Synthesis

Adaptation of irrigation to climate change in the European Union: effective actions of member states to save water

How have water abstractions for irrigation in the European Union evolved? What schemes have been implemented in the Member States to save water? What have been the most convincing results and with which innovative practices? During the conference Water saving in irrigation organised in November 2019 in Montpellier, European experts took stock of the situation. Their varied testimonies show that, on a European scale, water savings are possible thanks to the improvement of the overall efficiency of irrigation, by combining technologies (infrastructures, application systems, planning tools) and more efficient practices.

How are crop water requirements affected by climate change across Europe?

Crop water deficit is defined as the difference between crop-specific water requirement and available water through precipitation. It represents the net irrigation water requirement (NIR) for the full satisfaction of crop requirements. Observed climate change led to a decline of precipitation combined with an increase in the crop water demand. As shown on Figure ❶a, the crop water deficit of maize raised from 1995 to 2015 in large parts of Southern and Eastern Europe to more than 50%, whereas a decrease has been estimated for parts of North-Western Europe.

The projected increases in temperature will lead to increased evapotranspiration rates, thereby increasing crop water demand across Europe. The projected changes in crop water deficit for grain maize are shown in Figure ❶b. Simulations are based on the WOFOST crop model, which includes also the effect of increased CO_2 concentrations on the water use efficiency of maize. The simulations show an increasing crop water deficit for large areas of Europe, in particular over central Europe. This may lead to irrigate crops that have been rainfed so far and to extend irrigation systems in regions currently without irrigation infrastructure. However, this expansion may be constrained by projected reductions in water availability and increased demand from other sectors. Adaptation measures and the integrated management of water, often at the catchment scale, are needed.

How is water abstraction for irrigation evolving?

Agriculture is responsible for approximately 70% of total freshwater withdrawal in the world, mostly through irrigation (FAO, 2015). In Europe, irrigation is currently concentrated along the Mediterranean. The water abstraction rate is estimated at 24% for the whole European Union (European Environment Agency, 2009), although strong regional variations are apparent (Figure ❷).

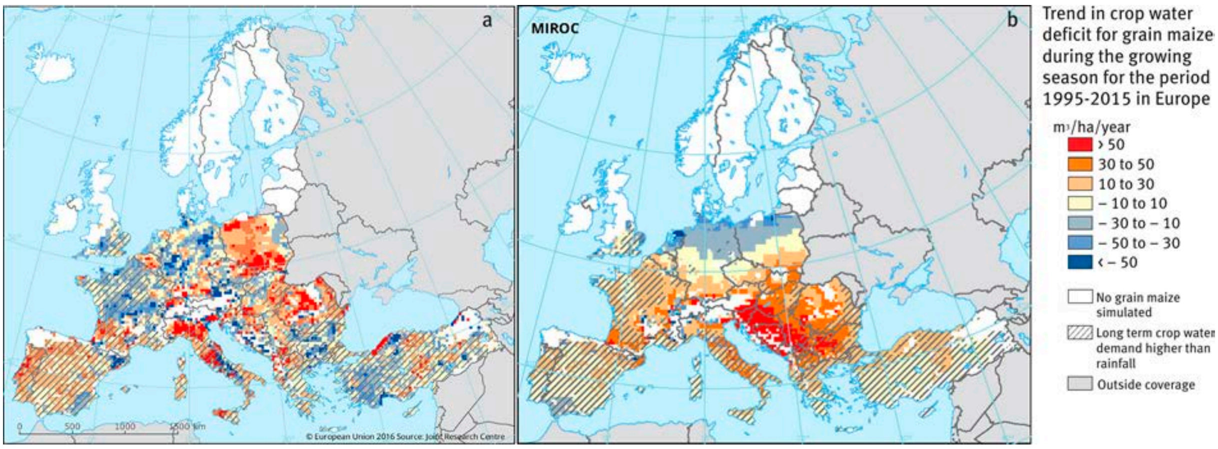
In Northern Europe (Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom), irrigated agriculture is only little developed, and is generally limited to horticultural production in the summer time. Abstraction for agriculture doubled between 1990 and 2000, from 1,500 to 3,300 Mm^3 and then decreased until 480 Mm3 in 2015, representing less than 3% of the global use.

In Eastern Europe (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia), water abstraction for agriculture was almost 14,000 Mm^3 in 1990, when irrigation played an important part in the large scale collectivized agriculture promoted under the Soviet regime. After the break-up of the USSR, there was a general decrease in the irrigation area due to economic factors and the unfit structure of old irrigation systems for the newly emerging pattern of private farming (FAO, 2016). Water abstraction dropped to 3,300 Mm^3 and remained stable since 2000, representing about 12% of total abstraction.

