EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

MINIPAPER: Tools for improving crop/farm management - "Scientific crop and/or environmental models and their utilization as decision-making tools"

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Introduction and rationale

Agricultural need to forecast or estimate several agronomic parameters that can not be measured directly, leads to the use of mathematics and statistics, that means creating a "numerical illustration": a model. A model can be a simple representation of a natural interaction between two or more variables. For example, the observed decrease of temperature with increase altitude can be represented by a non linear equation. Since the environmental and biological processes that govern crop growth are usually more complex than what can be described with a simple formula, crop models can be represented by compound equations, and are sometimes provided in the form of software organized for further utilization.

Models can be mechanistic, physics based, or rely on a statistical foundation of the parameters that govern crop growth, or, based on a hybrid approach combining both methodologies.

Local statistical models are sometimes easier to construct with local empirical data, based on local farmer knowledge; for example, for a specific area experts or farmers may have observed a correlation between a certain climate trend and crop production. Such as low winter temperatures and high March rainfall usually lead to a good olive crop production. This specific trend may not necessarily hold for another geographic area, but a simple correlation or a linear regression model, based on historical climate and crop production data, could for example represent it. Local trends / models can be very useful for the geographic area of origin and for the crop management typically adopted, but they cannot always be widely applicable. Also, the various environmental modifications (i.e. decreased water availability, increased heat stress, anticipation of blooming time etc.) that are expected to occur due to climate change may further modify local crop/environment interactions, increasing the difficulty to forecast crop responses simply basing on historical data. This leads to the need of introducing and adopting more inclusive models on a wider scale, capable to take into account the complex interactions between plant, environment and management.

Identification of the target issue

When models take inputs from field weather stations and soil/crop evaporation variables (either in real time or for assessment/planning purposes), they can constitute concrete Decision Support Tools (DSS) that can aid for example in automated irrigation scheduling and generally, in water management.

Water scarcity and climate variability are specifically addressed by various DSSs, since these are major issues for irrigated areas of the agricultural land that produces a vast quantity of the world's fiber and food. So, the main end user and target audience of such management efforts are farmers and their local stakeholders.

However, the main identified issue is that farmers make only limited use of the DSSs available to improve their water management and reduce problems related to water scarcity. Many of these systems are being developed to aid farmers with their irrigation management, but they are currently hardly used by them.

There are several reasons for the limited use of DSSs: costs, complexity, risks of failures/mistakes, knowledge needed, unfamiliarity, lack of professional, continuous support.

On the contrary, farmers need cost-effective, robust and simple DSS tools:

- The value of existing cost-effective, robust and simple DSSs has to be put forward to farmers
- Other promising DSSs have to be made more cost-effective, robust and simple.

How to solve the complexities above, and disseminate knowledge on the use of simple DSSs and water management advices to farmers is an important issue, especially under water scarcity and climate variability conditions.

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National, EC, and international case studies

Ongoing examples at national and international level

Crop models, mechanistic or statistical, under long term development, have been parameterized by the scientific community for a wide variety of geographic areas, modeling various agronomic conditions, crop species and varieties. Thanks to their applicability to various environments, such as temperate, tropical and Mediterranean ecosystems, such models are versatile tools either for a local research station, or for a wide area of application.

At the EC level, JRC (1) is using "Crop yield forecasts and crop production estimates", as a support to Common Agricultural Policy decision makers. Outputs from this tool are also useful to "trade, development policies and humanitarian assistance linked to food security".

Crop model development relies on long term scientific work and it is a subject extremely lengthy to be reported in the context of this paper. Just to mention a few of the models developed during the past decades from the international scientific community, we could refer to STICS(2,3,4), DSSAT(5,6,7), CROPSYST(8), WOFOST (9,10,11,12) and its simplified version, SWAP (13). Many of these models are internationally used in crop growth and yield modeling, agro–environmental simulations, crop suitability, climate change assessments and numerous other cases. Such models are suitable for both research-based studies, and also in management or monitoring for larger areas. Usual inputs to default runs of such software are soil profile information, climate or meteorological data, crop species and its characteristics, and other agro-ecological parameters, depending on model approach.

