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Technological Innovations in Irrigation Engineering: Impact on Climate Change, Water Quality and Transfer of Technology

Sílvio Carlos R. Vieira Lima
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INOVAGRI International Meeting

IV WINOTEC
International Workshop on Technological Innovations in Irrigation

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TECHNOLOGICAL INNOVATIONS IN IRRIGATION ENGINEERING: IMPACTS ON CLIMATE CHANGE, WATER QUALITY AND TRANSFER OF TECHNOLOGY

TECHNOLOGICAL INNOVATIONS IN IRRIGATION ENGINEERING: IMPACTS ON CLIMATE CHANGE, WATER QUALITY AND TRANSFER OF TECHNOLOGY

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Foreword

My father, Jack Keller, loved everything about irrigation. His 1980 Utah State University Faculty Honor Lecture, Irrigating for Rainbows, reflects this love from the opening paragraph:

> "Quite simply, irrigation is the act of applying water to land. It is usually done to improve plant growth and it lies somewhere between an art, a science, and plain hard work. Even though we do not often think about it, irrigation is very important to the well-being of the world. It is important because we need basic foods to survive, and luxury foods and pleasant views to enjoy this survival. For the many people directly involved in irrigation, especially farmers, it provides a livelihood which is both satisfying and peaceful. And for the few of us lucky enough to be irrigation engineers, it is a love affair."

Thirty two years later, Jack had an opportunity to visit the Baixo Acarau Irrigation District with colleagues following the INOVAGRI International Meeting and IV WINOTEC Technology Innovation Workshop in Irrigation in Fortaleza, Brazil. Still irrigating for rainbows, and in his ceaseless quest to learn by doing and sharing, and in his dedication to help small farmers and advance irrigation, Jack drafted a concept note on using the Baixo Acarau Irrigation District as a Learning Laboratory. Jack always believed that the real world provided the best classroom and that farmers were among the best teachers, and he saw this opportunity in Baixo Acarau.

Earlier in his career Jack focused on advancing irrigation science and engineering, particularly pressurized irrigation. This culminated with his textbook, Sprinkle and Trickle Irrigation. In the latter part of his career Jack's focus was on championing the needs of small farmers. Small farmers are typically short on capital and long on labor, this requires rethinking the design approach and different optimal solutions. Jack took the same irrigation engineering principles explained in Sprinkle and Trickle Irrigation and applied them to developing irrigation technologies and designs appropriate for smallholders. The note, Holistic Pressurized Irrigation Development, summarizes this and highlights that style so uniquely Jack, at once technically relevant and philosophical.

What Jack loved about irrigation was its integration of water, soil, crops, and people. To get it right requires a holistic approach.

Jack concluded his Irrigating for Rainbows honor lecture:

"With optimistic vision I see the Sun is slowly rising, bringing a brighter tomorrow; and though progress is painfully slow, I sense a feeble but relentless momentum toward a universal concern for all mankind - so I truly believe in Irrigating for Rainbows."

Jack's contributions to this book are a reflection of that vision, as true and dear now as it was 32 years ago.

Andrew Keller
Keller-Bliesner Engineering

Foreword

These proceedings are dedicated to Jack Keller, former Professor of Irrigation Engineering at Utah State University, Logan, UT, USA, and cofounder of Keller-Bliesner Engineering.

I was first 'exposed' to Jack Keller in 1978 when I attended a public meeting in Boise, Idaho conducted by the USDA-SCS on irrigation efficiency improvement. A learned and confident sounding voice came from the middle of the audience cautioning the SCS study team members to consider hydrologic principles and the law of conservation of mass when interpreting the end results of low irrigation efficiencies. The voice suggested that they must 'follow the water and see where it ends up and whether it is used by some "downstream user."' That voice was from Jack Keller, who at the time was compiling a textbook on high efficiency sprinkle and trickle systems. That he cautioned against downplaying the value or role of low efficiencies for some situations (for example for ground-water recharge high in a river basin) while at the same time being a proponent of high performance systems, attests to the breadth and thoughtfulness and intellect of the man Jack Keller. His gentle and kind, but persuasive criticism of the SCS study was very 'early' for that kind of thinking, illustrating just one more subtopic of irrigation in which Jack Keller was a pioneer.

My second encounter with Jack Keller was during a short course on pressurized drip and sprinkler system network design conducted on Utah State University campus with Jack Keller as the instructor. It was during that course that I got better acquainted with Jack Keller the man. Jack Keller, the 'grinning man.' It seemed like a majority of the time during the workshop, Jack wore a grin on his face. It was not a common grin. It was a grin that communicated "hey, I have figured this complicated process out, and I love knowing how it works, and I love sharing that knowledge with others." Jack's grinning eyes complimented his grinning lips and teeth and cheerful voice, and seemed to almost physically exude a sweet syrup of caring, joy and knowledge.

This was the man behind the grin. Each time I saw Jack Keller since those early times, I was struck by the similarity of Jack and the clever, legendary 'silver fox.' The silver fox who was more crafty, more intelligent and elite among the number of 'red foxes' in the irrigation engineering community of faculty, professionals and students. We red foxes all knew it, that this silver fox was set apart from the rest of us, and we even celebrated that fact with Jack. It was impossible not to celebrate, given Jack's very pleasant (and grinning) demeanor and love for people and life and love of spreading truth and discovery.

I can talk briefly about Jack Keller's professional accomplishments, which are profound and pioneering. As was stated in the forward of his book "Sprinkle and Trickle Irrigation Design," coauthored with Ron Bliesner, Jack Keller's work opened up new and clear windows through which readers could view the physics, economics, design and management of irrigation and other systems. As an engineer and designer, Jack Keller had the rare ability to peer inside many processes which have been opaque to many designers, and to decompose those processes to add form and structure. He developed relationships that combined theory, rationale, and empiricism in a balanced and thoughtful manner. His approaches to design were often new, refreshing and illuminating. One example of this was Jack's decomposition of irrigation efficiency of sprinkle and trickle systems into three and four components that allowed users to make much more careful, thoughtful and exact estimates. Most of Jack Keller's design procedures were a healthy combination of common sense and sound theory.

Jack Keller's impacts on the world went well beyond his design publications and research papers. As described well by his son Andy Keller in his contribution to this publication, Jack injected his intellect and savvy into making very low cost, yet very robust irrigation and water supply systems available to small and poor farmers around the world. It was clear that Jack's objectives and motivations in that work were to improve the economic lot of small farmers and to move them out of subsistance farming into income-based farming. It would be impressive for us to know how many children of farmers around the globe are now better educated because their parents were able to send them, or keep them, in school because of higher cash flows to their home. I know that it is many. They all pay tribute to this very special silver fox, Jack Keller.

Richard Allen
Professor of Water Resources Engineering
University of Idaho

Preface

Irrigation is the economic activity that most consumes water and it is the most granted use in Brazil, accounting for about 72% of all consumed water in local soil, as occurs worldwide. In addition, this use is distant of reaching its potential, given that irrigated agriculture occupies only 15% of the total area identified as irrigable in Brazil. In other words, it is the activity with the highest consumption of water with significant growth potential and use nor always rational of the water resources. Therefore, it is necessary to find ways to increase the water use efficiency in irrigated districts.

The increasing scarcity of water supply has induced the INOVAGRI Institute to promote events as a reason to discuss different aspects of science and technology in irrigated agriculture. In 2012, the INOVAGRI Institute held the I INOVAGRI INTERNATIONAL MEETING and the IV WINOTEC (International Workshop on Technological Innovations in Irrigation) aiming to promote an upgrade of the technological innovations applied to the irrigated agriculture by presenting this event as a tool for discussion of R&D in irrigation and drainage. The reason for the organizing of that event in Ceará State is the fact that this state has handled throughout its history, the issue of uncertainty and scarcity of water supply, usually inadequate. The occurrence of prolonged and periodic droughts has caused great economic, social and environmental damages. The average rainfall in the rainy season (Feb - Apr) in Ceará is 607.5mm. In the past 2 years (2012-2013), the precipitation were under the average. For 2014, there is a probability that the rainy season precipitation might be 40% under the average. In January 2013, 63 of the 144 major water reservoirs in the state had less than 30% of the total storage capacity volume. In the semiarid region of Ceará, water availability is limited to water reservoirs: more than 8,000 water reservoirs have been built, representing a potential accumulation of 18 billion m^3. This ability to build water reservoirs is almost running out, with the limit capacity of 22 billion m^3, which becomes even more urgent the necessity of this innovation for saving water and dealing with drought.

Now, from April 13 to 16 2014, the INOVAGRI will be promoting the II INOVAGRI INTERNATIONAL MEETING in Fortaleza that will focus on technological innovation, planning, generated technology transfers and applied in irrigation management.

This book presents comprehensive texts about several subjects divided in 21 chapters, discussed in the round tables of the 2012 meeting on technological innovation, planning, management and new technologies applied in irrigation. The main topics were related to technologies to support improvements in irrigation scheduling; irrigation advisory service; optimal pipe size computation; irrigation district; use of saline water as a strategic approach; challenges for sustainable agriculture, and several then different subjects.

This publication was prepared from the perspective of some experiences discussed in 2012 I INOVAGRI INTERNATIONAL MEETING, as was to preserve them.

Francisco de Souza, Ph.D
President of I INOVAGRI INTERNATIONAL MEETING

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- Dr. Jack Keller (in memoriam), by the wonderful contribution to the Irrigation and to the INOVAGRI INTERNATIONAL MEETING. Our always many thanks.

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Irrigation Science and Technology to the Service of Farmers, Food Security, and the Environment

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1 Retrospective view
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Technological Innovations in Irrigation Engineering:
Impacts on Climate Change, Water Quality and Transfer of Technology
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INOVAGRI
INSTITUTO DE PESQUISA E INOVAÇÃO NA AGRICULTURA IRRIGADA

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1 Irrigation Science and Technology to the Service of Farmers, Food Security, and Environment

1 A RETROSPECTIVE VIEW

If the advance of irrigation engineering could be summarized in a short sentence, that sentence could be "progressive increase of application uniformity". This kind of advance has fed-back with the spread of high yielding, genetically homogeneous cultivars and hybrids (Clemmens, 2006). As the genotype and water limiting factors were superseded, other inputs (i.e., fertilizer) contributed to further yield improvement, understood as higher yield potential and lesser spatial variability.

The advances on irrigation agronomy were marked by three milestones. Agronomists and soil scientists defined field capacity and wilting point to establish the subrogate concept of root zone soil water holding capacity (Veihmeyer & Hendrickson, 1927); in collaboration with agro-meteorologists, agronomists defined the concepts of reference evapotranspiration and crop coefficient used to compute crop water consumption (Penman, 1948; Doorenbos & Pruitt, 1977). These concepts conformed the foundations of irrigation scheduling base on the root zone soil water balance. Thirdly, understanding the response of crops to water deficit further helped to optimize irrigation management when water is scarce (Hsiao, 1973; Stewart & Hagan, 1973).

An expanded sentence to describe the recent history of irrigation engineering and science could be "a race to increase irrigation efficiency (by increasing distribution uniformity and accommodating the applied depth to crop consumption) and crop yield, therefore a race to increase irrigation water productivity". This is illustrated in Figure 1. The red lines represent a hypothetical situation before the green revolution. The solid red line represents how yield increased as crop evapotranspiration increased. This is typically a linear relationship. The dashed red line represents the amount of irrigation water that had to be applied to obtain a given yield and its corresponding evapotranspiration. This line curved as the applied water increased due to the loss of water as percolation or runoff (Warrick & Gardner, 1983). The water that is evapotranspirated by the crop but not supplied with irrigation must come from rain or the soil storage.

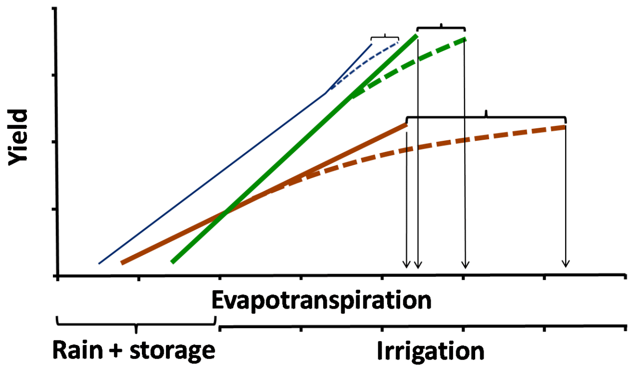

Figure 1 Schematic water response functions (yield-evapotranspiration in solid line, yield-irrigation in dashed lines) before (red) and after (green) the Green revolution and in a hypothetical future (blue)

After the green revolution, the yield-water response function has reached greater yield values and may be greater evapotranspiration as well (green solid line in Figure 1). Moreover, in contrast to old local varieties, the new cultivars and hybrids perform poorly at low input. The curved green dashed line represents the new yield response to applied irrigation water. Now, if the difference between irrigation water and evapotranspiration for the maximum yield in each period (before the green revolution and nowadays) is compared, it may be observed that the gap has decreased, reflecting that water losses have decreased too. This is consequence of greater irrigation efficiency resulting in turn from more irrigation uniformity. As a corollary, the amount of irrigation water necessary to obtain maximum yield in a field has decreased with time while evapotranspiration has remained equal or has increased slightly. The thin (solid and dashed) blue lines in Figure 1 will be discussed later.

A different form of presenting the journey along the recent history of irrigation engineering and science is in Figure 2. Deficit coefficient is defined as the relative evapotranspiration deficit in relation to maximum evapotranspiration, thus zero means full evapotranspiration and one no evapotranspiration. The curves in the abacus correspond to different distribution uniformities (Playán & Mateos, 2006). Fifty years ago irrigation uniformity was low compared to nowadays. Even though significant portions of the fields were over irrigated, other sites did not receive sufficient water to satisfy crop evapotranspiration. This situation is represented in Figure 2 as the origin of the red arrow. With the advent of laser leveling for surface irrigation, the advances in the design of sprinklers and sprinkler irrigation machines, and the introduction of trickle irrigation, irrigation distribution uniformity increased notably, allowing greater irrigation efficiency and lesser deficit coefficient. The arrow head would thus represents the current situation, and the curved shaft the progress along the last fifty years.

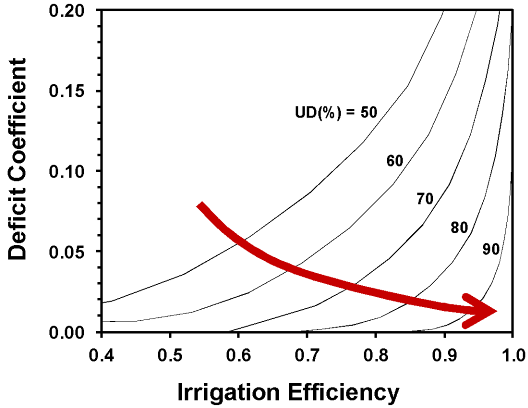

Figure 2 Relationship between the deficit coefficient and the irrigation efficiency for different distribution uniformities. The red arrow symbolizes the progress of irrigation science and technology

Therefore, irrigation engineering and science are mature disciplines where further advances are unlikely; they seem to be dying from success at the lower right corner of Figure 2. Only if new paradigms arise, irrigation will pay new services to farmers, food security, and the environment. It is advocated here that these new paradigms will emerge from a holistic irrigation research approach (Kuper et al., 2009; Keller, 2012).

2 EFFICIENCY AND PRODUCTIVITY: CONCEPTS OR JUDGMENTS?

Irrigation farmers form part of socioeconomic environments with boundaries that are more or less diffuse and permeable. In countries such as Brazil there are large irrigation farms oriented to the exportation of commodity crops and high value crops targeting specialized markets. These products travel far away crossing boundaries that have been made relatively permeable by the agribusinesses industry, so they reach international markets. Moreover, these farms use latest irrigation technology: i.e., center pivots manufactured by North American companies or Israeli automated drip systems. Irrigation technology is therefore global. International manufacturers provide irrigation equipments; the same manufacturers together with other public organizations and private consultancies provide knowledge and software. The information and technology used in these large irrigation farms flow worldwide rapidly.

At the other extreme, small growers such as those in the public irrigation schemes of the Brazilian Semiarid North East use mostly traditional surface irrigation because that is the common practice in the region where they farm and also because, in collective irrigation schemes, water delivery rules make difficult the introduction of other irrigation methods. Their production is for subsistence or it goes to local or regional markets. Paradoxically, the technological challenge in these irrigation farming systems is today much greater than in the large farms of the agribusiness industry. The technical constraints and the socioeconomic context for irrigation improvement and development must be thoroughly understood before selecting the appropriate technologies. This is the first message in this paper.

Let's deepen in this discussion by analyzing the irrigation efficiency and irrigation productivity concepts in the two contrasting systems mentioned above. In many agribusiness-type farms in Brazil, land is virtually unlimited while water is limited. Therefore, there water productivity is the objective. For instance, recently I visited a large commercial farm on the Chapada Diamantina, state of Bahia. This farm pumps water from the Paraguaçu river to irrigate tropical fruits, vegetables, and coffee oriented to national and international markets. Each year, the farm manager optimizes irrigation water use by, first, fully irrigating the permanent crops localizing the water next to the trees under the mulch created by the pruning and cover crop residues, second, limiting the area of annual crops irrigated with center pivots according to the amount of water that is available, and, third, fallowing the rest of the farm using soil conservation practices. Moreover, the farm manager uses estimations of evapotranspiration to schedule the irrigations. All this appears to me as the right irrigation strategy to achieve high water productivity.

However, if we think about small-holder collective irrigation schemes in the Semiarid North East, normally there water is not the limiting factor. Contrary, the size of the land lots is small, so they are fully cultivated. Land productivity is therefore the goal (English, 1990; English et al., 2002). Production in these schemes could be increased mainly by increasing the irrigable area, and only marginally by increasing irrigation efficiency or irrigation water productivity.

Therefore, the second message in this paper is that irrigation efficiency, water allocation efficiency, or water productivity are neither universal goals nor neutral concepts. In fact, policies based on established standards for these concepts may negatively affect the general interest or the interests of vulnerable communities within the irrigation societies (Boelens & Vos, 2012). I advocate that slogans such as that of FAO "more crop per drop" should be revised because the discourse behind them has held back the development of regions where food insecurity coexists with unexploited renewable water resources. The case of sub-Saharan Africa is paradigmatic at this respect. The reader is invited to watch two World maps published in the Comprehensive Assessment of Water Management in Agriculture (2007). The first map (Comprehensive Assessment of Water Management in Agriculture, 2007, page 63) shows areas of physical and economic water scarcity. Sub-Saharan Africa stands out as the largest region where economic scarcity is the problem. The second map (Comprehensive Assessment of Water Management in Agriculture, 2007) shows the share of population below the poverty line. Sub-Saharan Africa stands out again in this map, in this case as the region where the proportion of population living below the poverty line is greatest. Where economic water scarcity rather than physical water scarcity is the bottle neck for development, neither irrigation water productivity nor irrigation efficiency should be conditions for investment. Fortunately, international funding agencies seem to be moving away from stringent irrigation water productivity requirements and are starting to follow investment strategies with wider perspective (World Bank, 2008a,b).

Furthermore, the meaning of irrigation efficiency is often overemphasized if the basin is closed (Willardson et al., 1994; Keller et al., 1996; Mateos, 2008). When irrigation efficiency is analyzed from the basin approach, one may find that improving on-farm irrigation efficiency may have little impact at the basin scale, which should be the scale of general interest (Mateos et al., 2000). The operational losses in collective irrigation schemes and the water that runs off the fields are partially reused within the same scheme and often later on in other districts located downstream. Therefore, in closed basins, the significant reduction of on-field irrigation water requirement achieved with the modernization of the irrigation systems has little impact on basin-scale water availability. Only the reduction of evapotranspiration through deficit irrigation or the reduction of soil evaporation (non beneficial consumption), using for instance sub-surface drip irrigation (Lamm et al., 1994), will contribute to increase water availability in closed basins. The effect of reducing soil evaporation is shifting the yield-evapotranspiration function to the position of the thin blue line in Figure 1.

Therefore, the slogan that Professor Jack Keller coined at the WINOTEC 2012 meeting could be a good alternative slogan for developing regions: “more poverty reduction per drop of water consumed” (Keller, 2012). This new slogan incorporates the two aspects highlighted above: first, the primary goal of irrigation should be reducing food insecurity; second, the primary, basin-scale interest should be reducing the volume of consumed water rather than reducing the use of water.

Moreover, where water is multifunctional or irrigated cropping systems coexist with other agricultural (or non-agricultural) systems, then less irrigation efficiency or less water productivity sometimes contribute to higher social or environmental efficiency. In collaboration with colleagues from the Institute for Sustainable Agriculture in Córdoba (Spain), I studied an example of multifunctional use of water in one of the ancestral irrigation systems developed one thousand years ago by the Arabs in mountainous area of Southern Spain (Figure 3, Mateos et al., 2007). Water runs off as the snow package melts. Then it is diverted to irrigate pasture and horticultural crops. Traditionally, the acequias were unlined, thus seepage allowed the growth of trees along the acequias. These trees became distinguishing landscape features. Moreover, when there is oversupply of water, the acequiero diverts part of the flow to non-cropped areas in order to recharge small aquifers that feed downstream springs. With this practice, water availability is extended beyond the snow melting period. When someone decided that irrigation efficiency should be increased, the acequias were lined. This decision demonstrates that the efficiency/productivity discourse may affect valuable cultural landscapes severely. Old chestnuts standing up along the water

Figure 3 Acequiero operating a turnout, Acequia Nueva, Poqueira watershed, Spain

lines (distinctive feature of this picturesque region that attracts tourists from all over the world) are dying after centuries greening the landscape.

3 IRRIGATION SCIENCE AND TECHNOLOGY TO THE SERVICE OF LARGE AND SMALL-SCALE FARMING

The question is then: Is the same technology valid for everyone? I said that irrigation efficiency, water allocation efficiency, and water productivity are no neutral concepts. However, technology is neutral (third message). That is, what I just wrote about irrigation efficiency and productivity should not be used to question the potential of technology for the improvement of irrigation in under-developed agricultural communities.

It is true that new technology is typically adapted to commercial agricultural systems. These systems and their technology may be compared to Formula One Cars. For instance, there are nice examples of site specific precision irrigation based on the use of sophisticated sensors for detecting spatially distributed crop biophysical properties (Kranz et al., 2010). Regulated deficit irrigation is another promising practice that allows reducing evapotranspiration with little yield penalty (Fereres and Soriano, 2007). This practice requires deep knowledge of the response of the crops to water deficit and intense monitoring of soil or crop water status; then, the uppermost part of the yield-evapotranspiration function may turn counterclockwise (see the thin blue line in Figure 1).

The same technologies may be appropriate for agricultural systems other than those for which they were developed, as the car industry profits from F1 technology. But the technology developed for F1 cars often cannot be used for utilitarian cars. Precision center pivot irrigation has been barely adopted (Evans et al., 2012) in industrial agriculture, thus it hardly will help small farmers. The same can be say for regulated deficit irrigation. However, small-holders in developing countries are now profiting from drip irrigation technology that was first developed for commercial farms and now has been adapted to their circumstances (Postel et al., 2001). For instance, pioneer small holders in collective irrigation schemes of the Brazilian North East have introduced small low pressure drip irrigation systems with fertigation equipment that allows them to obtain high yields of fruits and vegetables with minimum labor. The introduction of such systems is often constrained by the water delivery schedules in the collective networks. However, some locations, i.e., next to the main canal, or additional infrastructure, i.e., the small storage water tanks at the entrance of the farm lots in the Mandacaru irrigation scheme in the San Francisco Valley (Vieira, 2012), may allow overcoming those constraints.

My third message was that technology is neutral. However, I want to call attention about the responsibility that research leaders have on the development of technology that helps everyone. Research should be at the service of farmers and agriculture; however, too often we researchers act as “sellers” of fancy sensors, platforms, colorful maps, or software that are essentially “solutions looking for a problem”. Although technology is neutral, the use we make of it may not be neutral. This is the forth message in this paper. Research and Development Organizations have the responsibility of producing technology to rescue small-holders from the poverty trap and to promote their socioeconomic progress. I believe that the private sector and international manufacturers of irrigation equipments have driven the spectacular development of irrigation in Brazil. That is good news. Likely they will be the major financial backer of the agribusiness-oriented technology needed to double the irrigated area in the next 5 years, as the Brazilian Irrigation Plan aims to (Bezerra Coelho, 2011). Also they will be key contributors to make Brazil rich. But the slogan of the Brazilian government says “pais rico”, rich country, and also “pais sem pobreza”, country without poverty. In my opinion, in order to accomplish this second goal, public research funding should be concentrated on the development of technology that is appropriate for small-holder farming and collective irrigation systems that have a social function. The goal of doubling the irrigated area in four years sounds very ambitious. However, the goal of improving 140,000 ha of existing collective systems and developing new collective irrigation in 200,000 ha (Bezerra Coelho, 2011) sounds too modest to me.

4 RESEARCH FOR IMPROVING SMALL HOLDER FARMING IN COLLECTIVE IRRIGATION NETWORKS

Collective irrigation systems are not easy. Many of these systems in the world have failed and many perform well below expectations. We at the Institute for Sustainable Agriculture have recent experience in sub-Saharan countries. We have assessed the performance of a representative sample of small and large-scale collective irrigation systems along the Senegal Valley (García-Bolaños et al., 2011; Borgia et al., 2012, 2013). We have used participatory rural appraisal methods and benchmarking techniques in order to understand the reasons for the degradation spiral that the irrigation schemes suffer reiteratively. Soon after construction or rehabilitation, maintenance becomes insufficient, the systems deteriorate, operation is more difficult, the water delivery service is poorer, farmers become unhappy and they refuse to pay their water fees or to participate in collective maintenance works. Rehabilitation pulls the schemes back to the beginning, but in most schemes the spiral starts again. The challenge is therefore breaking this spiral.

We calculated the technical efficiency of the sample of irrigation schemes; then we were able to identified schemes that performed reasonably well, that used a reasonable amount of inputs, that produced satisfactory yields, and that have managed to break the degradation vicious circle (Borgia et al., 2013). The conclusion was that there is hope; that there are schemes that perform may be used as benchmarks to improve underperforming schemes in the Senegal valley.

This is just an example from one very poor region that lacks of technical skills. Brazil and other countries where irrigation is well developed, such as Spain or USA, are at the other extreme. Nevertheless, the gap between actual and potential yield for a given amount of water is notable everywhere (Lorite et al., 2004; Passioura, 2005; González-Dugo & Mateos, 2008; Sadras et al., 2012; Borgia et al., 2013; García-Ponce et al, 2013). Although science and engineering will contribute with innovative technologies, only new paradigms using holistic approaches (Keller, 2012) based on participatory action research (Kuper et al., 2009) will help to close the irrigation performance and yield gaps that continuously jeopardize food security. The numerous stories about successful collective irrigation should encourage new research in Brazil and other countries to ensure that collective irrigation schemes contribute both to wealth and equality. This is the greatest challenge in irrigation research.

5 TECHNOLOGY FOR MONITORING SUSTAINABLE WATER USE AND IRRIGATION RETURN FLOWS

Although irrigation has enormous beneficial effects on food production, its economic, social and environmental impacts can be notable as well. These detrimental effects can be at the site of the irrigation scheme (on-site effects), upstream of the scheme, and downstream.

Construction of dams in the rivers to store water for irrigation can cause great environmental damage. Abstraction of water from rivers reduces its flow with consequent negative effects on the rivers and associated wetland habitats. Abstraction of water from aquifers can deplete the ground water table and cause similar adverse effects on neighboring agricultural areas and natural wetlands. A recent simulation study has revealed that, for the year 2000, non-renewable groundwater abstraction contributed about 20 % to the global gross irrigation water demand (Wada et al., 2012). Basin water authorities need the participation and support of all actors in the basin to be able to implement systematically and in the long-term norms and measures that guarantee sustainable use of the water resources. Technology and models are the means for modern integrated water management.

The downstream off-site effects are caused by the irrigation return flows. Irrigation effluents are normally returned to the river systems, downstream of the irrigation scheme, loaded with nutrients, salts and pesticides that can have major negative effects on the water quality. Monitoring these effluents will help to keep track of agrochemical budgets and flows and may be the basis for alerting on the misuse of water, fertilizers and pesticides. Figure 4 presents a picture of a hydrological station installed at the outlet of an irrigated watershed in Southern Spain to monitor the return flows and its quality. The field station communicates on real time with a central station via GSM. Anomalous fluctuations of either flow rate or concentration of dissolved solids are transmitted to the central station as alarms.

Figure 4 Hydrological station for monitoring irrigation return flows at the Genil-cabra irrigation scheme, Spain

Poorly managed irrigation can cause salinization and water-logging (on-site effects). The irrigation water carries water-borne salts that have to be leached with an extra amount of water in order to avoid accumulation on the soil surface and the consequent reduction of the fertility of the soil. If too much water is applied the water table will raise, thus rendering the site water-logged. Maintaining the delicate balance between salt leaching and waterlogging (on-site effects) and between drainage and salts disposal (off-site effects) will require new irrigation management tools. Modern irrigation scheduling and application technologies are already improving water use efficiency to overcome these problems (Barros et al., 2012).

However, serious problems remain, not so much in the developed world, but in the developing world. Irrigation may be sustainable but at a cost (Hillel and Vlek, 2005). The challenge is to improve the irrigation practice to feed a growing population with water resources that are more and more limited; without causing unsustainable environmental impacts.

6 CONCLUSIONS

The technical constraints and the hydrological and socioeconomic contexts for irrigation improvement must be thoroughly understood before selecting the appropriate technologies. Although irrigation technology is neutral, irrigation efficiency, water allocation efficiency, and water productivity are not neutral facts. Therefore, Research and Development organizations have the particular responsibility of producing technology for small-holders.

Irrigation research is likely to evolve over the next few decades from the recent intense advances in technology and equipment to intense developments in knowledge. The increased complexity of the analysis will necessitate new sophisticated tools. A new holistic approach based on participatory action research will emerge to respond to the challenge of improving the irrigation practice to feed a growing population with water resources that are more and more limited and without causing unsustainable environmental impacts.

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2

Challenges for Sustainable Irrigated Agriculture: Towards Efficient Water Use

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1 Introduction
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2 Challenges for Sustainable Irrigated Agriculture: Towards Efficient Water Use

1 INTRODUCTION

One of mankind's greatest challenges during the present century is the need to guarantee food and environmental security for a world population which in 2030 will be of approximately 8,3 billion people. Population growth will demand more food, a fact which together with the new energy demands for renewable sources, can modify present standards of use of water resources in agriculture. The problem is more complex than it seems because it doesn't only consist in the need to produce more food but also to produce food in a sustainable way.

The development of agroenergy and irrigation, activities that are water intensive, butstrategic for the agricultural sector and for Brazil, require adequate planning with respect to land allocation so as not bring about risks in terms of restrictions and conflicts associated to demands for water for growth.

The increase in competition for the use of water between several sectors of society will imply in the need to use the water resources in a more efficient way in order to guarantee the sustainability of production in different sectors. In some regions of Brazil, especially in those where there has been excessive and unorganized growth of irrigated agriculture, there are already conflicts for the use of water, which in general are associated to the unequal distribution of this resource.

In the São Francisco River Basin, for example, studies have indicated potential conflicts among water uses, particularly between energy generation and agriculture. In the Verde Grande river basin, an important tributary of the São Francisco River, the demand for water for irrigation corresponds to 88% of the total demand for water in the region. In the Paraiba do Sul basin there have been reports of several conflicts. These and other conflicts which have already taken place in Brazil indicate the necessity to organize the use of water, through the definition of protocols which can be realistically followed by the users of water.

Brazil is one of the few countries in the world capable of increasing its agricultural production without jeopardizing the environment. It has about 12% of planet's available water resources and a potential irrigated area of 30 million hectares. Of this, only a little more than 5 million hectares are irrigated, of which 35% are used for national agricultural production.

Until a few years ago, irrigation was regarded and studied only as an input factor and the objective was to increase production. Today, irrigation is intimately associated to environmental issues and to water resources allocation. It is known that of the total amount of water used in Brazil, about 70% is for irrigation and that a significant part of the irrigation systems still present low efficiency levels in water use. It is common to have systems that operate at efficiency levels of 40%. This fact has led Brazilian society to question the real benefits of irrigation.

Challenges in order to attain sustainable agriculture are diverse and of several orders and they necessarily include irrigated agriculture. In the light of sustainability, irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. A stable relationship should be maintained between these two objectives now and in the future, while potential conflicts between these objectives should be mitigated through appropriate irrigation practices (Cai et al., 2003).

Increasing water scarcity and competition for the same water from non-agricultural sectors drive the need to improve crop water productivity to ensure adequate food for future generations with the same or less water than is presently available to agriculture (Challenge Program Book, 2002).

In this context, it is necessary to improve the efficiency in the use of water and energy in irrigation.Some water-saving measures involve taking more advantage of the scientific, engineering and technological advances in soils, plants and irrigation. Other measures focus on administrative and managerial reforms to improve efficiency, including the decentralization of public irrigation agencies and a greater reliance on farmer-owned and farmer-operated irrigation (FAO, 1993).With respect to research, uncertainties associated the several biophysical processes involved in irrigation and the quality of data used in the decision-making process are critical factors which must be studied and better understood.

In the strategic area of irrigation policies several factors have contributed to the low development of irrigated agriculture in Brazil such as: (i) the lack of orientation of the sector with respect to factors regarding location favorable to its development, in particular with respect to the availability of water, (ii) the lack of articulation between public and private institutions involved in scientific, technological and education, as well as producers of equipment to stimulate exchanges and the integration of actions to create a national network for improvind irrigation.

It is necessary to point out that it is not possible to separate food security from water security. The articulation between both water sector and agriculture sector is strategic for water quantity management, once agriculture sector is the main consumptive water user. It is also strategic for management of water quality and to maintain a balance of the hydrological cycles in watershed, through the use of conservationist practices that are adequate for agriculture.

As a result, in this chapter, we present some general thoughts on some themes that must be worked on since they directly have an impact on the efficient use of water and energy, jeopardizing the sustainability of irrigated agriculture (IA). Meeting current and future food requirements will require rapid increases in productivity to avoid an undesirable expansion onto fragile and marginal lands. However, increases in production need to take place without further damaging the environment. For this to happen, principles of sustainability must be a core part of agricultural policies, to provide incentives and enabling conditions for sustainable resource use. (Agricultural Sustainability, 2004).

2 CHALLENGES FOR IRRIGATED AGRICULTURE

The challenges for irrigation practice in Brazil are ofdifferent natures. In this chapter,we will not discuss the strategic challenges, which depend on public policies, such as for example, the lack of basic infrastructure. We will specifically discuss some scientific challenges that affect the decision making process and the management of water for irrigation,emphasizing the lack of data, its quality and uncertainty.

2.1 Lack of data and/or basic information

The lack of data regarding soil, climate and plants has jeopardized the decision making process (planning and management) in irrigated systems, especially when models are used in the process.

Soils: In the case of soils, because of theirimportance in the irrigation processes, the lack of data is more evident and easily perceived. The largesoil spatial variability, which increases parameter uncertainty, and the high costs of survey needed to obtain someparameters make the decision-making process difficult. Basic questions still need to be answered. It is necessary to point out: (1) the need to establish simple criteria to define the survey and minimum amount of data needed to represent effectively the system; (ii) the need to define the location where in the field data should be collected; and (iii) the need to define where more detailed monitoring should take place. To make things worse, available financial resources to do basic research are increasingly scarce, being necessary to develop and/or improve techniques that enable soil data spacialization, improving the decision-making process.

Regarding this, pedotransfer functions (FTP) can play an important role. They use simple pedological data, which is easy to collect and cost effective, to generate, with a certain degree of precision, more difficult to obtain physical-hydrological parameters of soils.

Many pedotransfer functions have been developed and are described in the literature (Gupta e Larson, 1979; Rawls e Brakensiek, 1982; Tomasellaet al., 2000), but few have been developed for the conditions of Brazilian soils.

Rodrigues et al. (2011) developed FTP to estimate wilting point (PMP) and field capacity (CC). In Figure 1, values of observed CC and predicted using FTP are depicted. The authors concluded that the functions obtained presented average predictive capacity with the tendency to underestimate predicted CC levels for higher values within the respective variation amplitudes. Thus, its use, should consider the presence of this type of tendency/bias and the resulting uncertainties from the variability fraction which was not explained by the predictors.

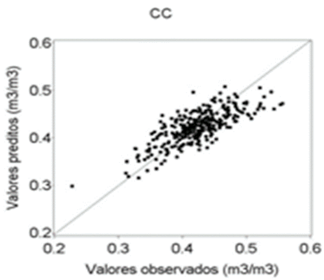


Figure 1 Observed and predicted field capacity values

Climate: With respect to climate, the absence of a network of weather stations, Figure 2, which would provide minimal climatic elements necessary to calculate the reference evapotranspiration (Eto), has limited the use of models and made decision making process more difficult.In general, reference evapotranspiration is less variable spatially than precipitation. Thus, farmers that cannot obtain their own weather station should rely on data made available by public weather station network,even if they are 50 to 100 km away from their property.

Figure 2 Basic weather station with the minimum sensorsneeded for the estimation of the reference evapotranspiration

In general, precipitation presents more variability than reference evapotranspiration, besides the fact that in most of the time precipitation is localized, Figure 3. Thus, it should be treated more carefully by farmers. Ideally, each irrigated area should have a rain gauge installed in it. It does not need to be a complex rain gauge with a datalogger, once that decision-making regarding irrigation is done on a daily basis. Thus, in most situations a standard rain gauge such as the one presented in Figure 4A, is more adequate and cheaper than a data logging rain gauge (tipping bucket or weighing, optical, etc.) Figure 4B. In addition, the standard rain gauges are of simple maintenance. The fact that they have to be verified on a daily basis to register the precipitation amounts levels helps irrigators to have a better understanding of how the irrigation system works. It is important to point out that in the case of the data logging rain gauge it is necessary to establish a cleaning and maintenance routine. It is also necessary to train the person who is going to operate the equipment and to have a data

Figure 3 Illustration showing localized rains

A. B. C.

Figure 4 Standard (A) data logging (B) rain gauges and dirt and residues accumulated on a data logging rain gauge in which periodical maintenance has not been undertaken adequately (C)

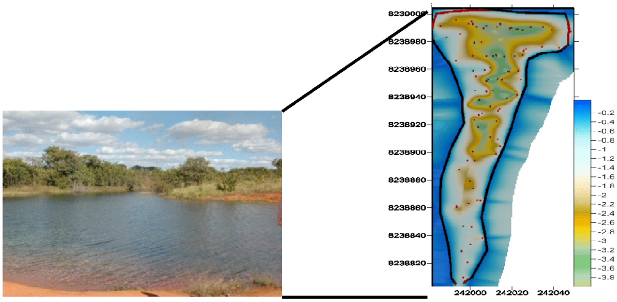
consistence routine. It is essential to highlight that if the equipment is not cleaned on a regular basis, particles and dirt will accumulate and with time this will jeopardize significantly the quality of the data the farm's decision making process (Figure 4C).

Plant: With respect to crop, there are several variables of interest, being the root system one of the most important (Figure 5). For good irrigation practices, it is necessary to have knowledge of the root growth dynamics and their maximum depths. With such information it is possible to estimate the effective root depth, which is a basic parameter for irrigation design and management. Maximum root depth varies from crop to crop and depends on several factors associated with soil such as, for example, the soil strength expressed by its mechanical resistance on roots. Rodrigues et al, (2012) presented values for maximum root depth for different plants in the Cerrado region.

Figura 5 Maximum depth of the root system of the bean

Small Reservoirs: There are several other important aspects for irrigation sustainability. Water resources availability and water demand in agriculture watersheds should be well known in order to avoid water conflict and irrigation failing. In this context, small reservoirs play an important role in supporting the local economy in the savannah areas of Brazil and are primarily used for the provision of water for irrigation and watering livestock. Thus, it is very important to have information about this infrastructure. In recent decades, thousands of these small reservoirs were built in Brazil. In the Preto River Basin, for example, Rodrigues et al (2007) using remote sensing technique identified 253 small reservoirs. The problem is that there is no information about the physical characteristics of these infrastructures, what has been a constraint in decision-making processes regarding planning and management of existing water resources.

With the objective of better understanding these systems and contributing to the management of water, studies were developed to quantify water loss from infiltration and evaporation (Rodrigues et al, 2010 e Rodrigues et al., 2012). In addition to this, methods for estimating reservoir volumes based on landsat surface area measurements



$V = 12.803\ A^{1,1144}$ ($R^2 = 0,83$)

Figure 6 Picture and 3D model of a small reservoir in the Savannah Region (Maximum water depth = 4.05 m and surface area =1.4 ha). In the equation,V = volume (V, m^3) and A = surface area (A, m^2).(Rodrigues et al., 2012)

were tested (Figure 6) and adapted for conditions in the Preto River Basin in the Brazilian savannah (Rodrigues, 2012).

2.2 Measurements and data quality and uncertainty

Data quality is another aspect to be pointed out when thinking of sustainable water use in irrigated agriculture. In some situations data quantity is quite good, but quality is low. This situation is worse than the situation where there is no enough data in quantity because information will be obtained based on wrong data and as a result decision-making will be incorrect and the consequence can be significant. This contributes to low efficiency in the use of water and energy in irrigation. This fact becomes clearer when one uses modeling.

Gains are often obstructed by complex problems such as uncertainty. Uncertainty associated with data variability and quality is a critical aspect which makes the decision-making process vulnerable. These two aspects needs to be better studied and understood in order to develop simple methodologies and protocols that can be used by technicians.

Climate: As mentioned before, precipitation is a climatic element that is a fundamental input for irrigation management. From a management perspective, inaccuracies in rainfall inputs directly compromise model predictions and hence also compromise robust decision making on water and risk management options. Furthermore, errors in rainfall reduce our ability to identify other sources of error and uncertainty, slowing scientific advancement and compromising the reliability of operational applications (McMillan et al., 2011).

Because of its importance in the process, rain gauges are the most critical equipment and where problems area observed more often. Several types of rain gauges have been developed such as weighing gauges, capacitance gauges, tipping-bucket gauges, optical gauges, disdrometers, underwater acoustic sensors, and others. However, tipping-bucket rain gauges are often used for ground-based rainfall measurements by farmers.

The wide use of data from tipping-bucket gauges indicates the importance of understanding their measurement errors and their ability to capture the complex structure of the rainfall process (Habib et al., 2001). Habib et al., 2003 citing Sevruk and Lapin, 1993 commented that several studies demonstrated that tipping-bucket gauge data are corrupted by errors, both random and systematic.

It is known that errors in measuring rainfall using rain gauges arise from a number of systematic causes, including the sitting of the instrument, its height above the ground and varying wind speeds over the gauge orifice. There is also a random error which cannot be ascribed to any particular cause (Hutchinson). The failure may be caused by partial or complete clogging of the funnel that drains into the bucket, data transmission interruption, or temporary power failures. Such errors are unpredictable and some attempts have been made to develop on-line detection and data quality techniques (Giuliani et al. 1997). To help detect malfunctioning instruments, Krajewski et al. (1998) and Ciach and Krajewski (1999) advocate the use of dual gauges side by side.

The tipping-bucket rain gauge is known to underestimate rainfall at high intensities because of the rain water amount that is lost during the tipping movement of the bucket. The related biases are known as systematic mechanical errors and, since their effect increases with rain intensity, have a significant influence on the derived statistics of rainfall extremes (Molini, et al., 2005). There are also errors associated with the electronic equipment, such as dataloggers.

The systematic error is the most significant source of error and includes losses due to wind, wetting, evaporation, and splashing. The wind-induced error, which is the largest component, has been extensively investigated using different methodologies ranging from field intercomparisons(Habib et al., 2001).

Most of the errors we discussed so far can be either accounted for or removed with a certain degree of accuracy from the rain gauge observations. However, another source of error that has not been addressed as extensively as the others is the sampling mechanism of the TB gauge. The operational principle of the TB is rather simple: falling rain is collected into a fixed-size bucket that tips and drains when it gets full. Recording the number of tips along with information about their time of occurrence can be used to estimate rainfall accumulations and rates.

Uncertainties associated with the different recording scenarios, and the chosen time scale of the final products of the TB gauges need to be investigated. As a result, and as mentioned previously, it is better to use a standard rain gauge, which is simpler to read and presents less uncertainty.

In order to evaluate rain gauges errors in measuring precipitation in the BuritiVermelhowatershed, a tube was adapted to a datalogging rain gauge to conduct the precipitation collected by it to a specific container, which had the objective of storing rain which fell during one day (Figure 7A).The amount stored in the container, after one day, was measured and compared with the amount registered by the rain gauge. This procedure was undertaken with 3 rain gauges.

In Figure 7B a graph is presented indicating the errors observed in total rainfall occurred in one day. Positive number means that rain was collected in the container, but not registered by the equipment. This is the type of error more commonly observed and is more regular in small rains. The analysis of this Figure indicated the need to critically analyze data which results from such equipment, corroborating with the observation made previously, that often the use of standard rain gauges is more adequate, as well as the fact that they provide better quality data.

Uncertainty associated with the rainfall data quality, which occurs due to rain gauge limitations, is a critical problem, which in a certain way can be solved with the use of more robust equipment and of techniques to treat data (such as corrections, filling missing data, etc.).

Providing both accurate evapotranspiration estimation on a daily basis and estimation of the magnitude of error associated with this estimate is vital for informed water management decisions that allow irrigation managers to account for the associated uncertainties and risks (El Khoury, 2010).

Behavior of the monthly reference evapotranspiration curves calculated with data from three weather stations apart other by approximately 50 km is presented in Figure 8. It can be noted in this figure that the ETo curves for the three stations havein general the same behavior/tendencies.

A. B.

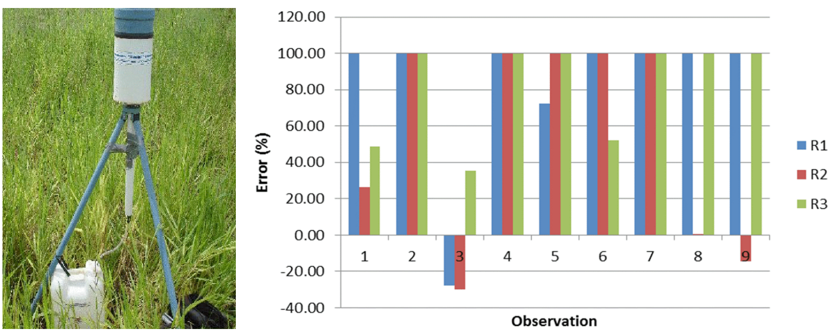


Figure 7 (A) Picture of a datalogging rain gauge with tube and storage container; (B) errors observed in total rainfall occurred in one day in three datalogging rain gauges (R1, R2 and R3)

One can observe, however, that at some moments, highlighted in the figure below by circles, the trends in the curves changed, which can indicate problems in data. This type of problem is more difficult to be detected and corrected when the stations networks are more disperse.

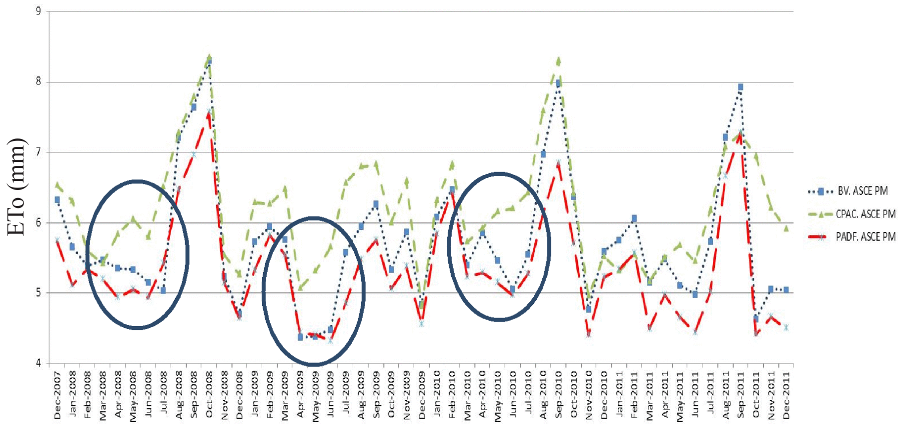


Figure 8 Monthly reference evapotranspiration (ETo) curves for three weather stations

Soil: Soil parameters present a great spatial variability what can reduce the advantages gained by using advanced and more sophisticated models, jeopardizing the irrigation decision-making process. The drainage area of BuritiVermelho experimental watershed is showed in Figure 9A. Several soil samples were collected in the basin and available

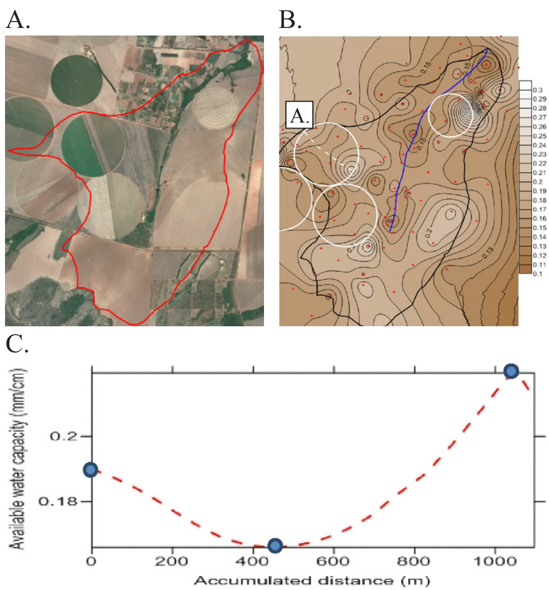


Figure 9 (A) Drainage area of BuritiVermelho experimental watershed; (B) Soil samples and center pivot where an imaginary longitudinal line was drawn to analyze soil available water capacity (AWC) variability; (C) soil AWC variation occurred in the longitudinal line drawn in pivot A

water capacity was calculated, Figure 8B. In this Figure, in the Center Pivot A a longitudinal line was drawn and the available water capacity (AWC) variability occurred in this line was verified. In Figure 8C, the red line indicates the variation in AWC according to the longitudinal line drawn in pivot A. It can be seen that this property varied from 0.08 to 0.3 mmcm^{-1} and each one of these values could have been used to decide when and how much to irrigate, indicating how difficult is to take decision considering soil variability.

