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Rinaldi M., Ubaldo R.

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SPATIAL SIMULATION OF WATER USE EFFICIENCY IN A MEDITERRANEAN ENVIRONMENT

M. Rinaldi and R. Ubaldo
CRA – Istituto Sperimentale Agronomico, via Celso Ulpiani 5 - 70125 Bari, Italy

SUMMARY - Simulation models are often used to verify the potentiality of crop management, allowing multi-year and multi-location runs with minimum time spending. In Southern Italy, where water-limited conditions are frequent, is important to identify crop management which allows better the transformation of water (and irrigation water) in commercial yield.
In this research a spatial analysis of a long-term simulation was carried out with AEGIS/WIN, a Geographic Information Systems (GIS) interface of DSSAT crop simulation package. The case-study is referred to a 1000 km^2 area (Foggia, Southern Italy), characterized by 481 soil samples collected at a regular grid. Durum wheat and processing tomato have been simulated punctual-based using soil and long-term weather data (45 years). The two crops have been compared in the following management scenarios: rainfed and three automatic irrigation levels based on soil water content thresholds. Average and standard deviation of commercial yield (grain and fruit), seasonal evapotranspiration and irrigation amount were evaluated as model output. Water use efficiency (WUE) and irrigation water use efficiency (IRWUE) were then calculated. All the above variables were visualised and mapped with GIS.
The wheat productivity was increased by irrigation of 19% and no difference occurred among automatic irrigation thresholds. WUE resulted similar in the 4 irrigation scenarios, while the southern part of the plain showed the higher IRWUE. In tomato the irrigation increased 3 times the yield respect to rainfed, with no difference among irrigation scenarios. WUE did not differ spatially, while IRWUE was higher in the southern part. Climatic conditions (rainfall and temperature) and soil water holding capability resulted the variables that more influenced the above use efficiencies, especially for tomato crop.

Key words: simulation model, durum wheat, processing tomato, irrigation scenarios, soil water content.

RESUME *– Les modèles de simulation sont souvent utilisés pour vérifier la potentialité de la gestion de culture, en permettant de comparer plusieurs années et plusieurs localités en bref temp.*
En Italie Méridionale, où les conditions de limitation hydrique sont fréquentes, est important d'identifier la meilleure gestion culturale qui permet de transformer l'eau (et l'eau d'irrigation) en produits commerciales.
Dans cette recherche on a effectué une analyse spatiale d'une simulation à long terme avec AEGIS/WIN, un système d'information géographique (GIS, Geographic Information Systems) interface du modèle de simulation cultural DSSAT. Le case étudié est référé à une superficie de 1000 km^2 (Foggia, Italie Méridionale), où on a réalisé 481 échantillons de sol prélevés selon une grille régulière. Blé dur et tomate de transformation ont été simulés 'punctual-based' en utilisant le sol et les données à long terme du climat (45 années). Le blé dur et la tomate de transformation ont été comparés dans les suivants traitements: non irrigué (seulement l'eau de précipitation) et trois niveaux automatiques d'irrigation basés sur les seuils d'humidité du sol. La moyenne et l'écart type des produits commerciales (grain et fruit), l'évapotranspiration saisonnière et le quantitatif d'eau d'irrigation ont été évalués comme output du modèle. L'efficacité d'usage de l'eau (WUE, Water Use Efficiency) et l'efficacité d'usage d'eau d'irrigation (IRWUE, Irrigation Water Use Efficiency) on été calculés. Toutes les variables décrites précédemment ont été visualisées et tracées avec GIS.
La productivité du blé a été augmentée par l'irrigation du 19% et aucune différence s'est produite parmi les différents seuils automatiques d'irrigation. WUE résultée est presque la même dans les 4 scénarios d'irrigation, au contraire la zone située plus au sud du plan a montré la plus haute IRWUE. Avec la tomate l'irrigation a augmenté 3 fois la productivité envers celle non irriguée, avec aucune différence entre les niveaux d'irrigation. WUE n'a pas résulté de différence dans l'espace, au contraire IRWUE a été plus haute dans la part située plus au sud. Les conditions climatiques (pluviosité et

température) et la capacité de rétention hydrique du sol, ont été les variables qui ont influencé l'efficacité d'usage de l'eau d'irrigation, surtout pour la culture de la tomate.

***Mots-clés**: modèle de simulation, blé dur, tomate de transformation, scénarios d'irrigation, contenu hydrique du sol.*

INTRODUCTION

The need to support policy formulation and decision-making in agriculture at large spatial scales is emerging. Typical issues are climate change impact assessment and formulation of mitigating measures, water resource allocation in a district and basin scale, and environmental impact assessment of agriculture activities (Rinaldi *et al*., 2006). In order to develop a decision support system, biophysical processes and human interactions such as adaptive changes of agricultural practice have to be modelled. The model should simulate, for example, how the changes of environment such as climate change may influence crop yield and how the changes in cropping pattern (crops, cultivars and sowing times), cultivation intensity (rotations) and management practices (irrigation, fertilization) may affect the environment over time. Spatial variability of soil and climate and changes of the processes need special attention in the modelling process (Basso et al., 2000).

When we focus major crop production, it would be appropriate to apply process-based crop simulation model for the purposes above. However, crop simulation models usually need site specific characteristics such as weather, physical and chemical parameters of soil, water management, and agronomic practices (Whistler, et., al, 1986, Penning de Vries et al., 1989) as input data. Applicability of these models can be extended to much boarder spatial scales by combining them with a Geographic Information System (GIS). Several researchers have demonstrated or discussed the strength of this concept for agricultural management decision and planning at various spatial scales (Dent and Thornton, 1988; Hartkamp et al., 1999**a**; Hoogenboom and Thornton 1990; Thornton et al., 1995).

Experiences of application of DSSAT software at spatial scale are reported by Hoongenboom and Thornton (1990) that applied GIS to bean, maize and sorghum crop models to test potential of linked systems for agro-technology transfer in Guatemala. Calixte *et al*. (1992) developed an Agricultural and Environmental Geographic Information System (AEGIS), which combined DSSAT crop models with GIS to assess the impact of different agricultural practices of Puerto Rico. Georgiev *et al*. (1998), Heinemann *et al*. (2002), Batchelor *et al*. (2002) and Nijbroek *et al*. (2003) reported further applications of DSSAT at spatial scale, especially for water requirement estimation.

In previous studies of our research group the models embedded in DSSAT software have been calibrated and validated for Southern Italy conditions (Rinaldi *et al*., 2003; Rinaldi, 2004; Rinaldi *et al*., 2007): it revealed to be a good tool in simulation of field crops in several soil and climatic conditions; large number of users and the upgrade with user-friendly interface and new applications are further reasons to choose DSSAT software in this case-study in Southern Italy.

In the same environment CERES-Wheat and CROPGRO models were applied in a spatial and temporal analysis using soil information derived from 118 soil samples in a 100 km^2 area with only one meteorological data-set for 45 years: it was showed the partial (+ 5÷20 % respect to rainfed crop) effect of one irrigation supply at booting stage on durum wheat grain yield, while for processing tomato no difference was observed between automatic irrigation starting at 75 and 50% of available crop water in the first 0.3 m soil layer (Rinaldi and Borneo, 2006**a**). In another case-study, CERES-Wheat model was run in 481 soils and using 8 meteorological data-set for 17 years (Rinaldi and Borneo, 2006**b**) and the wheat productive level and variability resulted dependent by soil water holding capacity and climatic conditions.

In this paper we reported an evolution of these last two researches, applying seasonal and spatial simulation of CERES-Wheat and CROPGRO models for two important field crops in Southern Italy in a large area. The objective of this paper is to apply a GIS-based crop model to compare irrigation strategies in durum wheat and processing tomato, to predict crop yield, water use and calculate, on a long-term seasonal time scale, crop water use efficiency and irrigation water use efficiency.

MATERIALS AND METHODS

The “Capitanata” is a plain of about 4000 km^2 in South-Eastern Italy, mainly cropped with durum wheat, tomato, sugar beet, olive and grape orchards. Irrigation is managed by a local authority “Consorzio per la Bonifica della Capitanata” of Foggia, that give irrigation water on demand and at low pressure (2-3 bar) at a large part of the plain (1800 km^2). A part of this plain (about 1000 km^2) has been characterized from pedological and climatic point of view. A large number of soil samples (481) were collected at 0–20 and 20–40 cm depth and 115 soil profiles were examined up to 2,5 m depth. The main chemical and physical characteristics were recorded (texture, hydrological characteristics, nitrogen and phosphorus content, organic matter, bulk density, etc.). Daily climatic data (maximum and minimum temperature, solar radiation and rainfall) derived by eight meteorological stations located in the area and managed by the above reported “Consorzio”. Averages long-term values are reported in *Table 1*.

Table 1. Yearly averages (sum for rainfall) and standard deviations (in brackets) of climatic data of eight meteorological stations used in this case-study in Southern Italy. The placement of stations is mapped in Figure 1.

