clearing, the litter is removed to expose a severely water-repellent topsoil. Severe erosion then results (Fig. 4).

Severity of water repellence

The soil/water contact angle is the best measure of the degree of water repellence. This angle is measured inside a water droplet sitting on a surface or soil (for example Fig. 1). For water-repellent soils this angle is large (around 90°), but wettable soils commonly have lower contact angles (60° to 70°).

The simplest method of assessing water repellence is to apply a droplet of water to the soil surface and time its disappearance. This technique enables a broad classification of soils which are wettable (water penetrates immediately), slightly water-repellent (water sits on the surface but penetrates in less than one minute), and severely water-repellent (water sits on the surface for more than one minute). Wettability is also affected by the surface tension of the contacting liquid. In the soil situation, water is the liquid involved and surface tension does not vary, although wettability may be improved by lowering the surface tension with wetting agents.

Other more accurate techniques are available for measuring wettability, but none are as simple to use in the field as timing water drop penetration.

In some of the work below, contact angles were accurately determined by comparison of water movement through columns of the natural soil and corresponding samples which had been ignited at 500°C, to burn out organic matter. The ignited samples are considered to be completely wettable with a contact angle of zero degrees.

Causes

Water-repellent soils are normally sandy and it is well established that the cause is a coating of organic matter on the mineral soil particles. There has, however, been much conjecture on the origin of the organic coating, although to be

*This article is based on research done while at the University of Western Australia. The research was financed by a Commonwealth Postgraduate Research Award and the Western Australian Department of Agriculture.
effective it must contain a water-repellent (non-polar) as well as wettable (polar) component.

**Mallet hill study**

Initial interest in the cause of water repellence in this study arose because the water-repellent mallet hill soils responsible for much erosion in the Great Southern region were not sands but varied from sandy-clay-loams to sandy clays. Normally, the addition of clay, even in fairly low proportions, to a water-repellent sand will overcome the water repellence. Clays have a far higher surface area per unit weight than do sands and so require more material to coat their surface if water repellence is to develop. The virgin mallet hill soil was examined using an optical microscope and found to contain many fine particles of organic matter, much of which could be recognised as broken-down leaf and stem material derived from the overlying litter layer.

A cross section through the litter and soil showed the litter to be more finely broken down as depth in the litter layer and soil increased. The organic matter content decreased with depth but severe water repellence was present to a depth of 15 cm.

The surface few centimetres of some long-cleared (40 years) sites were wettable but a zone of water-repellent soil was often present under this (Fig. 5). Here, sufficient water repellent organic matter was present for the soil to remain non-wetting long after clearing.

The effect of finely-ground mallet litter on water repellence was tested by adding it in varying proportions to two wettable sands and a wettable soil with 20 per cent clay. Different particle sizes of both the organic matter and sand grains were then examined and results are shown on Fig. 6.

Higher contact angles developed on the coarse than on the fine sand and finely ground organic matter produced more severe water repellence than did coarser material. Similar results were obtained with the heavier soil although more litter was required to cause a similar degree of water repellence to that developed on sands.

A study of the litter itself showed that its water repellence could only be reduced by an effect similar to the softening of soaps*.

* The replacement of calcium magnesium or hydrogen cations (Ca$^{2+}$, Mg$^{2+}$ or H$^{+}$) with sodium or potassium cations (Na$^{+}$ or K$^{+}$). Water repellence was not caused by any easily extractable component of the litter. Polar (such as water) and non-polar (such as oil) solvent treatments of the natural mallet hill soil and litter/wettable soil mixtures showed the orientations of the clay and organic matter to be important in determining water repellence. Sequential treatment with polar and non-polar solvents converted the originally water-repellent soils to wettable and then back to water-repellent again. The cycle could be repeated several times.

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**Table 1. Contact angles of mixtures of a fired (wettable) sand with 2 per cent of the ground (1mm) senesced tops of plant species.**

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Mean Contact Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subterranean clovers</td>
<td>83</td>
</tr>
<tr>
<td>Medics</td>
<td>81</td>
</tr>
<tr>
<td>Cereals</td>
<td>66</td>
</tr>
<tr>
<td>Trees (mallee, powder bark wandoo, marri, mallet and sheoak)</td>
<td>83</td>
</tr>
</tbody>
</table>
**Water repellence of other plants**

Some pasture, crop and native species were tested for their effect on water repellence by mixing with a wettable sand. Sub clover pastures caused strong water repellence while the cereals and sandplain (W.A. blue) lupin gave quite wettable mixtures.

Most native trees examined also caused severe water repellence and mallee, mallet and marri have been observed to cause severe water repellence in the field. The results suggested that different plant species should have variable effects on the development of water repellence. The differences appeared large enough to markedly affect soils on which the species were growing. (Table 1)**

**Fungi and water repellence**

In this study, sand grains covered only by fungal strands were never water-repellent, but when pieces of mallet litter were also on the surface of sand grains (Fig. 7), water repellence developed. The water repellence was often less than when litter alone was present. However, fungal growth made the more wettable plant species more water repellent, although the water repellence developed on species such as wheat, sandplain lupin and lucerne was never as severe as naturally occurs with the most water-repellent species.