Crop Coefficient: Crop coefficients (Kc) are another important source of uncertainty in irrigation. They depend on numerous factors that cause large uncertainties in their estimation. These factors include the difference in planting density and cover, stage of growth of the crop, difference in varieties, soil moisture, the equation that is used to estimate ET0 (Temesgen et al., 2005) and the variation in aerodynamic resistance between the reference crop and the crop of interest (El Khoury, 2010).

Guerra et al. (2003) presented a Kc curve in function of the day of crop emergence is presented, Figure 10. It can be seen in this figure that Kc values have a great variability. In Figure 9 is presented Kcmid for irrigated corn, 1.85, and the value for it proposed by Allen et al., 2007. It can be seen that Allen's value is about 65% lower. What is the impact of this variation in irrigation management? The mid-season stage (Kcmid) runs from effective full cover to the start of maturity. At the mid-season stage the Kc reaches its maximum value. Deviation of the Kc mid from the reference value '1' is primarily due to differences in crop height and resistance between the grass reference surface and the agricultural crop and weather conditions (FAO, 1993).

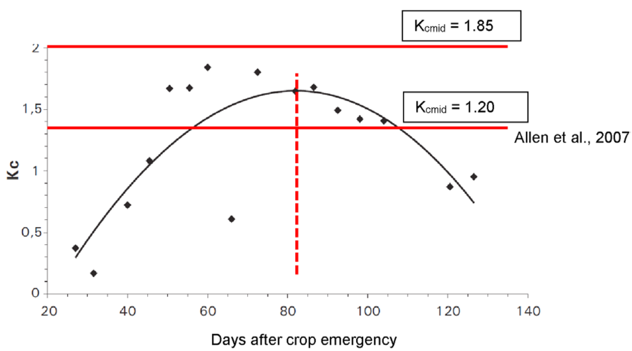


Figure 10 Crop coeficients (Kc) curve as a function of day of crop emergence

3 CONCLUSIONS

Without irrigation, increases in agricultural yields and outputs that have fed the world's growing population would not have been possible. Further, irrigation has stabilized food production and prices by enabling greater production control and scope for crop diversification (Rosegrant et al, 2002). Population and income growth will boost demand for irrigation water to meet production requirements and household and industrial water demand (Rosegrant et al, 2002). The success of irrigation in ensuring food security and improving rural welfare has been impressive. Considering the growing pressure on finite freshwater and soil resources, it becomes clear that the challenge of feeding tomorrow's world population is, to a large extent, about improved water productivity within present land use. Meanwhile water requirements for different purposes will increase, so all efforts focused on a rational use of water will be indispensable (Billib et al., 2009).

The current challenge to achieve irrigated agriculture sustainability is to grow more food with less water. It is not an easy task, however, and it is associated with different dimensions of the irrigation process. It requires substantial increases in productivity of water in agriculture.Rosegrant et al., 2002 state that the most promising avenue for addressing water shortfalls into the future is water management and incentive policy reform to enhance the efficiency of existing water use, supported by infrastructure investment to modernize and upgrade existing irrigation and water delivery system. In severely water-scarce basins, however, relatively little room exists for improving water use efficiency, and food production and farms income could fall significantly if water for irrigation is transferred to other uses

In this context, different strategies should be used in other to achieve sustainability in irrigated agriculture. New incentives and policies will be crucial; water conflicts have to be resolved and effective integrated management of water resources at basin level implemented. Scale is another important issue. In moving from field to system level scale, the level of heterogeneity increases. Environmental characteristics and land use vary spatially and temporally. It is important to consider new technologies. Information and communication technologies, such as remote sensing, open new opportunities for investigating complex crop-soil-water environment systems, while contributing to reduce uncertainty. Simulation models facilitate ex-ante evaluation of technological interventions. Irrigation efficiency has to be analyzed very carefully, since not always increasing efficiency will save water in the same proportion. In this context it is important to take into account other factors, like soil conservation practices.

In this chapter, data quality, quantity and uncertainty in soil, plant and climate were presented as important aspects to be considered. There is still are a scientific challenge to develop sustainable irrigated agriculture. Research needs to be developed to better understand those issues and simple methodologies to deal with them need to be developed. The impact of uncertainty and the lack of data in the hydrological system varies and it is difficult to evaluate, but for sure its magnitude will depend on the adopted water management strategies. To achieve sustainability, advances in irrigation technology and clear environmental policies are necessary. On the scientific side, uncertainty is the challenge and for farmers, uncertainty brings environmental and economic risks that have to be taken into account.

To study some of those issues a Reference Nucleus of Innovation in Irrigation and Water Resources (NURII) was recently created. It is a location where topics related to irrigation and water resources can be studied and discussed. NURII resulted from a partnership between Embrapa, the National Water Agency, the UNESCO-HIDROEX Foundation and the Secretariat the state of Minas Gerais for Science, Technology and Higher Education.The objectives of NURII are related to four pillars, information, capacity-building, research and innovation. Its creation resulted from the need not only of governmental institution but also of agricultural producers to have a focal point: (i) to concentrate and filter information for its diffusion and training (ii) to define and propose priorities for research (iii) to integrate results (iv) to consolidate protocols for the certification of endeavors with respect to adequate use of water and to improve grant criteria and (v) to identify needs with respect to the development of equipment and instruments, etc.

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3

Irrigation in Transition – Changing Purpose, Policy, Infrastructure and Practice for Greater Productivity

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3 Major historical periods affecting irrigation
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3 Irrigation in Transition – Changing Purpose, Policy, Infrastructure and Practice for Greater Productivity

1 INTRODUCTION

This paper sets out the important context and identifies the changes that have shaped irrigation practice in Australia. There is a very brief description of the major historical events that have influenced irrigation. However the main attention is on changes in institutional arrangements, practice and attitudes in the last two decades. Within this time there has been much greater recognition that irrigation practice is set within a complex social-ecological system and hence that technological and management changes are significantly mitigated or enhanced through people's actions. We have observed that single technology improvements rarely have substantial system effects unless there is predisposition to the change. Changed, improved practice is more successfully enabled by whole system change. The introduction of new technology is highly likely to be much more influential if it is supported by government policy and by on-going, reliable service and knowledge.

It is evident that irrigation practice is in transition with change being effected by people using technology. There is evidence that well directed irrigation in an area increases total economic activity and strengthens social viability relative to rain fed areas (Meyer 2005a). However not all irrigated areas are bio-physically or economically viable in the medium to long term and improvements must be sought. Sustained water productivity improvement can occur when there is an alignment of motivation, relevant and informed influencers and committed actions. Ideally there needs to be the alignment of an imperative to act, committed community and political leaders, policy that is clear and encouraging, effective and controlled conveyance and application systems, community education and training and improved equipment and service provision. The recognition that irrigated areas are social-ecological systems has assisted in planned change moving from the naive notion of improvement only through technology transfer to a more encompassing and sophisticated understanding of the need for system harmonisation to give the best chance of aligning all elements of change. The driving factors that have caused the need for significant change are described in the following sections.

2 CONTEXT OF IRRIGATION IN AUSTRALIA

Continental Australia is climatically dry, with low average rainfall and hence low accompanying runoff as indicated in Table 1. The major irrigated areas are in the south eastern portion of the continent (Figure 1) and most often associated with the water supplies from the inland flowing river systems.

With a generally dry climate and high year to year variability of rainfall there has been ongoing enthusiasm for irrigation. Hence irrigated agriculture is the sector that uses the most water (Table 2) in the Australian economy. Census data indicates that the area of land that can be irrigated is about 2.5 million hectares which is less than

Table 1 Comparison of rainfall and run-off for the continents

Continent	Area (km^2)	Rainfall (mm/yr)	Run-off (mm/yr)	Run-off (%)
Africa	30,300,000	690	260	38
Asia	45,000,000	600	290	48
Australia	7,000,000	465	57	12
Europe	9,800,000	640	250	39
North America	20,700,000	660	340	52
South America	17,800,000	1,630	930	57

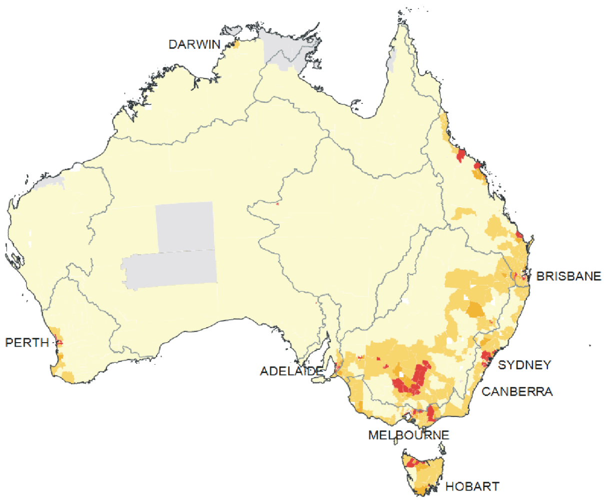

Figure 1 Irrigated areas of Australia. Red areas have 20% or more of the agricultural area that is irrigated. Light brown areas have 10 to 20% of the agricultural area that is irrigated. Source: Australian Bureau of Statistics, 2004

Table 2 Water use within Australia from 2010 to 2011 (ABS 2012)

Water use	Volume of water (GL)*	Proportion of total water (%)
Total water consumed (6% of total)	~13,300	100
Water consumption by sector		
Agriculture	~7,200	54
Households	~1,700	13
Sewage and drainage	~1,600	12
Mining and manufacturing	~540	4

* Note: 1 GL = 1,000,000 m^3 and 1,000 GL = 1 km^3

1% of the irrigated area in the world. Not all of this land will be irrigated in any year due to annual cropping rotation practices and variable water availability.

The Australian mean rainfall total for 2011 was 705 mm, 240 mm above the long-term average of 465 mm, placing the year at second-wettest since records began in 1900 (BoM 2012). This much wetter than average period is a major reason for agricultural water consumption to be lower than the longer term use of 10,000 to 12,000 GL per year. Of the rainfall on the continent it is estimated that 90% evaporated, 8% was evident in surface water and 2% went to groundwater recharge.

3 MAJOR HISTORICAL PERIODS AFFECTING IRRIGATION

The irrigation areas and practices that are evident today have been shaped by the many decisions and actions since the mid 19th century. A listing of some of these events is given in Table 3.

Table 3 Description of major periods and some critical events that have shaped irrigation areas and practice in Australia

Time	Event
1850 - 1900	Inland rivers dammed by private schemes; almost all failed. Various government funded schemes came into existence.
1896 - 1901	Water owned by the country. Australian constitution assigns responsibility for conservation of soils and water to each of the Australian States.
1920 - 1930	Post WW1 large government irrigated area schemes developed.
1947 - 1960	Post WW2 major water infrastructure and several new irrigated areas developed.
1970 - 1990	Expansion of irrigation areas in the south of the continent while new areas were started in the semi arid tropics of the north west and north east.
1990 - 2000	Older areas in the south were consolidating and new infrastructure to improve water distribution was needed.
1994 - 2010	Legislation to restrict additional extraction from major southern rivers. Agreement on National Water Initiative to implement major reforms for sharing, owning and costing of water.
2010	New areas in Tasmania and north west Australia being developed with modern distribution and application technology.

In the Australian Federation the country is divided into states and territories with these individual states and territories being responsible for looking after land (soils) and water. Constitutionally, water is owned by the country and administered by state and territory governments. Until very recently, access to irrigation water was tied to land.

Throughout Australian history, irrigation management, policies and technologies have been changing with public need. From 1850 to 1900 inland rivers were dammed by private interests but all of these private schemes failed and many were replaced by government schemes. From 1886 to 1901 it was established that water was owned by the country and soils and water were consequently controlled by the states and territories. After World Wars 1 and 2 large government schemes were developed primarily as soldier settlement and social support schemes. Quite rapid expansion of irrigated areas took place between 1970 to 1990 in both existing areas and new areas in northern Australia. With several persistent dry periods in the last 20 years there has been reduced area in some southern areas (consolidation) together with a major effort to upgrade supply and application infrastructure. Interest in developing new areas such as in Tasmania and north west Australia persist because of the real and perceived benefits of consistent production when irrigation water is supplied.

In summary, the development of irrigation areas and associated practice has been within several critical government constitutional and policy requirements. These are:

- All water is owned by the country – therefore it is government controlled;
- In the Australian Federation, the States are responsible for the maintenance of land (soils) and water resources within their boundaries; and
- Until 2004, access to irrigation water was tied to land. After 2004 a property right to water entitlement was established and water volumes can now be traded as a separate property asset.

4 DRIVERS OF CHANGE

With a steady increase in population and therefore growing demands on the country's resources, especially productive land and freshwater, a national audit of these resources was undertaken between 1997 and 2002 (ANRA 2002). An important finding from the audit was the substantial value of irrigation in Australia (Table 4). It showed that half the profit from all agriculture came from irrigation that occupied just 0.5% of the agricultural land area.

Table 4 Comparing profits from rain fed to irrigated agricultural land

	Net return ($m/yr)	Mean profit ($/ha)	Area ($x10^6$ ha)
Rain fed	3,691	8	470
Irrigated	3,839	1,669	2.3

While this result highlighted the importance of irrigation it was set against the growing awareness that in southern Australia the major irrigation areas were in a “mid life crisis” as set out in a comprehensive review of irrigation areas by Meyer (2005a). There was need for major upgrading and maintenance of supply and distribution infrastructure and the need for rejuvenation of irrigation management. In many areas excessive leakage to groundwater was causing regional water tables to rise, compounding the ever present problem of salt accumulation in the upper soil layers.

Coinciding with and contributing to these issues was the growing realisation that the demand for water expressed through excessive extraction was significantly degrading both the river and riverine floodplain ecosystems. Periods of drought with accompanying low river flows compounded these problems. Assessment of the effectiveness and productivity of existing irrigation systems at the time showed considerable losses in all components of the distribution and application system as illustrated in Figure 2.

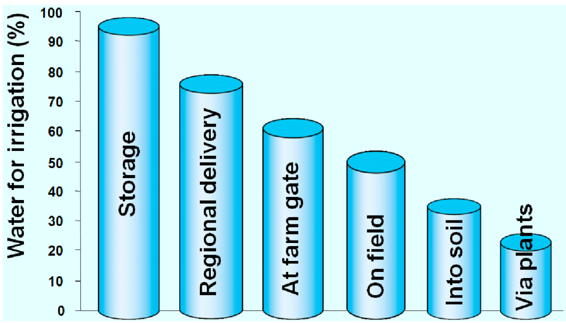

Figure 2 Approximation of irrigation water losses during the various stages of storage, delivery and application

Audits of the older irrigation area delivery systems showed considerable leakage from channels; they showed poor control of water within most systems and all needed significant upgrading of the infrastructure. The situation on many farms was similar with the need to upgrade application systems and to exert greater control on water applications to reduce excessive surface and subsurface drainage. Much of this analysis came from a series of regional land and water management plans (e.g. Murray Irrigation, Murrumbidgee Irrigation) that were requested by several State Governments (Bonetti 1997, McDonald 1997). This process was set up to identify problems with the irrigation areas and to identify and evaluate different ways of alleviating the problems. While there was some attempt to gain widespread community support this was only partially successful. Accompanying this was the increasing availability of new and improved technology. In essence there was a technology “push” from private and public innovators who were aware of the critical need for improvement in the use of water and its productivity. Examples of technology included low cost piping, wireless monitoring and control (SCADA-*Supervisory Control And Data Acquisition*) systems and modular control structures for distribution systems. On farm, soil water measurement, micro irrigation and sub-surface systems, weather station availability and increased information access were becoming available and in many cases, were cost effective.

The audits of national resource use and of irrigation system and farm assets raised awareness that irrigation was a capital intensive sector, if well managed it could be very productive with good returns to capital but much of it was operating well below its potential. One obvious effect of this situation was the increasingly unacceptable environmental effects caused by excessive extraction, poorly controlled drainage, salinisation and degradation of groundwater resources. As the review by Meyer (2005a) pointed out, to strive towards achieving full irrigation potential, government policies needed to be modernised, new management arrangements with both government and private companies needed to be established, infrastructure upgrades were needed in supply structures, and drainage, control and monitoring were required. At a farm level there needed to be land forming, increased application control, decreased drainage, management of salt and improved productivity. To bring this about skills and education of all involved in irrigation needed significant improvement and retail and service sectors need improved skills and information access. In short, there needed to be whole system change, not simply singular improvement that was often the focus of "technology transfer" programs.

5 WATER POLICY REFORM AND WATER TRADE

Policy and governance of irrigation rests with the government. The Federal and State Government water reform agenda (COAG 1994) aimed to implement full cost recovery, eliminate cross subsidies associated with the cost of water, define "water access entitlement" and completely separate water ownership from land ownership. The Australian (Federal) Government had a role because waters (surface and groundwater) are not confined by state boundaries, the different states have different rules, water is traded between states and there is excessive extraction from major rivers that often cross State borders. The Federal Government is the primary source of money that could be directed to major public investment needed to improve irrigation systems.

Shi and Meyer (2009) provided a comprehensive review of the water reform process with a particular emphasis on the effects for the irrigation sector. They point out that while the intention for reform was set in 1994 it was not until 2004 that COAG's (Council of Australian Governments) principal water policy agreement, the National Water Initiative (NWI) was set in place. Through it, governments across Australia agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water (NWC 2012). Under the NWI, governments made commitments to:

- prepare water plans with provision for the environment;
- deal with over-allocated or stressed water systems;
- introduce registers of water rights and standards for water accounting;
- expand the trade in water;
- improve pricing for water storage and delivery;
- meet and manage urban water demands.

5.1 Water entitlement, allocation and use approval

A very important part of the institutional and governance reform was the re-defining of the entitlement, allocation and use rules for water. While ownership of all water still remains with the Government, a property right or volumetric entitlement to water is now defined. This entitlement is no longer tied to land and can be traded as an asset. This entitlement is best thought of as equivalent to a share in a company and in essence it can be traded in a "water share" market. Accompanying the entitlement is a variable allocation that sets, on a season to season basis the proportion of the entitlement that will be available for use. Hence if storages are full, an irrigator can expect to receive 100% of the entitlement. Conversely, in dry times when storages are limited, irrigators may have an allocation that is less than 100% even though the entitlement remains the same. The allocation process can be thought of as equivalent to the value of an equity share in a company. As the fortunes of the company change (the volume of water held in storage) so does the value of the share (allocation percent) change. An additional part of the reform process has been encouragement to State and regional water authorities to promote and assign regulations that direct the conditions needed for the safe and responsible use of water and management of drainage.

With these reforms it became increasingly obvious that robust and accountable methods of measurement and record keeping are critical. It was recognised at the time of the National Water Initiative that management of water without measurement was critical. Similarly it is not possible to have an orderly water market without proper accounting and documentation of the trading. The primary motivation for these reforms has been to facilitate adjustment, innovation and investment.

5.2 Water trade and its effectiveness

With clarification of the property rights to water and the rules regarding the allocation and use of water the elements of an orderly trading regime were put in place. Government legislation effectively defines water property rights and sets the rules associated with any exchange. It also maintains the record of titles so that entitlement ownership and volumes associated with those titles is known. Operation of the water market is largely managed through a number of private companies (e.g. http://www.waterfind.com.au) that have developed innovative electronic communication systems that enable public trade to occur. Trade is possible in both entitlement (called "permanent water") and in allocated water (called "temporary water"). In the later case a volume of water is bought at a known price and becomes available to the buyer but only for one season.

While a water trading system has been active for less than 10 years, irrigators have adapted rapidly. The increased flexibility that comes from water trading allowed many irrigators to manage through a persistent drought in south eastern Australia between 2003 and 2009. The growth in allocation trade ("temporary water") is illustrated in Figure 3.

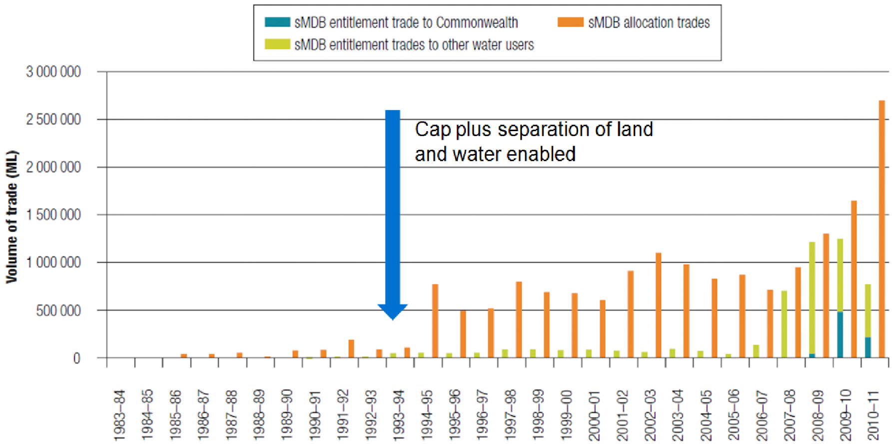

Figure 3 Volume of water traded between 1983 and 2011. sMDB refers to the southern Murray Darling Basin of south eastern Australia. Entitlement trade is often called "permanent water" while allocation trade is seasonal "temporary water"

5.3 What have we learned

The significant water reform process identified several important principles during its implementation. These are summarised as

- the complexity of prior decisions and institutional arrangements limited new, well intentioned reforms to be effective and increased confusion rather than clarifying. In this situation improvement is only possible when the fundamental purpose is redefined;
- water entitlements are defined as shares rather than volumes of water;
- standardising the terminology and definition of water "products" is important; and
- accurate and responsive title registration systems are critical.

6 INFRASTRUCTURE AND MANAGEMENT CAPABILITY IMPROVEMENT

Improved management of irrigated areas was initially attempted at a regional level through land and water management plans. To satisfy State Government requirements the plans identified the problems limiting productivity and efficient practices, identified and evaluated different ways of dealing with these problems and started some community engagement. This process had limited success often because the resources required for significant improvement were well beyond those that could be found by the region alone and often there was limited business and individual buy in.

In an irrigation system, water, costs and knowledge are interlinked. Efforts to decrease water use and increase water productivity will only be achieved through either increased costs and or an increase in knowledge. An important part of this knowledge is the timely and professional management of the irrigation water supply system (Meyer 2005b). To improve this, irrigated area management was changed from largely State Government control to public private partnerships within a range of state owned corporations, private companies or public corporations.

It was quickly established that both delivery infrastructure and on farm application systems needed significant upgrading. Studies such as Pratt Water (2004) identified that water savings were possible through upgrading and lining of channel supplies and changing from surface irrigation to pressurised systems. Costs associated with this ranged from AUS$ 500 to AUS$ 7,000 per megalitre (ML) of water saved for supply system improvement and from AUS$ 50 to AUS$ 7,000 per megalitre (ML) of water saved for farm application system improvement. With the price of water between AUS$ 1,000 to AUS$ 2,000 per megalitre (ML) it is clear that only some low cost improvements would be economically justified. The availability of this type of information has lead to upgraded distribution and farm application systems. Revamped irrigation area water supply authorities have established a new awareness of control, monitoring and measurement for the supply systems. They have also encouraged on farm improvements such as improved measurement of amounts applied, provided forecasts of crop needs and assisted measurement of crop and soil water status. Farm water control has improved by land forming with laser leveling (reducing labour costs), increased use of drip and micro irrigation systems (a steady increase in pressurized systems), water control for quality control (already used for vegetable and grape production), regulated deficit irrigation (manipulating vegetative growth and fruitfulness through selective water management) and partial root zone drying (controlling growth and using less water).

7 EMERGENCE OF TRIPLE BOTTOM LINE REPORTING

It has become increasingly evident that the demand for water from all sectors is increasing. This has been accompanied by an increased awareness of environmental issues and the degrading effects on water, soil and vegetation resources that some irrigation practices have in particular. As described by Christen et al. (2005) “The combined effects of infrastructure development, water extraction for irrigation, return drainage, groundwater discharge and accompanying salt loads and reduced flow especially of small and medium floods, has caused noticeable and highly publicised changes to the rivers. Concerns by downstream water users together with a heightened sense of environmental awareness have raised the issues of water quantity, water quality and river health to state and national political levels.

This political and community perception has led irrigation communities and irrigation water supply companies to look for approaches and methods to assist with performance improvement and to transparently demonstrate the total benefits and costs of irrigation. By doing this, a more rational debate and policy implementation can be undertaken as all stakeholders will be more aware of the potential socio-economic tradeoffs associated with the increased demand for some water used by irrigation to be returned to the rivers for environmental flows.

However, irrigation dependent communities have found it difficult to communicate to the wider populace the benefits of irrigation to their regions and the initiatives and investment undertaken to become more sustainable. To address this, irrigation water supply businesses are investigating the use of a broader reporting structure that includes financial, environmental, social and cultural elements. This triple bottom line (TBL) reporting is a holistic approach and should provide a more balanced view of the socio-economic benefits and environmental consequences of water use."

8 ROLE OF RESEARCH AND EDUCATION

As indicated above, the achievement of improved irrigation systems will occur within the nexus of water, costs and knowledge. Improved knowledge is associated with better and more informed management. It is also highly dependent on the continued understanding of the basic processes associated with soils, water and plants and on continued innovation of irrigation practice. Research and education is therefore fundamental to improved irrigation. Two significant National programs contributed to this need. The National Program for Sustainable Irrigation (http://www.npsi.gov.au/) and the Cooperative Research Centre for Irrigation Futures (http://www.irrigationfutures.org.au/) brought together government agencies, research and development agencies and irrigation water supply companies to focus on new developments to improve irrigation. From 2002 to 2009 the Cooperative Research Centre for Irrigation Futures (CRC IF) invested AUS$72m from 14 research, education and industry partners. CRC IF was formed to facilitate cooperative research networks and programs that continuously improve irrigation policy, tools, practices and processes to double irrigation water use efficiency, improve profitability for commercial irrigation enterprises and protect and enhance landscapes and the environment. A significant success of CRC IF was the training of 50 post graduate students who have become widely distributed within the water and irrigation sectors.

From studies within the CRC IF it was clear that for future improvement and sustainability, with Australia's limited rainfall and the current water situation there was need to recognise the finite amount of water available and identify how best to apportion this water in an attempt to achieve the most environmentally, socially and economically productive outcome from its use (Meyer *et al*. 2006). In short, there is an ongoing need to increase multi-purpose water use productivity.

9 CHANGED THINKING - TECHNOLOGY TRANSFER TO SYSTEM HARMONISATION

Much of the institutionalised approach to irrigation system improvement has been strongly influenced by the idea that improved technology, if taken up by irrigators will result in greater water productivity i.e. improvement simply through "technology transfer". This idea has repeatedly been shown to be naive primarily because new technology has to fit within existing management capability and most often it does not replace or alleviate the most limiting aspect in the whole irrigated system (Meyer, 2003). A much more system aware approach is needed.

9.1 Regional irrigation business partnerships

To improve irrigation within the multi-purpose water use system there is need to recognise that irrigation practice is primarily a business. The most significant improvements occur when:

- There is a fundamentally viable business case;
- Irrigated communities identify the need(s);
- Institutional arrangements are simple and clear;
- Distribution and application systems are upgraded;
- Technical capacity and know how is well developed;
- Equipment, service and advisory services improve;
- Skill and management capacity is improved at all levels; and
- There is an increase in production and value-add diversity.

The recognition of this combination of factors led to the description of what was needed as a "regional irrigation business partnership" (Meyer *et al*. 2006). In this model regional engagement and "ownership" is critical. For successful improvement in irrigation, all the elements need to come together for system harmonisation; policy, management, technology and knowledge. Subsequently the system wide approach became known as "system harmonisation" (Khan *et al*. 2008). A narrative report on how the application of system harmonisation as a research team from the CRC IF interacted with four regions is given in Bristow and Stubbs (2010).

9.2 A prototype case study

An example of "system harmonisation" was developed during "rehabilitation" of the Riverland irrigation area in South Australia in the period 1982 to 1997. The main irrigated crops of the area were wine grapes, citrus and a variety of stone fruits. Irrigation was largely by surface furrow or overhead fixed sprinklers supplied through open channels scheduled on a set rotation. Water productivity was poor, there were increasing problems with salinity (Cole, 1985) and viability of many farms was frequently in jeopardy as markets and prices fluctuated. A cost sharing arrangement between the Australian Government, the State Government and local irrigators facilitated a very significant overhaul of irrigation supply and practice. Governance and water supply management was revised and new supply infrastructure delivered pressurised pipe supplies to the farm gate. Rationalisation of the irrigation area occurred with some small farms and unsuitable areas not being supplied with water access. On farm, soil surveys identified variability and application systems and plantings were modified to achieve greater irrigation application uniformity. Testing of irrigation application systems provided information to farmers, auditing of systems was undertaken and training was provided to irrigators often as a prerequisite for financial support to the irrigator. Subsequently, irrigation practices and associated water productivity have shown considerable improvement (Skewes *et al.*, n.d.). Results from the comparison of irrigated areas in south east Australia (Meyer 2005a) show that the largest profit per megalitre of irrigation water from 1995 to 2001 was in the Riverland area of South Australia. The factors which contributed to this system harmonisation within the Riverlands included policy, management, technology and knowledge improvements (Table 5).

Table 5 Factors contributing to the Riverland rehabilitation

Imperative to act	Limited water Salt load increasing Restricted drainage to river Productivity poor
Leaders	Progressive community leaders Support from political leaders Engaged with government
Policy setting	Water allocation policy clear Improved productivity encouraged
Conveyance system	Upgrade from channel to pipe
Application systems	Furrow to sprinkler Over tree sprinkler to micro under tree
Community education	Government extension focused Local training available
Equipment and service provision	Soil survey introduced Systems designed for site differences Equipment testing available New measurement techniques developed

10 CONCLUSIONS

Within the last two decades changes in technology, policy, commodity markets, water availability, water pricing and trading as well as social expectation have caused significant and ongoing change in irrigation in all parts of Australia. The functions, productivity and consequences of irrigation practice have been under scrutiny and can be shown to be in significant transition.

National policy changes such as re-definition of water property ownership and the associated development of a well defined water trading regime have caused very significant shifts in the way water is valued and used. Accompanying this has been a major change in attitude to water resources. Water is now understood to be a finite resource that has legitimate environmental, economic, social and cultural value. The advent of water trading has increased irrigator flexibility and has been demonstrated to have assisted irrigators to adapt to a recent drought with low water availability. With many irrigated areas becoming managed by regional irrigation water supply companies there has been a refreshing focus on improved systems with much improved measurement and control of water distribution. The array of delivery and control technology is increasing.

Irrigation management on farms has shown improvement. The level of awareness for water control is increasing. It has been shown that reductions in water use by up to 30% are possible without yield loss due to a shift from furrow to drip irrigation in vines. Drainage volumes have decreased and the use of soil water monitoring has increased. The level of irrigation measurement and reporting has increased. Overall improvements in irrigation practice have been achieved through people learning and changing practices and through improved technology. Education opportunities are improving and in service training is now much more readily available.

Irrigation practice is set within a complex social-ecological system. Sustained water productivity improvement can occur when there is an imperative to act, committed community and political leaders, policy that is clear and encouraging, conveyance and application system upgraded, community education and training and improved equipment and service provision. Successful change is made by people making new decisions. The role of researchers and technical advisors is to identify the development, technology and management options that are well tested and well grounded and highlight the consequences, both positive and negative, of those options. Continuation of these positive improvements will ensure that the transition of the last two decades results in an irrigation sector that is well located, resilient, productive and valued by the community.

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4

The Right Training for the Right Job

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4 The Right Training for the Right Job

1 INTRODUCTION

The availability of properly trained personnel in the irrigation industry is essential for proper system performance and preservation of natural resources. People are often confused by the difference between training and education. Being properly trained infers that a person has the knowledge, skills, and competency to accomplish the job. Education, on the other hand, infers that a person is learned in a variety of topics but most certainly including problem solving. However, training is specific to a certain job, and education is applicable to nearly all situations. Training is measured by how well you can do a specific job. An important element of training is that a person must have the appropriate level of education in order to benefit from specific training. I've heard it said that education prepares one for life; training prepares one for a job.

2 ELEMENTS OF TRAINING

2.1 Knowledge

Training involves at least three elements. First, one must have the knowledge which is the theoretical and/or practical understanding to do a job. With the proper knowledge base, the learned capacity to get results is developed. Finally, training isn't complete until the skills needed can be demonstrated both intellectually and physically. For a watch repair person, it is not sufficient to know how to repair the watch. One must also have the manual dexterity to accomplish the job. The same is true in the irrigation industry. An irrigation system designer must have the proper knowledge consisting of formal education and experience in order to design a system. The formal education includes mathematics and science with specific applications to hydraulics. However, it isn't sufficient to merely have the formal education. The designer, in order to be proficient at the task, must have experience.

2.2 Skills

The skill set includes both formal education and experience. Most certifications have both education and experience requirements. Given documentation of the skill set, the next step is demonstration of competency.

2.3 Competency

Competency is demonstrated through examination, certification, or licensure. If the specific task for which one is applying does not have specific examinations, certifications or licenses, the job resume is often accepted.

2.4 Certification

Certification is documented proof that one has the competency to complete a job. Many occupations have very formalized certification processes. The ones which come to mind are medical doctors, attorneys, and engineers. In my title above, I show that I hold a PhD. That is an indication of formal education. However, in addition to that I hold a Professional Engineer's license and certifications in Irrigation Design and Landscape Auditing. The license and certifications are documentation of education, experience, and competency.

3 JOB TITLES IN IRRIGATION

Below are listed a few of the job titles one might have in irrigation. Clearly, the education and training requirements for each of these titles differ significantly.

3.1 Planner

The planner is the person who thinks on a large scale and helps decide an irrigation project might be appropriate. A planner would need to understand the general requirements of an irrigation system, the political system, availability of resources, and infrastructure.

3.2 Designer

The designer probably doesn't need to fully understand the political system in order to properly design an irrigation system, but he/she certainly needs to understand the needs and availabilities of resources, materials, and labor. He/she needs to understand the limitations of the labor force and budget. He/she does not need to have the skills and experience to install the system, but does need to understand the constraints of the installation. The designer uses this background information along with formal education and experience to design a system which delivers the water efficiently.

3.3 Installer

The installer does not need to know how to design the system, but needs to have specific skill related to following the design and assembling the system as the designer has designed it with the caveat that it has to be operational when installed. The installer must have a very specific set of skills related to system installation that the designer does not need, but he/she must also be able to communicate with the designer.

3.4 Technician

A technician ensures that the system operates as was planned. The skill set this person needs includes understanding of the system and how to get the subsystems and elements of the system to do what they were designed to do. For example, if a designer develops an irrigation system with automatic controls to ensure proper pressure throughout the system, the technician needs to understand how to get the system to do that in the automatic mode. A properly designed and installed system is of no value if it isn't configured or programmed properly to perform the desired function.

3.5 Farm Manager

Ultimately, the farm manager is responsible for ensuring that the systems are operated so as to meet farm objectives. On smaller systems, the manager might also serve as the installer and technician. On very large systems, there might be several levels of farm management including those with oversight of pumps, electrical controls, or mobile systems. There is a high degree of interaction between the technician and farm manager. In many cases, the owner serves as the farm manager.

The following are objectives for which the farm manager might be responsible. Yield in generally the primary objective of the farm manager. Profitability is a key factor, so yield might extend to optimal production, water use and fertilizer use.

4 PAY SCALES

Which of the job descriptions would command the highest level of compensation? I would argue that it depends on which demands the highest level of training including but not limited to formal education. Secondly, compensation often relates to the vulnerability of the system failure due to the failure of the specific job. Clearly, a perfectly designed system operated poorly by the farm manager will not produce optimal results. Likewise, a perfectly designed system operated well but rendered inoperable by a component failure will not produce optimal results. Understanding that considerable debate could arise given the order I list below, I believe the pay scale should reflect all of the components I have mentioned above and could be listed in decreasing order as:

1. Manager
2. Designer
3. Technician
4. Planner
5. Installer.

I suspect that this is not the order of compensation on most irrigation system installation and operations.

5 JOB TASKS

In the plan development and operation, Table 1 is a matrix of job tasks along with the level needed by each job description. If is important to note that each person has at least one task requiring both the understanding of the basics **and** the operational particulars.

Table 1 Job tasks

	Planner	Designer	Installer	Technician	Manager
Develop regional plan	4				
Communicate the plan	4				
Execute the plan		3	2	1	3
Install system			3	2	3
Start-up checklist			2	2	3
Operation				2	3
Maintenance				3	3

1 - Understands the basics; 2 - Understands the basics and technical particulars; 3 - Understands the basics and operational particulars; 4 - 3 above plus global perspective

6 COMPETENCY RELATED TO PHYSICAL COMPONENTS

Table 2 is used to demonstrate the level of competency regarding physical components of a mobile irrigation system required of each of the five job descriptions.

Table 2 Competency related to physical components

	Planner	Designer	Installer	Technician	Manager
Controls		2	1	2	3
Economics/Tradeoffs		2			2
Motors		1	1	2	3
Pipe		2	1	2	3
Pumps		2	1	2	3
Sprinklers		2	1	2	3
Tires		1	1	2	3
Valves		2	1	2	3

1 - Understands the basics; 2 - Understands the basics and technical particulars; 3 - Understands the basics and operational particulars; 4 - 3 above plus global perspective

6.1 Components

Some discussion of components and what constitutes understanding of the components is in order. For example, when it is said that one should have competency in pumps, what is meant? Competency in pumps extends to understanding the operation of pumps to include day-to-day operation and performance. The manager requires greater competency in pumps that the designer does because the manager's responsibilities include the operation of the pump. The technician does not need to know how to design with a pump, but needs more operational knowledge, hence his/her overall competency, while significantly different from the designer, is comparable.

Table 3 shows examples of what is meant by understanding and competency with regard to components.

Table 3 Extent of competency regarding irrigation system components

- Pumps
  - Performance curves
  - Operation
- Pipe
  - Materials
  - Hydraulics
- Sprinklers
  - Performance (flow, distribution)
  - Pressure and drop size
- Controls
  - Valves, VFD's, limit switches

7 OPERATIONAL CONTROL/SYSTEM INTERDEPENDENCIES

Good management of an irrigation system requires that one not only understand how components work, but how parts of the system are dependent on other parts. For example, plants use water from the soil. Irrigation adds water to the soil, but the rate at which it can be added and the amount it can hold depend on the soil type. Table 4 shows some of the interdependencies. The level of competency needed rises significantly when one considers system interactions or interdependencies.

Table 4 The soil as a reservoir

- Looking at the soil as a reservoir for water
  - Holding capacity depends on
    - Soil type
    - Soil depth, root zone
- Crops use water from the soil reservoir
  - Use rate depends upon
    - Crop stage (K_c)
    - Climate/weather: solar radiation, wind, temperature, relative humidity
  - Water shortage results in
    - ET reduction and Yield reduction
- Irrigation system refills the reservoir
  - System capacity

7.1 Center Pivot Example

Potential runoff under a center pivot is a good example of system interdependencies as is shown in Figure 1.

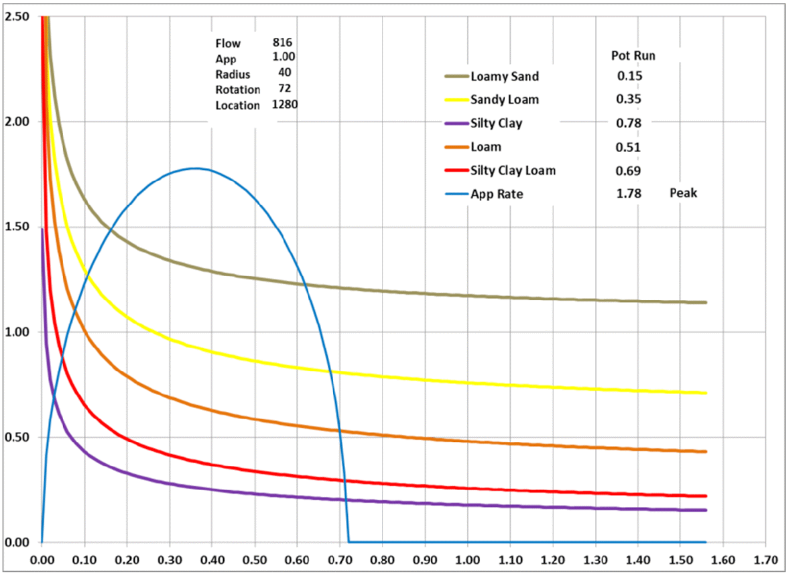

Figure 1 Center pivot application rate versus soil infiltration rate: potential runoff

Potential runoff under a center pivot depends on many factors. Among those factors are system flow rate, distance from the pivot, type of application device, and soil. In Figure 1, the potential runoff at a point 1280’ (390 m) from the pivot on a system with a flow rate of 816 gpm (51.5 l/s) with a radius of throw of 40’ (12.2 m) on a loam soil is the area beneath the blue line (application rate) and the orange line (infiltration rate), and it is more than 50% of the application.

8 SOILS COMPETENCIES

Tables 5 and 6 detail some soils data as it relates to the understanding needed to properly manage irrigated soil.

Competency in soils would include the understanding of infiltration rate graphs, moisture holding graphs, and soil moisture release curves. Infiltration rates are shown in Figure 3, soil moisture release is shown in Figure 4, and soil moisture holding is shown in Figure 5.

Figure 4 shows how matric potential increases (becomes more negative) as volumetric moisture content decreases, and Figure 5 shows how much water is held by volume between field capacity (0.3 bars) and the normally assumed level to trigger

Table 5 Soil textural classes

Texture	Texture class name
Coarse	Sands Loamy sands
Moderately Coarse	Sandy loam Fine sandy loam
Medium	Loam Silt loam Silt
Moderately Fine	Clay loam Sandy clay loam Silty clay loam
Fine	Sandy clay Silty clay Clay

Table 6 Soil data

Soil	Infiltration		Moisture holding capacity	
	in h^{-1}	mm h^{-1}	in ft^{-1}	cm cm^{-1} or in in^{-1}
Coarse	1.00	25	0.8	0.07
Moderately Coarse	0.50	13	1.1	0.09
Medium	0.40	10	1.4	0.12
Moderately Fine	0.15	3.8	1.9	0.16
Fine	0.10	2.5	1.7	0.14

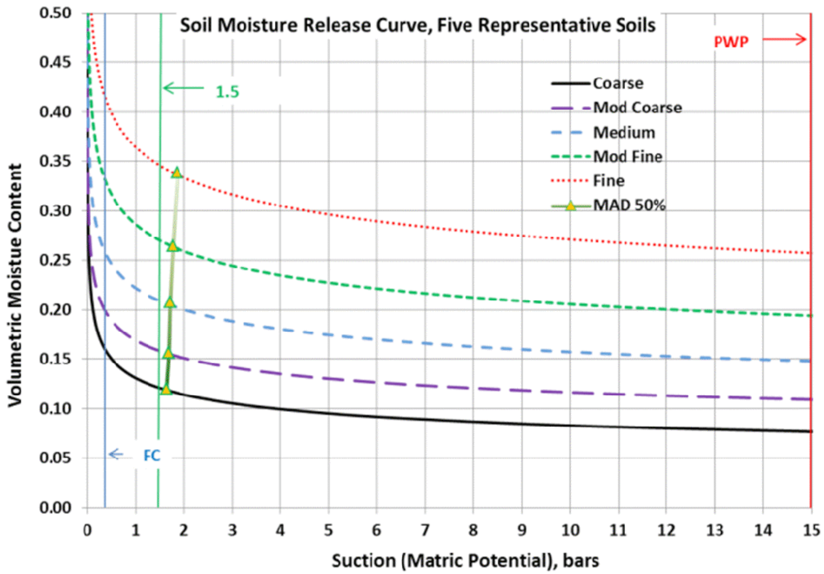

Figure 2 Soil moisture release

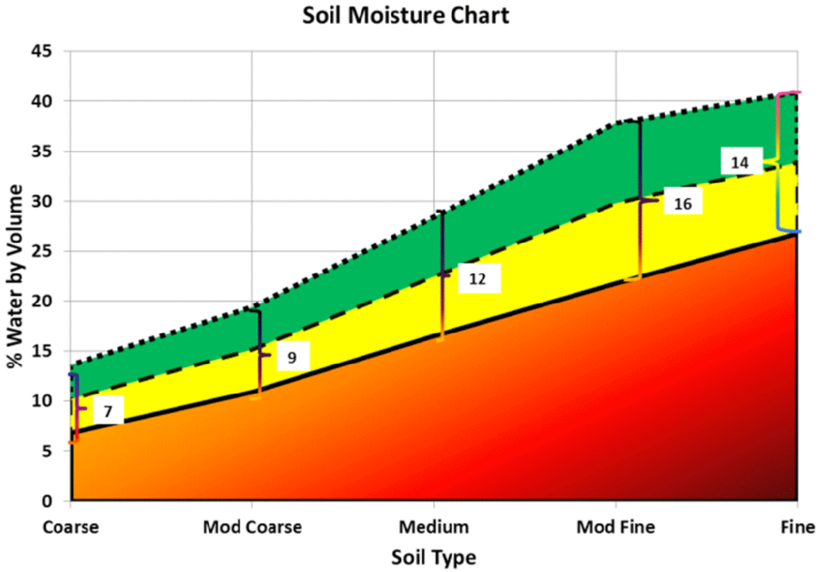

Figure 3 Soil moisture holding

irrigation (1.5 bars). Competency at the level of understanding operational particulars would necessitate fully understanding these figures. This would lead to realizing that the potential runoff for a sample system (different from that shown in Figure 1) is

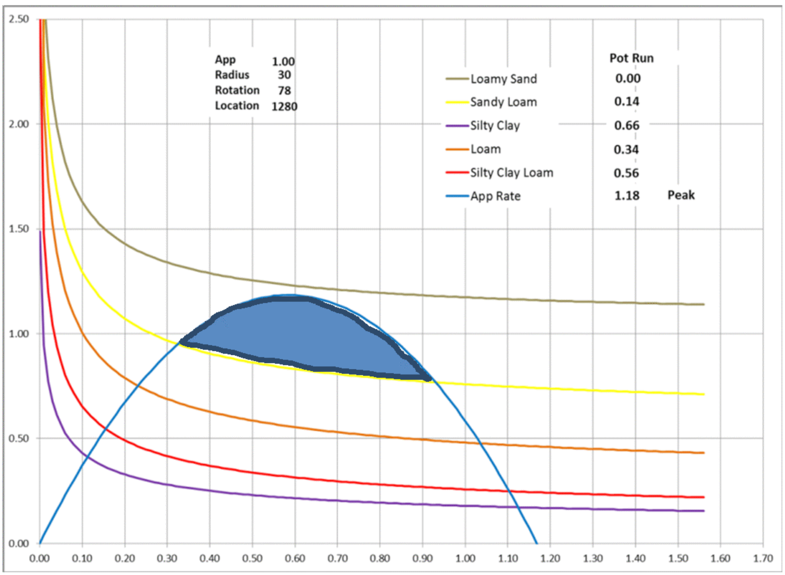

Figure 4 Center pivot potential runoff

14% of the total application for the system shown in Figure 6. An individual with complete understanding would know that slope, soil surface conditions, crop residue, and cultural practices affect how much of the potential runoff actually can run off.

Another aspect of understanding irrigated soils involves understanding how soil salinity affects the available water (that held between field capacity and 1.5 bars matric potential). That is shown in Figure 7. This shows that salinity as represented by 2.0 dS/m prevents the irrigator from keeping soil suction less than 1.5 bars.

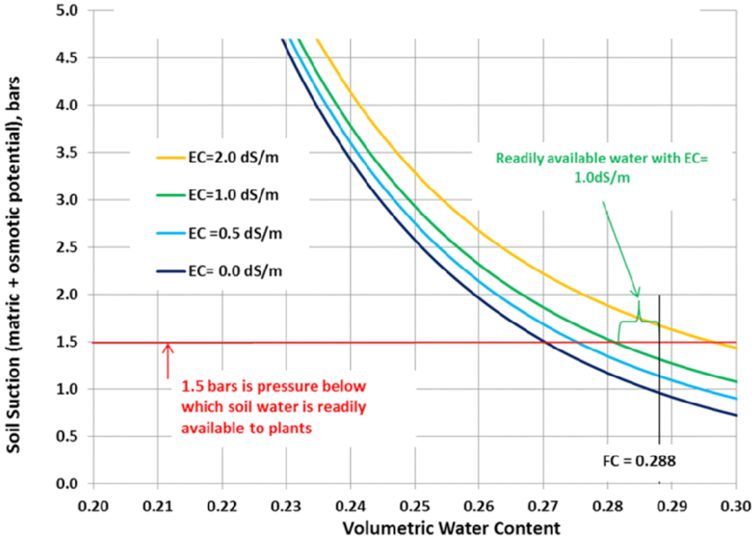

Figure 5 Effect of salinity (electrical conductivity, dS m^{-1}) on soil suction in a medium soil

9 COMPETENCY, PLANTS

The last competency to be discussed relates to plants. The competencies include evapotranspiration, crop coefficients, yield response, fertilizer response, and salinity response. The manager would be expected to understand the basics and the operational particulars. None of the other jobs described would be expected to have this level of understanding. Lastly, if optimization is included in the farm objectives, the manager competencies would include understanding yield response factors and managing crop stress.

