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USE OF AGRICULTURAL CENSUS DATA FOR THE ESTIMATION OF IRRIGATION WATER CONSUMPTION AT FARM LEVEL

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ABSTRACT In the European Union (EU) as whole, 24% of abstracted water is used in agriculture and, in some regions of Southern Europe, agriculture water consumption rises to more than 80% of the total national abstraction. Therefore agriculture can be considered unquestionably the main driving force in the water management.

Overexploitation of water resources along with conflicts among different water uses, due to water scarcity problems, are becoming a pressing issue for environmental stewardship in various areas. Moreover climate change is expected to intensify irrigation requirements and water scarcity in the Mediterranean region.

Accurate estimation of irrigation demands as well as irrigation consumption is therefore, a key requirement for more precise water management and an overview on European water use can contribute to develop suitable policies and management strategies.

The paper analyses a methodology for the estimation of the irrigation water consumption at farm level in Italy by using, as a key source of information, the 2010 Italian Agriculture Census. The methodology will be applied after the Census to estimate the water consumption for the entire Italian farm universe answering to the requirements of a regulation established by European Statistical Office (Eurostat) binding all Member States to collect farm data along with an estimation of the water irrigation consumption.

The methodology grounds on the development and integration of three models which take into account the main aspects related to irrigation water consumption at farm level: crop irrigation requirement, irrigation systems efficiency and farmer irrigation strategy. Each model requires specific data on farm, crops, climate and soil, all information that are scattered among different national institutions and that often exhibit low quality, low resolution and different standard.

The paper describes the methodology and the strategy adopted to tackle with the issues related to the use of Census data, data collection, models integration and accuracy assessment.

Keywords: agricultural census; irrigation; water consumption.

INTRODUCTION Agriculture is the main driving force influencing water use management. In the EU as whole, 24% of abstracted water is used in agriculture and, in some regions of southern Europe agriculture water consumption rises to more than 80% of the total national abstraction (EEA report no. 2/2009).

Overexploitation of water resources along with conflicts among different water uses are becoming a pressing issues for environmental stewardship in various areas due to water scarcity problems. Climate change is expected to intensify water scarcity and irrigation requirements in the Mediterranean region (IPCC 2007; Goubanova and Li, 2006, Rodriguez Diaz et al., 2007).

Accurately estimating irrigation demands (and other water uses as well) is therefore a key requirement for more precise water management (Maton et al. 2005) and, an overview on European water use can contribute to develop suitable policies and management strategies.

Eurostat, with the last regulation about the Farm Structure Survey (FSS), binds all European Member States to provide an estimation irrigation water consumption for each surveyed farm; the aim is to elaborate useful statistics about agricultural water consumption at European level.

Italian estimation of irrigation water consumption will be realized by developing a methodology based on computational models and by fully exploiting the data gathered by the 2010 Italian Agriculture Census (carried out by Italian National Institute of Statistics (ISTAT)) which will provide the enumeration of the Italian farm universe.

The paper describes the characteristics of the estimation methodology made up of three integrated models, data collection process, input data pre-processing, it also highlights the main issues related to the input databases.

We underline that the methodology will be applied after the completion of the 2010 Census, therefore any results or statistics are reported in the paper. Moreover some elements of the models are still not completely defined since the calibration and validation process are not yet completed.

MATERIALS AND METHODS

Methodology The proposed methodology grounds on the development of three integrated models (Fig. 1): Crop Irrigation Requirements Model (Model A), Irrigation Efficiency Model (Model B) and Irrigation Strategy Model (Model C). The models uses readily available information (census data, administrative statistics, spatial data, etc.), information collectable through regular surveys and expert knowledge.

