Organic soil management reduces soil water repellency

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ABSTRACT

The objectives of this study were to determine the effects of agricultural management, related to conventional and organic soil management, on the soil water repellency (SWR). Besides the relation between the agricultural variables and the SWR, the influence of soil organic matter and pH was examined. To classify SWR, the persistence and severity was measured using the water drop penetration time, respectively the water-drop contact angle. Organic soil management was shown to have a significant higher SWR compared to conventional soil management and a strong positive correlation between soil organic matter concentration and SWR was found. The soil pH showed a negative correlation in relation to SWR.

Keywords

Soil water repellency, organic, soil management, agriculture, soil organic matter

INTRODUCTION

Soil water repellency (SWR) is an important soil property which reduces the affinity of soils for penetrating water. The SWR has several impacts on the hydrology of the soil, e.g. an increase in soil erosion (Doerr and Shakesby, 2000) and a potential higher risk for contamination of groundwater (Ritsema and Dekker, 1994).

The eventual effect of the SWR on the soil hydrology is related to its persistence and its severity, by which mostly their combination is determining for the effect on the hydrology (Chau, Biswas et al. 2014). The persistence is defined as the time the soil stays water repellent in presence of water. The severity of SWR is defined as the strength of the water repellency.

The factors influencing the SWR can be subdivided in abiotic and biotic factors. The most important abiotic factors are soil texture, soil moisture, soil organic matter and pH. For soil texture it can, in general, be stated that more coarse material has a higher SWR compared to finer material. This is due to the lower surface area relative to the volume of more coarse material, resulting in easier coating of the material by hydrophobic organic compounds (Orfanus, Dlapa et al. 2014). For the relation between the abiotic factor soil moisture (Ritsema and Dekker 1994) and SWR, a negative correlation can be found. The repellency can even completely disappear when a certain soil moisture content is reached. After drying, the SWR will restore, however not to its initial level (Doerr, Shakesby et al. 2000). For soil organic matter (SOM) it appears that the type of the SOM seems to be more important for SWR than the total amount of SOM in the soil (Doerr and Shakesby et al. 2000), e.g. fresh and partly decomposed SOM is more water repellent than almost completely decomposed SOM (Dekker, 1994). Finally, the abiotic factor pH determines the SWR. Several studies found acidic soil to be more prone for SWR than alkaline soils (Wallis and Horne 1992, Mataix-Solera, Arcenegui et al. 2007, Lebron, Robinson et al. 2012). The influence of pH on the SWR might be the result of changes in surface charge density of soil material. (Diehl, Bayer et al. 2010). Biotic factors influencing SWR can be related to several hydrophobic organic compounds (Dekker, 2009) e.g. waxy substances originating from leaves, fungi, microbes and root exudates (Taumer, Stoffregen et al. 2005).

Although several studies explored the effect of specific agricultural managements on the SWR (Ghadim 2000, Blanco-Canqui 2011, González-Peñaloza, Cerdà et al. 2012), the effect of organic compared to conventional soil management on SWR is yet unknown. An effect on SWR can be expected, since different amendments can add different organic compounds to the soil, leading to different SOM-content, a different SOM type and different pH of the soil, which can in turn affect the SWR. However, how the SWR will be influenced exactly is difficult to predict.

The objectives of this research are the following [1] to study how the severity and the persistence of the SWR is influenced by organic and conventional soil management, [2] to study the effect of the addition of different soil health treatments, to decrease soil pathogens, on the severity and persistence of the SWR, [3] to study how the use of different agricultural practices, regarding harvesting times and types of cover-crops, affect the severity and persistence of the SWR, [4] to analyse the relationship between the soil abiotic factors soil moisture, SOM and pH and the SWR.

MATERIALS AND METHODS

Study site

The soils that have been used in this study originate from a long-term field experiment which started in 2006 in Vredepeel farm (WUR, The Netherlands). This experiment is designed to compare conventional and organic agricultural practices. This study focusses on 10 soil health treatments (SHT) to decrease soil pathogens, each tested on 2 agricultural practices both for an organic system and a conventional system. 7 SHT were chosen to examine the SWR, selected on their potential impact on soil microorganisms functionality. These 7 selected SHT are: compost, chitin, marigold, grass-clover, biofumigation, anaerobic soil disinfestation and a control treatment. The two agricultural practices are defined as “good practice” and “best practice”. Good practice represents the most common agricultural practice in this region. Best practice is an improved agricultural practice. The main differences between the good and best practice are the harvesting time and the cover crop used. At total the number of samples used in this experiment is 112, since 2 systems (conv/org), 2 practices (best/good), 7 SHT and 4 replicates.

