Agriculture, Ecosystems and Environment 144 (2011) 208–221

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Review

Review of the remediation strategies for soil water repellency

Karin Müller[a,*], Markus Deurer[b]

[a] The New Zealand Institute for Plant & Food Research Limited, Private Bag 3123, Waikato Mail Centre, Hamilton 3240, New Zealand
[b] The New Zealand Institute for Plant & Food Research Limited, Private Bag 11030, Manawatu Mail Centre, Palmerston North 4442, New Zealand

ARTICLE INFO

Article history:
Received 12 May 2011
Received in revised form 5 August 2011
Accepted 10 August 2011
Available online 24 September 2011

Keywords:
Hydrophobicity
Amelioration
Soil management

ABSTRACT

Many regions of the world are predicted to experience water scarcity due to more frequent and more severe droughts and increased water demands. Water use efficiency by plants can be negatively affected by soil water repellency (SWR). It is timely to review existing techniques to remedy SWR. Ideally remediation addresses the origins of a problem. However, the fundamental mechanisms of how and why SWR develops are still poorly understood. In this review it was hypothesized that SWR occurs where the balance of input–decomposition of organic matter is impaired, due to either increased input or decreased decomposition rates of hydrophobic substances. Direct and indirect strategies to remedy SWR were distinguished. While direct remediation aims at abolishing the causes of SWR, indirect strategies seek to manage sites with SWR by treating its symptoms. The 12 reviewed strategies include applying surfactants, clay, slow-release fertilizers, lime, and fungicides, bioremediation of SWR through stimulating earthworms, choosing adapted vegetation, irrigation, cultivation, soil aeration and compaction. Some of the techniques have been applied successfully only in laboratory experiments. Our review highlights that it is not straightforward to cure SWR based on easily measurable and site-specific soil and vegetation properties, and that long-term, large-scale field experiments are required to improve the understanding of the evolution of SWR as cornerstone to develop cost-effective and efficient remediation strategies. We also identified current research gaps around the diagnosis and prevention of SWR.

Contents

Abbreviations: CA, contact angle; MED, molarity of ethanol droplet; MPN, most probable number; SOM, soil organic matter; SWR, soil water repellency; WDPT, water drop penetration time.

* Corresponding author. Tel.: +64 7 959 4555; fax: +64 7 959 4430.
E-mail address: karin.mueller@plantandfood.co.nz (K. Müller).

0167-8809/$ – see front matter
doi:10.1016/j.agee.2011.08.008

1. Introduction

The wettability of soils is a dynamic surface property that is interlinked with many other biological, chemical and physical soil properties. It can be quantitatively measured, for example, by the equilibrium contact angle (CA) between water and a soil surface in air. The results allow defining three different wetting situations: Spontaneous complete wetting (hydrophilicity), for which the CA is zero, and partial wetting with $0^\circ < CA \leq 90^\circ$ and $CA > 90^\circ$, which are referred to as subcritical soil water repellency (SWR) and hydrophobicity, respectively. Water repellency of peat soil has been observed in The Netherlands as early as in the 11th century, when the first polders were built and Dutch engineers noted that the soils did not wet up spontaneously once the polders had been drained (Kirkham, 2005). In the 1940s, research on SWR focused on the identification of vegetation types leading to SWR and developing quantitative measurement techniques for the degree and persistence of SWR. Evidence on the occurrence of SWR under various soil types, climates and land-use scenarios has been gathered in over 50 countries worldwide (Dekker et al., 2005b). SWR occurs in soils of different texture and across a variety of climatic conditions ranging from tropical to subarctic (DeBano, 2000b; Deurer et al., in press; Doerr et al., 2000, 2006; Woche et al., 2005). For example, a recent survey conducted under pastoral land use in New Zealand found no impact of climate on the occurrence of SWR (Deurer et al., in press). Similarly, Jaramillo et al. (2000) based on investigations in the arid Middle Rio Grande Basin in New Mexico (USA) and the humid Piedras Blancas Watershed in Colombia, had to reject their hypothesis that SWR predominantly occurs in dry climates. SWR affects land used for agricultural and pastoral production, coastal dune sands, parks and golf courses (Doerr et al., 2006; Wallis and Horne, 1992) but has also been shown to occur under different types of forest and shrubland (DeBano, 2000b; Doerr et al., 2007). The phenomenon of SWR is an 'emerging' issue in the sense that it has received increasing attention internationally in recent years, with the enhanced awareness of global water scarcity and a more regular occurrence of extreme droughts (Doerr et al., 2000, 2007).

