# Citrus orchards management and soil water repellency in Eastern Spain

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## Introduction

Water repellency is a property of soils that reduces the infiltration of water into the soil, which has important hydrological and geomorphologic implications. Some of the reported consequences of SWR in cropped soils are reduced agricultural production, decreased and uneven infiltration of water in soils, poor and delayed germination in crops and yields, increased runoff and enhanced soil erosion, decreased vegetation canopy, leaving soil bare and prone to wind erosion, or accelerated leaching of agrochemicals. SWR has been reported as a common phenomenon in no-tilled soils as a consequence of the return of crop residues and reduced soil disturbance.

Citrus production has triggered intense erosion processes in citrus-cropped soils from Eastern Spain since new plantations were planned on sloping terrain. Citrus production in Spain has grown from sustainable types of management in traditional orchards from alluvial plains and fluvial terraces, to new highly mechanized orchards on slopes. In contrast to conventional tillage (CT), strategies for controlling soil losses include different practices: annual addition of plant residues and organic manure with no-tillage and no chemical fertilization (MNT), annual addition of plant residues with no-tillage (NT), and application of conventional herbicides and no-tillage (H). Research gaps and future research directions in the study of SWR in the context of no-till farming include positive and negative impacts of the small differences in SWR between no-till and conventionally tilled soils on crop production and analyze the occurrence and impacts of subcritical SWR. The aim of this paper is to study the impact of different soil management practices (MNT, NT, H, and CT) on SWR in the long-term.

## Methods


Figure 1. Study area

The experiments were conducted in four experimental plots located in the Canyoles river basin (Figure 1). Elevation ranges between 160 and 400 masl, with most slopes between 8 and 14%. Parent material is Cretaceous limestone. The climate is Mediterranean semi-arid, with warm, dry-hot summers and wet-mild winters. Four groups of ten citrus-cropped soil plots were selected under different types of management (MNT, NT, H and CT) and different periods of treatment (N = 40×4). At each plot, 100 points were selected along inter-row areas, 10 cm spaced. Periods under each type of management ranged from 1 and 29 years.

SWR was assessed under field conditions by 1-6 August 2009 after a period of at least 30 days without rainfall by the water drop penetration time (WDPT) test. Soil samples (0-20 mm) were collected at each plot for soil organic matter content analysis.

## Results

The experiments were conducted in four experimental plots located in the Canyoles river basin (Figure 1). Elevation ranges between 160 and 400 masl, with most slopes between 8 and 14%. Parent material is Cretaceous limestone. The climate is Mediterranean semi-arid, with warm, dry-hot summers and wet-mild winters. Four groups of ten citrus-cropped soil plots were selected under different types of management (MNT, NT, H and CT) and different periods of treatment (N = 40×4). At each plot, 100 points were selected along inter-row areas, 10 cm spaced. Periods under each type of management ranged from 1 and 29 years. SWR was assessed under field conditions by 1-6 August 2009 after a period of at least 30 days without rainfall by the water drop penetration time (WDPT) test. Soil samples (0-20 mm) were collected at each plot for soil organic matter content analysis.

Figure 2. Citrus orchards under different types of management.

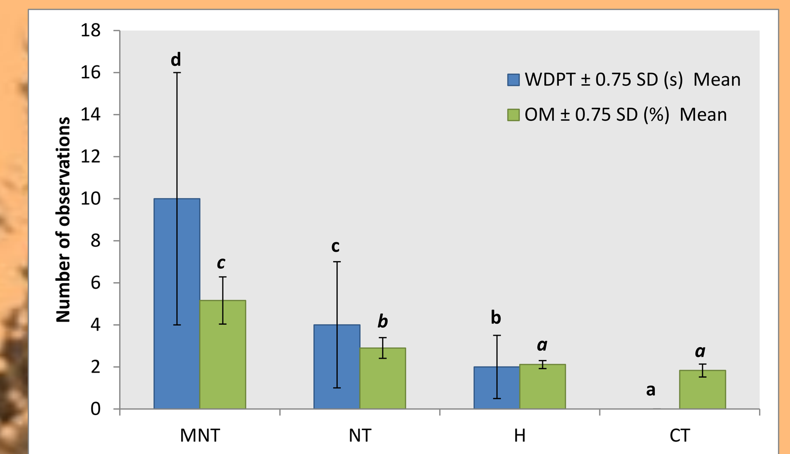


Figure 2. Results of the WDTP test and organic matter content from different types of management. Different letters show significant differences.

