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SALTMED 2013 Model as an Integrated Management Tool for Water, Crop, Soil and N-Fertilizers

2. Water Management Strategies and Productivity: Field and Simulation Study

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Abstract

This paper is a follow up from the first paper which described the SALTMED model. In this paper the focus is on the model application using data of tomato and potato from field experiments in Italy, Greece (Crete) and Serbia. Drip full irrigation, drip deficit irrigation, drip as partial root drying (PRD), sprinkler and furrow irrigation were used in three years experiment between 2006 and 2008. In drip irrigated experiments, the drip line was 10 to 12 cm below the surface. Dry matter, final yield, soil moisture and soil nitrogen were successfully simulated. The study showed that there is a great potential for saving water when using subsurface drip, PRD or drip deficit irrigation compared with sprinkler and furrow irrigation. Depending on the crop and irrigation system, the amount of fresh water that can be saved could vary between 14 to 44%. PRD and deficit drip irrigation have proved to be the most efficient water application strategies with the highest water productivity.

Keywords: SALTMED model, PRD, water saving, deficit irrigation, soil moisture, yield.

1. Introduction

In the first paper, the SALTMED model was described in detail with a reference to some applications and examples of output. In this paper some of the model applications that took place in a number of sites [Italy, Greece (Crete), Serbia] will be reported.

Given the world population is expected to reach 9 billion while food needs to be doubled by 2050, the world will have no option but to increase the productivity of the limited natural resources (land, water and nutrients). In that respect, the Water-Food-Energy nexus will be the focus of the current and future research (De Fraiture et al., 2014).

Models are proven to be useful tools for water, crop and fertilizer management. In fact, they can be used to run "what if "scenarios instead of running several field experiments. For examples, soil salinisation is a slow process and many experiments have a life time that falls short of showing the long term impact of poor management on soil salinisation. In such cases, reliable models can be used to predict the long term impact and can replace the expensive field experiments. Several models have been developed for management of water, crops, and fertilizers. In brief, these models differ in their structures, objectives, the processes involved, descriptions of the processes, the spatial scale and the time step (daily or seasonal). Example of seasonal models is the SALTMOD model (Oosterbaan, 2002) that was developed to simulate the salinity of soil moisture, ground and drainage water. The model is based on seasonal water and salt balance. Sarangi et al. (2006) used this model to simulate subsurface drainage effluent and root zone soil salinity in the coastal rice fields of Andhra Pradesh, India.

Examples of daily time step models are HYDRUS-1D and HYDRUS-2D (Šimünek et al., 1998 & 1999) which are finite element models for simulating the one-and two dimensional movement of water, heat, and multiple solutes in variably saturated media. Nakamura et al. (2004) used HYDRUS-1D to assess the root zone nitrogen leaching as affected by irrigation and nutrient management practices. The potential for drip irrigation and, particularly, low-flow/high-frequency systems to enhance the use of drainage water, while minimizing the deleterious effects on yield and on water and soil resources, is examined using the HYRDUS-2D model (Dudley et al., 2008).

CropSyst (Stöckle and Nelsen, 2005; Stöckle et al., 2003) is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. CropSyst simulates the soil water and nitrogen budgets, crop growth and development, crop yield, crop residue and decomposition, soil erosion by water, and salinity.

SWAP (Soil-Water-Atmosphere-Plant) has been developed to evaluate management options with respect to field-scale water and solute movement (Van Dam et al., 2008).

Vazifedoust et al. (2008) calibrated and validated the SWAP model to investigate the water productivity of irrigated crops under limited water supply at field scale in Iran.

ENVIRO-GRO model was developed to simulate the effects of irrigation amount, irrigation salinity, and N application on yield and N leaching (Pang and Letey, 1998). The model was tested by Feng et al. (2003) who found that model is able to predict the yield and to account for both osmotic and matric effects on corn yield when irrigating with saline water.

Pereira et al. (2007) investigated the water use efficiency and salinity control under basin irrigation system in China using three different models, SRFR, SIRMOD, and ISAREG.

WAVE and EURO-ACCESS II models were used to simulate the fate of water in a soil–crop system of a semi-arid Mediterranean area using data from an experimental plot cropped with maize under furrow irrigation (Fernandez et al., 2002). Eitzinger et al. (2004) compared CERES, WOFOST and SWAP models in simulating soil water content. Bonfante et al. (2010) compared the performance of three models (SWAP, MACRO and CropSyst) in two contrasting soils cropped with maize in Northern Italy for their reliability to predict soil water content at 10 depths over 2 years. Eitzinger et al. (2004) compared CERES, WOFOST and SWAP models in simulating soil water content. Mermoud et al. (2005) investigated the impact of different irrigation schedules on the water balance components, particularly crop transpiration and drainage below the root zone, using the HYDRUS - 2D model.

The SALTMED model (Ragab, 2002; Ragab et al., 2005) is designed to simulate water and solute movement under different agricultural water management strategies. The model runs with different water qualities ranging from fresh water to saline water (brackish groundwater or brine water) and simulates the soil salinity evolution with time. The SALTMED model includes evapotranspiration, plant water uptake, water and solute transport under different irrigation systems, drainage, salinity and nitrogen leaching, crop growth, dry matter, yield and nitrogen processes (mineralisation, nitrification, denitrification, N-uptake, N- leaching). The model has been developed under different EU funded projects, SALTMED, SAFIR, SWUP MED. The early version of the model was successfully tested against field experimental data from Egypt and Syria (Ragab et al., 2005). Since then, the model underwent several modifications and improvements. The model is a free download at the website of the International Commission on Irrigation and Drainage, ICID at:
http://www.icid.org/res_tools.html

and at the EU funder project “Water4Crops” web site at:

http://www.water4crops.org/saltmed-2013-integrated-management-tool-water-crop-soil-n-fertilizers/

The model has been applied successfully on a field experiment of maize in Syria (Najib et al., 2007), a sugar cane field experiment in Iran (Golabi et al., 2009), on a cotton plantation in Greece (Kalfountzos et al., 2009) and on several field crops in north east of Brazil (Montenegro et al., 2010). More recently the SALTMED model has been calibrated and validated under dry and wet year conditions using chickpea field data from Southern Portugal by (Silva et al., 2012); using saline irrigation water on quinoa (*Chenopodium quinoa Willd*) in Denmark (Razzaghi et al., 2011) and in Italy (Pulvento et al., 2013); and in applying deficit irrigation on quinoa, sweet corn and chickpea in Morocco (Hirich et al., 2012, 2013).

These investigations showed that the SALTMED model can simulate soil moisture, salinity and nitrogen content, grain yield, and total dry matter of different field crops reasonably well in both wet and dry conditions using fresh and saline water. The main objectives of this paper are to investigate the water productivity and water saving under different water strategies using SALTMED model and field experiments from three different countries when applying different irrigation water management strategies.

2. Materials and Methods

Three different sites with different climatic conditions were selected. The sites selected are in Bologna, north of Italy, near Belgrade in Serbia and in north east of Crete Island, Greece (Figure 1). The SALTMED model new version accounts now for: subsurface irrigation, partial root drying (PRD) or deficit irrigation, fertigation, soil nitrogen fertilizer application and plant nitrogen uptake, biomass and dry matter production and nitrate leaching. Description of the new version of the SALTMED model, the processes and expected output are given in a separate paper (submitted to the J. of irrigation and Drainage, Ragab, 2014). The crops used in the sites are tomato and potato in Italy, potato in Serbia and tomato in Greece (Crete). The irrigation systems used were, furrow, drip and sprinkler irrigation systems with different irrigation strategies such as deficit irrigation (water applied was less than the crop water requirement either as Regulated Deficit Irrigation, RDI, or Partial Root Drying, PRD, strategy) and full irrigation. More details about the sites and the experiments are given in the following sections.

2.1 Italy field site

Site location: The field is located nearby the village of Mezzolara di Budrio (Bologna) in the plain of the Po valley (44^{o}34´N, 11^{o}32´E).

Soil: The soil is typical of the Po valley low land with high content of both silt and clay (48% and 47%, respectively) and low content of fine sand.

Statistical experimental design: Split-plot design with three replicates.

Irrigation strategy: RDI (Regulated Deficit Irrigation), FI (full irrigated) and PRD (Partial Root Drying, PRD).

