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Steduto P., Todorovic M.

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The Agro-Ecological Characterisation of Apulia Region (Italy): Methodology and Experience

Pasquale Steduto[1] and Mladen Todorovic[1]

Introduction

The Apulia region is situated in the eastern part of Southern Italy and comprehends a surface area of approximately 19,500 km^2. The region is relatively long (350 km) and narrow (60 km), extended from NW to SE and it is largely opened to the Adriatic and Jonian Sea with a coastal zone of nearly 700 km. The climate is mainly of Mediterranean semi-arid type, characterised by hot and dry summer and moderately cold and rainy winter season.

The Apulia region is prevalently levelled to slightly sloping, with more than 60% of territory below 200 m above sea level. The high and steep land zones are located only in NE (Gargano) and NW (Sub-Apennian Dauno) with several peaks of more than 1,000 m above sea level.

Five physiographic units may be distinguished in the Apulia region. Three of them (Sub-Apennian Dauno, Tavoliere delle Puglie and Gargano) are situated in the North from NW to NE respectively, the Murge covers predominantly the Central part of the region, and the peninsula of Salento is located in the South. The dominant soils are Cambisols, Luvisols and Vertisols, characterised by cretaceous limestone, marl and clayey to sandy deposits.

The agricultural area represents about 70% of the total surface area of the region. The most important agricultural land for production of cereals and vegetables is situated in the Central Northern

[1] CIHEAM - Mediterranean Agronomic Institute of Bari, Italy.

zone (Tavoliere delle Puglie), while olive trees and vineyards dominate Central and Southern parts of the region.

During the last decades, some attempts for the characterisation of the Apulia region from the climatic and soil point of view were carried out as it is reported in several maps and publications (Mancini, 1966; Mancini and Ronchetti, 1968; Vianello and Zecchi, 1988-1990). However, these works did not provide sufficient analysis of climatic and soil parameters over the whole region. Moreover, the detailed agro-ecological analysis of the region in response to climatic and soil conditions was missing. These were basically the reasons for the development of the Agro-ecological Characterisation of the Apulia Region (ACLA) Project, which aims to assess the potential productivity and to offer the basic territorial information system necessary for decision making processes of local governmental and research institutions.

This paper describes the methodology used and experiences acquired during the development of the project and presents some preliminary results related to the soil and climatic database and crop modelling approaches. Moreover, it represents a reference framework that can be applied to many other Mediterranean Regions.

Background and Objectives

The activities on the agro-ecological characterisation of the Apulia region started in the beginning of nineties within the frame of the ACLA-1 project (acronym is the same with the one described above). This project represented an initial step in developing soil and climatic databases for the Apulia region. However, in this phase, the databases were created from very limited information and they were not integrated in a Geographic Information System (GIS). Moreover, the crop database was missing and the crop productivity models were not used. Consequently, the ongoing project, named ACLA-2, aims:

- to extend the existing databases through the acquisition of new information;

- to develop digital soil, climatic and crop databases of the Apulia region,
- to estimate the potential agricultural productivity of the region using a modelling approach, and
- to integrate and analyse databases within a GIS environment and produce the agro-climatic and agro-pedological maps of the region.

The final scope of the Project is to establish an efficient computer-based support system, which will assist the regional scientific and administrative institutions in storing and managing large, spatially referenced, environmental databases. These databases have to provide responses to the following issues:

- the plant species most suitable for growing at an administrative unit with limited and/or non-limited input of resources (water and nutrients);
- the area most suitable for growing a certain crop with limited and/or non-limited input of resources;
- the area which satisfies the query-defined requirements about climatic variables;
- the area which matches the query-imposed soil characteristics.

It basically means that the regional authorities have to access a GIS database and through an evaluation of the thematic queries identify the areas of particular interest. The results of each query have to be synthesised in spatial, tabular and graphical forms and to be printed in an appropriate format on user’s request.

Methodology

The ACLA-2 Information System (Fig. 1) consists of the spatial GIS-based data comprehending administrative units, land use, soil, climate and topographic data and a non-spatial crop database (Steduto et al., 1999). The former is used for generation of various thematic maps whereas the latter provides input data for the crop productivity models and necessary information for development of the various scenarios relating to the data query analysis and design of homogeneous agricultural zones.

