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Temporal stability and patterns of runoff and runon with different cover crops in an olive orchard (SW Andalusia, Spain)

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ABSTRACT

Conventional tillage (CT) and cover crops (CC) trigger different runoff (Q) and runon (Q_{in}) magnitudes and patterns in woody crops. The spatial and temporal stability of these patterns is not well known yet. In this study, we run the uncalibrated *DR2-2013© SAGA v1.1* model (0.5×0.5 m of cell size) to simulate time to ponding (Tp), runoff duration (T_Q), initial runoff per raster cell (q_0), Q_{sim} and Qin in six olive plots (480 m^2 per plot) during two years (108 rainfall events and 648 simulations). Two plots were managed with a mixture of plant species (CC-I), two with one single plant species (CC-II) and two with CT. Runoff yield from each plot was collected (Q_{obs}) in gauging-stations during 27 time-integrated samples and used for modelling validation (162 control points). On average, Q_{obs} was 9% higher under CT than under CC-I, and 8% higher than under CC-II. Topsoil saturation was simulated for the entire plots during 29 events (test-period), and Q_{sim} appeared in another 51 and 52 events in the plots with CC and CT. Tp with CT was 2.3 times higher (59 s) than the average duration with CC and the topsoil became saturated 3.3 times faster in the inter-rows than below the trees. Values of q_0 with CC were 2.3% lower than with CT and total Q_{sim} with CC was 2% higher than with CT. However, the differences of Q_{sim} between the different treatments were not statistically significant. The mean observed and simulated runoff coefficients were of 11 and 14%, with median values of 7 and 10%. Q_{sim} correlated well with Q_{obs} (Pearson ca. 0.861), and Q_{sim} was overestimated ca. 10%. The model performed better when rainfall depth and intensity were high, and the range of variability of both Q_{sim} and Q_{obs} was similar. The average, best and worst Nash–Sutcliffe coefficients were 0.665, 0.791 (P6) and 0.512 (P3) and thus model simulations were satisfactory. The four plots with CC presented on average a worse performance (Kling–Gupta coefficient = 0.607) than the two plots with CT (KGE = 0.769). The lowest spatial variability of q_0, Q_{obs}, Q_{sim} and actual available water (Waa, the sum of Qin and stored water in the soil surface) were found in the plots with CC. CT triggered higher spatial variability of runoff and higher temporal variability of runon than CC.

1. Introduction

Cover crops (CC) in olive orchards and other woody crops (vineyards, almond groves and other fruit trees) provide an environmental-friendly alternative to conventional tillage (CT) for land management (Gómez et al., 2011). Indeed, CC reduce soil, nutrients and organic matter losses and pesticide delivery in comparison with CT and no-tillage systems (Gómez et al., 2009a; Gómez et al., 2011) and typically higher soil total organic carbon and total extractable carbon are usually found under this management (Gucci et al., 2012). Plant covers are also important for retaining and releasing nutrients under different tree demand rates (Gómez-Muñoz et al., 2014). On average, water infiltration improves in the inter-row area with CC compared to CT and thus runoff coefficients (QC, hereafter) decrease though these changes are highly dependent on soil permeability values (Gómez et al., 2009a; Taguas et al., 2010). In spite of these advantages, mechanical tillage and bare soil after using herbicides still represent the most common techniques of soil management in olive orchards within the Mediterranean Basin, mainly to avoid the development of a natural plant community in the inter-row area, leading to a competition with the olive trees for the scarce soil water.