Irrigation method/system**:** Subsurface Drip Irrigation (SDI) and Sprinkler (traditional)

Crops: Potato, cultivar Agata. Processing tomato, cultivar Perfect Peel.

Field measurements**:** Biometric samples were taken during the growing season. The dry matter of aboveground vegetation and fruits/tubers was determined by destructive sampling. Soil moisture distribution around emitters was measured both by gravimetric sample and time domain reflectometer, TDR, measurements. Meteorological data were collected by weather station close to the experimental field (about 3km distant) following the International Standards. Yield and its quality were measured at harvest. Soil water samples were taken with suction cups at two depths, three times per season, at the same time of soil sampling.

Sowing dates and harvest dates: **Potato** was planted March 30, 2006, March 13, 2007 and from March 04 to 10, 2008. Harvest took place in the period from August 4 to 9, 2006, from July 3 to 5, 2007 and from July 15 to 17, 2008. **Processing tomato** was transplanted on June 5, 2006, from May 17 to 24, 2007 and from May 22 to 24 2008. Harvest took place in the period September 11-13, 2006, September 5-7, 2007 and September 1-5, 2008.

2.2 Crete field site

Site location: The experimental field site was part of the experimental fields of the Institute for Olive Trees and Subtropical Plants of Chania, located in the area of Chania, Crete, Greece (35^{o}28’N, 24^{o}02’E). Tomato plants were grown for 3 years (2006-2008) during the period between April and August.

Soil: The experimental site had an alluvial soil, with texture varying from sandy loam to sandy clay loam. On average, the percentages of sand, clay and loam were 58.7, 22.0 and 19.3 %, respectively.

Experimental design: The experiment included 3 replications, in a randomized complete block design.

Treatments, irrigation systems and management: Drip irrigation was used as: a) full surface irrigation, b) full sub-surface irrigation, c) PRD surface irrigation, d) PRD sub-surface irrigation and e) deficit surface irrigation (only in years 2007 and 2008). For the full and deficit irrigation treatments single drip lines were used, with drippers placed next to each plant (traditional method), while for the PRD treatment specially constructed double drip lines were used, with drippers placed in the mid-point between two plants. During years 2006 and 2007, PRD and DI treatment were applied at a constant percentage of 70% ETc from the time that the first fruit in the first cluster reached its final size until the end of the experiment (roughly between late June and mid-August). In 2008, the water saving strategy in both treatments included an initial 15% of water saving (early season), followed by 35% (middle season) and ending up at 50% (late season), during the same period.

Crop: Tomato plants of hybrid 'Verdoun' were planted during the second half of April at distances of 50 cm.

Measured parameters**:** a) Soil analysis before planting for pH, EC, organic matter, total $CaCO_3$, soil texture and mineral nutrients. b) Soil water content (v/v) using PR2 profile probes (Delta-T, UK). c) Above ground dry matter and total leaf area (used for calculating LAI) for different plant parts at 15 day intervals during the deficit irrigation period, using 5 plants per plot. Total yield per plant was measured during the harvesting period.

Sowing and harvest dates**:** Tomato plants were planted in the second half of April and the growing season lasted 120, 117 and 123 days during the years 2006, 2007 and 2008, respectively. Repeated harvesting has started on average by the end of June and lasted until the second or third week of August.

2.3 Serbia field site

Site location*:* field experiments were carried out during the growing seasons of 2006, 2007 and 2008 in a vegetable commercial farm ("Salate Centre"), located 10 km north of Serbian capital, Belgrade. The longitude of the field is 20^0 20` East, latitude: $44^0$ 47` North and elevation of 68 m above sea level.

Soil: The soil is humoglay according to the USDA classification. The topsoil (0-0.4 m) contained 3.8 % coarse sand, 22.8 % fine sand, 42.5 % silt, 29.1 % clay and 1.93 % of organic matter.

Experimental design: organized as split plot design with 3 replicates in a randomized block design. Plot area was 11.70m x 6m, with 8 rows and 39 plants per row.

Irrigation systems: furrow and drip sub-surface methods were used for irrigation in all seasons, although the irrigation strategies; full Irrigation (FI), partial root drying (PRD), and regular deficit irrigation (RDI) were different. In 2006 season plants were irrigated with FI and PRD furrow and drip subsurface methods, while in 2007 and 2008, FI furrow and FI, PRD and RDI subsurface drip were applied. In the 2007 season the plants in PRD and RDI treatments received 70% of FI treatment, though in 2008 during the last 3 weeks of the irrigation period, 70% PRD and 70% RDI were replaced by 50% PRD and 50% RDI. The shifting time interval varied between 3 to 7 days depending on evaporative demand and soil water content. Irrigation was applied at least twice per week and ended at the beginning of August. In subsurface drip irrigation plots, the drip lines were placed 10 cm below the top of the ridges. Emitters were spaced at 30 cm intervals and positioned exactly at the middle between two plants, with discharge rate of 1.0 l h^{-1}. Water for irrigation was taken from a canal located 100m away from the field.

Crop: Potato (*Solanum tuberosum* L.) cultivar Liseta was used for the investigation.

Measured parameters: soil water content was measured with TDR probes installed at 3 positions within the ridge: top, middle and bottom of the ridge. Soil water content was calculated as the average of measurements from 3 investigated ridge positions. Number of soil water content measurements per week (3 to 5) depended on climatic conditions and rainfall during measuring time. Crop dry matter (leaf, stem and tuber), leaf area, leaf area index (LAI) and N concentration were recorded several times during the season. Dry matter and leaf area were measured in 8 plants per treatments.

Sowing and harvest dates**:** tubers were planted in May 5th (2006), April 4th (2007) and April 9th (2008). Harvest was done 25th September (2006), 8th September (2007) and 10th September (2008) and samples (15 per plot) were taken for measuring fresh and dry weight and quality parameters of produced tubers.

3. Results and Discussion

Although different water qualities have been used in the experiments, the results reported here are associated with the fresh water.

3.1. Biomass, dry matter, final yield and water productivity

3.1.1 Tomato, Italy and Greece (Crete)

In **Italy**, the yields of processed tomato under drip, PRD and sprinkler irrigation systems for years 2006, 2007 and 2008 are shown in Figure 2 top. In 2006 and 2007, the PRD had the highest yield followed by drip then sprinkler while in 2008, PRD and drip were close to each other but still higher than sprinkler. The model was calibrated for 2007 for the dry matter and growth parameters under the drip irrigation. Following this, the model was validated with the remaining data sets. The model was able to simulate the final yield of the drip, PRD and sprinkler irrigation systems as shown in Figure 2 (bottom) with coefficient of determination R^2 of 0.95. Table 1 shows the simulated total dry matter yield versus the observed values, as well as the irrigation amount and rainfall. The table shows that PRD received relatively less water and produced relatively the highest yield.

The water productivity was calculated as the amount of the dry matter, DM, in kg per cubic meter of water (irrigation + rainfall). The table shows that the water productivity was consistently high in PRD followed by drip then by sprinkler. The productivity was higher in 2006 than in 2007 then 2008. This is in opposite trend to rainfall for those years where 2006 received 48 mm, 2007 received 178 mm and 2008 received 240 mm. Subsequently, the dry years received more irrigation that contributed to the higher yield of 2006 when compared with 2008.

The highest values were 3.91, 1.9 and 1.55 kg m^{-3} for PRD for years 2006, 2007 and 2008, respectively, followed by drip productivity of 2.6, 1.66 and 1.25 for years 2006, 2007 and 2008, respectively, while the lowest productivity was observed for sprinkler with values of 2.05, 1.23 and 0.81 for years of 2006, 2007 and 2008, respectively.

In **Crete**, drip and PRD were used. Figure 3 (top) shows the final yield DM for drip and PRD for the years 2006, 2007 and 2008. The figure also shows a good agreement between the observed and simulated values with R^2 of 0.98. Table 2 shows a small difference between drip and PRD in final yield in 2007. The table also shows the water productivity under drip and PRD for the three years. The productivity under PRD was higher being 0.99, 1.23 and 1.12 kg m^{-3} versus the drip values of 0.85, 1.10 and 0.87 kg m^{-3} for years 2006, 2007 and 2008, respectively. However, the PRD received less water as shown in the table. The final yield of tomato of Italy and Crete are different with higher yield in Italy compared to Crete. The variety grown in Italy is for processing tomato while the one of Crete was for fresh salad.

