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Improving water resources management using different irrigation strategies and water qualities: Field and modelling study

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ABSTRACT

The aim of this study was to investigate the effects of two different irrigation strategies, regulated deficit irrigation, RDI and partial root drying, PRD using surface freshwater (SW) and brackish treated waste water (TWW) for maize and potato crops. The SALTMED model has been applied using the field measurements of two cropping seasons 2013 and 2014 at the Canale Emiliano Romagnolo, CER's experimental farm located in Mezzolara di Budrio (Bologna, Italy). In 2013, PRD irrigated potato received 17% less irrigation water than RDI but produced nearly the same yield as under RDI. The water productivity, on average, was 11% higher for PRD compared with RDI. For maize 2014 season, the PRD strategy received almost 15% less irrigation water, but produced a yield only 6% lower than that of RDI and gave equal water productivity to RDI. Given that the two strategies received the same amount of rainfall the results favour the PRD over RDI. Had the site not received above average rainfall (258 mm in 2013 and 259 mm during the 2014 growing seasons), PRD might have produced higher yield and water productivity than RDI.

In terms of model simulations, overall, the model showed a strong relationship between the observed and the simulated soil moisture and salinity profiles, total dry mater and final yields. This illustrates SALTMED model's ability to simulate the dry matter and yield of C3 and C4 crops as well as to simulate different water qualities and different water application strategies. Therefore, the model can run with "what if" scenarios depicting several water qualities, crops and irrigation systems and strategies without the need to try them all in the field. This will reduce costs of labour and investment.

1. Introduction

Food demand across the world has been significantly increased which has resulted in increased water demand for the growing population. Irrigation water has the main share of the fresh water consumption. Around 280 million hectares of agricultural land is irrigated using freshwater that provides around 60% of total food production worldwide (Tilman et al., 2002). About half of the world's food is produced on irrigated land and irrigated water accounts for over two thirds of the global water consumption (Letey et al., 2011). The agricultural water consumption has increased five-fold since the 1940′s and now accounts for 70%–80% of the world fresh water use (Ragab et al., 2015). It will further increase in the future due to the increase in the food demand for the growing world's population. By 2050, food demand is expected to double in comparison to the current global food demand which poses a threat for the sustainability of the both food production and the natural ecosystem (Tilman et al., 2002). The availability of the water resources is not only under threat due to the increase in water demand for agriculture but also due to climate variability. Therefore, the gap between water supply and demand is expected to increase. In several parts of the world, climate variability is expected to reduce water availability for agriculture and subsequently for crop yield. Therefore, it is very important to increase the crop productivity as the world population is expected to reach 9 billion and food production needs to be doubled by 2050 (Ragab et al., 2015).

Water productivity can be increased by applying different water saving techniques in agriculture including drip irrigation (Geerts and Raes, 2009). Water saving strategies such as regulated deficit irrigation (RDI) and partial root drying (PRD) can be used in regions with limited water resources. Both RDI and PRD irrigation allow

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significant quantities of water to be saved. Both strategies aim to induce moderate water stress to control vegetative and reproductive growth. The principle behind PRD-irrigation is to alternatively wet one half of the root system and let the other half dry (Belimov et al., 2007). The latter triggers a hormonal signal, known as abscisic acid (ABA), that travels from the roots to the stem and leaves where it causes the stomata to partially close and thus minimizes losses by transpiration, thereby improving water use efficiency (Davies et al., 2002).

Integrated crop-soil-water models have been proven to be effective tools for water resources management in agriculture. These models allow to study the impact of using different water resources and qualities, including freshwater, treated waste water and saline/brackish water on crop yield and soil productivity. Considering the pressure on water resources, different drought and salinity tolerant crops need to be considered. The SALTMED model, developed by Ragab (2002, 2015), has been widely used for different irrigation and fertigation systems for different crops. The model has been successfully applied in different parts of the world. It has been used in Egypt and Syria for tomato crop (Ragab et al., 2005a,b), for sugarcane in Iran (Golabi et al., 2009), for chickpea in Portugal under both dry and wet conditions, (Silva et al., 2013), for quinoa in Morocco (Hirich et al., 2012; Fghire et al., 2015), for quinoa in Denmark (Razzaghi et al., 2013), for quinoa in Italy (Pulvento et al., 2013), for amaranth in Italy (Pulvento et al., 2015a), for sweet pepper in Antalya, Turkey (Rameshwaran et al., 2015), and for legumes in Syria, (Arslan et al., 2015). The model was also applied with climate change scenarios by Pulvento et al. (2015b) to predict the impact of climate change on the length of the growing season of amaranth in Italy. They predicted a shorter season, from 114 days for climatic condition (2009–2010) to 98 days, for the high emission scenarios in 2095. This study also projected a decrease in grain yield.