10 CONCLUSIONS

1. The following are the key points of this discussion of competencies needed for various job descriptions in irrigation design and management.

2. The designer does not need to know the particulars of crops, soils, and evapotranspiration. He/she does need to know general parameters.

3. The technician does not need to know details of natural system interdependencies, be he does need to know irrigation system interdependencies.

4. The manager does not need to know how design the system, but he/she does need to know how to operate if for best results.

5. The technician needs to know how a lot of physical things work and how to fix them.

6. He does not need to know to build a pump; he needs to know how to make it do what it was designed to do.

7. He does not need to know biological (soil or plant) characteristics. He/she does need to know physical (electrical, hydraulic, control systems) characteristics.

5

Boas Práticas na Irrigação: Manejo Integrado da Irrigação, o Solo e a Aplicação de Fertilizantes

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5 Boas Práticas na Irrigação: Manejo Integrado da Irrigação, o Solo e a Aplicação de Fertilizantes

1 INTRODUÇÃO

A agricultura enfrenta um grande problema em todo o mundo com a escassez de recursos hídricos adequados, forçando os produtores a utilizarem águas com elevada concentração de sais para irrigação das culturas. O uso da fração de lixiviação é uma prática de manejo bastante comum na irrigação quando se dispõem de água salina; assim, uma percentagem considerável da água fornecida às plantas por meio de irrigação é destinada a lixiviação do excesso de sais abaixo da zona radicular (Guitjens et al., 1997). Além disso, a ausência ou a precisão na quantificação da necessidade hídrica individual das culturas e ainda a desuniformidade da vazão individual dos emissores dos sistemas de irrigação são outras razões que forçam os produtores a fornecer mais água que o consumo da planta.

No entanto, na agricultura moderna, a nutrição das plantas é feita via água de irrigação, prática conhecida por fertirrigação (Bar-Yosef, 1999). Assim, o excesso da solução nutritiva drenada abaixo da zona radicular, após cada ciclo de irrigação, denominada de água de drenagem ou solução de drenagem, contém quantidades consideráveis de nutrientes como nitratos e potássio e é, portanto, considerado um poluente ambiental (Incrocci et al., 2006).

Um manejo integrado da aplicação de água e de fertilizantes pode ser utilizado a fim de evitar ou minimizar a salinização dos solos e a contaminação do ambiente decorrente da lixiviação da fertirrigação. O manejo adequado da irrigação é muito importante para a redução no consumo de água na agricultura e eliminação dos riscos de salinização, já o fornecimento preciso de nutrientes evita a contaminação ambiental e problemas com a nutrição das plantas. Daí, uma economia considerável de água de irrigação e de fertilizantes pode ser conciliado com altos rendimentos, aumentando a eficiência do uso da água pela cultura.

O manejo integrado da fertirrigação pressupõe conhecer as inter-relações de diversas áreas do conhecimento das ciências agrárias como engenharia agrícola, ciência do solo, fisiologia vegetal, meteorologia etc, ou seja, aprofundar-se nas relações da prática de irrigar com a dinâmica da água e de soluto no solo, a qualidade da água para irrigação, as práticas de manejo da água salina, o manejo da fertirrigação e o controle da salinização dos solos irrigados e, por fim, as interações solo-água-clima-planta.

2 DIRETRIZES PARA INTERPRETAR A QUALIDADE DA ÁGUA PARA FINS DE IRRIGAÇÃO

Todas as águas utilizadas para irrigação contêm sais dissolvidos, os quais estão diretamente relacionados à sua qualidade, que varia significativamente, de acordo com o tipo e a quantidade de sais dissolvidos. A acumulação excessiva de sais solúveis no solo acarreta diversos problemas às culturas, e varia com o tipo de solo e intensidade de ocorrência, dependendo também, do clima da região. A avaliação da adequabilidade da qualidade da água para fins de irrigação é realizada levando-se em consideração os efeitos potenciais sobre o rendimento das culturas e as mudanças nas características do solo.

De acordo com Ayers & Westcot (1999), os indicadores mais importantes para avaliar a qualidade da água são: concentração total de sais solúveis, concentração relativa de sódio, concentração dos íons tóxicos e outras características. A Tabela 1 apresenta um resumo dos principais indicadores utilizados na avaliação da qualidade da água de irrigação.

Dentre esse indicadores, a quantificação dos sais solúveis na água expressa o nível de salinidade da água, sendo a condutividade elétrica da água (CE_a) o parâmetro mais empregado. A CE_a, é normalmente expressa em dS m^{-1} a 25 ºC, e indica a concentração total de sais solúveis na água, pelo fato de estar relacionada com a concentração total de eletrólitos dissolvidos na solução.

Tabela 1 Principais indicadores utilizadas na avaliação da qualidade

Características	Símbolo	Unidade
Concentração de sais		
Condutividade elétrica a 25 ºC	CE	dS m^{-1}
Sólidos dissolvidos totais	SDT	mg L^{-1}
Concentração iônica		
Cálcio	Ca	$mmol_c$ L^{-1}
Magnésio	Mg	$mmol_c$ L^{-1}
Sódio	Na	$mmol_c$ L^{-1}
Potássio	K	$mmol_c$ L^{-1}
Soma de cátions		
Bicarbonato	HCO_3	$mmol_c$ L^{-1}
Carbonatos	CO_3	$mmol_c$ L^{-1}
Cloretos	Cl	$mmol_c$ L^{-1}
Sulfatos	SO_4	$mmol_c$ L^{-1}
Soma de ânions		
Relação de Adsorção de sódio	RAS	$(mmol\ L^{-1})^{0,5}$

Fonte: Ayers & Westcot (1999)

Já a proporção relativa de sódio na água de irrigação, em relação a outros sais, pode ser expressa pela Razão de Adsorção de Sódio (RAS), sendo o procedimento mais usual para a detecção de problemas de infiltração. A RAS pode ser calculada pela Equação apresentada a seguir:

$$RAS = \frac{Na}{\left[\frac{(Ca+Mg)}{2}\right]^{0,5}} \left[\left(\text{mmol } L^{-1}\right)^{0,5}\right]$$

em que:

Na - teor de sódio na água de irrigação, $mmol_c\ L^{-1}$

Ca - teor de cálcio na água de irrigação, $mmol_c\ L^{-1}$

Mg - teor de magnésio na água de irrigação, $mmol_c\ L^{-1}$

O risco de sodicidade passou a ser avaliado com mais segurança relacionando a RAS corrigida (RAS^o) com a salinidade da água, estimada pela Equação:

$$RAS^o = \frac{Na}{\sqrt{\frac{(Ca^o+Mg)}{2}}}$$

em que:

Ca^o - teor de cálcio na água, corrigida pela relação HCO_3^-/Ca ($mmol_c\ L^{-1}$)

CE_a ($dS\ m^{-1}$), de acordo com a Tabela 2

As diretrizes para interpretar a qualidade para fins de irrigação é baseada nos efeitos dos sais sobre o solo e a planta, sendo esta avaliada pelo grau de restrição de uso da água quanto aos riscos de salinidade, infiltração de água, toxicidade de íons (cloreto, sódio e boro) entre outros.

2.1 Riscos de salinidade

A salinidade depende da concentração total de sais solúveis na água de irrigação, dada em CE ($dS\ m^{-1}$) ou em Total de Sólidos Dissolvidos – SDT (ppm). A Tabela 3 indica o grau de restrição de uso da água quanto aos riscos de salinizar os solos quando utilizada para irrigação, variando de nenhum, ligeiro a severo risco dependendo da CE_a ou do SDT.

2.2 Problemas de infiltração

Os riscos de uso da água causar problemas de infiltração no solo, devido a desagregação de partículas pelo excesso de sódios trocável, depende do TSD ou CE

Tabela 2 Teor de cálcio (Ca^o) contido na água do solo, próxima à superfície, que resultaria da irrigação com água de determinada relação HCO_3/Ca e CE_a [1 e 2]

HCO_3/Ca	Salinidade da água aplicada (CE_a) – dS m^{-1}											
	0,1	0,2	0,3	0,5	0,7	1,0	1,5	2,0	3,0	4,0	6,0	8,0
0,05	13,20	13,61	13,92	14,40	14,79	15,26	15,91	16,43	17,28	17,97	19,07	19,94
0,10	8,31	8,57	8,77	9,07	9,31	9,62	10,02	10,35	10,89	11,32	12,01	12,56
0,15	6,34	6,54	6,69	6,92	7,11	7,34	7,65	7,90	8,31	8,64	9,17	9,58
0,20	5,24	5,40	5,52	5,71	5,87	6,06	6,31	6,52	6,86	7,13	7,57	7,91
0,25	4,51	4,65	4,76	4,92	5,06	5,22	5,44	5,62	5,91	6,15	6,52	6,82
0,30	4,00	4,12	4,21	4,36	4,48	4,62	4,82	4,98	5,24	5,44	5,77	6,04
0,35	3,61	3,72	3,80	3,94	4,04	4,17	4,35	4,49	4,72	4,91	5,21	5,45
0,40	3,30	3,40	3,48	3,60	3,70	3,82	3,98	4,11	4,32	4,49	4,77	4,98
0,45	3,05	3,14	3,22	3,33	3,42	3,53	3,68	3,80	4,00	4,15	4,41	4,61
0,50	2,84	2,93	3,00	3,10	3,19	3,29	3,43	3,54	3,72	3,87	4,11	4,30
0,75	2,17	2,24	2,29	2,37	2,43	2,51	2,62	2,70	2,84	2,95	3,14	3,28
1,00	1,79	1,85	1,89	1,96	2,01	2,09	2,16	2,23	2,35	2,44	2,59	2,71
1,25	1,54	1,59	1,63	1,68	1,73	1,78	1,86	1,92	2,02	2,10	2,23	2,33
1,50	1,37	1,41	1,44	1,49	1,53	1,58	1,65	1,70	1,79	1,86	1,97	2,07
1,75	1,23	1,27	1,30	1,35	1,38	1,43	1,49	1,54	1,62	1,68	1,78	1,86
2,00	1,13	1,16	1,19	1,23	1,26	1,31	1,36	1,40	1,48	1,54	1,63	1,70
2,25	1,04	1,06	1,10	1,14	1,17	1,21	1,26	1,30	1,37	1,42	1,51	1,58
2,50	0,97	1,00	1,02	1,06	1,09	1,12	1,17	1,21	1,27	1,32	1,40	1,47
3,00	0,85	0,89	0,91	0,94	0,96	1,00	1,04	1,07	1,13	1,17	1,24	1,30
3,50	0,78	0,80	0,82	0,85	0,87	0,90	0,94	0,97	1,02	1,06	1,12	1,17
4,00	0,71	0,73	0,75	0,78	0,80	0,82	0,86	0,88	0,93	0,97	1,03	1,07
4,50	0,66	0,68	0,69	0,72	0,74	0,76	0,79	0,82	0,86	0,90	0,95	0,99
5,00	0,61	0,63	0,65	0,67	0,69	0,71	0,74	0,76	0,80	0,83	0,88	0,93
7,00	0,49	0,50	0,52	0,53	0,55	0,57	0,59	0,61	0,64	0,67	0,71	0,74
10,0	0,39	0,40	0,41	0,42	0,43	0,45	0,47	0,48	0,51	0,53	0,56	0,58
20,0	0,24	0,25	0,26	0,26	0,27	0,28	0,29	0,30	0,32	0,33	0,35	0,37
30,0	0,18	0,19	0,20	0,20	0,21	0,21	0,22	0,23	0,24	0,25	0,27	0,28

[1]Supõe-se: a) Cálcio do solo proveniente do calcário ($CaCO_3$) ou silicatos ; b) Não existe precipitação do Magnésio; c) Pressão parcial de CO_2 perto da superfície do solo (pCO_2) é 7.10^{-2} kPa.
[2]Ca^o e HCO_3/Ca são expressos em $mmol_c$ L^{-1}, e a CE_a , em dS m^{-1}.

Tabela 3 Indicadores de qualidade da água para irrigação quanto a problemas de salinidade

Problema potencial	Unidade	Grau de restrição de uso		
		Nenhuma	Ligeira e moderada	Severa
Salinidade (afeta a disponibilidade de água para as culturas)				
CE_a	dS m^{-1}	< 0,7	0,7 – 3,0	> 3,0
SDT	mg L^{-1}	< 450	450 – 2000	> 2000

(dS m^{-1}) e da RAS, sendo estes parâmetros avaliados conjuntamente de acordo com os critérios estabelecidos na Tabela 4.

A infiltração da água no solo, geralmente, aumenta com a elevação CE da solução do solo e, diminui com a redução desta ou com o aumento da RAS. Isto por que a alta

Tabela 4 Indicadores de qualidade da água para irrigação quanto a problemas de infiltração

Problema potencial	Grau de restrição de uso		
	Nenhum	Ligeira a moderada	Severa
Infiltração (Avaliação conjunta dos parâmetros CE_a a RAS)			
RAS – (mmolc $L^{-1})^{-0,5}$		CE_a (dS m^{-1})	
0 – 3	>0,7	0,7 – 0,2	<0,2
3 – 6	>1,2	1,2 – 0,3	<0,3
6 – 12	>1,9	1,9 – 0,5	<0,5
12 – 20	>2,9	2,9 – 1,3	<1,3
20 – 40	>5,0	5,0 – 2,9	<2,9

concentração iônica agrega as partículas de solos tornando-os permeável, enquanto que o excesso de sódio trocável ou a baixa concentração iônica dispersa as partículas de argila, obstruindo a porosidade do solo e, reduzindo a infiltração. Por exemplo, na Tabela 4 para que uma água de irrigação com alta relação de sódio - RAS entre 20-40 ($mmol_c$ $L^{-1})^{-0,5}$ não apresente nenhum grau de restrição quanto a problemas de infiltração necessariamente a sua CE deve ser maior do que 5 dS m^{-1}.

2.3 Efeito osmótico e toxicidade de íons específicos

De forma geral, a inibição do crescimento das plantas sob salinidade ocorre por duas razões. A primeira é devido ao efeito osmótico ou déficit hídrico provocado pela salinidade, que reduz a absorção de água. A segunda é devido ao efeito específico dos íons ou excesso de íons, que entram no fluxo de transpiração e eventualmente causam injúrias nas folhas, reduzindo assim o crescimento (Munns, 2005).

A redução no potencial hídrico dos tecidos causada pelo excesso de sais provoca restrição no crescimento uma vez que as taxas de elongação e de divisão celular dependem diretamente do processo de extensibilidade da parede celular. Dessa forma, o balanço osmótico é essencial para o crescimento dos vegetais em meio salino e qualquer falha neste balanço resultará em injúrias semelhantes aos da seca, como a perda de turgescência e a redução no crescimento, resultando em plantas atrofiadas, desidratação e finalmente a morte das células (ASHRAF; HARRIS, 2004).

Os problemas de toxicidade acontecem quando as plantas absorvem os sais do solo, juntamente com a água, permitindo que haja toxidez na planta por excesso de sais absorvidos. Este excesso promove, então, desbalanceamento e danos ao citoplasma, resultando em danos principalmente na bordadura e no ápice das folhas, a partir de onde a planta perde, por transpiração, quase que tão somente água havendo, nessas regiões, acúmulo do sal translocado do solo para a planta e, obviamente, intensa toxidez de sais.

A Tabela 5 indica o grau de restrição de uso da água para irrigação quanto aos problemas de toxicidade de íons específicos; em que se observam graus de restrição

Tabela 5 Indicadores de qualidade da água para irrigação quanto a problemas de toxicidade de íons específicos

Problema potencial		Grau de restrição de uso		
		Nenhum	Ligeira e moderada	Severa
Toxicidade dos íons específicos				
Sódio (Na)	Unidades			
Irrigação por superfície	RAS	<3	3,0 – 9,0	>9
Irrigação por aspersão	$mmol_c L^{-1}$	<3	>3	
Cloreto (Cl)				
Irrigação por superfície	$mmol_c L^{-1}$	<4	4,0 – 10	>10
Irrigação por aspersão	$mmol_c L^{-1}$	<3	>3	
Boro (B)	$mg L^{-1}$	<0,7	0,7 – 3,0	>3,0

diferenciados para os cultivos em sistemas de irrigação localizada e aspersão, sendo este último com maior risco de toxicidade, principalmente por que a água é aspergida sobre as folhas da planta aumentando a absorção e o acúmulo de sais nas plantas. A absorção foliar acelera a velocidade de acumulação de sais contendo íons tóxicos na planta sendo, muitas vezes, a fonte principal da toxicidade.

Ainda em relação à Tabela 5, utilizaram-se como parâmetros para estimar os riscos de toxidez por excesso de sódio a RAS em irrigações por superfície e o próprio elemento sódio ($mmol_c L^{-1}$) em irrigações por aspersões.

2.4 Outros Problemas

Os outros problemas se referem aos efeitos indiretos que a água de irrigação pode causar aos solos como a presença de nitrogênio e bicarbonato em excesso e valores elevados de pH, conforme grau de restrição de uso (Tabela 6). Por exemplo, o excesso de bicarbonato na água ou no solo, poderá precipitar o cálcio e afetar o crescimento das plantas pela falta do elemento precipitado e não pelo excesso de outro íon; já valores de pH acima de 8,3 podem diminuir a disponibilidade de micronutrientes como zinco, cobre, manganês, ferro e boro para as plantas.

Quanto aos problemas relacionados à corrosão e à formação de crosta proveniente de água de irrigação, a Tabela 7 resume as diretrizes para estimar a intensidade de danos. Biezok (1972) sugere que se deve efetuar uma avaliação mais abrangente, mesmo quando um dos valores indicar perigo potencial.

Tabela 6 Níveis dos indicadores de qualidade da água para irrigação quanto a outros problemas relacionados a salinidade (nitrogênio, bicarbonato e pH)

Problema potencial	Unidade	Grau de restrição de uso		
		Nenhuma	Ligeira e moderada	Severa
Outros (afetam culturas sensíveis)				
Nitrogênio (NO_3 - N)[4]	$mmol L^{-1}$	< 5,0	5,0 – 3,0	
Bicarbonato (HCO_3)	$mmol L^{-1}$	< 1,5	1,5 – 8,5	
pH			Faixa normal: 6,5 – 8,4	

Tabela 7 Valores limites para avaliar a agressividade das águas sobre o concreto[1]

Análises	Intensidade relativa de danos			
	Nenhuma a ligeira	Moderada	Forte	Muito forte
pH	> 6,5	6,5 – 5,5	5,5 – 4,5	< 4,5
CO_2 dissolvido do $CaCO_3$, mg L^{-1}	< 15	15 – 30	30 – 60	> 60
NH_4, mg L^{-1}	< 15	15 – 30	30 – 60	> 60
Mg, mg L^{-1}	< 100	100 – 300	300 – 1500	> 1500
SO_4, mg L^{-1}	< 200	200 – 600	600 – 3000	> 3000

[1] Fonte: Biezok (1972)

Deve-se ressaltar que esses critérios servem apenas como diretrizes para interpretar a qualidade da água de irrigação, uma vez que os problemas ou os efeitos dos sais sobre o solo e a planta não dependem somente da salinidade da água, mas do tipo de solo, das condições climáticas e do manejo do sistema água-solo-planta.

O comportamento do solo em contato com água salina depende de suas propriedades físicas e do conteúdo de sais iniciais (Kovda et al., 1973). Assim, o conteúdo de argila do solo afeta a capacidade de adsorção de íons que, por sua vez, influencia as propriedades físico-hídricas do mesmo. Segundo os autores, tendo em vista que a composição química do solo influencia os processos de troca durante o contato solo-água, a aplicação de água salina num solo sem problema de salinidade transforma-o em salino, porém o uso de água desta mesma qualidade pode reduzir o nível de salinidade de um solo salinizado, se a drenagem for adequada.

Ademais, como a infiltração e percolação de água podem variar bastante para diferentes tipos de solo, diferentes graus de salinização do solo podem ocorrer com a mesma quantidade e qualidade de água de irrigação aplicada (Kovda et al., 1973). A adequação da água em relação ao tipo de solo se refere principalmente aos aspectos estruturais que condicionam à sua permeabilidade e consequente condução de água e ar. Solos de baixa permeabilidade causam maiores problemas em terras irrigadas, limitando a lixiviação de sais, favorecendo a dispersão de partículas e intensificando o grau de salinização.

O tipo de solo pode ser o indicador do risco de salinização das águas de superfície. A influência depende do escoamento interno que, por sua vez, varia quantitativamente com a permeabilidade do solo e qualitativamente com a disponibilidade de sais. Os Latossolos são solos bem desenvolvidos e bastante permeáveis, entretanto, por serem continuamente lavados dispõem de pouquíssimos sais para liberação. Os Planossolos permitem boa infiltração na camada arenosa superior, mas as argilas das camadas inferiores podem liberar grandes quantidades de sais. O escoamento subterrâneo é desprezível sob condições de solo pouco espesso, de baixa permeabilidade e com subsolo impermeável como no caso do substrato cristalino do sertão (Molle & Cadier, 1992).

3 PRÁTICAS DE MANEJO DA ÁGUA SALINA

O uso de águas salinas na irrigação é um desafio que vem sendo superado com sucesso em diversas partes do mundo, graças à utilização de espécies tolerantes e à adoção de práticas adequadas de manejo da cultura, do solo e da água de irrigação.

Os efeitos negativos da irrigação com água salina em diversas culturas têm sido observados por vários autores na literatura científica nacional. Porém em várias pesquisas têm-se recomendado a utilização das práticas adequadas de manejo quando se dispõem de águas salobras para a irrigação (Savvas et al., 2007), obtendo-se produções rentáveis em diversas partes do mundo.

Dentre as práticas de manejo recomendadas para se produzir satisfatoriamente, em condições de solo ou de água com altos riscos de salinização, destaca-se o manejo da água, associado ao uso de plantas tolerantes à salinidade, sendo importantes os estudos de avaliação e critérios de qualidade da água para um adequado manejo. A seguir seguem exemplos de técnicas que estão sendo testadas na região do semiárido brasileiro.

3.1 Utilização de culturas tolerantes

As culturas não respondem igualmente aos efeitos da salinidade, algumas produzem rendimentos aceitáveis a níveis altos de salinidade e outras são sensíveis a níveis relativamente baixos. Assim, várias pesquisas têm sido desenvolvidas no sentido de verificar a salinidade limiar das culturas, isto é, o nível salino a partir do qual o nível de produção das culturas começa a declinar (Santos Júnior et al., 2011).

Um exemplo da utilização de culturas tolerantes é relatada por Silva et al. (2008); os autores observaram que o cultivo de *Atriplex nummularia*, popularmente conhecida como erva sal e utilizada como forrageira alternativa, em áreas que recebem rejeito salino de dessalinizadores através da irrigação, melhora a qualidade biológica do solo. Verificaram ainda que tal cultivo melhora a fertilidade do solo com reflexo nos teores de carbono, fósforo e nitrogênio.

3.2 Misturas de águas

Em Mossoró, parte da água utilizada para irrigação é proveniente de poços artesianos profundos, que apesar da boa qualidade, apresenta alto custo de obtenção, que, às vezes, inviabiliza seu uso na agricultura. Entretanto, há também poços abertos no calcário Jandaíra que mesmo apresentando custo de obtenção mais baixo, possui água com níveis de salinidade elevada. Nos cultivos irrigados desta região, tem sido comum a substituição de água de boa qualidade, isto é, de baixa condutividade elétrica, por água salobra dos poços rasos, devido ao baixo custo.

Uma alternativa para esta situação seria misturar águas de boa e de qualidade inferior, e assim, aumentar a disposição para as culturas. Essa mistura pode permitir a irrigação de áreas maiores, mas não diminui o total dos sais; por esta razão, tornam-se imprescindíveis investigações sobre o uso racional destas águas salobras, pois a sua utilização indiscriminada pode salinizar os solos, agravando os problemas de desertificação (Dias et al., 2011).

Silva et al., 2010, estudando a combinação da água natural de um poço tubular profundo (3,51 dS m^{-1}) e água de rejeito da dessalinização da água natural (6,69 dS m^{-1}), verificaram que não houve efeito das fontes de salinidade (águas salobras de origem subterrânea e águas salobras por NaCl) sobre a produção da rúcula hidropônica cultivada no sistema hidropônico NFT. Outro exemplo foi observado por Medeiros et al., 2011, no cultivo do melão irrigado utilizando mistura de águas de duas fontes de água: uma de origem calcária, de baixa qualidade, extraída do sedimento calcário através de poços tubulares com média de 100 m de profundidade; a outra fonte de água é originaria do arenito Açu, que neste ponto está localizado a aproximadamente 1000 m de profundidade, sendo sua água considerada de excelente qualidade. Na irrigação da cultura do melão. Eles observaram que os valores médios de sólidos solúveis e de firmeza de polpa não são influenciados pela salinidade da água de irrigação.

3.3 Frequências de irrigação

A diminuição do turno de rega, ou seja, o aumento da frequência de irrigação visa à manutenção do estado de capacidade de campo por um tempo maior, evitando que o processo de evapotranspiração do solo reduza a quantidade de água disponível no solo e, consequentemente, eleve a concentração de sais no solo. Uma vez que a frequência de irrigação é aumentada acontece uma maior solubilização dos sais e a redução do seu efeito osmótico, fato que favorece a absorção hídrica pelas plantas.

Dias et al., 2004, pesquisando sobre a evolução da salinidade em um Argissolo sob cultivo de melão irrigado por gotejamento notaram que a evolução da salinidade do solo é proporcional à concentração de sais da água de irrigação, independente da frequência de irrigação.

De acordo com Silber et al. (2005), uma alta frequência de irrigação pode melhorar o desempenho das culturas, devido a uma maior disponibilidade de nutrientes, especialmente P e Mn. Além disso, a alta frequência de irrigação está associada com níveis de umidade constantemente elevados na zona das raízes das plantas cultivadas. Como consequência, a condutividade hidráulica e disponibilidade de água são mantidos por mais tempo em níveis elevados. A única precaução em relação à aplicação de um cronograma de irrigação frequente é a possível criação de condições de umidade excessiva na zona de raiz que pode reduzir a disponibilidade de oxigênio (Schro der & Lieth, 2002). No entanto, esse problema pode ser resolvido com o uso de substratos de cultivos com ótimas características físicas ou solos bem drenados.

3.4 Aplicação de fração de lixiviação (FL)

A fração de lixiviação de sais capaz de manter o nível de sais tolerável pela cultura pode ser obtida a partir da Equação:

$$FL = \frac{Ld}{Li} = \frac{CEi}{CEd}$$

em que:

FL - fração de lixiviação
Ld - lâmina de percolação profunda, mm
Li - lâmina de irrigação, mm
CEi - condutividade elétrica da água de irrigação, dS m^{-1}
CEd - condutividade elétrica da água de drenagem, dS m^{-1}

Para se estimar a CE_d a partir da CE_i e FL, deve-se considerar que a planta não absorve água uniformemente, de toda a zona radicular. Ayers & Westcot (1999) consideram que a planta absorve do solo, para suas necessidades hídricas, um padrão de extração de 40, 30, 20 e 10% da água consumida pelas culturas, respectivamente, da quarta parte superior à inferior da zona radicular. Portanto, a estimativa da CE_d média da zona radicular deverá ser ponderada de acordo com a proporção de água retida de cada parte da zona radicular.

A Tabela 8 apresenta o fator de concentração de sais no solo (CEes/CEi) com base nas considerações do padrão de extração normal, aliado à relação CEes = 2 x CEd.

As frações de lixiviação para distintos grupos de culturas podem ser estimadas através da Figura 1 (A e B) em função da salinidade da água e do método de irrigação a ser utilizado. No caso de culturas sensíveis e águas de salinidade elevada, satisfazer-se uma fração de lixiviação acima de 0,25 ou 0,30 não é realmente prático, devido à lâmina excessiva de água a ser aplicada. Neste caso, deve-se considerar a alternativa de selecionar uma cultura de maior tolerância que, consequentemente, irá requerer fração de lixiviação menor.

Tabela 8 Fatores de concentração (fc) para se estimar a salinidade do extrato de saturação do solo (CEes) a partir da salinidade da água (CEi) e da fração de lixiviação (FL) (Ayers & Westcot, 1999)

Fração de lixiviação (FL)	Água necessária (% ETc)	Fator de concentração (Fc)
0,05	105,3	3,2
0,10	111,1	2,1
0,15	117,6	1,6
0,20	125,0	1,3
0,25	133,3	1,2
0,40	166,7	0,9
0,60	250,0	0,7
0,70	333,3	0,6
0,80	500,0	0,6

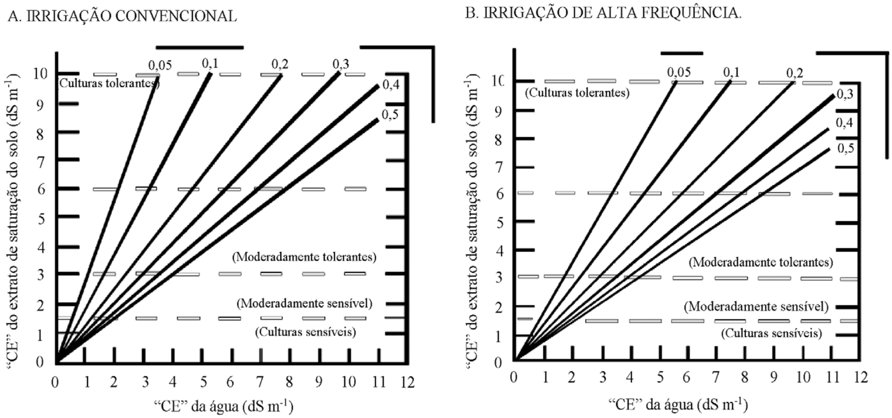

Figura 1 Relação entre salinidade média da zona radicular (extrato de saturação do solo), condutividade elétrica da água de irrigação e fração de lixiviação para o uso em condições de irrigação convencional (A) e de alta frequência (B)

3.5 Cultivos hidropônicos

Os sistemas de cultivo hidropônico têm se constituído em uma das alternativas que busca equacionar problemas relativos salinidade na agricultura, isso porque dado ao estado de saturação e a ausência da matriz do solo, o potencial matricial tende a ser zero, assim, nesse sistema, a tensão total com que a água é retida tem origem exclusivamente osmótica (Santos Júnior et al., 2011).

Vislumbrando o potencial do aproveitamento de águas salobras no preparo de solução nutritiva para cultivos hidropônicos estudos recentes (Dias et al., 2011; Soares et al., 2007) tem sido desenvolvidos no sentido de avaliar a rentabilidade das culturas em tal sistema, dentro da perspectiva técnica, ambiental, social e de custos de produção.

Entre as principais culturas estudadas dentro do contexto hidropônico estão as hortaliças (Gomes et al., 2011) e as flores (Santos Júnior et al., 2011).

4 MANEJO DA FERTIRRIGAÇÃO E O CONTROLE DA SALINIDADE

4.1 Os efeitos da salinidade e a tolerância das culturas

A condutividade elétrica do extrato de saturação do solo (CE_{es}) está relacionada ao conteúdo de sais na solução do solo. O excesso de sais na zona radicular, sem considerar o tipo de espécie iônica predominante, ou seja, qualquer que seja o sal, prejudica a germinação, o desenvolvimento e a produtividade das plantas. Isto ocorre porque a maior concentração da solução nas raízes requer maior energia para que a planta consiga absorver a água, devido ao efeito osmótico, energia esta, que será desviada dos processos metabólicos essenciais.

Pode existir também efeito tóxico direto ocasionado pelos íons presentes em excesso, como o sódio, o cloreto e o boro. Esses efeitos estão intimamente ligados ao desajuste no funcionamento dos sistemas enzimáticos das plantas. O excesso de sódio trocável afeta também a estrutura do solo, deteriorando-a. De modo geral, a resposta das plantas a diferentes níveis de condutividade elétrica do extrato de saturação pode ser resumida conforme apresentada na Tabela 9.

Tabela 9 Resposta das plantas a diferentes níveis de salinidade do solo

CE_{es} à 25 ºC ($dS\ m^{-1}$)	Respostas das plantas
0 – 2,0	Os efeitos da salinidade são imperceptíveis
2,0 – 4,0	A produtividade das plantas muito sensíveis à salinidade pode ser reduzida
4,0 – 8,0	A produtividade das plantas muito sensíveis à salinidade é reduzida significativamente
8,0 – 16,0	Somente plantas tolerantes à salinidade podem produzir satisfatoriamente
> 16,0	Poucas plantas tolerantes à salinidade produzem satisfatoriamente

A tolerância relativa da maioria das culturas é razoavelmente conhecida, o que permite a preparação de diretrizes técnicas para se lidar com a salinidade. A Tabela 10 inclui valores de tolerância de algumas hortaliças para os sais normalmente encontrados nos solos e na água de irrigação de regiões áridas e semiáridas. Estes valores, entretanto, estão baseados no acúmulo de sais que ocorre em regiões áridas e semiáridas, e são apenas indicativos quando se trata de manejar a salinidade em estufas de regiões úmidas, como por exemplo, no caso da região Sudeste do Brasil, pois nestas o excesso de sais geralmente advém da aplicação excessiva de fertilizantes, cujos efeitos possivelmente são diferentes e ainda não foram suficientemente investigados.

4.2 Métodos de controle de nutrientes da fertirrigação

A prática da fertirrigação constitui uma das técnicas que visam garantir a alta produtividade; no entanto, quando não se tem um controle adequado da quantidade de cada fertilizante aplicado via água de irrigação, o acúmulo de sais no solo ocorre

Tabela 10 Valores de tolerância à salinidade de algumas hortaliças e seu rendimento potencial, em função da salinidade do extrato de saturação do solo

Culturas	Rendimento potencial - %				
	100	90	75	50	0
	CE_{es}				
Beterraba	4,0	5,1	6,8	9,6	15,0
Brócolis	2,8	3,9	5,5	8,2	14,0
Tomateiro	2,5	3,5	5,0	7,6	13,0
Pepino	2,5	3,3	4,4	6,3	10,0
Repolho	1,8	2,8	4,4	7,0	12,0
Pimentão	1,5	2,2	3,3	5,1	8,6
Alface	1,3	2,1	3,2	5,1	9,0
Cebola	1,2	1,8	2,8	4,3	7,4
Cenoura	1,0	1,7	2,8	4,6	8,1
Melão	2,1	3,5	5,6	9,1	16,1

com frequência. Esse aumento é proporcionado pela ausência de precipitações e pelas aplicações em excesso de fertilizantes, tornando o solo improdutivo em curto espaço de tempo. Além disso, o excesso de solução nutritiva que drena abaixo da zona radicular, após cada evento de fertirrigação, contém consideráveis teores de nutrientes como nitrato e potássio que é considerado um poluente ambiental.

Deve-se ressaltar que o teor de sais, ou seja, de fertilizantes no solo ou substrato de cultivo deve ser sempre inferior ao nível nocivo às plantas cultivadas; assim, a manutenção da concentração da solução do solo a níveis inferiores ao máximo tolerado pela cultura e superiores ao mínimo necessário para sua nutrição, é uma prática considerada ideal, por ser mais econômica e menos agressiva ao ambiente. Desse modo, faz-se necessário realizar um monitoramento da concentração iônica ao longo do ciclo dos cultivos, devido ao fato de haver variabilidade da salinidade, tanto no espaço como ao longo do tempo. Neste monitoramento são verificados quais os fatores que estão ocasionando o aumento da salinidade do solo e a partir daí, elabora-se planos estratégicos de manejo e recuperação das áreas.

Para eliminar o lixiviado com excesso de nutrientes da solução nutritiva drenada, reduzindo assim a contaminação do lençol freático, Savvas et al. (2007) recomendam a utilização de 'sistemas automáticos inteligentes' baseados em modelos de balanço de massa, em que a solução nutritiva do lixiviado é totalmente reciclada, ou seja, retornada para compor uma nova solução nutritiva padrão.

A Figura 2 mostra esquematicamente o funcionamento desses sistemas inteligentes para reciclar a solução nutritiva lixiviada, entretanto, estes sistemas restringem-se apenas a cultivos sem solos (cultivos hidropônicos abertos e fechados). Outra vantagem desse sistema é o fato de se controlar a concentração de sais na zona radícular pelo manejo da frequência de irrigação, podendo contribuir para reduzir a salinidade do substrato de cultivo, uma vez que sob tais condições de crescimento o aumento da porcentagem de solução drenada não agrava a poluição ambiental, já que esta é reciclada.

Quando a solução nutritiva não é reciclada, a fração de lixiviação deve ser mantida a um valor mínimo para evitar a menor descarga de resíduos fertilizantes no solo, a menos que a cultura necessite lixiviar o excesso de sais abaixo da zona radicular para impedir a salinização. Nos sistemas de cultivo sem solo, tradicionalmente a fração de lixiviação recomendada é de 25-35%; porém o fornecimento preciso de água e nutrientes podem resultar na maior eficiência do uso da água, evitar situações de estresse e garantir a produção (Savvas et al., 2007).

Outra técnica bastante utilizada para o manejo de nutrientes e controle da salinidade dos solos é o uso de extratores de solução no solo. Considerando que os extratores de solução no solo providos de cápsulas porosas proporcionam informação imediata e são de fácil fabricação e uso, os mesmos surgem como uma excelente opção para manejar a fertirrigação e controlar a salinidade dos solos em campo aberto ou em ambientes protegidos (Dias et al., 2005). Neste aspecto, seria mais viável racionalizar

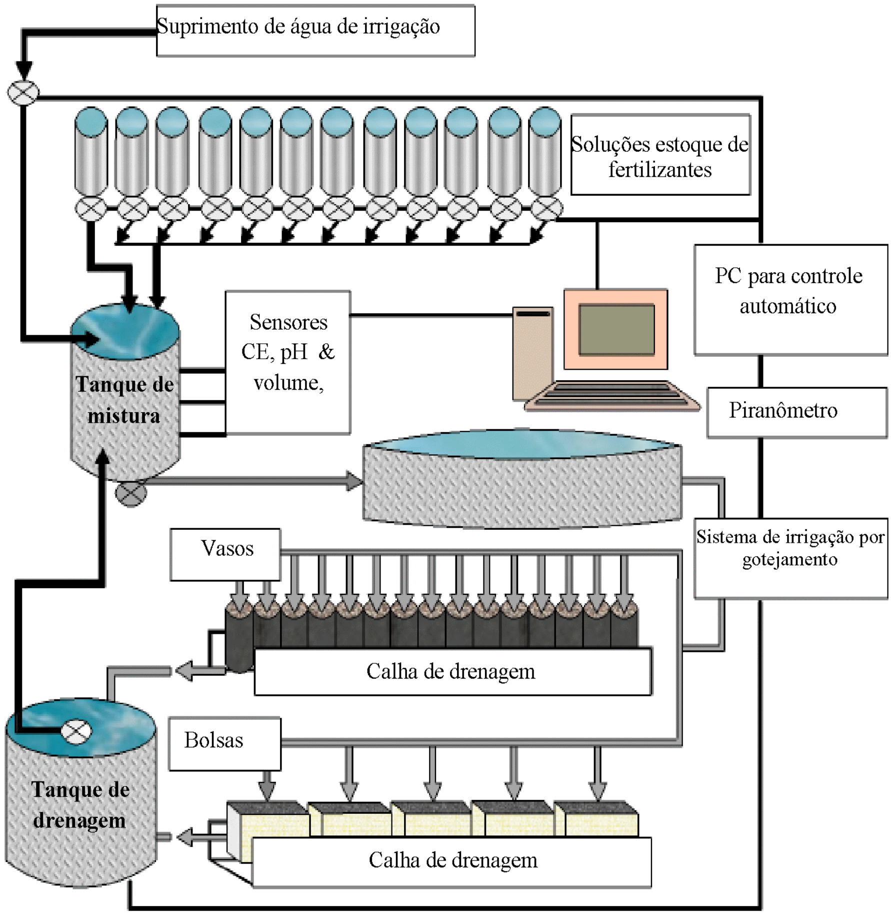

Figura 2 Sistema hidropônico de ciclo fechado: Reciclagem de nutrientes da solução nutritiva lixiviada (Adaptado de Savvas et al., 2007)

o manejo da fertirrigação por meio da determinação da condutividade elétrica e/ou da concentração parcial de íons na solução do solo utilizando os extratores de solução (Figura 3).

A utilização de cápsulas porosas para extrair a solução do solo é bastante difundida, principalmente devido ao manejo fácil, custo relativamente baixo e pelo fato do extrato obtido não requerer tratamentos prévios às determinações físico-químicas e as quantificações de seus componentes. Com o auxílio dos extratores de solução do solo, pode-se conhecer os valores de pH, conditividade elétrica da solução do solo, teores de nitrato e nitritos, assim como de outros íons presentes que são de importância para a nutrição das plantas (Dias et al., 2004).

Resultados de pesquisas indicam que, com o auxílio dos extratores providos de cápsulas porosas cerâmicas e medidores de íons específicos, é possível determinar a

Figura 3 O monitoramento da fertirrigação e o controle de nutrientes em solos com auxilio dos extratores de solução evita a salinização e o desequilíbrio nutricional

concentração de nitrato e de potássio, com boa precisão e monitorar a concentração do íon cálcio na solução do solo, quando comparado ao método padrão. É evidente que o monitoramento da condutividade elétrica da solução do solo, extraída por cápsulas porosas, permite evitar possíveis processos de salinização e/ou deficiência nutricional em culturas como tomate, pimentão e pepino em ambiente protegido.

Tradicionalmente, o manejo da fertirrigação é realizado ministrando-se quantidades pré-estabelecidas de fertilizantes, parceladas de acordo com a marcha de absorção da cultura, não existindo, normalmente, nem monitoramento da concentração de íons na solução do solo, nem do estado nutricional da planta. Neste aspecto, seria mais viável racionalizar o manejo da fertirrigação por meio da determinação da condutividade elétrica e/ou da concentração parcial de íons na solução do solo. Caso a condutividade elétrica da solução do solo apresente valores inferiores ao máximo tolerado pela cultura, sem decréscimo no rendimento relativo, e superiores ao mínimo necessário para sua nutrição, a salinização estaria controlada (Burgueño, 1996).

4.3 Concentrações iônicas adequadas à nutrição das plantas

A exigência nutricional de cada cultura é variável e em cada fase fenológica do ciclo a concentração de nutrientes na solução do solo apresenta um valor ideal específico. Poucos trabalhos têm sido desenvolvidos com o objetivo de calibrar a técnica de monitoramento da solução do solo para as diferentes culturas. As pesquisas realizadas permitem afirmar que a técnica funciona, mas não se sabe a concentração adequada dos nutrientes para todas as culturas e, mais especificamente, qual seria a concentração adequada de um determinado nutriente durante as diferentes fases do ciclo, quais sejam, estabelecimento, desenvolvimento vegetativo e produção (Dias et al., 2004).

Trabalhos preliminares sugerem valores de condutividade elétrica e de concentração de alguns nutrientes para determinadas culturas; entretanto, é necessário que novos trabalhos venham a explorar outras culturas, além de refinar os resultados, a ponto de se obter o valor mais adequado de concentração dos nutrientes para que maiores produtividades sejam alcançadas. Na Tabela 11 pode-se observar alguns desses resultados para as culturas do tomate, do pimentão e do pepino.

Tabela 11 Valores máximos e mínimos sugeridos de alguns nutrientes na solução do solo para as olerícolas mais cultivadas em ambientes protegidos (Dias et al., 2004)

Culturas		NO_3	K
		(mmol L^{-1})	
Tomate	Limite inferior	7,5	3,6
	Limite superior	15,0	5,0
Pimentão	Limite inferior	7,0	3,0
	Limite superior	15,0	4,0
Pepino	Limite inferior	12,0	5,0
	Limite superior	16,0	7,0

Os valores sugeridos nesta tabela foram determinados diretamente na solução de um solo de textura média, obtida com extratores providos de cápsula porosa, sendo o vácuo aplicado 24 horas após a fertirrigação.

Deve-se ressaltar que o uso de extratores de solução do solo é uma nova proposta de manejo rigoroso da concentração iônica em cultivos intensivos, que visa prover uma nutrição ideal das plantas e o controle da salinidade proporcionada por excesso de fertilizantes, sendo sua aplicação recomendada principalmente para cultivos fertirrigados.

5 MANEJO DA IRRIGAÇÃO: ASPECTOS GERAIS

Dentre os métodos mais adequados de aplicação de água, o gotejamento se destaca, pois colocar a água necessária junto ao sistema radicular reduz o aparecimento de plantas invasoras, reduzindo o aparecimento de doenças das folhas e das raízes. Os métodos de irrigação por aspersão são os menos indicados por favorecerem o aparecimento de doenças foliares.

A utilização da irrigação localizada tem sido preferida pelos agricultores em decorrência das suas vantagens em relação aos demais sistemas de irrigação, apesar de o seu custo de implantação ser maior inicialmente. Neste sistema, além do aumento da eficiência da aplicação de água, pode-se aplicar fertilizantes via água com baixos custos operacional e de manutenção. Os sistemas localizados permitem maior parcelamento dos fertilizantes, é possível manter a disponibilidade dos nutrientes na solução do solo próximo aos níveis adequados, minimizando as perdas de nutrientes por lixiviação, notadamente, o nitrogênio e o potássio. Na cultura do meloeiro, por exemplo, o uso de tecnologias adequadas de manejo da cultura e da fertirrigação em condições protegidas, pode-se elevar a produtividade do meloeiro a níveis superiores a 100 t ha^{-1}.

Para a irrigação em solos sob estruturas de proteção, a fonte de água deve ser de boa qualidade, usar preferencialmente a irrigação por gotejamento com cabeçal de controle dotado de um bom sistema de filtragem e injetor de fertilizantes, sendo recomendável o uso de temporizador e válvula solenóides para automação do sistema. O controle da irrigação deve ser realizado com tensiômetros ou tanque classe A, ou ainda com a combinação dos dois. Na combinação dos dois métodos, o tensiômetro é usado para determinar o momento da irrigação e checar as condições de umidade do solo e o tanque classe A para determinar a lâmina de água de reposição.

Em áreas cobertas com solo homogêneo devem ser instalados no mínimo dois tensiômetros, sendo um instalado na profundidade de maior concentração radicular. As irrigações devem ser reiniciadas quando as tensões estiverem dentro do intervalo de 30 - 60 kPa. A quantidade de água a ser aplicada (evapotranspiração de cultivo) é calculada multiplicando-se a evapotranspiração de referência (ET_0) pelo coeficiente de cultivo (Kc), ETc = ET0 * Kc.

Um aspecto mais importante da irrigação é a reposição da água ao solo em quantidade adequada e na ocasião oportuna. O excesso de irrigação geralmente reduz a produtividade e a qualidade da produção, pode provocar o crescimento excessivo da planta, o retardamento da maturação das frutas, a lixiviação de nutrientes solúveis (N e K), queda de flores, maior ocorrência de doenças de solo e distúrbio fisiológicos, maiores gastos com energia e o desgaste do sistema de irrigação.

Busca-se cada vez mais a importância para produtos de melhor qualidade. A experiência de técnicos e as pesquisas têm demonstrado que diversas práticas de cultivo, entre as quais a irrigação é uma das mais efetivas, vem influenciando marcadamente sobre a qualidade dos produtos.

Os métodos de irrigação influenciam na acumulação de sais no solo e na planta. Por exemplo, uma água relativamente salina aplicada por sulcos em solos permeáveis não trará nenhum efeito prejudicial ao crescimento da planta, enquanto, água de mesma qualidade aplicada por aspersão, poderá reduzir a produtividade (Kovda et al., 1973).

6 CONCLUSÕES

A agricultura irrigada é uma alternativa para a produção de alimentos em regiões de clima árido e semiárido, contudo, quando não se tem um manejo adequado da irrigação e controle da aplicação de fertilizante, esta prática é um fator de degradação ambiental, seja por salinização dos solos e/ou pela contaminação de mananciais pelo lixiviado dos nutrientes da fertirrigação. Além disso, o uso irracional dos recursos hídricos para a irrigação, seja superficial ou subterrâneo, pode levar a escassez de água e agravar a crise da oferta de água.

Deve-se, escolher preferencialmente solos aptos para a irrigação, ou seja, solos profundos e bem drenados, evitando assim a contaminação do ambiente. Algumas práticas de conservação dos solos devem estar associadas à práticas de irrigação como, por exemplo, a cobertura vegetal do solo, o dimensionamento adequado e a escolha do métodos de irrigação com base no tipo de solo podem evitar o escoamento superficial e perda de matéria orgânica e da fertilidade do solo.

Desse modo, a prática de irrigação deve ser realizada em um sistema integrado, considerado não apenas um fator isolado para a tomada de decisões, mas interações solo-água-clima-planta com a finalidade de evitar a desertificação das áreas.