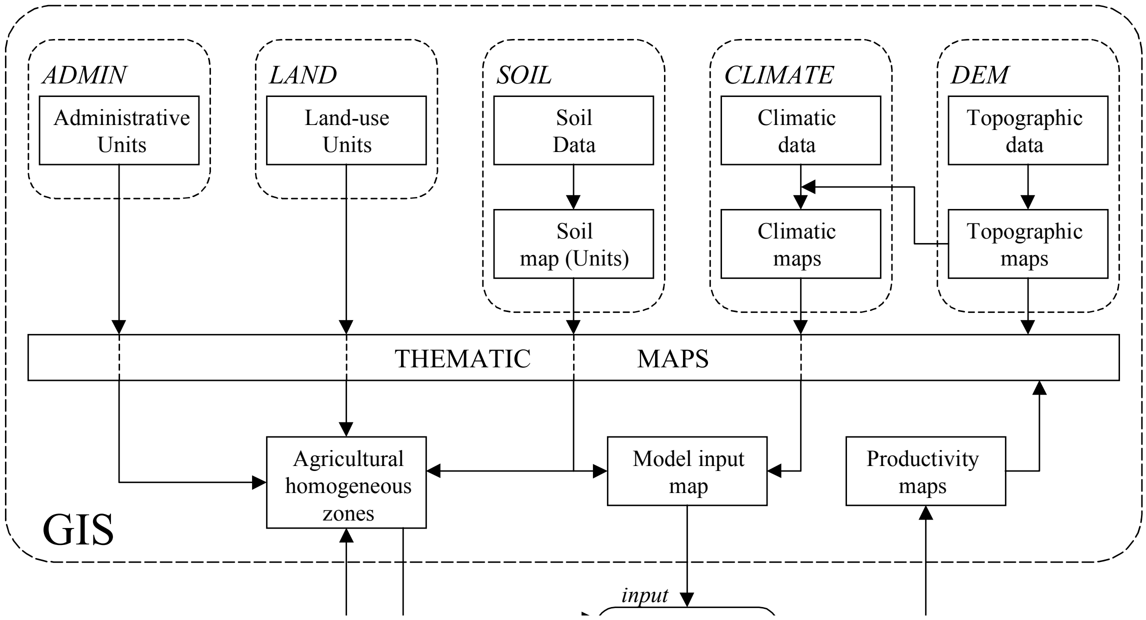

Figure 1. Schematic structure of the ACLA-2 information system and flowchart of main operations.

The ACLA-2 applies an "adaptation" methodology for the integration of different data sets at various steps of the project development. This essentially means primarily constructing the database of soil, climate and crop information, based on the already existing data, and subsequently implementing (while advancing) the new information and the extension of the procedures for agro-ecological characterisation and crop modelling. Progressively, this primary information is transformed into more detailed databases and used for the running of the crop productivity models and the generation of the thematic maps.

Soil database development

The ongoing project aims at designing the regional soil map at 1:100,000 scale. The primary regional soil database is developed from a number of soil information belonging to soil surveys and maps realised in the previous investigations. The ongoing activities are focused on the realisation of about 5,000 new soil sampling sites, which include 4,000 auger observations, 500 soil profiles, and 500 general soil observations. Soil survey is mainly oriented towards highly productive agricultural zones of the Apulia region where soil information is lacking or it is inconsistent and/or insufficient for the realisation of the regional soil map.

A GIS-based progressive sampling procedure is applied for the determination of new sampling locations. The procedure involves a series of successive samplings, where the soil data set is updated and analysed systematically after each series of samplings (Todorovic et al., 1998). A relational semantic database is developed in GIS where the results of soil physical and chemical analysis are associated with digitised geographic locations of soil sampling sites. Then, this site-based information is integrated with the soil data pertaining to the previous analysis. Finally, the new soil sampling locations are derived as the areas of inconsistency identified from the thematic sequential queries, which compare the soil characteristics derived in the previous investigations with the soil data belonging to the new soil survey campaign.

The preliminary soil map of the Apulia region is prepared at a scale of 1:250,000. It is derived basically from the soil information coming from previous surveys, which is integrated and compared with soil characteristics obtained during the actual soil campagn. The soil mapping units are determined as cartographic units having similar geolitology, morphology and land use. The soil mapping units are delimited adopting the minimum surface area of 1.5 km^2 for a polygon and the minimum distance of 1 mm between arcs on the map, as it is proposed by the European Soil Bureau Manual of Procedures for the development of the European Soil Database (ESB, 1998).