Decision Support Systems for Irrigation scheduling

A certain amount of DSSs are already available for irrigation scheduling, offering a wide range of services, from the simplest estimation of the crop ET_c to the integrated support for several management aspects (irrigation, fertilization, pest management etc.)

Some of them are already available for end-users, and they can be accessed online, free of charge; like several expert systems (www.irriframe.it; www.riegos.ivia.es; http//siam.imida.es); some others are provided by private companies, start ups or associations, like "uMAnage", the "Netafim" DSS system for irrigation and fertilization scheduling (www.netafim.com), the "Hort@" integrated DSS for pest, nutrient and irrigation management of vineyards (www.horta-srl.com), or the fruit-based decision support system for orchard management (www.hkconsulting.it/en). These latter are examples of new consulting services offered by young start-ups.

Many other tools represent the promising results of EU funded research projects, which are there, ready for use (or almost ready), but they have not been adopted on a wide scale yet. Examples of these DSS are: the "GESEQ system" a toolbox for the management of drought events to detect drought conditions, predict their impact and provide support in the decision making (www.futurewater.es); "GARANTES", an integrated system for the optimization of irrigation and pest management in urban green areas (www.garantes.it).

The "SPIDERWebGiS", a satellite assisted irrigation management and farm advisory service providing support for sustainable irrigation management under conditions of water scarcity and drought (www.sirius.gmes.es; www.agrisat.es)

These are just a few examples of the technologies already available at EU level; some of these systems can be used by farmers and farm advisors directly, some other needs the support of the local water management authorities. Despite the availability of these services, few EU farmers are adopting them for their day-by-day irrigation management of their crops.

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Computer Based Decision Making Tools for End Users - Examples

Besides the decision support systems available online and specifically developed for irrigation scheduling, several other computer-based services and tools exist, such as DSS and models, that are customized for, and available to general public and that can be used with minimal expertise from the side of the end user. Some examples are given below.

Irrigation Decision Tree

The Irrigation Decision Tree (14) was developed for starch potato growers in the North East of the Netherlands to calculate the attainable height of investments in irrigation equipment. Based on information on the texture of the topsoil and subsoil, potential rooting depth, organic matter content, groundwater level, crop rotation and the estimated dry period it is calculated which risks are present for yield loss by drought. This is recalculated to an investment value per hectare per year. The decision tree was built in Excel.

Irrigation Expert Simulator (IES)

The Irrigation Expert Simulator (IES)(15) is a web platform for training and supporting farmers in developing personalized irrigation schedules. With this web-tool, users can define their crops, irrigation set up, soil and environmental conditions and then program a virtual irrigation controller to irrigate them. . The tool simulates the daily crop water balance and the yield limitations derived from the irrigation schedules proposed by the users and compares them with those proposed by a "virtual expert".

By means of the comparison of the different categories of irrigation and the recommendation of good practices, the users of this tool will learn to minimize the use of water, while maximizing their production. Also, this system aims at improving the awareness of farmers regarding better water-use strategies and their ability to cope with water shortages; IES is currently being used in classrooms and distant learning courses about irrigation and it is freely accessible at **www.ies-sim.com**

Farm level applications

Several alternative field approaches are also available and can be used by farmers as decision-making tools in various farm level management needs. Such methods and tools can be based on empirical field knowledge, research experiments, can be a small part of research data collection method, and can be useful on providing simple solutions to farmers to monitor and manage plant-water resources

A simple method to determine soil moisture content in the soil and the amount of irrigation

A simple method (16) to determine moisture content in the soil is to dry a sample of about 250 gram soil in a Microwave for about 10 minutes. By weighing the sample before and after the drying the moisture content can be calculated: (weight before – weight after) / weight after drying * 100%.

The amount of irrigation can be calculated by determining also the soil moisture content at about 48 hours after a large rain event. The maximum irrigation amount is then derived from the amount of water in the soil sample after the rain event minus the amount of water in the soil sample before irrigation.

