doi: 10.17221/623/2017-PSE

The impact of drip irrigation on soil quality in sloping orchards developed on marl – A case study

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ABSTRACT

Muršec M., Leveque J., Chaussod R., Curmi P. (2018): The impact of drip irrigation on soil quality in sloping orchards developed on marl – A case study. Plant Soil Environ., 64: 20–25.

The impact of drip irrigation on structural stability of soil aggregates was studied in soils of an apple (*Malus domestica* Borkh.) orchard, developed on marl. The field study was carried out in a sloping (20%) terrain in the north-eastern Slovenia at three slope positions (upslope, mid-slope and downslope), involving a comparison of irrigated versus non-irrigated situations after 6 years of drip irrigation practice. Structural stability was studied in three soil layers (0–5, 5–15 and 15–30 cm) at the end of the irrigation season (in September). In the same samples, soil organic carbon, total carbonates and soil moisture contents were determined. Drip irrigation significantly reduced structural stability and soil organic carbon in the surface soil layer (0–5 cm), while total carbonates increased. Based on the whole set of data, structural stability was strongly positively correlated with total carbonates and negatively correlated with soil organic carbon. This means that the effect of higher level of organic matter mineralisation on structural stability, due to irrigation, is counterbalanced by the increase of total carbonates content in the fine textured calcareous soils. Thus, a negative effect of irrigation on soil organic carbon had less destructive consequences on structural stability than expected.

Keywords: water; topography; stable soil aggregates; soil organic matter; $CaCO_3$

In the eastern part of Slovenia, many orchards are established on hilly terrain, with a vertical system of plantations. Soil erosion processes are prevented mainly by covering the area between rows by grasses, while area within rows are mostly uncovered due to herbicide treatments, and are therefore more vulnerable. To ensure a supplementary source of water in dry summer periods, many orchards are equipped with drip irrigation systems. Drip irrigation is a common agricultural practice in Slovenian orchards and its positive effect on yield has been well documented. The benefits of irrigation may also include earlier crop maturity, higher yields, lower yield variation, more efficient nutrient distribution, reduced stress and improved yield quality (Cetin et al. 2004). However, in the long run, inappropriate irrigation practices can lead to soil degradation with declining structural stability (Amézketa 1999, Pagliai et al. 2004). Due to focusing on crop yield mostly, consequences of irrigation on soil quality remain questionable. Specific characteristics of irrigation, considering plant production, weather conditions, soil and topography characteristics should be a part of sustainable fruit production aiming at the maintenance of good soil quality.

Soil structure is one of the most important properties affecting crop production because it determines the depth that roots can penetrate, the amount of water that can be stored in the soil and the move-

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ment of air, water and soil life. Aggregate size and stability can affect the ability of soil to transfer essential nutrients, liquids and gases, which is crucial for crop production and ecosystem health (Tisdall and Oades 1982). Orchards have high requirements for macro- and micronutrients and their efficiency is influenced by soil structure, too (von Bennewitz et al. 2011, 2015). Therefore, soil structural stability is commonly used as an indicator of soil quality (Albiach et al. 2001).

Aggregate stability is usually strongly associated with clay, calcium carbonate and soil organic matter (SOM) contents (Cañasveras et al. 2010). Liming of acid soils and supply of Ca and Mg can improve the aggregate stability and soil structure (Lošák et al. 2012). Topography and vegetation influence the dynamics of soil structure and texture, through SOM, clay, calcium carbonate and soil water contents (Bronick and Lal 2005, Chaplot and Cooper 2015).

The main objectives of this study were: (1) to investigate the effect of drip irrigation on soil structural stability in intensive orchards; (2) to estimate the effects of environmental factors (i.e., slope effect and soil water conditions) on structural stability of soil aggregates and (3) to investigate the effects of mineral soil matrix and soil organic carbon content on structural stability.