Applying an ascending method, the soil mapping units are grouped first into eco-pedological units (Fig. 2) and then also into soil regions (Fig. 3).

Soil classification is available in both the USDA Soil Taxonomy classification (USDA, 1998) and the FAO (FAO, 1990) and WRB system (FAO, ISRIC and ISSS, 1998). The design of the regional soil map at a scale of 1:100,000 will be possible at the end of the actual soil survey campaign and the acquisition of new 5,000 soil samples.

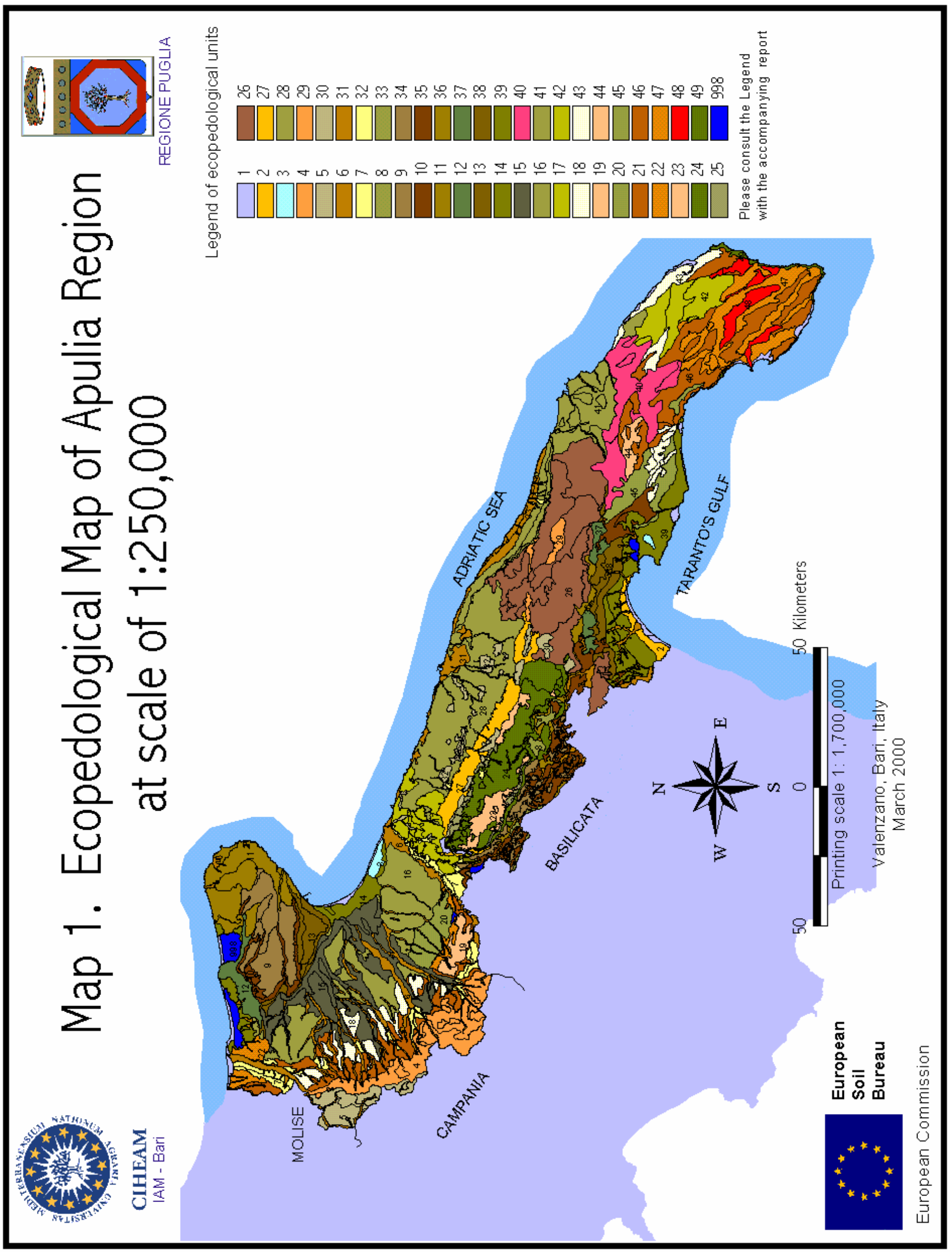

Figure 2. Eco-pedological map of Apulia region at 1:250,000 scale (Detailed description of eco-pedological units is available at IAMB).