Agrometeorological stations	Altitude (m a.s.l.)	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)	Solar radiation (MJ m^{-2} d^{-1})
APR (Apricena)	55	22.0 (1.0)	10.7 (0.9)	578 (149)	14.0 (1.4)
CAS (Castelnuovo)	177	20.7 (1.2)	10.5 (1.1)	659 (125)	13.2 (3.0)
FOG1 (Foggia, Pod. 124)	92	21.6 (0.7)	10.3 (0.5)	499 (108)	14.4 (1.1)
FOG2 (Foggia, Polluce)	21	23.6 (1.5)	10.4 (1.4)	511 (148)	15.8 (2.1)
FOG3 (Foggia, Tavernola)	36	23.9 (1.1)	9.8 (1.3)	476 (153)	14.7 (2.4)
LES (Lesina)	13	21.4 (1.1)	9.6 (1.2)	606 (154)	13.8 (1.1)
LUC (Lucera)	102	23.3 (1.3)	10.3 (0.9)	572 (154)	14.4 (2.2)
TOR (Torremaggiore)	110	21.6 (0.9)	10.4 (1.0)	636 (129)	14.9 (2.1)

CERES–Wheat model, embedded in DSSAT program (Jones *et al*., 2003), previously calibrated and validated for durum wheat (cv. Simeto) in the test area (Rinaldi, 2001; 2004) was used in a seasonal (44 cropping cycles, from 1955 to 1999) and spatial analysis comparing the following irrigation scenarios:

1. Rainfed;
2. Automatic irrigation starting at 10% of crop available water (CAW) in the 0.3 m soil depth (IRR10), with water amount refilling up to field capacity, until head emission stage; a sprinkler irrigation method was used;
3. Idem, at 30% (IRR30);
4. Idem, at 50% (IRR50).

The use of low thresholds to start automatic irrigation derive by the fact that in the test area durum wheat is usually not-irrigated or irrigated occasionally (1-2 applications) in the spring. Durum wheat management was simulated with fixed sowing date (15th November), fertilisation with 100 kg ha^{-1} of ammonium phosphate pre-sowing and 100 kg ha^{-1} of ammonium nitrate at 1st March. Harvest date was simulated by the model at crop maturity. Output variables were analysed and mapped: grain yield (t ha^{-1}), seasonal actual evapotranspiration (ETa, mm), seasonal irrigation volume (mm).

CROPGRO model, embedded in DSSAT program, has been calibrated and validated in the test area for a processing, self pruning, globe shape, tomato variety (PS 1296, Rinaldi *et al*., 2007). The simulation was run for the same years and location as before described for wheat, and similarly for the irrigation scenarios, except for thresholds of soil crop available water to start automatic irrigation, fixed for tomato to 30 (IRR30), 50 (IRR50) and 70% (IRR70).Tomato crop, according to local management, was simulated with fixed sowing date (30th April), fertilization with 100 kg ha^{-1} of ammonium phosphate pre-sowing and 100 kg ha^{-1} of ammonium nitrate at fruit formation (30th May). Harvest date was simulated by the model at crop maturity. Output variables were analysed and mapped: fresh fruit yield (t ha^{-1}), seasonal actual evapotranspiration (ETa, mm) and seasonal irrigation volume (mm). Standard deviations of means of obtained yearly yield values for each polygon (soil-climate interaction) were mapped to visualize temporal variability for both crops.

The water use efficiency (WUE, kg m^{-3}) and irrigation use efficiency (IRWUE, kg m^{-3}) were calculated according the following equations:

$$WUE = \frac{Y}{ETa} \tag{1}$$

$$IRWUE = \frac{Y - Yr}{I} \tag{2}$$

where Y is the fruit (for tomato) and grain (for wheat) dry matter yield, ETa is the seasonal actual evapotranspiration estimated by the model, Yr is the yield of rainfed scenario and I is the seasonal irrigation volume applied. For durum wheat the IRWUE was calculated only in the years when irrigation occurred.

The 481 referenced points have been converted in polygons using the Thiessen methods (threshold value = 5) and overlaying these polygons with a soil map with pedological characteristics (Hartkamp *et al*., 1999**b**). The interface with a GIS program, AEGIS/WIN, allowed to run the model in the 481 polygons and to display the output of the model using map visualization (Engel *et al*., 1997). The total of run was 21164 for wheat and 21645 for tomato and each polygons represent the average of 44 (45 for tomato) yearly values. For every mapped variable the separation in eight classes has been carried out by the Jenks Natural Breaks method, which identifies breakpoints between classes using a statistical formula (Jenk's optimization), minimizing the sum of the variance within each of the classes.

RESULTS AND DISCUSSION

The climatic stations are located in plain area: CAS only is placed on a smooth hilly (177 m a.s.l.), while LES is very close to homonym lake and Adriatic sea coast. The coldest and rainiest place is CAS, the warmest are FOG2, FOG3 and LUC; the less rainy locations are FOG1 and FOG3. The place characterised by lower solar radiation is CAS for the cloud influence, while latitude showed low effect on thermal regime (*Table 1*).

The main difference of 481 polygons derived by the soil texture, that influenced the hydrological characteristics (wilting point and field capacity). The crop soil water (CSW, difference between Field capacity and Wilting point), expressed in mm m^{-1} of soil depth, is mapped in Fig. 1. It was noticed a distribution of soils with greater CSW (mainly clay soils) in the central part of the tested area, close to FOG2 and LUC weather stations, while sandy soils were located in the inner part (FOG1) and close to TOR and APR stations (Fig. 1)

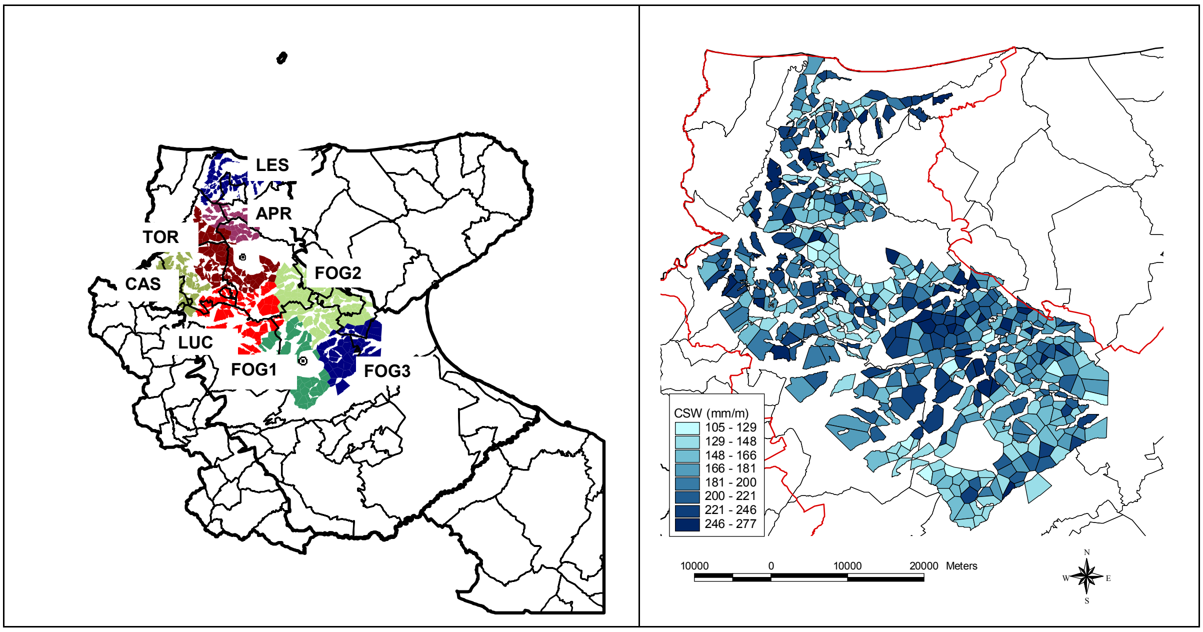

Fig 1. On the left side: weather stations locations in Capitanata Plain area (Southern Italy), with city administrative borderlines (thin lines) and “Consorzio per la Bonifica della Capitanata” area (thick lines). On the right side: crop available soil water (mm m^{-1}) for the 481 soil polygons.

Wheat

Wheat is usually not irrigated in the test area but, in the farms were irrigation sprinkler equipment are available, 1-3 irrigation supplies at sowing and at boot stage are frequent to increase and stabilize grain yield.

The simulation with CERES-Wheat model of wheat cropped without irrigation (rainfed scenario) produced an overall mean of 3.0 t of grain yield ha^{-1} (*Table 2*), with a large variability ranging, at single run simulation level, from 0.3 to 6.4 t ha^{-1}. These values are not so different by local long-term average. In general, the areas more productive resulted the central and northern parts, the less yielding the southern one (FOG1 and FOG3) (Fig. 2).

Table 2. Averages, standard deviations and variation coefficients (in brackets) of durum wheat simulated by CERES-Wheat, in the case-study, referred to the 44 crop cycles of simulation and to the 481 soils.