With this method the timing of irrigation has to be determined visually by inspecting crop or soil or soil hydraulic properties must be known.

The method was developed in the Netherlands in the '90s. The use of the method was limited. New irrigation advices have been developed based on satellite images in combination eventual combined with soil moisture sensors. This method is easier in daily use but much more expensive than the simple method described above.

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Determining relative crop stress with a Near Infrared and Red Camera Spectrum Filters

The methodology hereby described may seem rather technical, but with the wide availability to the general public of digital cameras, smart handheld devices and software, it can be feasible. The proposal made in this paragraph is based on similar applications available on the web [(17), and references within].

The method consists of two images taken from the same point of view of the crop field (preferably a perpendicular aerial field view), one with the red color filter and the other with the near infrared color filter. Healthy, unstressed vegetation with high chlorophyll content has high values in the near infrared, and low in the red channel. If plants are stressed during the crop growth stages (due to nitrogen, water, competition levels or other stresses), or are towards maturity, they will have higher values in the red photo channel, and lower in the near infrared one. To make the comparison easier, division of the two images can help using the red one as denominator, which can be done with various open source or free software packages available on the Internet.

Most probably, the near infrared filter should be purchased separately, since it is not included for common devices which capture imagery in the visible range of the solar spectrum.

This approach allows to identify drought stress sooner than the typical visible signs of crop stress appear on plants, thus allowing a management reaction (such as an irrigation event) can be done sooner to alter any stress.

Generally, the ratio of near infrared to red spectrum channels is the basis for many satellite vegetation indices, such as NDVI (18), SAVI (19), and many others.

Evaporation of bare soil versus mulch covered soil

Reduction of bare soil evaporation and other benefits can be delivered by mulching, which can be also produced on site by cover crops or transported off site, depending on management regime.

To empirically derive how much soil water is conserved a rule of thumb (20) is that for every 10% surface cover of non photo-synthetically active mulch, soil evaporation is reduced by 5%, comparing to bare soil evaporation. This simple rule of thumb can be used with the previous paragraphs to help estimate future water needs for a farm or orchard, or how much irrigation water can be preserved if a farmer shifts to a mulching agriculture regime.

Plant physiology as an indicator of (water) stress

When irrigated summer crops, such as maize for example, are experiencing drought, they adopt a series of physiological and biophysical defensive strategies to avoid water losses. Leaves tend first to close their stomata, reducing their transpiration, but also their photosynthetic rates, with negative consequences on the plant carbon assimilation. Furthermore, in conditions of heavy drought stress plant can also modulate their leaves inclination in order to reduce the incidence of sun beans on their surface:. In fact it is quite common to observe how at noon and during the warmest hours of the day, drought stressed leaves tend to fold their upper face along their longest vein, to reduce the heat stress; instead, during the coolest hours of the day, like in the early morning leaves show their natural shape, with their face up open, to intercept solar radiation.

This behaviour can be observed in many crop species, from deciduous trees to other types of plants. Of course, such a stress evidence can be caused also by other reasons than drought (i.e. some pests). However, when the farmer observes this phenomenon, the stressing conditions have already caused a certain amount of losses in terms of carbon assimilation and thus of productive performances. It is therefore crucial not to reach this observable stress point in plants, but rather to act prior to that. Current DSS have exactly this purpose: the early detection of an upcoming drought stress and the adoption of prompted responses to avoid it (like an irrigation), thus maintaining the highest crop productive performances.

Gaps identified

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Significant efforts have been carried out at national and EU level to improve water management as well as monitoring the environmental conditions and crop productive performances. Specifically, for the target issue identified in this paper, focus is required both on improving the tools available and on efficient and comprehensive knowledge dissemination to reach the target audience. More specifically:

1) The tools available have often been tested only in the area/region where they have been developed and where they are currently used. So they would need further tests and research to widen their applicability in a higher range of environments. Also, some DSSs, although based on sound approaches, are available only for some crops, while other crops, though water consuming, lack DSSs.

