How much mulch?
No tillage and mulching practices contribute to enhanced soil water repellency

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Introduction

Mulching is an agricultural management technique aimed at protecting and improving soil physical properties. Mulching consists of application of crop residues and other materials to cropped soils, and may be used in combination with no tillage and other conservative practices. These techniques contribute to improved water management, increased organic matter (OM) content, soil fertility, crop yields and control of soil erosion risk. Conservative practices as mulching and no-tillage increase soil organic matter input in soils and contribute to reduce the soil hydrological response by improving soil structure, regulating the pore system and causing surface irregularity. In contrast, mulching and other conservative practices have been considered recently responsible of enhanced soil water repellency (SWR). SWR reduces infiltration rates and increases soil erosion risk.
To what extent conservative practices as mulching and no tilling impact soil hydrological processes? What is the impact after medium- or long-term conservative management? These are important questions that need to be assessed. Conventional tillage is considered to trigger erosion risk in sloping Mediterranean soils. In contrast, management practices, as addition of crop or plant residues and reduced or no tillage, are considered strategies for reducing soil erosion risk in sensible areas. But the impact of SWR has been only recently studied in crop soils under conservative practices. The study of the impacts of even subcritical water repellency from soils under conservative types of management has been proposed recently to fill a gap in current research. Intensive research on SWR in no-till mulched soils after a significant period of time is necessary to study the impacts of conservative farming in SWR. The objectives of this research are to study the development of SWR in mulched no-tilled soils from southern Spain during a period of 15 years and the impact of SWR on the hydrological response of mulched no-tilled soils.

Methods

The experimental work was carried out in Mediterranean calcareous soils from the province of Sevilla (southern Spain; Fig. 1).
Soils from fruit orchards (peach, *Prunus persica*, and apricot, *P. armeniaca*) were selected under different management types: conventional tillage (CT), notilling
and low mulching rate (1–4 Mg ha^{-1} $year^{-1}$ wheat straw residues on untilled soil; MR1), no-tilling and moderate mulching rate (5–8 Mg ha^{-1} $year^{-1}$; MR2), and no-tilling and high mulching rate (9–12 Mg ha^{-1} $year^{-1}$; MR3). Periods under each type of management ranged from 1 year to 15 years. At each area under the same type of management and time of treatment, four experimental plots (2 m × 2 m) randomly distributed in inter-rill areas with slope 8–12% were selected for determination of OM content and SWR by the WDPT method (Fig. 2).
Rainfall simulations were carried out in 2 plots from each area (49.1±2.1 mm h^{-1} intensity, 60 min.). At each case, time to ponding (Tp), time to runoff (Tp), and runoff rate were determined.

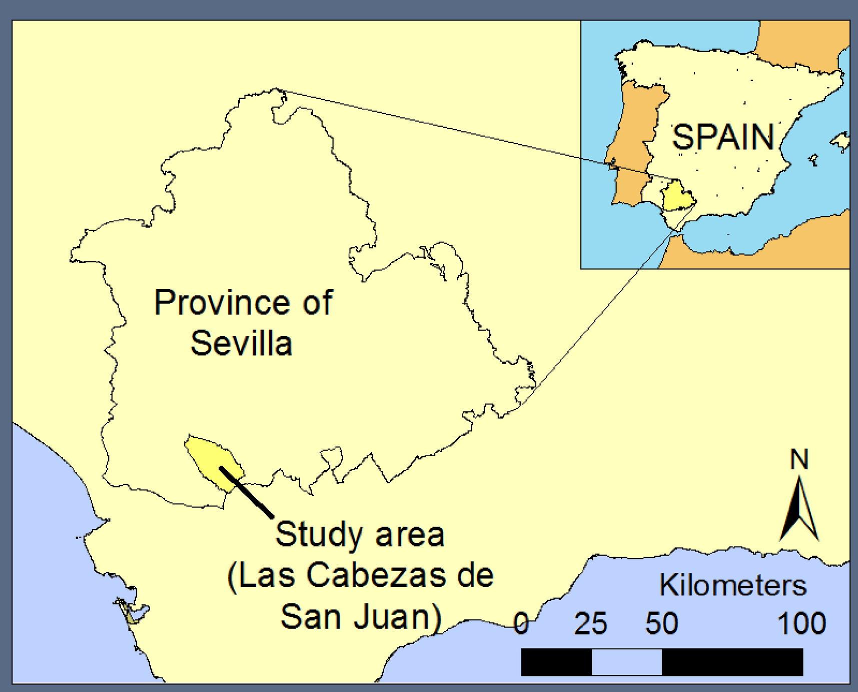

Figure 1. Study area.