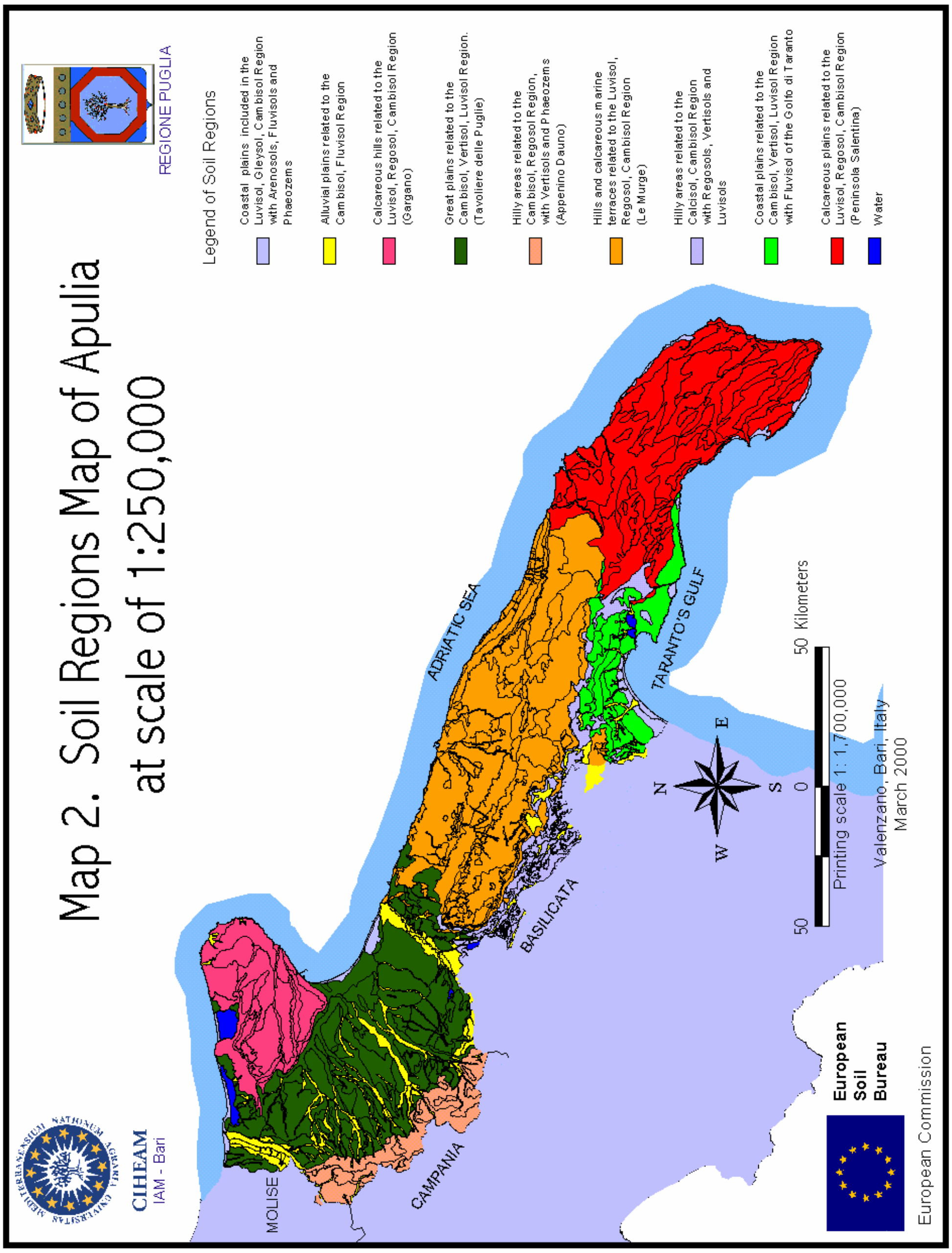

Figure 3. Soil regions of Apulia region at 1:250,000 scale.

Climatic database development

The climatic database aims at long-term assessment of weather conditions over the entire region. Furthermore, the climatic data should be used for the realization of the thematic agro-climatic maps and as an input for the modelling of crop productivity in the region.

