Working Paper:
Water Efficiency in Agricultural Irrigation

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'Adequate governance and knowledge levels are crucial for ensuring that water savings deliver their benefits of reducing pressure on water bodies, so that sustainable management of water quantities in all river basins of the EU can be achieved. Lastly, many solutions allow water saving in agriculture, but each solution must be adapted to the local situation. [...]

To find adapted solutions, the whole ecosystem must be considered, to account for all water needs, including environmental needs, and ensure they are met as adequately as possible.'

(BIO Intelligence Service 2012)

Abstract

Irrigation has been practiced worldwide for thousands of years. Irrigation systems and methods developed throughout history, but still improvement can be established, especially with regard to water efficiency. Worldwide depleting water resources increase, water scarcity spreads, whilst water demands also increase. The world population relies on irrigation for food production and therefore it is critical to reduce the pressure on freshwater bodies, while still maintaining crop productivity. Irrigation management has varying effects on different stakeholders according to ample components affecting the irrigation management scheme like: soil type, climate, water availability, crop type and socio-economical influences in an area. One technique may be beneficial for short-term purposes, but may cause negative consequences in the long run – this must be taken into consideration before implementation. Therefore, there is no one-way approach towards water efficiency. This paper will discuss the responses, methods, policies and alternatives proposed and practiced, as well as the corresponding difficulties and limitations, to increase water efficiency in agricultural irrigation.

Keywords: sustainable irrigation, water efficiency, water research and innovation

This is a working paper reflecting ongoing work. Comments and suggestions are welcome, please refer them to ruvival@tuhh.de.

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Introduction

Irrigated agriculture is one of the biggest water users in the world, with enormous regional variations. In Europe alone, an estimate of 40 billion cubic meters of water was used to irrigate approximately 10 million hectares of land in the year 2010 (European Union 2016). Acquiring water supplies for irrigation has been a challenge and difficulty in many parts of the world where water is scarce and supplies are limited (Vaux 2012). Looking ahead, climate change will cause more severe droughts and intensify the pressure on water resources around the world (IEEP 2000). Climate change adaptation measures are already implemented in many parts of the world, however, these efforts need to be intensified.

Currently, irrigation has received much criticism due to environmental effects, such as damaged habitats and ecosystems, soil salinisation and erosion, and water pollution from pesticides, which are washed out during irrigation. As much as 60 % of abstracted water for irrigation does not reach the crops and is wasted due to losses from evaporation, leakage, spillage, or infiltration (IEEP 2000). With rising global water challenges today, much importance has been given to water efficiency. This has become a legislative priority and has led to the adoption of several policies worldwide.

In the European Union (EU), policy instruments were established by the European Commission (EC) to promote water sustainability. The Water Framework Directive (WFD) aims for the protection of available water resources and is therefore the Blueprint to Safeguard European Waters. Legislations are proposed for local implementation to improve water legislation throughout Europe (Poláková et al. 2013).

Water for irrigation relies mostly on surface and groundwater sources and the amount of water used depends on several factors, such as: climate, weather conditions, water quality, crop type, soil characteristics and irrigation techniques (European Union 2016). Accordingly, to reduce the pressures on freshwater resources caused by irrigation these options are suggested: (1) to reduce water losses through technology and management; (2) to use alternative sources; and (3) to comply with socio-economic measures (BIO Intelligence Service 2012). Multiple actions and responses under these approaches are currently implemented across the globe. However, in order to develop more technologies to improve water efficiency, research and scientific studies are needed. The results aid in information collection and sharing, as well as decision making by various actors involved (Poláková et al. 2013). On the European level, the European Innovation Partnerships on Water (EIP Water) and Agriculture (EIP Agriculture) were established to focus on research and innovation in promoting sustainable and efficient use of water (Poláková et al. 2013).

This paper discusses irrigation as a key activity for the survival of humans throughout history across the globe and presents common types of irrigation methods and systems. The relation of water and irrigation is described in more detail, including the impacts of water inefficiencies caused by irrigation. Finally, the roles of policy, research, technologies and management to improve water use efficiency in irrigation, as well as their difficulties and limitations, are discussed and reviewed.

Irrigation in Agriculture

Irrigation is the practice of applying water, additional to what is provided by rainfall, to soil to allow plant growth and yield (Sojka, Bjorneberg & Entry 2002). This agricultural practice is believed to have begun around 6000 BC in both Egypt and Jordan, where the first archaeological evidence of irrigation was found (Hillel 1994). A thousand years later, irrigation had spread to the Middle East and towards the Mediterranean. Simultaneously, it had independently began across Asia, particularly in India and China (Reisner 1986).