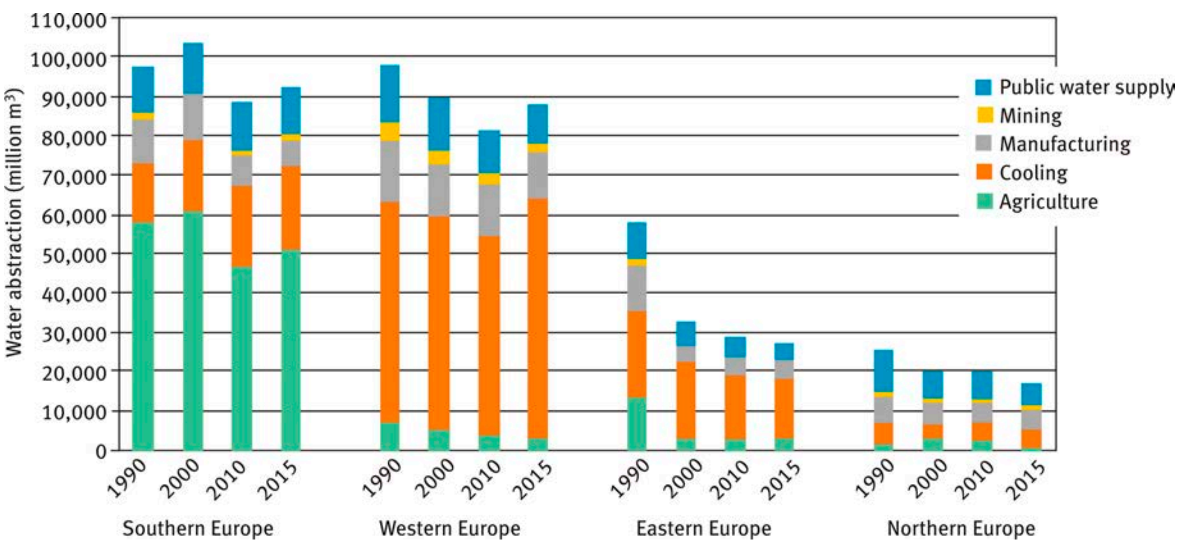
In Western countries (Austria, Belgium, Switzerland, Germany, France, Liechtenstein, Luxembourg, Netherlands) irrigation is carried out mainly as a complement to natural rainfall, which is otherwise generally sufficient for productive agriculture. In these countries, farmers invest in irrigation equipment primarily in order to reduce risk and increase yields of certain crops such as maize, vegetables and industrial crops. Note that the European Environment Agency included France in "Western Europe", even if this group better fits Northern France than Southern, which would more belong to "Southern countries". Water abstraction for irrigation diminished regularly from 7,000 Mm^3 in 1990 to 3,400 Mm^3 in 2015, accounting then for 4% of total abstraction in this area (12% in France; Gleick, 2014).

Southern countries (Albania, Bosnia and Herzegovina, Cyprus, Greece, Spain, Croatia, Italy, Montenegro, Malta, Portugal, Serbia and Slovenia) are characterized by a Mediterranean climate with semiarid conditions that makes irrigated agriculture much more productive than rainfed agriculture. In most cases, irrigation is a long-established feature of agriculture and it is often the principal user of water. With about 60,000 Mm^3, abstraction for irrigation typically accounted for nearly 60% of the total abstracted volume in 1990 and 2000, and about 55% in 2010 and 2015 (46,000 and 51,000 Mm^3, respectively), rising to 73% in Portugal and 89% in Greece (Gleick, 2014).

❶ Crop water deficit of grain maize during the growing season in Europe.
a. Trend for the period 1995-2015. Red colors show an increase of the gap between crop water requirement and the available water, blue colors indicate a reduction of the deficit. b. Projected annual rate of change for the period 2015-2045 with the MIROC model (Model for Interdisciplinary Research On Climate). European Environment Agency, 2016.



❷ Evolution of water abstraction by economic sector since the 1990s (European Environment Agency, 2019).



Overall, despite the intensification of crop water deficit in many parts of Europe, a decrease in water abstraction for irrigation is observed in all regions between 1990 and 2015 (75%, 69%, 51% and 12% for Eastern, Northern, Western and Southern Europe, respectively). It is lower, yet effective, in the regions where crop water deficit is highly pronounced (Southern Europe). This reduction of irrigation water abstraction may have various causes, such as historical/political strategies, choice of cultivated crops, or improvement of irrigation technology. The latter will be detailed below and includes switch from surface to pressurized irrigation systems, upgrade of existing distribution networks, development of more efficient systems, improvement of irrigation practices, adoption of automatization and scheduling methods.

How to save water through the improvement of irrigation technology and management?

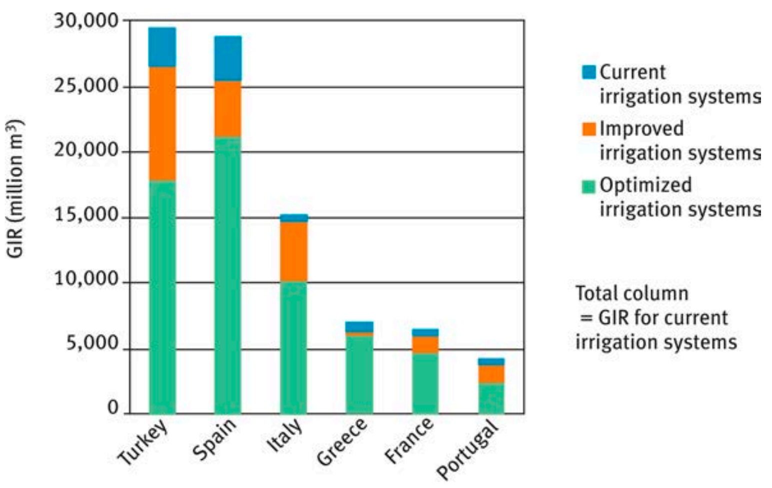
Potential water savings today and tomorrow

There are several levers to save water in irrigation, such as modernization of the conveyance network to reduce leaks, soil and crop management practices (no-till farming, mulching, weeds' management), and improvement of irrigation technology (more efficient irrigation systems) and management (scheduling, deficit irrigation). Concerning the upgrades at the plot level, it is known that localized irrigation systems (microsprinkler, surface and subsurface drip) can help reduce the amount of water applied compared to sprinkler systems (spray gun, center pivot, solid-set), and that adoption of scheduling tools such as soil probes can contribute to saving water, although the observed water savings are highly variable according to the situations (Serra-Wittling et al., 2019).

