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Simulation of agronomic and nitrate pollution related parameters in vegetable cropping sequences in Mediterranean greenhouses using the EU-Rotate_N model

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ABSTRACT

The capacity of the EU-Rotate_N model to simulate agronomic parameters (dry matter production, yield, crop N uptake, evapotranspiration (ET_c), soil water content dynamics) and parameters associated to nitrate (NO_3^-) pollution (drainage, NO_3^- leaching, accumulation of mineral N in soil) was evaluated in sequences of melon and pepper crops grown in plastic greenhouses. Simulated values of all output variables were compared to measured values. Two sequences with either conventional or improved management for water and N were examined during the 2005 and 2006 cropping seasons. Additionally, simulation of drainage and NO_3^- leaching was evaluated during the period between crops following irrigations associated with soil disinfection and leaching of accumulated salts. Calibration of parameters related to crop growth, the critical N curve and ET_c considerably improved simulation of drainage, NO_3^- leaching and of soil water and soil mineral N dynamics. Following calibration, the EU-Rotate_N model accurately simulated dry matter production, crop N uptake and marketable fruit yield; the simulation errors being lower or similar to those reported elsewhere. ET_c and drainage were accurately simulated in the 2006 melon and pepper crops and in the 2005 melon crop; they were respectively over- and under-estimated in the 2005 pepper crop probably on account of a virus infection. EU-Rotate_N accurately simulated soil water content for the 0–30 and 30–60 cm soil layers. Soil mineral N and NO_3^- leaching were generally underestimated by EU-Rotate_N, the error being larger in the 2005 sequences; however, the model effectively simulated seasonal trends.

1. Introduction

The EU-Rotate_N model was developed to simulate nitrogen (N) use and losses in rotations of European open field vegetable crops. Outputs of EU-Rotate_N include crop growth, fruit yield, crop N uptake, crop evapotranspiration (ET_c), drainage, and nitrate (NO_3^-) leaching (Rahn et al., 2010). Additionally, EU-Rotate_N calculates soil mineral N and water dynamics, N mineralization from organic material, various soil N transformations, and root development (Rahn et al., 2010). The model has been used as (i) a tool to assess effects of different fertilizer and rotation practices on N losses to the environment and gross margin returns, and (ii) as a decision support system for improving N management to reduce N losses while maintaining yield. The EU-Rotate_N model has been used across a wide range of crop growing conditions, such as open field crops in northern Europe and the Mediterranean region (De Waele et al., 2017; Doltra and Muñoz, 2010; Nendel et al., 2012; Rahn et al., 2010), and in greenhouses in China (Guo et al., 2010; Sun et al., 2012). EU-Rotate_N is a versatile simulation model of both agronomic (e.g. yield, growth) and environmental parameters (e.g. NO_3^- leaching, drainage) that has been calibrated for more than 70 vegetable and cereal species (Rahn et al., 2010). It can be used with rain-fed crops and with different irrigation systems, with conventional split fertilizer applications or fertigation,

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and can be used with crop sequences (Rahn et al., 2010). The EU-Rotate_N model is unique for the number of vegetable species for which default calibrations are provided (Thompson et al., 2017). Most simulation models for vegetable crops are specific to a single species (Thompson et al., 2017).

A number of studies have evaluated the performance of EU-Rotate_N for simulation of (i) agronomic parameters such as dry matter production, marketable yield or crop N uptake, and (ii) trends of soil water and mineral N content, by comparing simulated with experimentally measured values (Doltra et al., 2010; Guo et al., 2010; Nendel et al., 2012; Rahn et al., 2010). In most of these evaluations, the default calibration values provided by EU-Rotate_N for each species were used (Doltra and Muñoz, 2010; Guo et al., 2010; Nendel et al., 2012; Rahn et al., 2010), rather than determining calibration values for the crops and systems being examined. In most of the studies where NO_3^- leaching and drainage were simulated, the simulated values of NO_3^- leaching and drainage were not compared to experimentally measured values (De Waele et al., 2017; Doltra and Muñoz, 2010; Guo et al., 2010). With the exception of the study with tomato by Soto et al. (2014), there are no published studies with EU-Rotate_N that have compared simulated to measured values of ET_c, drainage and NO_3^- leaching. This is surprising given that simulation with EU-Rotate-N is commonly used to determine the impact of crop management on NO_3^- leaching (e.g. De Waele et al., 2017; Doltra and Muñoz, 2010; Guo et al., 2010; Rahn et al., 2010; Sun et al., 2012).

The greenhouse vegetable production system on the south-eastern (SE) Mediterranean coast of Spain, with 37,000 ha is one of the largest concentrations of greenhouses in the world (Castilla and Hernández, 2005). Nitrate leaching and drainage are important issues with this vegetable production system. There is substantial NO_3^- contamination of underlying aquifers, and a rising water table caused by drainage returns to a shallow aquifer that risks flooding low lying areas (Pulido-Bosch et al., 1997; Pulido-Bosch, 2005). Due to NO_3^- contamination of underlying aquifers, most of the areas where the greenhouses are located have been declared "Nitrate Vulnerable Zones" in accordance with the European Union Nitrate Directive (Anon, 1991), which requires the adoption of improved management practices.