	Grain yield (t ha^{-1})	Actual evapotranspiration (mm)	Seasonal irrigation volume (mm)	Water use efficiency (kg m^{-3})	Irrigation water use efficiency [1] (kg m^{-3})
Rainfed	3.03 ± 1.30 (42.7%)	311.5 ± 55.5 (17.8%)	-	0.94 ± 0.31 (33.5%)	-
IRR10	3.57 ± 1.18 (33.1%)	382.3 ± 55.6 (14.5%)	138.5 ± 72.4 (52.3%)	0.91 ± 0.20 (21.9%)	0.28 ± 0.77
IRR30	3.64 ± 1.18 (32.5%)	394.9 ± 58.9 (14.9%)	183.0 ± 73.1 (39.9%)	0.90 ± 0.19 (21.1%)	0.19 ± 0.58
IRR50	3.62 ± 1.18 (32.7%)	397.7 ± 58.3 (14.7%)	208.8 ± 71.9 (34.4%)	0.89 ± 0.19 (21.8%)	0.17 ± 0.51

[1] Calculated for the years when irrigation occurred

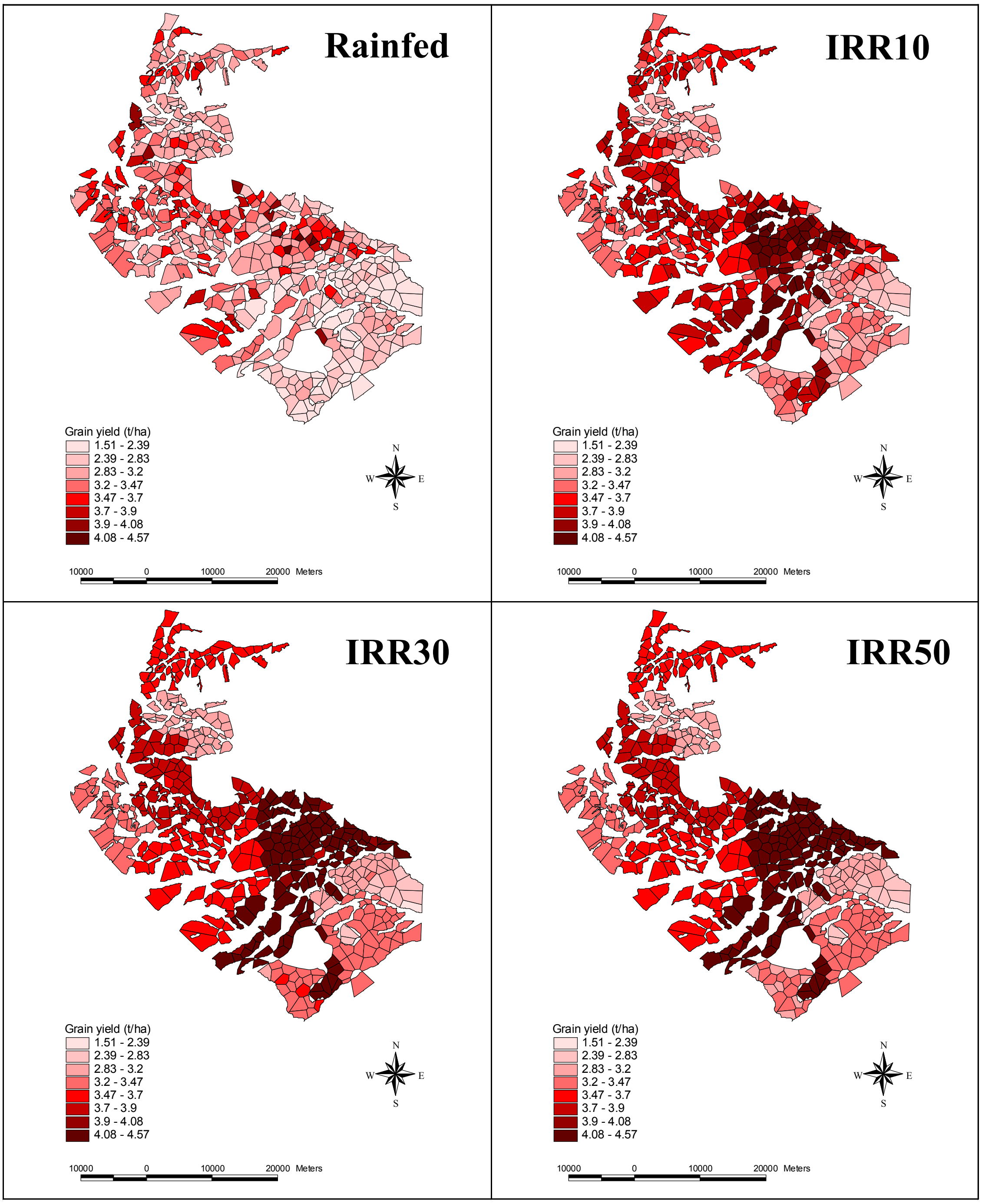

Fig 2. Grain yield (t ha^{-1}) of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons.

The actual evapotranspiration was very similar in three scenarios, and also the differences in soil evaporation, runoff and drainage were negligible: the only component of water balance that changed was the crop available soil water at harvest (*Table 3*) meaning that the latest irrigation supplies were not used completely by the crop and remained in the soil. This is a normal risk in irrigation practice, when rain events following the irrigation, make vain the irrigation supply. The re-initializing of soil condition at every starting date of simulation (two days before sowing) did not allow to consider this beneficial effect of the previous year.

Table 3. Averages and standard deviations of water balance components of durum wheat.

	Plant transpiratio n (mm)	Soil evaporation (mm)	Drainage (mm)	Runoff (mm)	Crop soil water available at harvest (mm)
Rainfed	186 ± 68	125 ± 28	9.0 ± 29.8	34.9 ± 28.0	77 ± 43
IRR10	255 ± 67	127 ± 22	10.4 ± 31.1	39.4 ± 25.5	121 ± 46
IRR30	267 ± 71	128 ± 23	13.0 ± 34.2	42.1 ± 25.3	142 ± 49
IRR50	266 ± 72	132 ± 25	15.3 ± 37.0	43.7 ± 25.3	158 ± 50

The yearly vtariability of grain yield decreased with irrigation in the overall area, except for CAS area (Fig. 3), where the more rainy conditions caused a leaching of nitrogen due to rainfall subsequent to irrigation applications. The most productive areas showed higher values of ETa (Fig. 4). The seasonal irrigation volume (Fig. 5) ranged on average from 42 to 333 mm, without large difference among the IR30 and IR50 scenarios. This happened because the irrigation scheduling has been thought to refill the soil up to Field Capacity with every water application. The number of yearly irrigations increased with the threshold (2 for IRR10, 3 for IRR30 and 5 for IRR50) and, inversely, the water amount of each application decreased (66 for IRR10, 54 for IRR30 and 43 mm for IRR50). The amount of nitrogen leached did not differ among the scenarios, with averages values of 5.6, 7.0 and 8.4 kg of N ha^{-1} y^{-1}, for IRR10,a IRR30 and IRR50, respectively.

The WUE (*Table 2*) did not diverge among the irrigation scenarios, decreasing from rainfed to IRR50 treatment (on average 0.91 kg of grain m^{-3} of used water). This confirms the stability of this crop parameter especially in winter cereals (Sinclair *et al*., 1984) and the absolute values obtained, similar to others reported in literature (Tanner and Sinclair, 1984; French and Schultz, 1984; Zhang and Oweis, 1999). Mapping this indicator we can observe the lowest values in the southern part of the area (FOG1 and FOG3) (Fig. 6) for the climatic conditions, warm and dry and for the prevailing sandy soils.

The IRWUE decreased with increasing of irrigation thresholds (*Table 2*); the area whit lowest IRWUE was CAS, while higher values were simulated in the south-eastern parts (FOG1, FOG2, FOG3 and LUC) (Fig. 7). In some polygons (CAS and LES areas) the grain yield of irrigated scenarios was the same or, in some years, was less than the rainfed one; this is due to soil nitrogen availability reduced for leaching of deep percolation that, in certain conditions, reached also 100-150 kg of N ha^{-1} y^{-1}.