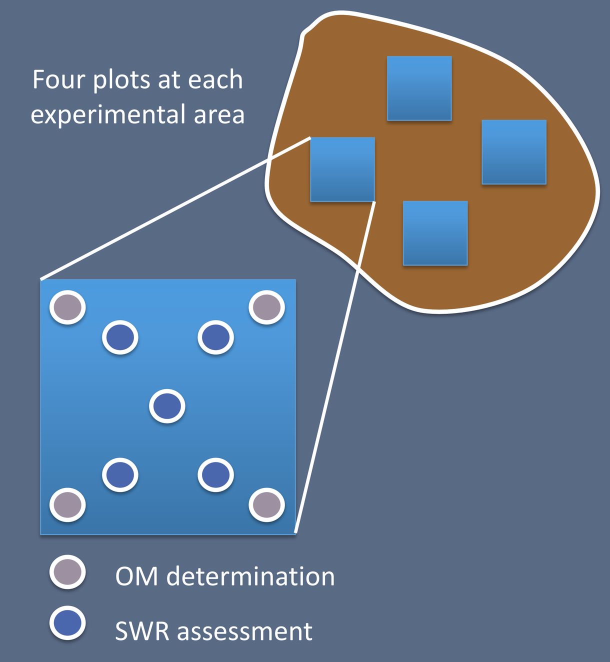

Figure 2. Experimental design.

Results

Fig. 3 shows the influence of different mulching rates in SWR from fruit orchards in the study area. WDPT varied between 0 and 1 s (CT), 1 and 7 s (MR1), 1 and 16 s (MR2) and 1 and 20 s (MR3). SWR assessment, performed after a period of at least 30 days without rainfall, were not affected by soil moisture content. Soils under CT did not show significant changes in SWR for all periods of treatment, with WDPTs ranging between 0 and 1 s in all cases. On average, WDPT from mulched soils was 3 ± 1 s (MR1), 6 ± 3 s (MR2) and 9 ± 5 s (MR3) (Table 1). Independently of the period of time under treatment, the proportion of wettable samples was 100.0% in soils under CT, but decreased between 93.3% (MR1) and 25.0% (MR3) in mulched soils. Differences between WDPT from soils under CT and MR1 are significant, but, together, 116 from 120 soil plots were considered wettable (60 samples under CT and 56 samples under MR1). Respectively, 60 and 75% of soil plots under MR2 and MR3 were considered slightly water repellent (Table 2).

The results of the Kruskal-Wallis test (KW, p) for SWR (WDPT) from different years of treatment and mulching rates are shown in Table 2. No significant differences were found for SWR after different periods of time under CT (with water drops infiltrating almost instantaneously). Significant differences were found for water repellency from soils under different mulching rates after different number of years. No water-repellent samples were observed in any case for mulching periods of treatment shorter than 4 years, but WDPT increased slightly with the number of years of treatment. WDPT increased progressively with time in mulched soils between 1 ± 1 and 5 ± 2 s (MR1), 2 ± 1 and 13 ± 2 s (MR2) and 1 ± 1 and 18 ± 2 s (MR3) (Fig. 3).

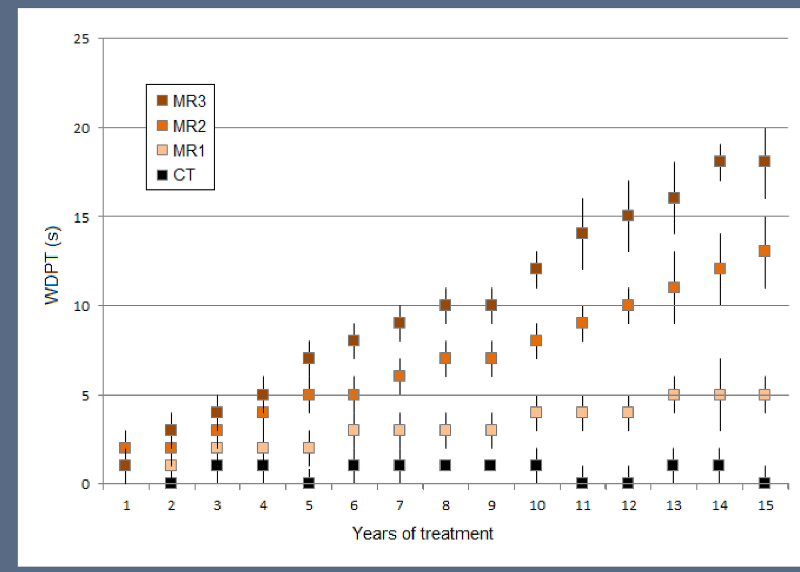

Figure 3. Evolution of WDPT in time for different management practices.