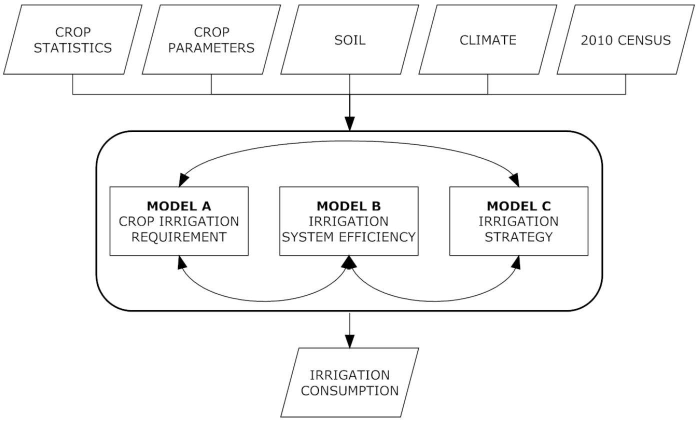

Figure 1. Framework of the methodology: typology of required data and models relationships.

Model A: Crop Irrigation Requirements Model The model simulates the amount of water required by each crop of the farm and the relative irrigation dates by computing a daily root zone water balance:

$$RZWD_i = RZWD_{i-1} - \mathrm{Re}_i - I_i + ET_i + (RO_i + D_i) \quad (1)$$

where $RZWD_i$ and $RZWD_{i\text{-}1}$ (mm) are the root zone soil water deficit on days i and i-1, respectively, and Re_i (mm), I_i, ET_i, RO_i and D_i (all in mm) are the effective rainfall, irrigation, crop evapotranspiration, irrigation runoff and drainage, respectively, on day i.

Generally the root zone is full of water ($RZWD=0$) when the water content is at field capacity, and it is empty when the water content is at the wilting point. Runoff of rain water is not directly considered but through the concept of effective rainfall, while runoff of irrigation water is set as negligible. Drainage of rain water is computed as the excess of the root zone soil water content over field capacity, on the given day of the water balance. Drainage of irrigation water is dependent on the applied water depth in relation to the required depth and the irrigation uniformity, this part is treated by Model B.

The root zone water holding capacity (*RZWHC*) is the depth of water (within the root zone) between field capacity and wilting point.

Effective rainfall as well as reference evapotranspiration (ET_o, mm), estimated by Penman-Monteith equation, are derived from the agro-meteorological database.

Crop evapotranspiration (*ET*, mm) is computed using FAO methodology, based on the concepts of crop coefficient and reference evapotranspiration (Doorembos and Pruitt, 1977).

The crop coefficients are derived using the dual approach (Wright, 1982) in the form popularized by FAO (Allen et al., 1998). The approach separates crop transpiration from soil surface evaporation as follows:

$$ET = (K_{cb}K_s + K_e)ET_o \qquad (2)$$

where K_{cb} is the basal crop coefficient, K_e is the soil evaporation coefficient and K_s quantifies the reduction in crop transpiration due to soil water deficit.
The variation of K_{cb} is typically represented based on the values of K_{cb} at the initial, middle and final stages of the crop growth cycle and the duration of the initial, rapid growth, mid season, and late season phases.

K_e is obtained by calculating the amount of energy available at the soil surface as follows:

$$K_e = K_r\left(K_{c\,max} - K_{cb}\right) \qquad (3)$$

where K_r is a dimensionless evaporation reduction coefficient dependent on topsoil water depletion (Allen et al., 1998) and $K_{c\ max}$ is the maximum value of K_c following rainfall or irrigation.

The stress coefficient, K_s, is computed based on the relative root zone water deficit as:

$$K_s = \frac{RZWHC - RZWD_i}{(1 - p)RZWHC} \text{ if } RZWD_i < (1\text{-}p)RZWHC \qquad (4)$$

$$K_s = 1 \text{ if } RZWD_i \geq (1\text{-}p)RZWHC \qquad (5)$$

where p is the fraction of the *RZWHC* below which transpiration is reduced.

Irrigation is triggered in the model when the soil water deficit in the root zone reaches the management allowed depletion, which is then computed by Model B and C.