The main source of climatic data was the National Hydrographic Institute that provided the historical series of monthly values of precipitation and minimum and maximum temperature at 162 locations for a period of 42 years (from 1951 to 1992). The homogeneity and integrity of data was assessed for each station by comparison with the nearby stations through the double mass analysis.

The available climatic data imposed the use of the Hargreaves method (Hargreaves and Samani, 1985) for calculation of reference monthly evapotranspiration from minimum and maximum air temperature at each of 162 locations. The climatic water deficit is calculated for each station as a difference between precipitation and reference evapotranspiration. Then, the primary climatic database is created containing for each of 162 locations the long-term monthly and yearly averages of precipitation, evapotranspiration, climatic water deficit and minimum and maximum air temperature.

The spatial interpolation of weather variables is performed using the kriging method for both annual and monthly data sets. The results of interpolation are integrated in a cell-based (raster) GIS format. This database provides the input information for the modelling of the crop productivity at the regional scale. Moreover, the same database is used for the evaluation of spatially-referenced queries and the development of various agro-climatic maps. An example is given in Figure 4 where the isolines of the climatic water deficit on a yearly basis are presented along with the locations of agro-meteorological stations with known on-site climatic information.

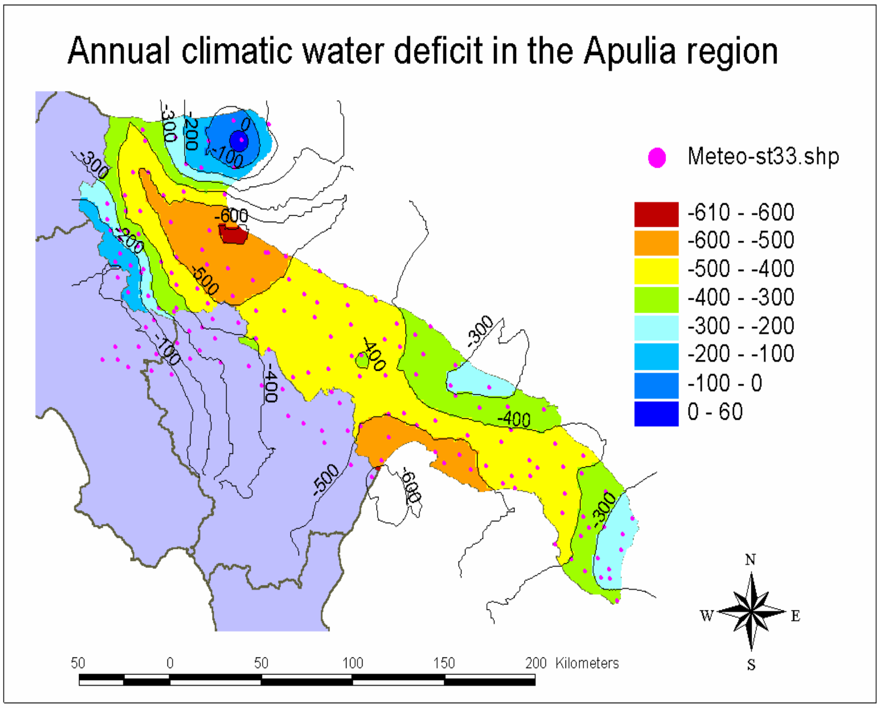

Figure 4. Spatial distribution of climatic water deficit in the Apulia region on an annual average basis.

Land Evaluation and crop modelling criteria

Once the soil and climate information systems of the Apulia Region are established with adequate correctness, an important, subsequent step is the classification of the various "zones" in terms of their productivity attitude for the crops of major interest in the region.

A classical approach to such a task would be the "land capability evaluation" (e.g., FAO, 1983, 1985, 1996) according to some qualitative parameters of the pedo-climatic environment. In the ACLA-2 project, a more quantitative approach of the "capability evaluation" has been adopted through the determination of potential productivity of the "zones" (for the various crops) making use of appropriate crop modelling criteria.

While mechanistic modelling of field crops overcomes the qualitative and static limitations of the conventional methods, it cannot be applied satisfactorily to tree crops yet. Nevertheless, empirical modelling of tree-crops productivity can be adopted with a similar quantitative manner as the mechanistic modelling of field crops.

Hereafter, the "productivity attitude" criteria of the "zones" are described along with the mechanistic modelling approach adopted to determine potential productivity of the region.