Among the main environmental, economic and management limitations of much of the Mediterranean cultivated soils for fruit groves are the steep slopes and the shallow soil depth (Casalí et al., 2009). Under these conditions, the total volume of water that can be stored and used by the plants is limited. Soil erosion decreases the soil depth even further thus threatening long-term sustainable agriculture. To date, after requirements related to the Common Agricultural Policy (CAP) of the European Commission and decades of research and promotion, around 30% of the olive orchards in Spain are under CC management (MAGRAMA, 2015) aiming among other benefits the reduction

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of soil and water losses. Indeed, Durán-Zuazo et al. (2009) found in mountainous olive plots in Granada (SE Spain) a significant reduction in runoff (between 94 and 95% lower) and erosion rates (between 59 and 71% lower) with CC in comparison to plots without plant strips. Gómez et al. (2009a) also described a significant reduction of soil losses and *QC* (from 11.9 to 1.2%) with CC of barley near Cordoba (S Spain). Gómez et al. (2009b) measured near Seville (SW Spain) an efficient reduction of runoff and sediment yield down to tolerable levels (*QC* ca. 5.7%) with CC in comparison with CT. The adoption of CC has also a positive economic impact such as that reported by Taguas et al. (2012), in terms of management operations, transformation of olives into olive oil, obtained yield income, and subsidies received by the farmer, in an olive micro-catchment in Cordoba. Simoes et al. (2014) found that olive production did not differ between CT and natural vegetation cover, although Ferreira et al. (2013) measured in a long-term experiment on a Portuguese rainfed orchard a decrease in yield for a CC treatment compared to bare soil management. Gucci et al. (2012) found lower fruit yield but similar oil content in irrigated orchards under permanent natural cover treatment than with CT.

To the best of our knowledge Castro et al. (2006) and Pedrera-Parrilla et al. (2014) are some of the few authors who reported on the spatial patterns of runoff (Q, hereafter) and runon (Q_{in}, hereafter) across an olive orchard. Although olive orchards have long been recognized as consisting of a mosaic pattern of infiltration and runoff (Gómez et al., 2001a; Romero et al., 2007), there are almost no studies comparing these factors under CC and CT treatments. There are a limited number of studies that deal with the spatial patterns of Q and Q_{in} in olive groves and their temporal stability. Hence, further studies aiming at solving this issue are required. The lack of studies is surprising, as farmers and land managers consider Q and Q_{in} to be two critical attributes in fruit tree orchards regardless of their management (rain-fed, irrigated, with conventional, conservation or precision agriculture). CC are strongly recommended within the agricultural policy strategies of the European Union among other good agricultural practices (Taguas and Gómez, 2015). Results of this study will be of interest for agronomical and environmental studies and will offer valuable data for encouraging the implementation of CC by reducing the uncertainty in runoff-runon dynamics in olive groves.

The accurate description, quantification and modelling of Q and Q_{in} are complex tasks that can be achieved by the combination of different measurement, statistical and modelling techniques (Cafarelli et al., 2015; López-Vicente et al., 2015). This goal appears as a non-solved question in olive orchards due to the significantly different effective diffusivity relationships that appear in the unsaturated zone in both the inter-row and under canopy areas (Espejo et al., 2014). Palese et al. (2014) found a higher storage of water from rainfall at different soil depths and an improved soil structure (macroporosity) in an olive orchard in Southern Italy under CC treatment than with CT.

Direct measurements of Q and Q_{in} are costly and relatively rare, so there is interest in methods to predict the hydrological response of the soil at ungauged sites. In spite of the current limitations of the hydrological models (Semenova and Beven, 2015), spatially distributed approaches provide the possibility for evaluating soil physical properties across fields and temporal scales and even to assess the impact of different land uses and management practices (López-Vicente et al., 2014a; Bussi et al., 2014). Taguas et al. (2012) ran the AnnAGNPS model at event and monthly scales and analyzed the results together with other data to assess the environmental and economic impacts of different soil management strategies in an olive crop microcatchment. Zema et al. (2016) also executed the AnnAGNPS model in a large watershed covered by olives, obtaining low accuracy by the default model, and better predictions after model calibration. Other models used in olive groves have been the ArcSWAT2009 (Napoli and Orlandini, 2015) and the WEPP (Licciardello et al., 2013) models. However, these two models only provided good predictions of runoff yield after model calibration and under specific temporal scales and humidity conditions. Additionally, there are specific models developed for olive orchards, such as the numerical approach proposed by Gómez et al. (2002) and used to simulate runoff and runon in a virtual olive grove. More recently, Abazi et al. (2013) developed a water balance model (WABOL) to simulate the effect of different soil management alternatives on soil water balance using process-based methodologies. And López-Vicente and Navas (2012) developed the GIS-based distributed rainfall-runoff (DR2) model for Mediterranean agro-ecosystems.