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6

Fontes de Água Salina e Estratégias de Uso na Agricultura

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1 O PROBLEMA DA SALINIDADE NO MUNDO E NO BRASIL

A salinidade é um dos estresses abióticos que mais limita a produção agrícola em razão de seus efeitos negativos no crescimento e desenvolvimento vegetal. Estima-se que 19,5% das áreas irrigadas em todo o mundo, o que corresponde a 45 milhões de hectares, enfrentem problemas devido à salinidade sendo que 40% destas estão localizadas em regiões áridas e semiáridas (Carvalho, 2012). Dentre os países, os Estados Unidos têm uma área cultivada de 189,91 milhões de hectares, sendo 18,1 milhões de hectares irrigados e deste total, 23% estão salinizadas. A Índia tem a segunda maior área cultivada com 168,99 milhões de hectares, com 42,1 milhões de hectares irrigados com 16,6% salinizadas (Tabela 1).

No Brasil, aproximadamente nove milhões de hectares são afetados pela presença de sais *(*salinização por fatores naturais e salinização induzida por irrigação). A

Tabela 1 Estimativa global de salinização secundária de áreas irrigadas no mundo

Local	Área cultivada	Área irrigada	Terras afetadas por sais em áreas irrigadas	Percentagem de áreas irrigadas afetadas por sais (%)
	(10^6 ha)			
China	96,97	44,83	6,70	15,0
Índia	168,99	42,10	7,00	16,6
Estados Unidos	189,91	18,10	4,16	23,0
Paquistão	20,76	16,08	4,22	26,2
Iran	14,83	5,74	1,72	30,0
Tailândia	20,05	4,00	0,40	10,0
Egito	2,69	2,69	0,88	33,0
Austrália	47,11	1,83	0,16	8,70
Argentina	35,75	1,72	0,58	33,7
África do Sul	13,17	1,13	0,10	8,90
Sub-total	610,23	138,22	25,92	20,5
Mundo	1.473,70	227,11	45,40	20,0

Fonte: Central Soil Salinity Research Institute (2004) salinidade abrange 2% das terras brasileiras e compreende sete Estados. Solos salinos e sódicos ocorrem, principalmente, no Rio Grande do Sul, no Pantanal Mato-grossense e na região semiárida do Nordeste (Fageria et al., 2010; Ribeiro, 2010).

A região Nordeste, com o constante aumento da população e a pressão econômica pela produção de alimentos, aumentou a área em que os solos encontram-se degradados por salinidade e sodicidade (Ribeiro, 2010). Este mesmo autor relata que 91.000 km^2 de solos na região Nordeste se encontram afetados pela salinidade. A maior área de solos comprometidos pela salinidade no semiárido nordestino está localizada no Estado da Bahia (44% do total), seguido pelo Ceará que representa 25,5% da área total do País (Fageria et al., 2010).

Segundo Cavalcante et al. (2012) no mundo, o uso pouco eficiente da água para produção de alimentos transformou, pelo acúmulo de sais, extensas áreas antes produtivas em terras devolutas e sem nenhum valor produtivo. As regiões semiáridas do Nordeste brasileiro se assemelham à situação descrita acima.

Embora não existam levantamentos detalhados e precisos do problema de salinidade nos diversos perímetros irrigados do Nordeste, de acordo com o DNOCS, nos Estados do Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco e Bahia, em média, 12% da superfície agrícola útil foram desativadas e 7,6% estão salinizadas, sendo que, nos Perímetros irrigados de Sumé, São Gonçalo, Vaza-Barris e Jacurici, a percentagem de área salinizada é superior a 20% (Gheyi, 2000; Bezerra, 2006).

Dentre as causas da salinização destas áreas destacam-se o manejo inadequado da irrigação, a deficiência ou inexistência do sistema de drenagem e a qualidade da água utilizada na irrigação. A expansão das áreas irrigadas em terras marginais, o uso de águas salinas na irrigação, o manejo inadequado da água e do solo e a ausência de drenagem, levam a grandes prejuízos para a economia regional e o abandono destas áreas.

2 FONTES DE ÁGUA SALINA E POSSIBILIDADES DE USO PARA IRRIGAÇÃO

Atualmente, existe grande preocupação a respeito do uso da água, não somente no tocante a quantidade disponível para uso nos diversos setores da sociedade, mas principalmente no que tange à qualidade dessas águas (Singh & Gupta, 2009).

A agricultura irrigada é conhecida como a maior usuária de água doce no mundo, sendo responsável por 69% do consumo (Pires et al., 2008). Diante disso, surge o desafio de desenvolver estratégias para produzir alimentos com economia de água e produzir com águas de qualidade inferior, sem afetar o solo e o meio ambiente como um todo. A necessidade de uso de água de qualidade inferior na irrigação vem do requerimento progressivo e elevado de água boa pela irrigação, quando este recurso é limitado. Essa situação tem levado ao reuso e reciclagem da água na agricultura, em muitas regiões do mundo (Malash et al., 2005, 2008; Bao & Li, 2010; Santos et al., 2012).

Dentre as águas de menor qualidade que podem ser utilizadas na irrigação podemos citar: água do mar, água salobras de origem subterrânea, águas salobras superficiais, rejeito de dessalinizadores e águas residuárias. O sucesso do reuso de águas salinas e salobras requer a seleção de culturas tolerantes à salinidade, desenvolvimento de estratégias de manejo adequadas e da escolha do sistema de irrigação mais apropriado. A água para irrigação pode ser constituída da mistura de água salina e água doce ou mesmo da água salina sem mistura, porém aplicada durante as fases de maior tolerância da cultura (Gawad et al., 2005; Oliveira et al., 2007; Chauhan et al., 2008; Malash et al., 2008; Segal et al., 2010; Morales-Garcia et al., 2011).

No caso de regiões áridas e semiáridas são utilizadas águas de qualidade inferior para suprir a demanda hídrica de muitas comunidades e para uso na irrigação. Essas águas são obtidas de poços tubulares que possuem, em sua maioria, água salobra ou salina e apresentam teores de sais acima do nível aceitável de potabilidade, devido ao fato das regiões semiáridas brasileiras, particularmente aquelas localizadas no Estado do Ceará, estarem localizadas no embasamento cristalino, cujas águas têm sua composição de sais alterada pela intemperização das rochas (Matos et al., 2000; Campos, 2007).

Atualmente o semiárido brasileiro possui um elevado número de poços tubulares, com cerca de 70.000 poços perfurados, sendo que nos casos dos poços com água salobra a utilização desse recurso natural através da utilização de dessalinizadores pode contribuir para resolver o problema da falta de água para consumo humano. Apesar dos benefícios do processo, a dessalinização gera grande quantidade de rejeito que representam de 40 a 60% da água processada e apresentam salinidade muito superior a da água captada antes do processo (Azevedo et al., 2005; Soares et al., 2006; Santos et al., 2010; Santos et al., 2011).

O uso crescente de equipamentos de dessalinização de água salina pelo processo de osmose reversa na região do semiárido brasileiro poderá trazer impactos ambientais severos devido ao rejeito produzido, que é composto de água com elevados teores de sais (Porto et al., 2001). Considerando-se o número de dessalinizadores no Estado do Ceará, estimado em 450 equipamentos, atendendo 87 municípios de acordo com a SOHIDRA (2011), grande volume de rejeito está sendo gerado, e quase que na totalidade dos casos, o rejeito não vem recebendo nenhum tratamento, sendo despejado diretamente no solo.

As águas de qualidade inferior, tais como efluentes de processos industriais e de esgotos, particularmente os de origem doméstica, águas de drenagem agrícola e águas salobras devem, sempre que possível, ser consideradas fontes alternativas para usos menos restritivos. Uma das fontes hídricas cada vez mais populares para uso na produção agrícola são as águas residuárias, tratadas ou não tratadas. Essas águas são fontes de matéria orgânica e de vários outros nutrientes e estão disponíveis em grande volume o ano todo, devido ao crescimento acelerado dos centros urbanos. No que concerne às discussões relacionadas ao uso destas águas podem ser citados vários problemas, tais como: problemas públicos, se o tratamento for inapropriado; se tem potencial para contaminação química (sais, nitrato, sódio, fósforo, etc.) de águas superficiais ou subterrâneas; constituintes solúveis que podem causar toxicidade às plantas, permanecer no solo ou serem lixiviados para as águas subterrâneas.

3 ESTRATÉGIAS PARA USO DE ÁGUA SALINA NA AGRICULTURA IRRIGADA

A salinidade afeta as culturas pela redução do potencial osmótico do solo, restringindo a disponibilidade de água, além de provocar acumulação excessiva de íons nos tecidos vegetais, podendo causar toxicidade iônica, desequilíbrio nutricional, ou ambos. Elevadas concentrações de determinados elementos, principalmente o sódio, o boro, os bicarbonatos e cloretos, causam distúrbios fisiológicos às plantas, afetando o rendimento e a qualidade da produção. Além disso, o excesso de um íon inibe a absorção de outros íons, causando deficiências nutricionais, como por exemplo, quando a concentração de Na^+ e Cl^- no solo é alta, a absorção de nutrientes minerais, especialmente NO^-_3, K^+ e Ca^{2+} é quase sempre reduzida (Trindade et al., 2006; Chaves et al., 2009; Dias & Blanco, 2010; Nobre et al., 2010).

O grau de severidade com que cada um desses componentes influencia o crescimento e o desenvolvimento das plantas é dependente de muitos fatores, dentre eles, pode-se citar: a espécie ou cultivar vegetal, o estádio fenológico, a composição salina do meio, a intensidade e duração do estresse, bem como, as condições edafoclimáticas e o manejo da irrigação (Yeo, 1999; Silva et al., 2003; Gheyi et al., 2005). De acordo com Larcher (2000), a taxa de crescimento e a produção de biomassa são bons critérios para avaliar o grau de estresse e a capacidade da planta em superar o estresse salino, pois os processos de crescimento são particularmente sensíveis à salinidade. O conhecimento dos mecanismos de tolerância das plantas que não afetam significativamente seus rendimentos pode favorecer a utilização de águas salinas, que são comuns na Região Nordeste do Brasil (Nobre et al., 2010).

A utilização de águas salinas e salobras na irrigação é possível, desde que seu uso esteja associado a técnicas de manejo, tais como: seleção de culturas ou variedades tolerantes à salinidade; seleção dos métodos de irrigação que reduzam a aplicação direta da água salina na cultura; aplicação de água além da necessidade da cultura, de modo a favorecer a lixiviação do excesso de sais da zona radicular; irrigação com água salina em conjunto com água doce durante todo ciclo ou de forma alternada; além de diversas intervenções agronômicas (Bahri, 2008; Rodrigues et al., 2009; Muyen et al., 2011; Pereira et al., 2011). A seguir serão discutidas algumas destas estratégias.

4 UTILIZAÇÃO DE CULTURAS TOLERANTES À SALINIDADE (HALÓFITAS E GLICÓFITAS)

As espécies vegetais podem ser agrupadas em halófitas e glicófitas em relação às suas respostas a salinidade. As halófitas são espécies nativas de ambientes salinos, enquanto que as glicófitas ou não halófitas compreendem a maioria das espécies cultivadas, que sofrem reduções no crescimento e produtividade mesmo em níveis baixos de sais (Greenway & Munns, 1980; Willadino & Câmara, 2010). O incremento da tolerância à salinidade em plantas sensíveis, as glicófitas, e a domesticação de espécies silvestres tolerantes, as halófitas, são fundamentais para favorecer o crescimento das culturas em ambientes salinos.

No entanto, a maioria das plantas cultivadas, são glicófitas. Para estas espécies o efeito da salinidade do solo para a produção agrícola é considerável, podendo gerar importantes perdas na agricultura (Willadino & Câmara, 2010). Nas plantas cultivadas o nível máximo de tolerância à salinidade na zona radicular das culturas sem que ocorra danos ao desenvolvimento e consequentemente na produtividade das culturas é denominado de salinidade limiar, em que o rendimento é 100%. A partir da salinidade limiar, o crescimento diminui linearmente com o aumento da salinidade do solo (Maas & Hoffman, 1977).

De acordo com Ayers & Westcot (1999), os valores de salinidade limiar (do solo e da água) e as taxas de decréscimo no rendimento das culturas são critérios que permitem classificar as diferentes espécies cultivadas de acordo com o seu grau de tolerância à salinidade. Entre as mais sensíveis encontram-se, principalmente as hortaliças e algumas árvores frutíferas, como a laranjeira e o abacateiro. O algodão e a cevada estão entre as mais tolerantes. No entanto, é importante ressaltar que muitos dos dados de classificação de tolerância à salinidade foram obtidos em condições climáticas diferentes daquelas observadas no semiárido brasileiro e utilizando-se genótipos diferentes (Lacerda et al., 2010).

Além das variações na tolerância relativa das culturas, também podemos encontrar variações na tolerância absoluta, sendo que esta última varia com as condições climáticas, com o solo, além de diversas práticas de cultivo (Medeiros et al., 2009). Uma cultivar ou espécie poderá apresentar diferenças no crescimento e produtividade para um mesmo nível de salinidade desde que as condições de cultivo sejam diferentes ao longo do ciclo. Por exemplo, quando as plantas estão crescendo em ambiente com alta umidade relativa do ar o efeito da salinidade no crescimento é atenuado. Outro aspecto que se deve considerar é o estabelecimento do estande, devendo-se buscar minimizar os impactos da salinidade nessa fase e garantir um estande composto de plantas vigorosas capazes de enfrentar o estresse salino (Melo et al., 2006).

Em algumas áreas, o cultivo de glicófitas é inviável, particularmente onde somente águas salinas são disponíveis, onde há rejeitos de dessalinizadores ou quando o lençol freático é salino e raso e a permeabilidade do solo é baixa. Nestes casos, práticas culturais como aração profunda e subsolagem podem ser recomendadas. Em outras circunstâncias a melhor opção é a utilização de espécies altamente tolerantes, as halófitas.

Muitas halófitas apresentam a habilidade de extrair sais do solo devido a suas altas taxas de absorção e acumulação de sais nos tecidos, sobretudo na parte aérea. De acordo com Freire et al. (2010) a fitorremediação é uma eficiente estratégia de recuperação de solos salinos e sódicos tanto pela remoção de quantidades consideráveis de sais, quanto pela melhoria da estruturação do solo e incremento da atividade biológica quando as plantas são introduzidas em áreas sem cobertura vegetal. Experimentos realizados com a espécie *Atriplex nummularia*, forrageira de boa aceitabilidade pelo gado, registraram taxas de absorção de sais de, aproximadamente, 1,15 t ha^{-1} ano^{-1}, quando as mesmas foram cultivadas com rejeitos de dessalinizadores no Nordeste brasileiro (Porto et al., 2001).

Silva et al. (2008) avaliaram o efeito da irrigação com rejeito da dessalinização, oriundo de tanques de produção de tilápia-rosa, sobre as propriedades químicas e microbiológicas de solos cultivados com erva-sal (*Atriplex nummularia* Lindl.). De acordo com estes autores, a presença da *Atriplex nummularia* melhora a fertilidade do solo com reflexo nos teores de carbono, fósforo e nitrogênio e melhora a qualidade biológica do solo. Souza et al. (2012) verificaram que a alta produtividade da matéria seca da *Atriplex nummularia* indica o potencial uso desta halófita para restauração de solos afetados por sais.

5 ROTAÇÃO CULTURAL

O uso da rotação de culturas na agricultura, prática que consiste em alternar anualmente espécies vegetais numa mesma área agrícola, é uma prática bastante interessante do ponto de vista conservacionista e econômico. Ela se estabelece pelo plantio sequenciado de espécies com diferentes tipos de sistema radicular e diferentes exigências nutricionais na busca de garantir a cobertura vegetal permanente do terreno, adicionar ao solo material orgânico, nitrogênio e garantir a redução da emissão de CO_2 e N_2O, principalmente quando a rotação é realizada com espécies leguminosas, além de reduzir perdas de nutrientes por lixiviação e melhorar a qualidade física e química do solo (Siqueira Neto et al., 2009; Segal et al., 2010; Correia et al., 2011; Pacheco et al., 2011).

A rotação de culturas também tem implicações positivas sobre a ocorrência de plantas espontâneas, sobre aspectos fitossanitários como o aumento do número de esporos de fungos micorrízicos arbusculares em áreas salinas e até na redução da salinidade do solo quando a rotação é realizada com culturas extratoras de sais, favorecendo assim o crescimento vegetal e a produtividade da cultura principal (Bezerra et al., 2010; Correia et al., 2011; Abdel-Fattah & Asrar, 2012).

No caso do uso da rotação de culturas em áreas salinas ou onde se faz uso de águas com elevada salinidade na irrigação, recomenda-se o cultivo das culturas mais tolerantes durante a época seca, haja vista a baixa qualidade da água e maior limitação de água de melhor qualidade nesse período. O cultivo de culturas mais sensíveis é recomendado na estação chuvosa, devido a disponibilidade de água de boa qualidade proveniente das precipitações do período (CSSRI, 2004; Bao & Li, 2010; Kang et al., 2010).

Com essa prática, em regiões semiáridas pode-se obter produção de forragem ou de grãos o ano inteiro, utilizando águas salinas na estação seca e água de chuva na estação úmida, sem alterar significativamente o ambiente (Rhoades et al., 2000; Vieira, 2006; Murtaza et al., 2006). O acúmulo de sais durante a irrigação de culturas na estação seca pode ser revertido, total ou parcialmente, durante o período chuvoso, sendo que esse processo de lavagem dependerá do total de precipitação anual, da intensidade das precipitações e das características físicas do solo (Sharma & Rao, 1998; Assis Júnior et al., 2007; Bezerra et al., 2010; Lacerda et al., 2011a; b).

6 MISTURA DE ÁGUA, USO CÍCLICO DE ÁGUA SALINA E DURANTE A FASE TOLERANTE DA CULTURA

Diversos estudos no mundo têm demonstrado a eficiência do uso alternado de águas de diferentes salinidades na irrigação, bem como da mistura de água e da aplicação de água com elevados teores de sais apenas nos estágios de maior tolerância. Essas estratégias se constituem importantes alternativas que permitem os impactos da irrigação com esses tipos de água sobre as plantas e sobre o ambiente (Lacerda et al., 2010).

De acordo com CSSRI (2004), o uso cíclico, também conhecido como modo de aplicação rotacional de água na irrigação, facilita a efetiva utilização conjunta das águas doce e salina. Uma grande vantagem da estratégia de uso cíclico é que as condições de estado estacionário de salinidade no perfil do solo não são alcançadas. Isso se deve ao fato de que a qualidade da água de irrigação muda ao longo do tempo. Outra vantagem desta estratégia é que não exige grandes investimentos em estruturas para a mistura de águas de diferentes qualidades.

O CSSRI (2004) realizou experimento com trigo, milheto e sorgo utilizando água salina e água do canal em um modo cíclico. A água do canal foi utilizada para a irrigação de pré-semeadura e, posteriormente, quatro irrigações foram aplicadas com água do canal e água de drenagem salina. Durante a estação chuvosa, não foi realizada irrigação para as culturas de miheto e sorgo, pois a precipitação atendeu ao requerimento das culturas. Os resultados experimentais de quatro anos de estudo com a rotação cultural de trigo-milheto-sorgo indicaram que o uso cíclico de água salina e água do canal em diferentes sequências, pode resultar em boas produtividades (Tabela

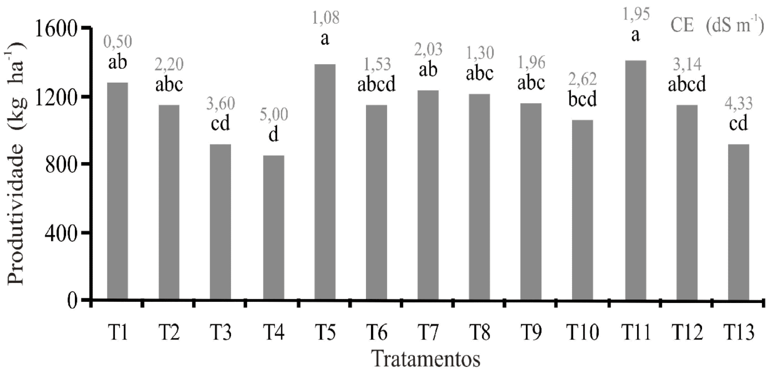
2). Os resultados também indicam que se a água de boa qualidade está disponível, irrigam-se as culturas nos estádios iniciais (germinação e estabelecimento da plântula) com esta água, quando as culturas são mais sensíveis à salinidade, e usa-se a água de qualidade inferior para as irrigações posteriores, quando as culturas se tornam mais tolerantes à salinidade.

Tabela 2 Efeito do uso cíclico de água salina e água do canal na produtividade de grãos de trigo, milheto e sorgo

Modo cíclico	Trigo	Milheto	Sorgo
		(t ha^{-1})	
4 x Água do canal	6,1	3,3	43,3
Água do canal : Água salina (Alternada)	5,8	3,2	39,8
Água salina : Água do canal (Alternada)	5,6	3,2	39,5
2 x Água do canal + 2 x água salina	5,7	3,2	40,2
2 x Água salina + 2 x água do canal	5,4	--	39,5
1 x Água do canal + 3 x água salina	5,1	3,1	37,8
4 x Água salina	4,5	2,8	34,1

Fonte: Central Soil Salinity Research Institute (2004)

Um estudo realizado com a cultura do feijão-de-corda demonstrou que a aplicação de água com até 2,2 dS m^{-1}, mesmo de forma contínua (T2), teve pequena influência na produtividade do feijão-de-corda (Figura 1). Porém, as águas com maiores



T1-Água de baixa salinidade (A1), durante todo o ciclo (Controle); T2-Água com CE de 2,2 dS m^{-1} (A2), durante todo o ciclo; T3-Água com CE de 3,6 dS m^{-1} (A3), durante todo o ciclo; T4-Água com CE de 5,0 dS m^{-1} (A4), durante todo o ciclo; T5-Água com CE de 2,2 dS m^{-1} na fase final do ciclo (floração e frutificação);T6-Água com CE de 3,6 dS m^{-1}, na fase final do ciclo (floração e frutificação); T7-Água com CE de 5,0 dS m^{-1}, na fase final do ciclo (floração e frutificação);T8-Uso cíclico de A1 e A2 (6 irrigações com A1 seguidas de 6 irrigações com A2), iniciando com A1 no plantio;T9-Uso cíclico de A1 e A3 (6 irrigações com A1 seguidas de 6 irrigações com A3), iniciando com A1 no plantio; T10-Uso cíclico de A1 e A4 (6 irrigações com A1 seguidas de 6 irrigações com A4), iniciando com A1 no plantio; T11-Uso de água com CE de 2,2 dS m^{-1}, aplicada 11 dias após o plantio (DAP) até o final do ciclo;T12-Uso de água com CE de 3,6 dS m^{-1}, aplicada 11 dias após o plantio (DAP) até o final do ciclo; T13-Uso de água com CE de 5,0 dS m^{-1}, aplicada 11 dias após o plantio (DAP) até o final do ciclo.

Figura 1 Produtividade relativa de plantas de feijão-de-corda irrigadas com água salina em experimento de campo na Fazenda Experimental Vale do Curu, Pentecoste-CE salinidades resultaram em queda de rendimento, principalmente quando aplicadas continuamente (T3 e T4). Em relação ao controle, a aplicação de água com 5,0 dS m^{-1} desde o plantio (T4) e após a germinação (T13) resultou em reduções de 34 e 28% na produtividade, respectivamente. A mesma fonte de água utilizada no estádio de maior tolerância (T7) ou de forma cíclica (T10) resultou em reduções da ordem de 3 e 17%, respectivamente (Neves, 2012).

O estresse pode se manifestar em vários graus de severidade, com duração variável, de modo contínuo ou alternado. Em relação às plantas, a intensidade do estresse vai depender do órgão ou do tecido alvo, do estádio de desenvolvimento da planta e do genótipo em questão. As respostas de muitas espécies vegetais em relação à salinidade pode variar de acordo com o seu estádio de desenvolvimento (Maas & Hoffman, 1977). No entanto, as informações sobre os estádios mais sensíveis e mais tolerantes são desconhecidas para a maioria das culturas, principalmente em condições de campo (Shannon & Grieve, 1999). Para Morales-Garcia et al. (2011), o manejo apropriado da água e práticas culturais adequadas, podem reduzir a salinidade do solo e manter a produtividade das culturas. O uso de água salina e não salina pode ser uma abordagem para o manejo da água em muitas áreas ao redor do mundo. Neste contexto, os autores sugerem que a água salina seja usada somente durante o estádio mais tolerante de muitas culturas.

A sensibilidade das culturas é maior nos estádios iniciais de crescimento, sendo que a tolerância torna-se maior durante as fases de floração e frutificação (Fageria et al., 2010). Resultados de experimentos conduzidos em casa de vegetação mostram que o sorgo, o trigo e o feijão-de-corda são mais sensíveis durante o estádio de crescimento vegetativo e no início da fase reprodutiva, menos sensíveis no estádio de floração e insensíveis durante o enchimento de grãos (Shalhevet et al., 1995). Outros trabalhos têm mostrado que os efeitos da salinidade sobre a produção de trigo e de algodão podem ser sensivelmente reduzidos, quando a irrigação com águas salinas é iniciada após o estabelecimento da plântula (Murtaza et al., 2006; Chauhan & Singh, 2008). Desse modo, é possível irrigar muitas culturas anuais com água salina durante os estádios menos sensíveis e usar água de baixa salinidade no estádio de maior sensibilidade, ou seja, na fase inicial e no período de crescimento vegetativo.

Diversos trabalhos têm mostrado que a tolerância à salinidade em plantas de melão varia de acordo com o estádio de desenvolvimento (Botía et al., 2005; Porto Filho et al., 2006), sendo que a aplicação de águas salinas na fase de frutificação pode melhorar a qualidade dos frutos (Botía et al., 2005). Os resultados obtidos por esses últimos autores demonstraram que a aplicação de água salina durante a frutificação não afeta a produção comercial da cultura, sendo observadas melhorias na qualidade dos frutos com incremento no teor de sólidos solúveis totais. De acordo com Rhoades et al. (2000) a produção de algodão não é afetada quando se irriga com água salina (6.000 mg L^{-1} de sais dissolvidos) nas fases do ciclo da planta que sejam tolerantes à salinidade e, com água de melhor qualidade (300 mg L^{-1} de sais dissolvidos), nas fases susceptíveis, principalmente as fases de germinação e estabelecimento da cultura. Ainda, segundo esses autores, a rotação de culturas com diferentes graus de tolerâncias e o manejo de águas de diferentes qualidades pode permitir o cultivo por vários anos sem prejuízos ao solo e às produções.

Estudo com feijão-de-corda demonstrou que a aplicação de água salina durante todo o ciclo em plantas de feijão-de-corda, cultivar EPACE 10, durante a germinação e estádio inicial de seu crescimento provocou redução na produtividade, enquanto que aplicação de água salina na fase de frutificação resultou em maior economia de água de baixa salinidade, sem afetar a produtividade e a eficiência de utilização de água (Neves et al., 2008; Lacerda et al., 2009). Na Tabela 3 verifica-se que a contribuição da água salina para a lâmina total de irrigação variou de 0 a 92,1% nos diferentes tratamentos. As plantas que foram continuamente irrigadas com água salina após a germinação (tratamento T2) receberam 92,1% de água salina, enquanto os tratamentos T1, T3, T4 e T5 receberam 0; 26,7; 33,9 e 39,4% de água salina, respectivamente. A aplicação de água salina nas fases de intenso crescimento (T4) e na fase reprodutiva (T5) permitiu maior economia de água de boa qualidade, sem causar impacto negativo na produtividade de grãos pela cultura. Isso demonstra a eficiência dessa estratégia de uso de águas de diferentes qualidades, levando em conta a tolerância de cada estádio de desenvolvimento da cultura (Murtaza et al., 2006).

Morais et al. (2011), trabalhando com a influência da irrigação com água salina nos diferentes estádios de desenvolvimento do girassol em condições de campo, ao avaliar o crescimento e produção da cultura, encontraram que o crescimento não foi influenciado pela irrigação com água salina (CEa de 2,16 e 3,53 dS m^{-1}), independente

Tabela 3 Produtividade do feijão-de-corda irrigado com água salina em diferentes estádios de desenvolvimento ao longo do ciclo

Descrição dos tratamentos	Água do poço (mm)	Água salina (mm)	Produtividade (kg ha^{-1})
T1-Plantas irrigadas com água de poço (CE de 0,8 dS m^{-1}) durante todo o ciclo	326,3 (100)	0,0 (0,0)	1864,5 a*
T2-Água salina com CEa de 5,0 dS m^{-1}, com aplicação iniciada após a germinação e permanecendo até o final do ciclo	25,9 (7,9)	300,4 (92,1)	984,8 b
T3-Água salina com CEa de 5,0 dS m^{-1}, durante as fases de germinação e crescimento inicial	239,2 (73,3)	87,1 (26,7)	1241,4 b
T4-Água salina com CEa de 5,0 dS m^{-1}, aplicada na fase de intenso crescimento vegetativo até a pré-floração	215,8 (66,1)	110,5 (33,9)	1827,3 a
T5-Água do poço (CEa de 0,8 dS m^{-1}) durante as fases de floração e frutificação	197,6 (60,6)	128,7 (39,4)	1877,4 a

*Médias seguidas de mesma letra, na coluna, não diferem estatisticamente pelo teste de Tukey ($P \leq 0,05$). n = 5
Fonte: Lacerda et al. (2009; 2010)

da fase de desenvolvimento; também não foi observado diferença significativa para os componentes de produção, que não foram influenciados pela salinidade da água. Os resultados indicam que o girassol tolerou água de elevada salinidade na irrigação, sendo possível utilizar água com CE de até 3,53 dS m^{-1} durante todo ciclo, sem prejuízos ao crescimento das plantas e sem diminuição na produção.

7 CULTIVOS ADENSADOS

O adensamento de cultivos consiste na redução do espaçamento das plantas com vista à otimização da área cultivada, aumento da cobertura do solo e redução da competição com plantas daninhas, dentre outras características (Andrade et al., 2008; Carvalho & Guzzo, 2008). Dependendo do espaçamento de plantio é possível se observar interferências na utilização de luz, absorção de água e nutrientes ou até modificações fisiológicas em determinadas culturas (Deparis, 2006).

Em se tratando de plantas submetidas a estresse salino, o aumento da densidade de plantio é uma alternativa bastante interessante, haja vista, que essas plantas podem apresentar maiores taxas de fotossíntese líquida que plantas irrigadas com águas de baixa salinidade, devido ao tamanho reduzido de suas folhas proporcionar maior exposição destas a radiação em comparação às plantas não estressadas (Gomes et al., 2011).

Estudo desenvolvido por Assis Júnior et al. (2007) mostrou que a salinidade reduz mais o crescimento vegetativo do que a produção de feijão-de-corda, sendo que cada planta ocupa uma área menor do que as irrigadas com água de baixa salinidade. Como consequência, de acordo com Lacerda (2009), as plantas sob estresse salino apresentam taxas de fotossíntese maiores que as plantas irrigadas com água de boa qualidade. Isso ocorre devido ao menor sombreamento das plantas sob estresse salino, sugerindo que, nesta condição, seu cultivo pode ser realizado utilizando-se um menor espaçamento.

Em estudo com rotação das culturas feijão-de-corda e milho submetidas a irrigações com águas de baixa e alta salinidade e diferentes densidades de plantio, a fotossíntese das folhas apicais de ambas as culturas foi limitada apenas pelo estresse salino e somente as folhas basais sofreram influência do adensamento (Lacerda et al., 2011a). Nesse mesmo trabalho, os autores concluíram ser possível com o adensamento manter o índice de área foliar e a distribuição da radiação fotossinteticamente ativa com valores apropriados para o processo fotossintético, resultando em aumentos consideráveis na produtividade, eficiência do uso da água e eficiência do uso da radiação.

Mesmo em se tratando de espécies halófitas como a erva-sal, o adensamento pode ser vantajoso. Silva et al. (2009) testando diferentes espaçamentos verificaram que a arquitetura das plantas de erva-sal sofreram alterações em função das densidades de plantio, sendo o espaçamento 1 x 1 m o que proporcionou melhores características estruturais, sendo o mais indicado para obtenção de maior produção de biomassa.

Apesar das vantagens do aumento da densidade de plantio das culturas sob estresse salino é importante destacar que, o adensamento pode promover em determinados tipos de solo, o acúmulo de sais nas primeiras camadas do perfil, como resultado do movimento lateral da água (Lacerda et al., 2011b). No caso de sistemas de rotação cultural em que as precipitações não são suficientes para lixiviar os sais, o efeito residual da salinidade em áreas mais adensadas pode provocar redução no rendimento de plantas sensíveis a salinidade nas fases de germinação e início do crescimento, como no caso do milho (Gomes et al., 2011; Lacerda et al., 2011a).

8 DRENAGEM AGRÍCOLA E LIXIVIAÇÃO DOS SAIS

A drenagem agrícola é uma prática que, além de permitir a incorporação de áreas mal drenadas ao processo produtivo, evita que ocorram inundações, encharcamento e salinização de solos, propiciando a retirada do excesso de água no perfil do solo, criando condições de aeração que permitem o desenvolvimento adequado das culturas e a execução de operações mecanizadas, como preparo do solo e colheita. Quando de caráter superficial, tem a função de remover o excesso de água da superfície do solo, enquanto que a drenagem subterrânea visa a remoção do excesso de água do perfil do solo, com a finalidade de propiciar aos cultivos condições favoráveis de umidade, aeração, manejo agrícola e de prevenir a salinização ou remover o excesso de sais. Dessa forma a drenagem interna facilita a melhoria das condições físicas, químicas e biológicas do solo, criando condições favoráveis para o aumento e a melhoria da produtividade e da qualidade dos produtos. Portanto, a drenagem tem como objetivo possibilitar condições ambientais propícias ao desenvolvimento das plantas, além de preservar as propriedades físicas e químicas do solo (Batista et al., 2002, Lima et al., 2010).

A drenagem subterrânea tem por finalidade rebaixar o lençol freático através da remoção da água gravitacional localizada nos macroporos do solo, propiciando, em áreas agrícolas, melhores condições para o desenvolvimento das raízes das plantas cultivadas. Em regiões semiáridas e subúmidas evita o encharcamento e também a salinização de solos irrigados. De maneira geral, os projetos de irrigação e drenagem têm sido implantados sem que sejam feitos os estudos necessários da parte relativa à drenagem subterrânea dos solos, o que tem propiciado condições favoráveis ao encharcamento e salinização de grande parte das áreas irrigadas (Batista et al., 2002; Lima et al., 2010).

A drenagem superficial e a subterrânea são fatores chave para o sucesso do manejo da salinidade. O nivelamento da área é necessário em terras irrigadas para prevenir o acúmulo de água na superfície do solo, além disso, uma aração profunda e subsolagem são necessárias para aumentar a condutividade hidráulica do solo e para prover a infiltração e percolação da água de irrigação. Se a quantidade de sódio é alta, melhoradores, como o gesso, são recomendados para manter a estabilidade da estrutura e a taxa de infiltração do solo.

Em muitos casos, particularmente em solos de boa drenagem, o aparecimento do período chuvoso pode contribuir significativamente para a lixiviação dos sais e, consequente, redução da salinidade do solo. Por outro lado, em solos de pior drenagem pode-se realizar uma aração profunda ou uma subsolagem, que favorece a infiltração de água, diminuindo a salinidade na camada superficial do solo.

A água de drenagem pode ser reutilizada, fato que aumenta a eficiência de aproveitamento da água e reduz os impactos ambientais da agricultura irrigada. O manejo da água de drenagem salina inclui, de acordo com Rhoades et al. (2000), a interceptação dessa água para ser dessalinizada e reutilizada, uso de lagoas de evaporação, colocá-la em aquíferos profundos e isolados, ou utilizá-la de forma apropriada.

A irrigação deve ser usada de forma consciente, pois as condições de clima do Nordeste brasileiro, como altas temperaturas, baixa umidade do ar e baixa e irregular pluviosidade, e os sais presentes na água de irrigação têm causado problemas de salinidade nos solos (Dias et al., 2004; Andrade et al., 2010). Quando se utiliza águas salinas na irrigação, o uso de frações de lixiviação pode também contribuir para reduzir o acúmulo de sais no solo (Sharma & Rao, 1998; Ayers & Westcot, 1999). A fração de lixiviação consiste na lâmina de água que atravessa e percola a zona radicular da cultura. Assis Júnior et al. (2007) avaliaram o acúmulo de sais no perfil do solo em função da fração de lixiviação e da salinidade da água de irrigação. Os autores verificaram que nos tratamentos com frações de lixiviação de 0,14 e 0,28, ocorreu distribuição mais uniforme dos sais no perfil do solo, enquanto no tratamento sem fração de lixiviação, ocorreu maior acúmulo de sais e de sódio nas camadas superiores. Carvalho et al. (2012) com o objetivo de avaliar o desempenho da cultura do milho em relação à produção e biometria quando irrigado por gotejamento com água salina e sob diferentes frações de lixiviação em estação lisimétrica de drenagem, concluíram que as variáveis produção de grãos verdes, matéria seca e fresca da parte aérea apresentaram elevados valores quando se utilizou água de 3,3 dS m^{-1} com a fração de lixiviação de 10%.

9 APROVEITAMENTO DE ÁGUAS SALOBRAS EM CULTIVOS HIDROPÔNICOS

O cultivo hidropônico consiste na técnica de cultivo sem solo, na qual as plantas são cultivadas em solução nutritiva. A solução nutritiva é preparada com água e fertilizantes, devendo ter pH e concentração de nutrientes adequados para cada cultura. Dentre as vantagens da hidroponia, se tem as maiores eficiências na utilização de água e fertilizantes e o menor impacto ambiental (Santos et al., 2010; Cosme et al., 2011; Santos Júnior et al., 2011).

Estudos têm sido desenvolvidos no sentido de avaliar o potencial do aproveitamento de águas salobras de poços profundos e de rejeito de dessalinizadores em cultivos hidropônicos, visando a rentabilidade das culturas (Haber et al., 2005; Albornoz et al., 2007; Soares et al., 2007; Dias et al., 2011; Santos Júnior et al., 2011). Segundo Maciel et al. (2012) utilizando-se águas salinas em hidroponia, espera-se produzir culturas de interesse com maior economia de água e eficiência de insumos, menor risco ambiental e menor depleção do rendimento comercial. Além das hortaliças, principal produto hidropônico do Brasil, culturas de aptidão ornamental são particularmente interessantes, devido à sua alta rentabilidade, para justificar e viabilizar o empreendimento hidropônico com águas salobras.

Soares et al. (2007) concluíram que é possível utilizar águas salinas para produção de alface em hidroponia, podendo a tolerância aos sais ser superior àquela obtida em cultivos convencionais em solo. Santos et al. (2011) com o objetivo de avaliar o rendimento da cultura da alface cv. 'Elba' produzida em sistemas hidropônicos NFT e floating, quando submetida às diferentes águas do processo de dessalinização, verificaram que o sistema floating proporcionou melhor rendimento do que o NFT. De acordo com estes autores, a água salina do poço pode substituir a água doce na reposição da lâmina evapotranspirada, sem perdas no rendimento, o mesmo pode ser feito com o rejeito da dessalinização.

Gomes et al. (2011) trabalhando com o cultivo do tomate cereja em sistema hidropônico com rejeito da dessalinização, encontraram que a adição de 25% de rejeito de dessalinizador, com CE de 3,55 dS m^{-1}, à solução nutritiva permite o cultivo desta espécie, sem haver redução na produtividade. Maciel et al. (2012) estudando o uso de águas salinas sobre o rendimento e a inflorescência do girassol ornamental 'Sol Vermelho' em hidroponia NFT, concluíram que a salinidade da água, não prejudicou o tamanho da inflorescência e nem a qualidade comercial da haste.

10 ESTRATÉGIAS QUE FAVORECEM A ABSORÇÃO DE NUTRIENTES PELAS PLANTAS EM CONDIÇÕES SALINAS

Sob condições de salinidade, a disponibilidade e os processos de absorção e transporte de nutrientes se tornam bastante complexos, podendo afetar a nutrição mineral das culturas. Dentre os resultados mais prováveis do efeito da salinidade na nutrição mineral estão a redução no crescimento e as alterações na qualidade do produto vegetal. Nesse contexto, alguns estudos têm sido desenvolvidos visando o emprego de fontes alternativas que favoreçam a aquisição de nutrientes pelas plantas em condições de salinidade, como por exemplo, a aplicação de biofertilizante líquido (Cavalcante et al., 2010; Silva et al., 2011; Gomes et al., 2012) e a inoculação de fungos micorrízicos em raízes de plantas (Lúcio et al., 2012; Abdel-Fattah & Asrar, 2012).

Diversas pesquisas têm demonstrado que o uso de biofertilizante em ambientes salinos pode atenuar, parcialmente, os efeitos da salinidade sobre o crescimento das plantas. Estudo conduzido por Gomes et al. (2012), avaliando o efeito da água de alta e baixa salinidade no crescimento inicial do milho utilizando adubação com biofertilizante bovino, mostrou que quanto maior a concentração do biofertilizante, menor é o efeito degenerativo da água salina à cultura do milho. Em feijão-de-corda submetido à salinidade, Silva et al. (2011) verificaram que a aplicação de biofertilizante bovino melhorou o desempenho de todos os parâmetros analisados (crescimento e fotossíntese), em relação as plantas que não receberam o insumo.

Cavalcante et al. (2010) conduziram experimento para avaliar os efeitos da salinidade da água de irrigação e do esterco líquido bovino durante o período de formação de mudas de goiabeira Paluma. Os autores verificaram que a salinidade do solo foi marcadamente elevada com o aumento da salinidade da água de irrigação, refletindo em declínio no crescimento das plantas em altura, diâmetro caulinar, área foliar, crescimento de raízes e produção de biomassa pelas goiabeiras, mas sempre com menor intensidade nas plantas com esterco líquido bovino. As plantas sob irrigação com água salina e o insumo orgânico superaram as dos tratamentos sem o insumo em 86,9; 72,4; 11,0; 252,4; 351 e 39,7% o crescimento em altura, diâmetro do caule, comprimento de raízes, área foliar e biomassa das raízes e parte aérea, respectivamente. Portanto, o uso de biofertilizante pode ser uma alternativa viável para permitir o aumento da produtividade em condições de salinidade moderada, sendo necessários novos estudos que busquem aumentar a sua eficiência em condições de campo.

Estudos recentes indicam que a associação simbiótica de plantas com os fungos micorrízicos arbusculares (FMA) promovem maior tolerância das plantas aos vários tipos de estresses abióticos, dentre eles o salino. Lúcio et al. (2012) observaram que a associação simbiótica entre o FMA e as plantas de melão proporcionou aumento nos totais extraídos de N, P e K, e redução na absorção de íons potencialmente tóxicos como o Na^+ e o Cl^-. Esta associação também proporcionou um incremento no crescimento vegetativo e na taxa de fotossíntese, porém o efeito benéfico da micorriza decresceu com o aumento da salinidade. De acordo com Abdel-Fattah & Asrar (2012) plantas de trigo cultivadas em condições salinas micorrizadas absorvem menos Na e mais P, N e Mg.

11 OUTRAS ESTRATÉGIAS - SEMEADURA, MÉTODOS DE IRRIGAÇÃO, AGRICULTURA BIOSSALINA E USOS MÚLTIPLOS DE ÁGUA

Em muitos cultivos em solos salinos, as reduções na produção são maiores do que as previstas com base nos dados de tolerância. De acordo com Maas (1984) isto ocorre devido a maior sensibilidade à salinidade durante a fase de desenvolvimento da plântula, o que acarreta grandes reduções no estande de plantas. Uma alternativa para resolver tal problema seria usar uma quantidade de sementes acima da necessária para o plantio, uma prática aceitável em Israel (Ayers & Westcot, 1999).

Outra alternativa é a manutenção de baixos níveis de sais na zona de plantio, pelo menos nos estágios iniciais do crescimento da plântula. Assim, a escolha do método de irrigação parece de fundamental importância. No caso da irrigação por sulcos, os sais se acumulam no topo do sulco, assim, o semeio sendo realizado na rampa do mesmo favorece a formação de um bom estande de plantas. Por outro lado, a irrigação por gotejamento mantém um alto nível de umidade na zona radicular da planta, o que reduz os efeitos dos sais na germinação e estabelecimento da plântula, mantendo o potencial mátrico próximo de zero no ambiente radicular, o que reduz os efeitos osmóticos dos sais na planta.

Quando a irrigação é feita com água salina, os métodos de aplicação por gotejamento, sulcos, inundação e microaspersão apresentam melhores resultados do que a aspersão, visto que este método pode acarretar o acúmulo e toxidez de sais nas folhas. Além disto, na aspersão e na irrigação por sulcos observam-se ciclos de umedecimento e secagem o que resulta em maiores prejuízos à planta (Lacerda et al., 2010).

A agricultura biossalina se apresenta como uma opção para aproveitamento de águas marginais, a qual pressupõe a utilização de halófitas ou de glicófitas tolerantes, como o coqueiro (Ferreira Neto et. al., 2002; Marinho et al., 2006; Fernandes et al., 2010). Há uma grande variedade de plantas que são capazes de crescer em condições de solo e água salinos. Muitas dessas plantas podem ser utilizadas para alimentar o gado. Nos níveis mais baixos de salinidade (< 15 dS m^{-1}) as leguminosas e gramíneas, que são consideradas moderadamente tolerantes, são capazes de fornecer de 5 a 10 toneladas de matéria seca comestível por ano, particularmente quando a disponibilidade de água é elevada. Em altas concentrações salinas (> 25 dS m^{-1}), a produção e as opções de plantas diminuirá significativamente. No entanto, mesmo com estas altas salinidades há uma gama de halófitas que irão produzir entre 0,5 e 5 toneladas por ano de matéria seca. A proteína bruta e fibra digestível dessas plantas são variáveis, mas provavelmente não são diretamente influenciadas pelo nível de salinidade.

Importante, porém, a composição mineral das plantas pode ser significativamente alterada pela concentração e tipo de sais no solo e na água. Para plantas com tolerância moderada a salinidade, pode ocorrer o acúmulo de enxofre e selênio. Nas plantas halófitas, pode ocorrer o acúmulo de sódio, potássio, cloreto, cálcio e magnésio acima dos níveis máximos tolerados para o gado. Altas concentrações de cloreto de sódio, em particular, podem comprometer a saúde animal. É importante notar que estas plantas podem ser usadas de modo a proporcionar uma contribuição significativa para um sistema de alimentação de ruminantes. As perspectivas para o futuro são boas, porém, tem havido pouco esforço para melhorar o valor alimentar de plantas tolerantes ao sal através da reprodução ou seleção, ou para selecionar animais que são capazes de tolerar elevado teor de sais (Masters et al., 2007; Freire et al., 2010).

Torna-se necessário a procura de outras opções para a utilização de dejetos de águas de rejeito de dessalinizadores. Diante disso, uma solução seria explorar a piscicultura utilizando a água salobra proveniente diretamente do poço ou do rejeito (Soares et al., 2006). Segundo Dias et al. (2012) a EMBRAPA desenvolveu um sistema integrado de uso da água do rejeito de dessalinizador na criação de peixes (tilápia) e posteriormente o efluente dessa criação, enriquecido em matéria orgânica, é utilizado para irrigação da erva-sal (*Atriplex nummularia* L.). A erva-sal é posteriormente utilizada na produção de feno, que é utilizado para a engorda de caprinos e/ou ovinos na região. Desta forma, minimizam-se os impactos ambientais negativos e contribui para a segurança alimentar da localidade beneficiada.

12 CONSIDERAÇÕES FINAIS

No caso de regiões áridas e semiáridas, como é do caso da maior parte da Região Nordeste do Brasil, deve-se buscar o desenvolvimento de estratégias que permitam a utilização de águas de qualidade inferior para suprir a demanda hídrica de muitas comunidades e para uso na irrigação. Nesse sentido, as pesquisas devem ser focadas em problemas reais e seus resultados devem gerar tecnologias de uso permanente e não apenas em épocas de escassez. Em outras palavras, os habitantes do semiárido brasileiro devem estar preparados para conviver com a escassez de água, visto que esta é a realidade definida pelo clima regional.

Outro aspecto relevante é a conscientização das populações para o uso eficiente da água, conceito que deve envolver não apenas o uso criterioso do recurso hídrico disponível, mas também a possibilidade de reuso ou a multiplicidade de uso. Isso está diretamente associado à educação formal e ao desenvolvimento de uma consciência em prol da sustentabilidade social e ambiental do planeta onde habitamos.

No que diz respeito ao uso de águas salinas/salobras verifica-se que o sucesso no seu uso requer a seleção de culturas tolerantes ao sal, a escolha do sistema de irrigação adequado e aplicação de estratégias adequadas de manejo de irigação. Muitas dessas estratégias podem resultar em menor acumulação de sais no solo, contribuindo assim para reduzir os impactos do estresse salino no crescimento da planta, aumentar a disponibilidade de água para irrigação e aumentar a eficiência de utilização de água de boa qualidade. No entanto, é preciso uma nova abordagem nas pesquisas, devendo-se avaliar conjuntamente diferentes estratégias, que possam resultar no melhor aproveitamento da terra e dos recursos salinos (solo e água).