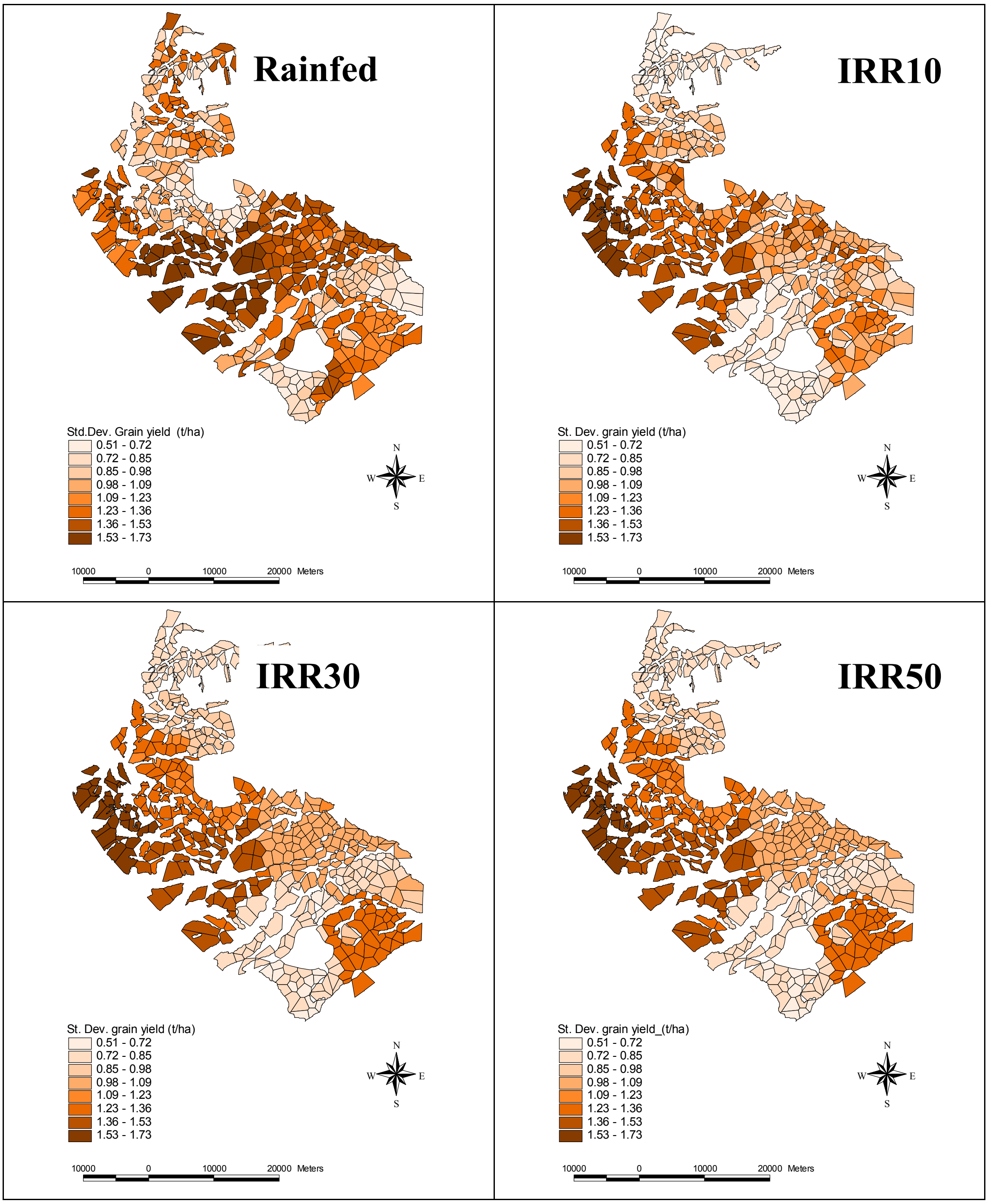

Fig. 3. Standard deviation of 44 years of grain yield (t ha^{-1}) of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons

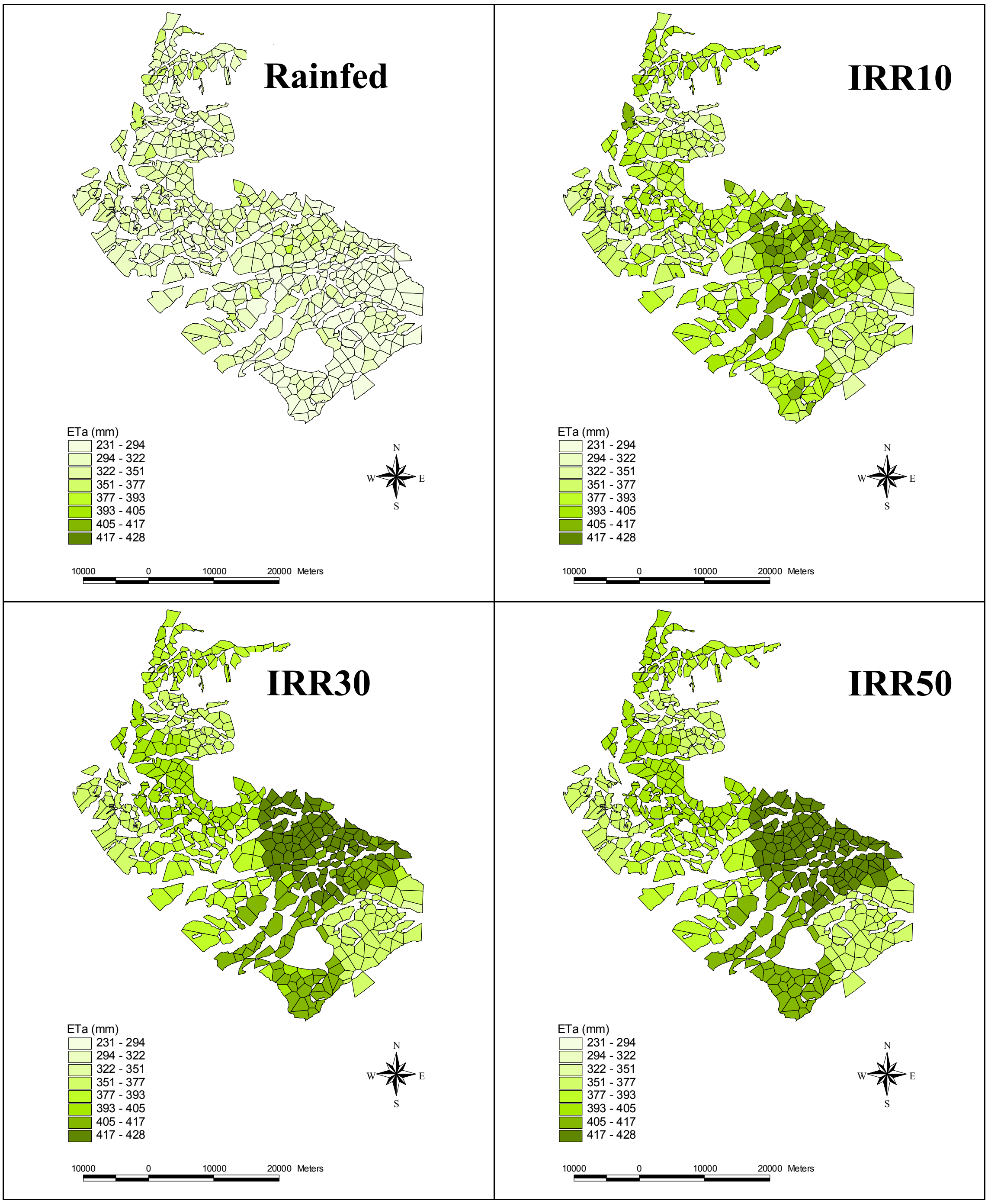

Fig. 4. Actual evapotranspiration (mm) of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons.

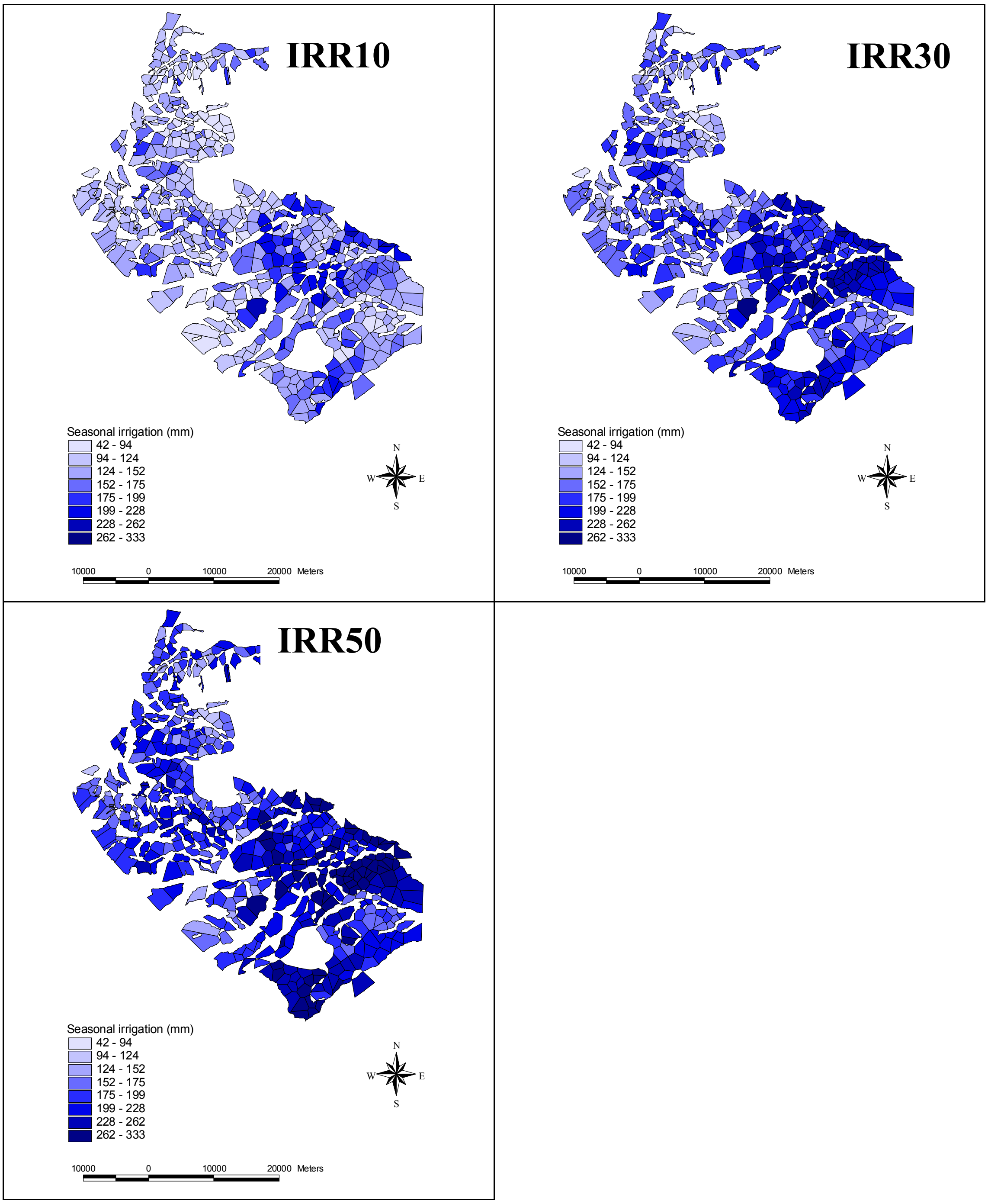

Fig. 5. Seasonal irrigation volume (mm) of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons.