Model B: Irrigation Efficiency Model The model takes into account the irrigation application efficiency and the irrigation drainage losses that are related to the irrigation system and the management factors.
The irrigation system is characterized by its application uniformity, while the management factors are considered by a management deficit coefficient. If the deficit coefficient is high, a large fraction of the field will not receive the water required to maintain full evapotranspiration; contrary, if it is low and the application uniformity is low as well, then a significant part of the applied irrigation will be lost as drainage, i.e., the application efficiency will be low.

By assuming the frequency distribution of the applied depth relative to the required depth across the field as a uniform statistical distribution, for a given required depth may be identified three areas that represents: the water available for crop consumption, the water lost by percolation and the part of the root zone receiving any irrigation water. Therefore, three irrigation performance indicators may be defined – Irrigation Application Efficiency (E_a), Percolation Coefficient (*CP*) and Deficit Coefficient (*CD*) - (Wu, 1988):

$$E_a = \frac{X}{(1 - CD)} \tag{6}$$

$$CP = 1 - E_a \tag{7}$$

$$CD = \frac{(X - a)^2}{2bX} \tag{8}$$

where a and b are determined by the application uniformity and X is the ratio between required and applied depth.

The parameters a and b can be derived by using the distribution uniformity *DU* (Warrick, 1983), defined as one minus the ratio between the average applied depth in the quarter of the field receiving less water and the average applied depth in the whole field. *DU*, which is characteristic for each irrigation system, has been tabulated by analysing experimental researches carried out in Spain and Italy and by expert judgment.

Table 1. Average values of *DU* for the main irrigation systems.

Irrigation system	DU (%)
Furrow	70%
Basin	70%
Sprinkler	80%
Drip/Micro-irrigation	90%
Others	80%

E_a can be computed by Eq. 6 after deriving X by using the management deficit coefficient (*CD*) provided by Model C.

The irrigation drainage losses can be expressed as $I_i \times E_a$ where I_i is the irrigation computed knowing the required water depth estimated by Model A.

Irrigation Strategy Model (Model C) The irrigation strategy refers to the decision of the farmer in relation to the degree of stress to which the crop will be subjected. The strategy depends on the crop type, but also on other factors such as the water availability, the distribution system, the economic dependence on irrigated crops, the farmer's educational level, the irrigation equipment, the size of the farm, etc.

Model C consist of a set of rules implemented by decision tree to determine the management deficit coefficient (*CD*) to be used then in Model B. The rules are defined through the analysis of the farm data collected during the calibration campaign and from experts advise. The decision tree allows to assign a value to *CD* per each crop based on a set of information related to farmer irrigation strategy. *CD* values can be greater, less or equal to p (the fraction of the total available soil water a crop can extract from the root zone, under no water stress conditions).

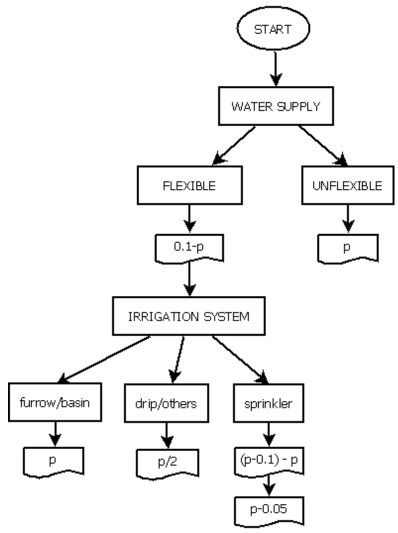

Figure 2. Example of a branch of the decision tree employed to determine the value of *CD* based on specific farm information.

Data collection Data identification, quality assessment and collection have been the main issue of the methodology development process, since it entails a trick procedure of data inventorying at national level. Aiming at an estimation at farm level per every censued Italian farm, data as accurate as possible are requested in order to achieve results with a good level of accuracy. Unfortunately working at national level appear clearly a context where data are scattered among several institutions (national, regional and local) and each one follow different standards in terms of data quality, data collection, data storage, scale and resolution.