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7

Importância do Reuso de Esgoto Doméstico na Preservação dos Ecossistemas Agrários

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1 Situação dos recursos hídricos no mundo
2 Uma perspectiva dos recursos hídricos, do seneamento básico e do reuso agrícola de águas residuárias no Brasil
3 Uso das águas residuarias na irrigação (“pros e contras“)
4 Legislações e diretrizes para o reuso de esgoto na agricultura
5 Recomendações
6 Conclusões
Referências

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1 SITUAÇÃO DOS RECURSOS HÍDRICOS NO MUNDO

Uma das maiores preocupações atuais é a escassez de água, ultimamente a atenção da população mundial tem se voltado para o suprimento de água potável, a qual é um recurso natural finito, essencial à vida na Terra e está relacionada à grande parte das atividades humanas. Hoje, são cada vez mais constantes as discussões entre organizações, instituições acadêmicas e científicas e autoridades governamentais sobre a escassez iminente dos recursos hídricos em nosso planeta.

Segundo Hespanhol (2003), nas áreas urbanas a demanda em ritmo crescente vem sendo sistematicamente reprimida, não só pela redução da disponibilidade específica, esta pressionada pelo crescimento populacional e pela expansão industrial, como também pela degradação sistemática dos mananciais, ainda passíveis de serem utilizados para usos benéficos mais restritivos. O autor enfatiza a necessidade de programar mecanismos a nível nacional para estabelecer equilíbrio entre oferta e demanda de água, além da necessidade de se desenvolver uma cultura e uma política de conservação de água em todos os setores da sociedade. Segundo ele, o reuso consciente e planejado das águas de baixa qualidade, esgotos domésticos e esgotos industriais, por exemplo, constituem o mais moderno e eficaz instrumento de gestão para garantir a sustentabilidade da gestão dos recursos hídricos nacionais.

De maneira geral, existe uma quantidade abundante de água no mundo, mas que se encontra distribuída de forma desigual e devido à suas características físico-químicas nem todo o volume de água disponível pode ser utilizado sem algum tratamento prévio. Na Tabela 1 é possível observar a distribuição da água no mundo.

De toda a água doce superficial existente no planeta, o Brasil tem uma condição aparentemente confortável comparada a outros países, mas não pode ficar alheio a essa questão uma vez que os recursos hídricos no Brasil não estão distribuídos de forma homogênea. São muitas as regiões brasileiras que sentem os problemas de falta de água e convivem com frequentes conflitos por essa razão. Existem regiões onde a disponibilidade per capita diária de água excede o volume mínimo necessário, enquanto

Tabela 1 Distribuição da água no mundo

Tipo de água	Volume (km³ x 10³)	Fração do volume total (%)	Fração de água doce (%)
Oceanos	1338000	96,5	-
Água subterrânea doce	10530	0,76	30,1
Umidade do solo	16,5	0,001	0,05
Geleiras e coberturas de neve permanente	24064	1,74	68,7
Permafrosts	300	0,022	0,86
Água em lagos	176	0,013	-
Doce	91	0,007	0,26
Salgado	85,4	0,006	-
Água de pântanos	11,5	0,0008	0,03
Rios	2,12	0,0002	0,006
Água em seres vivos	1,12	0,0001	0,003
Água na atmosfera	12,9	0,001	0,04
Total de água doce	35029,2	2,53	100

Fonte: Adaptado de Shiklomanov & Rodda (2003)

que em outras não há quantidade suficiente de água para suprir as necessidades diárias da população.

De acordo com as últimas projeções feitas no The Economist (US) (2011), à população mundial chegará a 10 bilhões em 2085. Esse crescimento será advindo principalmente, dos países em desenvolvimento; na África, por exemplo, em 2010 a população era de 1 bilhão de habitantes e em 2100 espera-se que a população africana alcance um total de 3,6 bilhões. Esse fato é, portanto preocupante, pois como pode ser observado na Figura 1 diversos países no continente africano e no mundo já apresentam

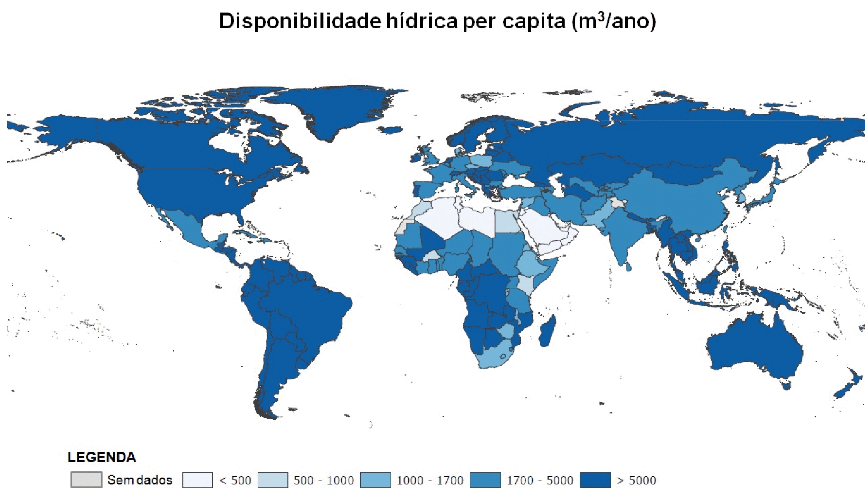


Figura 1 Disponibilidade global de água (Fonte: Adaptado de FAO - AQUASTAT)

baixa disponibilidade hídrica e quanto maior for a população maior será o impacto sobre os recursos hídricos, criando assim, conflitos pelo uso da água.

O Programa Internacional Hidrológico da UNESCO realizou um estudo (Shiklomanov, 1999) sobre o aumento contínuo do consumo de água em todos os continentes no século XX, como mostra a Figura 2. Nesse estudo é evidente o impacto do crescimento populacional sobre a demanda dos recursos hídricos, percebe-se, por exemplo, que na Ásia o acelerado acréscimo no contingente populacional causa aumento considerável no consumo desse bem, indo de pouco mais de 200 Km^3 para mais de 1400 Km^3 de água em 100 anos. A projeção para o ano de 2025 realizada nesse mesmo trabalho mostra que esse aumento populacional continuará ocorrendo, e consequentemente, a disponibilidade hídrica se agravará cada vez mais. Estes fatos mostram a importância de garantir às gerações futuras o acesso à água de boa qualidade e a necessidade de enveredar todos os esforços para a preservação dos recursos hídricos.

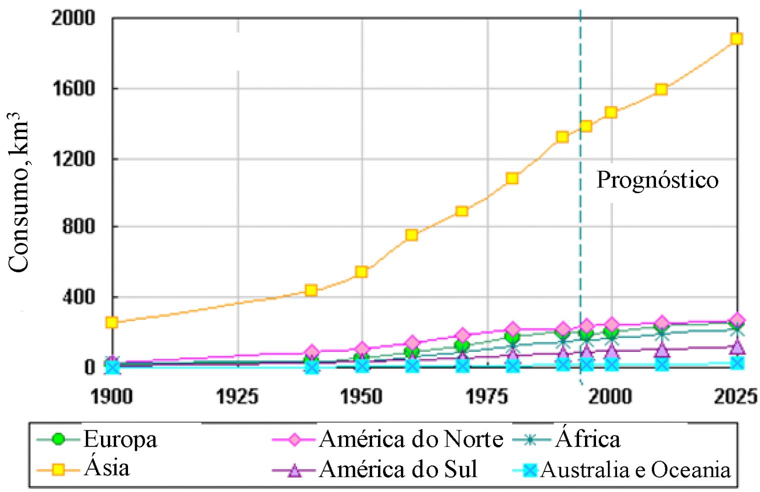


Figura 2 Prognóstico mundial do consumo de água (Fonte: Shiklomanov, 1999)

Os prognósticos de Shiklomanov (1999) mostram que o já então elevado consumo de água será ainda mais intenso nos próximos anos, principalmente para fins agrícolas. Nessas predições (Figura 3) o setor agrícola continua sendo o maior consumidor de água, e como esta é o componente essencial e estratégico ao desenvolvimento da agricultura, torna-se necessário implementar estratégias voltadas para o controle e a administração adequados e confiáveis desse bem que possibilitarão o manejo justo e equilibrado, preservando sua qualidade.

Esse aumento acelerado na demanda pelos recursos hídricos criará, inicialmente, o problema da escassez quantitativa do recurso, sendo que, concomitantemente, diminuirá a qualidade das águas pelo aumento da população

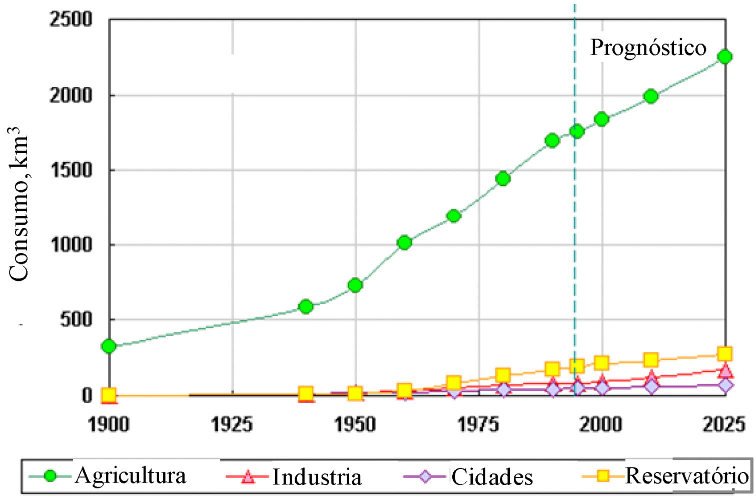


Figura 3 Prognóstico do consumo de água por atividade (Fonte: Shiklomanov, 1999)

e pela falta de capacidade em construir estações de tratamento de esgoto (ETE) que acompanhem o crescimento populacional. O crescimento populacional produz um incremento na industrialização, no uso de agrotóxicos na agricultura e no uso inadequado do solo e da água. As águas poluídas pelas atividades antropogênicas retornam com qualidade inferior aos corpos d'água de que foram retirados (Folegatti et al., 2010).

2 UMA PERSPECTIVA DOS RECURSOS HÍDRICOS, DO SANEAMENTO BÁSICO E DO REUSO AGRÍCOLA DE ÁGUAS RESIDUÁRIAS NO BRASIL

O Brasil é considerado um país privilegiado em recursos hídricos, segundo Tundisi e Scheuenstuhl (2012) cerca de 12% da água doce do planeta Terra está no Brasil, no entanto esse recurso se distribui de forma desigual em todo o território nacional. Portanto, mesmo nessa condição de privilégio a situação brasileira não é de tranquilidade, conflitos de qualidade, quantidade e déficit de oferta já são realidade. No Nordeste, por exemplo, a escassez é cada vez mais grave e a sobrevivência, a permanência da população e o desenvolvimento agrícola tornam-se prejudicado devido essencialmente à baixa oferta de água, sendo, portanto um bem limitado as necessidades humanas (Tucci et al., 2001).

Segundo a FAO-AQUASTAT, no mundo 70% das águas consumidas são dedicadas à agricultura, 19% à indústria, e 11% ao abastecimento da população, mostrando, portanto, que a agricultura é o maior consumidor de água no mundo. No Brasil, essas porcentagens são, respectivamente, 72, 7 e 10%. O consumo total de água no Brasil pode ser observada na Figura 4.

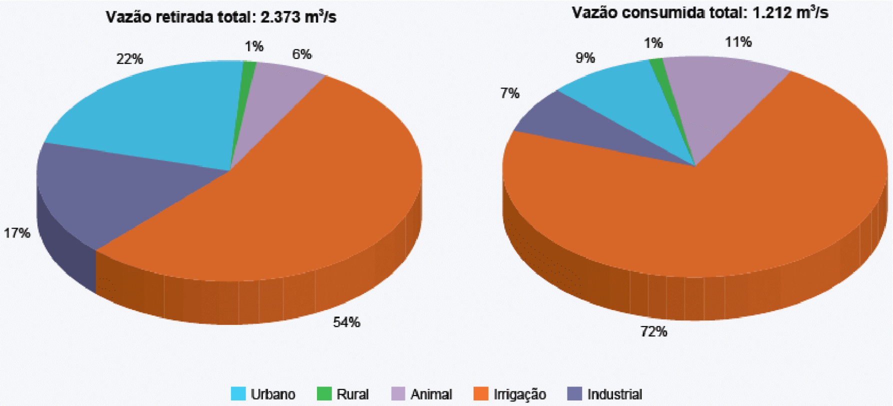


Figura 4 Demandas consuntivas no Brasil (Fonte: ANA, 2012)

Diante desse quadro a reutilização de águas residuárias na agricultura tem um papel importante no planejamento e na gestão dos recursos hídricos. Os principais benefícios dessa prática são a diminuição da demanda pela água de boa qualidade e diminuição da poluição dos nossos corpos de água (Asano et al., 2007).

Jiménez et al., (2010) afirmam que o uso de águas residuárias na agricultura irrigada ocorre de maneira predominantemente indireta, ou seja, através da utilização de águas poluídas e que esse fato não ocorre exclusivamente em países de baixa renda, mas também em países de renda crescente, como a China e o Brasil.

Essa afirmação pode ser confirmada através dos dados do relatório de conjuntura dos recursos hídricos da Agência Nacional de Águas (ANA, 2009) que mostram a falta de redes coletoras de esgotos no Brasil, o que indica a disposição final inadequada das águas residuárias e, consequentemente, a poluição das águas superficiais que são utilizadas na agricultura irrigada (Figura 5).

Esses dados também mostram que as redes de coleta estão disponíveis principalmente em locais com grande concentração populacional, nos quais, obviamente, há maior geração de esgoto. Porém, o mesmo relatório (ANA, 2009) evidencia que nem todo volume coletado é tratado, como observado na Figura 6.

Neste mesmo relatório constata-se que as relações entre produção e coleta e entre produção e tratamento de esgoto são muito baixas, indicando a poluição dos corpos d'água, já que grande parte do volume de efluente gerado não é coletado e/ou não recebe tratamento adequado antes de ser lançado no ambiente.

O lançamento descontrolado de águas residuárias sem tratamento no ambiente é uma realidade preocupante, pois ao analisarmos a extensão das áreas irrigadas no Brasil (Figura 7) é possível perceber que a região hidrográfica do Paraná tem a maior área irrigada do país, área essa que recebe anualmente um volume de 2.153 x 10^6 m^3 de esgoto sem tratamento, ou seja, o uso indireto de águas residuárias é uma realidade na agricultura nacional.

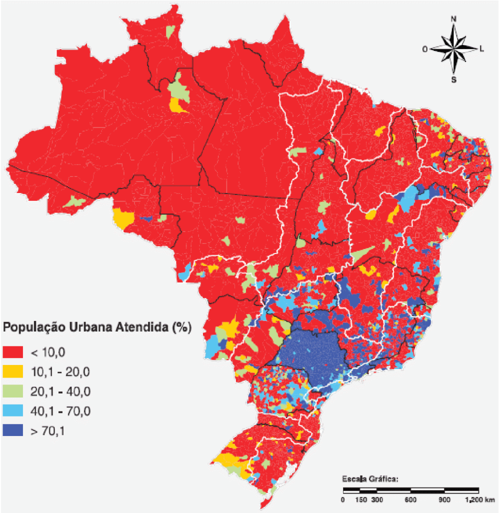


Figura 5 Atendimento urbano por rede coletora de esgoto (Fonte: ANA, 2009).

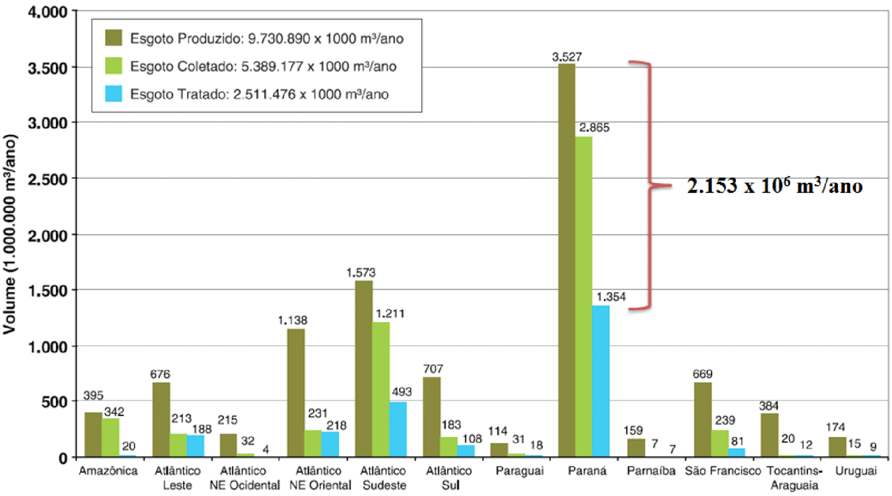
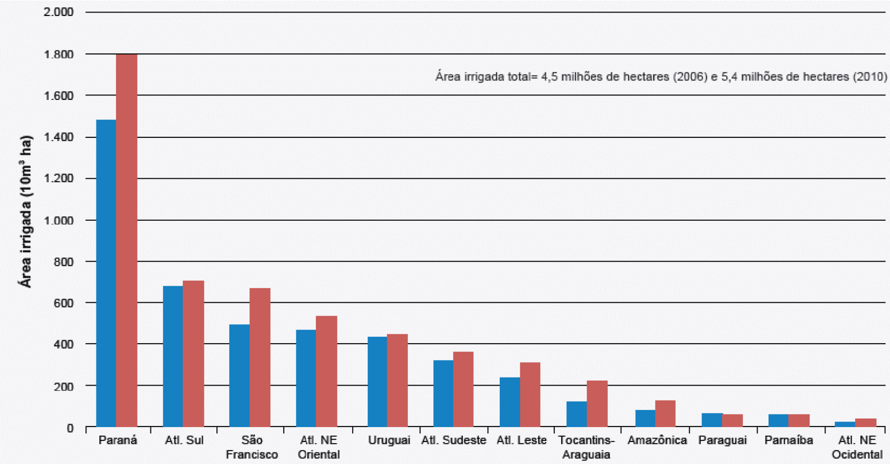


Figura 6 Volumes de esgoto tratado por Região Hidrográfica (Fonte: ANA, 2009)

Além disso, outro fato preocupante são os métodos de irrigação utilizados nessa região. Segundo Paulino et al. (2011) o uso de sistemas de irrigação por aspersão é predominante no Brasil, principalmente nas regiões Sudeste, Centro-Oeste e Nordeste (Figura 8). O uso de sistemas de aspersão na agricultura irrigada facilita o contato direto entre a cultura e os contaminantes que podem estar presentes nas águas poluídas com águas residuárias, assim representando um risco à saúde tanto dos produtores quanto dos consumidores.



	Paraná	Atl. Sul	São Francisco	Atl. NE Oriental	Uruguai	Atl. Sudeste	Atl. Leste	Tocantins-Araguaia	Amazônica	Paraguai	Parnaíba	Atl. NE Ocidental
2006	1.481.122	684.486	494.939	476.398	436.126	320.391	243.610	124.237	80.839	66.783	60.298	29.839
2010	1.811.583	714.112	674.186	539.531	451.854	359.083	304.831	230.197	127.320	72.577	63.736	36.931

Figura 7 Extensão das áreas irrigadas por Região Hidrográfica (Fonte: ANA, 2012)

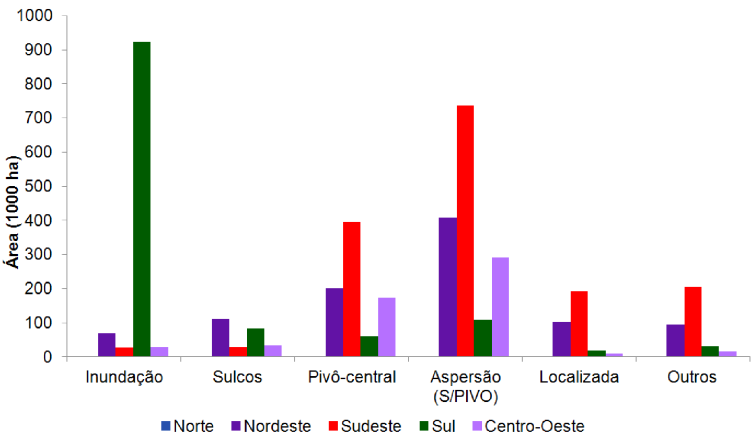


Figura 8 Distribuição dos sistemas de irrigação no Brasil (Paulino et al., 2011)

Mediante esses dados percebe-se que já é real a utilização das águas poluídas com esgotos na agricultura por meio da irrigação sem um adequado tratamento ou fiscalização.

3 USO DAS ÁGUAS RESIDUARIAS NA IRRIGAÇÃO ("PROS E CONTRAS")

Diante da necessidade de reduzir a poluição hídrica e reduzir o consumo, torna-se importante investir em pesquisas sobre tratamento e posterior reutilização das águas residuárias na agricultura. A prática do reuso dentro do setor agrícola mostra-se, portanto, como ferramenta do contínuo processo de desenvolvimento sustentável.

Um dos grandes desafios dos profissionais em gestão hídrica e ambiental é despertar a atenção dos agricultores quanto às vantagens de uma produção voltada à minimização de impactos ambientais, assim como a redução dos custos na produção com utilização das águas residuárias.

Dentre os setores que mais têm difundido o uso de águas residuárias, destaca-se o setor agrícola, o qual, quando utiliza esta prática de forma controlada, além de permitir a conservação dos corpos hídricos aporta consideráveis quantidades de nutrientes ao solo, refletindo-se em melhoria de sua fertilidade, tendo como consequência o incremento da produtividade das culturas e redução dos custos com adubação química.

De acordo com Machado (2005), a grande vantagem da utilização da água de reuso é a de preservar água potável exclusivamente para atendimento de necessidades que exigem a sua potabilidade, como para o abastecimento humano. Dentro dessa ótica, o reuso de água na agricultura é um instrumento adicional para a gestão dos recursos hídricos, visando ao controle da poluição de corpos d'água, disponibilização de água e fertilizantes para as culturas, reciclagem de nutrientes e aumento de produção agrícola.

Outro aspecto positivo da utilização das águas residuárias na agricultura é que elas estão disponíveis durante todo o ano, uma vez que não dependem das precipitações pluviométricas e das estações do ano. Esse aspecto permite o aumento das áreas irrigadas, a produção anual de alimentos e a irrigação em locais que sofrem com falta de água, principalmente regiões com climas árido e semiárido (Keraita et al., 2008) com uma vazão segura. Um estudo realizado na Jordânia por Carr et al. (2011) constata que os produtores reconhecem a disponibilidade contínua de águas residuárias urbanas, o que lhes permite a produção de alimentos durante todo ano, bem como os benefícios econômicos consequentes.

A composição destas águas é outro aspecto benéfico, pois as excreções humanas podem ser importante fonte de nutrientes para as plantas. A cada dia, o ser humano excreta, em média, cerca de 30g de carbono (90g de matéria orgânica), 10-12g de nitrogênio, 2g de fósforo e 3g de potássio (Drangert, 1998) e, assim, em um ano, gerará aproximadamente 500L de urina e 50L de fezes; correspondentes a 4,5kg de nitrogênio, 0,6kg de fósforo e 1,2kg de potássio; o que seria suficiente para produzir 250kg de cereais no ano. Em outras palavras, cada ser humano, poderia ajudar na adubação orgânica de sua própria alimentação (Strauss, 2001).

Outro aspecto importante é que a elevada concentração de nutrientes das águas residuárias permite que os produtores reduzam, ou até eliminem, a aplicação de fertilizantes comerciais em suas culturas. Também, a matéria orgânica presente nos efluentes pode alterar a estrutura do solo, aumentando a capacidade de retenção de água (Hespanhol 2008).

De acordo com Singh et al. (2012), os resultados práticos obtidos na Índia com a utilização de águas residuárias na agricultura confirmam que estas águas não só fornecem os nutrientes essenciais às culturas, como também aumentam a disponibilidade de nutrientes e de micronutrientes e a concentração de matéria orgânica no solo. Este estudo indica, portanto, que o uso de efluentes na agricultura aumenta a fertilidade dos solos. Estudos reportam que a economia no custo de produção pode atingir até 50% com o uso desta técnica. Outros fatores, porém, também merecem destaque, como: disponibilidade mais frequente de água, melhoria na qualidade dos solos e consequente aumento do rendimento dos cultivos, permitindo em alguns casos, a ampliação da fronteira agrícola. Entretanto, a falta de informações sobre a qualidade da água a ser utilizada na agricultura pode propiciar efeitos negativos nas propriedades físico-químicas do solo e no rendimento das culturas.

Em contraste, o excesso de nutrientes pode induzir ao crescimento vegetativo das culturas, à eutrofização de corpos d'água, ao crescimento das algas nos sistemas de irrigação e à contaminação das águas de subsuperfície (Qadir e Scott, 2010). Além do eventual excesso de nutrientes, outros componentes do esgoto podem causar impactos negativos às culturas, ao ambiente e à saúde humana. Sais, metais pesados, sólidos suspensos, compostos orgânicos, ácidos e bases podem causar salinização e poluição dos solos, danos aos sistemas de irrigação, crescimento vegetativo das culturas, alteração da mobilidade de metais no solo, poluição das águas subterrâneas, contaminação das culturas e danos à saúde dos consumidores (OMS, 2006).

O maior risco associado ao uso de esgoto na agricultura são os possíveis impactos à saúde pública devido à presença de patógenos nessas águas. As bactérias, vírus, protozoários e helmintos estão presentes nas águas residuárias e podem contaminar os solos e as culturas representando um risco à saúde tanto dos trabalhadores como a dos consumidores de alimentos produzidos nas áreas irrigadas com esgoto (Scheierling et al., 2010). Segundo a OMS (2006), os maiores riscos de contaminação por patógenos estão relacionados ao consumo de alimentos crus. Além disso, alguns desses microrganismos sobrevivem por longos períodos de tempo no solo e nas culturas, e também podem sobreviver após a colheita tanto ao transporte quanto a estocagem dos alimentos.

São muitas as vantagens e desvantagens que envolvem a questão do reuso, portanto, antes do uso indiscriminado de águas residuárias na agricultura irrigada é necessário adotar sistemas de desinfecção destas águas que garantam a proteção da saúde humana, da saúde animal e do meio ambiente.

4 LEGISLAÇÕES E DIRETRIZES PARA O REUSO DE ESGOTO NA AGRICULTURA

No Brasil, a legislação estabelece padrões de qualidade para águas tratadas destinadas ao consumo, para águas brutas destinadas a diversos usos (irrigação, proteção da fauna e flora, etc.) e para águas destinadas ao lazer.

Os padrões microbiológicos de potabilidade são definidos pela Portaria nº 2914 de 12/12/2011 do Ministério da Saúde. Está Portaria define que a cada 100 mL de água para consumo as concentrações de Coliformes Fecais e de *E. coli* devem ser iguais a zero.

Os padrões ambientais de qualidade para águas brutas e seus diferentes usos são definidos pela Resolução CONAMA nº 20 de 18/06/1986. Nesta resolução os padrões são definidos em função do uso da água. Padrões de balneabilidade são definidos pela Resolução CONAMA nº274 de 29/11/2000 e os padrões de lançamento de efluentes são definidos pela Resolução CONAMA nº357 de 17/03/2005 que foi alterada pelas resoluções 410/2009 e 430/2011.

Atualmente, os padrões microbiológicos para o uso de esgotos na agricultura não são definidos por nenhuma legislação específica no Brasil. A Portaria nº154 de 22/07/2002 da Superintendência Estadual do Meio Ambiente do Ceará (SEMACE) dispõe sobre padrões e condições para lançamento de efluentes líquidos gerados por fontes poluidoras. No artigo sexto desta Portaria são definidos os padrões de qualidade necessários para o reuso de esgotos domésticos na agricultura. Na Tabela 2 podem ser observados os valores determinados nesta Portaria.

Tabela 2 Padrões de qualidade definidos pela Portaria 154 da SEMACE

Irrigação	Coliformes fecais (NMP/100 mL)	Geohelmintos (ovos/L)	Condutividade elétrica (μS/cm)
Irrestrita (a)	<1000	<1	<3000
Restrita (b)	<5000	<1	<3000

(a) - Refere-se à irrigação de alimentos ingeridos crus
(b) - Refere-se à irrigação de alimentos que não são consumidos crus
Os limites para coliformes fecais devem ser determinados pela média geométrica de amostras coletadas durante 5 (cinco) semanas consecutivas
Os limites para geohelmintos devem ser determinados pela média aritmética de amostras coletadas durante 5 (cinco) semanas consecutivas

5 RECOMENDAÇÕES

Na ausência de normas e diretrizes para a regulamentação do reuso agrícola de águas residuárias podem ser adotadas as recomendações definidas pela Organização Mundial da Saúde. Segundo a OMS (2006), as concentrações de Coliformes Fecais em águas residuárias que serão utilizadas na irrigação irrestrita devem ser $\leq 10^3$ CF/100 mL e as concentrações de helmintos devem ser ≤ 1 ovo/L.

6 CONCLUSÕES

Mesmo existindo relatos de iniciativas sobre o reuso da água em algumas regiões, verifica-se que há carência de ações efetivas visando este assunto.

O papel da educação ambiental no processo de formação de capacidades na gestão dos recursos hídricos é primordial, pois só através dela é possível, romper a herança cultural de que a água é um recurso abundante e ilimitado.

As águas residuárias estão sendo utilizadas na irrigação no Brasil: é um fato, portanto, o reuso delas com uma fiscalização que garanta qualidade microbiológica apropriada para a produção agrícola sem risco para a população é necessária.

Faz-se necessário elaborar legislação adequada para as nossas condições, que seja fácil de aplicar, fiscalizar e que seja efetiva e eficiente.

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8

Conservation Agriculture: An Integrated Approach for Conserving Soil, Water & "Farmers' Savings"

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1 INTRODUCTION

Soil erosion is a major environmental threat to the sustainability of agriculture in the Mediterranean region as climate is characterized by a long dry summer followed by heavy bursts of erosive rain in autumn (Jones et al., 2003). Erosion of the topsoil significantly decreases soil organic matter and nutrients. The damage is highest when rain falls on clean fallow or recently sown crop land on steep slopes. Unfortunately, erosion has reached a stage of irreversibility in parts of the Mediterranean region while in others the situating is quite serious, e.g. soil losses in cultivated land in Southern Spain may reach 40 t ha^{-1} y^{-1} (Junta de Andalucía, 2003). Soil erosion is not uniquely linked to rainfed agriculture. The development of sprinkler and drip irrigation has resulted in an expansion of irrigated agriculture in sloping land and, therefore, increasing alarmingly the erosion risk is in irrigated systems.

Controlling soil erosion is not easy and requires new integrated management strategies under the so-called Conservation Agriculture (CA). CA aims at more sustainable agriculture and rural development through the application of three major principles: minimal or no soil disturbance, permanent soil cover (at least 30%) and crop rotations. Conservation agriculture has increased worldwide steadily since the 1990s to reach more than 111 million hectares in 2009 (Derpsch et al, 2010): 47% is practiced in South America, 38% in the United States and Canada, 12% in Australia and New Zealand and around 3% in the rest of the world including Europe, Asia and Africa. In the Mediterranean basin, CA has expanded in rainfed systems but it is practically inexistent in irrigated cereal-based systems (Gómez-Macpherson et al., 2009). This is surprising considering that water use efficiency is a general goal in Mediterranean countries due to insufficient water irrigation allocation for covering full crop requirements. Furthermore, the situation is worsening as irrigated land expands as well as the water demand for urban and industrial uses.

2 BENEFITS AND CONSTRAINTS OF CONSERVATION AGRICULTURE IN IRRIGATED SYSTEMS

A major problem for CA adoption in irrigated annual crop based systems is the excessive amounts of residues produced. Traditionally, residues are incorporated into the soil with tillage (sometimes burnt), however, the presence of crop residues on the soil surface is necessary for obtaining most agronomic benefits of CA. The seed drill has then to be adapted to cut the residues and sow the crop. This often represents an extra cost for the farmer. Also, soil temperature is lower under a layer of residues than without it because radiation does not reach directly the soil surface and cannot heat it (Licht & Kaisi, 2005). Lower temperatures slow down emergence and seedling growth of crops like maize (Griffith et al., 1977). This is particularly important for the maize and cotton crops sown in southern Europe because the cycle is tightly adjusted to the growing period and a late sowing is not desirable.

Part of the residues may be removed from the field before sowing. In northern Mexico, results from a long term experiment in a wheat-maize irrigated system, showed that removing the maize residues and leaving those of wheat had similar effect on soil properties and yield as full retention (Sayre et al., 2005). The amount that should be left will depend in the agroenvironmental characteristics of the system. If too much residues are removed, the CA system will worsen the physical and chemical soil properties (Sayre & Hobbs, 2004). Crop rotations, sowing date, soil fertility and irrigation management can also help to reduce the amount of residues produced by the system.

CA may lead to soil compaction (Bayhan et al., 2006), particularly with the use of heavy drills in the spring sowing or heavy cotton harvesters in autumn. Alternatively, occasional deep ripping or subsoiling may then be needed (Wild et al., 1992). The introduction of controlled traffic may result in a general improvement of soil characteristics (Unger & Musick, 1990). Controlled traffic implies that the tractor wheels are restricted to the same tracks in the field for all operations while the crop is cultivated in the zone within these tracks (Tullberg et al., 2007). The adoption of controlled traffic in CA can increase soil water content and crop yield (Li et al., 2007) and farm profit (Kingwell & Fuchsbichler, 2011).

The conversion from conventionally tilled systems to CA with residue retention affects positively some chemical, physical and biological soil properties. Long term use of CA improves soil nutrients availability by increasing soil organic matter (SOM) and associated nutrients (Verhulst et al., 2010) and by reducing the loss of soil nutrients in the runoff and sediment (Hansen et al., 2000). Additionally, the increase of SOM is assumed to stabilize aggregates, particularly in the upper layer surface (Martinez et al., 2008). This increase of stable macroaggregates and improvement of SOM usually results in higher water infiltration and lower water runoff and soil erosion (Franzluebbers, 2002; Zhang, et al., 2007). Additionally, residues protect the soil from water drops and slow down the rate of water flow across the surface, increasing the opportunity for water to infiltrate (Boulal et al., 2011a).

A field survey in Nebraska (US) has shown that no-tilled pivot irrigated maize-soybean fields had 20% lower applied irrigation but the highest yield (Grassini et al., 2011). The beneficial effects of CA, however, may not always result in higher yield. In irrigated Mediterranean conditions, results are variable and often no effect on yield is detected (Khaledian et al. 2004; Mygdakos et al. 2005; Lo Cascio 2008; Gürsoy et al. 2010; Boulal et al. 2012). On one hand, significant improvements may be observed only several years after the adoption (Sayre et al., 2005). On the other, adoption of CA is not immediate as there is not a single recipe that works for all systems. CA requires local adaptation in close collaboration with researchers, extension agents, farmers and local manufacturers. The first step is to modify local seeders and machinery, e.g. develop a drill that removes or cut residues at sowing, particularly if available CA machinery in the market is expensive. The fine-tuning or adaptation process is dynamic and new problems may arise when old ones are resolved.

3 IRRIGATED PERMANENT BED PLANTING SYSTEM AND CONTROLLED TRAFFIC

Permanent bed or ridge plantings systems (PB) are forms of irrigated conservation agriculture. In general, residues are left on the ground and soil disturbance is limited to reshaping furrows before sowing if necessary. Compared to conventional systems, the expected benefits in the field include water savings, reduced soil erosion and lower production costs (Hulugalle & Daniells, 2005; Ozpinar & Isik, 2004; Sayre & Hobbs, 2004), as well as increased production in fields that are frequently waterlogged (Hamilton et al., 2005). However, its success compared to conventional systems depends mainly on management of residues (Limon-Ortega et al., 2000; Limon-Ortega et al., 2002), crop rotation (Wightman et al., 2005), weed control (Sayre & Moreno-Ramos, 1997) and prevention of soil compaction (Li et al., 2007).

PB is promoted in irrigated regions with limited water resources, as it may save irrigation water with equal or higher crop yield compared to the conventional system, as shown in northwest India (Lumpkin and Sayre, 2009), Pakistan (Akbar et al., 2007) and northwest Mexico (Sayre & Hobbs, 2004). In Mexico, the system can fit two crops (wheat and maize) in a single season (Limon Ortega et al., 2000) as it requires no time for soil preparation and there is enough water to irrigate both crops. Similarly, in India, wheat cultivation is possible after cotton cropping the same year while costs are reduced when crops are direct sown (Jalota et al., 2008). No tillage is also possible for the rice-wheat rotation, rice being transplanted and sometimes partially submerged (Yadvinder Singh et al., 2009). PB is also being adopted in Uzbekistan and Kyrgyzstan to improve productivity of the cotton-wheat rotation

(Lamers et al., 2009). In the early 1990s, around 85% of Australian cotton growers had adopted some form of PB, although the area involved has now decreased after the introduction of compulsory postharvest tillage for heliothis (*Helicoverpa* spp.) control (Hulugalle & Scott, 2007).

In Southern Spain, a permanent bed system combined with controlled traffic has been developed successfully to deal with soil compaction and excessive residues produced by an irrigated maize-cotton rotation (Boulal & Gómez-Macpherson, 2010). Irrigation was applied from a central pivot but beds were formed to facilitate controlled traffic and to have residues in the furrows rather than on the beds where crops are sown. Applied irrigation was reduced by 17% since the introduction of the system, without yield loss (Gómez-Macpherson et al., 2009), but most important to the farmer, the costs were also reduced (Calleja, personnel communication). The economic benefits of no-tilled irrigated systems have been shown in other regions, in particular, reductions in operating costs (largely due to fuel and labor reductions) and reductions in machinery ownership costs in spite of higher N fertilizer requirements (Archer et al., 2008).

The system was studied in detail in a field experiment established at the Institute of Sustainable Agriculture (IAS-CSIC, Córdoba, Spain) for a maize / low-input cotton rotation (Boulal et al., 2012). PB and the conventional system, which includes tillage for soil preparation, incorporation of residues into the soil and beds formed each year (CB), were compared. Controlled traffic was followed in both systems and furrows with traffic (F+T) alternated with furrows without (F-T) leaving beds in the middle where 1-row crop was established (Figure 1). Compared to CB, the introduction of the PB system resulted in higher soil resistance to penetration in the first 30 cm but this difference did not result in a yield penalty in PB in years 2 and 3 after establishment (Table 1), even in year 6 (October 2012), the last cultivated season, there was no yield penalty in maize grown in PB compared to CB (Cid, 2013). PB did not result in an improved WUE but it did soil organic matter (SOM), already one year after the introduction of the system, and this difference was due to higher SOM in the 0-5 cm layer, particularly in the furrows (Figure 2). In PB, SOM (0-5cm) have continued increasing with each sampling and in year 5 it reached 2.9% in furrows and 1.9% in beds (Cid et al., 2013).

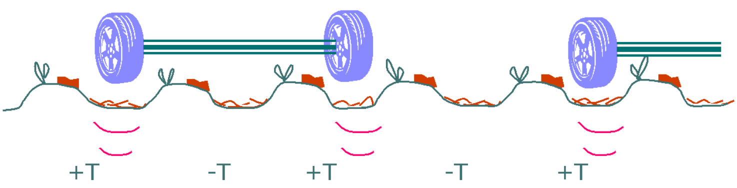

Figure 1 Scheme of furrows with traffic (+T) and without traffic (-T) in PB system. Controlled traffic was also followed in CB after bed formation

Table 1 Above-ground dry matter and yield (grain in the case of maize and lint/seed in the case of cotton), evapotranspiration and water use efficiency of maize crop in 2008 and cotton crop in 2009 (adapted from Boulal et al., 2012)

	AGDM	Yield	ET	WUE
	g m^{-2}		mm	G l^{-1}
Maize 2008				
PB	2698a	1358a	696a	1.94a
CB	2465a	1259a	689a	1.76a
Cotton 2009				
PB	597a	152a	656a	0.23a
CB	468b	123b	649a	0.19b

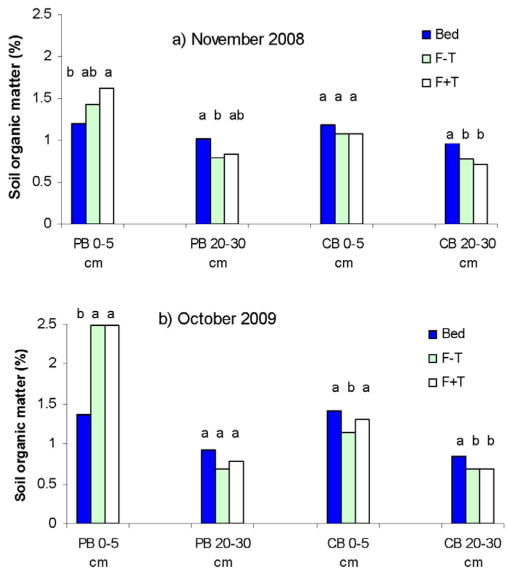

Figure 2 Soil organic matter (%) for 0-5 and 20-30 cm layers in bed and furrows positions in PB and CB two (November 2008) and three (October 2009) years after setting the experiment (adapted from Boulal et al., 2012)

The two systems were also compared in terms of water infiltration and soil erosion in two field scale tests with water application intensities 0.26 and 0.30 mm min^{-1} in Test 1 and Test 2, respectively (more details in Boulal et al., 2011a). Relative differences between treatments were similar in the two tests. In Field Test 1, cumulative infiltration increased more rapidly in furrows with no wheel traffic than with traffic and more rapidly in PB than in CB (Figure 3). Interestingly, wheel traffic resulted in similar infiltration in PB+T, after two years of traffic and leaving crop residues on the soil surface, and in CB+T, after only one year of operations but incorporating residues in the soil (158 and 149 mm, respectively). Additionally, for a given runoff rate, the sediment load was lower for PB than for CB (Figure 4) probably as a result of higher soil organic matter in the top soil and reduced soil erodibility and to the reduced unit stream power because of the presence of residues.

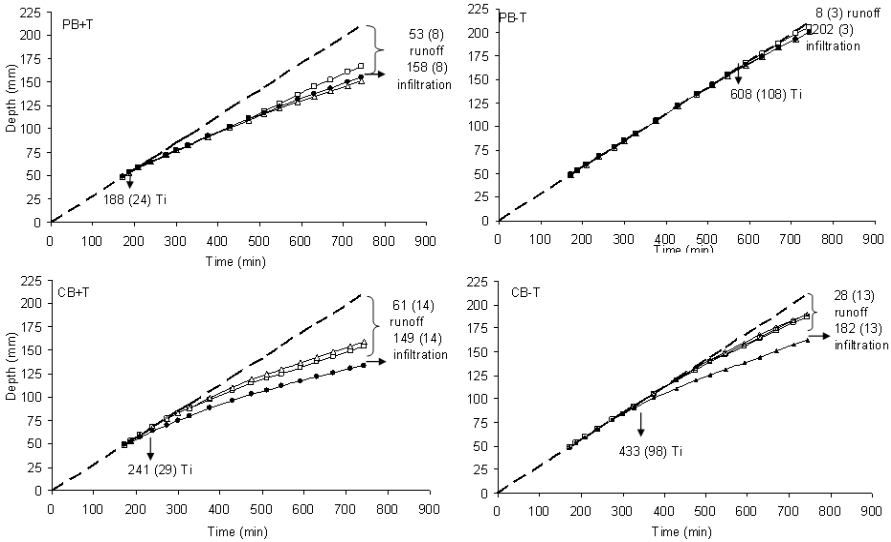

Figure 3 Cumulative infiltration with time during Test 1 (adapted from Boulal et al., 2011a)

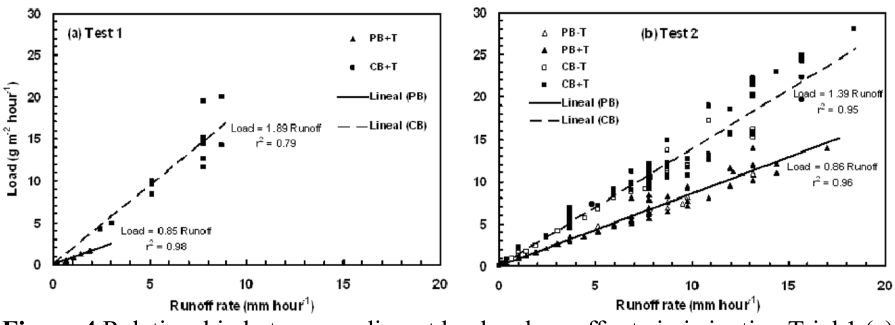

Figure 4 Relationship between sediment load and runoff rate in irrigation Trial 1 (a) and Trial 2 (b) in the permanent (PB) and conventional (CB) bed systems, with (+T) and without (−T) traffic, with separate linear regressions for PB and CB in each trial (+T and –T combined in each case) (Boulal et al., 2011b)

4 RECOMMENDATIONS

Residues production is high under irrigation and long term research is needed to establish the minimum residue retention needed, as well as the timing of residue removing, for improving soil fertility and for carbon sequestration. Long term experiments are also needed to continue the evaluation of PB and its derived effects in both, experimental stations and commercial farms. Research groups formed by all main actors, including private companies, should work together to develop sustainable, practical and economical options for farmers. For increasing adoption, these options should not be considered fixed recommendations but dynamic systems that may include sporadic tillage operations if needed (Carmona et al. unpublished).

5 ACKNOWLEDGEMENTS

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9

Dealing with Water Shortage in the Western United States: Can Engineers and Social Scientists Work Together to Promote Multi-Sector Water Sharing?

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1 Introduction
2 South platte river basin water sharing model
3 Convening of wastern U.S. water leaders to consider obstacles to multi-sector water sharing strategies
4 Conclusions
References

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1 INTRODUCTION

Increasingly, we must link the central task of providing irrigation services to the necessity of integrating the demands for water for agricultural production with the demands of other users, including urban and environmental. We must manage delivery systems and on-farm systems in in ways that incorporate informed decisions on the use and reuse of agricultural water. Not only must we consider technological aspects such as modernizing infrastructure and automating irrigation systems for better operation, we must also consider such aspects as institutional modalities; financial, legal and policy implications; and environmental issues.

The authors of this paper attempt to combine their engineering and social science experiences and perspectives to address many of these issues in one paper. To accomplish their intent, their paper consists of three distinct sections. First is a review of international perspectives on the need to better incorporate the social sciences with technological sciences and to meaningfully involve diverse stakeholders in order to optimize use of water to meet growing global needs. Second is a description of a water sharing model under development in the South Platte River Basin of Colorado in the western United States to show how engineers are attempting to incorporate social science considerations into their technological formula to achieve success. Third, they will discuss the 2010 convening of western U.S. water leaders from agricultural, urban and environmental sectors in an attempt to override polarized interests and remove obstacles to multi-sector water sharing.

2 SOUTH PLATTE RIVER BASIN WATER SHARING MODEL

Engineers and water scientists are working with economists, water attorneys, and social scientists to develop a model for water sharing in the South Platte River Basin of Colorado in the western United States (Figure 1), with the intent that the model can be used in other places where agriculture is under pressure to give up water for urban and environmental needs.

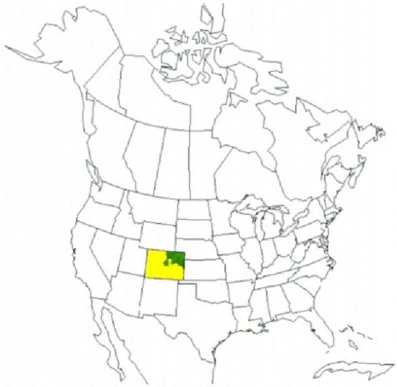

Figure 1 South Platte River Basin, Colorado, Western United States

A Colorado study researching water supply availability and needs for each of Colorado's river basins, projects that water supply in the South Platte Basin will be significantly short of demand by 2030.To meet a forecasted 65% population growth, an additional 400,000 acre feet of water will be needed. The prevalent presumption is that the additional 400,000 acre feet will likely come from transfers of water from irrigated agriculture to municipal and industrial uses.

This population growth and water demand dynamic is playing out throughout Colorado and elsewhere in the western United States in the form of municipal acquisition of whole farms - along with the water - through outright willing-seller, willing-buyer purchases. The transferrable portion of the water right is often 100% removed from the farm and the use of the water is most often changed to municipal use. The farm is dried up into perpetuity. This process of permanent dry up is often referred to as "buy and dry."

Concerned about the negative effects of buy and dry on agriculture, rural communities, and even the environment, the State of Colorado has funded research into alternatives to permanent transfer of water from agriculture. These methods allow farmers to share water to which they have rights in ways that prevent permanent sale of the water. Such methods include interruptible water supply agreements, rotational fallowing, water banking and reduced consumptive use through changed irrigation and farming practices.

Given western water law, transferrable water from agriculture is typically limited to the portion of the water a farmer's crop historically consumes via evapotranspiration, not the full amount the farmer has rights to divert. This portion used directly by the crop is referred to as "consumptiveuse" (CU) and does not include "return flows" - water diverted that must return to the system for use by others. For example, after diversion into an earthen canal, the diverted flow immediately begins to diminish because of conveyance losses, the most notable of which is seepage. Seepage can be quite significant especially over the full length of the canal and is likely the single highest source of loss in earthen canals. Most seepage returns to the river as subsurface flows. Farmers desiring to "conserve" water by reducing such seepage are typically not allowed to do so because that would affect supplies anticipated by downstream users. Most definitely, a farmer is not allowed to conserve that water and put it to additional use, for instance for expanding crop acreage. Farmers are not allowed to transfer such return flow water for use by others such as municipalities.