In SE Spain, many greenhouse vegetable growers cultivate two crops per cropping season. A common cropping sequence is a spring melon crop, grown from February-March until June-July followed by an autumn-winter sweet pepper crop from July to late December-February. During the period between crops in the summer, additional irrigations involving large volumes of water are applied (i) to leach salts, (ii) for soil disinfection, and (iii) to moisten the soil profile immediately prior to transplanting the following crop (Thompson et al., 2007). Results of a survey conducted by Thompson et al. (2007) showed that salt leaching irrigations with volumes >20 mm and >40 mm were applied in, respectively, 69 and 42% of greenhouses, and that volumes of water of >20 were applied in 78% of greenhouses for soil disinfection. Drainage associated with the large irrigations used for salt leaching, soil disinfection, and for moistening the soil profile, is likely to be an important contributing factor to aquifer NO_3^- contamination (Thompson et al., 2007). Analysis of the environmental impact of this system in relation to NO_3^- leaching loss should consider cropping sequences, including the management of bare soil between crops. The EU-Rotate_N model is uniquely suited to simulate and examine such sequences.

The mains objectives of this work were to evaluate the capacity of the EU-Rotate_N model to simulate (a) agronomic variables (dry matter production, marketable fruit yield, crop N uptake, ET_c, dynamics of soil water content (SWC)), and (b) variables associated to NO_3^- pollution (drainage and NO_3^- leaching, accumulation of soil mineral N) in sequences of melon-bare soil-pepper for soil-grown crops in plastic Mediterranean greenhouses. An additional objective was to evaluate the effect of calibration of various parameters on the accuracy of the model compared to the use of default calibration values.

2. Materials and methods

2.1. Location and cropping details

The crops were grown in two plastic greenhouses at the research station of the Cajamar Foundation, located in El Ejido, in the province of Almeria, southeastern (SE) Spain (2°43′W, 36°48′N and 151 m elevation). The growing conditions were similar to those of commercial vegetable production on the SE coast of Spain. This vegetable production system is described by Castilla and Hernández (2005), Castilla (2013), Thompson et al. (2007) and Valera et al. (2016). The two greenhouses were identical, and were adjacent to one another along their east-west axis. Each greenhouse was 24 m long by 18 m wide; they were unheated, passively ventilated and had an east-west orientation. The greenhouse cladding was low density polyethylene tri-laminated film. Crops were grown in an artificial layered soil, typical of the region (Castilla, 2013; Thompson et al., 2007), which was formed by placing a 30 cm layer of clay soil, imported from a quarry, over the original loam soil. A 10 cm layer of coarse river gravel (with a particle size distribution of 9, 62 and 29% for 0.05–2.0 mm, 2.0–5.0 mm and >5.0 mm, respectively) was added over the surface of the imported clay soil as mulch. In 2003, 115 t ha^{-1} of mature sheep manure (64% dry matter, 1.7% N content and 0.7 t m^{-3} density) was mixed into the top layer of the imported soil following local practices of periodic manure application (Thompson et al., 2007). The gravel layer was temporarily removed when the manure was added. Relevant details of the soil are given in Table 1. Surface drip irrigation was used, with 1 m spacing between drip emitter lines and 0.5 m between emitters within emitter lines. The drip emitters had a discharge rate of 2.8 L h^{-1}. The irrigation water had an electrical conductivity of 0.4 dS m^{-1}. Complete nutrient solutions were applied by fertigation through the drip irrigation system, in all irrigations during the crops.

Two cropping sequences of Galia type muskmelon (*Cucumis melo* L., cv. Deneb) and California sweet pepper crops (*Capsicum annum*, L., cv. Vergasa) were grown in succession between 2005 and 2007. The dates of transplanting and end of each crop are given in Table 2. Irrigations associated with chemical soil disinfection and salt leaching in the period between the two crops of a given sequence, were considered as part of that sequence (Table 2).

In all crops, six week old seedlings were transplanted with a planting density of 2 plants m^{-2} with one plant adjacent to a drip emitter. Melon was planted in equidistant single parallel lines with all plants on the same side of its associated emitter. Pepper was planted in paired parallel lines by placing seedlings on the inside of each of a pair of emitter lines. Plants were vertically supported by nylon cords. All aspects of crop management apart from irrigation and N application (i.e. training of crops, prunings, pest management etc.) in all crop and treatments followed established local practice.

Climatic conditions during crop growth were similar to those reported by Fernández et al. (2010) when determining long term climate inside plastic greenhouses in this region. Averaged for each month, daily maximum and minimum temperatures, were, respectively 21–37 °C and 7–21 °C. Daily integral values of solar radiation were 6–17 MJ m^{-2} d^{-1}, and the daily average vapor pressure deficit (VPD) was 0.7–2.0 kPa. During warmer periods of the pepper crops, whitewash (suspension of calcium carbonate) was applied to the greenhouse roof to reduce the temperature inside the greenhouse.