Fear of water

> "Soil hydrophobicity is a recurring condition.

Does this sound familiar? You finally get round to watering the cactus after weeks of neglect. You pour a generous amount of water into the pot but the water either sits on the soil surface refusing to budge, or it runs straight through the pot via cracks in the soil and you have to mop up the mess on the windowsill. Welcome to the strange world of hydrophobic soil.

This is not how soil is meant to behave. Soil science textbooks will rarely tell you about this strange behaviour. Instead they inform you that soil draws in water by powerful capillary forces – the same forces that help a paper towel to soak up water from your windowsill. Capillary forces are so strong that many soils can hold more than half their weight in water against gravity.

Any porous material draws in water when the attraction between a water molecule and the material is stronger than the attraction between individual water molecules. Soil is a porous material, consisting of various minerals that normally attract water, as well as organic material from decomposing vegetation and many micro-organisms. Soil may or may not attract water depending on its chemical composition and structure.

We know that in hydrophobic soil the mineral surfaces do not attract water. This behaviour has little to do with the soil's mineral content, but is caused by an organic coating around the minerals. Organic coatings with hydrophobic properties are actually very common in the environment. Most organisms produce them to keep, for example, bird feathers dry or waterproofing the skin of insects. A coating of only a single molecular layer can render a surface that normally attracts water hydrophobic.

When soils develop hydrophobicity, it can cause three problems: more flooding and erosion; enhanced transfer of nutrients and agricultural chemicals to the

Stefan Doerr (right) explains the strange world of hydrophobic soils.

groundwater; and reduced plant growth. In some of the drier regions of Australia farmers have struggled for decades to make a living from cultivating vast areas of soil that just don't wet normally. Horticultural industries use soil detergents to eliminate hydrophobicity and in many of the world's fire-prone regions researchers think soil hydrophobicity is one of the main causes of increased flooding and soil erosion following wildfire.

During the last decade scientists have discovered that hydrophobicity can affect many different types of soil. For example, when we sampled soils along a transect across southern England and Wales we found that most soil types under grass, heather, bracken or conifer forest showed high levels of hydrophobicity. Fine-textured soils, either bare or covered with crops, were less affected.

If it is so common even in our temperate climate, why do we know so little about it? One reason is that in the UK dense vegetation covers the most strongly affected soils, which makes it difficult to spot. But equally important, soil hydrophobicity is not a permanent condition. During prolonged wet periods it tends to eventually disappear, but when soils dry out again the condition reappears.

How exactly this switch occurs is subject of much debate and one of the key scientific challenges in this area. To tackle this question we analysed a wide collection of hydrophobic and wettable soils including some provided by European and Australian collaborators. To our surprise chemical analysis showed that not only the hydrophobic, but also the wettable control soils contained organic compounds that could form hydrophobic coatings. This suggests that most soils have the ingredients to become hydrophobic. To make further progress we had to find a way to directly examine the organic coatings on the soil particle surfaces. A potential method that had not been applied to this problem before is Atomic Force Microscopy. This nano-technological microscope provided the high magnification necessary to obtain detailed images of these very thin particle coatings.

Our images show that the coatings are not continuous; they form nano-scale globules that expand and shrink depending on water availability. This flexible behaviour may be a key factor underlying the switches between hydrophobic and wettable soil conditions. This is not the full story: over longer timescales, microbiological processes create and destroy these organic coatings.

Of direct practical relevance is the question: how long will a hydrophobic soil resist wetting during rainfall? A very hydrophobic soil will quickly move rainwater into streams and rivers. At Swansea we probably hold the widest collection of hydrophobic soils worldwide. Laboratory experiments on these samples demonstrate that even moderately hydrophobic soil can resist wetting for hours or even days. These findings are supported by experiments where we used artificial rainfall and also by observations from the Netherlands, which show that hydrophobic areas in grassland soil can remain dry throughout the wet winter months.

The next obvious challenge is to include this soil behaviour in flood forecasting. We need to know how long it takes for hydrophobic soils to wet, and at what stage during a dry spell hydrophobicity reappears.

Evidence is mounting that soils can switch rapidly from a wettable to a hydrophobic state once their water content falls below a critical threshold. For soils with a medium texture this switch occurs when water occupies 20-30 percent of the total soil volume. This situation can arise even during short dry spells in many soils in the UK. The longer and more frequent droughts that climatologists are predicting will increase the areas of soil that fall below this critical moisture threshold and thus become hydrophobic. As drought periods often end with intense rainstorms, which are also expected to become more severe, the ability to predict where and when hydrophobicity occurs is likely to become increasingly important in flood forecasting. ❖

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Dr Stefan Doerr is a NERC Advanced Research Fellow in the Department of Geography, University of Wales Swansea. He is also the Associate Editor of the International Journal of Wildland Fire. Tel. 44 01792 295147, email: S.Doerr@Swansea.ac.uk

More information:
http://geography.swan.ac.uk/hydrophobicity/