Towards the 19th century, irrigation principles were adapted based on developments in chemistry, mineralogy and biology. This gave birth to sub-disciplines such as agronomy and soil chemistry (Sojka, Bjorneberg & Entry 2002). The past century has seen even more advanced innovations in agricultural research and irrigation technologies advanced. With growing food demands of the increased world population (from 2.5 billion in 1950, to 7.5 billion 2015) the irrigated area doubled and water withdrawals tripled (FAO 2015). Irrigated agriculture has helped to provide food supplies for the growing demands, however, there is much improvement needed for sustainability and productivity, in order to face and address the environmental problems today and in the future.

There are various irrigation methods being practiced today, each having their own advantages and disadvantages. The three commonly used methods are surface irrigation, sprinkler irrigation and drip irrigation.

Surface Irrigation

Currently, surface irrigation is the most commonly used irrigation technique using gravity to move water directly onto the field. There are three subcategories of surface irrigation: basin irrigation, furrow irrigation and border irrigation (Brouwer et al. 1990). This system is most appropriate for soils with good water holding capacity and internal drainage (Putnam 2012). The advantage of surface irrigation is that it does not involve operation of sophisticated equipment, nor much capital investment, which is why most small farmers prefer this method. Additionally, surface irrigation does not require much energy and can be used for all types of crops. It has been found that under certain conditions, surface irrigation can be efficient, as long as precise grading of topography and high level of management are present (Evans & Sadler 2008). However, compared to other irrigations systems, this traditional method tends to have high amounts of water losses through evaporation. Another disadvantage is that surface irrigation requires more labour in the construction, operation and maintenance. Other problems caused by this system are waterlogging and soil salinisation (FAO 2002a).

Sprinkler Irrigation

The second type of irrigation is sprinkler irrigation, which is a method of applying water through a system of pipes and spraying it into the air through sprinklers, mimicking rainfall (Brouwer et al. 1990). The two most commonly used sprinkler systems are centre pivot and linear systems. This type of system can save water, compared to surface irrigation, and can also be used where soil texture is light, such as sandy loams. The main advantage of sprinklers is their ability to distribute small amounts of water uniformly, reducing water wastage. Further, unlike surface irrigation, sprinklers require neither a till system nor land levelling. The main disadvantage of this system is its higher capital investment and operating costs, compared to surface systems. All the more, these systems need pressure and, where there is no elevated reservoir, external energy to operate pumps. Another major disadvantage is the evaporative loss of water droplets, which can vary depending on weather and wind conditions of an area.

Due to its high cost and capital investment per hectare, sprinkler irrigation is mostly used for high value cash crops, such as vegetables and fruit trees (Putnam 2012).

Drip Irrigation

Also known as trickle irrigation, drip irrigation is the application of water onto the soil at very slow rates through pipes with outlets called drippers or emitters. Similar to sprinkler irrigation, this system is appropriate for areas with limited water and for sandy soils. An advantage of drip irrigation is that due to the dry surface, weeds are less likely to grow and farmers can even irrigate during harvest periods (Putnam 2012). Other advantages include minimising salinity hazards to plants, reducing labour through a simple automation system, and improving the soil-water regime for better crop yield (Bresler 1977). However, like the sprinkler, drip irrigation's major disadvantage is that it requires high maintenance costs and capital investment. Moreover, some practical problems in the usage of this system are operational difficulties due to clogging, accumulation of salt at the emitters and difficulty in system design due to external conditions and soil hydraulic properties. Drip irrigation has been promoted in several countries for its significant water saving potential, however the approach to push this technology without considering the scale and socioeconomic environment is criticised. A case study in Spain shows, that drip irrigation may actually increase water consumption in total considering the whole water shed, if drip irrigation makes agriculture possible in areas without previous agricultural land usage and possible crop shifts (Sese-Minguez et al. 2017).

Subsurface Irrigation

Similar to drip irrigation, subsurface irrigation involves the application of water through pipes, but the tubes are about five inches below the surface. Unlike other types of irrigation, where water wets the entire soil, water is applied to a wetted area in subsurface irrigation (Brouwer et al. 1990), removing any water losses from evaporation. Much water can be saved with this type of irrigation. Other advantages include less labour, a reduced amount of energy for pumping, and no soil or nutrient run off. They are also protected from UV-damage and are not easily hit by tools of farm labour. Weeds can be reduced due to a lack of water at the surface – however, after seeding, the flow has to be increased to reach the seeds. It is advisable to select systems of high quality; there are some cheap but not well functioning systems on the market. Subsurface systems must be able to resist roots. The main disadvantage of this system is that problems are not visible immediately as the pipes are below the ground, so maintenance, such as chemical injections and yearly clean-up flushing, is required (McDonald 2015).

Choosing an irrigation method is both an art and a science, and experience proves the advantage of making a sound choice according to the applied environment. Several criteria are taken into consideration in the method selection: soil type, climate, water availability, crop type, economics, and even social and cultural influences (Brouwer et al. 1990). Further, the irrigation system is designed to maximise productivity, minimise labour and capital. Farmers will implement those methods that are economically feasible and attractive. However, the irrigation system is also critical in achieving water efficiency and the following questions should be considered in irrigation system design: how much to apply, when to irrigate and how to improve efficiency? Each system has its own advantages and disadvantages, as stated above, but more often than not, there are additional unforeseen consequences and negative impacts that arise from the implementation of these systems.