In this study we hypothesize that the spatial patterns of time to ponding (*Tp*), Q and Q_{in} yields in an olive orchard are affected by the different inter-row cover strategies, and the temporal stability of these patterns also depend on the different treatments. To test this hypothesis, and during 2 hydrological years (2009/10 and 2010/11), we: i) ran the water-balance *DR2-2013© SAGA v1.1* model at event scale and at high spatial resolution (0.5×0.5 m cell size) in six comparable olive orchard plots but under three different inter-row management practices (CT, CC with one and various plant species); ii) validated the simulated values of runoff (Q_{sim}) with those measured (Q_{obs}) in six gauging stations; and iii) analyzed the spatial patterns and the temporal stability of the observed runoff yield and simulated initial runoff per raster cell (q_0), Q_{sim} and Q_{in} in the six plots and three treatments. These results will be of interest to evaluate the effects of soil management in olive orchards on runoff and water balance, and thus for agricultural production and environmental services.

2. Material and methods

2.1. Study area and vegetation management scenarios

In 2002, a field experiment was established on the "Santa Marta" olive commercial farm (SW Spain; 37° 20′ 36″ N, 6° 13′ 45″ W) with an average elevation of 92 m above sea level (Fig. 1). The olive plantation was established in 1985 with trees planted at 8 m × 6 m (more details in Gómez et al., 2009b). The climate is subtropical semi-humid Mediterranean with an average annual precipitation of 534 mm and a strong inter-annual oscillation (576 mm between 2003/04 and 2006/07, 976 mm in 2009/10 and 713 mm in 2010/11), concentrated mostly in late fall and winter, and an average annual air temperature of 18.6 °C. The soil belongs to the Petrocalcic Palexeralf series (García del Barrio et al., 1975), well drained, with an average organic matter content of 1.3%, 28% of $CaCO_3$, and a sandy loam texture class. There is no presence of rills below the tree lines and small rills (<2 cm of maximum depth) only appear along the inter-row land after the most intense rainfall events.

Six bounded runoff plots were established between 2003 and 2005. Each plot was 8 m wide (between 2 tree lines) and 60 m long (480 m^2), laid out with the longest dimension parallel to the maximum slope and to the tree lines. The slope is uniform, oriented in the north-west direction with an average steepness of 12.5%. The olive variety, Gordal, used as a table olive, is very common in the area. Differential inter-row soil management started in the area the season before the delimitation of the runoff plots. Two plots (P2 and P4) were devoted to conventional tillage (hereafter CT) consisting of regular chisel plow passes (2–3 times a year at 10–15 cm depth) depending on weed growth. Another set of two plots (P1 and P5) consisted in a mixture of different selected plant species as cover crop (CC-I) of *Borago officinalis*, *Daucus carota*, *Echium plantagineum*, *Foeniculum vulgare*, *Hedysarum coronarium*, *Matricaria chamomilla*, *Melilotus officinalis*, *Moricandia moricandioides*, *Cichorium intybus*, *Fagopyrum esculentum* and *Taraxacum officinale*. These plants were manually sown during early fall at 15 kg of seed per ha in the area outside the vertical olive canopy projection. The third set of two plots (P3 and P6) was a uniform CC (CC-II) of *Lolium multiflorum* sown at 40–80 kg of seed per ha depending on the year. The maintenance of the CC includes two or three mowing passes during winter and spring, and a bare soil strip under the tree line maintained with herbicides. The inter-crop strip was fertilized every year with nitrogen during the fall by direct application on the soil in the CC plots. In the two plots with CC-I plants