### Soil water repellency and practices management

Persistence of SWR (Figure 3) varied between WDTP 0 s (wettable soil) and 52 s (slightly water repellent soil), except for one only measurement (65 s, strongly water repellent soil, after 19 years under MNT treatment). As field water repellency determinations were performed after a period of at least 30 days without rainfall, soil moisture content did not affect water repellency. Slight SWR was found in MNT plots (wettable, 223 plots; slightly water repellent, 776 plots; and strongly water repellent, 1 plot). Mean SWR from NT plots was 4 ± 4 s (wettable, 626 plots; slightly water repellent, 374). All H and CT plots were classified as wettable (2 ± 2 and 0 ± 0 s on average, respectively). Differences between NT, H and CT treatments are significant but generally small, with WDPTs ranging between 0 and 32 s.

MNT treatment induced slight water repellency. Small but significant SWR observed under NT and H treatments may be regarded as subcritical SWR. Slight water repellency observed in soils under MNT treatment may be attributed to the input of hydrophobic organic compounds as a consequence of the addition of plant residues and organic manure.

The limited occurrence of SWR under H, and CT treatments appear to be caused by the absence of organic matter due to the low input of organic substances and high mineralization rates in not amended-cropped soils.

Annual addition of plant residues (NT) or plant residues + organic manure (MNT) have contributed to increased soil organic matter content and, as a consequence, the input of hydrophobic substances in soil, especially in the latter. This may be attributed to the higher soil organic matter in the first centimeters of soil. In contrast, plowing in CT soil plots enhances organic matter mineralization rates, reducing SWR induced by organic residues.

Table 1. Results of the Kruskal-Wallis test (KW, p) for the WDTP test (mean   SD, s) and organic matter content (mean   SD, %) for different years of treatment and types of management. Within a column mean values followed by the same letter do not show significant differences (p<0.05).