2) Most of the times these tools, although promising, are not used just because they are not known. Also, they are perceived as complicated and time consuming and sometimes they need investments for which grower don't perceive the actual added value.

3) Besides, these tools lack information and training material and activities to make farmers and advisors aware of their benefits, and capable to adopt them in their productive environment.

Training

The most promising tools and strategies to improve water management should be identified and selected. Their performances in different environments should be validate by further research, while if possible their applicability should be extended to further crops/irrigation systems. The practical implementation and technological transfer of the most promising tools that are still at a prototype stage, or ready to use but not available yet, should be promoted and the results disseminated.

Training activities and courses should be made available to farmers and farmer advisors, as identified elsewhere in this report.

Pilot plots and demonstration sites where some of these tools are applied should be set up in different EU regions, depending on the suitability of the various tools to a certain specific environment/crop.

For any training material or activities, it should be emphasized that specialized education experts with the use of visual and generally multimedia means can develop comprehensive material for the end users. And, broadband Internet availability is one of the most efficient ways to circulate useful instructive material to the interested audience.

Advisor personnel training

Crop models and decision support tools based on one or more modeling approaches with weather and soil inputs have several requirements, with which farmer advisors should be familiarized in order to use and disseminate usable information towards farmers.

Some key factors include:

* The treatment, use in models, and also the collection and management of climate data records: long term series of climate parameters (Temperature, Relative humidity, rain, PAR etc.) collected from weather stations at daily or monthly time scale.

* Familiarity with the main physical and or chemical soil features, and also soil sampling techniques and equipment.

* Use of other, interpolated variables, such as agro-meteorological, ecological, or plant-based parameters related to drought stress.

* Knowledge on crop species and variety characteristics, such as phenological stages and specific requirements per stage

* Such data cannot be always available for each farm or geographic area, but they can be estimated with various statistical and other approaches, and/or be based on expert opinion.

* User familiarity with technical terminology and agronomy, software GUIs or command line tools and computer languages

Farmer training

As more and more computer based applications are developed for end users with minimal expertise (see paragraph "Decision Support Systems for Irrigation scheduling") farmer training needs can be limited to familiarity with the most common computer operating systems, web browsers, and possibly spreadsheets for a more advanced use.

On the agronomic side, farmers should be more familiar with the terminology used in models and DSSs, something that can be done directly in the web/software interface.

At the field level, farmers could get apt help from agronomists for the use of low or no cost, field based methods to estimate key variables for their water management.

Measuring the application impact of decision making tools

National Statistical Services (21) of the EU Member States, the EUROSTAT (22) and also other agencies of the EC collect periodic data and produce information directly or indirectly related to agriculture. In particular, for agricultural production, acreage, crop information, farm ownership level data (i.e. farm size, status) irrigation and rainfed conditions, and generally a wealth of information is collected and available at the smallest municipal unit level of EU member states by their National Statistical Services. This information could be extremely useful for the improvement of existing tools and models, which can be used to assist decision makers. In fact, such statistical data could serve to validate crop model and DSS forecasts based on historical data, and to further calibrate them if needed. Also, they could be used to test local models in other locations.

Furthermore, the availability of historical data on water use and crop productivity both at farm and at plot level could help assessing the actual impact of the use of DSS both from the economical and environmental point of views. The quantification of the economic and environmental benefits of the various models could facilitate their dissemination and adoption on a wider scale.

Websites and Links to resources

EIP-WATER WIRE Action Group: Projects and Demo sites
www.ies-sim.com
www.irriframe.it
www.riegos.ivia.es
http://siam.imida.es
www.netafim.com
www.horta-srl.com
www.hkconsulting.it/en
www.futurewater.es
www.garantes.it
www.sirius.gmes.es
www.agrisat.es

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21 National Statistical Services of the EU Member States

22 Statistical Office of the European Communities. Website: http://ec.europa.eu/eurostat - Agriculture and Fisheries, Eurostat, European Commission

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