3.1.2 Potato (Italy and Serbia)

The results of potato tuber yield for 2007 and 2008 under drip, PRD and sprinkler irrigation in Italy are shown in Figure 4 (top). The model was calibrated with drip 2007. The figures show a good agreement between the simulated and observed tuber yield with R^2 of 0.96 as shown in Figure 4 (bottom). The observed and simulated values are given in Table 3 together with the irrigation and rainfall. The table shows the water productivity being higher for PRD followed by drip then by sprinkler. The productivity was higher for 2007 being 4.36, 4.12, 3.42 kg m^3 when compared with 2008 being 1.96, 1.90 and 1.99 kg m^3 for PRD, drip and sprinkler, respectively. The productivity was higher in 2007 as plants received more irrigation and less rain when compared with 2008 which received more rain and less irrigation. The impacts of irrigation strategies and systems have obvious impact in absence of rainfall. More rain would eliminate the effect of the irrigation strategy. PRD for example would not operate under rainfall and the system would be similar to sprinkler in such case.

In **Serbia,** drip, PRD and furrow were used for 2006, 2007 and 2008. In addition, deficit drip irrigation was introduced in 2007 and 2008. The model was calibrated with drip 2008. The observed dry matter during the season as well as the final total yield are shown in Figure 5 for 2006 (top), 2007 (middle) and 2008 (bottom). Figure 6 (top) shows the final yield for all irrigation treatments for the 2006, 2007 and 2008 as well as the irrigation + rainfall applied every year for the different treatments. The figure shows that the model was able to simulate the dry matter production over the season for the different irrigation treatments. Figure 6 (middle) shows a R^2 of 0.91 for the relation between the observed and simulated dry mater during the season. The final total yields were also successfully

simulated as shown in Figure 6 (top) and the relation between the observed and simulated produced a good R^2 of 0.98 as shown in Figure 6 (bottom).
Table 4 shows the observed and simulated final yield together with the irrigation and rainfall.
Year 2008 received less rain than 2007 and 2007 received less rain than 2006. The significant amount of rainfall in 2007 (237 mm) and in 2006 (338 mm) did mask to some extent the impact of irrigation treatment when compared with 2008 (187 mm). The latter, which was a relatively dry year, allowed the treatment to show their effect with clear differences in terms of water productivity being 2.69, 2.29 and 2.05, 1.90 kg m^{-3} for PRD, drip deficit, drip, and furrow irrigation treatment. The furrow has the lowest productivity in the three years and the productivity was lowest when the rainfall was highest and the amount of irrigation applied was the lowest.

3.2. Soil moisture and soil nitrogen

Soil moisture was monitored using the TDR system in the three sites. At the Italian site soil moisture values at 40 cm depth are shown in Figure 7 for the drip irrigated tomato and in Figure 8 for the PRD, drip and sprinkler irrigated potato. Figure 7 shows that the soil moisture content under drip irrigated tomato was kept around 0.30 to 0.4 m^3 m^{-3} in 2006 and between 0.20 to 0.4 m^3 m^{-3} in 2007 and around 0.3 m^3 m^{-3} in 2008, closer to the field capacity. Figure 8 also shows that the water content under potato was kept around 0.3 m^3 m^{-3} during the season under drip, PRD and sprinkler. Keeping the soil moisture closer to the field capacity means the plants were not subjected to significant water stress. The difference between observed and simulated values as a % of the observed value (RE) was 10% for tomato and 4.32% while the root mean square error (RMSE) was 0.003 for tomato and 0.042 for potato.

At the Crete site, soil moisture was measured at different depths. Figure 9 shows some examples of the soil moisture at different soil depth for drip and PRD irrigated tomato in 2006 and 2007. The figure shows that the soil moisture content of the top 10 cm layer was kept around 0.12 m^3 m^{-3} and around 0.20 m^3 m^{-3} for 30 and 40 cm depth layers. Soil type is sandy clay loam with field capacity of 0.25 m^3 m^{-3}. This top 10 cm surface layer (evaporation depth) is subjected to soil evaporation all the time, hence the low moisture content. The RE here averaged at 6.04% and the RMSE was 0.017.

At the Serbia site, soil moisture was measured at 20 and 60 cm depth using the TDR. Similar results to the other two sites were obtained. Here as well the soil moisture content fluctuated around 0.2 m^3 m^{-3} in most cases. Soil type is silty clay (field capacity ranges between 0.20 and 0.33 m^3 m^{-3} depending on depth).

Soil nitrogen was measured in soil solution using suction samplers at the Italian and Serbian sites. A limited number of measurements were available. Figure 10 (top) as an example shows the soil nitrogen at 60 cm depth in the Italian site under drip irrigated tomato for 2007 with Soil – N ranging between 20 and 40 mg l^{-1}. The RE here was 14.4% and the RMSE 4.72. Figure 10 (bottom) shows an example of the Soil-N at 40 cm depth under drip, irrigated potato in the Serbian site in 2006. The soil here has a range of Soil –N ranging from 100 to 220 mg l^{-1}. The RE was 2.49% and the RMSE was 29.14. This soil seems to have a good reserve of nitrogen to supply the plant.

In terms of model application, generally, the model was able to simulate reasonably well both the soil moisture (Figures 7 to 9) and soil nitrogen (Figure 10) under different irrigation treatments of the three sites.

4. Conclusions

The SALTMED model was applied on data from Italy (tomato and potato), Crete (tomato) and Serbia (potato). Several irrigation systems were used. They included furrow, drip irrigation (full and deficit irrigation), sprinkler and drip as PRD system. The modelling and experimental results indicated that:

1. SALTMED successfully simulated the biomass production, yield, soil moisture, soil nitrogen and crop growth under different climatic and field management conditions. Therefore we recommend the models as useful tools for agriculture water management.

2. High quality data are essential for good model predictions. More frequent measurements and continuous records (no data gaps) are needed for better model application and prediction.

3. The model is sensitive to the soil hydraulic parameters and these should be given more attention and resources to obtain these parameters from field measurements.

4. The SALTMED model and field results of Serbia indicated that the average water productivity of all drip treatments was 2.10 kg potato dry matter per m^3 of water while it was 1.69 kg m^{-3} for furrow irrigation. The water productivity for deficit drip, full drip and PRD drip were very close, being 2.17, 2.10 and 2.04 kg m^{-3} potato dry matter, respectively. The ratio of water productivity of the furrow to the drip irrigation was 0.80. This is a 20% water saving. Therefore, the drip irrigation is highly recommended. The water productivity is calculated here as a ratio of yield to total seasonal amount of applied irrigation water including the rainfall.

5. The SALTMED model and field results of potato in Italy showed that on average, the productivity under sprinkler was 87.47 % of that under PRD and the normal drip was very close to the PRD, 95.20%. The average water productivity was 3.16, 3.01 and 2.70 kg m^{-3} for PRD, normal drip and

sprinkler irrigation system, respectively. Water saving would be about 14.4% if PRD is used instead of sprinkler irrigation.

6. The SALTMED model and field results of Italy on tomato indicated that PRD was the highest in water productivity followed by the normal drip followed by the sprinkler irrigation system being 2.45, 1.84, and 1.36 kg m^{-3} on average, respectively. The water productivity of sprinkler was 56% of the PRD and was 74 % of the normal drip. This means that PRD would allow water saving of 26% and 44% when it is used instead of normal drip and sprinkler irrigation systems, respectively.

7. The SALTMED model and field results of Crete on tomato indicated that the PRD productivity was 16% higher than normal drip irrigation. The average water productivity for PRD was 1.11 kg m^{-3} for PRD and 0.94 kg m^{-3} for drip.

8- The SALTMED model was able to simulate reasonably well both the soil moisture content and the Soil – N under different irrigation systems.

In conclusion, the SALTMED modelling results recommend the use of subsurface drip-PRD as it could make a good saving in fresh water that ranges from 14% to 44% depending on the irrigation system and the crop as detailed above.

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Table 1. Observed and simulated total dry matter yield of tomato and water productivity, Italy.