Land productivity attitude

In the ACLA-2 project, the minimum size of the "zone" considered homogeneous as a pedo-climatic environment was estimated to be a cell of 500x500 m. The whole surface area of the Apulia region, then was subdivided into a raster grid having "pixels" with 500 m side, coincident with the grid resulting by the spatial interpolation of the climate data. A different criterion was adopted to attribute the physical and chemical soil characteristics to each cell. When soil polygons were converted into regular cells and more than one soil unit was presented in the cell, the attributes of the soil unit with the greatest area in the cell were assigned. Then, soil characteristics, obtained in such a way, are compared and eventually modified in respect to the soil sampling site characteristics.

In this way, each cell represents a homogeneous simulation unit (zone), which is identified deterministically and has its quantitative soil and climate information necessary for the crop model and for the subsequent classification.

The evaluation criteria for the "productivity attitude" of the various cells for the various crops is based on "supply" and "demand" analysis of resources within each cell. In other words, the soil and climate system represent the "supply" of natural resources by a cell, while a given crop represents the "demand" for resources to reach its potential productivity. The "deficit" between "demand" and "supply", then, represents a measure of the “productivity attitude” of the cell, where larger deficit means lower attitude. The above concept is schematically depicted in Fig. 5.

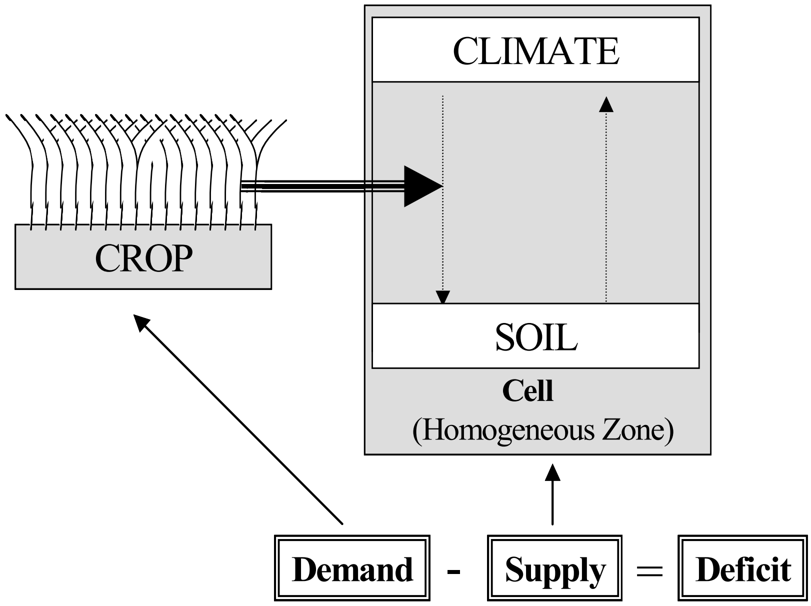

Figure 5. Schematic representation of the "demand" and "supply" approach for the evaluation of the "productivity attitude" of a "zone" for a given crop.

The "demand" of resources changes from crop to crop for a given cell, while the "supply" of resources may (or may not) be fixed. Therefore, the "deficit" of resources by a given cell for crop potential productivity, is dynamic depending on the crop that is going to be grown into the cell. This means that, for a given cell (or zone), we can have a "specific productivity attitude" (for each crop) and a "general productivity attitude" (for all crops together). Both "specific" and "general" attitudes are criteria of land capability evaluation that can be used for classification.

The way to quantify the "specific productivity attitude" is through the calculation of the "attitude productivity index" (APIij) of a given cell (i) and for a given crop (j), defined as:

$$API_{ij} = \left\lfloor \frac{(Actual\ Yield)_j}{(Potential\ Yield)_j} \right\rfloor_i \qquad (1)$$

The APIij, index, having values ranging between the theoretical limits of 0 and 1, can rank a relative "specific productivity attitude" for a given cell. To rank the "general productivity attitude" of the cell i (GPAi), the average of the APIij values for the whole set of n crops can be utilised, i.e.,

$$GPA_i = \overline{API_i} = \left[\frac{\sum_{j=1}^{n} API_{ij}}{n} \right]_i \qquad (2)$$

Examples of "specific" and "general" productivity-attitudes ranking are sketched in Fig. 6.