The particular case of the Mediterranean area

Fader et al. (2016) studied the potential irrigation water saving through more efficient application and conveyance systems, in the specific context of the Mediterranean area (Figure ❸). They compared gross irrigation water requirements (GIR) for the currently used systems, the improved scenario (upgrading of conveyance infrastructure and application devices) and the optimized scenario (water conveyance through pipelines combined with drip irrigation systems). GIR stands for the water abstraction for irrigation and is obtained by dividing the net irrigation water requirement (NIR) by the global system efficiency. Thus, the difference between GIR and NIR represents the irrigation water losses at the conveyance system and plot levels. The results of this work show that the Mediterranean area could save at present 35% of water by strongly improving the irrigation systems and the conveyance infrastructure (optimized scenario). A minor improvement (improved scenario) could lead to 10% water savings. Some countries (Turkey, Spain) have a higher saving potential than others (Greece, France, Portugal) do. The authors conclude that political incentives for water saving technologies as well as the development of efficient public water conveyance systems may help to reduce water extractions already today but also under future climate change.

❸ **National gross irrigation water requirements (GIR) in some European Mediterranean countries for current irrigation systems, improved irrigation systems and optimized irrigation systems, as the average of the period 2000–2009 (adapted from Fader et al., 2016).**



Germany. Diversifying crops: a lever for adaptation to climate change, in addition to improving irrigation scheduling[1]

In Germany, 373,000 ha were used for irrigation in 2010, accounting for 3% of the total cultivated area and 1% of the total country area (FAOSTAT, 2019). Irrigation is performed primarily to ensure yield and quality level. In the light sandy soils in the North and East German regions, soil water-holding capacity is low, and yearly precipitation is not sufficient to supply optimally the cereals, potatoes, and vegetables. In southern Germany, clayey and silty soils with high water-holding capacity might need additional water supply at lower precipitation and for crops that are more sensitive to water stress, such as sugar beets, potatoes, and vegetables (Drastig et al., 2016a).

During the 1902-2010 period, the mean annual precipitation increased approximately by 1 mm/yr, whereas the annual temperatures increased by 0,01 °C per year. However, no significant increasing or decreasing trend in the modeled irrigation water demand (mm/year) was noted (blue line in Figure ❹) (Drastig et al., 2016a). Simultaneously, the net volumetric irrigation water demand (Mm³/year) decreased (blue area in Figure ❹) as a consequence of a pronounced change in cropping pattern and areas (less potato and oat). Thus, the choice of crops in Germany had a stronger impact on irrigation water demand than climate change.

In the last ten years (2008-2018), agriculture in Germany had to cope with relatively higher irrigation water demand on five extremely dry years, leading to a rethinking of the crop production systems. Technology improvements, such as drip irrigation, subsurface drip irrigation, precision irrigation, irrigation scheduling software are considered innovating technological solutions to save water. In Germany, six irrigation scheduling systems are currently used, but, among 13,700 farmers using irriga-

1. See presentation of Katrin DRASTIG here: https://watersaving.sciencesconf.org/293112

tion, only less than 10% have adopted irrigation scheduling tools (Baroni et al., 2019). However, adaptation to climate change will involve not only an improvement of irrigation systems via irrigation scheduling, but also a higher diversification of crops (Drastig et al, 2016b).

Examples of water saving attempts and achievements in different EU countries

More efficient conveyance and application systems

Spain. Water savings through a large irrigation modernization program since the end of the 1990s [2]

Spain holds the first position in the European Union with 3,77 Mha of irrigated area, or 22% of the total cultivated area. Irrigation in Spain has to address the challenges of agricultural profitability, climate change, water deficit in some regions where agriculture is the main engine of economic activity, environmental issues such as the reduction of pollution in nutrients, and finally social challenges such as improving the living and working conditions of the irrigators. Therefore, at the end of the 1990s, Spain began an enormous modernization program of the irrigation systems by improving infrastructures, implementing new technologies such as localized irrigation and providing new methods of irrigation management. 1,5 Mha were modernized, thanks to almost 3,000 M Euros of public investment. Nowadays (Figure ❺) gravity and sprinkler irrigation represent each nearly a quarter of the irrigated surface. Localized irrigation accounts for 52% of the irrigated surface, mainly for olive groves, vineyards, citrus fruits plantations, orchards and vegetables. This modernization program allowed reducing the water consumption by the agriculture sector: in 2002, the agricultural sector represented 80% of the total water consumed in Spain, while currently, this figure has dropped to approximately 65%. **Estimated water savings due to modernization are estimated to 3,096 Mm³/year.**

This modernization process, which is currently ongoing, is supported by the European Rural Development Program that is implemented through 17 different Regional Rural Development Programs in Spain. Investments supported by the sub-measure "Modernization of public irrigation infrastructure" are eligible if they are linked with irrigators' commitment to (1) include a water use measurement system, (2) collect the data required for irrigation indicators (to facilitate the evaluation of public investments), (3) determine the potential water savings that must exceed the values established in the national rural development, and (4) possibly determine the effective water saving (if the water to be used is declared not to reach the good quantitative state).