SWR is not a static soil property, because the soil water content can alter the wetting properties. Conceptually, three key site-, soil- and climate-specific properties need to be known to predict the phenomenon of soil water repellency in soils:

1. *The degree of SWR* in form of the CA of the air-dry soil. This maximum CA describes the maximum SWR for the site that might be reached after prolonged dry periods.
2. *The persistence of SWR* in form of the time that is needed for water to infiltrate a water-repellent surface. During rewetting the maximum CA of a water repellent air-dry soil gradually decreases until water can infiltrate.
3. *The critical water content* below which the degree and persistence of SWR are functions of the soil water content. It is neither clear what factors determine the critical water content of a site nor if it is a constant value within a year or over the longer term.

Irregular patterns of degree and persistence of SWR with depth have been reported (Keizer et al., 2007; Ritsema and Dekker, 1998; Woche et al., 2005). Rodríguez-Alleres et al. (2007) found a decrease of the degree of SWR with depth. Generally, the top few centimeters of a soil profile often exhibit the highest SWR (DeBano, 2000b; Vogelmann et al., 2010). The surface soil layer links pedosphere and atmosphere, and SWR has a significant impact on various soil-water related processes that occur at the interface between the two spheres. SWR thereby threatens different key ecosystem services that soils provide, including support of plant growth for food and fiber production (Bond, 1972), water retention, facilitation of high infiltration rates as a way to avoid flooding and erosion (Doerr et al., 2000; Müller et al., 2010; Shakesby et al., 2000; Wallis and Horne, 1992), and the provision of clean drinking water by filtering of agrichemicals (Aslam et al., 2009). This renders SWR an important issue for primary industries, especially for those with permanent vegetation like the pastoral industry in locations without access to irrigation.

However, under specific circumstances, SWR can also be an advantageous soil property. It has been attributed a positive role in sustaining the stability of aggregates (Blanco-Canqui and Lal, 2009; Wang et al., 2000), and the sequestering of organic carbon (Piccolo and Mbagwu, 1999). Recent research highlighted the positive impact of subcritical soil water repellency on aggregate stability in no-tillage arable farming (Blanco-Canqui, 2011), and in vineyards (Bartoli and Dousset, 2011). In addition, SWR reduces the loss of soil water by evaporation (Hallett, 2007), which might be significant in arid and semi-arid climates. Another beneficial aspect of SWR is the ecohydrological advantage of certain tree species over shallow-rooted herbaceous species: In semi-arid southeast Utah, Robinson et al. (2010) found that the shaded leaves of a two-needle pinyon pine (*Pinus edulis* Engelm.) – Utah juniper [*Juniperus osteosperma* (Torr.) Little] woodland led to seasonal SWR in the fine sandy loam resulting in channeling of rainwater into deeper depths where water uptake of shallow-rooted competitive vegetation was reduced. Organically derived hydrophobicity as a bioengineering tool of deep-rooted tree and shrub species to optimize their water and nutrient command was discussed (Verboom and Pate, 2006). These few examples demonstrate that a true understanding of the ecological significance of SWR is still limited, mainly because the occurrence of SWR is spatially and temporally very variable (Regalado and Ritter, 2008; Ritsema and Dekker, 1998; Täumer et al., 2005), and because its effects at larger scales, i.e. catchment or regional scales, have not been fully investigated (Doerr et al., 2003).

Similarly, our understanding of what causes soils to become water-repellent is still incomplete (Dekker et al., 2005b) even though numerous research projects have had the sole objective of determining the evolution of SWR. There is universal agreement