Irrigation and Water

Approximately 1.2 billion people, who account for almost one-fifth of the global population, live in areas where water is physically scarce, and another 1.6 billion deal with economic scarcity (UN Water 2005). With imminent urbanisation and effects of climate change, amongst other drivers, the demand for freshwater will increase and exacerbate water scarcity, especially in arid and semi-arid regions (Vaux 2012).

The agricultural sector is the largest user of water, accounting for 70 % of global freshwater usage, and more than 90 % in most of the least-developed countries (WWAP 2014). Most of the volume of water goes to irrigation. Figure 1 illustrates areas equipped for irrigation in percentage of land area (Siebert et al. 2013).

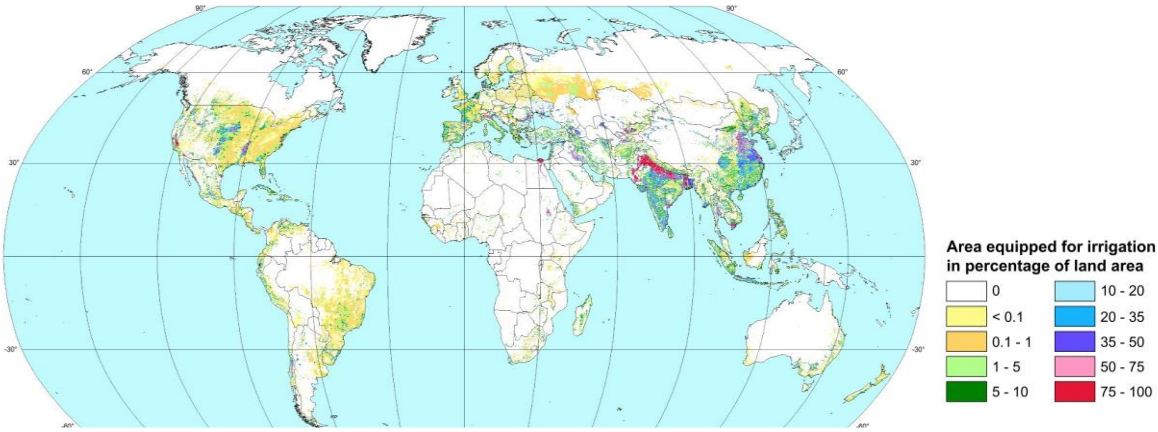

Figure 1 - The Digital Global Map of Irrigation Areas (Siebert et al. 2013)

To illustrate the relation between supply and demand of freshwater sources, the Millennium Development Goal (MDG) Water Indicator uses a ratio measuring the amount of human stress on water resources (see Figure 2). The relation is between water withdrawal by agriculture, municipalities and industries over total renewable water resources (WWAP 2016).

The comparison of both maps illustrates, that most renewable resources suffer water stress in areas with irrigation in place.

By the year 2050, there will be a need to produce 60 % more food in the whole world and 100 % more in developing countries, however, excessive blue water[1] withdrawals for irrigation can further intensify water scarcity and lead to various environmental problems (WWAP 2015). The global need to satisfy food demands and water conservation objectives are creating a paradox that will require a paradigm shift. This requires shifting the focus from maximising productivity per unit of land area to maximising productivity per unit of water consumed (Evans & Sadler 2008).