MATERIAL AND METHODS

The trials were conducted at the Gačnik experimental station in north-east Slovenia (46˚61'N, 15˚68'E, 300 m a.s.l.) in a six-year-old apple plantation of cv. Braeburn, after six years of application of two contrasted treatments: irrigated (IRR) and non-irrigated (NIR) rows of trees. The soil type was Eutric Cambisol (FAO 2006), developed on the Helvetian marl bedrock with a homogeneous silty clay texture along the slope (47% clay, 50% silt, 3% sand, on average). The plantation was established on a 20% north-east facing slope. The rows ran vertically along the slope, the length of each row was 100 m and inter-row spacing was 3 m. Soil surface between rows was covered by natural grass, while the surface under the rows was uncovered (bare soil surface) as a result of herbicide treatment. All plant residues (leaves, fruits, branches), which are collected during the season in the rows, are mechanically raked in the inter-row and mulched together with grass, 7 to 8 times per growing season. The climate is temperate, with mean annual precipitation of 1047 mm and mean annual temperature 9.7°C, for the referenced period 1961–1990. The drip irrigation was performed from May to September, at the rate of 2 L/tree/day, with max. 70 days of irrigation/season, from the beginning of plantation – six experimental years successively. Irrigation water originated from an accumulation pool located at the foot of the slope and had the following characteristics: pH = 7.8, EC (electrical conductivity) = 61 mS/m, SAR (sodium adsorption ratio) = 0.38, NH_4^+-N < 0.1 mg/L, NO_2^--N = 0.045 mg/L, NO_3^--N = 10 mg/L). Undisturbed soil samples were collected at the end of irrigation period (in September), in irrigated and non-irrigated rows in triplicates from three soil layers (0–5, 5–15 and 15–30 cm), at three locations along the slope: upslope (UP), mid-slope (MID) and downslope (DOWN).

The samples were kept in plastic containers and brought to the laboratory in such a way that minimum structural deformation and/or destruction occurred. The percentage of water-stable aggregates (WSA) was determined using the method described by Kemper and Rosenau (1986) as adapted by Bartoli et al. (1991). The percentage of water-stable aggregates (> 200 μm) was quantified as the difference between oven-dried (105°C) soil remaining on the 200 μm sieve (aggregates + coarse sand) and coarse sand fraction (Goulet et al. 2004). Soil organic carbon (SOC) was determined by wet oxidation following the Walkley-Black method (Nelson and Sommers 1996), while total soil carbonates ($CaCO_3$) contents were measured by analysing the volume of CO_2 released after the addition of HCl (ISO 10693, 1995).

The statistical data evaluation was performed using the Statgraphics Centurion XV statistical program (Statgraphics®, 2005), with one-way ANOVA considering the statistical significance $P < 0.05$. The Duncan's multiple test was used for mean separation of statistically significant factors. The significance of linear relationships between the pairs of data parameters was expressed in terms of the Pearson's correlation coefficients ($^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$).

RESULTS AND DISCUSSION

Distribution of the WSA values observed in samples taken in the surface (0–5 cm) soil layer, after