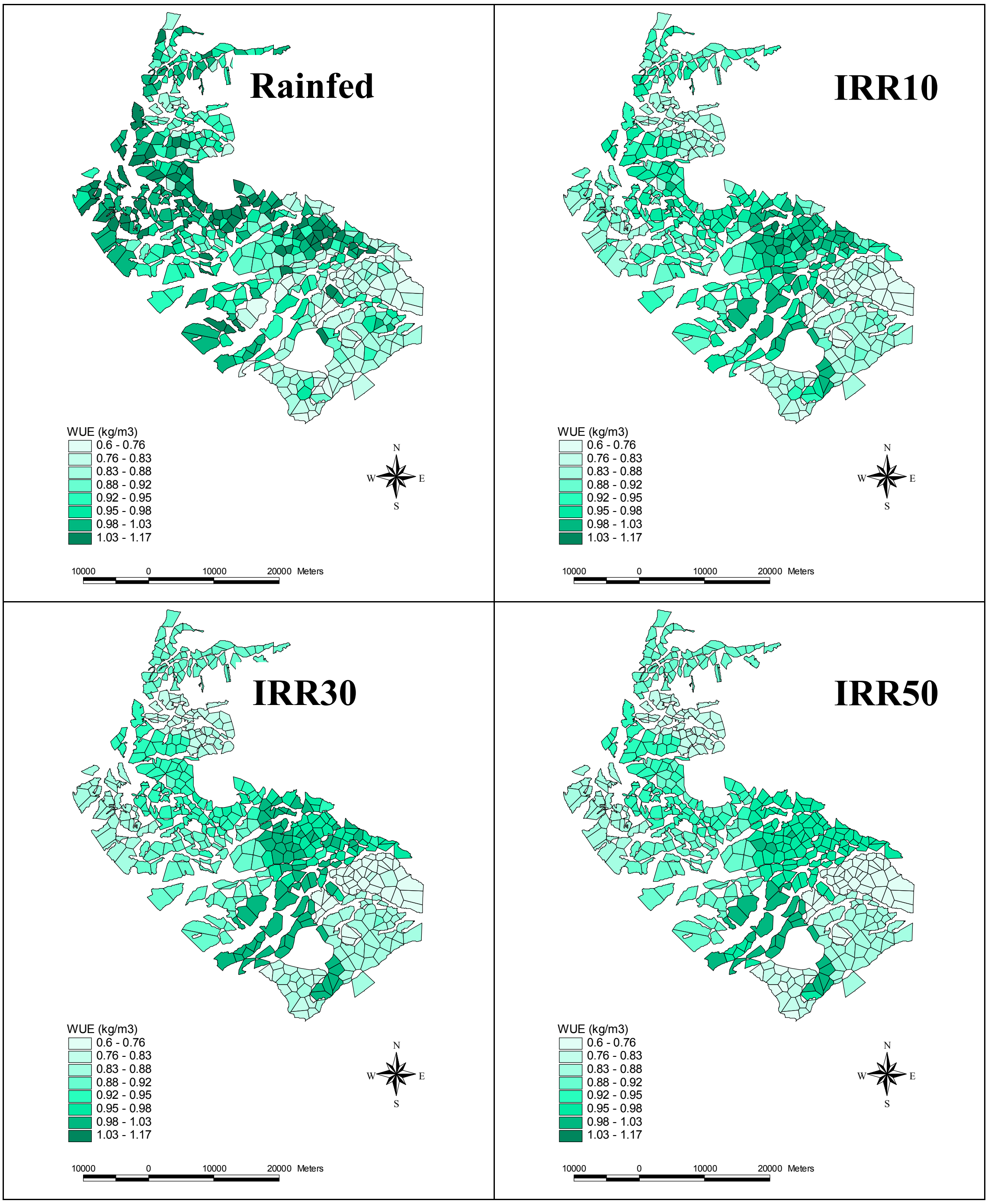

Fig. 6. Water use efficiency in grain dry matter yield of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons

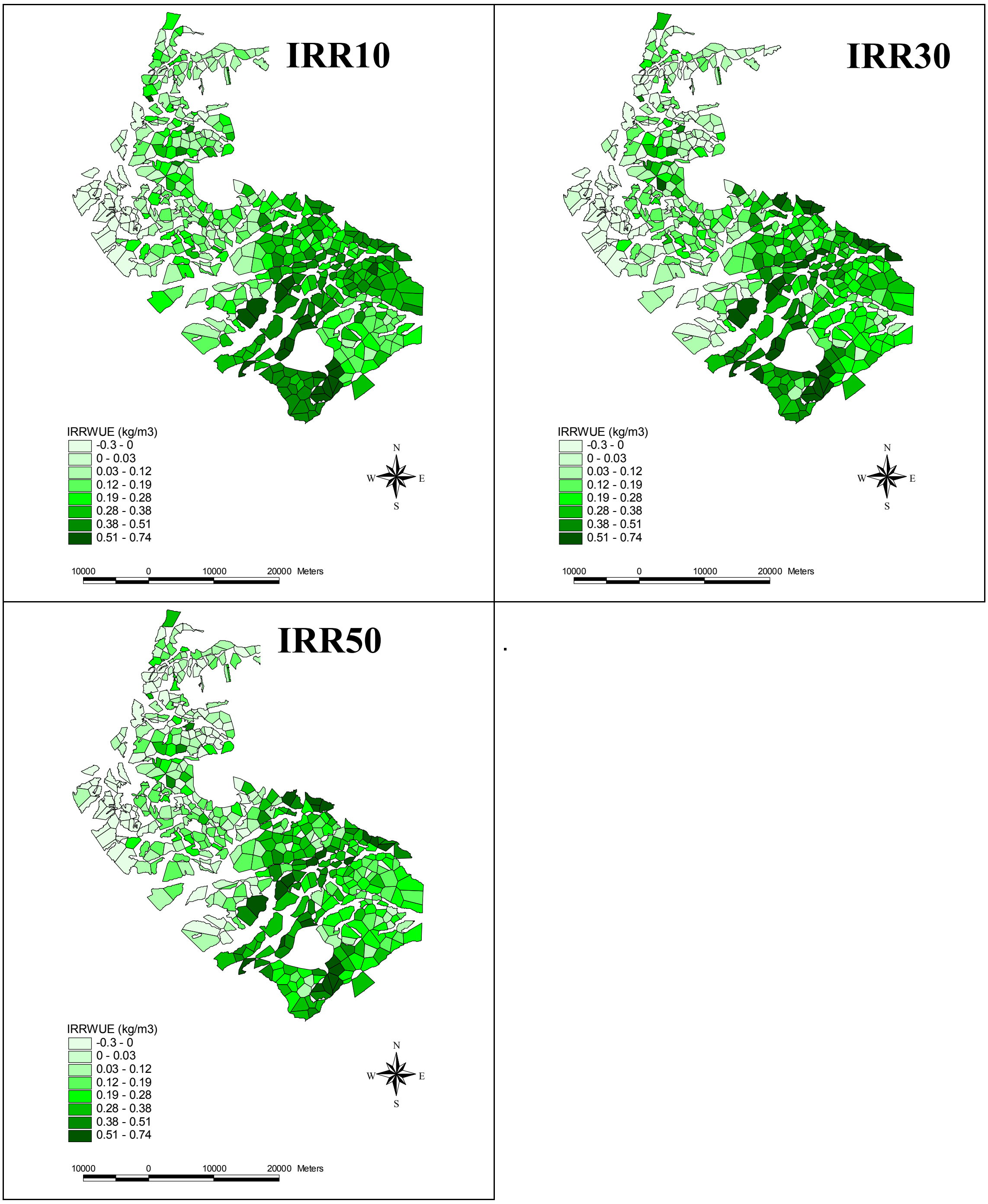

Fig. 7. Irrigation water use efficiency in grain dry matter yield (kg m^{-3}) of durum wheat simulated by CERES-Wheat model in the four irrigation scenarios and mapped for the 481 soil polygons

Tomato

Tomato crop is usually irrigated in test area, with sprinkler and, more widely, with drip irrigation methods; seasonal irrigation volumes range between 300 and 500 mm. In this simulation activity, the seasonal irrigation volume ranged form 300 to 400 mm in the three irrigation scenarios (*Table 4*), but we choose these thresholds with the aim to reduce water application and increase water use efficiency.

Table 4. Averages, standard deviations and variation coefficients (in brackets) of processing tomato simulated by CROPGRO, in the case-study, referred to the 45 crop cycles of simulation and to the 481 soils.