Irrigation System	Yield, Yield t ha^{-1}		R. Diff*, %	Irrigation, mm	Rain, mm	Irrigation + rain, mm	Productivity, kg m^{-3}
	Observed	Modelled					
PRD 2006	10.96	9.97	9.10	207	48	255	3.91
Drip 2006	8.54	7.96	6.79	257	48	305	2.60
Sprinkler 2006	6.20	6.03	2.77	245	48	293	2.05
PRD 2007	8.12	7.72	4.93	228	179	407	1.90
Drip 2007	7.04	7.12	-1.12	251	179	430	1.66
Sprinkler 2007	4.73	5.26	-11.2	251	179	430	1.23
PRD 2008	5.37	6.41	-19.5	172	241	413	1.55
Drip 2008	5.59	5.39	3.46	190	241	431	1.25
Sprinkler 2008	3.58	3.52	1.59	193	241	434	0.81

* Relative difference = (Observed – Simulated) / Observed

Table 2. Observed and simulated total dry matter yield of tomato and water productivity, Crete.

Irrigation System	Yield, t ha^{-1}		R. Diff*, %	Irrigation, mm	Rain, mm	Irrigation + rain, mm	Productivity, kg m^{-3}
	Observed	Modelled					
Drip 2006	4.36	4.32	0.92	494	17	511	0.85
PRD 2006	4.22	4.23	-0.24	410	17	427	0.99
Drip 2007	6.15	5.91	3.93	512	50	562	1.10
PRD 2007	5.72	5.71	0.17	416	50	466	1.23
Drip 2008	5.19	5.13	1.16	563	31	594	0.87
PRD 2008	5.22	5.25	-0.57	435	31	466	1.12

* Relative difference = (Observed – Simulated) / Observed

Table 3. Observed and simulated total dry matter yield of potato and water productivity, Italy.

Irrigation System	Yield, t ha^{-1}		R. Diff*, %	Irrigation, mm	Rain, mm	Irrigation + rain, mm	Productivity, kg m^{-3}
	Observed	Modelled					
PRD 2007	9.26	9.20	0.594	84	127	211	4.36
Drip 2007	9.42	9.20	2.273	97	127	224	4.16
Sprinkler 2007	7.59	7.65	-0.844	97	127	224	3.42
PRD 2008	6.89	7.35	-6.696	77	299	376	1.96
Drip 2008	7.20	7.35	-2.042	88	299	387	1.90
Sprinkler 2008	7.80	7.57	2.923	82	299	381	1.99

* Relative difference = (Observed – Simulated) / Observed

Table 4. Observed and simulated total dry matter yield of potato and water productivity, Serbia.

Irrigation System	Yield , t ha^{-1}		R. Diff*, %	Irrigation, mm	Rain, mm	Irrigation + rain, mm	Productivity, kg m^{-3}
	Observed	Modelled					
Drip 2006	8.16	7.94	2.70	25	338	363	2.25
PRD 2006	5.66	5.66	0.00	16	338	354	1.60
Furrow 2006	7.12	7.14	-0.28	75	338	413	1.72
Drip 2007	8.65	8.57	0.92	197	237	434	1.99
Drip Deficit 2007	7.40	7.39	0.14	125	237	362	2.04
PRD 2007	6.67	6.78	-1.65	130	237	367	1.82
Furrow 2007	8.84	8.79	0.57	373	237	610	1.45
Drip 2008	9.49	9.43	0.63	277	187	464	2.05
Drip Deficit 2008	8.02	8.00	0.25	163	187	350	2.29
PRD 2008	8.83	9.09	-2.94	141	187	328	2.69
Furrow 2008	9.67	9.94	-2.79	322	187	509	1.90

* Relative difference = (Observed – Simulated) / Observed

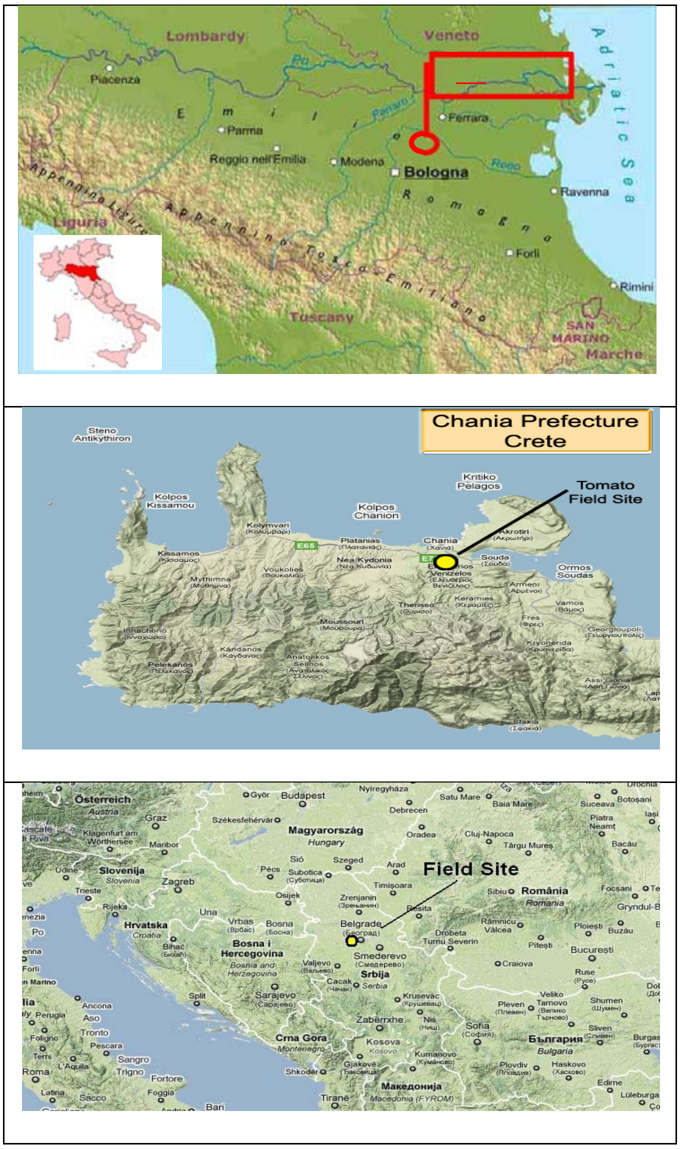

Figure 1. Experimental site locations in Italy (top), Crete (middle) and Serbia (bottom).