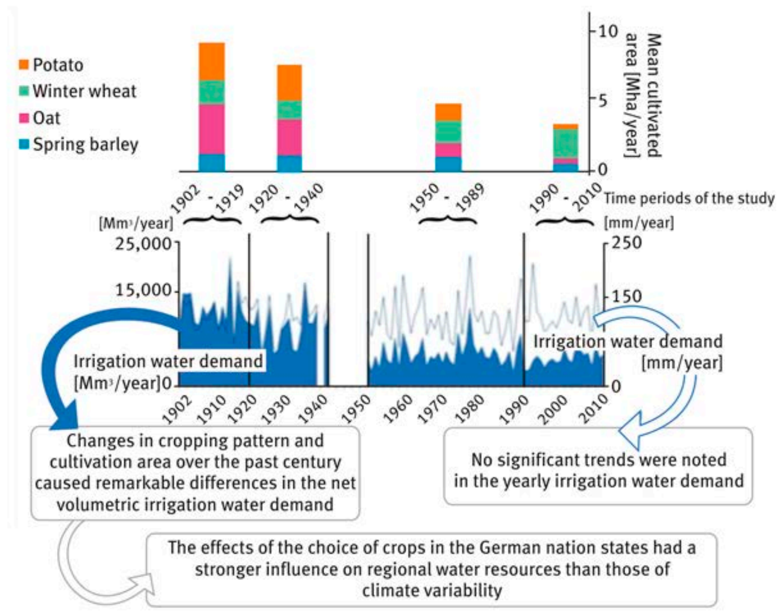
Hungary. Support of water efficient irrigation systems by the Rural Development Program [3]

In Hungary, three operations have been identified in the field of water management in the Rural Development Program: (1) investments in amelioration, (2) investments to improve water retention, or to improve the efficiency of water use, (3) increase of the surface of irrigated areas.

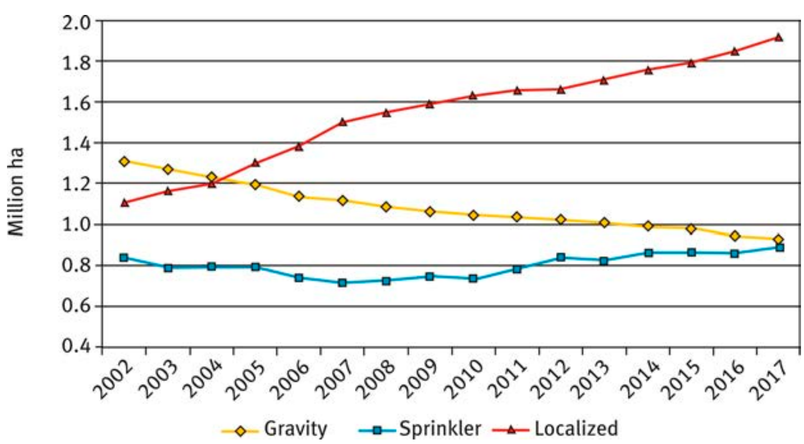
Concerning the improvement of water use efficiency, the project has to involve investments aiming at the sustainable improvement of agricultural water use, the application of water (and energy) efficient irrigation systems, the reduction of water loss. Following items are supported:

- Efficient irrigation technologies, improvement of water efficiency in irrigation facilities improvement and reconstruction of efficient irrigation infrastructure and the related facilities.
- Purchase of new irrigation facilities, as well as the establishment of new irrigation water services.
- Purchase of energy efficient irrigation technologies and improvement of the energy efficiency of irrigation facilities.
- Extra support for young farmers.

❹ **Modeled irrigation water demand in German agriculture between 1902 and 2010 (Drastig et al., 2016a).**



❺ **Evolution of irrigation systems in Spain. Source: ESYRCE (Annual survey on Crop Areas and Yields carried out by the Spanish Ministry of Agriculture, Fisheries and Food).**



2. See presentation of Inmaculada BRAVO DOMINGUEZ here: https://watersaving.sciencesconf.org/297731

3. See presentation of Attila NAGY here: https://watersaving.sciencesconf.org/293780

For example, one project was supported, as the purchase of new irrigation equipment (similar to the project shown at Figure ❻). The applicant wished to renew its old irrigation system with linear and water efficient system. The new machine was planned to cover the whole 46 ha irrigated area. Subsidy application included GPS, timer, pipes and water meters. **Estimated irrigation water saving was 20%, and energy saving 80%**. The requested amount was 72,141 Euros.

Italy. Improvement of distribution networks and installation of meters for water savings[4]

In accordance with the European Rural Development Policy 2014-2020, Italy combines a national rural development program (RDP) and 21 regional RDPs. At national level (national RDP), sub-measure 4.3 aims at saving water for environmental protection and adaptation to climate change. It supports off-farm and collective irrigation investments to reclamation consortia and public bodies responsible for agricultural water management. At regional level (regional RDPs), sub measure 4.3 is open to associated farms; in addition, sub-measure 4.1 supports on-farm investments.

