Spatial and temporal analysis of durum wheat productivity in Southern Italy (*)

Michele Rinaldi
CRA – Istituto Sperimentale Agronomico, Bari (I) michele.rinaldi@entecra.it

Vito Borneo
CRA – Istituto Sperimentale Agronomico, Bari (I)

Abstract
A spatial analysis of a long-term simulation carried out with AEGIS/WIN, a Geographic Information Systems (GIS) interface of DSSAT crop simulation package, is described. The case-study is referred to a 600 km^2 area (Foggia, Southern Italy), characterized by 481 soil samples collected at a regular grid. Durum wheat has been simulated punctual-based using soil and long-term weather data. Mapped output variables allowed checking the areas more or less suitable and productive for durum wheat and stable from a temporal point of view. Soil water holding capability influenced the above productive variables of not-irrigated wheat.

Keywords: AWGIS/WIN, CERES-Wheat model, spatial analysis, soil, grain yield, water holding capability

1. Introduction

The knowledge of spatial variability - due to climate and soil differences - is fundamental at country (district) level to plan crop choice, crop management and to forecast yield and crop requirements nutrients balance.

Crop simulation models, combing "soil-crop-weather" relationships can lead to simulation of crop management for several years on large areas. In developing countries the application of simulation models are reported to evaluate the potential yield of a new crop (Matthews, 2002). In developed countries application of model at larger spatial scale about identifying the best crop management (sowing date, irrigation scheduling, N application) in order to maximise yield, reduce waste and pollution, are reported (Heinemann et al., 2002; Nijbroek et al., 2003).

In Southern Italy durum wheat is the most widely cultivated crop; the Mediterranean climate with rainfall mainly distributed from November to March and warm winter, promotes yield and quality of durum wheat. The erratic rainfall can, however, lead to high variability of grain yield ranging from 0 to 6 t ha^{-1}. Spatial and temporal variability will be evaluated in this paper simulating durum wheat with CERES–Wheat model.

2. Materials and methods

(*) This work is supported by Italian Ministry of Agriculture and Forestry Policies under contract n. 209/7393/05 (AQUATER Project)".

An area of about 600 km^2 in Capitanata Plain (Southern Italy) (Fig. 1) 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 soil profiles (115) were examined up to 2,5 m depth. The main chemical and physical characteristics were recorded. Eight meteorological stations located in the area collected daily temperature, humidity, radiation, rainfall and wind velocity.

CERES–Wheat model, embedded in DSSAT program (Jones et al., 2003), previously calibrated and validated for durum wheat in the test area (Rinaldi, 2001; 2004) was used in a long-term (1989 – 2004) simulation. The interface with a GIS program, AEGIS/WIN allowed to display the output using map visualization (Engel et al., 1997; Hartkamp et al., 1999**a**) Thiessen polygons method was used to spatialyze the soil samples results (Hartkamp et al., 1999**b**).

Rainfed wheat management was simulated with automatic sowing date, nitrogen fertilisation with 100 kg of N ha^{-1}; harvest date was simulated by the model at crop maturity. Output variables were analysed and mapped: grain yield (kg ha^{-1}), total plant biomass (kg ha^{-1}), seasonal actual evapotranspiration (ETa, mm), and unit grain weight (g). Standard deviations of means of obtained yearly values for each polygon (soil-climate interaction) were mapped to visualise temporal variability.

3. Results

The average output variables were slightly lower than the common long-term values in the area, due to the particularly dry years occurred in the simulation period. Variability was higher among soils than among years, greater for total plant biomass, lower for grain unit weight (Tab. 1).