**Reason for species differences**

A detailed examination of the clover, mallet and wheat litters showed that the variation in water repellence was related to the species of cation balancing the surface exchange sites. Mallet had mainly H⁺ with some Ca⁺⁺, Mg⁺⁺, Na⁺ and K⁺⁺, clover had mainly Ca⁺⁺ with low proportions of the others and wheat had its sites balanced largely by Na⁺ and K⁺⁺. The wettability of the different plant materials reflects the wettability of acidic groups with the cations listed above bound to them.

**Treatment**

A physical mixing of a water repellent and a wettable soil is an old but successful way of reducing water repellence. Another similar technique involves mixing a heavier soil with the water-repellent soil. Both of these methods dilute the effect of the water-repellent organic matter.

Another possible treatment is incorporating wettable plant residues. To test this, dried foliage of mallet, wheat and clover was ground and mixed with four water-repellent soils. The changes in wettability were assessed by measuring the contact angle or the time for 5 ml of water to infiltrate the mixtures, and these are summarised in Figure 8.

Wheat improved the wettability of the strongly water-repellent soils (Fig. 8, soils 1, 2 and 4) and did not change the most wettable soil (3).

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**Fig. 7.** — Fungal strands and pieces of mallet litter on the surface of sand grains

**Fig. 8.** — Effect of wheat, mallet and clover litter on the wettability of four soils.
Mallett and clover generally increased the water repellence of sands (1, 2 and 3) but when added to the mallet hill soil (4), the mallet litter maintained the very high water repellence while the clover reduced it. However, the soil still remained severely water-repellent. The plant material increased the water repellence or wettability (depending on the wettability of the plant species) as more material was added to the soil.

**Variation in a wheat/clover rotation**

Contact angles were measured on samples of the sandy, surface soil from plots of a long-term rotation trial on the Department's Newdegate Research Station. Contact angles increased during the pasture phase and decreased after cropping (Table 2). Soil organic matter decreased with cropping but it was not just the amount of organic matter that affected contact angles.

Samples of sand grains from several of the rotation phases were examined using a scanning electron microscope and these showed that the type (plant species) of organic matter sticking to the sand grains changed with the phase of rotation. Generally, the build-up of organic matter in soils, particularly sands, is desirable. Organic matter improves the structural, nutritional and water holding characteristics of the soil. However in some cases, enough of the organic matter may be water repellent to impair the ability of the soil to take up water and pastures may deteriorate. This occurs naturally and (especially with perennials) helps reduce competition or improve the shedding of water to strategically-sited roots. The soil must wet before annual crops and pastures can germinate. When water repellence is severe, then cereal cropping is one alternative. The effect of one crop will depend on the yield of the crop and the amount of the residues that are ultimately incorporated into the soil.

Part of the yield loss of annual crops on water repellent sands can be attributed to a reduced germination, and cultivation techniques may be used to improve this.

**Cultivation**

Cultivation of water-repellent soils should aim to provide a moist seed bed. Conventional machinery may place seeds in dry soil and these will not germinate. Alternatives are:

- Cultivate in the rain. By mixing the moist surface soil, dry soil and rain, a more even wetting can be obtained. Seed can then be sown into a moist seed bed. Seasons with intermittent dry spells make this method ineffective as the surface soil will probably dry quickly and once dry it will be difficult to re-wet.
- Deep plough. A wettable subsoil may be mixed with a water-repellent surface soil to improve the overall wettability. Abrasion of the organic coating during this process may also improve wettability.
- Furrow sowing. Placement of seed beneath the furrow guarantees that it lies in the zone most likely to be wet by following rains. A head of water acts at this point and the water repellence may be overcome. The advantages of furrow seeding are obvious (see Fig. 3). Machinery may be modified to place seed at the bottom of furrows. Mr Ray Westphal of Dowerin has developed a very effective trailing skid (Fig. 9) which gives excellent placement of the seed in the furrow (Fig. 10).

**Caution**

Before treating water-repellent soils, farmers should determine how much water repellence is affecting crop and pasture production. The wetting pattern should be examined on problem areas, and if the problem is severe, treatment should be attempted.

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**Table 2. Variation of contact angle with crop rotation**

<table>
<thead>
<tr>
<th>Water droplet penetration time (seconds)</th>
<th>Continuous pasture (16th pasture)</th>
<th>Continuous crop (11th crop)</th>
<th>1 crop/4 pasture</th>
<th>1 crop/2 pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>more than 300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>84</td>
<td>89</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>98</td>
<td>91</td>
<td>93</td>
<td>87</td>
</tr>
</tbody>
</table>

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![Fig. 9 — A trailing skid to place seed at the bottom of a furrow.](image)

![Fig. 10 — Furrows in a water-repellent soil.](image)