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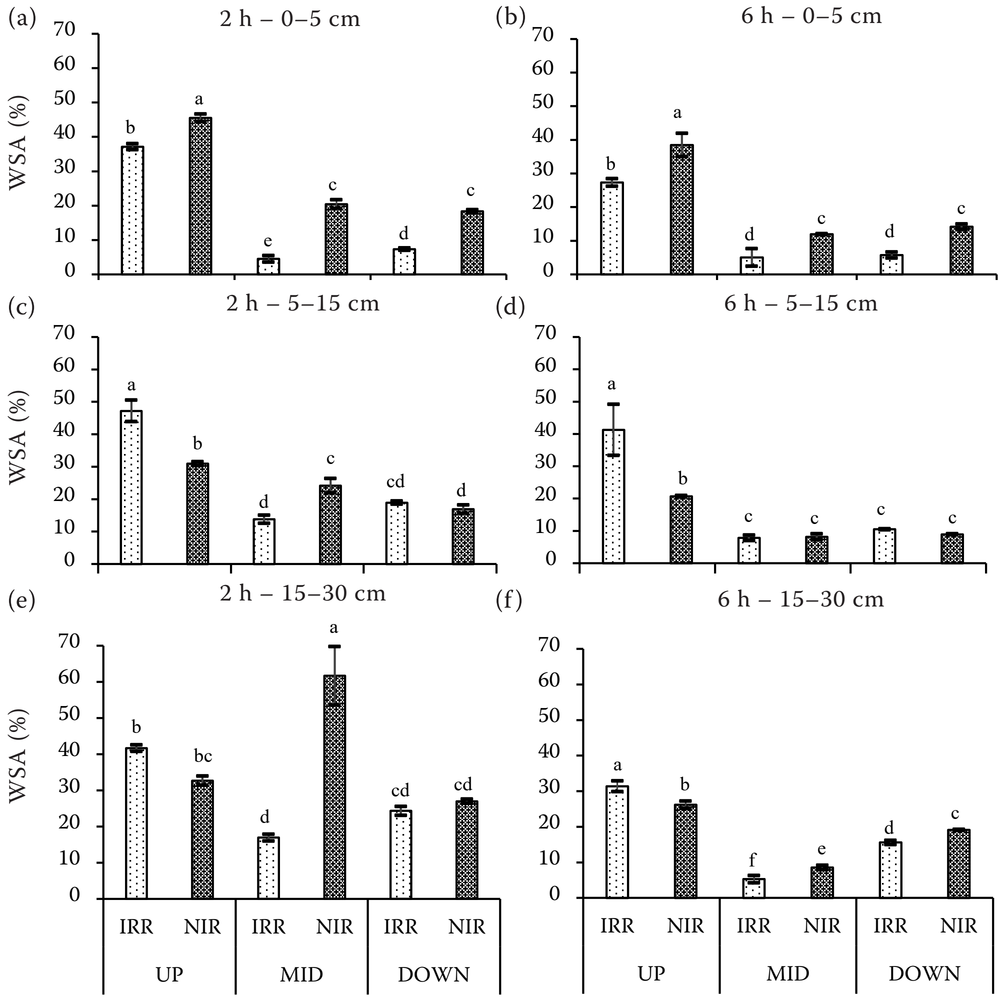

Figure 1. Water-stable aggregates (WSA) distribution in soil layers (0–5, 5–15 and 15–30 cm) according to slope and water treatment after 2 h and 6 h of wetting. IRR – irrigated; NIR – non-irrigated; UP – upslope; MID – mid-slope; DOWN – downslope

2 h of wetting were in accordance to the WSA values obtained after 6 h of wetting, regarding slope and water treatments (Figures 1a,b). In the surface layer, drip irrigation significantly decreased WSA-2 h along the slope (UP: 37.1% in IRR and 45.5% in NIR; MID: 4.5% in IRR and 20.4% in NIR; DOWN: 7.3% in IRR and 18.4% in NIR). Considering both times of wetting, WSA values in 0–5 cm layer were higher at UP, compared to MID and DOWN. In the 5–15 cm soil layer (Figures 1c,d), WSA-2 h was still the highest at UP (47.3% in IRR and 31.0% in NIR), compared to MID (13.8% in IRR and 24.2% in NIR) and DOWN (18.9% in IRR and 16.9% in), without a significant effect of irrigation in lower slope positions. In the deepest layer (15–30 cm) (Figures 1e,f), lower WSA-2 h values still indicated a negative effect of irrigation at lower slope positions (MID: 16.9% in IRR and 61.7% in NIR; DOWN: 24.3% in IRR and 27.0% in NIR). Higher WSA in IRR soils was noticed only at UP in deeper layers. Our results related to negative effects of irrigation on structural stability are in accordance with some other authors (Amézketa 1999).