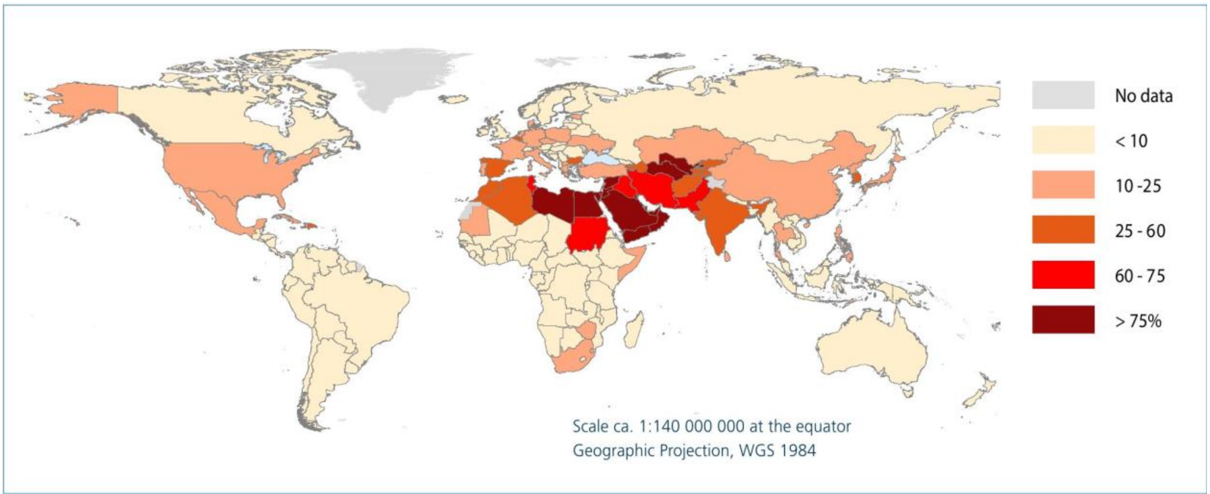

Figure 2 - Percentage of Renewable Water Resources Withdrawn (WWAP 2016)

Aside from aggravating water scarcity, inefficient water use through irrigation has reduced river flows, destroyed habitats and ecosystems, and depleted aquifers (WWAP 2015). Another perplexing environmental impact is land degradation. After irrigation, water evaporates from the soil. Irrigated water usually contains salt, which is left behind and accumulated in the soil. This is known as soil salinisation, a phenomenon which reduces soil productivity. Further, it can kill crops and lead to degraded and barren land (Ghassemi, Jakeman & Nix 1991). The common sources of irrigation salinity are over-irrigation, poor drainage and inefficient water use (State of New South Wales 2017). This can be addressed with proper drainage and improving the irrigation system.

As mentioned earlier, water in irrigation is sourced from either groundwater aquifers or surface water bodies (e.g. rivers, lakes and springs). With over-abstraction[2], the rapid decrease in the amount of water may affect the physical and chemical characteristics of these water bodies, together with biodiversity habituating in them (IEEP 2000). As for groundwater over-abstraction, aquifer water tables get lower and, consequently, flows into wetlands and rivers decrease (IEEP 2000). Another inefficiency in irrigation is that much of this water is

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[1] Hoekstra et al. (2012) define blue water as fresh surface and groundwater, which include water in lakes, rivers and aquifers.

[2] When water abstraction exceeds natural recharge

wasted through leakage, spillage, infiltration and unproductive evaporation (FAO 1996). Specifically, inefficient infrastructure has become an issue diminishing water supply and losing as much as 50 % of abstracted water from leakages (Poláková et al. 2013).

In order to reduce the pressure by irrigation on water bodies, there are several approaches and options for irrigated agriculture to increase its water use efficiency. According to Evans & Sadler (2008), water efficiency can be increased when the total amount of water used by crops, losses and other users are reduced. However, it must be noted that multiple stakeholders are involved in decision-making processes and each have their own knowledge on irrigation. Farmers often assume that their irrigation practices are already adequately efficient and have no incentive to adopt innovative or more water efficient methods. Additionally, farmers aim to maximise productivity to gain the most profit, while the government, water experts and advocates aim to conserve water (Knox, Kay & Weatherhead 2012). Therefore, a continuous knowledge-exchange system between stakeholders would be necessary to increase incentives to share responsibility for proper water management in irrigated agriculture. Moreover, these exchanges could construct practices that could benefit both the environment and the farmers (Levidow et al. 2014).

Actions toward Water Efficiency

This chapter discusses the roles of policy, technology, management and research in obtaining water efficiency in irrigated agriculture. Several actions have been taken in order to save water and optimise water use in irrigation and ultimately reduce the pressure on surface and groundwater resources. Sustainable water use and efficiency through water resource management is needed to tackle the water crisis.

While most publications on irrigation are concerned with large scale farms, it should not be forgotten that globally most food (at least 70 %), especially in low-income and middle-income countries, is produced by small family farms (Altieri, Funes-Monzote & Petersen 2012; Herrero et al. 2017; Quan 2011)and that these can be much more productive per hectare/acre (Iheke & Nwaru 2013). This also translates to more 'crop per drop', especially if efficient irrigation is applied, too. Water demand can be reduced by intercropping, where higher plants provide shade for smaller ones (Narayanamoorthy, Devika & Bhattarai 2016; Ramulu 1998), reducing evaporation loss, and also the wasteful use of water by weeds is reduced. At the same time, root-mycorrhiza-systems of deep-rooting species can deliver water from deeper parts of the plot. Agroforests with water storage in thick roots, like Moringa-trees (Debela & Tolera 2013; Sarwatt, Kapange & Kakengi 2002), can assure at least some production during the dry season without irrigation. It is also possible to make certain crops more water efficient by irrigating less, so that more and deeper roots will be developed (Buesa et al. 2017; Ford et al. 2017). Therefore, the irrigation system also needs to be implemented into a system of other water saving methods and combined with rainwater harvesting systems. These means of restoration farming can then turn farms into water producers providing irrigation water.