Soil analysis

The samples used for the experiment were taken on the 31st August of 2015. From each plot a combination sample was taken. After sieving the samples at 2 mm, the soil moisture was determined by measuring the difference in sample weight before and after overnight drying at 150°C. The SOM was calculated by Weight Loss- on-Ignition, where the dried subsamples were heated at 550°C for 4 hours and weighted after the temperature has been dropped below 150°C. The amount of SOM was determined by measuring the loss of weight. Finally, to measure the pH, a suspension was made with 5 mL of soil and 25 mL of deionized water in a polyetheen sample bottle. The suspension was shaken for 60 min and then settled for an hour. After this, the pH was measured.

Persistence (WDPT)

The persistence was defined by the water drop penetration time (WDPT). The WDPT was used to determine the actual persistence, measured on field-moist samples, and the potential persistence, measured on samples dried at 60°C for 3 days (Dekker, 1990; Ritsema & Dekker, 1994). The actual persistence was measured before the potential persistence. To reach equilibrium with the ambient air temperature, the samples were stored at standard laboratory conditions (19°C) during 2 days. With a standard medicine dropper 3 drops of deionized water were placed on the soil surface. The time for complete penetration was measured with a stopwatch. The average time of the three drops is determined as the eventual WDPT of the soil.

Severity (MED-test)

The severity of the SWR was determined with the MED-test. This test is based on the Morality of an Ethanol Drop (MED), measuring the liquid-water contact angles. A decreasing ethanol concentration is related to an increasing surface tension. In this test a series of aqueous ethanol solutions with the following concentrations of ethanol are prepared: 36%, 24% 13%, 8.0%, 5.0%, 3.0%, 0%. After the WDPT, the samples were dried at 60°C for 3 days and stored for 2 days at standard laboratory conditions (19°C). With a standard medicine dropper, one drop of each ethanol concentration was applied on the soil surface. The severity is measured by the lowest ethanol concentration that penetrates into the soil in 5 s or less (Richardson, 1984; Ritsema and Dekker, 1994).

Data analysis

R (Team 2014) was used for conducting the statistical analysis and for performing the graphs. Packages used are ggplot (Wickham 2009), plyr (Wickham 2011) and stepwise (Graham, McNeney et al. 2005). To analyse the effects of the soil variables on SWR an ANOVA test was performed with the following variables: soil management (conv/org), practices (best/good), the 7 SHT, block, and covariates SOM-content and pH. Separate ANOVA tests have been used to examine the relation between SWR and the abiotic factors SOM and pH.

RESULTS

Agricultural management

At field moisture, all 112 samples were wettable and exhibited a penetration time of less than 5s, indicating that the soil was not water repellent at field-moist conditions. After drying, the majority of the samples indicated water repellency, based on potential persistence.

When performing the MED-test, all samples showed water repellency ranging from hydrophilic to moderately hydrophobic, except for a few samples.

TABLE 1 Results from factorial ANOVA to test the effect of soil treatments and soil abiotic factors on soil water repellency (persistence and severity).

Persistence : p-value<0.001; adjusted R^2: 0.234

Severity : p-value<0.001; adjusted R^2: 0.488

	PERSISTENCE				*SEVERITY*			
	Df	Mean.sq	F value	Pr(>F)	Df	Mean.sq	F value	Pr(>F)
Management	1	75.6	5.40	0.022	1	231	21.2	1.2e-05
SHT	6	5.5	0.39	0.882	6	9.2	0.14	0.990
Practice	1	2.3	0.16	0.687	1	0.4	0.04	0.841
Block					1	87.5	0.72	0.396
SOM	1	422	30.2	3.0e-07	1	942	86.1	3.8e-15
pH	1	80.8	5.78	0.018	1	7.9	7.99	0.005
Residuals	101	14.0			100	10.9		

The results from the ANOVA test (Table 1) shows a very significant influence of SOM on both persistence and severity and explain a relatively big part of the variance of persistence and severity. Soil management is also indicated as an influencing factor for persistence and severity, as a significant higher persistence can be found for conventional soil management compared to organic soil management (Fig. 4). Also pH related significantly to persistence and severity of soil water repellency.

Soil water repellency and soil organic matter

The concentration of SOM and SWR were positively related both for persistence (r= 0.471, p< 0.001) and severity (r=0.661, p< 0.001) in relation to SOM. This relatively high correlation coefficient and the significant p-values indicate a strong relationship between SWR and SOM. No significant difference was found in SOM between soil management, good and best practice or the different SHT (Table 2).

