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Measurement of soil inter-particle adhesion using atomic force microscopy: Effects of hydrophobicity and humidity

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Several field and laboratory studies have shown indirectly the effects of atmospheric humidity on soil particle adhesion through reduced resistance to movement by wind as the humidity decreases. Similar studies have also shown that increased hydrophobicity has the same effect on susceptibility of soil particles to movement by wind as reduced humidity. Theoretical models of idealized soil particle cohesion by water menisci in equilibrium with the atmospheric humidity have been used to explain these results. However the interpretation of these phenomenological results has never been tested by direct measurement of soil inter-particle adhesion as a function of humidity and hydrophobicity.

To address this lack of direct measurements, force curves indicating adhesion force as a function of separation distance between two surfaces were obtained using an atomic force microscope (AFM) and colloidal tips of various sizes to represent one soil particle coming in contact with another. The model surfaces used were Ottawa sand, representing a soil particle with no organic coatings, and a quartz slide representing a more idealized smooth surface. These surfaces were coated with three types of silanes (two of which form polymers) and palmitic acid to mimic fatty acids coating the soil surface, inducing hydrophobicity of the surface. In addition to these model surfaces, field soil samples from grassed, bare, and creosote bush-covered soil surfaces in a desert ecosystem of the southwestern United States were also studied and the results compared to the model surfaces. The force curves were taken at various values of relative humidity in order to measure the combined effect of hydrophobicity and humidity.

The results provide a first glimpse of the complex nature of soil inter-particle forces as seen through the use of atomic force microscopy. In particular, these experiments show the following: (1) for most but not all surfaces, with increased relative humidity, there was increased adhesion force between the tip; (2) at high relative humidity, there was an increase in adhesion force with an increase in tip size and increased surface hydrophobicity; (3) with increased surface roughness there was decreased adhesion force at high relative humidity; and (4) at high relative humidity on rough surfaces, the distribution of measured adhesion force was bi-modal, indicating distinct wet (high adhesion force) and dry (low adhesion force) surfaces.