The aim of this study is to quantify the effects of different deficit irrigation strategies (RDI and PRD) using fresh water and treated waste water on soil moisture and salinity distribution, total dry matter and crop yield of potato and maize in Bologna, Italy, through field experiments and SALTMED model application.

2. SALTMED model

The new version of the SALTMED model (Ragab et al., 2015), which accounts for subsurface irrigation, partial root drying (PRD) or deficit irrigation, fertigation, soil nitrogen fertiliser application and plant nitrogen uptake, dry matter production and nitrate leaching was used in this study. A detailed description of the SALTMED model is provided in Ragab (2002, 2015), Ragab et al. (2015), Ragab et al. (2005a,b).

3. Materials and methods

A two years crop rotation was carried out on silty-clay soil at the Consorzio Bonifica CER' experimental farm “Azienda Marsili”, located in Mezzolara di Budrio (Bologna, Italy), Po valley (Fig. 1). The crops selected for model calibration were potato (2013) and maize (2014). Both crops were grown at the same field in following years. In this study only drip irrigation was used with two irrigation strategies, regulated deficit irrigation (RDI) and partial root drying (PRD) strategy with fresh water (surface water, SW) and treated waste water (TWW). The latter was spiked with salts (sodium chloride) to increase its salinity (up to 4 dS m^{-1}) to study the soil salinity distribution and its impact on growth and yield. All the samples required for the model calibration and validation were taken during each growing phase. The soil moisture and salinity were measured continuously by SMEC 300 sensors at two depths 0.25–0.35 m and 0.55–0.65 m depth.

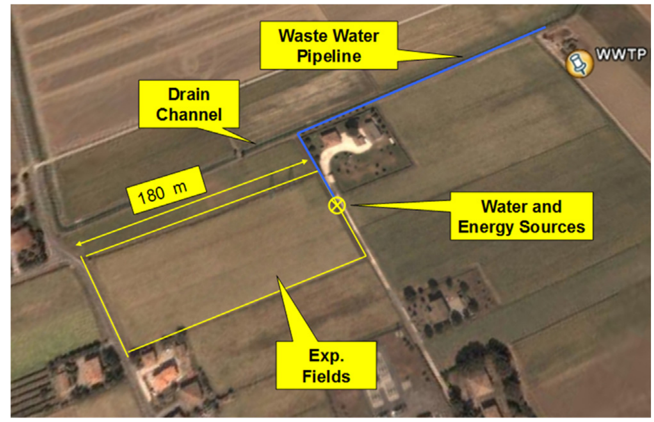

Fig. 1. Experimental site at CER (Bologna, Italy).

All the required climatic variables data were collected on site from the available weather station. The planting and harvesting dates for potato were 22nd of March 2013 and 24th of July 2013, respectively; whereas maize sowing and harvesting dates were 26th of March 2014 and 24th of September 2014, respectively. Climate data required as input to the model consist of precipitation, maximum temperature and minimum temperature, wind speed, the relative humidity, net and total radiation.

3.1. Irrigation strategies and field measurements

For the two crops, drip irrigation system was applied as shown in the plot layout (Fig. 2). The total number of plots was 16 with 600 m^2 area each. The irrigation line has drippers spaced at 0.3 m with an average discharge of 0.8 l h^{-1}. The number of drippers within 1 m^2 was the same, irrespective of the irrigation strategy (4.43 drippers/m^2). The sensors and the suction cups (to collect the soil solution) were placed in each plot to measure the soil moisture and the soil salinity. For the RDI irrigation strategy the drippers were placed next to the plant; whereas, for the PRD double lines were used, with drippers placed in the mid-point between two plants (Fig. 3). The soil moisture and salinity sensors and suction cups installation is shown in Fig. 3 for the potato crop.

In addition, dry matter and total leaf area, which were required to calculate the Leaf Area Index (LAI), were obtained in situ at regular intervals. Total yield was measured during the harvesting period. Other plant parameters such as plant height, root depth, length of each growth stage and harvest index were also based on field measurements. The growth period for potato and maize crops were 122 and 186 days, respectively. The irrigation and fertigation was managed by means of the FertOrgaNic and Fertirrigere Maize DSS model, respectively for potato and maize, which are calibrated and validated for these crops in the area (Battilani, 2006; Battilani et al., 2006). In this study Naan Dan Jain drip system was applied for irrigation. PRD-irrigated plots were managed as for RDI plots, with a reduction of the calculated irrigation depth during the PRD-treatment period (Fig. 4).

The irrigation management: In the early growth stage, from emergence to 80% of tuber > 2 cm in diameter, potato is very sensitive to water and nutrient stresses (Fig. 4). Furthermore, the variety used (Agata) has a tendency to rapidly reduce both growth and yield if subjected to water and nitrogen stresses at the early growth stage. Therefore, available water at field capacity, AW_{FC} and soil