In order to reach a more integrated approach in managing water resources, proper policies and regulations must be in place to provide strategies for implementation. Social and economic aspects must be considered in drafting policies, or they will be difficult to implement.

Sustainable water use policies focus on various sectors: agriculture, industry, energy and hygiene (WWAP 2015). This paper takes the EU as an example and focuses on the EU level. Actions towards water efficiency were established with the 'Roadmap to a Resource Efficient Europe', which defines goals for 2020 and 2050. By 2020, the impacts of droughts and floods should be minimised and abstraction of water should be below 20% of available renewable water resources (European Commission 2011). By 2050, each person should have access to sufficient water supply with acceptable quality to sustain their lives, and a 'water secure world' should have been achieved. Specifically, agriculture would be more resilient towards precipitation variability with the practice of efficient irrigation techniques (WWAP 2015).

The Water Framework Directive (WFD) (Directive 2000/60/EC), adopted in 2000, is a policy instrument that requires to 'promote sustainable water use based on the long-term protection of available water resources' (European Union 2016, p. 5). The Directive drafted the River Basin Management Plans (RBMP), with the main focus on integrated river basin management, a holistic approach in protecting the entire river basin and its parts. In 2012, the 'Blueprint to Safeguard European Waters' was published. The Blueprint's objective is to achieve sustainability for water-involved activities by proposing actions to improve water legislation and providing concrete solutions for implementation (European Commission 2014). The Food and Agriculture Organization of the United Nations (FAO) has a water scarcity program and it applies principles of Integrated Water Resource Management (IWRM) for the agriculture sector, centred on water efficiency and conservation (FAO 2014). However, all these policies would be useless without good governance and proper enforcement of regulations.

Water use efficiency reduces the pressure on water resources in several ways, called 'responses' (BIO Intelligence Service 2012), such as using alternative sources of water, monitoring water use or recycling water. In the BIO Intelligence Service study (2012), these responses were categorised under three approaches: (1) Technological and Management Approaches; (2) Use of other Water Sources; and (3) Socio-economic Responses.

Technological and Management Approaches

The first category, technological and management approaches, aims to save water by decreasing water losses. Water is lost in irrigation during several steps throughout the process. To address these, BIO Intelligence Service (2012) investigated responses:

1. Improvement of irrigation systems
2. Deficit irrigation strategies
3. Reduction of evaporation during storage
4. Decreasing soil evaporation
5. Irrigation scheduling
6. Reducing runoff
7. Water table management
8. Changing planting date
9. Crop selection

In the study of BIO Intelligence Service (2012), water losses were identified and located to strategies where and how these losses can be reduced. As seen in Figure 3, the texts written in red (storage loss, conveyance loss, leakage, flushing, etc.) are non-productive water losses.

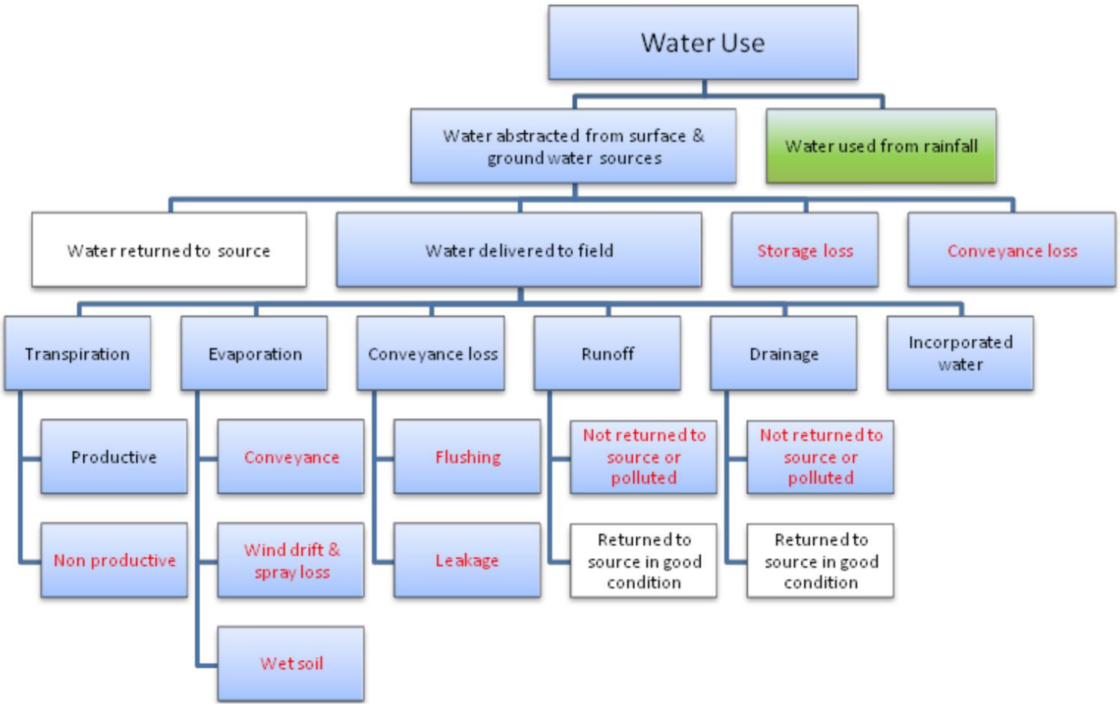

Figure 3 - Scheme of Water Use and Water Losses (BIO Intelligence Service 2012)