| MNT | | | NT | | | H | | | CT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Years | WDPT | OM | Years | WDPT | OM | Years | WDPT | OM | Years | WDPT | OM |
| 2 | 4 ± 3 a | 3.22 ± 0.69 | 1 | 1 ± 1 a | 2.38 ± 0.21 a | 2 | 0 ± 1 a | 2.25 ± 0.21 ab | 3 | 0 ± 0 | 2.23 ± 0.19 c |
| 4 | 6 ± 4 ab | 4.02 ± 1.24 | 3 | 2 ± 2 ab | 2.34 ± 0.17 a | 5 | 1 ± 1 ab | 2.29 ± 0.12 ab | 6 | 0 ± 0 | 2.27 ± 0.16 c |
| 6 | 7 ± 4 ab | 4.76 ± 0.09 | 5 | 2 ± 2 bc | 2.40 ± 0.20 a | 7 | 1 ± 2 abc | 2.51 ± 0.46 b | 7 | 0 ± 0 | 2.20 ± 0.14 bc |
| 10 | 9 ± 5 bc | 5.49 ± 1.55 | 9 | 3 ± 3 cd | 2.51 ± 0.14 ab | 12 | 2 ± 2 bc | 2.07 ± 0.06 ab | 9 | 0 ± 0 | 2.02 ± 0.12 abc |
| 14 | 11 ± 8 cd | 4.78 ± 0.66 | 12 | 4 ± 4 cde | 2.43 ± 0.32 a | 16 | 2 ± 3 c | 2.10 ± 0.14 ab | 11 | 0 ± 0 | 1.83 ± 0.21 abc |
| 16 | 12 ± 8 cd | 5.38 ± 0.98 | 15 | 4 ± 4 de | 2.79 ± 0.17 abc | 17 | 2 ± 3 c | 2.04 ± 0.07 ab | 13 | 0 ± 0 | 1.64 ± 0.34 abc |
| 19 | 13 ± 11 d | 5.91 ± 1.98 | 18 | 5 ± 4 de | 3.21 ± 0.30 abcd | 19 | 2 ± 3 c | 2.03 ± 0.08 ab | 14 | 0 ± 0 | 1.83 ± 0.24 abc |
| 22 | 13 ± 10 d | 5.45 ± 1.66 | 21 | 5 ± 4 de | 3.87 ± 0.99 d | 20 | 2 ± 3 c | 1.97 ± 0.15 a | 18 | 0 ± 0 | 1.40 ± 0.32 a |
| 25 | 14 ± 9 d | 5.82 ± 1.15 | 23 | 5 ± 5 e | 3.48 ± 0.21 bcd | 24 | 2 ± 3 c | 1.96 ± 0.05 a | 23 | 0 ± 0 | 1.36 ± 0.12 a |
| 27 | 14 ± 10 d | 6.75 ± 1.84 | 25 | 5 ± 5 e | 3.59 ± 0.29 cd | 26 | 2 ± 3 c | 1.87 ± 0.26 a | 29 | 0 ± 0 | 1.52 ± 0.56 ab |
| KW, p | 0.0000 | > 0.05 | | 0.0000 | 0.0002 | | 0.0000 | 0.0022 | | > 0.05 | 0.0029 |

### Possible implications of subcritical soil water repellency

Slight or subcritical SWR was observed in no tilled soils (MNT, NT and H treatments). How important are the observed small but significant differences between treatments? The contribution of different degrees subcritical SWR to hydrological soil processes may be unknown and cannot be approached from our results. But small differences between MNT, NT, H and CT soils may be important for surface runoff generation at plot scale, as well as for soil aggregate stability or for the development of preferential flow paths in studied soils. Slight water repellency improves soil aggregation, wet aggregate stability, soil water distribution, nutrient storage, C sequestration and stabilizes the pore system; also, it reduces soil erodibility, aggregate slaking, crusting and rapid decomposition of organic materials. Further investigation is needed to assess the impact of subcritical or slight SWR in other properties of cropped soils and the effect of seasonal variations.

### Temporal dynamics of soil water repellency under different treatments

Data in Figure 3 demonstrate the influence of management practices in SWR for citrus orchards in the study area. The results of the Kruskal-Wallis test (KW, p) for the WDTP test from different years of treatment and types of management are shown in Table 1. No differences were found for CT plots (100 % of plots were classified as wettable). Significant differences were found for H and NT plots according to the number of years of treatment, but mean WDTP varied only between 0 ± 1 (2 years) and 2 ± 3 s (16 - 26 years) in H plots and 1 ± 1 (1 year) and 5 ± 5 s (23 - 25 years) in NT plots. In both cases, WDTP value increased slightly with the number of years of treatment. Under NT treatment, slight SWR is observed after a period of years, but WDTP values become stable without significant variation after 12 years.

Table 2. Regression equations for soil water repellency (logWDPT), organic matter (OM, %) and number of years (NY) under different types of management, R2 coefficients and p-values of the ANOVA of residuals. Equations with p-value > 0.5 are not displayed.