However, consumptive use water, that portion of the diverted water that is fully consumed by the crop, can theoretically be transferred for other uses, such as municipal or environmental. Once an estimated or a fully decreed consumptive use is known for a given water right, it opens up the potential to consider options for how the CU might be utilized or allocated differently in the future. The consumptive use could be allocated to a new use priority or some balance between old and new priorities. The consumptive use can now be viewed more rationally as an on-farm CU water budget with potential alternative uses. A new use of the CU might be to portion off some of this "set aside" CU to a municipal or environmental water user for suitable monetary consideration.

The model described here is being developed to assist farmers in evaluating alternative irrigation or cropping practices to determine if they would want to consider changed practices in the future in return for an additional revenue stream to maintain or improve profitability of the overall farm operation. One such changed practice is that of rotational fallowing, a situation whereby a farmer chooses to allow some segment of his or her farm to lay fallow for a period of time so that the consumptive use water formerly used becomes available for temporary transfer for some other use, such as municipal. Lease of the water from the fallowed ground can be thought of as an additional crop-water.

A successful run of the optimization model indicates the projected net return associated with the crops to be grown, along with crop yields, the practices to be adopted, and the anticipated unit prices. This modeled net return can then be contrasted with the historic net return from the farming operation. The model utilizes farmer-user inputs for the simulated farming operation to mathematically optimize future farming operations against a quantified or presumed consumptive use water budget for the farm. The farm simulation input is easy to use by simple point and click entry of boundaries over the top of aerial imagery to outline the farm itself and existing or proposed fields, then inputs such as planned "willing to grow" crops and practices are added. When finished, the farmer has a precise computer-generated map of the farm that becomes the basis for planning and running scenarios.

A future low-risk revenue stream may be brought into the farm's revenue forecast by virtue of the lease of a proportional amount of water to a municipal, industrial, or environmental user. Optimization algorithms are used to evaluate a farmer-considered package of changed practices which may include deficit irrigation, new crops, dry land crops, permanent or rotational fallowing of fields, and crop rotations. Some farmers will also consider upgraded irrigation systems as an aspect of implementing these practices. The farmer-driven optimization may include any or all of these changed practices as well as continued full irrigation of crops. To evaluate and compare multiple practices as a cohesive package and in the context of the option to lease water is new.

The simulation and optimization model output assists in comparing historic practices and net returns with future practices and net returns which would include a revenue stream associated with a lease or sale of a proportion of the farmer's CU water. The actual comparison between alternatives is accomplished by evaluating the change in net returns between historic practices and modeled future practices. The model utilizes crop water production functions, some of which are very newly researched and reported, to forecast crop yields based on changed irrigation practices.

The model allows a farmer to view his or her CU water differently than in the past. Namely, the CU can be viewed within a farm water budget and evaluated for future uses. Might the farmer wish to part off a portion of the CU, under contract, to a higher economic value driven by non-agricultural interests? The optimization of future net returns, based on adoption of a package of changed farming practices, allows for a comparative analysis. Multiple runs of the model can provide understanding of the potential and, in effect, a useful sensitivity analysis.

The model allows for iteration with new cropping and management regimes, where field-based water and crop data can be fed instantly into computers and stored in databases. Annual water supply forecasts can be coupled with cropping plans, all to help farmers decide how best to use their water and to allow cities and industrial users easy entry to a water market where farmers can sell the use of an acre-foot of water almost as easily as they can sell a bushel of corn.

Farmers operating under a senior surface irrigation right within a ditch system may wish to work together as a new cooperative group, or as a subset of shareholders, wishing to implement this technology. This affords a larger block of CU water, and a larger block will be more attractive to the leasing entity. The ditch company or the cooperative would become the managing entity. The resulting implemented system would include SCADA hardware, software, and instrumentation suitable to farm management objectives, ditch company management objectives, and State Engineer operational reporting requirements.

Some farmers will not consider using this technology because their operations are profitable and sustainable in today's agricultural economy. Others are farming in a marginal financial sense. An operational change using these technologies might help increase profits, allow for, or support irrigation system improvements, and otherwise help those farmers stay in business and continue providing significant regional economic benefits. The fact that new measuring systems – computer-controlled irrigation gates, networks of stream gauges, soil moisture sensors, and remote data gathering devices – have become affordable enough to allow farmers and irrigation companies to use them, greatly increases feasibility for farmers to utilize this model.

The Figure 2 shows the geographic information system (GIS) style field data entry screen. The farmer does not need to know GIS program or input features in order to input field data into the system. Data entry is facilitated by using intuitive point and click tools. Field boundaries can be input, color coded, named, and resultant acreage returned.

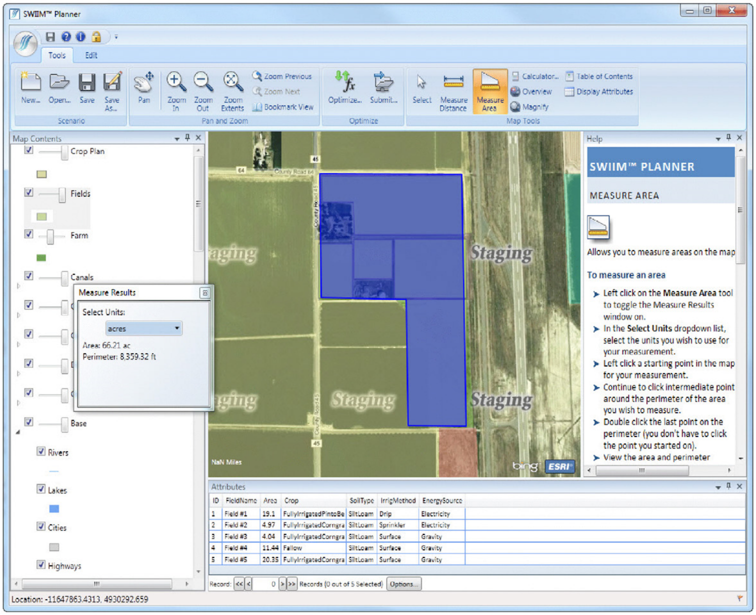

Figure 2 Geographic information system (GIS) style field data entry screen

The Figure 3 shows the reported results of the optimization run and indicates the projected net return given the farmer inputs.

Technology, however, isn't the only issue with re-allocating water to protect farms and streams. In Colorado and other western states, water laws make water marketing and leasing, as well as pure conservation, difficult. These laws also sharply limit the ability to move water from one use to another quickly. Both usually require expensive engi¬neering studies and years in special water courts, proving that the changes - from farm use to municipal or industrial use - aren't harming someone else's water rights.

It is critical, therefore, to combine precise measurement with in-depth, computerized record keeping, powerful databases, and easily accessible water models whose

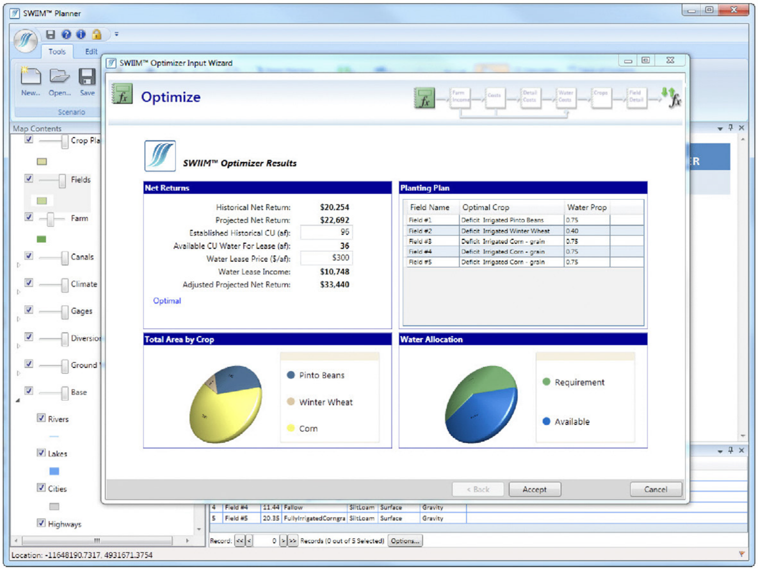

Figure 3 Reported results of the optimization run and indicates the projected net return given the farmer inputs

accuracy and data can be verified by regulators and those who want to buy or lease water. The model under development will minimize the amount of time farmers and cities must spend in court to transact sales and leases while creating an efficient system to manage these transactions in the long term.

Primary issues and pitfalls to implementing the process and strategies in this model are framed by questions like these:

- Can municipal interests view a long term lease as a viable part of their water portfolio and their projected safe yield at a future date?

- Can farmers accept the perceived dramatic changes to their farming operations?

- Can the science underpin the strategy sufficiently to satisfy change case objectors and the Colorado Water Court?

- Can water be physically transferred based on existing water diversion and delivery infrastructure or is new infrastructure required in some cases?

- Do existing State of Colorado statutes support the type of water transfer that is described?

3 CONVENING OF WESTERN U.S. WATER LEADERS TO CONSIDER OBSTACLES TO MULTI-SECTOR WATER SHARING STRATEGIES

In 2010, the Colorado Water Institute at Colorado State University convened representatives from The Nature Conservancy, Family Farm Alliance, Western Urban

Water Coalition and two dozen other influential groups to determine if long-held adversarial positions could be set aside and new alliances built in order to remove obstacles to creative water sharing strategies for mutual benefit. Their work resulted in a report, Agricultural/Urban/Environmental Water Sharing: Innovative Strategies for the Colorado River Basin and the West, which was recently presented to the Western States Water Council, the water policy arm of the Western Governors' Association.

The report was a response to a 2008 challenge by the Western governors: "States, working with interested stakeholders, should identify innovative ways to allow water transfers from agricultural to urban uses while avoiding or mitigating damages to agricultural economies and environmental values."

Strategies detailed in the report include:

- Farmers and cities in Arizona trading use of surface water and groundwater to the advantage of both;

- Ranchers in Oregon paid by environmentalists to forego a third cutting of hay to leave water in the stream for late summer fish flows;

- A ditch company in New Mexico willing to sell shares of water to New Mexico Audubon for bird habitat on the same terms offered to a farmer to grow green chiles;

- A California flood control and water supply project creatively managed to meet multiple goals of restoring groundwater, maintaining instream flows for wild salmon and steelhead, and providing water for cities and farms;

- Seven ditch companies cooperating in Colorado in a "Super Ditch" scheme to pool part of their water through rotational fallowing, for lease to cities, while maintaining agricultural ownership of the water rights.

"While these strategies sound like good common sense, they all face sizable obstacles," said Reagan Waskom, director of the Colorado Water Institute. If we want to share water for the benefit of all, we need a lot more flexibility, all members of the group agreed.

The group's recommendations to the Western Governors, developed to provide that flexibility, include:

- Design robust processes that give environmental, urban and agricultural stakeholders opportunities to plan together early on, instead of one-sided "decide, announce, defend" processes that frequently result in opposition and polarization.

- Foster a flexible, watershed based approach that can lead to cross-jurisdictional sharing of infrastructure, cooperatively timed water deliveries, and strategies to facilitate real-time, on-the-ground, state-of-the-art water management for optimal benefit of cities, farms, and the environment.

- Break down legal, institutional, and other obstacles to water-sharing strategies by developing criteria and thresholds that protect agriculture, the environment and any third parties to water sharing transactions. And experiment with creative approaches such as "water resource sharing zones" that could be set up for trading of water, financial resources, and even locally grown food while encouraging interaction between agricultural, environmental, and urban neighbors.

- Expedite the permitting process when programs or projects have broad support of agricultural, urban, and environmental sectors. A governor-championed federal/state pilot review process should be established where a state liaison and a federal designate are appointed to co-facilitate concurrent agency review and permitting without repetitive, costly information exchanges. Permitting is important to protect environmental, economic, and social values, the group agreed, but cumbersome permitting processes often lasting years need an overhaul.

Members of the group are promoting their recommendations and instigating dialogue throughout their constituencies.

4 CONCLUSIONS

Whether in the South Platte Basin of Colorado or elsewhere in the western United States, whether in Bolivia, Nepal, or Mexico City, water supply challenges are expected to increase. How scientists and engineers choose to tackle those challenges will determine whether water conflict is resolved or exacerbated. Technology is an important part of the solution, but drawing on the fields of economics, law, sociology, and other social sciences will be critical going forward. Engaging stakeholders in research and giving them a voice in the development of water policy will greatly increase the chances of success at solving very difficult water challenges. Whether humankind has the capacity to understand the necessity of setting aside personal gain for the benefit of all is yet to be seen, but our survival as a species may very well depend on it.

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10

Facts and Perspectives of Surface Irrigation in Brazil

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1 Introduction
2 Advantages of surface irrigation
3 Constraints in surface irrigation
4 Potentialities of surface irrigation in Brazil
5 Conclusions and recommendations
References

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10 Facts and Perspectives of Surface Irrigation in Brazil

1 INTRODUCTION

The irrigated area in Brazil is estimated in 4.55 million hectares, which represents 7% of the total cropped area and 15% of its irrigated potential. Surface irrigation systems are not widespread in the Brazilian irrigated lands, but still prevail in a high proportion of the irrigated areas around the world. In the United States, for example, they are prevalent in 40% of the irrigated acreage, estimated in 23 million hectares (Yonts, 2010). Only in the State of California, surface irrigation is present in more than 1.5 million hectares.

The Agricultural Census of 2007, revealed that the irrigated area in Nebraska reached 3.44 million hectares, being 72% by center pivot and 28% by furrows (963,000 ha). Corn crop prevail in 70% of the irrigated area while soybean represents 19%.

In many places in Brazil, the surface irrigated area in negligible; these systems are unknown by the majority of farmers and there is no endorsement that could increase its disclosure turning them more visible and revealing their potential. Figure 1 shows the representativeness of each irrigation system in Brazil published by IBGE (2006).

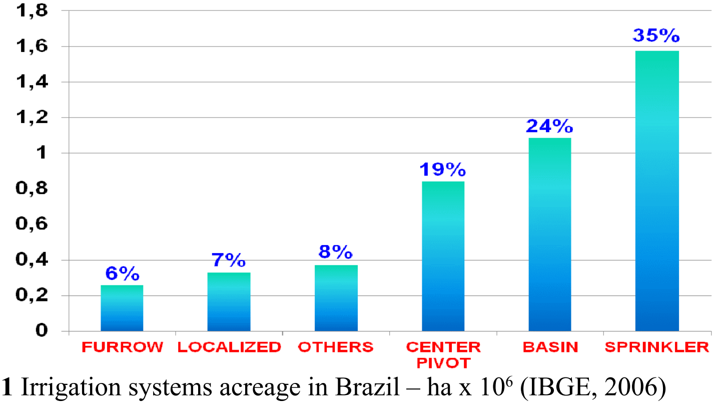

Figure 1 Irrigation systems acreage in Brazil – ha x 10^6 (IBGE, 2006)

In order to illustrate the importance of the surface irrigation systems in some distinguished agricultural areas, let us reproduce the findings of the survey "Irrigation Practices and Influencers Survey Findings" conducted by the Agricultural Water Management Council and California Farm Water Coalition, in San Joaquin Valley, February, 2010 (Figures 2, 3, and 4). The San Joaquin Valley contains seven of the top ten agricultural producing counties in the state with an agricultural production valued at more than US$ 25.3 billion annually.

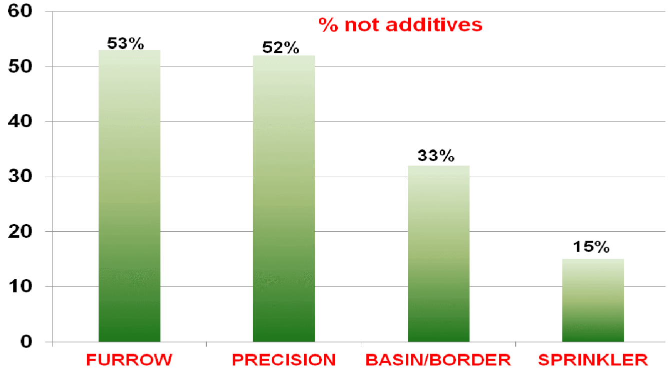

Figure 2 Annual crop irrigation methods in San Joaquin Valley

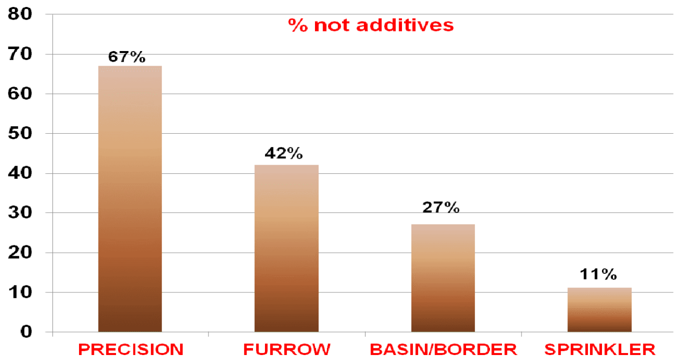

Figure 3 Permanent crop irrigation methods in San Joaquin Valley

Nine of the top 10 nation`s agricultural producing counties are in California. The USDA reported US$ 39 billion in gross receipts for California farm products in 2008, while farm related jobs totaled more than 1.4 million (USDA Economic Research Service).

2 ADVANTAGES OF SURFACE IRRIGATION

1) Smaller comparative cost. This represents the main argument to justify the high proportion of surface irrigation practiced in irrigated areas all over the world.

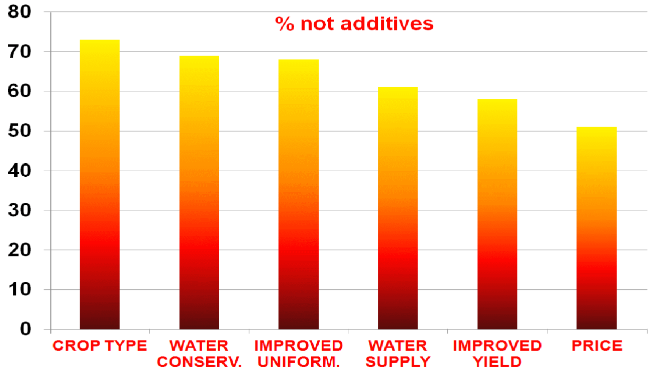

Figure 4 Irrigation system selection influencers in San Joaquin Valley

The equipment referred as “cablegation” originally developed by Kemper et al. (1981) has been successfully adapted to accomplish the requirement of “low cost irrigation”, reducing the investment cost to a figure as low as US$ 150/ha in furrows with 180 m of length. Longer furrows and successive displacement of the supply pipe in the irrigated area will reduce further the investment costs.

Besides that, the operational simplicity results in significant reduction of variable costs. Incidentally, Kemper et al. (1981) referred their development as “automatic furrow irrigation”. Even a kind of surge or pulse flow may be practiced by the system.

In an experimental field conditions, preliminary results adopting a reverse operation of this system are motivated. In this way, irrigation is started with the smallest flow rate and finish with the highest one. Therefore, the operation starts at the lower end of the supply pipe and follows toward its upper end. It is encouraging also increase the furrow length and therefore, eliminating runoff losses. In short, it is pretended to supply 1/3 of the furrow length with some acceptable percolation, 1/3 with an adequate water supply and 1/3 with an intentional water deficit, which is very convenient in supplemental irrigation (Figure 5). In case of a rainfall occurring soon after irrigation has been completed there will be enough room in the soil to store that free water which increases distribution uniformity. In this approach the water use efficiency (roughly the yield per unit of applied water) has been included as an index to evaluate the irrigation performance, in addition to the application efficiency and storage efficiency. Clearly,

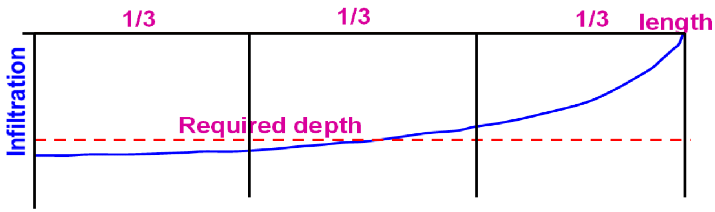

Figure 5 Infiltrated depths after furrow irrigation is completed

increasing the furrow length has been our main concern in designing this irrigation system because of its close relationship to cost. As a consequence, the irrigation process has been reduced basically to the advance phase, simplifying significantly any effort toward simulation modelling to help designers and operators.

Figure 6 Low cost furrow irrigation system in Brazil

Figure 7 Adapted cablegation using sewage pipeline in Brazil

Figure 8 Fishing rope and PET bottle to retain the flow in the sewage pipe

Figure 9 Small receiving box and the fishing rope attached to an adapted wire stretcher to displace the PET bottle inside the pipe

Figure 10 Low cost furrow irrigation in perennial and annual crops

2) Disregard pumping or reduces energy consumption. The pertinent equation to calculate energy consumption in irrigation is

$$E = \frac{VP}{\rho}$$

where E = energy consumption, kJ, V = volume of pumped water, m^3, P = pressure at the pump outlet, kPa, and ρ = global pumping yield, dimensionless and decimal.

To illustrate how much surface irrigation expend less energy than any pressurized irrigation system, let us assume that the required pressure in a pressurized irrigation system may reach 5 to 10 times that required in a surface system. By assuming a typical application efficiency of 80% for the pressurized system, one can realize that the application efficiency for the surface system to consume the same amount of energy should reach values between 16 and 8%, which are inacceptable for both technical and economical reasons.

3) Quantity and quality of water. Surface irrigation systems use mostly surface water, largely available in many places and, generally exhibiting lower costs than subterranean aquifers. With frequency, surface waters incorporate significant amounts of dissolved and suspended material, including contaminants that, eventually, may contribute to supply some of the nutritional requirements of the irrigated crops and also improving the physical-chemical characteristics of the soils.

4) Incorporate low cost fertigation. The fertigation equipment (Figure 11) may be integrated to the irrigation system at a negligible cost, applying common fertilizers, without the requirements of purity and solubility which make them cheaper and largely available elsewhere. Even suspended material may be advantageously applied, including fertilizers typically recommended for the organic agriculture.

Figure 11 Low cost fertigation in furrow irrigation

Both the dosage and the calibration of the equipment may be easily performed by the farmers, favouring a high frequency of fertigation, which results in higher distribution uniformity and lesser losses of fertilizers by leaching.

5) Independent of the high wind conditions that may prevail in many regions.

6) Allow to localize the water application to the row crops (or dense patterns) as observed in orchards, vineyards and coffee plantations.

7) No interference in the chemical treatments applied to the crop canopy.

8) Easily assimilated by the farmers. Simple operation summarized by only controlling the time of application to the irrigated plot. It allows farmers to practice their creativity and initiative.

3 CONSTRAINTS IN SURFACE IRRIGATION

1) Controlling the water application. While in pressurized systems the outflow discharge is very well predicted in each sprinkler or emitter that does not happen in surface systems.

2) Variable hydraulic parameters with successive irrigations, requiring operational changes, preferably, in real time.

3) Field topography should be preferably flat or softly waved to facilitate operation and reduces the risk of soil erosion.

4) Clay and deep soils are preferred allowing longer field lengths and lesser susceptibility to erosion.

5) Difficulties to be introduced by not involving commercial interest (John Merriam, 70's, 80's,...).

The awareness is restricted to government extension services and distinguished farmer cooperatives that have not been effective in Brazil.

Even in undergraduate, graduate and training levels of education, the concern of these systems has been limited, for unjustifiable reasons.

6) Undeserved reputation of low application efficiency.

Surface systems are not visually favourable to the universal concern to save water – a huge part of the applied volume remain temporarily on the soil surface, opposing, for example, to the trickle irrigation systems. However, 2000 L of applied water in furrows with 100 m^2 of replenished area seen to be excessive, even though this represent an average water depth of only 20 mm, which usually is much less than the required depth.

On the other hand, the Arizona Water Department adopt the level basin irrigation system as a standard to reach the goal of 85% of efficiency used to determine state water duties (Clemmens, 1998). Figure 12 reveals typical application efficiency for the major irrigation systems.

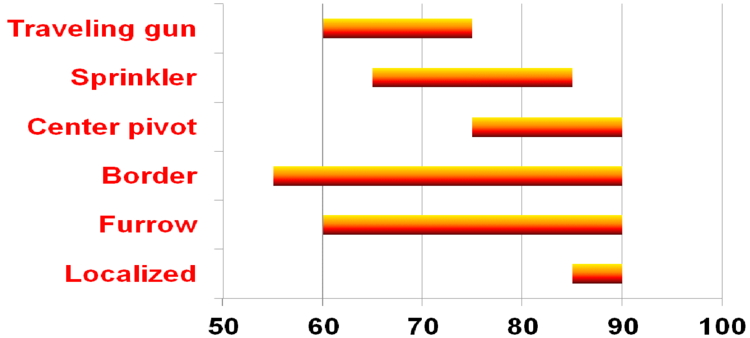

Figure 12 Attainable application efficiency (%) for the major irrigation systems (after Clemmens & Dedrick, 1994)

7) Technical unreliability when furrow systems practiced by unprepared farmers, with no technical advice, is compared to sophisticated irrigation systems designed by specialized irrigation establishments.

This attitude does not encourage the interest in surface irrigation, by ignoring its potential to improve the irrigation performance.

4 POTENTIALITIES OF SURFACE IRRIGATION IN BRAZIL

Potentialities of surface irrigation in Brazil are plenty, considering its successful performance revealed in many places in the world, by only observing the following points:

1) Stimulate effective extension practices, preferring small areas, with few investments, which coincide with the financial funding and expectations of the small farm agriculture.

2) Gradual land grading with small mechanized equipment. This practice results in a higher performance not only for irrigation but also for all mechanized practices developed in the cropped land. It should be light, compromising the agricultural potential of the soil, and being improved at each irrigation season. Grading should be concentrate first in the flow direction, tolerating some small slope variation between furrows. In Brazil, there are no manufacturers of specific mechanized equipments for land grading such as floating land planes.

3) Mechanization. The limited mechanization available for land grading can be extended to furrowing.

In an experimental scale we have been working in a joint seeding and furrowing operation that has to be adjusted for each set of conditions and needs improvements (Figure 13).

Figure 13 Experimental mechanized seeding and furrowing

4) Use representative equations of the infiltration process obtained under actual irrigation conditions integrating the entire furrow length (Scaloppi et al., 1995).

5) Consider the operation oriented by previous evaluations or in real time to overcome the variability of conditions determining the surface flow, as suggested, among others, by Turral (1996) and Khatri & Smith (2006).

6) In order to minimize runoff losses, it is recommended to build dikes, or to reduce the slope or to incorporate organic material to increase the infiltration rate at the lower end of the furrows.

7) Wherever applicable, the soil can be compacted by the tractor wheels on the furrows to reduce infiltration and percolation.

8) The every-other furrow irrigation criteria may be adopted to save water, notably in supplemental irrigation.

9) Consider to seed or transplant in the margins of the wetted perimeter of the furrows, mainly in salt affected soils. The possibility to increase the hydraulic roughness with plant growth can be fairly adjusted.

10) Suitable values of percolation and water deficits after irrigation is completed are fairly acceptable strategies.

11) The application of commercial polymers such as poliacrilamide to promote particle aggregation to reduce soil losses by arrest during irrigation may be applied wherever necessary.

12) Recognize as, probably, the major recommended system to dispose waste waters as domestic and rural effluents, animal dejects and sewage treatment plants.

13) Stimulate a greater involvement of researchers and technological development. A modest reallocation of personnel involved in irrigation scheduling would bring great advances to surface irrigation in Brazil.

14) Promote a larger involvement of educational initiative in undergraduate, graduate and training courses.

15) Stimulate the design, operation and management oriented by system simulation modelling that has been developed by many authors like Walker (1997), Clemmens et al. (1998) and Strelkoff et al. (1998).

5 CONCLUSIONS AND RECOMMENDATIONS

1) It is astonishing the discrepancy between the surface irrigation practiced in many parts of the world and that practiced in Brazil.

2) Since there is no commercial interest involved, the release should be made, necessarily, by competent extension offices, farmers associations or distinguished cooperatives.

3) Redesign the specialized training in all educational levels (undergraduate, graduate and training).

4) Install demonstration areas in strategic places and organize field trips in order to inform farmers about the system potential and encourage them to adopt it.

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11

Controladores de Irrigação Acionados Mecanicamente

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2 Controladores de irrigação
3 Controladores acionados mecanicamente
4 Princípio básico de funcionamento dos controladores acionados mecanicamente pela tensão de água no solo
5 Recomendações para uso dos controladores
6 Limitações operacionais dos controladores com uso de tensiômetros
7 Posicionamento do tensiômetro no solo
8 Tensão de acionamento
9 Conclusões
Referências

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1 INTRODUÇÃO

O manejo da irrigação utilizando controladores tem melhorado significativamente a eficiência de uso da água e a produtividade de culturas irrigadas (Munoz-Caperna et al., 2008). Entretanto, a maioria dos controladores de irrigação automatizados são supridos por energia elétrica (têm a energia elétrica como fonte de energia motriz) e, portanto, são inapropriados para uso em pequenas propriedades rurais onde não há disponibilidade de energia elétrica. Segundo Vaccaro et al. (2012) 40 % da população dos países em desenvolvimento não tem acesso a energia elétrica, e, portanto não tem como usufruir das vantagens do uso da automação dos sistemas de irrigação (SI). Adicionalmente, nos kits de irrigação (SI de baixa pressão para pequenas áreas hortícolas) a pressurização ocorre predominante por gravidade. Sendo assim, existe a necessidade latente de desenvolver tecnologias de controle para sistemas de irrigação pressurizados por gravidade sem requerimento de energia elétrica.

No mercado não há disponibilidade de controladores de irrigação com acionamento sem requerimento de energia elétrica, embora algumas propostas de controladores tenham sido desenvolvidas por alguns pesquisadores (Tal, 1975; Peterson; Glenn et al., 1993; Klein, 2001; Pinmanee et al., 2011). Uma prática usual nos países em desenvolvimento é utilizar tensiômetros para a construção de controladores de irrigação de baixo custo (Pinmanee et al., 2011). A estratégia comumente adotada é a utilização de leituras de tensiômetros para ligar o SI, tendo como objetivo a aplicação de uma lâmina fixa de água (utilizando tempo de irrigação ou volume de água como variável controle) toda vez que uma determinada tensão crítica da água no solo (ou ponto de reposição) é atingida (Dabach et al., 2011). Contudo, uma alternativa de aperfeiçoamento da estratégia de controle seria determinar o momento para desligar a irrigação por meio de leituras do mesmo tensiômetro (ou vários), quando atingir um baixo valor de tensão, o qual seria fixado previamente.

O desempenho de controladores de irrigação baseado no uso de sensores de umidade/tensão do solo é geralmente avaliado pela exatidão do controlador em acionar o SI nos valores de umidades estabelecidos (Miranda et al., 2005; Munhoz-Carpena et al., 2005). Entretanto, diversos fatores (incluindo tempo de resposta do sensor, profundidade de instalação, tensão da água no solo para acionar o SI, tipo de solo e taxa de aplicação da irrigação) influenciam a eficiência da irrigação (Coelho & Or, 1996; Ayars & Phene, 2007; Dabach et al., 2011). O objetivo deste capítulo é discutir: (1) a teoria básica da automação de sistemas de irrigação com controladores de acionamento mecânico; e, (2) os fatores que influem nas recomendações para uso dos controladores (baseados em informações de umidade de solo) em diversas condições de tipo de solo, taxa de aplicação da irrigação, tensões de acionamento e profundidade de instalação.

2 CONTROLADORES DE IRRIGAÇÃO

O manejo correto da irrigação visa à obtenção de alta eficiência de irrigação (com à obtenção do uso racional da água) e energia nos cultivos irrigados por meio da aplicação da quantidade de água demandada pela cultura no momento certo. Sendo que, para um manejo eficaz, é necessário monitorar o consumo hídrico da planta em todo seu ciclo vegetativo. Para que isso seja feito com alto grau de exatidão, exigi-se tempo e esforços consideráveis por parte do irrigante, uma vez que é um processo dinâmico de interação entre água-solo-planta-atmosfera, tornando difícil a decisão de quanto e quando irrigar. A automação da irrigação com a utilização de controladores torna mais funcional essa tomada de decisão e pode conferir melhorias na eficiência de uso da água (Evans, 2009), bem como redução da mão-de-obra.

Um controlador é um dispositivo que age sobre um processo, tendo como base, variáveis de entrada que influem na saída do processo controlado. No caso de SI as variáveis de entrada podem ser dados (em tempo real) de leituras de sensores que monitorem uma ou mais variáveis do sistema planta-solo-atmosfera ou históricos de dados climatológicos da região. O controlador toma a decisão em função dos critérios estabelecidos pelo irrigante e opera sobre os atuadores (válvulas, motores, bombas, switches). O tempo de irrigação é definido por um período fixo de tempo (controladores mais simplificados), por um período determinado pelo monitoramento da demanda da cultura ou por um período calculado por meio da lógica de controle inserida no controlador, tendo como base os parâmetros monitorados que indicam a demanda da cultura.

Independentemente da simplicidade do controlador, o desempenho do controle da irrigação é, predominantemente, dependente do método empregado para a determinação da demanda hídrica. Controladores de irrigação programados para acionar o SI com base no monitoramento da umidade de solo por sensores, localizados nas zonas de maior extração de água pelo sistema radicular da cultura, são muito utilizados. Esses instrumentos permitem aplicar a quantidade real de água necessária aos cultivos enquanto mantêm as altas produtividades das culturas irrigadas (Phene & Howel, 1984). A eficiência desse tipo de controle da irrigação é dependente da correta determinação dos parâmetros que influenciam no cálculo da lâmina de água a ser aplicada no solo (L_i, mm), definido por:

$$L_i = \int_{Z=0}^{Z_f} \left(\theta_f - \theta_i\right) dz \quad (1)$$

em que, Z_f é a profundidade do solo que se deseja umedecer até a capacidade de campo (mm); θ_f é o conteúdo de água na capacidade de campo ($cm^3\ cm^{-3}$); e θ_i é o conteúdo de água programado para iniciar o SI ($cm^3\ cm^{-3}$).

A determinação correta (precisão e exatidão) da curva de retenção de água do solo é essencial para que o cálculo da lâmina a ser aplicada represente a condição real de campo. Sua determinação, efetuada por meios de ensaios de laboratório, pode ser realizada utilizando equipamentos tais como a câmara de pressão e a centrífuga, sendo que esta última está sujeita a erros devido à influência do período de centrifugação (Silva & Azevedo, 2002). O número de pontos a ser observado (Silva et al., 2006) e o processo destrutivo de coleta das amostras são outras importantes fontes de erros.

A função da maioria dos sensores de solo é apenas fornecer um feedback dos parâmetros de controle para que o controlador tome a decisão do momento de ligar o SI, enquanto que a lâmina a ser aplicada dependerá das propriedades do solo, como curva de retenção, e da cultura a ser irrigada. O SI é acionado quando a umidade do solo atinge o valor crítico (θ_i) e é desligado após a aplicação do L_i. O tempo (duração) da irrigação é, por sua vez, definido pela lâmina que o SI deve aplicar. Diversos trabalhos foram desenvolvidos com essa estratégia utilizando sensores de medição do conteúdo de água (Nogueira et al., 2002; Bonquist et al., 2006; Munoz-Carpena et al., 2008) ou da tensão da água no solo (Augustin & Snyder, 1984; Munoz-Carpena et al., 2005; Hoppula & Sallo, 2007). Em sua maioria, os controladores operaram eficientemente na automação do SI nas mais variadas condições de clima e solo.

Na estratégia de manejo com turno de rega fixo e lâmina variável, o controlador é programado para acionar o SI em intervalos fixos (independentemente da umidade inicial, θ_i), e o sensor indica a umidade atual para o controlador calcular a lâmina de irrigação a ser aplicada, ou, indica o momento de desligar (detectores da frente de molhamento). A lâmina é definida pelo volume necessário para elevar a umidade do perfil do solo de interesse (Δz) até a capacidade de campo (θ_f). No controlador desenvolvido por Queiroz, Botrel e Frizzone (2008) a irrigação aplicada pelo sistema do tipo pivô central foi programada com turnos de rega fixos, sendo que, a lâmina foi calculada em função da umidade atual do solo (medida por tensiômetros). Zur et al. (1994) e Stirzaker & Hutchison (2005) desenvolveram controladores que utilizam o sinal da chegada da frente de molhamento a uma determinada profundidade (detectado por sensores inseridos no solo), para desligar o SI. O detector consiste de um recipiente em formato de funil, enterrado no solo. Com a chegada da frente de molhamento no funil, o fluxo passa de não saturado no topo do funil a saturado na base, ocasionando o aumento relativo da água livre que é eletronicamente detectada e, o SI é desligado.

Nos controladores que utilizam as informações dos sensores para definir tanto o momento de irrigar quanto a lâmina a ser aplicada, o SI é programado para ligar quando o conteúdo de água do solo atinge um valor crítico (θi) e para desligar quando o conteúdo de água em uma determinada profundidade é reposta à capacidade de campo (θf). Dukes & Scholberg (2005) utilizaram sensores TDR (a 23 cm de profundidade) acoplados aos controladores para ligar e desligar o SI de gotejamento superficial em conteúdo de água no solo de 10 e 14%, respectivamente, sob condição de solo arenoso, na Flórida.

O manejo da irrigação por controladores com sensores de parâmetros do solo não requer muitas informações para tomar as decisões de manejo da irrigação e estes são, geralmente, facilmente operados. Atualmente, vários controladores desse tipo estão disponíveis no mercado para automatizar os SI (Charlesworth, 2005), sendo que o manejo da irrigação baseado em controladores com sensores de tensão da água no solo têm a vantagem de serem aptos para uso em diversos tipos de solo, sem necessidade de calibração para cada tipo de solo (Mathew & Senthilvel, 2004; Ayars & Phene, 2007). Contudo, os controladores de irrigação disponíveis no mercado são acionados eletronicamente, existindo, portanto uma carência de controladores que possam ser utilizados em sistemas de irrigação pressurizados por gravidade, em lugares sem acesso a energia elétrica.

3 CONTROLADORES ACIONADOS MECANICAMENTE

Nos kits de irrigação (SI de baixa pressão para pequenas áreas hortícolas) a pressurização ocorre predominante por gravidade. Esses kits são muito empregados em regiões de baixo desenvolvimento tecnológico, onde não há disponibilidade de energia elétrica. Algumas propostas de controladores de irrigação com acionamento sem requerimento de energia elétrica têm sido desenvolvidas (Tal, 1975; Peterson et al., 1993; Klein, 2001; Pinmanee et al., 2011).

Tal (1975), Peterson et al. (1993) e Klein (2001) desenvolveram controladores de irrigação que utilizam a tensão gerada pela água no solo no interior de tensiômetros para ligar e desligar mecanicamente sistemas de irrigação. Sensores de pressão (diafragmas ou pistões) montados sobre tensiômetros controlam a abertura e fechamento e/ou fluxo de água em válvulas de irrigação, através de pinos atuadores. Os sensores de pressão se movem de acordo com a variação de pressão dentro do tensiômetro. No controlador desenvolvido por Tal (1975) e na proposta de controlador de Klein (2001) são utilizados sensores de pressão do tipo diafragma flexível. No

Figura 1 Sistemas de irrigação denominados kits de irrigação pressurizados por gravidade. Fontes: FAO e Zero hora (Websites)

controlador desenvolvido por Peterson et al. (1993), em vez do diafragma, dois pistões foram utilizados como dispositivos de controle. O primeiro pistão foi montado sobre o tensiômetro e entra em movimento de acordo com a variação de tensão dentro do tensiômetro. Enquanto que o segundo pistão possui a função de ajustar a abertura da válvula que controla o fluxo de água do SI. O controlador apresentou resultados satisfatórios no controle da irrigação de vasos com solo.

Pinmanee et al. (2011) desenvolveram um sistema de controle com acionamento mecânico da irrigação por gotejamento para a cultura da lichia. O controlador desenvolvido é composto das seguintes partes: tensiômetro, válvula de operação, alavanca, contrapeso, cilindro de controle (Fig. 2). Nos extremos da alavanca foi montado de um lado o contrapeso e do outro o cilindro de controle. O tensiômetro regula a entrada de água no cilindro de controle por meio da válvula de operação. O contrapeso mantém a válvula de irrigação fechada. Quando o solo seca e atingi a tensão de 45 kPa, a água da linha lateral enche o cilindro de controle e a alavanca abre a válvula da irrigação. Quando a tensão de água no solo reduz para 30 kPa, a água do cilindro é drenada, fechando a irrigação. O controlador manteve o solo na faixa de tensão desejada (entre 45 e 30 kPa) durante o período de avaliação.

Embora algumas propostas de controladores com acionamento mecânico tenham sido efetuadas por alguns pesquisadores, não há disponibilidade no mercado de controladores com esse tipo de acionamento, mesmo aquele desenvolvido por Pinmanee et al. (2011) que é relativamente simples de ser construído. Segundo os autores, materiais fáceis de serem encontrados em lojas de equipamentos hidráulicos

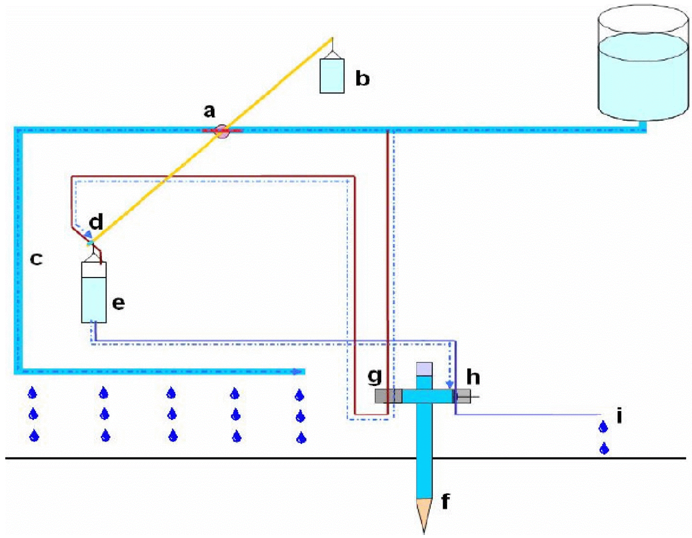
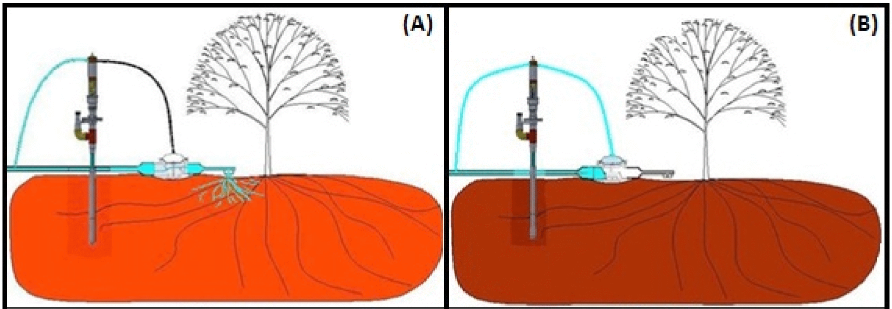


Figura 2 Controlador proposto por Pinmanee et al. (2011); a) válvula de operação, b) contrapeso, c) linha lateral, d) válvula de proteção, e) cilindro controle, f) tensiômetro, g) válvula de entrada, h) válvula de saída e i) descarga

foram utilizados para construir o controlador. Já os controladores desenvolvidos por Tal (1975), Peterson et al. (1993) e Klein (2001) requerem o uso de ferramentas e equipamentos mais sofisticados (tornos mecânicos) para serem construídos. Talvez o desinteresse das indústrias em desenvolver esse tipo de controlador seja sua limitação para áreas onde a pressurização é realizada por gravidade. Todavia é necessário fornecer alternativas tecnológicas de automação para SI em áreas sem disponibilidade de energia elétrica.

4 PRINCÍPIO BÁSICO DE FUNCIONAMENTO DOS CONTROLADORES ACIONADOS MECANICAMENTE PELA TENSÃO DE ÁGUA NO SOLO

Os controladores de irrigação acionados mecanicamente pela tensão da água no solo (Fig. 3), geralmente usam a variação de energia dentro do tensiômetro (instalado na zona radicular ativa da cultura) para acionar e desligar mecanicamente o SI, quando a tensão de água no solo atinge determinados limites. Almeida (2012) desenvolveu um controlador de acionamento mecânico, no qual a ação mecânica se dá por meio de válvula de três vias (válvula de atuação hidráulica), que, por sua vez, opera sobre válvulas de suprimento da irrigação (válvula hidráulica, VH). Com a redução da tensão da água do solo (Figura 3.a), parte da água do tensiômetro flui para o solo ocasionando uma tensão (ou vácuo parcial) na água dentro do tensiômetro atuando no diafragma localizado na parte superior do tensiômetro. Contrariamente, com o



Solo seco	Solo úmido
- Vácuo parcial dentro do tensiômetro - Diafragma tensionado - Válvula de 3 vias ativada (fechada) - Fluxo de água sobre a válvula de suprimento da irrigação bloqueado - Válvula de suprimento da irrigação aberta - Sistema de irrigação acionado	- Vácuo reduzido - Diafragma em repouso - Válvula de 3 vias em repouso (aberta) - Fluxo de água sobre a válvula de suprimento da irrigação - Válvula de suprimento da irrigação fechada - Sistema de irrigação desligado

Figura 3 Controlador de irrigação acionado mecanicamente pela tensão de água no solo sob condições de solo seco (A) e solo úmido (B) (Foto extraída da tese de doutorado de Almeida (2012))

aumento da tensão da água do solo (Figura 3.b), a água do solo flui para o dentro do tensiômetro e a tensão dentro do tensiômetro diminui.

Os componentes principais desse tipo de controlador de irrigação são: tensiômetro, diafragma, haste de ativação, mola de calibração e válvula de 3 vias (Figura 3). O diafragma atua convertendo a variação do potencial matricial (ou tensão) dentro do tensiômetro em energia mecânica para movimentar a haste de ativação, que aciona a válvula de 3 vias (de atuação hidráulica). A válvula de 3 vias, por sua vez, controla o acionamento da válvula de suprimento da irrigação. A tensão da água no solo, requerida para acionar o sistema de irrigação, é regulada por uma mola de compressão. A mola de calibração ajusta o controlador para acionar a irrigação a diferentes tensões de água no solo (quanto mais comprimida a mola, maior será a tensão de acionamento da irrigação).

Alguns protótipos de controlador de irrigação, com este tipo de acionamento, foram projetados e construídos na ESALQ/USP, tendo sido utilizadas conexões de PVC e outros componentes de PVC construídos em torno mecânico. Os protótipos foram avaliados em laboratório e em um experimento em campo para controle da irrigação de um pomar de fruteiras (Figura 4). Os resultados da avaliação em laboratório mostraram que o controlador foi capaz de controlar (ligar e desligar) a irrigação em várias tensões de acionamento.

No experimento de campo, que teve duração de dois meses, todas as amostras do protótipo de controlador de irrigação avaliadas foram capazes de ligar e desligar a

Figura 4 Experimento em campo para avaliação do controlador acionado mecanicamente no controle da irrigação de um pomar de fruteiras, com irrigação pressurizada por gravidade (Foto extraída da tese de doutorado de Almeida (2012))

irrigação nas linhas laterais da cultura. Porém foi observada uma variação na tensão de acionamento de irrigação entre as amostras testadas. Os controladores foram ajustados com uma calibração geral para acionar o sistema de irrigação quando a tensão da água no solo atingisse 20 kPa. Entretanto, apenas metade das amostras avaliadas acionou o SI em tensões de água no solo próximo de valor (20 ± 2 kPa). Uma alternativa para melhorar a precisão no acionamento seria a calibração individualizada de cada controlador.

5 RECOMENDAÇÕES PARA USO DOS CONTROLADORES

A recomendação de uso de controladores de irrigação com sistemas de acionamento mecânico no geral requerem que a linha lateral e/ou principal do SI esteja pressurizada. Portanto, são mais aplicados quando a pressurização se dá por gravidade. Já a recomendação de controladores de irrigação com base em informações de sensores de parâmetros do solo tem aplicação mais recomendada para áreas/talhões que não tenha alta variabilidade espacial das propriedades físicas do solo. Para utilização desses controladores em áreas com alta variabilidade espacial, é recomendada a divisão do talhão em área menores (zonas de manejo), em que as propriedades físicas do solo apresentem menor variabilidade, ou fazer o controle individual da irrigação de cada planta (inviável para a maioria das culturas).

A eficiência da irrigação manejada por meio de controladores baseados em informações de umidade de solo depende de vários fatores, sendo os principais: as limitações operacionais do controlador, posicionamento e profundidade de instalação do sensor no solo, propriedades físicas do solo (condutividade hidráulica e conteúdo inicial de água no solo) e SI utilizado (taxa de aplicação e percentual de área molhada). Como os controladores aqui discutidos utilizam tensiômetros como sensor da tensão de água no solo, as limitações operacionais do controlador discutidas serão direcionadas a esse tipo de sensor.

6 LIMITAÇÕES OPERACIONAIS DOS CONTROLADORES COM USO DE TENSIÔMETROS

O desempenho do tensiômetro depende do equilíbrio permanente entre a água dentro do equipamento e a solução do solo. Esse equilíbrio depende, sobretudo, do contato intenso entre a cápsula cerâmica do tensiômetro e o solo, que por sua vez, depende do tipo de solo e do valor de tensão de água no solo.