Soil water repellency and pH

The pH and SWR were negatively correlated, both for persistence (r= -0.261, p= 0.005) and severity (r= -0.179, p=0.005). This slightly higher negative correlation between pH and persistence, may influence the ANOVA results when explaining persistence and severity (Table 1), where pH is valued as a more significant explaining variable for persistence, compared to severity. A significantly higher pH was found for organic soil management, compared to conventional soil management. No difference in pH was found when comparing good and best practice or the different SHT (Table 2).

DISCUSSION

Agricultural management and soil water repellency

We found a significant difference in SWR for conventional soil management compared to organic soil management (Table 1), indicating that certain soil management influence SWR. The main treatment differences between these two management types is the form in which nutrients are added to the soil. Apparently the organic manure used in this experiment resulted in a lower SWR compared to the mineral nutrients used in the conventional management (Fig. 4). This difference might be related to the character of the SOM, while the amount of SOM between conventional and organic soil management was not significantly different (Table 2). This finding is in line with results found in earlier studies, where the characteristics of the SOM appeared to be just as, or even more, important than the total amount of SOM (Doerr, Shakesby et al. 2000). Moreover, a significant difference in pH was found for soil management (Table 2), with a higher pH in organic soil management, compared to conventional soil management**.** The negative correlation found for pH in relation to SWR, suggests that the lower SWR for organic soil management may be due to the higher pH as a result of organic soil management.

TABLE 2 Results from factorial ANOVA to test the effect of soil treatments on abiotic factors.
Soil organic matter: p-value: 0.976; Adjusted R^2: 0.056
pH: p-value<0.001; Adjusted R^2: 0.142

	SOIL MOISTURE			*SOIL ORGANIC MATTER*			*pH*		
	Mean sq.	**F-value**	**Pr(<F)**	**Mean.sq**	**F value**	**Pr(<F)**	**Mean.sq**	**F-value**	**Pr(<F)**
Management	0.109	0.083	0.774	0.597	1.323	0.252	0.242	19.4	2.6e-05
Practice	0.7010	0.541	0.464	0.117	0.261	0.611	0.006	0.446	0.506
Soil health treatment	0.355	0.271	0.949	0.038	0.086	0.998	0.014	1.089	0.374
Residuals	1.31			0.450			0.012		

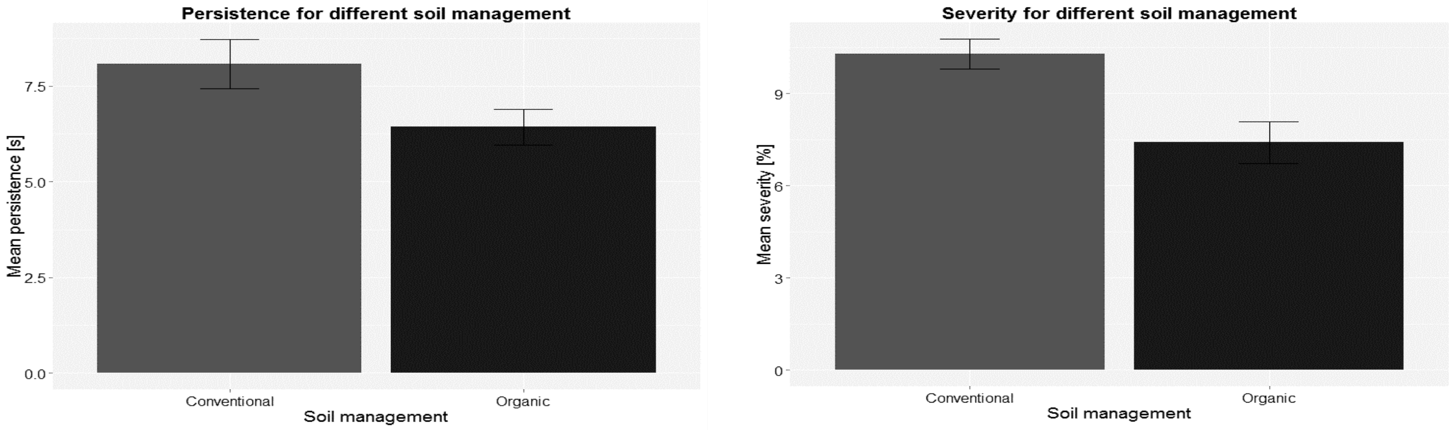

FIGURE 1
Measured average persistence and severity with standard errors for conventional and organic soil management. The persistence is measured in seconds. The mean persistence of conventional soil management is 8.07 s, with a standard error of 0.644. For organic soil management is the mean value 6.43 s, with a standard error of 0.467s. The severity is measured as alcohol concentration. For conventional soil management is the mean percentage 10.29%, with a standard error of 0.49%. The mean percentage of organic soil management is 7.41%, with a standard error of 0.676%. The graphs show a significant higher persistence and severity for conventional soil management.