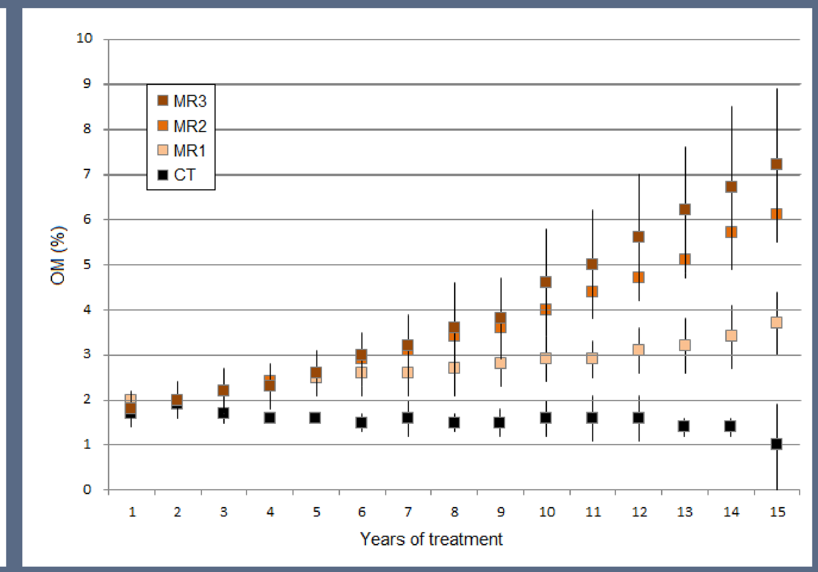

Figure 4. Organic matter content changes in time for different management practices.

Soil OM content for different treatments and years is shown in Table 2. Organic matter content from CT soils did not show significant variations between years. In contrast, mulch application increased OM content from 2.0 ± 0.2 to 3.7 ± 0.7% (MR1), 1.8 ± 0.4 to 6.1% (MR2) and 1.8 ± 0.2 to 7.2 ± 1.7% (MR3). Slight water repellency observed in mulched soils at the end of treatments may be attributed to the input of hydrophobic organic matter as a consequence of the addition of plant residues. As shown in Table 4, no significant temporal changes are observed in OM content from soils under CT, but significant changes are observed in OM content from mulched soils at MR1 (p = 0.0007), MR2 and MR3 (p = 0.0000).

Table 1. Statistical analyses of soil water repellency data (mean WDPT ± standard deviation, s) under different treatments. N: number of data; CV: coefficient of variation; PWS: proportion of wettable samples; KS, p: Kolmogorov-Smirnov p-value. KW, p: Kruskal-Wallis p-value. Values followed by the same letter within the same column do not show significant differences.

Treatment	N	WDPT (s)	CV (%)	Minimum	Maximum	Range	PWS (%)	KS, p
CT	60	0 ± 0 a	97.5	0	1	1	100.0	< 0.05
MR1	60	3 ± 1 b	47.8	1	7	6	93.3	0.0918
MR2	60	6 ± 3 c	51.6	1	16	15	40.0	0.5881
MR3	60	9 ± 5 d	54.2	1	20	19	25.0	0.5575
All	240	5 ± 5	95.5	0	20	20	64.6	< 0.05
KW, p (treatments)		0.0000						

Table 2. Statistical analyses of organic matter content (mean OM ± standard deviation, %) under different treatments. N: number of data; CV: coefficient of variation; KS, p: Kolmogorov-Smirnov p-value. KW, p: Kruskal-Wallis p-value. Values followed by the same letter within the same column do not show significant differences.