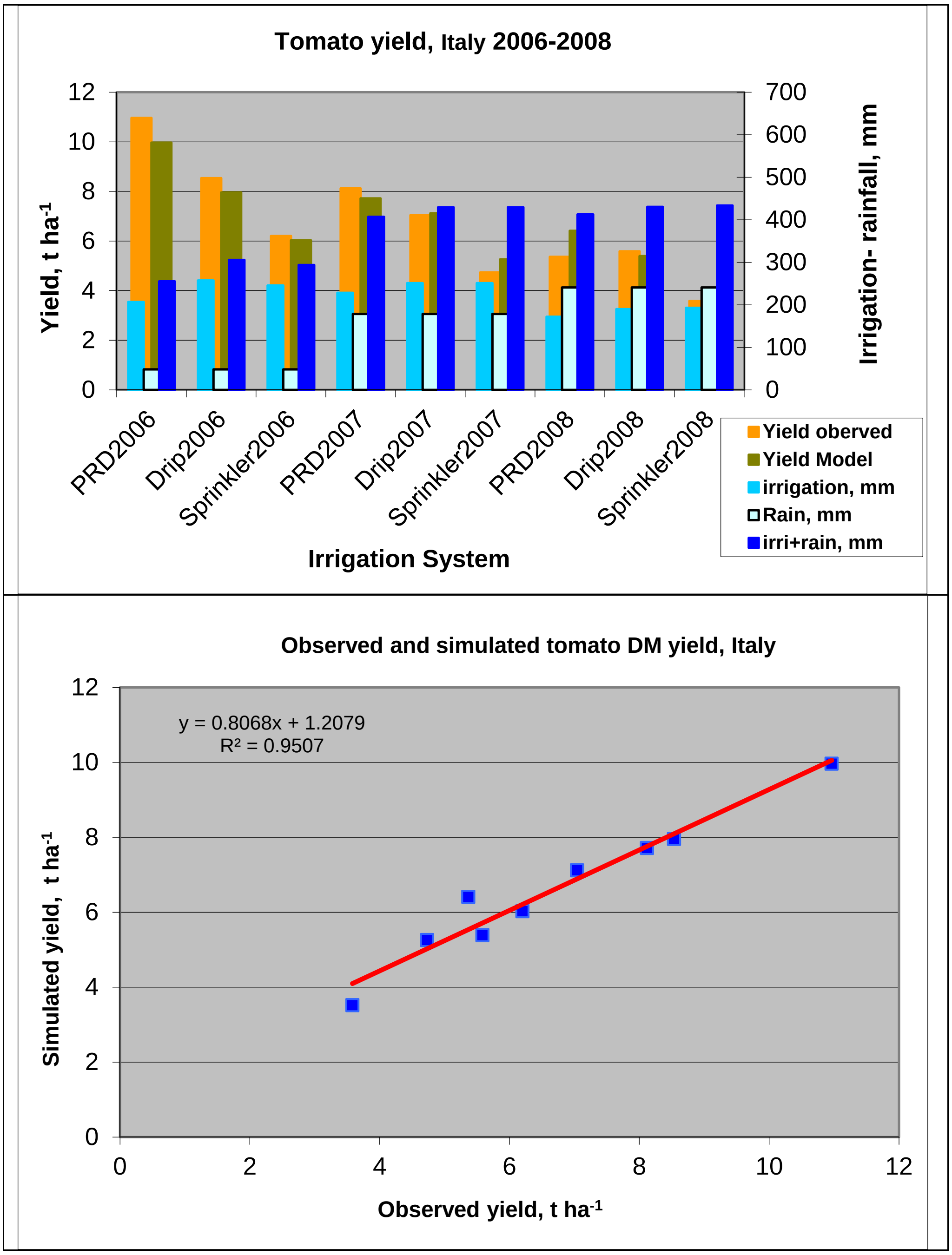

Figure 2. Observed and simulated tomato total dry matter yield under different irrigation treatments, Italy.

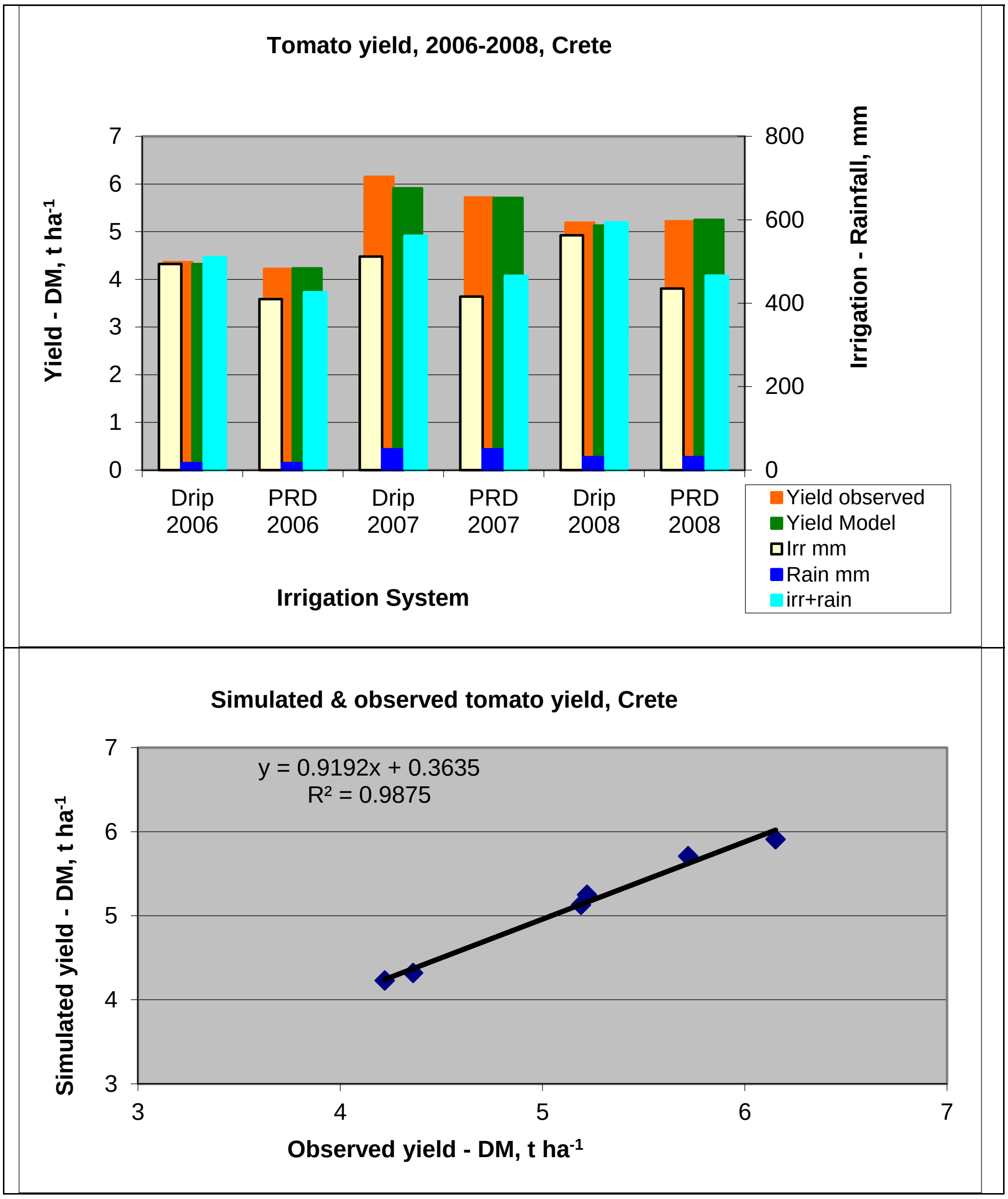

Figure 3. Observed and simulated tomato total dry matter yield under different irrigation treatments, Crete.