Em solos com alto percentual de areia e substratos altamente porosos esse equilíbrio é difícil de ser conseguido, devido ao contato insuficiente da cápsula cerâmica do equipamento com a matriz do solo. Com isso, maior vazão de água do tensiômetro é demandada para alcançar o equilíbrio e requer manutenções muito frequentes (Hansen & Pasian, 1999; Munoz-Carpena et al., 2005). Esse problema tende a se agravar em tensões elevadas acarretando frequentes entradas de ar no equipamento e crescimento orgânico na cápsula cerâmica. Quando a manutenção se torna altamente frequente o uso do equipamento se torna inviável. Munoz-Carpena et al. (2005) relataram economia de 50% na água aplicada em tratamentos que utilizaram tensiômetros para automação do manejo da irrigação na cultura do tomate quando comparado ao tratamento irrigado com 100% da evapotranspiração potencial. Porém, os autores ressaltaram que o requerimento de aproximadamente duas manutenções por semana para os solos arenosos da região da Florida inviabiliza o uso do tensiômetro como sensor de tensão para esses tipos de solos. No experimento conduzido por Almeida (2012) em solo do tipo argiloso, os controladores operaram continuamente ao longo do período de avaliação (64 dias) e não foram observados problemas de entrada de ar nos tensiômetros. Sendo que, nenhuma manutenção foi necessária e, também não foram verificadas presença de bolhas de ar nos tensiômetros durante todo o período. Estes resultados se devem também à manutenção da tensão da água no solo em valores menores que 35 kPa.

A faixa de tensão da água no solo na qual se pode utilizar o tensiômetro é de zero até aproximadamente 85 kPa (Richards & Gardner, 1936). Essa faixa parece pequena, visto que, teoricamente, o limite inferior da tensão em que a água se encontra disponível às plantas é de 1500 kPa (Assis Junior, 1995). Entretanto para a maioria dos solos, a maior quantidade de água é retida entre as tensões de 0 e 100 kPa, de modo que entre 100 e 1500 kPa resta apenas uma pequena quantidade (Reichardt & Timm, 2004). A faixa de tensão de 0 a 100 kPa corresponde de 25 a 75% da água disponível no solo, dependendo da sua textura e estrutura (Faria & Costa, 1987). Para o manejo da irrigação de alta frequência, os tensiômetros são eficazes devido à boa exatidão nas medidas de tensão na faixa de 10 a 50 kPa (Thompson et al., 2006). Almeida (2012) constataram que os controladores com tensiômetros operaram adequadamente em tensões inferiores a 35 kPa no controle da irrigação de fruteiras.

7 POSICIONAMENTO DO TENSIÔMETRO NO SOLO

As recomendações para a localização dos sensores no solo têm como base o conhecimento da distribuição radicular da cultura (Blonquist et al., 2006; Coelho et al., 2010), sendo que o sensor é instalado nas zonas de maior extração de água pelo sistema radicular. Muitas recomendações apontam a instalação do sensor a 50% da profundidade efetiva do sistema radicular (Z). Entretanto, o desenvolvimento do sistema radicular é condicionado pela percentagem de área molhada, que depende do SI utilizado (Coelho et al., 2007). No caso de SI que umedecem área parcial, o desenvolvimento do sistema radicular é condicionado ao volume de solo molhado. Em SI por gotejamento, Andreu et al. (1997) e Coelho et al. (2007) observaram que as zonas de extração de água foram influenciadas pela disposição e número de emissores, verificando que o aumento do número de emissores na linha de irrigação resultou em maior área efetiva de extração de água. Para a cultura da bananeira irrigada por gotejamento com emissores dispostos em faixa contínua, Coelho, Silva e Miranda (2010) recomendam a instalação de tensiômetros entre as profundidades de 0,20 – 0,40 m; 0,25 - 0,40 m; e 0 - 0,35 m para os sistemas que utilizam dois, quatro e cinco emissores por planta, respectivamente. Para a cultura da batata irrigada por aspersão, Stieber & Shock (1995) recomendam as instalações dos sensores em profundidades entre 0,1 e 0,2 m.

As recomendações de posicionamento dos sensores acima citadas são relacionadas aos sensores de solo, em que a função é definir o momento de irrigar. Para controladores em que os sensores de solo também têm a função de indicar o desligamento do SI, é imprescindível determinar a profundidade máxima a serem instalados, pois eles determinam o volume a ser aplicado. A maior profundidade de instalação será aquela em que a chegada da frente de molhamento ocorre depois de decorrido o tempo para aplicar o volume de água necessário para retornar a umidade à capacidade de campo (ZUR et al., 1994). Sendo assim, a chegada da frente de molhamento a essa profundidade é utilizada como sinal para desligar o SI (Stirzaker & Hutchison, 2005). Entretanto, a determinação dessa profundidade é complicada, uma vez que a velocidade da frente de molhamento depende de vários fatores, tais como: conteúdo inicial de água no solo, condutividade hidráulica do solo (que varia para cada tipo de solo) e aplicação da irrigação (método de irrigação utilizado) (Rubin & Steinhardt, 1963). Essa determinação pode ser realizada por uma série de experimentos de campo, que requer tempo e esforços consideráveis para sua execução. Uma alternativa para os laboriosos experimentos de campo é a utilização de modelos numéricos ou analíticos que tem como base o fluxo de água no solo (Dabach et al., 2011).

A utilização de modelos de simulação que solucionam numericamente ou analiticamente a equação de Richards do fluxo de água no solo com adequados dados de entrada e condições de contorno, permite estimar ou descrever a dinâmica de água no solo em qualquer tempo ao longo do ciclo de irrigação. Com isso, esses modelos têm se apresentado com uma ferramenta útil na otimização do manejo da irrigação. Cote et al. (2003), Kandelous & Simunek (2010) estimaram a distribuição temporal e espacial do conteúdo de água no solo irrigados por gotejamento enterrado com emissores instalados a diferentes profundidades. Dabach et al. (2011) otimizaram a eficiência de aplicação da irrigação com uso de modelos numéricos na definição das tensões críticas de acionamento e da lâmina a ser aplicada. Pinho (2010) utilizou modelo numérico para simular o movimento de água e solutos (Nitrato e potássio no solo) para os solos Latossolo Vermelho Amarelo e Nitossolo. Coelho & Or (1996) determinaram o posicionamento de instalação de tensiômetros na cultura do milho irrigado por gotejamento com a utilização de modelos semi-analíticos. Blonquist Jr. et al. (2006) estudaram a relação entre as profundidades de instalação de sensores de umidade (TDT) e os conteúdos de água críticos para acionamento do SI. Os resultados de simulação permitiram indicar a profundidade de instalação que maximiza a eficiência de uso da água evitando percolação.

Uma grande variedade de modelos numéricos e analíticos foram desenvolvidos recentemente (Pinho, 2010), sendo que, o aplicativo SWIMv2.1 (Soil Water Infiltration Movement, versão 2.1, Verbug et al., 1996) é um desses modelos apropriados para simular o movimento de água (Scanlon et al., 2002) e solutos no perfil do solo. Ele foi utilizado com sucesso em simulações de transporte de água e nutrientes (Bond et al., 1997) e em estudos de melhorias da eficiência de uso da água em SI (Hurst et al., 2004). Sendo assim, o aplicativo SWIMv2.1 foi utilizado por Almeida (2012) para identificar o desempenho do controlador de irrigação proposto em diversas condições de taxa de aplicação, instalação do sensor e tipos de solo, a fim de estabelecer recomendações para uso e operação do controlador.

8 TENSÃO DE ACIONAMENTO

A tensão de acionamento é um dos principais fatores que influem na eficiência da irrigação. Sendo que a sua definição depende do tipo de cultura a ser irrigada e do seu estágio de crescimento. Segundo Dabach et al. (2011) a tensão crítica de água no solo para acionar o SI determina a lâmina de água ser aplicada e, consequentemente, o tempo e a frequência (turno de rega) da irrigação. Os mesmos autores determinaram tensões críticas de 20 kPa e 5,3 kPa para turnos de rega de 4 e 1 dias, respectivamente, para o controle do SI na cultura do feijão irrigado por gotejamento. No caso deste trabalho o tensiômetro estava instalado a 10 cm de profundidade e 10 cm de distância do emissor.

A extração de água tende a ser maior nas menores profundidades, em que o tempo de resposta à variação na tensão é curto. Com isso, a tensão de acionamento deve ser maior quando o sensor de água no solo for instalado nessa zona. Ao passo que, quando instalado em profundidades maiores, onde a menor extração de água resulta em menor variação da tensão e longo tempo de resposta, a tensão crítica deve ser menor (Blonquist et al., 2006). A definição da tensão de acionamento é dependente da tolerância da cultura ao estresse hídrico e dos objetivos do manejo (Hoppula & Salo, 2007; Ayars & Phene, 2007). Quando a irrigação é manejada para manter a umidade próxima à capacidade de campo (baixa variação de tensão), o risco de perdas por percolação é maior (Andreu et al., 1997), portanto o manejo deve ser mais criterioso.

Ao utilizar sensores de solo para automação da irrigação, este comumente indica a tensão crítica para acionar o SI e um determinado volume de água é aplicado. Esse volume pode ser qualquer quantidade menor ou igual ao volume necessário para repor a umidade à capacidade de campo (válvulas volumétricas e temporímetros controlam o volume). Já para o controlador proposto por Almeida (2012) (se utilizado apenas um controlador, Figura 5), uma vez definida a profundidade de instalação e a tensão de acionamento, o volume de água a ser aplicado será fixo, visto que, obrigatoriamente a lâmina a ser aplicada será a necessária para que a frente de molhamento alcance a profundidade da cápsula do tensiômetro. Por outro lado, se utilizado dois controladores (Fig. 5), o irrigante terá maior flexibilidade na definição da lâmina a ser aplicada através do ajuste da tensão de desligamento do SI e da definição da profundidade de instalação do controlador responsável por desligar o SI. Dessa maneira, o irrigante tem

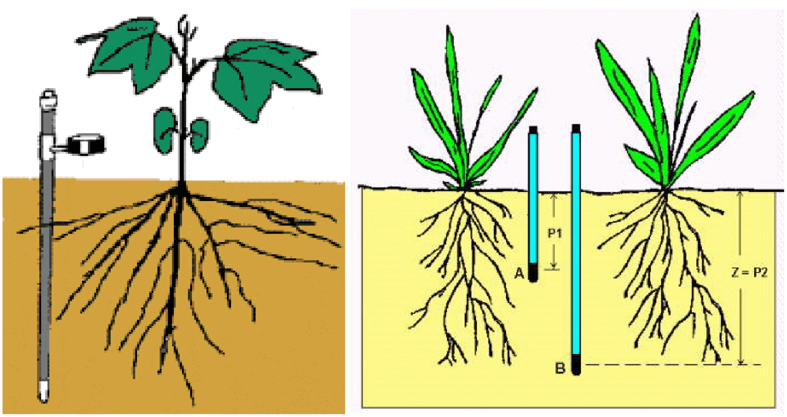


Figura 5 Número de sensores de solo no controle da irrigação. Fonte: EMBRAPA (Website)

maior flexibilidade de decidir o volume a ser aplicado, seja para atender determinado turno de rega ou para ajustar a capacidade operacional do sistema.

9 CONCLUSÕES

No estudo de caso do controlador construído por Almeida (2012) os protótipos do controlador de irrigação foram capazes de acionar mecanicamente o sistema de irrigação com erro ou incerteza de 1,15 e 0,43 kPa, respectivamente, para tensões críticas de 20 kPa. De acordo com o autor, pesquisas futuras devem testar novos materiais ou outros tipos de diafragmas e priorizar o emprego de processos industriais para fabricação de protótipos dos controladores.

Diante do exposto, fica evidente que o desenvolvimento de controladores de irrigação com acionamento mecânico, apesar destes não estarem disponíveis comercialmente, é uma realidade e encontra-se com uma base de desenvolvimento científico-teórico avançado. Contudo, avanços na tecnologia de fabricação e aumento da experimentação poderão fornecer resultados que permitam uma maior aceitação desses controladores na área prática. Ressalta-se que para SI de baixa pressão para pequenas áreas hortícolas, esses controladores apresentam desempenho satisfatório.

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12

A Framework for Integrating Satellite and Surface Observations to Support Improvements in Irrigation Scheduling

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1 Introduction
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1 INTRODUCTION

Proper scheduling of irrigation applications is critical to efficient water use. The most common method to estimate crop water use and schedule irrigation application is to use weather data to estimate the water use or evapotranspiration of a reference crop, and then apply a crop coefficient to convert the reference evapotranspiration (ET_O) to the evapotranspiration of a crop in a field (ET_c). This method is often referred to as the FAO-56 method (Allen et al., 1998).

In the western U.S., agricultural weather networks such as the California Irrigation Management Information System (CIMIS) provideWEB-based hourly information on weather conditions and ET_O. Within California, CIMIS (Temesgen et al., 2005) currently operates 139 stations across the state and provides data to growers and irrigation consultants on ET_O and weather conditions. CIMIS currently has about 40,000 users. However, the most recent farm and ranch irrigation survey conducted by the USDA indicated that only 12% of growers in California utilize reports on daily crop-water evapotranspiration in scheduling irrigation (USDA, 2008). Development of an automated system for mapping crop coefficients and delivery of data to users would enhance the use of ET data in irrigation management.

Satellite imagery can be used to estimate vegetation indices for crops. Vegetation indices are related to sunlight interception and thus crop water transpiration, and can be used to estimate crop coefficients. When combined with ET_O values from ground-based weather stations, they enable estimates of crop water use.

Integration of these data sources into current management practices and operational models presents a number of challenges, especially for applications such as irrigation scheduling that require information in near real-time. In addition to typical issues associated with processing large volumes of data from heterogeneous sources, satellite data must be atmospherically corrected to minimize artificial scene-to-scene variability and data gaps due to cloud cover or instrument failure must be filled.

The NASA Terrestrial Observation and Prediction System (TOPS, Nemani et al.,

2009) provides a modeling and computing framework for integrating satellite and surface observations in near real-time to address many of these challenges. In the following sections, we describe an application of the TOPS framework to develop a system for near real-time mapping of crop canopy conditions and associated crop irrigation requirements at the resolution of individual fields. To support continued improvements in management of agricultural water supplies, the data processing system is designed to provide growers and water managers with frequent, accurate, and easily available information that includes key indicators of crop canopy development and crop water use requirements.

2 A FRAMEWORK FOR SATELLITE IRRIGATION MANAGEMENT SUPPORT

The TOPS Satellite Irrigation Management Support (TOPS-SIMS) framework integrates satellite observations from Landsat and MODIS with meteorological data from CIMIS and ancillary data on crop type and site specific conditions (Figure 1). The system employs a modular architecture to facilitate support for a wide range of models and data. The initial implementation provides a capability for mapping of fractional

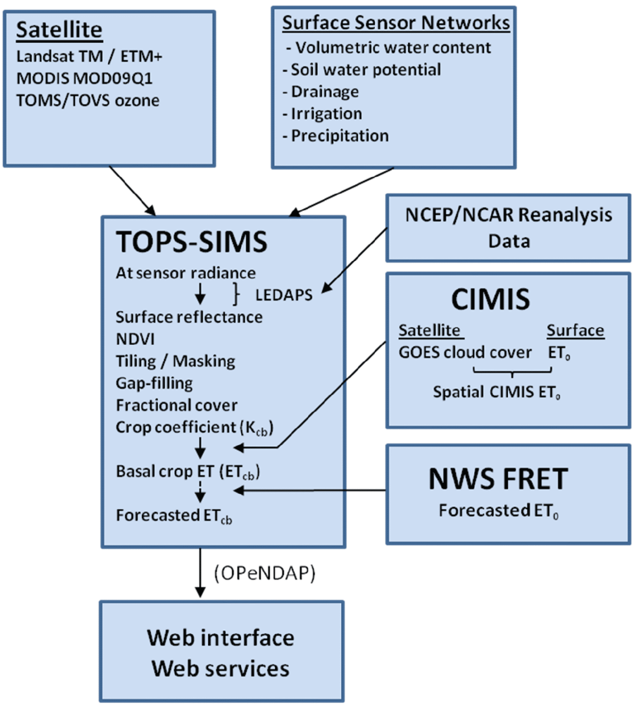

Figure 1 Overview of the TOPS-SIMS architecture with primary data inputs and outputs

cover (F_c), associated basal crop coefficients (K_{cb}), and basal evapotranspiration (ET_{cb}) over 6 million ha of farmland in California's Central Valley. F_c and K_{cb} are mapped every eight days, and ET_{cb} maps are produced on a daily basis at spatial resolutions that are useful for irrigation management at the field level (30m). Automated atmospheric correction and gap-filling algorithms are optimized for agricultural areas to provide a robust and reliable data stream. Information from TOPS-SIMS is distributed to water managers and agricultural producers via a browser-based irrigation management decision support system. Users can combine the supplied K_{cb} or ET_{cb} with formal or intuitive estimates of soil evaporation and crop water stress levels to derive total water consumption over the recent period at the field level. By accounting for the irrigation application rate, distribution uniformity, and any corrections for water replacement targets (e.g., intentional deficit irrigation or leaching requirement), users can translate TOPS-SIMS output into an irrigation management strategy.

3 TOP-SIMS INFORMATION COLLECTION AND ANALYSIS

TOPS-SIMS ingests Landsat-5 TM, Landsat-7 ETM+, and MODIS satellite imagery for California's Central Valley and other agricultural regions. Landsat provides the spatial resolution necessary to produce information at the scale of individual fields. The daily temporal resolution of MODIS provides a gap-filling capability to ensure data availability. At present, methods used by the remote sensing community for satellite mapping of ET at field scales (30 m) rely primarily on energy balance models (e.g., Bastiaanssen et al., 1998; Anderson et al., 2004; Allen et al., 2007) or reflectance based mapping of crop coefficients (e.g., Neale et al., 1989; Neale et al., 2003; Hunsaker et al., 2005; Rafn et al., 2008; see also review by Gowda et al., 2008). Of these approaches, strategies for full automation have only been developed for mapping of basal crop coefficients (K_{cb}) from surface reflectance, and thus the initial suite of algorithms implemented in the TOPS-SIMS framework rely on this approach. In the future, it may be possible to implement additional models, including energy balance models and models for downscaling of soil moisture estimates from satellite missions such as the Soil Moisture Active Passive (SMAP) mission.

Each Landsat scene is atmospherically corrected using software developed under the LEDAPS project (Masek et al., 2006). Landsat 5 and 7 data are tiled onto a common grid to form an 8-day composite to facilitate use of overlapping portions of each scene to increase the frequency of observations and reduce data gaps due to cloud cover. This compositing approach also reduces the effects of the Landsat 7 scan line correction error, as only the central portion of the Landsat 7 scenes are used, where the gaps are narrower.

The next step is to calculate the normalized difference vegetation index (NDVI; Tucker, 1979) from the composited scenes. NDVI is an index calculated from the red and near infrared wavelengths and provides a measure of photosynthetically active vegetation. At this stage, a suite of gap-filling algorithms are employed to ensure spatially continuous data over agricultural regions.

NDVI data is transformed to canopy ground cover, $F_{c,}$ via empirical relationships developed by USDA and NASA. Johnson & Trout (2012) and Trout et al. (2008) collected field measurements of F_c across multiple crop types in the California Central Valley. These data were compared with satellite observations collected on the same day, and revealed a robust relationship between NDVI and F_c (Figure 2A). This approach is also consistent with other previous studies showing that various spectral vegetation indices, calculated from visible and near-infrared (NIR) reflectance data, are linearly related to canopy light interception (e.g., Asrar et al., 1984; Goward & Huemmrich, 1992; Johnson & Scholasch, 2005).

A. B.

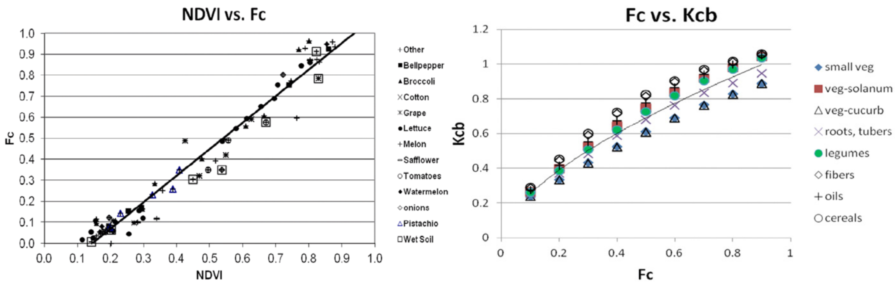

Figure 2 Relationship between normalized difference vegetation index (NDVI) and fraction cover - Fc (A) and fractional cover - (FC) and basal crop coefficiente - Kcb (B)

To convert F_c to the basal crop coefficient, K_{cb}, TOPS-SIMS uses different approaches for retrospective versus near real-time mapping of K_{cb}. For retrospective mapping of annual crops or for fields where information on the current crop type is available, F_c is converted to K_{cb} based on a physical description of the crop canopy (Allen & Pereira, 2009). For real-time mapping, while crop type for perennial fields (vineyards, orchards)can be reasonably determined from prior-year maps, the spatial distribution of annual crops is generally unknown within-season. A generalized F_c-K_{cb} relationship representing a best-fit to crop specific relationships (Figure 2B) is thus applied for near real-time mapping of fields deemed to contain annual crops. Use of this approach introduces K_{cb} mean estimation uncertainty ranging from 3-14% across the major crop categories (vegetables, roots/tubers, legumes, fibers, oils, cereals). For perennial crops, results from multi-year studies recently performed on large weighing lysimeters at the University of California Kearney Agricultural Center are used for F_c-K_{cb} conversion (Ayars et al., 2003; Williams & Ayars, 2005). Both studies reported a strong relationship between mid-day canopy light interception, which is closely related to F_c, and the crop coefficient.

Past studies conducted by USDA in collaboration with NASA (Trout et al., 2008; Johnson & Trout, 2012) provide the basis for linking NDVI to fractional cover using relationships that are robust across different crop types and canopy architectures (Figure 2A). Use of a generalized equation (after methods of Allen & Pereira, 2009) for converting fractional cover to FAO crop coefficients provides a robust approach for mapping K_{cb} values (Figure 2B). When the crop type at a particular location is specified or can be identified with confidence, crop specific equations may also be applied.

Finally, the basal crop evapotranspiration, ET_{cb}, for both annuals and perennials is calculated as the product of K_{cb} and ET_O. For California, ET_O is retrieved by TOPS-SIMS via FTP (file transfer protocol) from the standard Spatial CIMIS 2 km daily statewide ET_O grids.

4 DATA DISTRIBUTION VIA WEB INTERFACE AND WEB SERVICES

While TOPS-SIMS simplifies the process of integrating satellite and surface observations to map K_{cb} and ET_{cb} values, distribution of data and information via intuitive, easy to use interfaces is critical to facilitating use of the information by water managers and agricultural producers. A web-based user interface providing access to visualizations of TOPS-SIMS information eliminates the barriers to data access, as only a web browser is needed to view and query the information, and no knowledge of specialized data formats is necessary. TOPS-SIMS overlays a selection of open-source and commercial base map layers, including maps of streets, land use, and aerial imagery. NDVI, F_c, and K_{cb} overlays are updated on nominal 8-day intervals, and ET_{cb} is updated daily. These overlays can be requested for any date, and annual traces for the parameters for any location (30 m pixel) can be viewed graphically or downloaded to compare current to past conditions. In addition to providing views of TOPS-SIMS data at the native 30m resolution, the web interface also allows users to retrieve quantitative information from any variable by specifying a point or polygon and requesting the most current values or a time-series summary (Figure 3).

The TOPS-SIMS web interface provides capabilities for visualization and data access, including support for geographic queries and selection of data for visualization by date and parameter. The map in (Figure 3A) shows ETcb (mm/day) for ~6 million hectares of farmland in the Central and Salinas Valleys on 02-Aug-2011. Retrospective time-series for TOPS-SIMS output can be generated, as shown by the Kcb graph for 2011 for a location near Huron, CA (Figure 3B). Time-series data can be downloaded from the interface in CSV format directly into a spreadsheet for further analysis.

5 EXTENDING THE TOPS-SIMS FRAMEWORK

The current TOPS-SIMS K_{cb} and ET_{cb} mapping capabilities provide an initial demonstration of the potential utility of a modeling framework to integrate observations from satellite and surface sensor networks to provide new data and information services

A.   B.

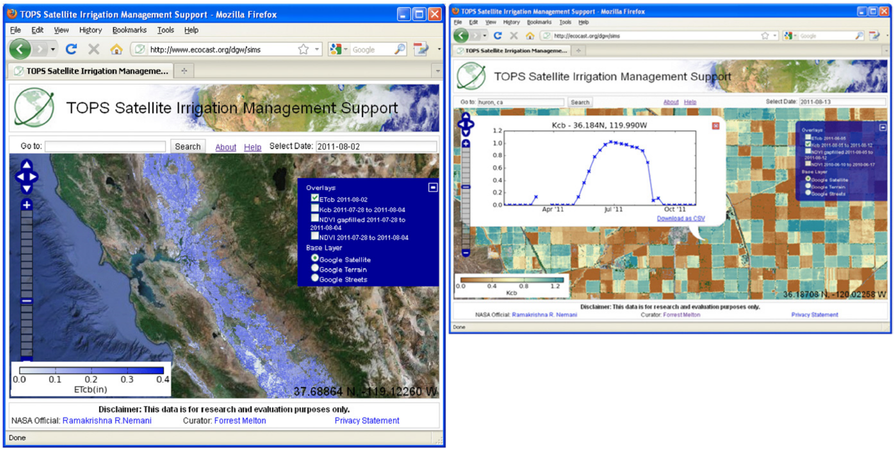

Figure 3 TOPS-SIMS web interface for visualization and data access (A) ET_{cb} (mm/day) for farmland in Central and Salinas Valleys on 2/8/2011 and (B) K_{cb} graph for 2011 for a location near Huron, CA

to the agricultural and water resource management user community. However, the TOPS-SIMS modular architecture also allows for a number of extensions that can be rapidly implemented to expand the data and information services available. Key short term objectives include: i) linking TOPS-SIMS to ET_O forecasts to provide forecasts of irrigation demand at various lead times; ii) use of web services and a model web approach (Geller & Melton, 2008) to integrate TOPS-SIMS outputs with operational and planning models utilized by water managers; iii) incorporation of site specific information provided by growers or uploaded automatically from flow meters or soil water sensors to allow generation of field-specific customized water balance reports; iv) expansion of inputs to include observations from a constellation of moderate resolution satellite sensors to increase observation frequency and improve the reliability and accuracy of data and information products from TOPS-SIMS; and v) incorporation of additional publicly available models for estimation of ET, including energy balance models for estimation of ET_c.

6 SUMMARY

TOPS-SIMS employs a “system of systems” approach and applies the TOPS modeling framework to ingest observations from satellite and surface sensor networks to provide new data and information products to agricultural producers and water managers via easily accessible web interfaces and web services (Table 1). The current framework provides capabilities for near real-time mapping of indicators of crop canopy development and crop water consumption at field scales over 6 million hectares

Table 1 Definitions

Parameter	Abbreviation	Definition
Evapotranspiration	ET	The total water lost to the atmosphere from the combined processes of evaporation from soil and plant surfaces, and transpiration from plant tissues. For agricultural crops, it is also an indicator of how much water is needed to support healthy crop growth and productivity.
Reference evapotranspiration	ET_0	The total evapotranspiration from a well-watered reference crop, typically grass or alfalfa.
Crop evapotranspiration	ET_c	The total evapotranspiration from an agricultural crop.
Basal crop evapotranspiration	ET_{cb}	The total evapotranspiraton from a well-watered agricultural crop on a dry soil surface.Primarily represents the plant transpiration component of ET and provides a measure of the crop's biological demand for water.
Fractional cover	F_c	The percent of ground area that is covered with photosynthetically active vegetation.
Crop coefficient	K_c	A unitless coefficent used to convert ET_0 to ET_c for a specific crop, and defined as the ratio of ET_c to ET_0. K_c values integrate differences in both the soil evaporation and crop transpiration rate between the crop and the reference surface.
Basal crop coefficient	K_{cb}	A unitless coefficent used to convert ET_0 to ET_{cb} for a specific crop, and defined as the ratio of ET_{cb} to ET_0. In a dual crop coefficient approach, K_{cb} is used to represent the contribution of plant transpiration to ET_c.
Soil water evaporation crop coefficient	K_e	Used to capture the contribution of evaporation from the soil surface to ET_c in a dual crop-coefficient approach.
Crop stress coefficient	K_s	A unitless coefficient used to capture the effect of crop water stress on ET_c. Water stress increases closure of plant stomata and reduces transpiration.
Normalized Difference Vegetation Index	NDVI	A frequently used remote sensing index that provides a measure of vegetation photosynthetic activity or “greenness”.

of California farmland. TOPS-SIMS is designed to integrate additional models and data services to support forecasting of crop irrigation requirements at weekly to seasonal lead times, and concurrent modeling of actual and potential evapotranspiration. Future integration of observations from a constellation of moderate resolution satellites would support further improvements in the frequency and long-term operational reliability of satellite-derived estimates of evapotranspiration and other hydrologic parameters.

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Intelligent Agriculture – The Integration, Mobility and Collaboration Challenge

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1 INTRODUCTION

The increasing diversity and capacity of information and communication technologies at our disposal, created a window of opportunity to innovate and create decision support systems that allow us to put on the field at the disposal of farmers and agricultural technicians sophisticated information systems that support real time decision making namely using Business Intelligence approaches.

A Business Intelligence (BI) platform in an organizational environment has traditionally four main components: data sources; a data warehouse; a business analytics component; and a user interface. In general and particularly important in the case of the agricultural sector, the last component, the user interface, which has to give simultaneous answer to "What information?", "For whom?" and "How to present it?" is an area of increased concerns very dynamic and with innovative solutions being delivered to the market continuously.

The present work addresses this BI platforms user interface challenge and proposes for the agricultural field the usage of smartphones and augmented reality as an effective mechanism to deliver in the field and in a transparent way information supply for decision making. With that purpose we present a augmented reality prototype to deliver information for decision support in a greenhouse using a BI approach and a smartphone Layar augmented reality interface.

2 OBJECTIVES

The evolution we can nowadays witness in the information and communication fields, namely in the mobile computing and remote sensing, making available in the market devices with growing processing capacities and smaller sizes which are able to offer sensing functionalities, wireless communication, integrated energy source and action capacities, are posing a very interesting challenge to the agricultural sector. This new reality places agronomic knowledge under the lights since these technologies can be seen as amplifiers of our data collection and storage capacities, challenging the farmers and the agricultural experts to develop processes that can convert data into information/knowledge and deliver it to the decision maker in order to support the everyday business actions.

Nowadays Business Intelligence (BI) platforms are being used to answer this challenge, and the final step of any such platform, the user interface layer is the key component of the system since it will be the interaction contact point of the user with the platform. We include in this layer the digital dashboards and information transmission tools that offers the users an integrated and comprehensive vision of the BI platform metrics, trends and exceptions, combining information from multiple sources. The present work addresses precisely this BI platforms final step that consists in the information delivery for user decision-making. For that purpose we propose the usage of smartphones and augmented reality as an approach capable of making available in the field and in an transparent way a effective information transmission mechanism to support decision making.

The main objective of this research was to develop an augmented reality early warning system prototype for B. cinerea in a tomato greenhouse supported by a wireless network of air relative humidity and temperature sensors installed inside the greenhouses. Our goal is to demonstrate the potential of this approach and the utility of the prototype we built as a tool for growers and technicians to improve climate and disease control in the greenhouse.

3 AUGMENTED REALITY

The term "Augmented Reality" was initially suggested by Caudell and Mizell (1992) who described it as the act of combining computer generated elements with the real world. However, the first experiences with "augmented" realities date back to 1962, when Morton Heilig recorded the patent of a machine, called Sensorama (Fig. 1), which had the ability to reproduce movies while adding wind, vibration, smell and three dimensional images. Some years later, Sutherland (1968) would invent a special helmet (Fig. 2) which he described as being a window into a virtual world. The helmet had the capability to reflect the users' movement in the images reproduced, contributing considerably to increase the human perception of motion within a virtual environment. This helmet system, closer in concept to what Augmented Reality offers nowadays, would be subject to imitation and further exploring in the nineties by the scientific community, for instance, to act as a support tool in the process of learning architecture (Feiner et al., 1995), to help in medical surgery (Wagner et al., 1996), to interact with the real world (Feiner et al., 1997, Thomas et al., 1998), and to aid the manufacturing industry (Chung et al., 1999).

When we talk about virtual elements we can be led to some associated terms like Virtual Reality or Mixed Reality, but it was Milgram and Kishino (1994) who

Figure 1 Sensorama by Heilig (1962)

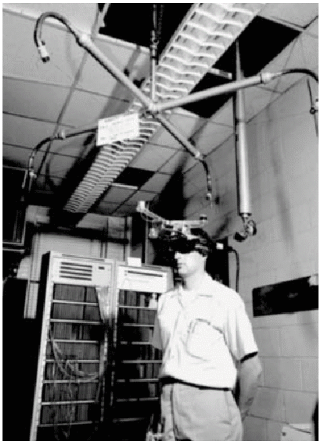

Figure 2 Head-mounted display by Sutherland (1968)

developed a spectrum called Reality-Virtuality Continuum (Fig. 3) which facilitates the understanding of these concepts. The Reality-Virtuality Continuum illustrates the intensity of the combination between virtual and real environments, organizing the Mixed Reality categories by weighing their level of combination.

Figure 3 Reality-Virtuality (RV) Continuum (Milgram and Kishino, 1994)

A few years later, in his research about Augmented Reality, Azuma (1997) defined three major characteristics about AR:

1. the mix of the real with the virtual;
2. real-time interaction;
3. and 3D scenes

These characteristics, pointed out by Azuma, can certainly be applied to most positions of the Reality-Virtuality Continuum (Fig. 3) without losing their validity. It is, however, important to mention that we follow the Augmented Reality perspective, meaning that the emphasis is on the real world first, followed by the added virtual elements, second.

3.1 Augmented reality meets the smartphones

Although there is no exact definition for smartphone, mostly due to the rapid technological changes in this context, a smartphone can be described as a communicating device with advanced processing skills, equipped with a video camera and means to access internet, namely 3G technologies and Wi-Fi. A smartphone device also incorporates motion sensors and a GPS navigation system. These characteristics make mobile phones (or smartphones) a privileged access point for information, and like a 2010 report from the International Data Corporation points out "*vendors shipped a total of 302.6 million smartphones worldwide, up 74.4% from the 173.5 million smartphones shipped in 2009*" (IDC, 2011), smartphones represent a significant share in the global market.

Augmented Reality can significantly flourish within the mobility context. In recent years, Augmented Reality investigations took full advantage of the technological evolution happening in the mobility area, like the mobile phone incorporation of motion sensors and the global positioning system (GPS). The results of these investigations were released in the most diverse contexts and, while not being directed specifically for smartphone devices, some proved worthy candidates for usage within the mobile context, for instance:

- games – the user plays using the real world as a background (Thomas et al., 2000, Cheok et al., 2004);
- exhibitions and futuristic art – virtual art exhibitions where virtual artworks are applied to the exhibition space (Wojciechowski et al., 2004);
- virtual guides for museums – users obtain information about the museums' points of interest (Miyashita et al., 2008);
- instant translators – to instantaneously translate a live-filmed text into several languages (Haritaoglu, 2001);
- mapping through recognition – mapping virtual textures in a real environment using predefined recognition patterns (Rekimoto, 1998, Kato and Billinghurst, 1999).

The examples referred above were supported, in most cases, by frameworks and hardware developed specifically for scientific purposes, and inaccessible to the general public. However, between 2008 and 2009, new platforms and paradigms emerged to propel AR development in smartphones, like Junaio (http://www.junaio.com), Layar (http://www.layar.com) and Wikitude (http://www.wikitude.org). All of these companies embraced a new concept which consisted in creating an Augmented Reality browser with a number of features that allowed developers to produce Augmented Reality content according to a specific set of rules, and, finally, allowed end-users to view computer generated elements (audio, video, images and animations) superimposed to the live camera view of common smartphones (Figure 4).

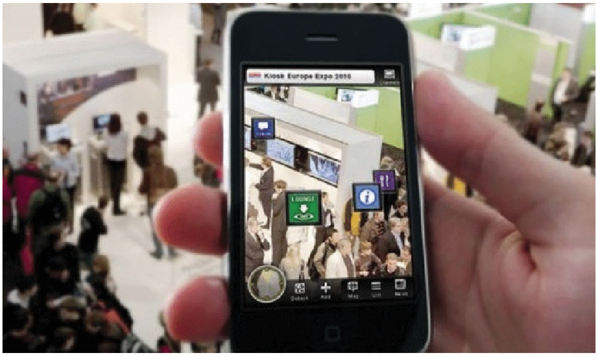

Figure 4 Geo-referenced content in live camera view

These AR browsers are compatible with most mobile operating systems like the Android (http://www.android.com), the iPhone OS (http://developer.apple.com), or the Symbian (http://licensing.symbian.org).

Smartphones' interaction potential, combined with AR technologies, represents the starting point for our prototype that is to be applied to a BI platform that collects data from a tomato greenhouse wireless sensors network. We are focused on testing a new information delivery interface of mixed realities where access to information and the possibilities for exploring and interacting can be enhanced.

Smartphones are nowadays a communication tool that allies portability, which is fundamental for the agricultural sector, with the access to an important bundle of information and localization services. At the same time, Augmented Reality – or the act of overlaying virtual elements over images captured in real time – is taking advantage of the growing processing capacities of smartphones and we have nowadays at our disposal several applications that take advantage of wireless networks, positioning detection capacities and movement sensors to deliver new and innovative information interfaces.

4 AUGMENTED REALITY GREENHOUSE PROTOTYPE

As referred previously, one of the most well known Augmented Reality browser for smartphones is Layar (http://www.layar.com), available free of charge for IOS and

Android, and for which it is possible to build information layers, published as web services, and consumed by Layar being visualized in the AR browser upon activation by the user. In that context and supported by a augmented reality framework developed by the authors it was tested the use of smartphones and augmented reality on Layar, with a prototype that was built and we will present to deliver the information in a Business Intelligence platform for an early warning system of Botrytis cinerea Pers. in a tomato greenhouse. The prototype takes advantage of a Layar browser for smartphones and augmented reality to enable in the field and in realtime the visualization of the environmental conditions in the greenhouse, identify and characterize the plots, as well as diagnose irrigation needs.

4.1 Augmented reality framework

The publication of the information to be consumed by the Layar browser in the smartphones is based in ISEGI-NOVA AR Project, a work developed previously (Cardoso & Neto, 2013). The ISEGI-NOVA AR Project consisted in developing and deploying an Augmented Reality system to assure a multitude of services, directed to the smartphone medium. These services, making use of existing AR third party technologies, allow users to interact with multimedia layers (images, sounds, video, web content, animations) superimposed to the image captured by the smartphone camera.

4.1.1 Architecture overview

The AR project was developed in compliance with Layar's architecture requirements. Figure 6 displays Layar's architecture (Layar, 2012) alongside the ISEGI-NOVA AR Project's architecture, which contains all components that were developed within the project's scope. Using the third-party Layar infrastructure requires some registration and configuration steps on the Layar site but, essentially, to be able to play an AR experience on a smartphone, the key aspect that the ISEGI-NOVA AR Project must assure is that a JavaScript Object Notation - JSON (JSON, 2012) message is delivered whenever a proper request is received. In the end, a smartphone with the Layar AR Browser installed, can then translate the JSON structured message into everything the points of interest (POI) the user sees and everything the user is allowed to do in the AR world.

To explain how the AR content is brought to the smartphone we will use Fig. 6 as an example:

a) The ISEGI-NOVA AR Project's content provider creates an AR experience using the AR Management Site (item 6, Figure 1), writing the contents to the AR Database (item 5, Figure 1). The AR creation process makes use the AR Libs intelligence (item 7, Figure 1), that knows all about the JSON language that the Layar AR Browser (item 3, Figure 1) understands.

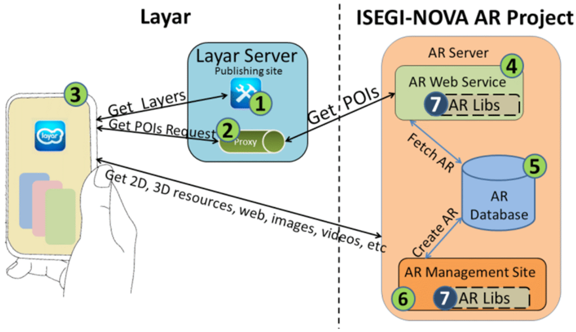

Figure 5 Architecture overview

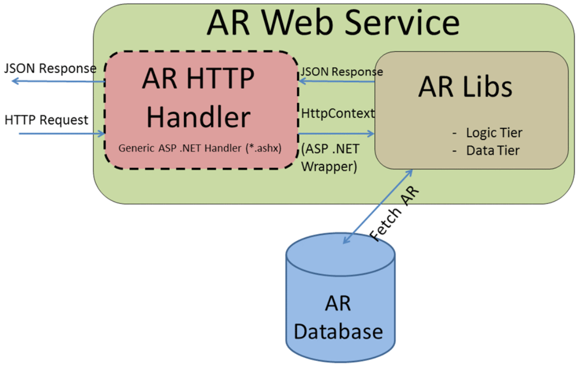

Figure 6 AR Web Service

b) The user opens the Layar application on the smartphone, finds our content layer through the application's search tool, and opens our AR world. This initial connection, which retrieves existing layers, is made between the smartphone (item 3, Figure 1) and the Layar Publishing Site (item 1, Figure 1);

c) Once the world is opened, the smartphone's Layar API performs content requests to the Layar server, forwarded via proxy (item 2, Figure 1). These requests are redirected to the AR provider's web service (item 4, Figure 1) – we are the provider, in this case. The request contains information like the AR world's ID, the GPS coordinates of the smartphone which performed the request, among other attributes;

d) Once the AR provider's web service (item 4, Figure 1) receives a request, it accesses our AR Database (item 5, Figure 1) and, using our AR Libs intelligence class library (item 4, Figure 1), prepares an answer in a JSON format that is returned to the Layar server which, in turn, forwards the response to the smartphone's AR browser;

e) After the AR browser API on the smartphone receives the JSON response, it can translate the structured language into visual information, and the user can finally engage in the Augmented Reality experience. Since the JSON response may contain portions that point to external links (images, video, sounds, webpages), for performance purposes, the AR browser will access these links directly, without using the Layar proxy as intermediary.

4.1.2 The AR web service

The AR Web Service is prepared to handle HTTP requests and to return a JSON response. As illustrated in Fig. 8, the access point for the AR Web Service is the AR HTTP Handler which, in fact, is a generic ASP .NET Generic Handler class. The class implements the *HttpHandler* interface (MSDN, 2012) and defines a default *ProcessRequest* method which receives the HTTP requests and returns the JSON output to the browser responsible for the request. The mentioned *ProcessRequest* method receives an *HttpContext* object as argument which encapsulates several elements associated with the request: the request parameters, the application state, and information about the session, to name a few.

4.2 Greenhouse augmented reality prototype

Tomato is a very important crop in the Mediterranean region in general and in Portugal in particular being the production for fresh consumption made essentially in greenhouses. One of the most important diseases affecting greenhouse tomato crops is Botrytis cinerea Pers.: Fr., the causal agent of grey mould disease and high relative humidity and the presence of free water on the plant surfaces have been recognized as favourable to the development of this disease.

In previous research Neto et al. (2011) proposed a business intelligence approach to create an early warning system providing to the tomato grower alerts with information of the potential favoured conditions for the grey mould disease appearance in its early stages or even before since they can have a very positive impact in reducing the economic and environmental impacts due to a more rational and efficient disease control management. The proposed early warning system was supported by a sensors wireless network and technologies such as SMS, e-mail and Web access to deliver the warnings.

Nevertheless, taking into consideration in one hand the developments in AR and the work of the authors in the field and in the other the known need to create new innovative ways of delivering information to the farmers, it was considered relevant to create a prototype that linked the above referred greenhouse tomato early warning system with the ISEGI-NOVA AR Project.

Our goal was to demonstrate the potential of this approach and the utility of the prototype we built as a tool for growers and technicians to improve climate and disease control using smartphones and Layar browser to deliver richer information in real time in the greenhouse. With this objective in mind a dynamic data connection was made between the data warehouse of the early warning system and the ISEGI-NOVA AR Project which supported the publication of a specific layer of information to be consumed in the greenhouse (Figure 4).

Figure 7 AR Greenhouse prototype

The AR Greenhouse prototype was tested in the field covering three different types of information to show the potential of this approach to present relevant POI for decision-making, namely:

a) Identification – information regarding the crop, installation date, variety information, etc.

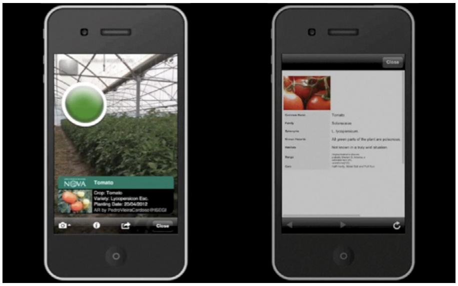

Figure 8 Identification POI and detailed information retrieved on clicking

b) Performance – information concerning soil water content status with the possibility of clicking the POI to obtain further information about irrigation (scheduling & amount).

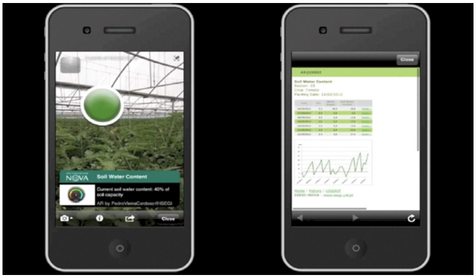

Figure 9 Performance POI and detailed information retrieved on clicking

c) Environment – information and several environment metrics, such as temperature, humidity, CO_2, etc.

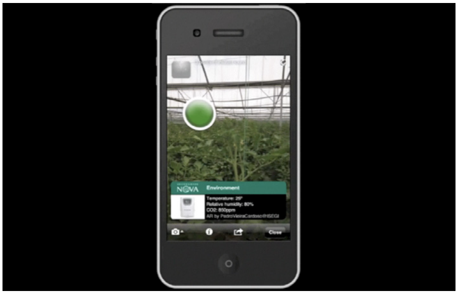

Figure 10 Environment POI

5 CONCLUSIONS AND FUTURE WORK

The plataform prototype that was built to test the the usage of augmented reality in a greenhouse following a business intelligence approach and taking advantage of Layar technology was sucessfull and the field tests were very promising.

One of the next developments will be on the Points of Interest potencial use to add aditional information. If for instance, we are seeing a temperature POI in the AR browser we can use a thermometer to display the actual reading in the greenhouse in that moment, or we can use a gauge as a POI with a red to green gradient scale to present a metric making very easy to understand not only the value but also the meaning.

Finnally, altough in the present work we only presented the prototype and the results of the first field tests, we are now developping a large scale evaluation of the concept altogether we the inclusion of image processing for crop diseases identification through the usage of Layar Vision technology.

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14

Holistic Pressurized Irrigation Development

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14 Holistic Pressurized Irrigation Development

Uniformly and timely replacement of the water depleted by crop evapotranspiration is the basic objective of irrigation. Holistic pressurized irrigation development involved a sequence of iterative steps, led by hardware innovations, i.e. irrigation technologies, and followed by design procedures and criteria for efficiently employing them. Irrigation systems require an operator to employ the hardware for applying the water and a designer to apply the software to plan and managing it. Our various pressurized irrigation systems (PISs) evolved where energy and capital were rather low-cost, labor was quite high-cost, and technical services were available. Recent attention has been given to re-evolving these systems to address the almost opposite set of circumstances faced by poor small-plot farmers.

The three basic types of PISs, surface, sprinkle, and drip, each have two main categories. These are: surface - piped water to furrows or level (or sloped) basins; sprinkle - aerial applied water from set or moving sprinklers; and drip - locally applied water from closely spaced emitters on or beneath the soil surface. Calculations based on the average depth of applied water to the water received by the average dept applied to the low quarter, low half, of the standard deviation of applied depth measurements are used to the define a PIS's application uniformity. A PIS's application uniformity depends on various mixes of the following parameters: irrigator skill and physical effort; variations throughout the field in soil infiltration rates, water holding capacity of the crop root zone; surface elevation difference; local temperature and wind conditions; and the desired irrigation water application depth.

The fraction of the applied irrigation water that is available and used by crop evapotranspiration is often called the irrigation application ratio (or efficiency). But if some of the applied water that exceeds what is consumed by crop evapotranspiration is reused, the effective irrigation application ratio (or efficiency) will be increased accordingly.

The selection of an optimum PIS for a given site depends on tradeoffs between; type of PIS and its water application uniformity: the crop's sensitivity to water-stress and salinity; water cost, availability, quality, and supply reliability; irrigator, management, energy, and technical services quality, availability, affordability, and reliability; net cropping system returns to irrigation water; PIS system component costs; pumping energy cost and reliability; and financial stability and capacity. Holistic pressurized irrigation development has involved taking all of this into account.