Table 1 – *Averages, standard deviations (in kg of dry matter ha^{-1}) and variation coefficients (in %) of durum wheat simulated by CERES-Wheat, in the case-study, referred to the 16 years of simulation and to the 481 soils.*

	Total plant biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Seasonal evapotranspiration (mm)	Grain unit weight (mg)
Averages	6644	2483	290	40.4
Standard deviation (Std)	1766	586	37	2.3
C.V.	27	24	13	5.7
Std among soils	3757	1338	76	4.2
C.V. among soils	57	54	26	10.4
Std among years	2990	1051	61	3.5
C.V. among years	46	44	21	8.7

For grain yield, high-productive soils in the central and west parts of the area were detected (Fig. 2). This spatial variability was explained mainly by soil water holding capability (Fig. 3), that in water-limited environment and in rainfed crop management is fundamental for crop productivity. The among-years variability was high in the west side for the land elevation more than 200 m a.s.l. and hilly conditions causing often less fertility than in flat areas (Fig. 4). The grain yield simulated in the northern part was stable along the years, for the nearness to sea (rainfall and temperatures more regular) and deep soils.

The spatial variability of plant biomass resulted similar to grain yield one (Fig. 5), while the unit grain weight, that indicates a good grain filling during May-June period, resulted inversely correlated with grain and plant biomass yield, showing the capability of wheat to compensate with seed size the ear density or plant growth (Fig. 6), moving substances from between source (leaves and stems) and sink (grain) of biomass.

Seasonal crop actual evapotranspiration was influenced by climate, soil water holding capacity and plant growth: the range from 214 to 379 mm is common in the test area, without large differences among the soils (Fig. 7).

4. Conclusions

Spatial and temporal analysses have been carried out in a typical durum wheat cropping region in to visualize the most productive and less variable pedo-climatic areas. CERES-Wheat simulation model, coupled with AEGIS/WIN, allowed to run long-term simulation and check the best and the worst sites where crop rainfed wheat yield. The climatic conditions (elevation and sea influence) and soil hydrological characteristics (mainly soil crop available water) influenced durum wheat yield, total plant biomass. Grain unit weight resulted inversely linked to grain and plant biomass yield. Seasonal crop evapotranspiration varied as function of climate, soil hydraulic properties and plant growth.

GIS coupled with agronomic models resulted a very useful tool to simulate a large number of soil/climate combinations and to display output. A future approach will be the use of GIS software to analyze the output of simulation models with geostatistical procedure.

References

Basso B., Ritchie J.T., Pierce F.J., Braga R.P., Jones J.W. (2000). Spatial validation of crop models for precision agriculture. *Agricultural Systems* 68, 97-112.

Hartkamp A.D., de Beurs K., Stein A., White J.W. (1999**b**). Interpolation techniques for climate variables. NRG-GIS Series 99-01. CIMMYT, Mexico, DF.

Hartkamp A.D., White J.W., Hoogenboom G. (1999**a**). Interfacing geographic information systems with agronomic modelling. A review. *Agron. J*., 91, 761–772.

Heinemann A.B., Hoogenboom, G., de Faria, R.T. (2002). Determination of spatial water requirements at county and regional levels using crop models and GIS. An example for the State of Parana, Brazil. *Agricultural Water Manag.*, 52, 177-196.

Jones J.W., Hoogenboom G., Porter C.H., Boote K.J., Batchelor W.D., Hunt L.A., Wilkens P.W., Singh U., Gijsman A.J., Ritchie J.T. (2003). The DSSAT cropping system model. *Eur. J. of Agronomy*, 18, 235-265.

Matthews R. (2002). Crop-soil simulation models: Applications in developing countries. CABI Publishing. Wallingford. Matthews, R. and Stephens, W (Eds).

Nijbroek R., Hoogenboom G., Jones J.W. (2003). Optimizing irrigation management for a spatially variable soybean field. *Agricultural Systems*, 76, 359-377.

Rinaldi M. (2001). Durum wheat simulation in Southern Italy using CERES-Wheat model. I. Calibration and validation. Proc. of 2nd International Symposium "Modelling Cropping Systems", Florence (Italy), 16-18 July, 81-82.

Rinaldi M. (2004). Water availability at sowing and nitrogen management of durum wheat: a seasonal analysis with CERES-Wheat model. *Field Crops Res.*, 89, 27-37.