Apparently, addition of the several soil health treatments did not influence the abiotic properties of the soil, e.g. changes in pH, amount of SOM or the character of the SOM, in a way it affected the SWR. However, the last addition of the soil health treatments was in 2009-2010 and only repeated twice since the beginning of the experiment in 2006 (Korthals, Thoden et al. 2014). A significant, or at least a more likely effect could be expected when measuring shortly after the application of the soil health treatments.

From the adjusted R^2 (Table 1), defined for both persistence and severity, can be stated that there are still other factors that determine SWR as well, which are not included in this model. A remaining explaining factor could be the chemical and physical characteristics of the SOM, since these characteristics are known as a possible influencing factor (Doerr and Shakesby, 2000; Dekker, 1994), but were not tested in this experiment.

For measuring the potential persistence, the samples were dried in the oven for 3 days at 60°C. However, the temperature of drying may influence the value resulting from the WDPT test (Dekker, Ritsema et al. 1998). Furthermore, it is questionable if the potential SWR, achieved by drying the samples, will occur at field conditions. To get more realistic results, it might be more reliable to get field-moist samples with different soil moisture contents throughout the year. Unfortunately, in this study it was not possible to take more samples from the field than already were available. Therefore, the drying was needed to get a potential SWR. It might be possible that this potential SWR is an overestimation of the SWR that could possibly occur at field conditions.

Most soil properties are determined on 2mm sieved samples. However, when determining SWR air-drying sieving can affect the results. Sieving changes the surface roughness and morphology of the soil and therefore changes the liquid-water contact angle. A study showed slightly overestimated values on sieved samples for the MED-test and slightly underestimated values on sieved samples for the WDPT (Badía, Aguirre et al. 2013). However, no significant differences were found in class level, used to characterize persistence, respectively severity, between undisturbed and hand-sieved samples. It might be interesting to compare persistence and severity values of sieved and undisturbed samples in a future experiment.

Soil water repellency and abiotic factors

SOM significantly affects the persistence and severity of the SWR (Table 1). This is in line with the results found for correlation between SOM and persistence and SOM and severity. This positive correlation is relatively strong, as indicated by the correlation coefficient and significant p-value of <0.005.

For both persistence and severity, pH is established to be a factor of influence (Table 1). However, the influence was less strong, compared to the influence of SOM. For the correlation between pH and persistence, respectively severity, a negative correlation was found. This is in line with the results found in literature (Wallis and Horne 1992, Mataix-Solera, Arcenegui et al. 2007, Lebron, Robinson et al. 2012).

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CONCLUSION

In this study, the relationship between the SWR and specific soil management and between the SWR and certain abiotic factors was examined using soils from the long-field experiment in Vredepeel (Korthals, Thoden et al. 2014). Differences in SWR were found between conventional and organic soil management. A lower SWR was found at the fields with organic soil management compared to the fields with conventional soil management. Furthermore, a relatively strong positive correlation has been indicated between the SWR and the SOM-content in the soil. The pH of the soil is negatively correlated with the SWR.

The influence of biotic and abiotic factors on the SWR is a complex property. Characterizing and understanding the role of agricultural soil management in the occurrence of SWR is valuable in determining sustainable adaptations for the hydrology of the soil.

ACKNOWLEDGEMENTS

I'd like to thank Gerlinde De Deyn and Laura Martinez Garcia for supervising me during this project and giving me the opportunity to take part of the bigger experiment. Furthermore, I'd also like to thank Piet Peters for his help with my lab work.

ROLE OF THE STUDENT

Sya Hoeke was an undergraduate student working under the supervision of Gerlinde De Deyn when the research in this report was performed. The topic was proposed by the supervisor as a part of an existing experiment. The design and performance of this experiment, the processing of the results as well as the formulation of the conclusions and the writing were done by the student.