The responses explained in this literature review are improvements of irrigation systems, decision support tools and irrigation scheduling, deficit irrigation, improvement of water-holding capacity of soil, and crop selection. These are the more recent approaches that demand management strategies and solutions, rather than simply implementing a technology (i.e. covers for reservoirs, addition of emulsion to solve reduction of evaporation during storage), which have been innovations practiced in the past 100 years (Evans & Sadler 2008).

Improvement of Irrigation System

The three types of irrigation systems, surface irrigation, sprinkler irrigation and drip irrigation, each have their own advantages and disadvantages, as mentioned previously. The amount of water to cultivate the land is dependent on the type of system chosen and can greatly impact the basin from which water is abstracted. Drip irrigation is found in some studies to be the most water efficient system as it applies water to areas needed by the crop, wasting little to none (FAO 2002a), resulting in numerous governments worldwide promoting its adoption. Based on the US Statistic Services, drip irrigation can achieve the efficiency of up to 95 %, when implemented with effective monitoring, proper design systems and management (Evans & Sadler 2008). In the US, it is currently used in approximately 5 % of the irrigated land (USDA & NASS 2002).
However, there has been recent debate and criticism questioning whether shifting from traditional irrigation practices to drip irrigation is actually more water efficient. Several studies have investigated unforeseen effects on water and energy consumption in the long

run. These recent works have focused on the rebound effect, explaining that adoption of a new technology aimed to increase the efficiency of resource does not necessarily lead to less consumption (Sanchis-Ibor et al. 2015). Previously, studies were done using just analytical or mathematical models to investigate the effects of drip irrigation in water saving, but only recently have studies been published examining an ex post analysis of implementing the drip irrigation (Sanchis-Ibor et al. 2015).

A recent investigation was conducted in the Canyoles watershed in Valencia to assess the consequences and impacts due to the shift from surface irrigation to drip irrigation during the past 25 years, and to highlight the significance of different stakeholders involved in irrigation. One of the most evident effects was that with the modernisation of irrigation, the amount of water and irrigated land increased. Drip irrigation actually led to the opening of more wells, allowing farmers to abstract groundwater. Additionally, there was an expansion in total irrigated area due to the technology advancement. These two effects actually contradict the whole purpose for adopting drip irrigation, which was to increase water savings (Sese-Minguez et al. 2017). Another consequence reported in this study was the increase of energy use. Drip irrigation requires power to operate effectively, in contrast to surface irrigation, which uses mostly gravity to work. Electrical pumps are used to lift the groundwater, resulting in high energy consumption (Sese-Minguez et al. 2017). In a similar study done also in Valencia by Ibor, Molla & Reus (2016), it was found from interviews that increases in energy costs are hindering farmers from adopting the drip irrigation system. Ibor, Molla & Reus (2016) discusses that policies and actions aimed to promote water efficient technologies should properly assess the projected reduction in water consumption, and increase in energy consumption. Further, they should evaluate the impacts on costs for farmers' finances, as well as the effects on heritage conservation (Ibor, Molla & Reus 2016, p. 503). In another report by van der Kooij et al. (2013), they conclude that improved water efficiency from drip irrigation will only be achieved under very defined operational conditions and specific spatial and temporal circumstances. Further, Evans & Sadler (2008) report that improving on-farm irrigation systems may not reduce water for the whole hydrological system, i.e. the river basin, raising some confusion. Therefore, researchers are imploring to policy makers to not base their findings on studies that report efficiency gains achieved at farm levels, which do not accurately reflect the implications on larger scales.

Another example is the production of dry rice. Flood irrigation (surface irrigation) is the traditional way of farming rice and requires at least 3 to 5 thousand litres of water to produce one kilogram. Shifting to the System of Rice Intensification (SRI), much more rice can be produced with the same amount of water. A study in India shows an increase in crop yield and with almost 30 % less water usage with this system (WWF 2017b).

Decision Support Tools and Irrigation Scheduling

Decision support tools, such as irrigation scheduling, can reduce water losses by maximising irrigation efficiency and optimising the water used on the crops in terms of timing and amount. Scheduling can be applied to most crops and to every basin, as long as information on weather, hydrological flow and soil are available (BIO Intelligence Service 2012). Farmers can receive training to monitor parameters in order to create their own irrigation schedules. Irrigation-scheduling services are provided in several EU countries. In France, agricultural agencies collect field data and publish irrigation bulletins via newsletters and training courses. Similarly, in Greece, irrigation-scheduling services are provided through fax and telephone. There are also web-based platforms, which give information based on weather data and models to assist with water management and irrigation scheduling. Examples of these online systems are CROPWAT, WaterBee and IRRINET, which assisted in reducing as much as 20 % of annual water usage in the Po River (Poláková et al. 2013).