Distribution of SOC and $CaCO_3$ content is represented in Figures 2a–f. SOC increased toward downslope and decreased with soil depth. In the surface soil layer, irrigation significantly decreased SOC at UP only (0.79% in IRR and 1.28% in NIR), while at lower slope positions the same trend was observed (Figure 2a). In the 5–15 cm soil layer, irrigation significantly decreased SOC at UP (0.64% in IRR and 1.07% in NIR) and MID (1.23% in IRR and 1.50% in NIR). In the deepest soil layer (15–30 cm), irrigation had no effect on SOC along the slope (Figure 2e). SOC content in all three soil layers were the lowest at UP.

doi: 10.17221/623/2017-PSE

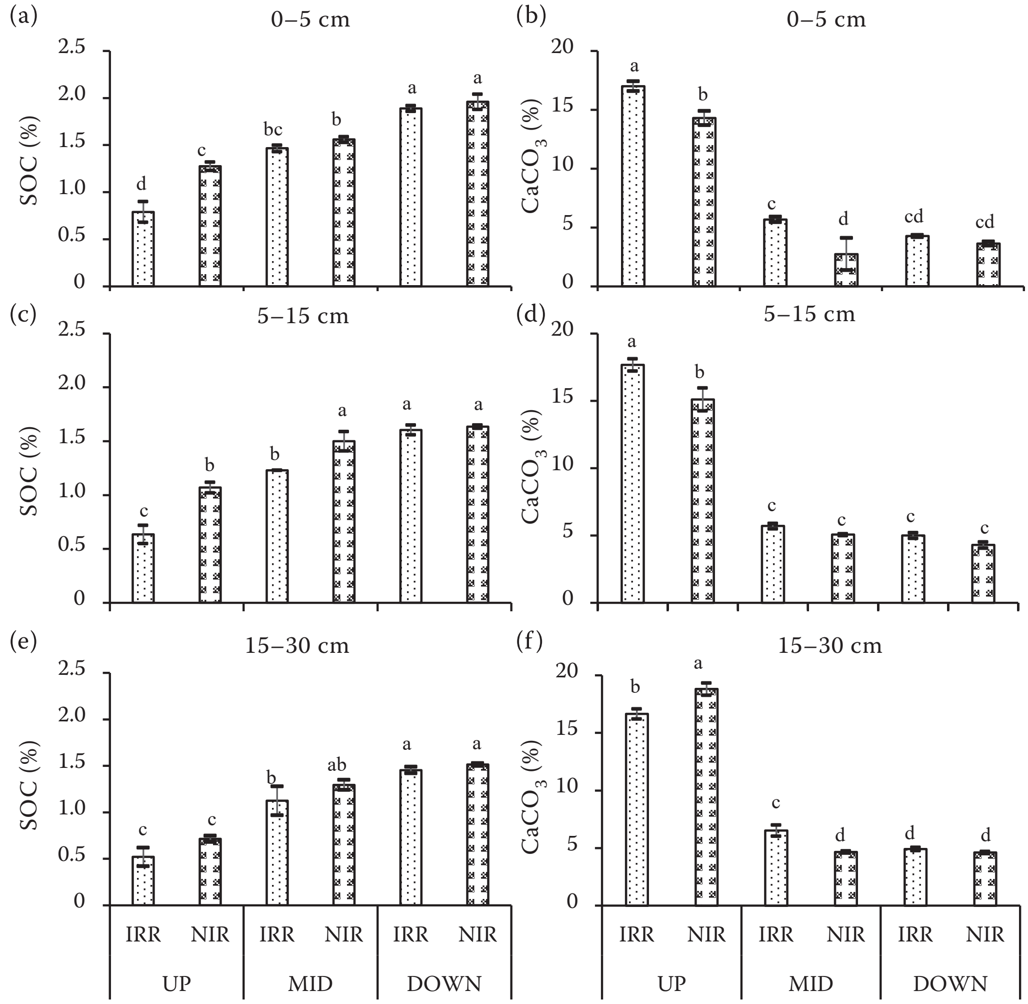

Figure 2. Soil organic carbon (SOC) and $CaCO_3$ distribution in soil layers (0–5, 5–15 and 15–30 cm) in association with slope and water treatment. IRR – irrigated; NIR – non-irrigated; UP – upslope; MID – mid-slope; DOWN – downslope