Treatments	N	OM (%)	CV (%)	Minimum	Maximum	Range	KS, p	KW, p (years)
CT	60	1.6 ± 0.3 a	17.7	1.2	2.2	1	< 0.05	> 0.05
MR1	60	2.7 ± 0.6 b	23.4	1.8	4.6	2.8	0.4016	0.0007
MR2	60	3.6 ± 1.4 c	38.3	1.5	6.6	5.1	0.5660	0.0000
MR3	60	4.0 ± 2.0 c	49.6	1.6	9.4	7.8	0.2108	0.0000
All	240	3 ± 1.5	52.3	1.2	9.4	8.2	< 0.05	0.0000
KW, p (treatments)		0.0000						

Regressions between WDPT and number of years under different treatments are shown in Table 3. No significant regression was observed for WDPT and number of years under CT. The correlation coefficient is moderately strong for MR1 treatment and strong for MR2 and MR3. The slope of regression equations increases progressively from MR1 to MR3, showing that persistence of SWR increases with time at different speed depending on mulching rate.
Significant regressions were found for OM content and number of years for MR2 and MR3 soils (Table 3). In the case of MR1, the correlation coefficient was near 0, but mean OM content increased from 2.0 ± 0.2 to 3.7 ± 0.7%. MR2 and MR3 mulching rates induced a great input of OM in soil.
The regression analyses between OM content and WDPT from soils under MR1 showed a positive but weak correlation coefficient. It may be suggested that at relatively low OM inputs (in comparison to MR2 and MR3), small differences in mineralization rates may cause variability in the composition of OM, inducing differences in SWR, as seen above. However, correlation coefficients for OM and WDPT under MR2 and MR3 treatments were stronger.

Table 3. Regression analysis of WDPT versus number of years, OM content versus number of years and WDPT versus OM content under different treatments. Non-significant regression equations are not shown.

Regressions	Treatment	Intercept	Slope	r	r2	p-value
Number of years/WDPT	MR1	0.9143	0.2732	0.8038	0.6461	0.0000
	MR2	0.6857	0.7706	0.9508	0.9040	0.0000
	MR3	0.2405	1.2116	0.9812	0.9628	0.0000
	All treatments	0.5946	0.5632	0.5004	0.2504	0.0000
Number of years/OM	MR1	1.7295	-0.0197	-0.3085	0.0952	0.0000
	MR2	1.8429	0.1078	0.7410	0.5491	0.0000
	MR3	0.8288	0.3922	0.8690	0.7552	0.0000
	All treatments	1.3954	0.1952	0.5465	0.2987	0.0000
OM/WDPT	MR1	0.0545	1.1259	0.4817	0.2320	0.0001
	MR2	-1.4464	2.3153	0.9005	0.8109	0.0000
	MR3	0.2803	2.4335	0.8895	0.7912	0.0000
	All treatments	-3.2286	2.8169	0.8938	0.7989	0.0000

On average, CT soils showed relatively short Tp, 166 ± 42 s (Table 4). Tp from MR1 soils sharply increased to 687 ± 426 s and MR2 and MR3 increased up to 298 ± 139 s, on average. On average, soils under MR1 showed the longest Tp, although data varied in a wide range (145 – 1562 s) when all periods of treatment were considered together. Generally, Tp increased with time when all treatments were considered together, showing a correlation coefficient near 0 (Table 5), although all treatments did not contribute equally to this. Soils under CT, MR2 and MR3 did not show significant differences between Tp from soil plots after different number of years of treatment (p < 0.05). In contrast, Tp from soils under MR1 varied significantly with time (p = 0.0000), and the correlation coefficient between number of years under treatment and Tp for soils under MR1 is moderately strong (Table 5).
On average, time required for runoff production since the beginning of rainfall simulation showed a similar behavior. Tr data from all treatments ranged between 275 and 2056 s. The shortest mean Tr was recorded in soils under CT. On average, the longest Tr was recorded in MR1 soils . Tr from MR2 and MR3 soils varied between 275 and 2056 s and did not show significant differences between both groups, but were on average longer than Tr from CT soils. Tr from MR1 and MR2 soils showed significant differences betweenyears. In both cases, Tr increased with time and the correlation coefficient between number of years and Tr was moderate. It is remarkable that higher mulching rates induced great differences in Tp and Tr in time. MR1 contributed to enhanced Tp and Tr, but no significant correlations were observed with the number of years of treatment.
Runoff rate decreased from CT to MR1 sols and icreased progressively with mulching rate, 46.6 ± 7.5 and 67.5 ± 6.1 s for MR2 and MR3 soils, respectively (Table 5). Correlation coefficients were strong in both cases.
Previous research has highlighted the strong impact of SWR on infiltration and runoff rates in forest soils. Changes in Tp, Tr and infiltration and runoff rates may be also influenced by changes in soil aggregation and by the frequency and geometry of pores. Addition of plant residues to soil may increase porosity, increase the roughness and the interception of raindrops, delaying runoff generation and enhancing infiltration rates. But several authors have found a major influence of SWR in the hydrological response of amended soils.