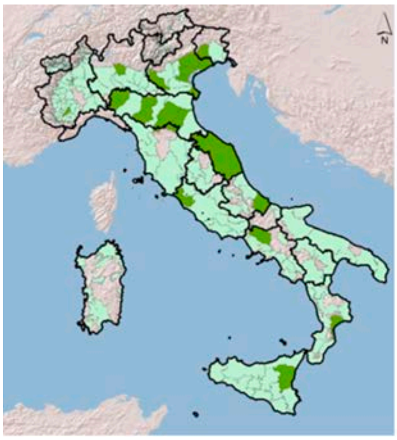
After evaluation and selection procedures, 35 projects were funded by NRDP to the first 19 irrigation agencies, accounting for around 273 M Euros. 82% of the funding concerned Center-Northern Italy, in particular the Po river basin district and the Eastern Alps river basin district. The main funded actions are related to investments on existing distribution networks and installation of meters, and only marginally on new realizations. They could potentially result in a **water saving of about 139 Million m³, which correspond to 0,66% of national collective abstraction** (Figure ❼) (SIGRIAN, 2019). In 2020, through additional financing resources, further 15 projects to 14 irrigation agencies (National Cohesion and Development fund - CDF) and 16 projects to 11 irrigation agencies (additional NRDP funds) have been funded, guaranteeing an increase of water saving of around **168 Million m³** (NRDP additional funds - about 97 Mm³; CDF - about 71 Mm³).

The *ex ante* evaluation of potential water saving was shown to have limitations because of, among others, the great variability among irrigation contexts and the lack of homogeneity in the methodology used for water saving

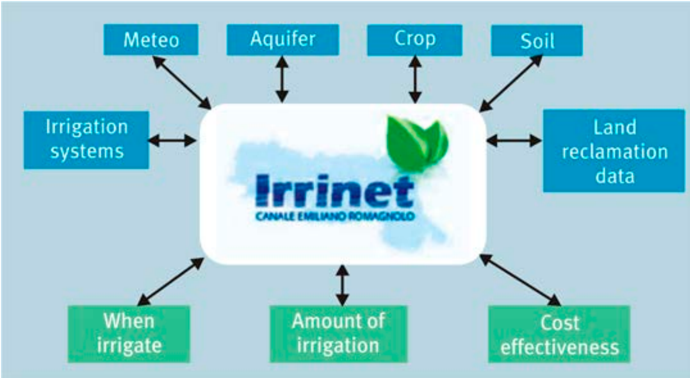
4. See presentation of Silvia BARALLA here: https://watersaving.sciencesconf.org/293315

❻ Pictures from a similar project that was supported from the Hungarian Rural Development Program (Source: YouTube. https://www.youtube.com/watch?v=XyMfK8QK85M)

❼ Italian irrigation entities with financed investment projects (SIGRIAN, 2019). Potential water savings achievable through these investments in the different river basin districts.



River basin district	Potential water saving through investments/withdrawals for agriculture use
	(%)
Eastern Alps	1.75%
Po River	0.22%
Northern Appennines	19.09%
Central Appennines	1.48%
Southern Appennines	5.47%
Sardinia	-
Sicily	6.42%
Total Italy	**0.66%**



❽ Input and output of the IRRINET system (source: European Climate Adaptation Platform Climate-ADAPT, 2019b).

❾ Emilia-Romagna region in Italy (source: Wikipedia, 2020).

assessment. However, at the farm level, some regions, especially Veneto, propose an interesting methodology to calculate the water saving considering the change in equipment efficiency. In all cases, ex post evaluation of the really achieved water saving will be possible as beneficiaries have the obligation of having or installing meters, and of collecting and transmitting the irrigation volumes abstracted to SIGRIAN (**https://sigrian.crea.gov.it/**) whose data are accessible to all competent authorities.

Scheduling tools and automatization

Italy. IRRINET – IRRIFRAME: an example of irrigation advisory service for water savings [5]

During the last 35 years, irrigated land ranged between 2,5 to 2,9 Mha, making Italy the second EU country with the largest irrigated area after Spain. More than 20% of the utilized agricultural area is irrigated. Sprinkler irrigation covers almost 40% of the total irrigated area, microirrigation accounts for about 20% and surface irrigation for 40% (typically for rice cultivated in the North).

The 6th General Census of Agriculture in Italy estimated that water savings allowed by irrigation advisory services were about 10% (Italian National Institute of Statistics, 2014). Among the irrigation advisory services available today, IRRIFRAME (former IRRINET) is based on a water balance model aimed at crop irrigation management at a field scale. The model's structure (Figure ❽) includes the soil, with its water balance; the plant, with its development, growth; and the atmosphere, with its thermal regime, rainfall and evaporative demand. IRRINET web service has been developed with public funding by the CER (Canale Emiliano Romagnolo, a water consortium located in the Emilia-Romagna region) since 1999. The National Association of Land Reclamation Boards (ANBI) developed IRRIFRAME, a similar IT service modeled on IRRINET.

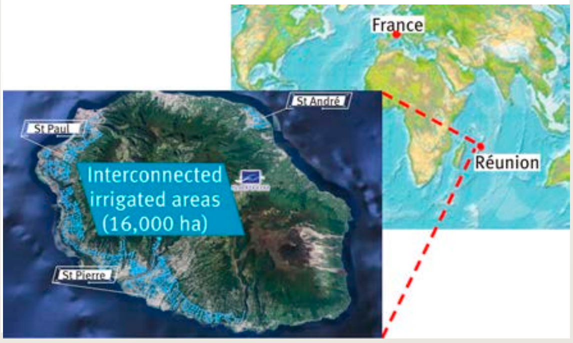
IRRINET service currently involves more than 12 000 farms, covering almost 22% of the irrigated area in the Emilia-Romagna region (Figure ❾). In the 2017 irrigation season 28,500 IRRINET SMS were sent and 147,000 irrigation scheduling were produced. **In 2017, it has been estimated that IRRINET application allows a yearly water saving of about 90 Mm³, corresponding to 20% of the total agricultural demand in Emilia Romagna region, without depressing yields** (European Climate Adaptation Platform Climate-ADAPT, 2019a).