REFERENCES

1. Arcenegui, V., J. Mataix-Solera, C. Guerrero, R. Zornoza, J. Mataix-Beneyto and F. García-Orenes (2008). "Immediate effects of wildfires on water repellency and aggregate stability in Mediterranean calcareous soils." Catena **74**(3): 219-226.
2. Badía, D., J. Aguirre, C. Martí and M. Márquez (2013). "Sieving effect on the intensity and persistence of water repellency at different soil depths and soil types from NE-Spain." Catena **108**: 44-49.
3. Blanco-Canqui, H. (2011). "Does no-till farming induce water repellency to soils?" Soil use and management **27**(1): 2-9.
4. Chau, H. W., A. Biswas, V. Vujanovic and B. C. Si (2014). "Relationship between the severity, persistence of soil water repellency and the critical soil water content in water repellent soils." Geoderma **221**: 113-120.
5. Dekker, L. and P. Jungerius (1990). "Water repellency in the dunes with special reference to The Netherlands." Catena, Supplement(18): 173-183.
6. Dekker, L. W., C. J. Ritsema, K. Oostindie and O. H. Boersma (1998). "Effect of drying temperature on the severity of soil water repellency." Soil Science **163**(10): 780-796.
7. Dekker, Louis W., et al. "Water repellency and critical soil water content in a dune sand." *Soil Science Society of America Journal* 65.6 (2001): 1667-1674.
8. Dekker, Louis W., et al. "Methods for determining soil water repellency on field-moist samples." *Water resources research* 45.4 (2009).
9. Diehl, D., J. V. Bayer, S. Woche, R. Bryant, S. Doerr and G. E. Schaumann (2010). "Reaction of soil water repellency to artificially induced changes in soil pH." Geoderma **158**(3): 375-384.
10. Doerr, S. H., R. A. Shakesby and R. P. D. Walsh (2000). "Soil water repellency: its causes, characteristics and hydro-geomorphological significance." Earth-Science Reviews **51**(1-4): 33-65.
11. Ghadim, A. A. (2000). "Water repellency: a whole-farm bio-economic perspective." Journal of Hydrology **231**: 396-405.
12. González-Peñaloza, F. A., A. Cerdà, L. M. Zavala, A. Jordán, A. Giménez-Morera and V. Arcenegui (2012). "Do conservative agriculture practices increase soil water repellency? A case study in citrus-cropped soils." Soil and Tillage Research **124**: 233-239.
13. Korthals, G. W., T. C. Thoden, W. van den Berg and J. H. M. Visser (2014). "Long-term effects of eight soil health treatments to control plant-parasitic nematodes and Verticillium dahliae in agro-ecosystems." Applied Soil Ecology **76**: 112-123.
14. Lebron, I., D. A. Robinson, M. Oatham and M. N. Wuddivira (2012). "Soil water repellency and pH soil change under tropical pine plantations compared with native tropical forest." Journal of Hydrology **414**: 194-200.
15. Mataix-Solera, J., V. Arcenegui, C. Guerrero, A. Mayoral, J. Morales, J. González, F. García-Orenes and I. Gómez (2007). "Water repellency under different plant species in a calcareous forest soil in a semiarid Mediterranean environment." Hydrological Processes **21**(17): 2300-2309.
16. Orfanus, T., P. Dlapa, N. Fodor, K. Rajkai, R. Sandor and K. Novakova (2014). "How severe and subcritical water repellency determines the seasonal infiltration in natural and cultivated sandy soils." Soil & Tillage Research **135**: 49-59.
17. Richardson, J. L. "Field observation and measurement of water repellency for soil surveyors." *Soil Horizons* 25.2 (1984): 32-36. Dekker, Louis W., and Coen J. Ritsema. "How water moves in a water repellent sandy soil: 1. Potential and actual water repellency." *Water Resources Research* 30.9 (1994): 2507-2517.
18. Ritsema, Coen J., and Louis W. Dekker. "How water moves in a water repellent sandy soil: 2. Dynamics of fingered flow." *Water Resources Research* 30.9 (1994): 2519-2531.
19. Taumer, K., H. Stoffregen and G. Wessolek (2005). "Determination of repellency distribution using soil organic matter and water content." Geoderma **125**(1-2): 107-115.
20. Team, R. C. (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2012, ISBN 3-900051-07-0.
21. Wallis, M. and D. Horne (1992). Soil water repellency. Advances in soil science, Springer**:** 91-146.
22. Wickham, H. (2009). ggplot2: elegant graphics for data analysis, Springer Science & Business Media.
23. Wickham, H. (2011). "The split-apply-combine strategy for data analysis." Journal of Statistical Software **40**(1): 1-29.