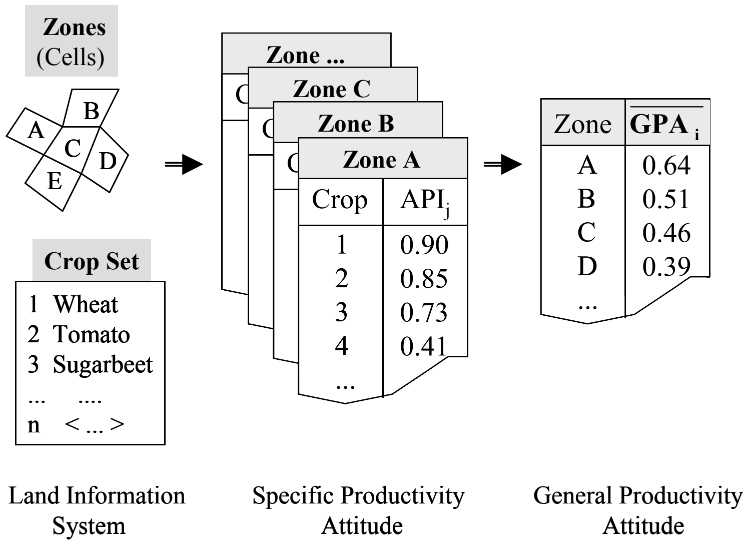

Figure 6. Schematic view of the Land Evaluation for "specific" and "general" productivity attitude of the Apulia region

One of the advantages of this "classification" approach (allowed by the mechanistic modelling) is given by the possibility of "deficit parameterisation" (Fig. 5), which in turn means the "parameterisation" of the "productivity attitude" of the zones of a territory, as function of the "resource" of major interest. For instance, it can be identified the "demand" and "supply" for water, for nutrients, for solar energy, etc. In the ACLA 2 project, the major deficits considered in the classification are water and nutritional.

Crop productivity modelling

The peculiarities of the field-crop model used in the ACLA-2 project are substantially similar to the mechanistic models found in the literature (Joyce and Kickert, 1987; Williams et al., 1989; Stockle et al., 1994). However, three major features distinguish this model from the others: (i) the spatial scale of adaptation; (ii) the combination of both the "solar-driven" and the "water-driven" "growth-engines" at the heart of the crop-growth model (Azam-Ali et al., 1994) and (iii) the algorithms implementation in a "stand-alone" and a "GIS-Linked/Automatic-running" software format.

The essential framework illustrating the basic relationships between variables in the crop model is shown in Fig. 7.

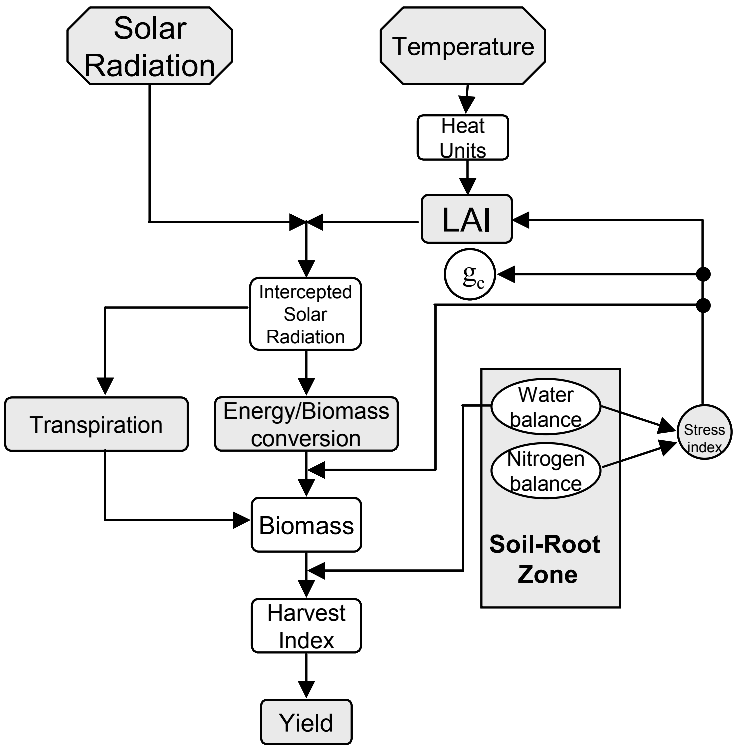

Figure 7. Schematic diagram of the relationships among the variables influencing growth and productivity in the crop model

The driving forces acting on the crop growth are located in the climatic component of the environmental system. Daily air temperature is the main variable influencing the growth and development of the crop during its cycle (emergence, leaf area development, flowering, senescence and maturity stages). Each growing stage is completed when a required amount of "heat" is satisfied. The required amount of "heat", in turn, is quantified by the so-called heat unit (HU), i.e., a relative expression of the centigrade degrees that cumulates each day to reach the given "heat" required.