Réunion Island. Implementing remote control tools to save irrigation water in a particular pedoclimatic context [6]

Réunion Island is a French overseas department in the Indian Ocean. Mainly located along the shoreline, the total cultivated area is 43,000 ha, accounting for less than 20% of the total island surface. About 16,000 ha are irrigated (Figure ❿). Sugarcane represents the main economic industrial activity and covers 57% of the cultivated area. Except in the mountains, where rainfall is sufficient, sugarcane fields are irrigated, with either solid set systems or subsurface drip irrigation. For vegetables and fruits, the main systems are drip and micro-sprinkler irrigation.

Several obstacles hinder the development of optimized irrigation. Sufficient water resource, securisation thanks to the interconnexion of the hydro-agricultural networks, and low price of irrigation water do not spur water savings. Flowrate at plot entry often constrain to irrigate

❿ Irrigated area in Réunion Island (source: SAPHIR).



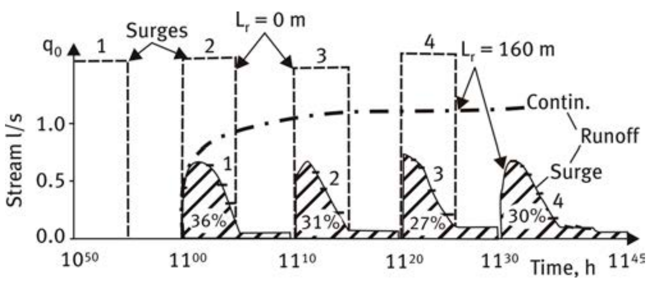
5. See presentation of Graziano GHINASSI here: **https://watersaving.sciencesconf.org/293716**
6. See presentation of Stephane GUILLOT here: **https://watersaving.sciencesconf.org/294525**

during day hours with high evapotranspiration. Moreover, the great variability of microclimates makes difficult for irrigators to know exactly the water demand of their crops. Many performing tools for irrigation scheduling are nowadays available, thus very few are used because of irrigators' lack of education or will.

In order to face these challenges, varied solutions are being implemented to encourage water savings: improvement and modernization of irrigation equipment at the plot level, promotion of subsurface drip irrigation in suitable sugarcane plots, development of automatization, individual support of irrigators, training on irrigation scheduling methods and tools, public subsidies such as EAFRD. Therefore, the SAPHIR Company (Company for the Development of Hydro-agricultural Perimeters in Réunion Island) is deploying tools to automate remote control of irrigation. At the end of 2019, about 30 controllers were installed (Figure 11). They allow meaningful progress in monitoring and collecting applied irrigation volumes, delivering direct advisory service on irrigation, reacting immediately in case of dysfunction. However, the implementation of such solutions can be difficult in very large plots, or in plots without electricity supply. So far, these devices do not take into account the meteorological data.

11 Irrigation controller to automate remote control of irrigation (photograph: SAPHIR).

12 Diagram of streams delivered at the furrows' head and runoff at the furrows' tail under surge irrigation. The runoff under traditional continuous irrigation is shown in "dot-dash" line (Varlev et al., 1998).



Innovative irrigation practices

Bulgaria. Surge irrigation instead of traditional continuous furrow irrigation for consistent water savings [7]

Irrigation has been one of the key policies for raising agricultural productivity during the soviet regime. Given the strong productivity increase achievable through irrigation in areas with hot, dry continental summers, the expansion of irrigated areas constituted an important objective (Dwyer et al., 2000). In Bulgaria, irrigation leads to a 1,6 – 2,1 larger crop productivity comparing to the yield under rainfed crops (Popova, 2012). Moreover, irrigation mitigates yield variability over the different climatic years, which is a prerequisite for a stable economic development without risks in Bulgaria (Popova et al., 2014). The percentage of irrigated land increased from 14% of the agricultural area in 1960 to 27% in 1989 (Dwyer et al., 2000). In 1990, 700,000 ha were irrigated (Varlev, 2012).

At the beginning of the 1990s, the period of transition from a central planning economy to a market economy started, accompanied by serious economic difficulties. Irrigated agriculture faced a deep crisis with a decrease in agricultural production, deterioration of irrigation and drainage on-farm infrastructure and breakdown of the previous markets (Zhovtonog et al., 2005). During the last 30 years, 800 pumping stations have been demolished, while 80 remained for irrigation. Presently, about 30,000 ha are under irrigation (Varlev, 2012). The traditional relationship between science and practice has been lost, a considerable part of gained knowledge on irrigation, experience and potential could not find a real practical application anymore.