Deficit Irrigation

Deficit irrigation involves the application of less water than the crop's requirement. This can be achieved by either decreasing the amount of water irrigated during certain growth stages or by a technique called partial root zone drying (PRD). This modern technique requires irrigating one part of the root zone while leaving the other part dry, before wetting the dry part later on (BIO Intelligence Service 2012). Deficit irrigation has been applied to various crops in countries around the world, but this technique involves significant crop and soil knowledge and accurate water control and management. Recently, major improvements have been developed with advanced technologies, such as soil water sensors, which aid farmers to manage their resources and strategise irrigation scheduling (FAO 2002b). As an example, deficit irrigation practiced in Australia with fruit trees has resulted in around 60 % increase of water productivity and gain in fruit quality, without yield loss (WWAP 2015).

Improve Water-Holding Capacity of Soil

The water-holding capacity of soil is an important characteristic because soils that hold more water can support more plant growth (Agvise Laboratories 2017). Knowing this capacity helps optimise crop production and the main components to determine this are soil texture and organic matter. Organic matter or compost is essential for the life and function of soil, as it increases the soil's magnetism and absorption of water. Further organic matter also influences soil structure and benefits the diversity of soil organisms (FAO 2005). Reports have found that that for every 1 % of organic matter content, the soil can hold 16,500 gallons of plant-available water per acre of soil (Gould 2015). Finally it was stated that water used for irrigation may be reduced with the efficient water use characteristics of compost, creating drought resistant soil (Gould 2015). Increasing the organic matter can be done by adding plant or animal material to the soil.

Crop Selection

Each crop has its own daily and seasonal water need. Using crops which need less irrigation water or that better tolerate drought is another way to save irrigated water. There are certain crops that have the ability to uptake water from deeper soil layers. To give an example, sorghum and sunflower are drought tolerant crops, which both have efficient root systems and can adapt to different water availability (BIO Intelligence Service 2012). Today, around 20 million tons of cotton, one of the most water intense crops, is produced every year globally, even in water scarce areas. An astonishing 20 thousand litres of water is needed to produce just one kilogram of cotton (WWF 2017a). Moreover, the massive production of biofuel crops, such as corn and sugar, has created additional stress on water supplies and can cause greater water depletion with the acceleration of biofuel production in future years (National Research Council 2008). Stronger agricultural policies covering these issues must be in place. Further, farmers need to be trained and educated regarding crop selection and should also be given incentives to use water efficient crops (BIO Intelligence Service 2012).

Using Water from Other Sources

The second approach, 'Use of other Water Sources', does not exactly save water, but does reduce the pressure on water bodies by reducing abstraction from ground and surface water and providing water for certain areas during times of drought or scarce water supply (BIO Intelligence Service 2012). The three responses under this category are: (1) Water Re-use, (2) On-farm Storage and (3) Water Harvesting.

Water Reuse

Water reuse or wastewater recycling is an option to irrigate green areas and some types of crops, and may even have nutrients beneficial to certain plants. Further, water reuse decreases the need and therefore also cost of fertiliser and can also recharge aquifers with treated water through infiltration, thus reducing the water treatment costs (Jiménez 2006). This technique is currently practiced in several countries, such as Spain, where approximately 76 % of reused wastewater is allocated to irrigated agriculture (AQUAREC 2006). Though water reuse is a way to reduce pressure on freshwater resources, the use of wastewater is a major sanitation and safety issue, creating an obstacle for it to be adapted as an alternative for farmers in countries where environmental and health standards have not yet been established.

On-Farm Storage and Rain Water Harvesting

There are two methods how water can be collected and stored in order to be used when supply is limited. The first is On-Farm Storage, wherein water is abstracted from surface or groundwater during times of abundant supply. Technically, water is not saved and could even lead to water losses through evaporation and seepage during storage, and, therefore, this method is not recommended. The second method is through Rain Water Harvesting, wherein water from rainfall is collected. Similarly, this does not necessarily save water, but it transfers to usage of water from blue water (surface and groundwater) to green water (rainwater). This method too has its side-effects – harvesting rainwater impacts the water balance in the basin, and these effects must be given attention as well (BIO Intelligence Service 2012).

Socio-Economic Responses

The third category, Socio-Economic Responses, seeks to change and improve the way farmers manage their resources by raising awareness (or through regulations), and giving incentives (through water pricing and trainings). Through these responses, water is saved directly by encouraging water efficient approaches and the use of modern technologies, and by enforcing the implementation of better water resource management (BIO Intelligence Service 2012).