| | Type of management | Regression equation | $R^2$ | p- value |
|---|---|---|---|---|
| logWDPT/NY | MNT | logWDPT = 14.253 + 0.0417 × NY | 0.8731 | 0.0007 |
| | NT | logWDPT = 0.4304 + 0.0418 × NY | 0.8455 | 0.0002 |
| | H | logWDPT = 0.1983 + 0.0235 × NY | 0.8575 | 0.0001 |
| | All cases | logWDPT = 1.128 + 0.037 × NY | 0.1231 | 0.0000 |
| OM/NY | MNT | OM = 3.694 + 0.101 × NY | 0.3246 | 0.0001 |
| | NT | OM = 2.079 + 0.063 × NY | 0.6105 | 0.0000 |
| | H | OM = 2.407 - 0.0202 × NY | 0.3862 | 0.0000 |
| | CT | OM = 2.323 - 0.037 × NY | 0.5044 | 0.0000 |
| | All cases | OM = 2.502 + 0.036 × NY | 0.0334 | 0.0207 |
| logWDPT/OM | MNT | logWDPT = 0.273 + 0.386 × OM | 0.8246 | 0.0003 |
| | NT | logWDPT = -0.768 + 0.668 × OM | 0.5332 | 0.0165 |
| | H | logWDPT = 3.658 - 1.485 × OM | 0.8265 | 0.0007 |
| | All cases | logWDPT = -0.428 + 0.519 × OM | 0.8342 | 0.0000 |

The regression equations and correlation coefficients for water repellency from soils under different no-till types of managements are shown in Table 2. WDPT from MNT plots showed the greatest increment between 4 ± 3 (2 years) and 14 ± 10 s (27 years). On average, MNT plots showed wettable character (WDTP 4 ± 3 s) during the first 2 years of treatment, but they became slightly water repellent after 4 - 27 years (11 ± 8 s, on average). WDTP value from MNT plots became stable between 14 and 27 years after treatment. Increased organic matter content in soils as a consequence of managing seems to be the main cause of induced slight water repellency.

Further investigation is needed to investigate the effects of subcritical or slight water repellency in no-tilled soils on other soil physical and chemical properties.

### Soil organic matter

The OM content from soil plots under different treatments varied significantly (Table 1), Although no significant differences were found between OM content from H and CT plots, and mean OM contents can be ordered as MNT > NT > H/CT. No significant differences were found for OM content between years in MNT plots (Table 1). In this case, OM content ranged between 2.25 and 8.27 (5.16 ± 1.50%, on average).

The mean OM content from NT plots increased from 2.38 ± 0.21% (1 year) to 3.59 ± 0.29% (25 years). In contrast, OM content from H and CT plots decreased significantly with time of treatment: OM content from H plots decreased from 2.25 ± 0.21% (2 years) to 1.87 ± 0.26% (26 years), and OM content from CT plots decreased from 2.23 ± 0.19% (3 years) to 1.52 ± 0.56% (29 years).

Significant regressions were found for OM and number of years under treatment for NT and CT plots (Table 2). The relationship between OM contents and SWR (logWDTP) was studied by regression analyses. Significant equations were found for MNT, NT and H plots. MNT treatment induced a great input of soil OM, which can vary according to its decomposition rate. High soil OM inputs contribute to increase biodiversity and microbial activity, increasing the organic C pool and improving soil structure.

The regression analyses between OM content and logWDPT from MNT and NT plots show positive trends, with both variables increasing along time. Subcritical water repellency observed in NT and H plots (not amended and no-tilled) is due to the moderate OM content (2.9 ± 0.66 and 2.11 ± 0.25% on average, respectively). Herbicides are applied to soils in order to improve yields by eliminating those plants competing for the same resources. This fact determines that OM content from H plots does not increase with time, as the SWR, showing a low correlation.