	Fresh fruit yield ($t\ ha^{-1}$)	Actual evapo-transpiration (mm)	Seasonal irrigation volume (mm)	Water use efficiency [1] ($kg\ m^{-3}$)	Irrigation water use efficiency [1] ($kg\ m^{-3}$)
Rainfed	54.3 ± 39.3 (72.4%)	244.7 ± 59.9 (24.5%)	-	1.08 ± 0.71 (65.1%)	-
IRR30	187.1 ± 28.1 (15.0%)	460.8 ± 70.3 (15.3%)	298.6 ± 76.8 (25.7%)	2.07 ± 0.38 (18.2%)	2.24 ± 0.63 (28.1%)
IRR50	198.0 ± 25.9 (13.1%)	487.8 ± 71.0 (14.6%)	342.8 ± 79.5 (42.5%)	2.07 ± 0.37 (17.8%)	2.11 ± 0.52 (24.9%)
IRR70	197.4 ± 27.0 (13.7%)	520.5 ± 70.4 (13.5)	398.2 ± 76.7 (19.3%)	1.93 ± 0.34 (17.6%)	1.79 ± 0.46 (26.0%)

[1] in fruit dry matter yield.

Fresh fruit yields in the irrigated scenarios were generally higher than the ones recorded in the test area (from 50 to 150 $t\ ha^{-1}$), but this overestimation is explained because the model does not consider the effect of pest damages and weed competition. The fruit yield of rainfed scenario was very low, 54 $t\ ha^{-1}$ on average, but with a very large variability (*Table 4*), depending by rainfall, very erratic in test area during the crop grown period (May-August). The areas with larger temporal fruit yield variability resulted the southern-eastern part, referred to FOG1, FOG2 and FOG3 weather stations, while the areas less variable areas were the northern ones (TOR, APR and LES). The areas where tomato resulted more productive and stable were the ones close to LES and FOG2 (Figs 8 and 9); in the first case the effect is due to mitigation of the climate (especially during the summer) due to lake and sea proximity and to the richness in organic matter of the alluvial soils. In the second case the hydrological soil conditions, mainly a greater CSW (Fig. 1), allowed a better tomato yield and stability.

The effect of irrigation was generally the same in all the area (Fig. 8) and was markedly evident, with fresh fruit yield three times greater than rainfed scenario. Further, the temporal variability of fruit yield was significantly reduced with irrigation application, with a variation coefficient reduced from 72% (rainfed) to 14% (on average, in irrigated scenarios) (*Table 4*) and a lower standard deviation in irrigated crop (Fig. 9).

The different irrigation scenarios highlighted a variation in the irrigation volume and actual evapotranspiration, but not in fresh fruit yield. Spatial analysis showed where the ETa was reduced due to climatic conditions (FOG1 and CAS) (Fig. 10) and where grater seasonal irrigation volume occurred (FOG2 and TOR) (Fig. 11).

The water use efficiency in fruit dry matter was very low in rainfed scenario (1.08 $kg\ m^{-3}$), about twice with irrigation and resulted similar among the three irrigation scenarios, (2.02 $kg\ m^{-3}$, on average) (Table 4); a large variability in the spatial analysis emerged, with higher values at FOG1 and CAS, where lowest plant evapotranspiration values occurred (Figs 10 and 12).

Irrigation water use efficiency decreased linearly with the amount of irrigation and was lower in the FOG2, TOR and APR areas (Fig. 13).

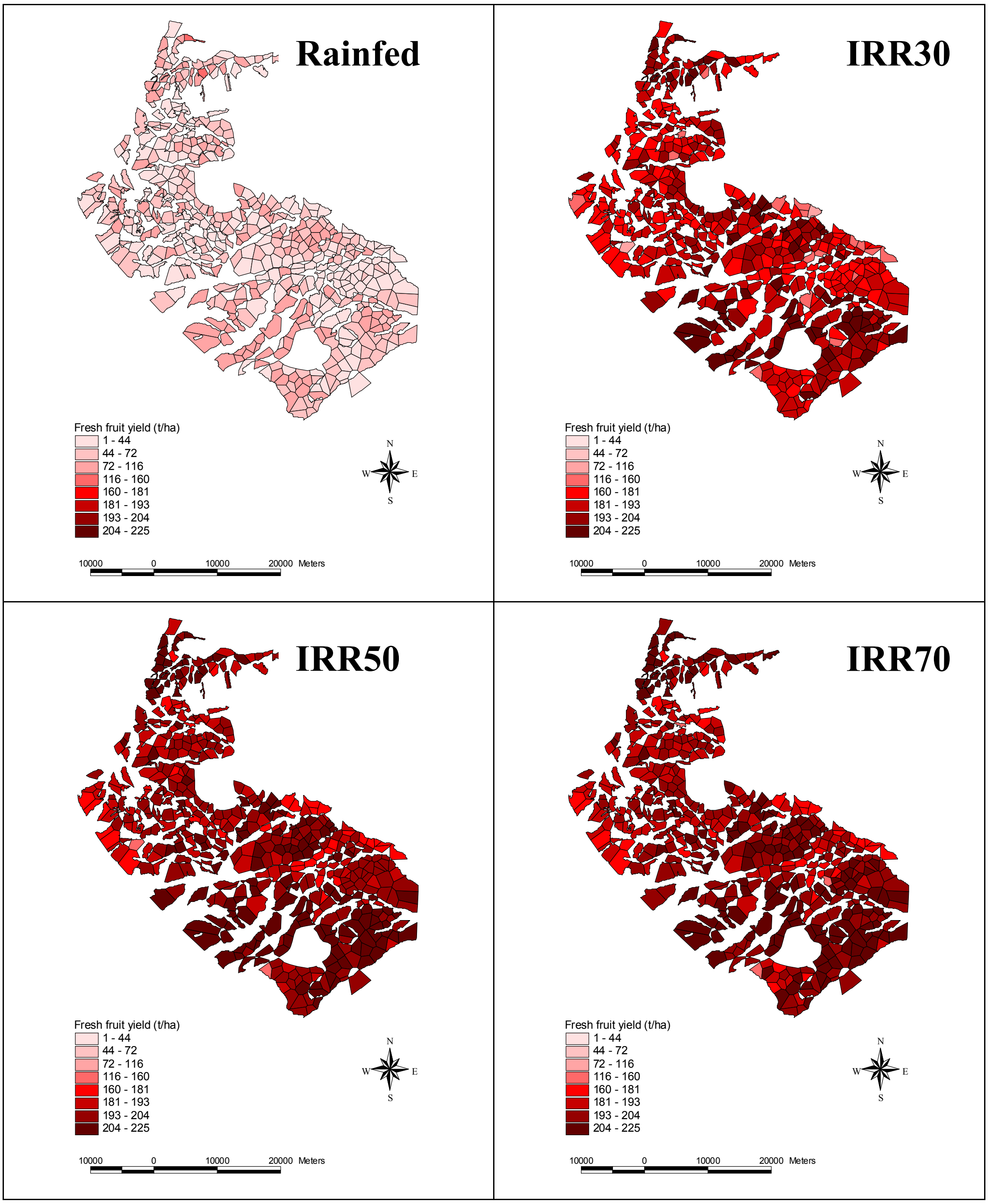

Fig. 8. Fresh fruit yield (t ha^{-1}) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons.

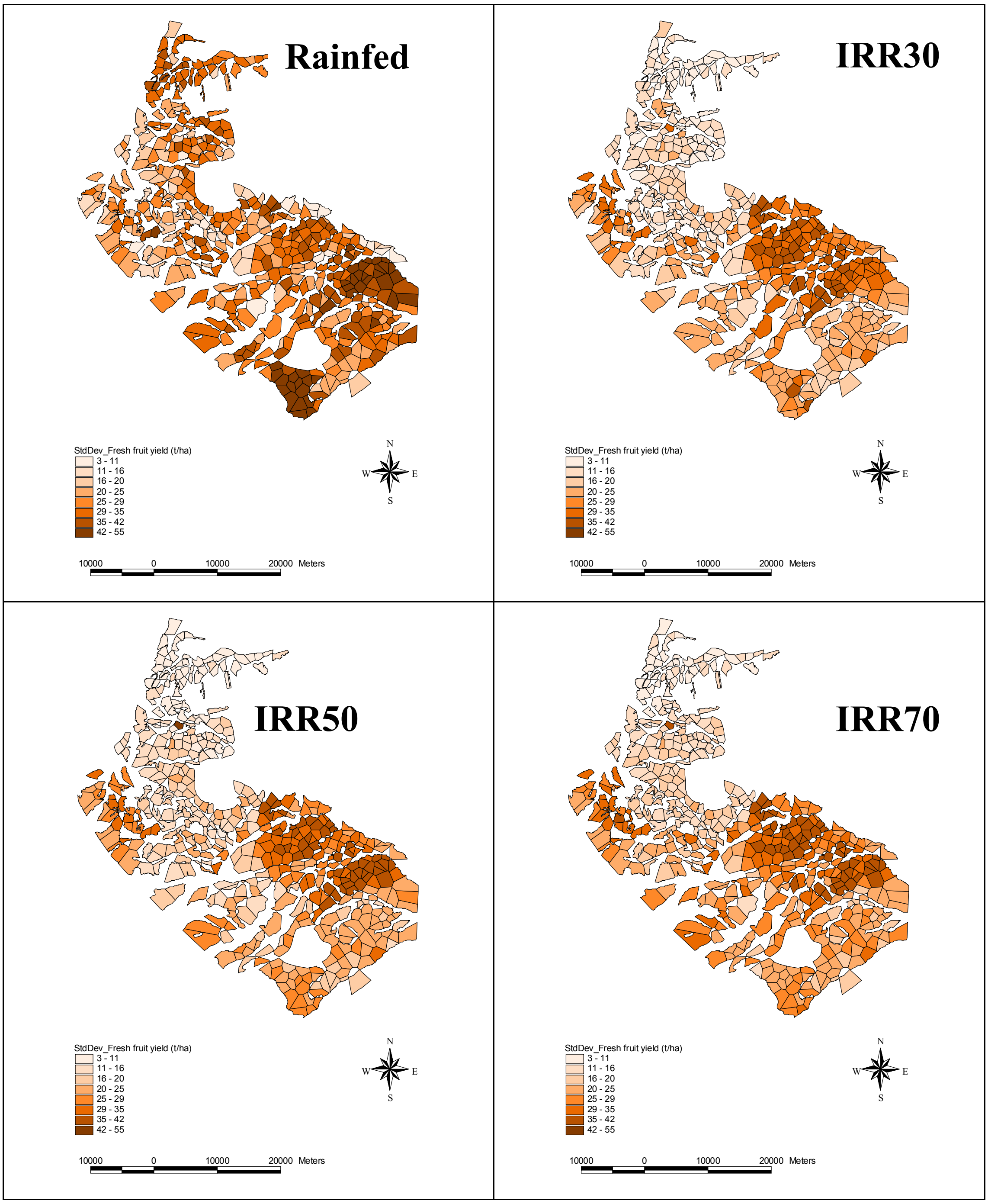

Fig. 9. Standard deviation of 45 years (t ha^{-1}) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons