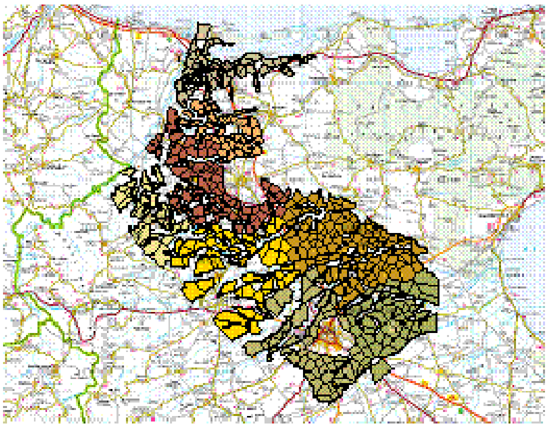

Figure 1: *Spatial localization of soil samples (polygons) and linked agro-meteorological stations in Capitanata Plain.*

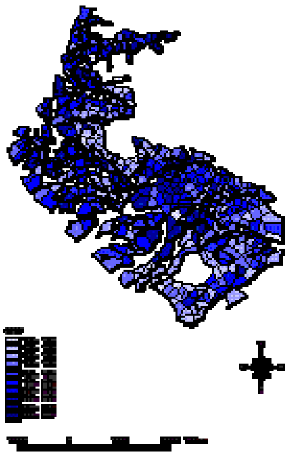

Figure 2: *Crop Soil Water (Field Capacity – Wilting Point in 1.0 m soil depth).*

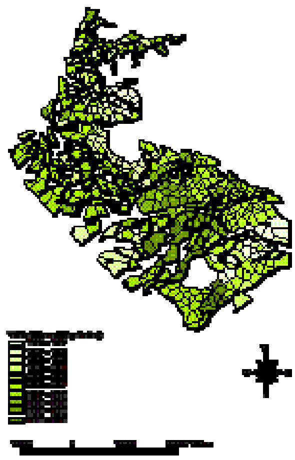

Figure 3: *Simulated grain yield (in kg ha^{-1}).*

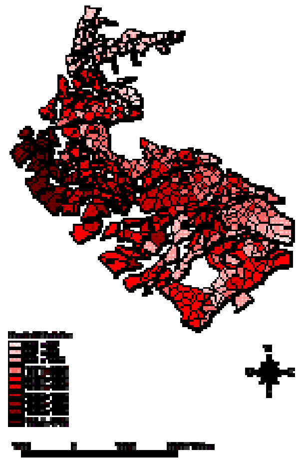

Figure 4: *Standard deviation of grain yield (in kg ha^{-1}) in the 16 years of simulation.*

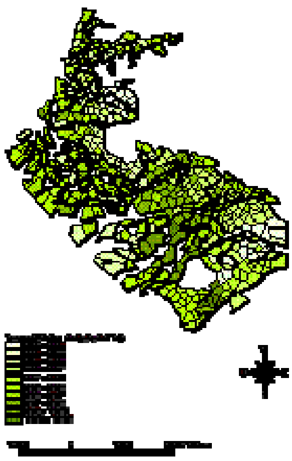

Figure 5: *Simulated total plant weight (in kg ha^{-1}).*

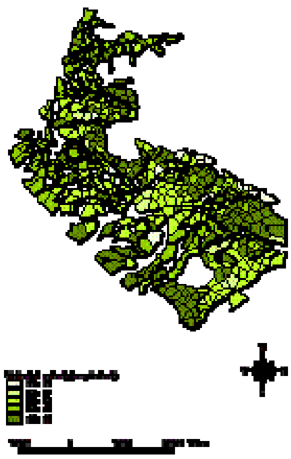

Figure 6: *Simulated unit grain weight (in mg).*

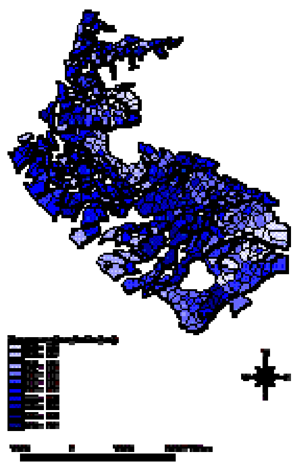

Figure 7: *Simulated of seasonal ETa (in mm).*