Due to the large water holding capacity of soils and appropriate terrain slopes of 0,3 to 3%, furrow irrigation is exceptionally favorable for application under Bulgarian conditions. Furrow irrigation used to be a subject of detailed scientific studies during the period 1970-2000 (Popova and Kuncheva, 1996; Varlev et al., 1998). Water distribution uniformity and application efficiency, soil erosion and nitrogen leaching to groundwater have been studied in several regions. Consequently, original water-saving and environment-friendly improved technologies have been investigated, developed and applied in furrow irrigation practice and fertilization, as: "surge" irrigation, "alternative furrow" irrigation with fertilization in "dry furrows" and others (Varlev et al., 1998, Figure 12; Varlev, 2011; Popova, 2016).

During traditional (continuous) furrow irrigation, significant run-off and deep percolation water losses occur (Varlev, 2011). An alternative to traditional furrow irrigation is surge irrigation, defined as on and off cycles of stream delivered at the head of the furrows. Stream advance is separated in 2 stages. During the first stage (stream advance phase), surge irrigation, in comparison with traditional furrow irrigation, saves 20-30% of the delivered water due to better uniformity of the stream advance. In the second stage (post-advance phase), surge

7. See presentation of Zornitsa POPOVA here: https://watersaving.sciencesconf.org/291861

irrigation reduces run-off losses and allows water savings of 10-15%. Combining both phases, **water savings with surge irrigation amount to 30-45% compared to continuous furrow irrigation** (Varlev et al., 1998; Varlev et al., 2011).

Turkey. Partial Root Drying: a sustainable irrigation system for efficient water use and water saving, without reducing yield [8]

In Turkey, 65% of the total agricultural area is irrigated with surface irrigation, 19% with sprinkler irrigation (field crops such as sugar beet, potato and groundnut) and 16% with drip irrigation (fruit orchards, vineyards, vegetable and greenhouses). A concerted effort is being made by the state to equip the new irrigation schemes with modern technologies such as closed pipes for conveying the water instead of open channels, and water-saving micro-irrigation methods rather than surface irrigation techniques (furrow irrigation and wild flooding).

The IRRISPLIT project, funded by the European Commission (ICA3-CT-1999-00008), aimed at evaluating the effects of PRD (partial root drying) on the vegetative and reproductive growth of a range of fruit crops in the Mediterranean area. The PRD practice consists in wetting of one half of the rooting zone and leaving the other half dry, thereby utilizing a reduced amount of irrigation water applied. The wetted and dry sides are interchanged in the subsequent irrigations (Figure 13).PRD can be performed with either alternate furrow or drip irrigation. It is adopted and practiced by some farmers in the Aegean Region in Turkey, particularly in maize and cotton fields irrigated from the groundwater resources and/or in water scarce areas. PRD (alternate furrow) nearly doubles the water use efficiency without a significant reduction of yield in cotton (Kirda et al., 2007a).

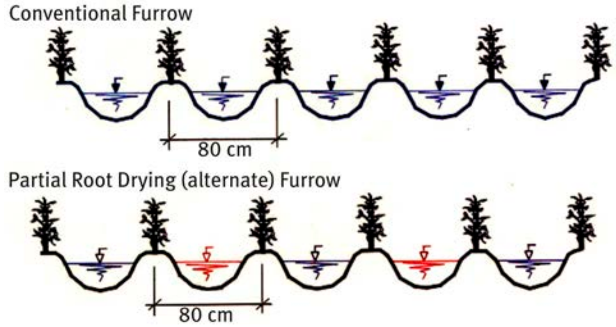
Topcu et al. (2007) have shown that **the PRD practice can save up to 50% of irrigation water without significant yield reduction in greenhouse grown tomato under drip irrigation**. The higher ABA (abscisic acid) content in the leaf tissue under PRD indicates that ABA is an important means of chemical signaling that regulates stomatal control and enables plants to use sparingly supplied water.

For mandarin, the reduction of fruit yield with PRD was only marginal and not significant compared with traditional irrigation over two seasons (Kirda et al., 2007b). However, irrigation water use efficiency (IWUE, in kg ha^{-1} mm^{-1}) increased to almost 3 times. The results suggest that savings of irrigation water as high as 70%, compared to traditional practice, are achievable for fruits with the PRD practice.

This variety of examples show that numerous attempts are made to save water, in countries with a long history of irrigation and in countries with a recent emerging need for irrigation as well. At the European Union scale, water savings are possible through the improvement of global irrigation efficiency, by combining more performant technologies (infrastructures, application systems, scheduling tools) and practices.

8. See presentation of Sevilay TOPÇU here: https://watersaving.sciencesconf.org/297729

13 Principle of partial root drying (PRD) practice by alternate furrow irrigation. One half of the rooting zone is wetted and the other half is left dry. Wetted and dry sides are interchanged in the subsequent irrigations (illustrated by Topcu).



The authors

Claire SERRA-WITTLING
G-EAU, INRAE, AgroParisTech, Cirad, IRD, Montpellier SupAgro, Univ Montpellier,
361 Rue Jean-François Breton, BP 5095,
F-34196 Montpellier Cedex 5, France.
claire.serra-wittling@inrae.fr

Silvia BARALLA
Council for Agricultural Research and Economics (CREA), Research Centre for Agricultural Policies and Bioeconomy, Via Po, 14 00198 Rome, Italy.
silvia.baralla@crea.gov.it

Inmaculada BRAVO DOMINGUEZ
Ministry of Agriculture, Fisheries and Food of Spain, General Directorate of Rural Development, Innovation and Agrifood Training, Unit for Irrigation and Rural Infrastructures, Gran Vía de San Francisco, 4-6, 3ª planta. 28005 Madrid, Spain.
ibravo@mapa.es