The depicted background has lead us to adopt a strategy based on the primary need of collecting data that are standardised at national level and then that are as detailed as possible. Given the context it has been decided to report geographical and statistical at municipal level by considered it as the minimum computational unit. Only the data acquired by the Census have higher resolution being clearly gathered at farm level.

Hereafter all the database, the relative information contained and the collection procedure are described.

<u>Agro-meteorological database</u> The lack of harmonization and standardization among the different institutions operating at national, regional and local level, makes complicated collecting agro-meteorological data at national level. The national scenario is characterised by a strong anisotropy of the quality and standard of the available dataset, thus we settled for a less accurate agro-meteorological database that ensure a complete standardisation and full coverage at national level.

The chosen database, widely exploited by several research projects, has been built in the framework of CLIMAGRI project (Perini, 2007) and contains a complete series of daily values of air temperature, precipitation, solar radiation, relative humidity, wind speed and evapotranspiration (ET0, calculated with the Penman-Monteith formula) estimated for

544 grid nodes covering the whole Italian territory. The daily values have been estimated by kriging techniques over a grid geometry with a regular structure where each node is the centroid of a "meteo cell" with a side length of 30 km. The source information was collected through the Central Office For Crop Ecology (CRA-CMA) meteorological network and others national meteorological services.

The methodology uses a subset of the mentioned data, namely precipitation and ET0. The values are attributed to each municipality by means of a GIS spatial join function.

<u>Soil database</u> Soil data availability in Italy shows the same pattern of the agro-meteorological data in terms of dispersion among local (regional) and national authorities. Indeed, soil maps have been produced by each Italian region at 1:250000 scale, but each region has followed different standard both in terms of mapping techniques and soil measurements.

In order to realize an homogeneous database, to be used at national level for the model simulation, we have set off a huge soil data collection activity that is still in progress. The aim is to make an inventory of all the available soil maps and data produced by the various Italian region building a consistent database of soil characteristics for the whole agricultural Italian territory. The main focus is to collect, for all prevalent soil of each municipality, the parameters required by Model A: field capacity, wilting point and soil depth that are evaluated by a weighted average along the soil profile till a maximum depth of 120 cm.

<u>Crop database</u> The database of crop characteristics is fundamental for crop irrigation calculation and it has been built by collecting information at national level for all the irrigated crops cultivated in Italy.

The main parameters requested for each irrigated crop are: planting and harvesting date, duration of the growing phases, crop coefficients (K_{cb}) for the initial, development, mature and final stage, crop height, root depth and depletion fraction. Data have been collected from experimental projects, literature review and FAO-56 book. Since climate in Italy is very different for geographical reasons, data are acquired for three macro-areas: North, Central and South Italy.

To realize a more accurate database that could reflect both climate and any local condition, a survey on the planting and harvesting date for the main irrigated crops in Italy has been launched. The survey is been carrying out by a brief web questionnaire addressed to farmers, Farm Accountancy Data Network (FADN) surveyors, agricultural technicians working at local and regional agricultural offices and it is intended to collect information based on expert and local knowledge. The data has been gathering at provincial level for three altimetrics zones: plains, hills and mountains.

<u>Census database</u> 2010 Agricultural Census data is the key source to be used to feed the three models. It will provides at farm level: crops acreages and relative irrigation system, crops location (at municipality level), farmer educational level, farm technological level and irrigation water supply (e.g. self-supply by wells/ponds/canals, supply by a public management authority on-demand/rotation).

Extracting information from the census questionnaire is not easy since it has been built following specific constraints laid down by ISTAT that often don't match with the input needs of the models. For example the key information for Model A, the crop acreages, is generally not surveyed crop by crop, but by several aggregation classes, e.g. horticulture. To overcome the issue a disaggregating procedure, based on crop statistics that are provided each year by ISTAT at provincial level, has been designed to extrapolate crop acreages for the crops belonging to the aggregated class.