Table 4. Statistical analyses of time to ponding (Tp, s), time to runoff (Tr, s) and runoff rate (%) under different treatments. N: number of data; SD: standard deviation; CV: coefficient of variation; KS, p: Kolmogorov-Smirnov p-value. KW, p: Kruskal-Wallis p-value. Values followed by the same letter within the same column do not show significant differences.

Hydrological response	Treatment	N	Mean ± SD	CV (%)	Minimum	Maximum	Range	KS, p	KW, p
Tp (s)	CT	30	166 ± 42 a	25.1	119	268	149	< 0.05	> 0.05
	MR1	30	687 ± 426 c	62.0	145	1562	1417	0.0249	0.0055
	MR2	30	285 ± 142 b	50.0	117	787	670	0.0480	> 0.05
	MR3	30	311 ± 136 b	43.8	137	637	500	< 0.05	> 0.05
	All	120	362 ± 305	84.2	117	1562	1445	< 0.05	0.0207
	KS, p		0.0000						
Tr (s)	CT	30	377 ± 67 a	17.8	305	522	217	0.0000	> 0.05
	MR1	30	1096 ± 529 c	48.3	328	2056	1728	< 0.05	0.0180
	MR2	30	562 ± 239 b	42.5	279	1354	1075	0.0215	0.0410
	MR3	30	660 ± 298 b	45.1	275	1235	960	< 0.05	> 0.05
	All	120	673 ± 420	62.3	275	2056	1781	< 0.05	0.0347
	KS, p		0.0000						
Runoff rate (%)	CT	30	50.1 ± 7.9 c	15.8	38.7	64.0	25.3	< 0.05	> 0.05
	MR1	30	37.3 ± 5.2 a	13.9	29.2	44.9	15.7	< 0.05	> 0.05
	MR2	30	46.6 ± 7.5 b	16.1	31.8	56.0	24.2	< 0.05	0.0219
	MR3	30	67.5 ± 6.1 d	9.0	54.5	77.4	22.9	< 0.05	0.0177
	All	120	50.4 ± 12.9	25.6	29.2	77.4	48.2	< 0.05	> 0.05

Table 5. Regression analysis of the number of years of treatments (NY) versus Tp, Tr and runoff rate (RR) under different treatments. Non-significant regression equations are not shown.

Regression	Treatment	Intercept	Slope	r	r^2	p-value
NY/Tp	MR1	198.8480	61.0170	0.6243	0.3898	0.0000
	All treatments	179.4752	22.8469	0.3242	0.1051	0.0000
NY/Tr	MR2	322.9264	29.8384	0.5449	0.2969	0.0000
	MR1	478.9900	77.0679	0.6344	0.4025	0.0000
	All treatments	409.7614	32.9471	0.3398	0.1155	0.0000
NY/RR	MR2	33.5987	1.6205	0.9478	0.8983	0.0000
	MR3	57.1929	1.2871	0.9354	0.8750	0.0000

The impact of subcritical SWR is not completely known. Low mulching rates (MR1) enhanced Tp as a consequence of organic matter input and its impact in soil physical properties, but higher mulching rates decreased Tp, as water infiltration rates through the soil surface were reduced by increased water repellency. As a consequence, time required for runoff generation showed a similar behaviour. Subcritical SWR observed in MR1 and MR2 soils might be related to reduced Tp and Tr. SWR seems to be the main cause of enhanced runoff rate in MR3 soils (compared to conventionally tilled soils). In contrast, decreased runoff rates from MR1 and MR2 soils may be mostly related to physical changes in the soil surface layer due to organic inputs. Irregularity of the soil surface favours infiltration through macropores and inter-aggregate cracks. Mulching contributes to decrease runoff flow and enhance infiltration. Under relatively low mulching rates, the effect of subcritical or slight SWR in runoff generation may be limited due to the most favorable effects of organic matter inputs.