The main crop expression representing the "capturing" tool in the climatic environment is the leaf area, quantified by the so-called leaf area index (LAI, leaf surface area over one square meter of ground surface area). Given some initial conditions, the crop growth process is triggered by the temperature that activates the leaf area development that "captures" the solar radiation (the second most important climatic driving force).

The energy content of the solar radiation is then converted into biomass. There is a strict relationship between the amount of solar radiation intercepted and the amount of biomass produced by the crop. This relationship is the "solar-driven growth-engine" of the model. It is typical for a given crop and represents the efficiency the crop converts the solar energy into biomass in a given environment. The biomass is then partitioned into the different organs (stems, roots, grains, etc.) and part of it is cumulated into the harvestable yield. The proportion of biomass in the harvestable yield, as compared to the whole biomass, is indicated as harvest index (HI).

If the climatic environment contains the driving forces for growth, the edaphic environment (the soil) may contain the forces opposing for a potential growth of the crop. Root is the main crop expression representing the "capturing" tool of resources in the soil environment. Given some initial conditions, the root starts to explore the soil where water and nutrient budgets are contabilized.

Part of rainfall and irrigation waters are entering into the soil and retained for some time, while some may be lost by runoff and/or deep percolation.

Under the given climatic conditions, the leaves are transpiring and soil surface is evaporating while roots supply water to leaves according to the demand, provided some particular conditions in the soil-plant-atmosphere continuum are not imposing a stress (e.g., low water availability, high evaporative demand, etc.). In a similar fashion, nutrients may start to be insufficient for a potential growth and some nutritional stress may develop.

The stress conditions are acting as feedback mechanisms to reduce leaf growth, in part canopy conductance for water vapour (g_c), efficiency of converting solar energy into biomass and partitioning of the biomass into the harvestable yield. The algorithms accounting for the feedback consider also the central relationship between water transpired and biomass produced, which represents the "water-drive growth-engine" of the model and deals specifically with water stress conditions.

The "GIS-Linked" version of the crop model has all the basic features of the "stand-alone" version, with a substantial advantage of providing graphical interaction between the user and geograhic area of interest. It basically means that the user of the system may define the size of area under consideration and select different crops for simulation. The model runs automatically throughout the pre-defined region and the results of each simulation are presented directly in a geo-referenced format. In such a way, the analysis and comparison of different scenarios is possible in a GIS.

The model has been calibrated for wheat, sugar beet, tomato, green pepper, lettuce, sunflower, artichoke and potato, while the mapping of the potential productivity is in progress.

Conclusions

The ACLA-2 project on agro-ecological characterisation of the Apulia region involves the use of Geographical Information System, for the development of databases and creation of thematic maps, and crop productivity modelling, for quantitative evaluation of land capability. Integration of GIS and crop model promotes the user interaction with the system, which facilitates modification and comparison of various scenarios and gives a clear insight with visualisation and interpretation of spatially referenced results.

The agro-ecological database is designed as an adaptive system, which can evolve new spatial information including attributes, logical relations, policy impacts, and models. This adaptive approach makes the information system applicable for different types of analysis and further assists GIS-based projects at local, regional and national scales. Moreover, the storage and management of regional soil, climatic and crop data in a consistent format provides an opportunity to facilitate the exchange of data and their integration for various purposes.

There are many opportunities to generate new projects from the information and databases developed through the agro-ecological characterisation of the Apulia region. Among them the most reliable seems to be the establishment of the regional monitoring system which takes into consideration the spatial and temporal variability of land use, climate, cropping patterns, irrigation and fertiliser applications, crop growing parameters and yield production, etc. This would be especially useful for a sound management of land and water resources. In addition, the agro-ecological database of the Apulia region could be used as an initial database for risk assessment studies of soil erosion, chemical and heavy metal pollution, evaluation of land, surface and groundwater vulnerability, a variety of hydrological and climate change studies etc.

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