Katrin DRASTIG
Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Investigators group `AgroHyd´, Department 2 'Technology-Assessment and Substance Cycles', Max-Eyth-Allee 100, 14469 Potsdam, Germany.
kdrastig@atb-potsdam.de

Graziano GHINASSI
Department of Agricultural, Environmental, Food and Forestry Science and Technology (DAGRI), University of Florence, Via San Bonaventura 13, 50145 Firenze, Italy.
graziano.ghinassi@unifi.it

Stéphane GUILLOT
SAPHIR (Société d'Aménagement des Périmètres Hydroagricoles de l'Ile de la Réunion), 4 route ligne Paradis, F-97454 Saint-Pierre, La Réunion, France.
s.guillot@saphir.re

Attila NAGY and Viktor NAGY
Ministry Of Agriculture - Kossuth Tér 11, 1055 Budapest, Hungary.
attila.nagy2@me.gov.hu
viktor.nagy@am.gov.hu

Zornitsa POPOVA
"N. Poushkarov" Institute of Soil Science, Agrotechnology and Plant Protection. Department of Physics, Erosion, Soil Biota. 7, Shosse Bankya Str, Sofia 1331, Bulgaria.
zornitsa_popova@abv.bg

Sevilay TOPÇU
(Emeritus Professor) Çukurova University, Faculty of Agriculture, Department of Agricultural Structures and Irrigation, 01330 Saricam-Adana, Turkey.
stopcu@cu.edu.tr

Further reading...

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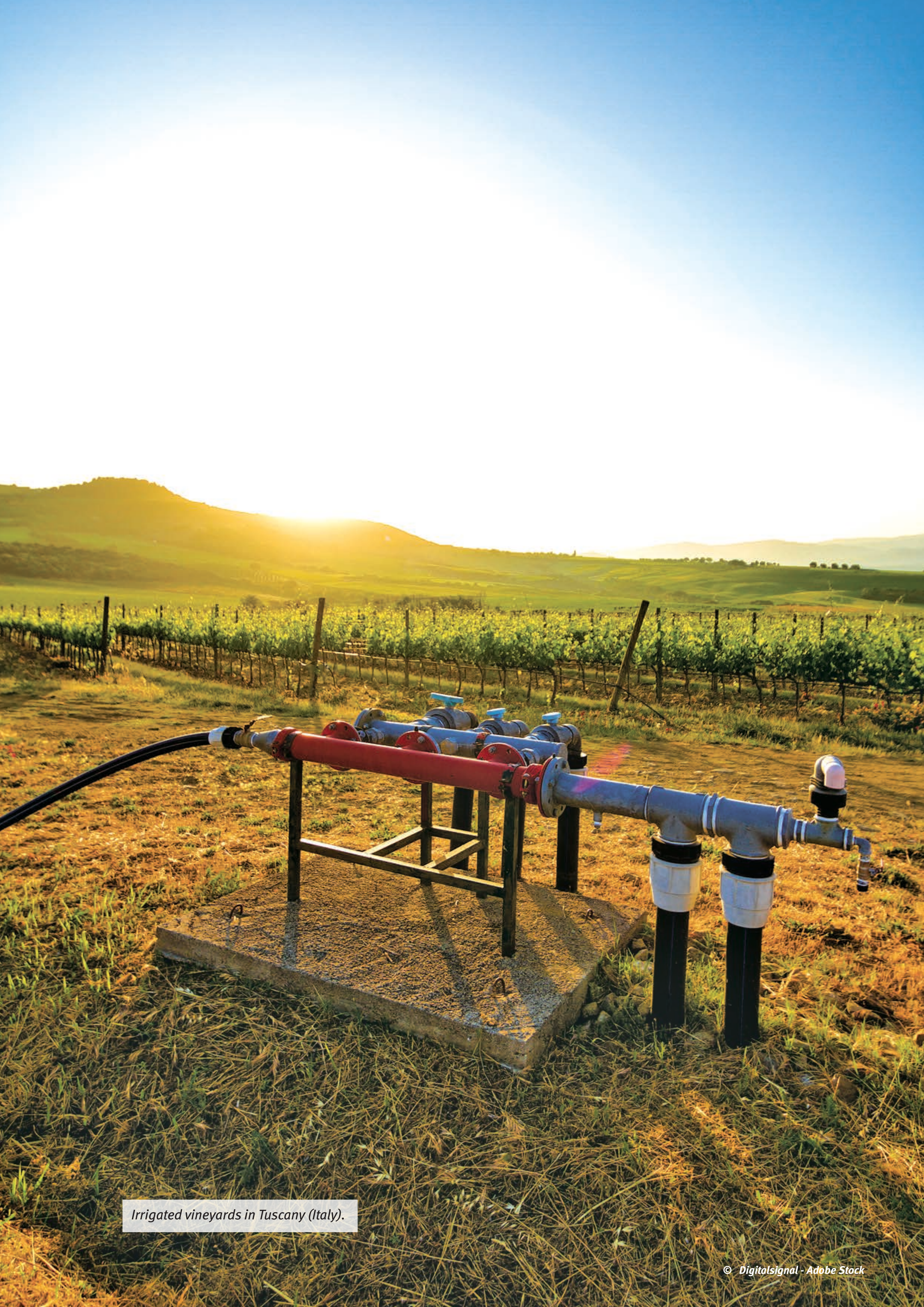

Irrigated vineyards in Tuscany (Italy).