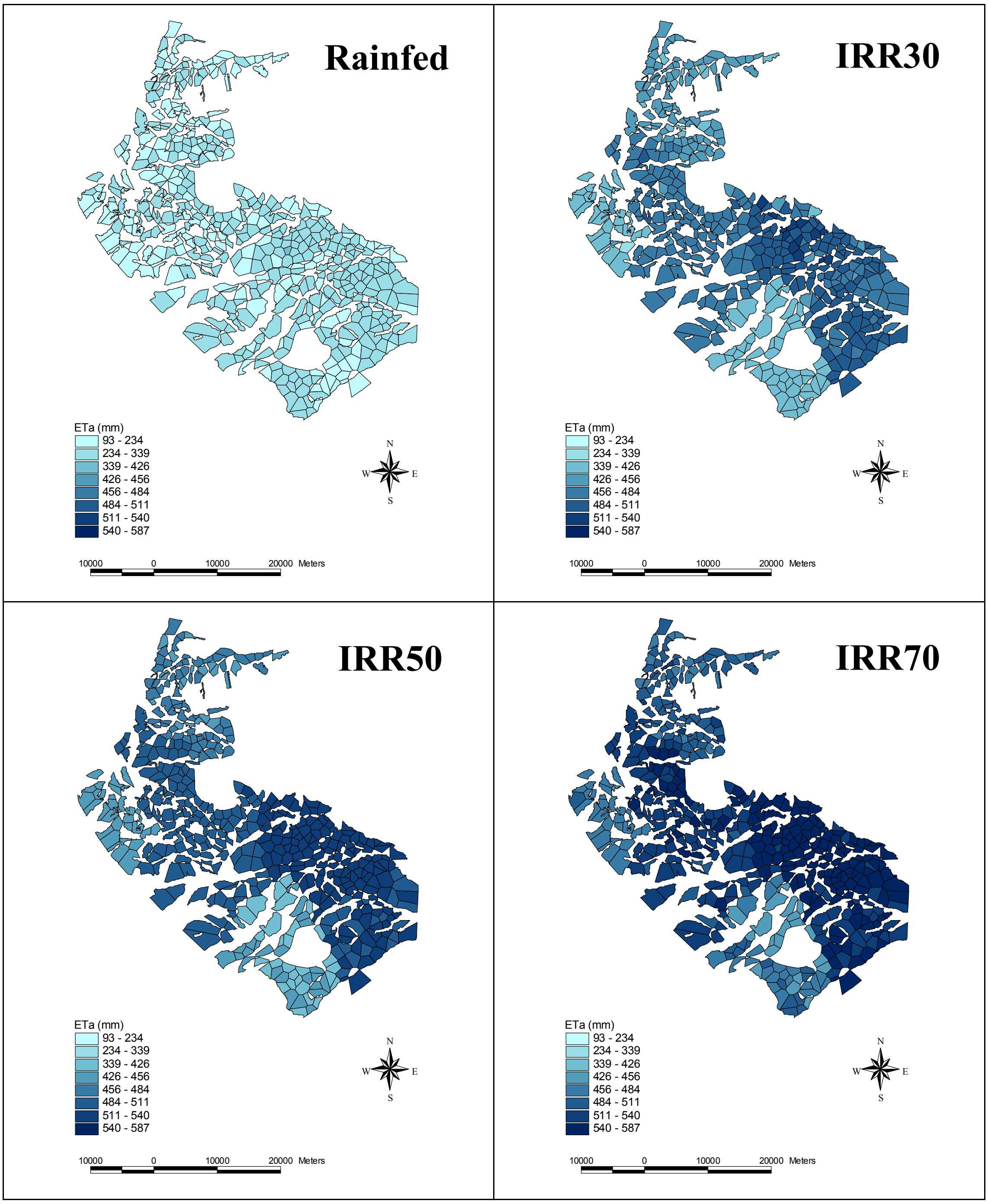

Fig. 10. Actual evapotranspiration (mm) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons.

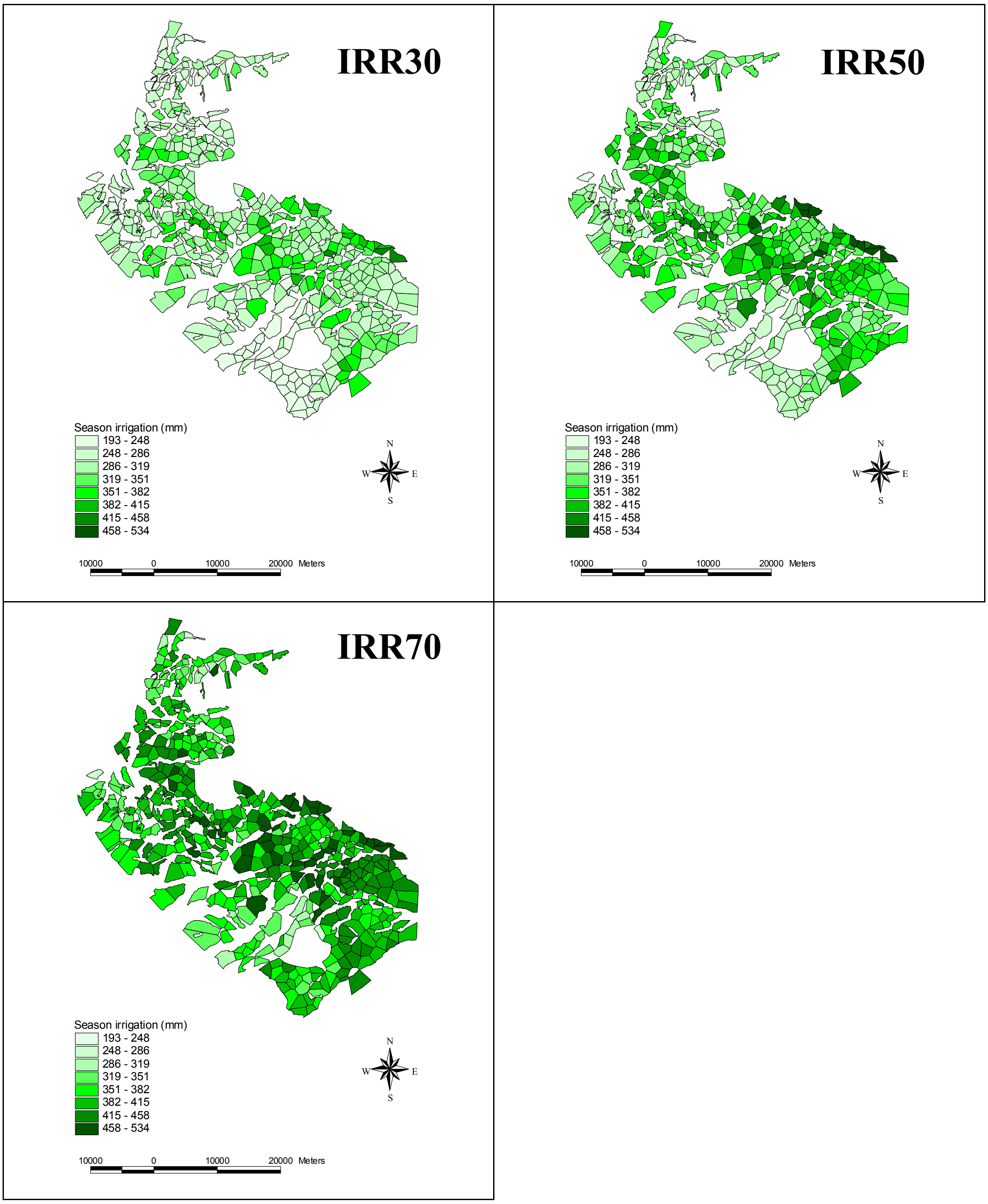

Fig. 11. Seasonal irrigation amount (mm) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons.