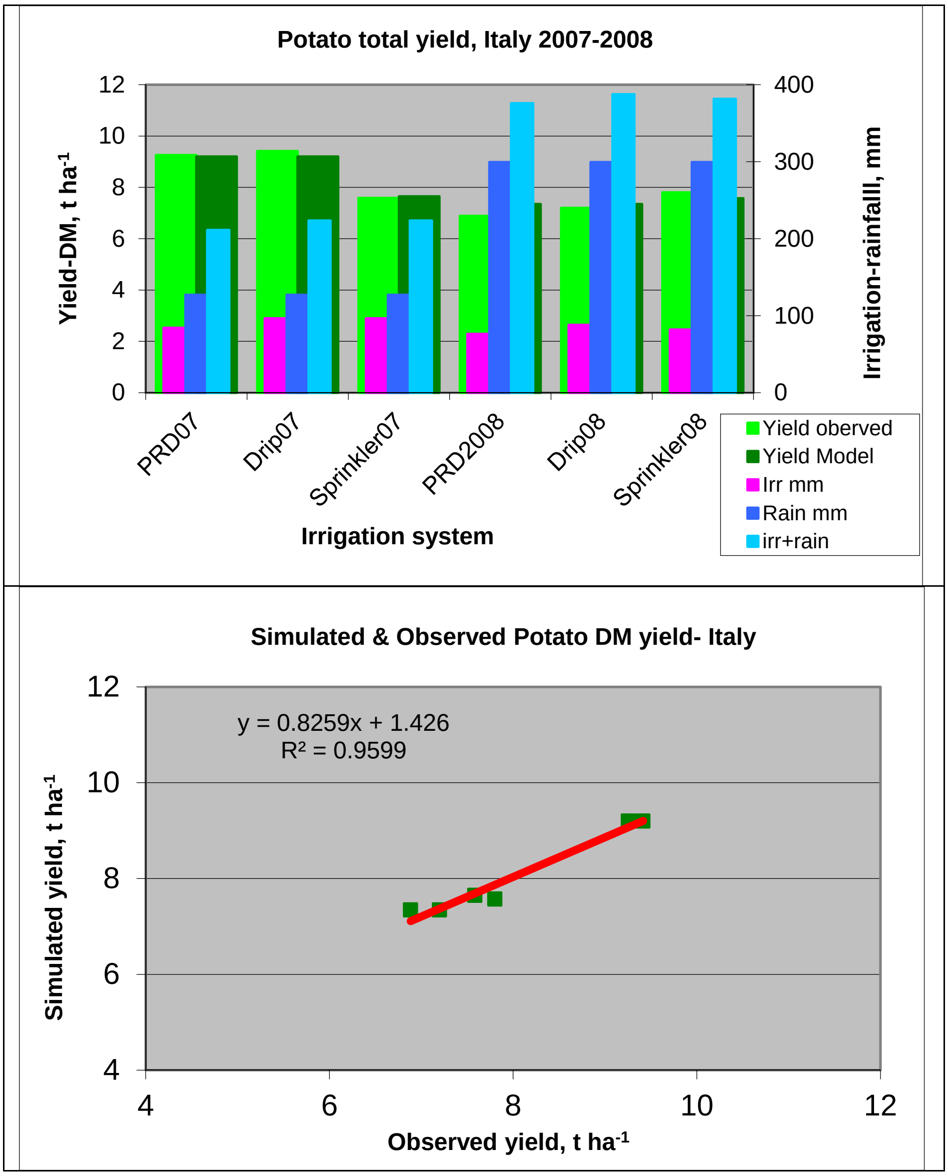

Figure 4. Observed and simulated potato total yield under different irrigation treatments, Italy.

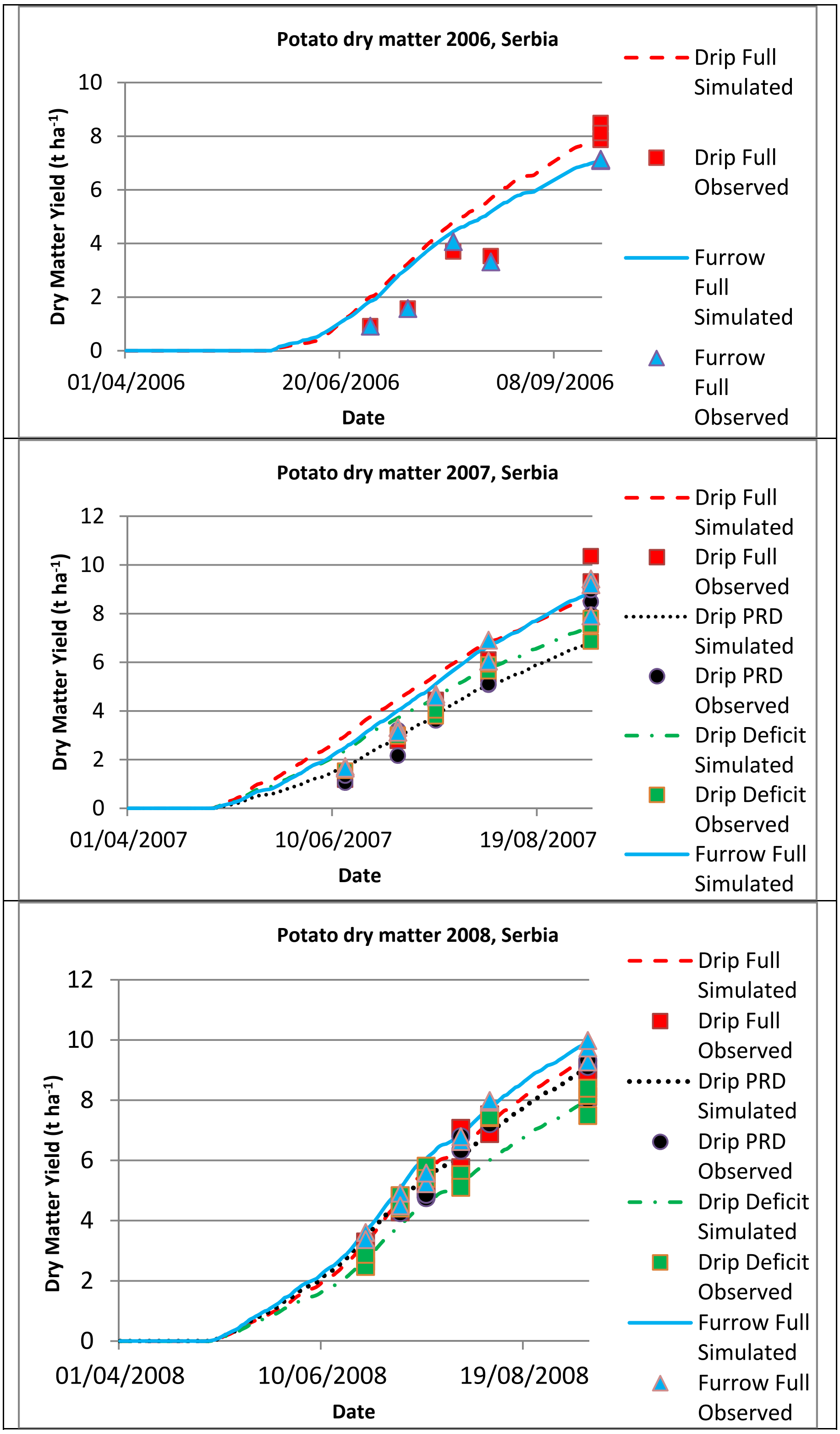

Figure 5. Observed and simulated potato dry matter yield during the season under different irrigation treatments, Serbia.

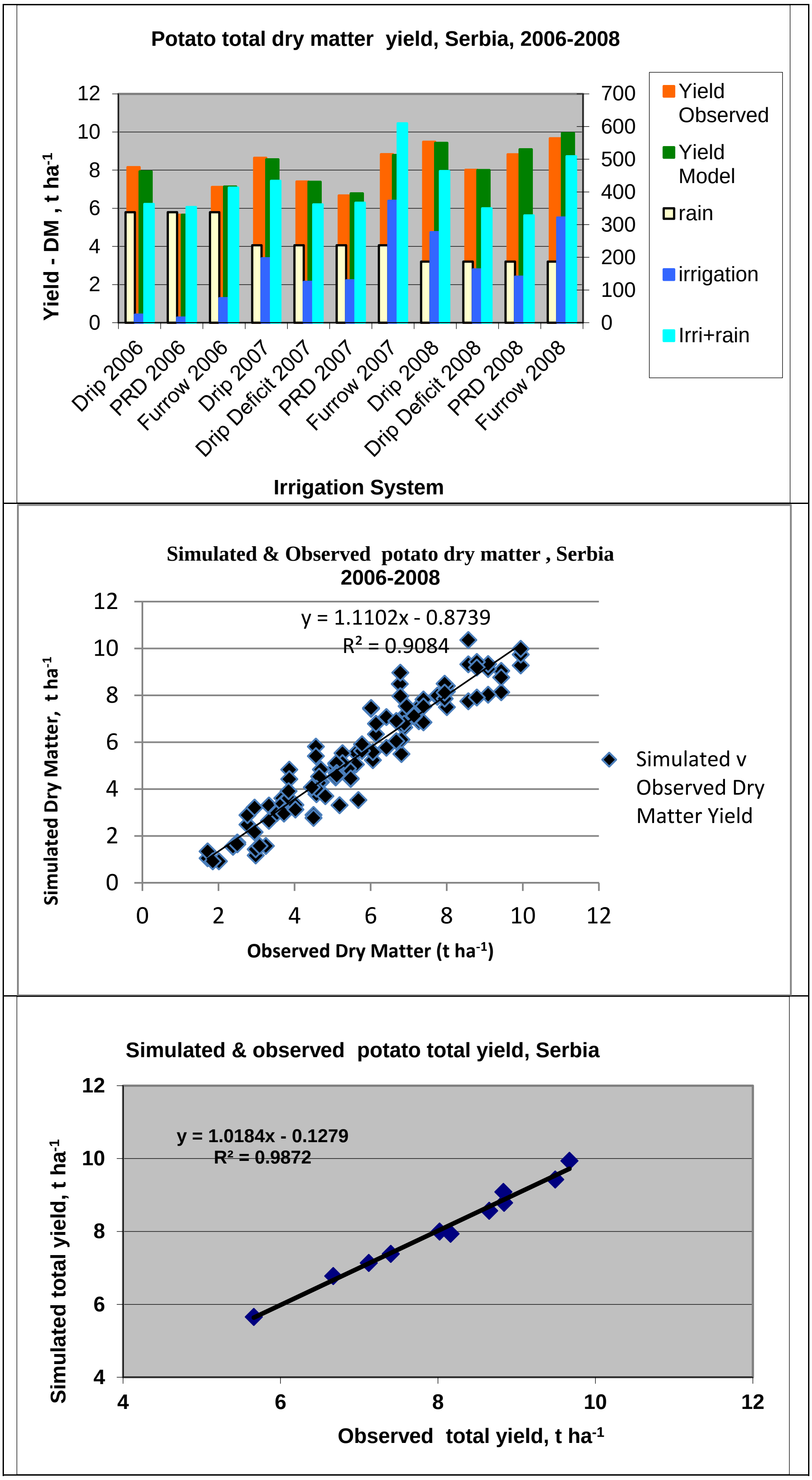

Figure 6. Observed and simulated potato dry matter (middle) and total yield (top & bottom) under different irrigation treatments, Serbia.