Models calibration Calibration deals with the tuning of the parameters of Model C to make the simulated farm irrigation consumption equals to the measured one for a representative sample of Italian farms.

The representative farms sample has been defined following a methodology based on a "reasoned sample" instead of a random sampling, avoiding to generate a sample geographically too dispersed and satisfying two constraints: the statistical representativeness at national level and the limited budget allocated for carrying out the sample survey.

The sampling methodology relies on the selection of a group of Italian region, according to a criterion based on agricultural peculiarities, where to localize the final farms sample. In order to achieve an high significance of the observed results on the sample, the eligible farms listed for each region have been stratified according to the variables considered as the most significant for the models in terms of sensitivity. The sample has been defined through a six steps method by using as data source statistics coming from 2003 Farm Structure Survey and from 2008 Farm Accountancy Data Network:

Step 1: Definition of homogeneous classes of annual irrigation water requirements for the irrigated crops.

Step 2: Identification of the prevailing homogeneous class per each Italian region (by using FSS 2003 database containing extensive information about irrigation for Italian farms) and pilot areas selection (by choosing a representative region per each homogeneous class taking also into account the presence of farms equipped with measurement devices).

Step 3: Definition of stratification variables (farm size, irrigation system and water supply) to be used per each regional sample.

Step 4: Definition of the farm sample size and the sampling rate.

Step 5: Listing of eligible farms per each pilot area;

Step 6: Extraction of the farm sample per each pilot area.

A total amount of 290 farms have been surveyed distributed in four pilot areas (Campania, Apulia, Emilia-Romagna and Sardinia region).

A subset of the farms sample will be used for validation after the completion of the calibration phase that is currently in progress.

Methodology application The methodology will be applied after the completion of 2010 Census of Agriculture when all the Italian farms will be enumerated and surveyed. To automate the simulation of water consumption, the methodology has been implemented by a software with a client-server architecture where input and output data are managed by an open-source Relational Database Management System (RDBMS). The software has an import feature to load the Census data in a proper structure and also with a tool to generate farm land use by disaggregating the crop classes contained in the Census questionnaire.

Simulation provided by the software will be done crop by crop per each farm and the final result will be stored in the output database. Simulation results obtained during the calibration phase has provided enough information about models sensitivity showing that the main parameters affecting simulation results are ET0, K_{cb} and soil parameters. In order to account how the resolution of the input data affects the simulation results, some experimental evaluation are in progress concerning soil and agro-meteorological data (e.g. analysis of results obtained with a 5 km agro-meteorological grid and/or with soil map at finer resolution).

Beyond sensitivity to the resolution of the available input data another factor, related to the lack of information on the Census questionnaire, heavily influences the reliability of the simulation results: the spatial uncertainty of the crops of each farms. Spatial uncertainty prevents the attribution of a given crop to a given soil and the relative parameters. To minimize the expected simulation errors, an appropriate procedure for crop to soil coupling has been designed based on GIS processing and experts rules by using soil and land use maps.

CONCLUSION The methodology proposed will provide a first Italian example of irrigation water estimation at farm level for the entire farms universe based on Census data. The approach will provide the water consumption estimation and an evaluation of the impact of the resolution of the input data, as well as the spatial uncertainty of the crops, to the models sensitivity. Unfortunately, working at national level, issues related to the required input data are unavoidable because data are dispersed among different authorities and also are characterized by anisotropy in standard, measurement procedure, scale and resolution and accuracy.

We have showed that a specific strategy for dealing with the data issues must be undertaken in order to apply an estimation methodology at national level. The major challenge is the collection of data as accurate as possible and the identification of standardized dataset at national level as well as the development of suitable procedure for import data from the Census questionnaire being the key source of information in the presented approach. We have stressed also that it is advisable to define a minimum computational unit (the municipality) where to extrapolate all the data necessary to the models and that it is relevant to account for sensitivity of the simulation results generated by input data.

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