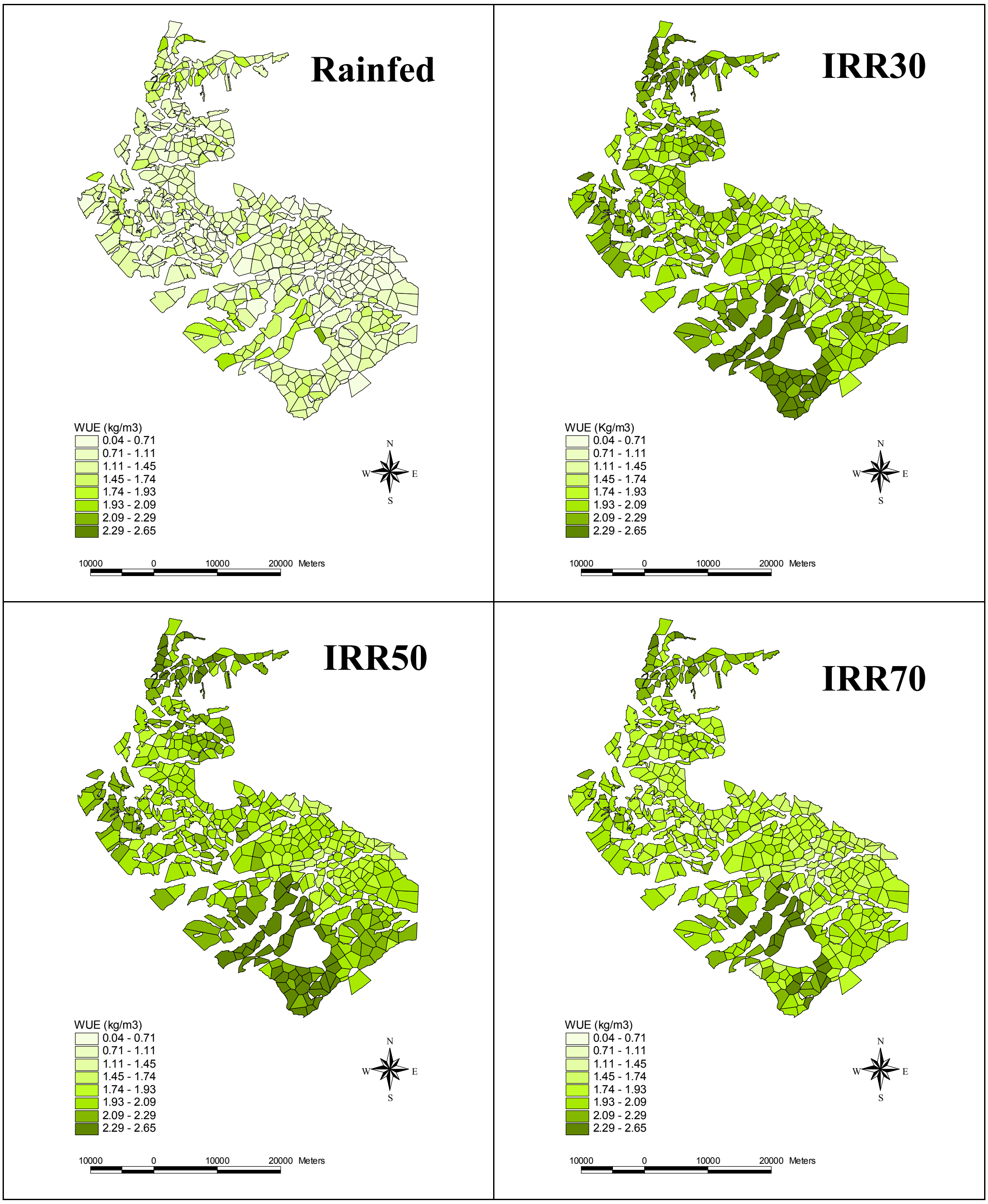

Fig. 12. Water use efficiency in fruit dry matter (kg m^{-3}) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons.

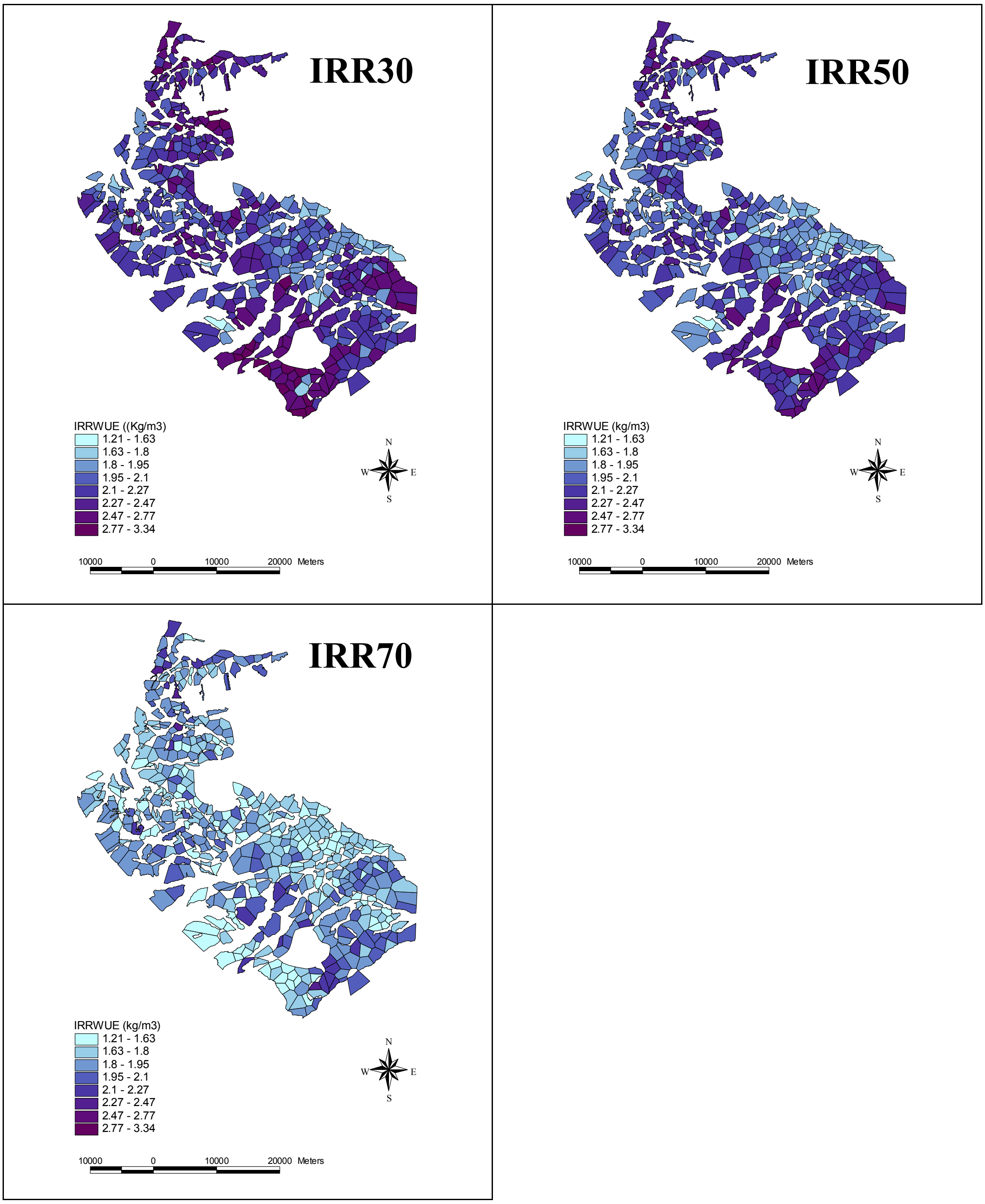

Fig. 13. Irrigation water use efficiency in fruit dry matter yield (kg m^{-3}) of processing tomato simulated by CROPGRO model in the four irrigation scenarios and mapped for the 481 soil polygons.

CONCLUSIONS

Spatial and temporal analyses have been carried out to visualize the most productive and less variable pedo-climatic areas for wheat and tomato crops, when submitted to different irrigation scenarios. DSSAT models, coupled with AEGIS/WIN, allowed to run long-term simulation and check the locations where the two crops give higher yields. The climatic conditions (elevation and sea influence) and soil hydrological characteristics (mainly soil crop available water) influenced crop productivity. Seasonal crop evapotranspiration varied as function of climate, soil hydraulic properties and plant growth. The irrigation scenarios revealed a minimum effect of irrigation on durum wheat (+19%) with no difference among irrigation scenarios. The rainfed scenario matched well with local averages and the areas more yielding resulted the central and northern ones.

The simulation of processing tomato showed a very low productivity in rainfed scenario and high in irrigation treatments. Water use efficiency in commercial dry matter yield was twice higher in tomato than in durum wheat and, this difference was particularly marked for IRWUE (about ten times). This is very important in irrigation water allocation between crops both at farm and district level. The temporal and spatial stability of this crop parameter emerged also from the simulation with two crop models (CERES-Wheat and CROPGRO) that are mainly solar radiation-driven.

The soil characteristics (soil water holding capacity), merged with climatic conditions, indicated the areas where WUE and mainly IRWUE resulted higher (southern part of the Capitanata Plain). In this way we can suggest to water distribution authorities where is more suitable allocate irrigation water, to obtain the best profitability of water.

GIS coupled with agronomic models resulted a very useful tool to simulate in a reduced time a large number of soil/climate combinations and to display outputs. The perspectives of applicative use of these tools are then encouraging.

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