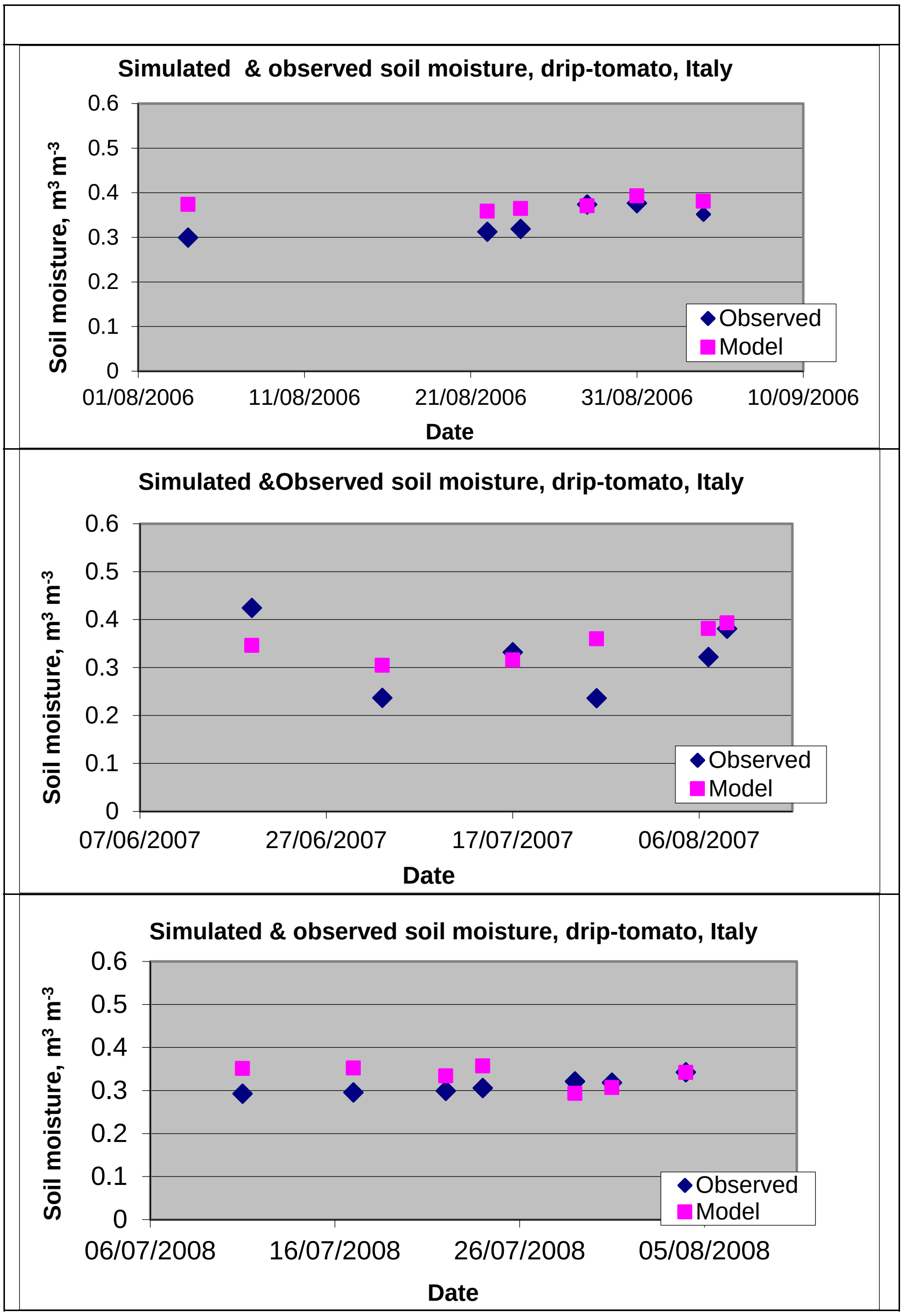

Figure 7. Soil moisture content during the growing seasons (2006-2008) of tomato, Italy.

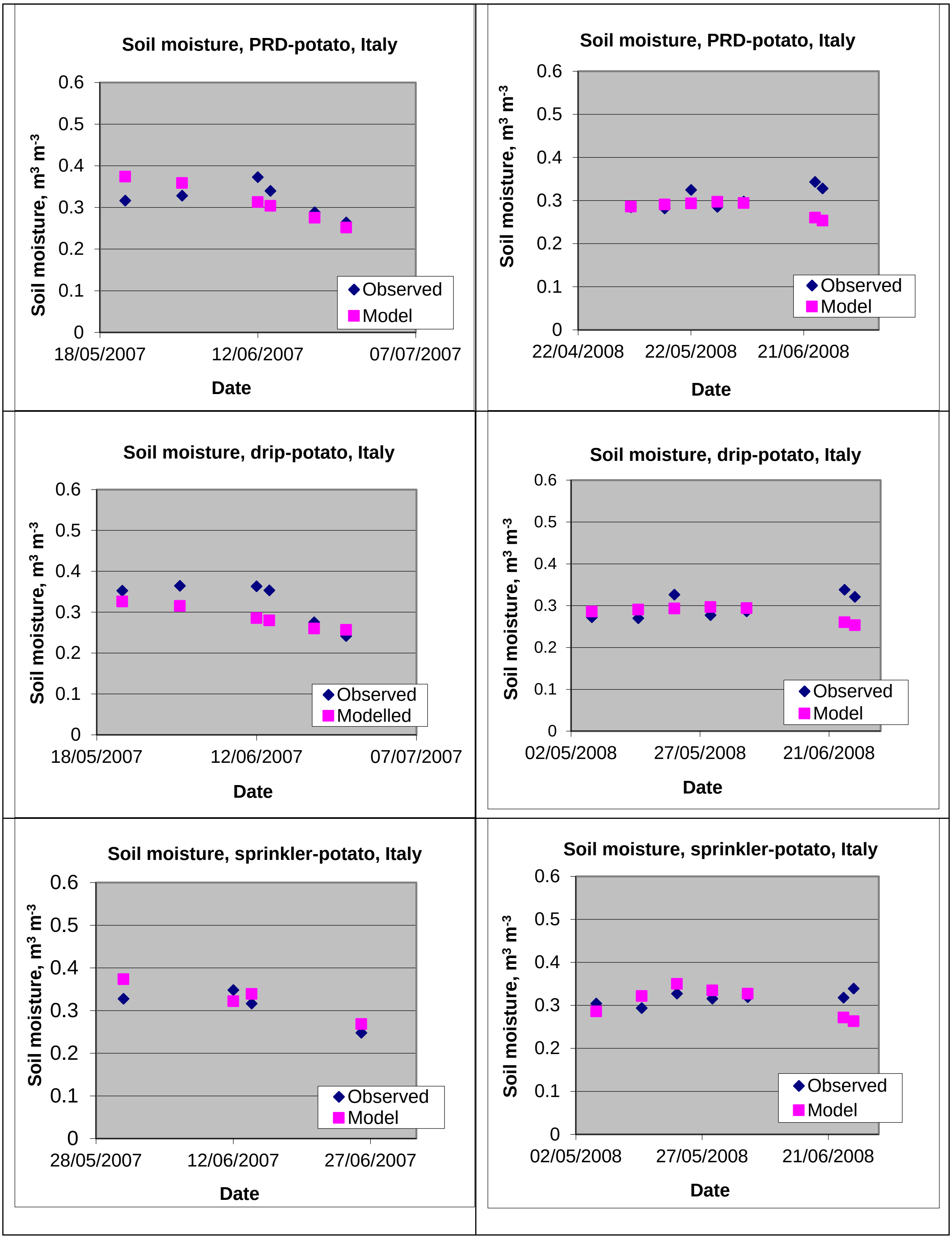

Figure 8. Soil moisture content during the growing season of potato, Italy.