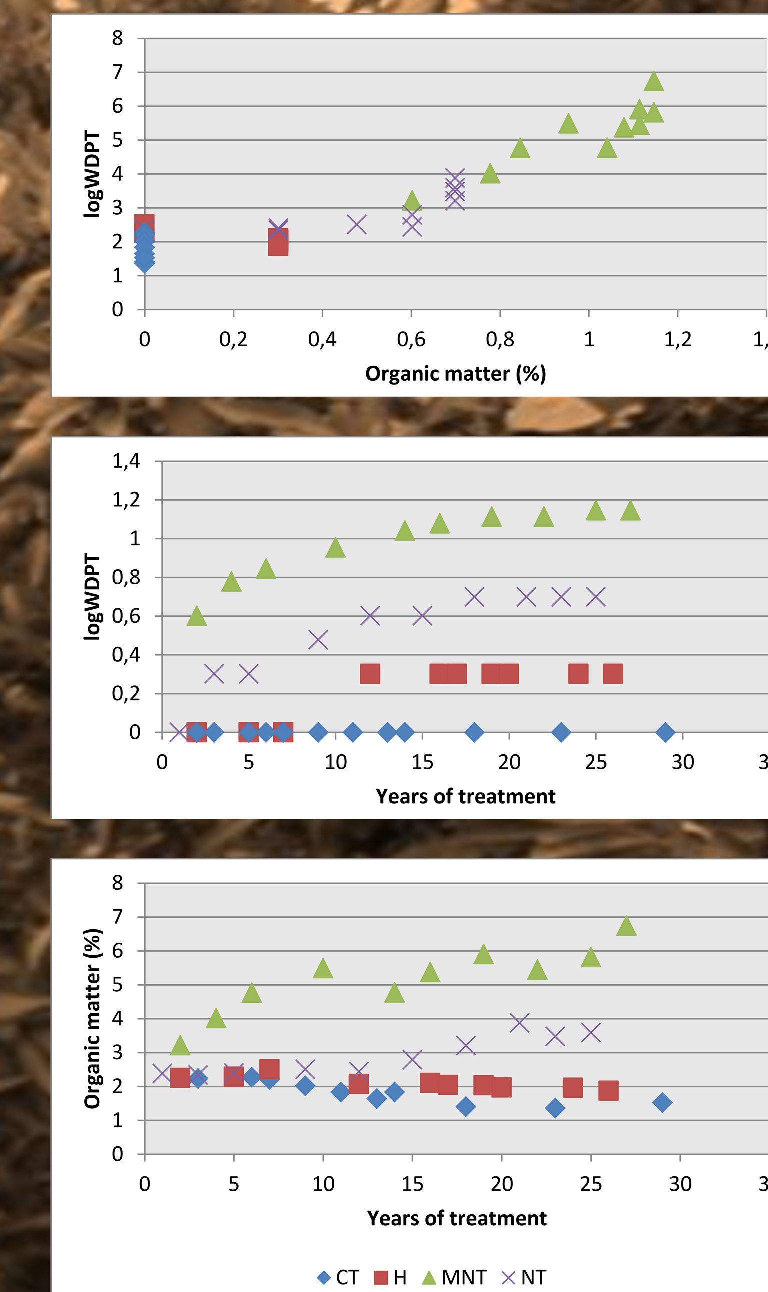


Figure 3. Relationship between for soil water repellency (logWDPT) / organic matter (OM, %); logWDPT / number of years (NY); and OM / NY under different types of management.

## Conclusions

WR is a common property of calcareous soils under long-term conservative agricultural practices in Eastern Spain. SWR may be considered as an indicator of management impacts on cropped soils.

No tillage and manure addition contribute to increase WR.

Wettable soils under no-tilling and manure addition with no fertilizer addition became slightly water repellent after 2 years.

No tilling practices combined with application of conventional herbicides or annual addition of plant residues induced subcritical soil WR after just 1-2 years of treatment.

No tilling contributes to the development or subcritical to slight WR due to the return of crop residues. Manure addition, increased OM content and reduced soil disturbance may also contribute to soil WR.

More research is necessary on the effect of long-term no till practices and other conservative types of management and the hydrological and geomorphological consequences at different scales for a better planning of soil resources. Also, the effect of hydrological subcritical SWR in soil properties, geomorphology, soil C sequestration rates and nutrients cycles must be studied.