$CaCO_3$ contents exhibited the opposite trend: they were higher upslope and increased with soil depth (Figures 2b,d,f). In the surface soil layer (Figure 2b), the highest values of total carbonates were recorded UP (16.6% in IRR and 13.7% in NIR) and decreased at MID (5.4% in IRR and 1.4% in NIR) and DOWN (4.2% in IRR and 3.5% in NIR). In the deeper soil layers (5–15 cm and 15–30 cm), distribution of $CaCO_3$ along the slope was very similar, with some changes of the irrigation effect (Figures 2d,f). Compared to control (NIR), irrigated soils contained higher total carbonates in the surface soil layer (Figures 2b,d), which was probably a contribution of irrigation water.

Soil water content (W) is presented in Table 1. Up to 30 cm, irrigation did not significantly affect soil humidity (Table 1). W was significantly affected by slope, especially in the surface soil layer, with the lowest values at UP (27.3% in IRR and 26.9% in NIR). Soil water content differed significantly between soil layers, with higher contents in the surface layer, whatever the slope position was.

Between each pair of the analysed soil characters, Pearson's correlation coefficients by soil layers are presented in Table 2. Up to 15 cm, significant positive correlations were found between WSA-2 h and WSA-6 h (*R* = 0.963 in 0–5 cm and *R* = 0.674 in 5–15 cm), for this reason, WSA-2 h could be considered as a reliable (sufficient) indicator for structural stability. A strong positive correlation was noticed between WSA-2 h (or WSA-6 h) and $CaCO_3$, especially in the surface soil layer (*R* = 0.824 for WSA-2 h or *R* = 0.839 for WSA-6 h). The apparent negative correlation between WSA-2 h and SOC is indeed the result of a strong negative correlation between SOC and $CaCO_3$ (from *R* =

doi: 10.17221/623/2017-PSE

Table 1. Distribution of gravimetric water content (W, %) of soil samples collected in irrigated (IRR) and non-irrigated (NIR) rows in three soil layers (0–5, 5–15, 15–30 cm) at three slope positions: upslope, mid-slope and downslope (means ± standard error of the mean*, n = 3)

Soil layer (cm)	Upslope		Mid-slope		Downslope	
	IRR	NIR	IRR	NIR	IRR	NIR
0–5	27.3 ± 1.2[c]	26.9 ± 1.3[c]	39.1 ± 0.5[a]	34.1 ± 1.5[b]	36.0 ± 1.8[ab]	38.4 ± 0.8[a]
5–15	22.9 ± 7.9[b]	27.8 ± 0.9[ab]	32.6 ± 0.2[a]	34.5 ± 0.8[a]	27.5 ± 0.3[ab]	33.5 ± 0.3[a]
15–30	26.1 ± 0.9[b]	27.4 ± 0.5[b]	32.4 ± 0.6[ab]	34.2 ± 1.4[a]	30.4 ± 0.0[a]	30.8 ± 0.6[a]

*Within rows: values followed by the same letter are not significantly different ($P < 0.05$) in between one soil layer in different slope position and water treatment combinations (Duncan's test)

–0.892 to –0.922) considering all the soil samples together.