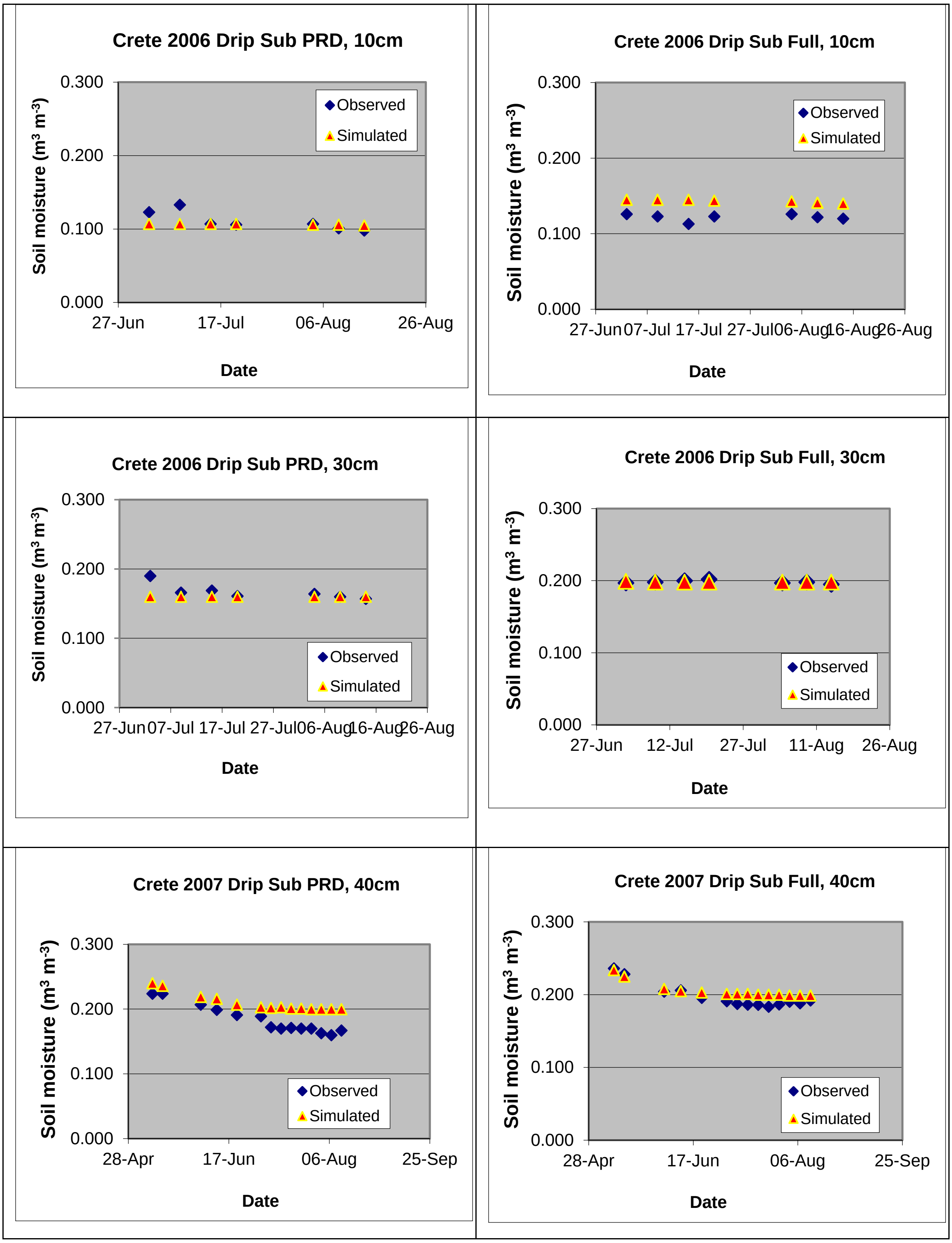

Figure 9. Soil moisture content during the growing season of tomato, Crete.

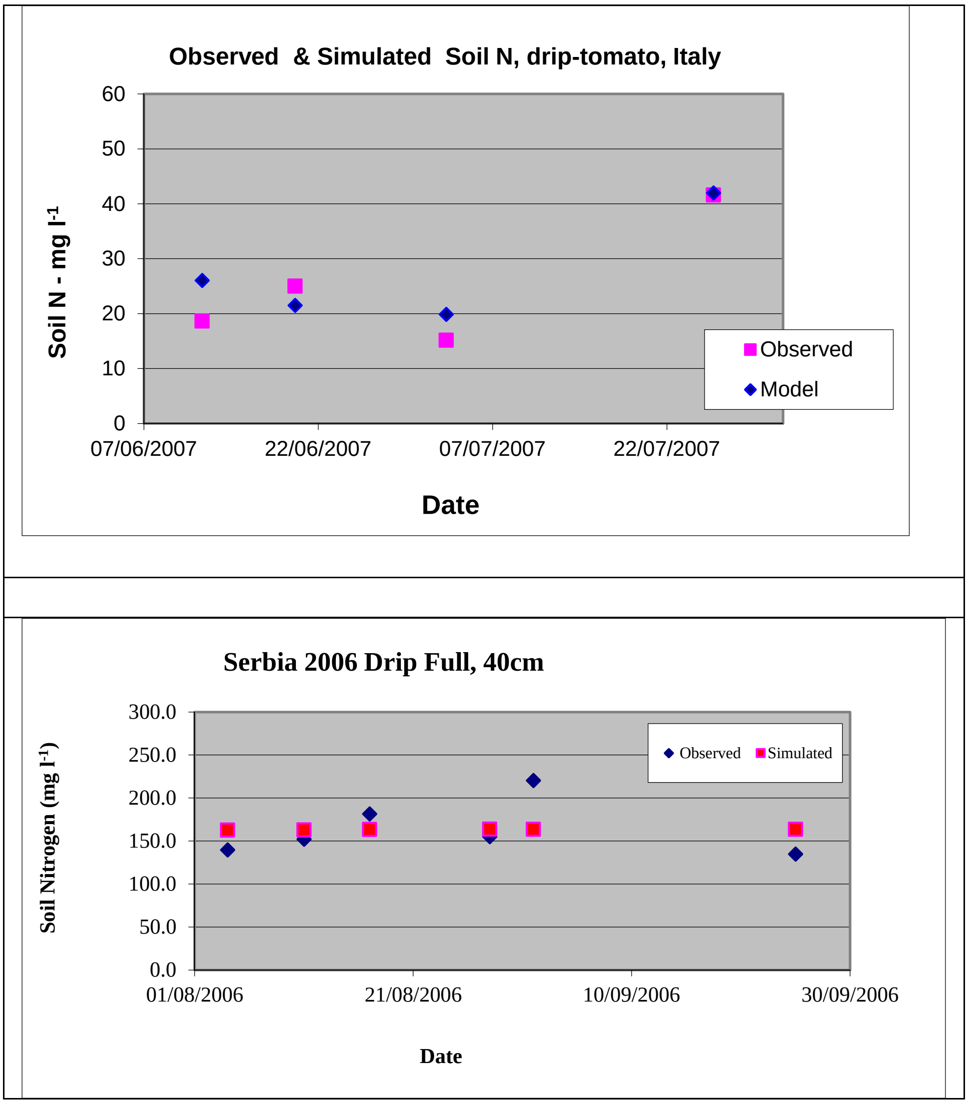

Figure 10. Soil nitrogen content during the growing season of tomato, Italy (Top) and Serbia, potato (bottom).