Water Monitoring and Auditing

Water monitoring aims to quantify the volume of water abstracted from surface and groundwater used for irrigation. Auditing aids farm owners to compute their water footprint and identify water losses and inefficiencies in their irrigation systems. Major advancements, such as remote sensing and GIS technologies, have significantly helped measure and monitor water. These tools do not directly save water, but they allow for the assessment of water needs by collecting information that could ultimately improve water efficiency (i.e. help farmers with the irrigation schedules) (Poláková et al. 2013). Moreover, Satellite mapping and Global Monitoring for Environment and Security programme (GMES/COPERNICUS), which are technological developments in water monitoring, locate illegal abstractions and allow governments to properly control water resources (European Commission 2013).

Water Regulation and Pricing

Water regulations aim to inform farmers and water users of scarcity issues and give them incentives to reduce their water use (BIO Intelligence Service 2012). In Portugal, regulations require farmers to report water losses, travel time of water and dates of irrigation, allowing them to schedule and organise their water use. Furthermore, the allocation of 'water rights' controls water abstraction amounts and encourages farmers to improve their irrigation and distributions systems, i.e. convert to drip irrigation (Dworak, Berglund & Laaser 2007). Water allocation is managed through water permits, which distribute the water among all sectors and users: industry, agriculture, municipal needs, etc. In terms of irrigation, water pricing is used as an economic tool to allocate water for crops that generate the highest value economically (BIO Intelligence Service 2012). However, there is much controversy regarding the setting of a tariff on water. Sometimes setting tariffs takes place for political rather than practical purposes, where free water is used as a campaign promise to gain votes (Ricato 2017). Further, there is a disagreement on the 'right' way to price water. A debate arises over the objectives of water pricing conflict with the needs of consumers and other stakeholders. Consumers want affordable and fair water services, while the utilities need stable revenue for operations and profit. There is a difficulty for a tariff structure to find the balance to satisfy both sides. First of all, people do not know the cost of providing water, making it difficult to agree on a fair price. Secondly, there is a lack of data to show what would happen if a certain tariff was implemented and how consumers would behave to these prices. Finally, there is no existing market test for these structures, thus prices are usually set by regulatory agencies without the participation of the private sector or consumers. All these factors play into the difficulty in reaching a consensus over water pricing (Whittington 2006).

Research and Innovation

The European Innovation Partnerships (EIP) Water, proposed by the Europe 2020 Flagship, is aimed to be a catalyst for research and innovation in finding solutions to water challenges, and to create jobs for economic growth in the water sector. To achieve this goal, integration is required among several disciplines: research, information and communication technologies (ICT), governance and financing, among others (European Union 2013b). The EIP Water seeks to promote efficient water use by identifying barriers to innovation and finding ways to eliminate them. Furthermore, water innovation will be accelerated through interactions between research, water users, technology development and legislative requirements. The EIP-Water serves as a key tool in supporting the policy options identified in the Blueprint to Safeguard Europe's Water Resources (European Union 2013a).

Conclusion

Irrigation has been critical in providing food to a majority of the Earth’s population throughout history and will be needed to supply future food demands. Despite its consequential problems and challenges, there is a trade-off between water conservation and the need to feed the population of the world. This created a paradigm shift towards maximising productivity per unit of water consumed. It is evident and imperative that water will be more efficiently used in agricultural irrigation and growing water intensive cash crops like cotton in water stressed areas is not a wise – but very common practice. Negative impacts of over-abstraction have affected water tables, soil quality, and biodiversity. Water loss through irrigation is a major issue that requires immediate attention and reducing losses would be a great contribution to water saving. Despite multiple problems faced today in regards to water – scarcity, soil-destruction, drought and climate change – there is still hope to improve water efficiency.
Through the canon of approaches: technological advancements, management improvements, policy regulations, and continued research and innovation, solutions can be found to reduce the pressure on our limited blue water resources – surface and groundwater. Responses include use of other water sources and socio-economic responses, such as water monitoring and auditing. However, all these changes will require a systematic approach, taking into consideration several factors and components before implementation. These include the positive and negative implications to all stakeholders, the relevance of these actions to local soil and crop conditions, and the impacts on the river basins and their habitats (Poláková et al. 2013). Recent research and investigations have questioned the validity of water conservation policies promoting ‘water efficient’ technologies, such as drip irrigation, which have actually resulted in unforeseen consequences, i.e. increase water use through the expansion of more irrigated land. Most of these policies were made based on mathematical models and projections. Therefore, changes in policy structures are necessary, based continued research,

ex post analysis, and complete assessments on how appropriate and effective an improvement would be in a larger scale. Despite the challenges presented, there is great potential for irrigated agriculture to reduce its water consumption while maintain productivity in order to satisfy food needs and requirements (Evans & Sadler 2008).

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