A similar correlation was found by Jirků et al. (2013). Several authors (Goulet et al. 2004, Bronick and Lal 2005, Cantón et al. 2009) reported that soil aggregate stability is generally positively correlated with SOM, that is why the application of organic fertilisers (e.g. compost) into soil is reasonable (Plošek et al. 2017). Albiach et al. (2001) reported that in loamy soils, total SOM played an important role in soil aggregation when other stabilizing agents such as clay, $CaCO_3$ and iron oxides were deficient. At low SOC content, macroaggregate stability can be enhanced by $CaCO_3$ (Boix-Fayos et al. 2001).

Correlation strength between WSA and soil water content decreased with soil depth, the strongest negative correlation being observed in the surface layer (R = –0.847). These results are in agreement with Perfect et al. (1990), who found a significant negative correlation between soil moisture and WSA. In our study, higher WSA values were noticed in the driest soils, rich in carbonates – UP, which is in agreement with Kemper and Rosenau (1984).

Six years of drip irrigation may have contributed to an increase of the $CaCO_3$ content, which is considered as a soil structure binding material in the soil surface (Figures 2b,d). Irrigation generally decreases structural stability, and thus can lead to higher soil erodibility risk. Kochsiek et al. (2009) reported that irrigated management regimes not only led to greater litter-C inputs but also to greater decomposition rates. The enhanced mineralization of carbon compounds through an increase of soil biological activity leads to a decrease of soil organic matter (Chaplot and Cooper 2015), which can explain the decrease of SOC in the surface soil layer of irrigated rows upslope. Consequently, irrigation may contribute to enhance CO_2 emissions towards the atmosphere (Chaplot and Cooper 2015), contributing to a climate change.

Especially in the surface layer (0–5 cm), drip irrigation significantly reduced structural stability and SOC. Higher WSA was recorded upslope in the driest soils, rich in carbonates and with low SOC. In our fine textured calcareous soils, $CaCO_3$ appeared as the prevalent contributor of the structural stability, even masking the effect of soil organic carbon. Thus, a negative effect of irrigation on SOC had less destructive consequences on structural stability than expected. This means

Table 2. Pearson's correlation coefficients (R) between pairs of the measured parameters by studied soil layers (n = 12; $^{*}P < 0.5$; $^{**}P < 0.1$; $^{***}P < 0.01$)

		WSA-6 h	$CaCO_3$	SOC	W
		(%)			
0–5 cm					
WSA	2 h	+0.963***	+0.824***	–0.647*	–0.847***
	6 h		+0.839***	–0.631*	–0.789**
$CaCO_3$ (%)				–0.892***	–0.813**
SOC (%)					+0.751**
5–15 cm					
WSA	2 h	+0.674*	+0.646*	–0.639*	–0.339
	6 h		+0.901***	–0.886***	–0.486
$CaCO_3$ (%)				–0.922***	–0.564
SOC (%)					+0.503
15–30 cm					
WSA	2 h	+0.076	+0.034	–0.101	+0.297
	6 h		+0.814**	–0.698*	–0.820**
$CaCO_3$ (%)				–0.910***	–0.835***
SOC (%)					+0.767**

WSA – % of water-stable aggregates after 2 h and 6 h of wetting. SOC – soil organic carbon; W – water content

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that the effect of higher level of organic matter mineralisation on structural stability, due to irrigation, is counterbalanced by the increase of $CaCO_3$ content in fine textured calcareous soils. In order to compensate this decline and to preserve the soil quality, organic matter input needs to be properly managed. For the increase of SOC in this orchard, it may be useful to modify the traditional management of plant residues by keeping them within irrigated rows instead of mulching them inside the inter-row area.

Our results indicate that WSA-2 h can be considered as a useful soil quality indicator in similar monitorings in order to assess the effects of various agricultural practices, such as irrigation. In carbonated soils, WSA as a soil quality indicator should be used with caution because high level of $CaCO_3$ could mask the decrease of SOC content, which may affect biological and chemical fertility of soil.

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Received on October 2, 2017
Accepted on December 14, 2017
Published online on January 5, 2018