During my lengthy (1953 to now) professional career in irrigation engineering I have been an innovator of both the physical technologies and the knowledge for efficiently utilizing them. My main focus has been devoted to developing the knowledge for efficiently utilizing the PISs along with utilizing and publishing it to make it broadly available. Much of this knowledge is presented in: Sprinkle and Trickle Irrigation, a 600+ textbook by Jack Keller and Ron D. Bliesner (which is available for purchase); and Farm Irrigation System Evaluation: A Guide for Management by John L. Merriam and Jack Keller, a 260+ page manual (which is out of print). I am in the process of making both of them available for downloading from a web site called "Open Library", see: http://openlibrary.org/works/OL4465974W/Sprinkle_and_trickle_irrigation. I have also begun developing a handbook Design and Evaluation of Small-Plot Irrigation for Agricultural Development to codify and make the knowledge I have gained from my most recent work. I plan to also make it freely available from Open Library.

Throughout my career I have had the opportunity to use this knowledge to design, evaluate, and manage irrigation system of all sizes and levels of sophistication. I have designed and evaluated PISs for large commercial irrigation projects and the smallest of household irrigated plots. I also have considerable hands-on innovative experience with all three basic PISs[1]. Since it is impossible to cover all of the details, this presentation focuses on a few highlights of my professional journey. It will also provide some simplified and intuitive ways to think about and deal with holistic PIS development.

[1] For surface irrigation they include: automated surge-flow (patented); and for small-very low-pressure, low-cost gated pipe for small-plot farmers. For sprinkle irrigation they include: center-pivot structures, DC electric drive mechanisms, sprinkler packages, and the initial spray nuzzling; gun and boom sprinklers; sprinkler pressure regulators (patented); and for small-plot farmers, low-pressure impact and impulse sprinklers along with low-cost tubing networks to supply them. For drip irrigation they include: pressure compensating emitters (patented): and for small-plot farmers, low-cost low-pressure high-flow emitters and low-cost tubing networks to supply them. I am also working on low-cost manual and small scale photovoltaic (PV) pumping and water storage for small-plot farmers.

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Optimal Pipe-Size Computation: A Reliability Based Approach

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1 INTRODUCTION

Over the past decades, objective functions minimizing capital and/or operating costs were formulated to optimize the pipe-size of water distribution networks (Alperovits & Shamir, 1977; Lansey & Mays, 1989; Simpson et al., 1994; Savic and Walters, 1997). However, the optimal design of distribution systems is a multi-objective process involving not only the cost but also the performance (Xu and Goulter, 1996 & 1997; Lamaddalena & Sagardoy, 2000; Bahayan et al., 2005). As uncertainties in water demand are relevant and can lead to uncertainties in the availability of pressure head at the nodes, they should be considered when new water distribution systems are to design or existing systems to rehabilitate (Bargiela and Hainsworth, 1989; Babayan et al., 2005).

Moreover, most of the efforts in formulating algorithms and approaches concentrated on drinking water distribution and only few considered irrigation systems.

In spite of the fact that the general concepts can be applied to both the systems, the formulation of the problem is completely different when dealing with irrigation, especially in case of on-demand operation (Lamaddalena & Sagardoy, 2000; Khadra & Lamaddalena, 2006; 2010).

One of the most important uncertainties in pressurized irrigation systems operating on-demand is the calculation of the discharges flowing into the network. As farmers control irrigation, it is impossible to know, a priori, the hydrants operating simultaneously. In such systems, the nominal discharge (d) attributed to each hydrant is much greater than the expected share, so that the hydrant operates for less than 24 hours. As a result, the probability of all hydrants being open simultaneously, is very low. Thus, it would not be reasonable to design the network for a discharge equal to the sum of the hydrants capacities. These considerations have justified the use of probabilistic approaches for computing the discharges in on-demand systems. As a matter of fact, the advent of on-demand large scale irrigation systems in early 1960's, in France, fostered the development of statistical models to compute the design flows. Examples of such models are the first and the second formula of Clément (1966).

After computing the discharges with the Clément model, the optimal pipe size diameters are computed by using optimization algorithms like Linear programming, Non-Linear programming, Dynamic programming or, more recently, Genetic Algorithms.

However, the one flow regime approach of Clément, commonly used, does not consider the important spatial and temporal variability occurring in the network and affecting the network performance and even crop yield (Pereira, 1999). Variabilities related to the discharges flow occur in such systems in relation to scheduling decisions over time depending on the cropping pattern, crops grown, meteorological conditions, on-farm efficiency and management strategy. These variabilities may produce failures related to the design options. Each group of hydrants operating simultaneously (or hydrants configuration), produces a discharge configuration (or a flow regime). The varieties of flow regimes cause variability in hydrant pressure and consequently, an adequate analysis of the hydraulic performance of the system is needed for better operation and adequate management. To this aim, models to assess the performance of pressurized distribution networks were developed assuming steady-state flow conditions, e.g., ICARE (CTGREF, 1979; CEMAGREF, 1983; Béthery et al., 1981; Béthery, 1990) and AKLA (Lamaddalena & Sagardoy, 2000; Calejo et al., 2008), or unsteady flow, e.g., FLUCS (Lamaddalena & Pereira, 2007 a & b), EPANET (Rossman, 2000) and GESTAR (Estrada et al., 2009) with convenient adaptations.

One of the indicators used to quantify the performance of water distribution systems is the reliability, which is usually defined by considering two different types of failures: i) demand variation failure (Bao & Mays, 1990; Duan & Mays, 1990; Li et al., 1993; Mays, 1996), and ii) mechanical failure (Germanopoulos et al., 1986; Goulter & Goals, 1986; Su et al., 1987; Wagner et al, 1988a, b; Ormsbee & kessler, 1990; Goulter & Bouchard, 1990; Park & Leibman, 1993; Wu et al., 1993; Goulter, 1995; Khomsi et al., 1996). The first is referred to situations where actual demands at the nodes exceed the capacity of the system, while mechanical failure relates to failures of the system components (e.g.: break of pipes, block of valves, etc).

Ait Kadi et al. (1990), and Lamaddalena (1996, 1997) presented a model for the optimization of pipe diameters in an on-demand irrigation network taking into account several demand conditions. Many hydrants configurations, delivering a total discharge corresponding to a pre-selected upstream peak discharge, are randomly generated. Each hydrants configuration generates a discharge configuration (r_1, r_2, ….., r_C) flowing into the network. Starting from the first generated discharge configuration r1, the optimal diameters are computed. This solution is considered as the initial solution for the next configuration r_2. The iterative process continues until all the discharge configurations, C, are considered. To be noted that the diameters of the sections can only increase or remain constant when moving from the configuration r_i to r_{i+1}. Therefore, the final optimal solution satisfies all the examined discharge configurations. This method gives interesting results when compared with the classical computation in which discharges are calculated by using the Clément approach. In fact, the cost of the network is usually lower while the performance is similar (Lamaddalena, 1996, 1997; Lamaddalena & Sagardoy, 2000). In spite of such a result, it should be noted that if one unfavourable hydrant is picked up (for example, a hydrant located in an unfavourable topographic condition) when applying this model, the cost of the final optimal solution may increase a lot, as each single hydrant of the generated configuration, needs to be satisfied in terms of pressure head.

Based on this consideration, a new approach for computing the optimal solution was developed. Three main aspects were, therefore, taken into account in the new model: i) the stochastic variability of the discharges flowing into each section of the network; ii) the reliability of the pressure head at each hydrant, as performance indicator, iii) the cost of the network.

The model was applied to an Italian irrigation network and the results were compared with the same network computed with the Clément discharges and with the cumulated random generated discharges (or FAO model). The optimization algorithm used for all the cases is the Labye iterative discontinuous method (Labye, 1981; Labye et al., 1988) which is a formulation of the dynamic programming, as described in the next session.

2 DESCRIPTION OF THE MODEL

The discharges flowing at the different sections of the irrigation network operating on-demand may strongly vary over time and space.

In order to account for such variability, a number of possible operation conditions of the network (configurations) are obtained by generating simultaneous openings of m hydrants out of the total number N (with $m < N$) using a random number generator. The adopted generation model assumes that the events follow a uniform probability of distribution.

Each generated configuration of hydrants corresponds to a discharge configuration. In fact, the discharge flowing into the sections of the network is calculated by considering the sum of discharges delivered by the open downstream hydrants.

The generation methodology of configurations adopted in this study, assumes that the upstream demand hydrograph is known or previously estimated.

After generating C configurations (r_1, r_2, ……, r_C), the Labye's Iterative Discontinuous Method extended for multiple discharge configurations was used to compute the optimal pipe-size diameters (Ait Kadi et al., 1990; Lamaddalena, 1995; Lamaddalena & Sagardoy, 2000). This method is divided into two stages.

In the first stage, an initial solution is obtained by assigning, to each section k of the network, the minimum commercial diameter $(D_{s,\,min})_k$ according to the maximum allowable flow velocity (v_{max}) when the section conveys the discharge of the first configuration r1 ($Q_{r1,k}$). The diameter for the section k is calculated by the relationship:

$$\left(D_{s,min}\right)_k = \sqrt{\frac{4Q_{r1,k}}{\pi v_{max}}} \quad (1)$$

After calculating the initial diameters, it is possible to calculate, for the first configuration r_1, the piezometric elevation $Z_{0\ in,\ r1}$ [m a.s.l.] at the upstream end of the network, satisfying the minimum head $H_{j,min}$ [m], required at the most unfavourable hydrant j:

$$\left(Z_0\right)_{in,r1} = H_{j,min} + ZT_j + \sum_{0\to M_j} Y_{k,r} \quad (2)$$

where:

$\sum_{0\to M_j} Y_{k,r}$ - are the head losses along the pathway (Mj) connecting the upstream end of the network to the most unfavourable hydrant, when the flow regime r_1 occurs.

The optimal solution for the configuration r_1 is then obtained by iteratively decreasing the upstream piezometric elevation selecting, for each iteration, the sections for which a change in diameter produces the minimum increase in the network cost. The selection process at each iteration is carried out as described below:

At any iteration i, the commercial pipe diameters (at most two diameters per section) D_{s+1} and D_s (with $D_{s+1} > D_s$) are defined for each section (Labye, 1988).

The coefficient

$$\beta_{Ds} = \frac{P_{Ds+1} - P_{Ds}}{J_{Ds} - J_{Ds+1}} \quad (3)$$

is calculated where P_{Ds} [€] and J_{Ds} [m m^{-1}] are respectively the cost and the friction loss per unit length of pipe diameter D_s [m], and P_{Ds+1} [€] and J_{Ds+1} [m m^{-1}] are respectively the cost and the friction loss per unit length of pipe diameter D_{s+1} [m],.

It can be demonstrated that any network can be reduced to an elementary scheme SN* (Figure 1). The minimum cost variation dP of SN* of any sub-network SN, and a section k in series with SN for any given variation dH_{SN*} of the head H_{SN*} [m] at the upstream end of SN*, is obtained by solving the following "local" linear programming (Ait Kadi et al.,1990; Lamaddalena & Sagardoy, 2000):

$$\min \cdot dP = -\beta_{Ds,SN} dH - \beta_{Ds,k} dY_k \quad (4)$$

subject to:

$$dH + dY_k = dH_{SN*} \tag{5}$$

where dH [m] and dY_k [m] are respectively, the variation of the head at the upstream end of SN and the variation of the friction loss in section k.

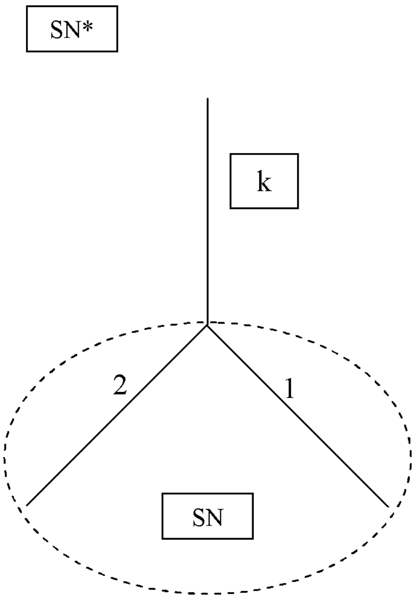

Figure 1 Layout of the elementary scheme SN* of the sub-network SN: an assembly of two sections 1 and 2, in series with the section k

The optimal solution of the equations (4) and (5) is:

$$dH = dH_{SN*} \text{ and } dY_k = 0 \text{ if } \beta_{Ds,SN} < \beta_{Ds,k} \tag{6}$$

$$dH = 0 \text{ and } dY_k = dH' \text{ if } \beta_{Ds,SN} > \beta_{Ds,k} \tag{7}$$

Therefore, the minimum cost variation, dP of SN* can be written as:

$$dP = -\beta * dH_{SN} \tag{8}$$

with:

$$\beta* = \min\left(\beta_{Ds,SN}, \beta D_{s,k}\right) \tag{9}$$

Hence, proceeding from any terminal section of the pipe network, the equation (9) can be used to determine the section that will vary at each iteration. In this process, $\beta_{Ds,SN}$ of the assembly of two sections in derivation is equal to:

$$\beta_{Ds,SN} = \beta_{Ds,1} + \beta_{Ds,2} \tag{10}$$

whereas, for two sections in series it would be equal to:

$$\beta_{Ds,SN} = \min\left(\beta_{Ds,1} + \beta_{Ds,2}\right) \tag{11}$$

It should be mentioned that in the case of a terminal section with a head in excess at its downstream end $H_j > H_{min}$, where H_j is the head at node j and H_{min} the minimum head required at j for an appropriate operation, the value of $\beta_{Ds,SN}$ to be used in the process is equal to zero as long as the excess head prevails.

The magnitude of $dH_{i,r1}$ for each iteration i of the configuration r_1, is determined as:

$$dH_{i,r1} = \min\left(EH_i, \Delta Y_i, \Delta Z_i\right) \tag{12}$$

where:

EH_i is the minimum value of the excess head prevailing in all the nodes where the head will change;

ΔY_i is the minimum value of $(Y_{k,i} - Y^*)$ for those sections which will change in diameters, with $Y_{k,i}$ the value of the head loss in the section k at iteration i, and Y^* for this section, the value of the head loss corresponding to the largest diameter over its entire length if the section has two diameters, or the successive greater diameter if the section has only one diameter. For those terminal sections with head in excess $(H_j > H_{j,min})$, ΔY_i is equal to the value of this excess $(H_j - H_{j,min})$.

ΔZ_i is the difference between the upstream piezometric elevation, $Z_{0\ i,r1}$ at iteration i when the flow regime r_1 occurs, and the piezometric elevation, Z_0, effectively available at the upstream end of the network.

The iterative process continues until Z_0 is reached, obtaining the optimal solution for the examined configuration r_1.

The process is repeated for each generated configuration, r_1, r_2, r_3, ….., r_C. Therefore, C *independent* optimal solutions are obtained, one for each configuration, each one having a different cost. The selection of the "*best solution*" is based on the reliability status, as explained hereafter.

3 ANALYSIS OF IRRIGATION SYSTEMS AND PERFORMANCE INDICATORS

Irrigation systems analysis is the process of using a computer simulation model to analyze the system performance capabilities and to define the system requirements necessary to meet the design standards for pressure and/or discharge.

Based on a computer model, network analysis can be used to determine the adequacy of the existing irrigation systems, to identify the causes of their deficiencies and to develop the most cost-effective improvements.

Results of the analysis allow for the mathematical definitions of some performance indicators which can help both designers and managers in selecting a satisfactory/optimal solution.

The model AKLA (Lamaddalena & Sagardoy, 2000) presented hereafter permits to analyze the performance at hydrant level considering two indicators: relative pressure deficit and reliability (Calejo et al., 2008; Khadra and Lamaddalena, 2010).

The water system operational status is described as either satisfactory or unsatisfactory, where unsatisfactory (failure) corresponds to a drop in pressure head (and/or discharge) at the hydrant below the minimum required for appropriate on-farm irrigation. AKLA consists of a multiple random generation of m hydrants simultaneously opened among the N total number (with $m<N$). Each generation produces a hydrants configuration (r) corresponding to a discharge configuration or a flow regime. Within each generated configuration (r), a hydrant (h) is considered satisfied when the following relationship is verified:

$$H_{h,r} \geq H_{min} \tag{13}$$

where $H_{h,r}$ [m] represents the head at the hydrant h within the configuration r, and H_{min} [m] represents the minimum pressure head required for an appropriate operation of the on-farm system.

The relative pressure deficit at each hydrant is defined as:

$$\Delta H_{h,r} = \frac{H_{h,r} - H_{min}}{H_{min}} \tag{14}$$

The following procedure is adopted for the computation. Once the upstream available piezometric elevation, Z_0 in m a.s.l, is established, the set of discharges to be tested, Q_r, and the number of configurations, C, to be investigated are selected. Assuming that each hydrant may withdraw the nominal discharge d [$l\ s^{-1}$] also when its pressure head is lower than the minimum required (H_{min}) (Lamaddalena and Pereira, 2007 a and b), for a given peak upstream discharge Q_r [$l\ s^{-1}$], the number of hydrants simultaneously operating is $m_r = Q_r / d$.

Two options are actually available in the computer software for the calculation of the head losses. Using the Darcy-Weisbach formulation, the head losses, Y (m), are

$$Y = \lambda_h \frac{L}{D}\frac{v^2}{2g}L \tag{15}$$

where D (m) is the pipe diameter, L (m) is the length of the section, v (m s^{-1}) is the flow velocity, g = 9.81 m s^{-2} is the acceleration of gravity and λ_h is the adimensional coefficient of resistance. This coefficient is calculated using the Colebrook equation:

$$\frac{1}{\sqrt{\lambda_h}} = -2.0\log\left(\frac{2.51}{R_e\sqrt{\lambda_h}} + \frac{\varepsilon/D}{3.71}\right) \tag{16}$$

where R_e is the number of Reynolds and ε is the absolute roughness (m) of the pipe. In a second option the head losses, Y (m), are computed from:

$$Y = 0.000857\left(1+\frac{2\gamma}{\sqrt{D}}\right)^2 \frac{Q^2}{D^5}L = uQ^2L \tag{17}$$

where γ is the roughness parameter of Bazin, expressed in $m^{0.5}$, Q (m^3 s^{-1}) is the discharge flowing in the pipe and u (m^{-1} s^2) is the dimensional coefficient of resistance. The other variables are the same as above. Hydrants having a pressure head lower than the minimum pre-established H_{min} are identified. Once the analysis is completed, it is possible to identify the range of variation of the head at each hydrant for each configuration, and the relative pressure deficit, $\Delta H_{h,r}$.

After the computation of the pressure heads ($H_{h,r}$) the reliability is defined at each hydrant. Reliability describes how often an irrigation system fails (Hashimoto, 1980; Hashimoto et al., 1982), and the definition is formulated by assuming that the performance of the system is described by a stationary stochastic process. Therefore, the probability distributions describing the time series (i.e., the time series of pressure heads and discharges at the hydrant being considered) do not change with time. This hypothesis is an approximation but, particularly during the peak periods, it is a reasonable assumption.

Let H_t be the random variable denoting the state of the system at a time t (where t assumes the values 1, 2,......, n_t). Then, H_t is identified as the pressure head at the hydrant level. At each instant t, the possible values of H_t fall into the category S, which is the set of all satisfactory outputs (the pressure heads at the hydrants are satisfactory when $H_{h,r} \geq H_{min}$), or the category F, which is the set of all unsatisfactory outputs (failure state: $H_{h,r} < H_{min}$).

The reliability of the system could be described as the probability α, that the system has a satisfactory state:

$$Re = Prob\left[H_t \in S\right] \tag{18}$$

Therefore the hydrant reliability ca be defined as follows (Lamaddalena & Sagardoy, 2000):

$$Re_h = \frac{\sum_{r=1}^{c} Ih_{h,r} Ip_{h,r}}{\sum_{r=1}^{c} Ih_{h,r}} \tag{19}$$

where:

Re_h - reliability of the hydrant h,

$Ih_{h,r}$ - 1 if the hydrant h is open in the configuration r,

$Ih_{h,r}$ - 0 if the hydrant h is closed in the configuration r,

$Ip_{h,r}$ - 1 if the pressure head at the hydrant h, open in the configuration r, is higher than the minimum pressure head,

$Ip_{h,r}$ - 0 if the pressure head at the hydrant h, open in the configuration r, is lower than the minimum pressure head,

C - total number of generated configurations.

For each discharge configuration the analysis performed with AKLA gives the available pressure head (m) at each operating hydrant. Indeed, the indexes $Ih_{j,r}$ and $Ip_{j,r}$ may be easily calculated and the relationship 7 may be applied for calculating the hydrant reliability.

Starting from the above definition, the reliability of the whole irrigation system can be defined (Lamaddalena et al., 2012):

$$Re_{Sys} = \sum \frac{Re_h}{N} \tag{20}$$

Combining the cost minimization with the reliability maximization, a Pareto-front optimal set of solutions can be produced and the trade-off between cost and reliability shown.

A non-dominated set of solutions is obtained and consequently, moving from one solution to another would improve reliability and degrade cost or vice versa.

An indicator I maximising the ratio Re sys to Cost sys where,

$$I = \max\left(\frac{Re_{Sys}}{Cost_{Sys}}\right) \tag{21}$$

allows for the selection of one solution in the Pareto-front: the selected configuration among all the identified optimal solutions is the one with the maximum amount of reliability per euro employed or, with the minimum average cost per unit of reliability.

This approach was applied to an on demand irrigation network as reported below.

4 APPLICATION

The irrigation network (Lamaddalena and Piccinni, 1993; Lamaddalena et al., 2012) serves an irrigable area of 582 ha equipped with 174 hydrants with nominal discharges of 5, 10 and 20 l s^{-1}. The area is up-sloping towards the origin of the network, with land elevations ranging from 15 m a.s.l. to about 24 m a.s.l. It is served by a lifting plant designed for a maximum discharge of 325 l s^{-1} with an upstream piezometric elevation Z_0 = 66.7 m a.s.l. The minimum pressure head at each hydrant (H_{min}) is 2 bars, the on farm equipment to serve, being low pressure sprinklers or drippers. The layout of the network is reported in fig 2.

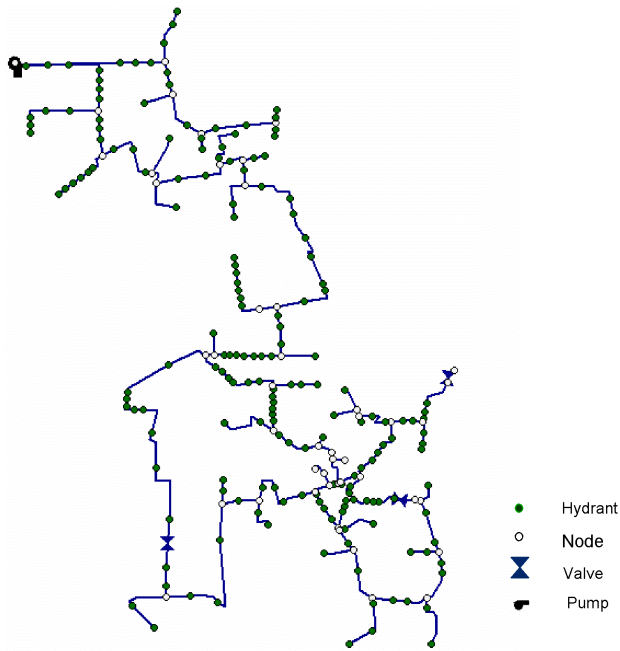

Figure 2 Layout of the network

By applying the same methodology as above, 500 different random discharge configurations were generated, each corresponding to a discharge of 325 l s^{-1}, and 500 different optimal solutions were computed, each one having a different cost and a different reliability Re_{Sys}.

In fig 3, the cost of the networks versus the configurations are represented, classified in a decreasing order. Also in this case, an important reduction of the cost is observed after few configurations are generated. In particular, the maximum reported cost is $5.41x10^5$ € and it decreases down to $5.26x10^5$ € and $5.17x10^5$ € when 5% and 10% of the most unfavourable configurations are respectively eliminated. The overall reliability Re_{Sys} (eq 18) is 0.98, 0.97 and 0.96 for the networks registering the maximum cost ($5.41x10^5$ €), a cost of $5.26x10^6$ € and of $5.17x10^6$ € respectively. The value of the overall system reliability considerably decreases when more than 10% of the most unfavourable configurations are eliminated (fig 4 and 5), the cost of the network remaining almost the same.

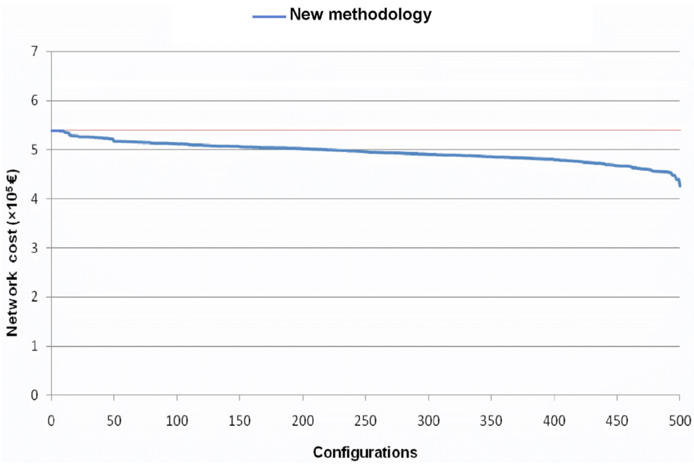

Figure 3 Variation of the cost of the network versus the generated configurations

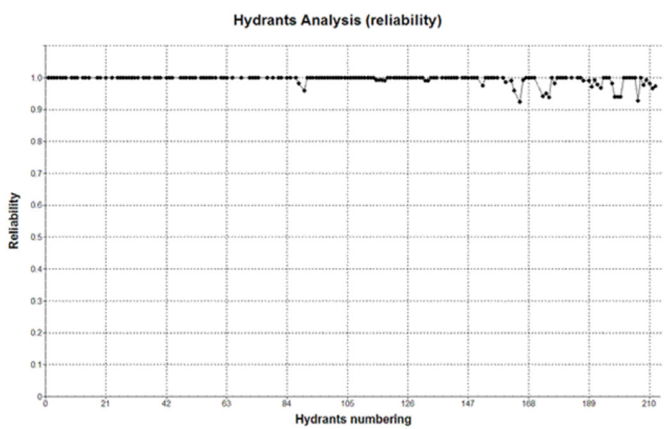

Figure 4 Reliability at hydrant level of the network eliminating 15% of the most unfavourable configurations

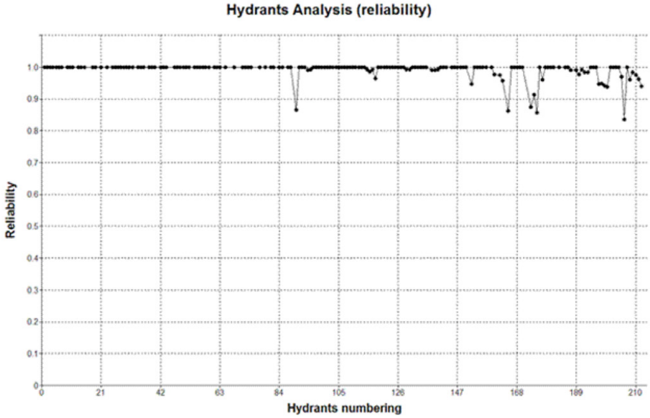

Figure 5 Reliability at hydrant level of the network eliminating 20% of the most unfavourable configurations

In fig 6 the costs of the network are represented, as for discharges computed using the Clément model, the cumulated random discharges model (FAO) and the new developed methodology. It can be observed that the cost related to the Clément solution is always the highest, while the cost calculated using the cumulated random discharges approach corresponds to the maximum cost registered as compared to the new methodology.

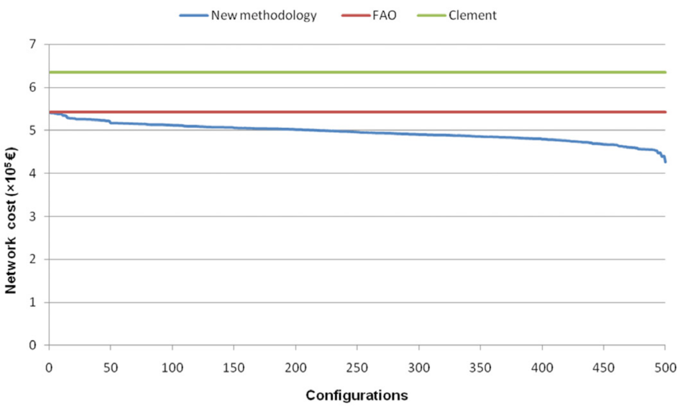

Figure 6 Variation of the cost of the network versus the generated configurations: comparison among three models

In Figure 7 the reliability Re_{Sys} versus the cost is represented, for the network. A cloud of points is generated showing a non linear relation cost- Re_{Sys}. Figure 8 shows the Pareto-optimal set of solutions produced and the trade-off between Reliability and cost. The indicator I (eq.21) allows for the selection among the identified optimal solutions of the configuration which gives the maximum amount of Re_{sys} per Euro employed,

$$I = \max\left(\frac{Re_{Sys}}{Cost_{Sys}}\right) \tag{22}$$

the cost and the performance respectively for the selected optimal network being $Cost_{Sys} = 5.1510^5$ € and $Re_{Sys} = 0.9$.

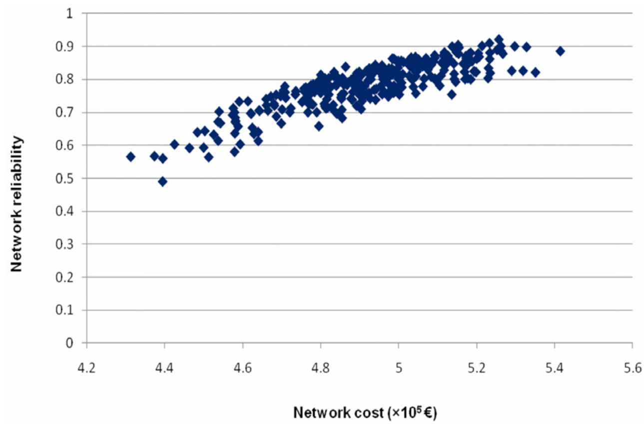

Figure 7 Variation of the network reliability versus the network cost

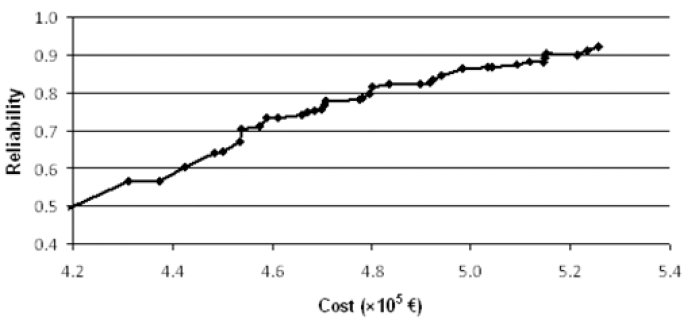

Figure 8 The optimal solution

5 CONCLUSIONS

Multiple configurations of hydrants or flow regimes occur in on demand irrigation systems. A new optimisation approach based on both the cost and the reliability of irrigation networks operating on demand, and considering the stochastic variability of the discharges flowing into each section of the network is reported.

A Pareto-front optimal set of solutions is obtained and a relationship established between cost and reliability allows for the selection of the optimal network with the minimum average cost per unit of reliability.

The new methodology was applied to an irrigation system operating on demand, in Southern Italy.

A comparison was made among the networks optimised using the models proposed by Clément, the FAO and the new methodology. From the above, the following considerations can be drawn:

The application of Clément model results in networks with higher costs as compared to the same networks optimized using FAO model. Applying the new methodology, the cost of the optimal network may be reduced by more than 20% as compared to FAO model, without any significant decrease in the system reliability or any reduction of the network capacity.

Future research aims to evaluate the benefits of gains in the system performance in monetary terms, in order to compare marginal cost and benefit and to identify the economic optimal configuration in the Pareto-optimal set.

6 ACKNOWLEDGEMENT

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APPENDIX - Notation

- C total number of generated configurations
- d hydrant nominal discharge, l s^{-1}
- dH variation of the pressure head, m
- dP minimum cost variation, Euro
- D_s commercial pipe diameter, m
- dY variation of the friction loss, m
- EH minimum value of the excess head prevailing in all the nodes where the head changes, m
- F set of all unsatisfactory states
- H pressure head, m

Ih hydrant operation index
Ip pressure head index
J friction loss of the pipe diameter per unit length, m m^{-1}
L generic length, m
M pathway starting form the network upstream end
m number of hydrants simultaneously operating
N total number of hydrants
P cost of the pipe diameter , Euro
Q discharge, l s^{-1} or m^3 s^{-1}
Re reliability
S set of all satisfactory states
SN sub-network
*SN** elementary scheme
u dimensional coefficient of resistance, m^{-1} s^2
v flow velocity, m s^{-1}
Y head losses, m
Y^* the value of the head loss corresponding to the largest diameter over its entire length if the section has two diameters, or the successive greater diameter if the section has only one diameter, m
Z_0 upstream piezometric elevation, m a.s.l
ZT topographic elevation, m a.s.l
β coefficient
ΔH relative pressure deficit, m
ΔY_i the minimum value of $(Y_{k,i} - Y^*)$
ΔZ the difference between the upstream piezometric elevation for a particular flow regime, and the piezometric elevation, effectively available at the upstream end of the network.
ε absolute roughness, m
γ roughness parameter of Bazin, $m^{0.5}$
λ_h adimensional coefficient of resistance

Subscripts

h hydrant
i iteration
in initial
j the most unfavorable hydrant
k section of the network
max maximum
min minimum
r configuration
sys system
t time

Pressurized Irrigation Dealing with Water and Energy Efficiencies

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16 Pressurized Irrigation Dealing with Water and Energy Efficiencies

1 INTRODUCTION

Irrigation of agriculture lands demands 70% of the total water world consumption and the FAO (2003) report foresees that irrigation water will increase by 14% until 2030. Over a quarter of a billion hectares of the planet are irrigated and entire countries depend on irrigation for their survival and existence. The water input per unit irrigated area will have to be reduced in response to water scarcity and environmental concerns. Water productivity is foreseen to increase through gains in crop yield and reductions in irrigation water. In order to meet these estimations, irrigation systems will have to be modernized and optimized. Thus, most of old irrigated districts in developed countries have undergone the modernization of its irrigation systems and have changed the open channel distribution systems to pressurized piped systems. In addition, these systems have been installed in new modern irrigation areas.

Nowadays, irrigated agriculture by pressurized systems is facing the challenges of both water and energy efficiencies since the widespread tendency of reducing water availability and increasing energy price. These factors would determine the feasibility of irrigated agriculture in many areas of the world in the short term. Within this framework, the management and operation of collective pressurized irrigation water networks to improve the energy efficiency will be a key point. So, there is a need for proper design and regulation of pumping stations in collective irrigation networks to supply water demand based on water and energy management strategies (irrigation scheduling, water duties distribution).

The following sections highlight some of the key issues in pressurize irrigation, taking as an example the Spanish context, and foresee some future challenges.

2 KEY ISSUES

2.1 Facing water scarcity: Surface irrigation versus pressurized irrigation

The application of more efficient irrigation methods is expanding rapidly as a result of the increasing demand for higher irrigation efficiency, improved utilization of water and intensification and diversification of production. An irrigation system consists of canals and structures for conveying, regulating and delivering water to the users. In general, water is conveyed by open channel systems (surface irrigation) and pressured piped systems (pressurized irrigation).

In surface irrigation (furrow, basin, border,. ..), the water is delivered to the field plots and is spread over the soil surface (Figure 1). In pressurized irrigation (sprinkler and localized methods), water in form of raindrops fall over the entire irrigated area in sprinkler irrigation and the water drips at low rates and localizes in a small soil surface area around the plant in drip irrigation (Figure 2).

Pressurized irrigation methods have developed worldwide in the last years. In arid and semi-arid zones they are replacing the traditional open canal surface methods. Their efficiencies and water productivity are higher than in the traditional methods since soil infiltration does not control irrigation, as it does in surface irrigation, although the wind and the evaporation rates may became an issue in sprinkler irrigation. Also, their operation can be easily programmed and controlled by means of hydraulic valves and other electronic devices. However, the technology for the automation of surface irrigation is not as simple as in pressurized irrigation and is less developed.

A. B. C.

Figure 1 Surface irrigation methods

A. B. C.

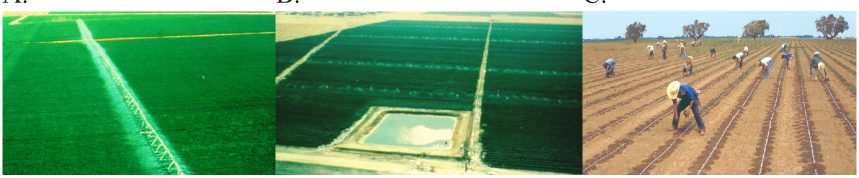


Figure 2 Pressurized irrigation. (A): Lateral move sprinkler irrigation; (B): solid set sprinkler irrigation, and (C): surface drip irrigation

In addition, surface irrigation requires less energy than pressurized irrigation. Unfortunately, the energy prices have drastically risen during the last decade becoming one of the main concerns for farmers' profitability. As an example, the energy cost could reach over 30 % of the total irrigation cost in some Spanish irrigation districts. Within this framework only the most profitable irrigated crops would be able to succeed in pressurized irrigation.

2.2 Modernization of irrigation systems

Considering the water scarcity scenario, the modernization of irrigation systems has changed the traditional open-channel gravity based systems to pressurized piped systems (Figure 3).

A. B. C.

Figure 3 Irrigation distribution systems: (A): Traditional surface irrigation field in south Spain; (B) open channel and (C) installation of pipes for pressurized irrigation

Modernization and optimization of irrigation systems have often been promoted in public and private agendas as tools to improve irrigation efficiency, saving water and producing more agricultural commodities with less water input. The transformation combines changes in rules and institutional structures, water delivery services, technical and managerial upgrading and advisory and training services, in addition to the introduction of modern equipment, structures and technologies. Specific objectives of modernization include the increase in the following issues: water productivity, cost effectiveness of funds, reliability and flexibility of irrigation deliveries, agriculture competitiveness (possibility to irrigate more profitability crops), and meeting environmental requirements. Table 1 shows a snapshot of the total irrigation area devoted to pressurized irrigation in several world countries.

The improvement of irrigation structures via construction works has been the traditional way to change irrigation efficiency. Many political decisions have adopted ambitious plans to improve irrigation structures with objectives such as improving the competitiveness of local irrigated agriculture, rural development, environmental protection and increasing the available water resources.

According to the Spanish Ministry of Agriculture, Rural and Environment (2002 and 2006), a surface of 2 000 000 ha has been modernized in Spain with an estimated cost of 7400 MEuros (80% paid by the Public Administration) in the National Irrigation Plan (Plan Nacional de Regadíos). 80% of the water consumption nationwide was devoted to irrigation before the transformation and this value has decreased to 65 % afterwards. The water savings has been estimated in 1132 hm^3/year.

In order to increase irrigation efficiency, water structures and water management can be improved. Playán and Mateos (2006) have developed a diagram which highlights the actions, effects, technical results and outputs in modernization and optimization of irrigation systems in Figure 4.

Table 1 Total irrigated area and its percentage devoted to pressurized irrigation

Country	Total irrigated area (Mha)	Sprinkler	Micro irrigation	Total sprinkler and micro irrigation	Percentage of total irrigated area	Year of reporting
		ha				
USA	21.6	10,900,000	1,200,000	12,100,000	56.0	2003
Russia	4.5	3,500,000	20,000	3,520,000	78.2	2008
China	55.9	2,634,000	371,000	3,005,000	5.4	2005
India	56.8	1,634,997	864,000	2,498,997	4.4	2007
Spain	3.36	715,102	1,502,327	2,217,429	66.9	2007
Brazil	3.5	1,570,000	340,000	1,910,000	54.58	2004
France	1.575	1,379,800	103,300	1,483,699	94.2	2000
Italy	2.535	1,047,680	365,700	1,413,380	55.8	2000
South Africa	1.6	848,000	296,000	1,144,000	71.5	2004
Saudi Arabia	1.17	716,000	198,000	914,000	78.1	2004
Australia	2.384	524,480	190,720	715,200	30.0	2000
Canada	0.87	683,029	6,034	689,063	79.2	2004
Mexico	6.2	400,000	200,000	600,000	9.7	1999

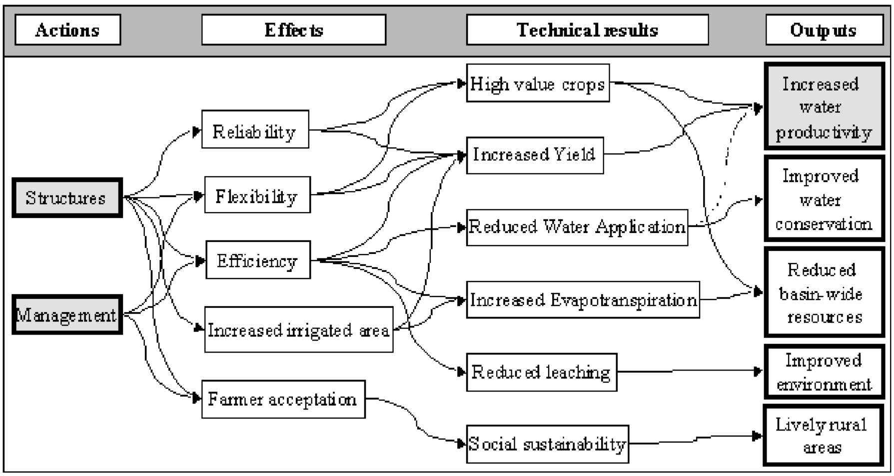


Figure 4 Flux diagram of the actions, effects, technical results and outputs related to irrigation modernization and optimization. (Source: Playán & Mateo, 2006)

2.3 Collective pressurized water networks

In Spain, the major part of the irrigation area, 69% of 3 700 000 ha, is managed by more than 7 000 Water Users' Associations (WUAs) (MAPA 2002). These organizations are corporations under public law which hold the water concessions for an irrigable area and have the responsibility of organizing collective exploitation of common public surface water and groundwater, and for managing the collective networks and pumping stations to provide water and pressure to every user. WUAs have a long tradition in Spain and some of them have a very old history (Plusquellec, 2009).

Modernized irrigation systems are based on collective pressurized water networks (Figure 5). Water is delivered to the final users on demand basis or on the contrary, it adopts a network's sectoring which is usually associated with an organization of irrigation events in turns. Irrigators file water orders at their WUAs. In addition, in in many areas of Spain, the Irrigation Advisory Services assist the farmers with proper scientific and technical support to make agriculture a sustainable activity compatible with the agro ecosystem.

A. B.

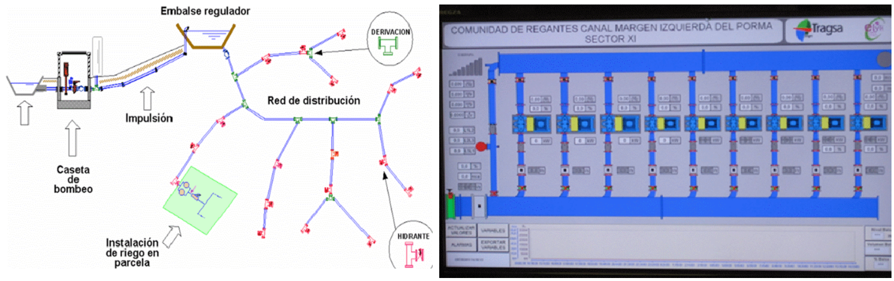


Figure 5 Pressure collective networks: Scheme of a small irrigation district (A) and control panel for the pumping station (B)

In order to improve the operation of the irrigation networks, several user friendly computer models are available for analysing the hydraulic networks such as: EPANET (Rossman, 2001), COPAM (Lamaddalena & Sagardoy, 2000), and GESTAR (Aliod et al., 1997). The calibrated hydraulic model can be used to characterize the hydraulic behaviour of the network for each possible scenario and could be used as a tool for pressure collective network management.

One of the main concerns on the design of water distribution networks is the selection of the pump's model that best fits the water demand under specific pressure head requirements. However, the behaviour of the pumping station depends mostly on the real performance conditions, and not on the conditions considered in the design process. Thus, the optimization of the management and regulation of pumping stations is one of the key points to improve the energy efficiency in collective irrigation networks.

2.4 Automation on operation, control and management of collective pressurized networks

The application of new technologies to the control and automation of irrigation processes is quickly gaining attention. The automation of irrigation execution (through irrigation controllers) is now widespread. However, the automatic generation and execution of irrigation schedules is receiving growing attention due to the possibilities offered by the telemetry/remote control systems currently being installed in collective pressurized networks. These developments can greatly benefit from the combination of irrigation system and crop models, and from the interaction with agro climatic databases, hydraulic models of pressurized collective distribution networks, weather forecasts and management databases for water users associations.

The efficient operation of an irrigation system depends on the type of the installation and the way the water is delivered to the farm. Sometimes, the irrigation installation fails to give full satisfaction because of poor design, faulty installation, or equipment that does not conform to specification. However, the way both the irrigation system as a whole and its component parts are operated and maintained will determine the success or failure of any properly designed and installed system.

Pressurized irrigation systems are fully automated in modernized irrigation districts. The typical elements from a pumping station of an automated irrigation district are shown in Figure 6. They consist of several centrifugal pumps driven by electrical motors, which speed is regulated by a frequency speed drive elements, flow devices and pressure gauges, which log discharge and pressure measurements at certain points to the central station, filters, air valves and solenoid hydraulic valves (shut-off valves, check valves, regulating valves, safety valves).

Pumps, filters and hydroneumatic tanks

Flow measuring devices

Pumps with control devices

Frequency speed drive

Hydrant in the field

Remote controller outside the pumping station

Figure 6 Typical elements from an automated pumping station in a modernized irrigation district in Spain

2.5 Coping with high energy prices

Modernization of irrigation systems has led to an increase in the energy consumption of collective networks for irrigation water distribution. Moreover, the users must face a substantial increase in energy cost plus the amortization cost of new infrastructures developed during the modernization of irrigation systems. Table 2 shows the average water use and energy consumption in Andalucía irrigation districts (Spain). In Fig. 7, we observe that the Spanish national energy consumption for the pressurized irrigation systems has gradually increased over the period from 2006 to 2010. 70% of the Spanish demand concentrates from May to September (summer season) and the other 30% from October to December. Nowadays, the energy consumption ranges over 600 GWh /year and the power requirement over 500 MW/year.

Table 2 Water use and energy consumption in Andalucian irrigation districts in 2008. (Source: Corominas, 2010)

Irrigation method	Average water use (m^3/ha)	Energy consumption	
		(kW h/m^3)	(kW h/ha)
Surface	5500	0.06	328
Sprinkler	5000	0.34	1723
Drip	2500	0.51	1264

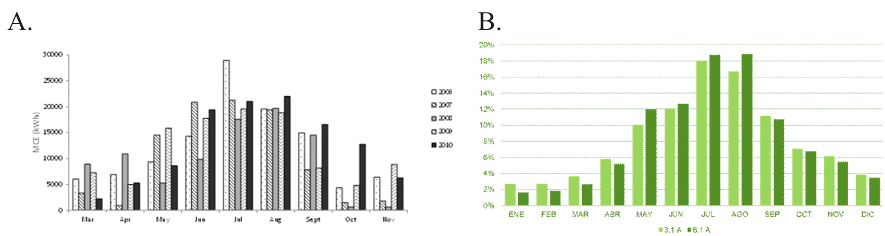


Figure 7 Energy consumption in Spanish irrigation districts. (A): Consumption (MCE, kWh) for different irrigation methods from 2006 to 2010, and (B): Monthly consumption on irrigation tariffs 3.1. A and 6.1.A in 2010. (Source: Iberdrola Generation SAU)

The energy dependence of irrigation water distribution systems has been aggravated by the drastic rise in electricity tariffs in Spain since the abolition of special rates for irrigation and liberalisation of the electricity market in 2008. The Spanish farmers can choose among several electrical tariffs which vary during the day and are grouped on three categories: peak, medium, low (Figure 8). Within the new scenario in energy prices, the farmers complain about the sustainability of irrigation with such as drastic increase in energy cost. This can be mostly explained by the subscription of high power specifications in the farmers' contract with the electrical supplier, and also because the power term cost is paid all year around although pumping is concentrated in five months.

Figure 8 Electrical tariffs in Spain. (Source: Iberdrola Generation SAU)

Since 2006, the Spanish electrical tariffs have increased the power term about 455 % and the energy term about 70% although the farmers' revenue has not changed accordingly (Figure 9). As a consequence, the irrigated area has decreased in 14% (see Table 3).

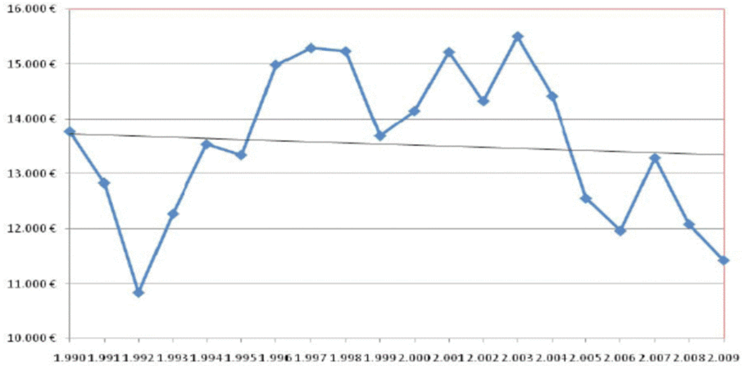


Figure 9 Evolution of Spanish farmers' revenue from 1990 to 2009

Table 3 Changes in irrigation area after the increase in electrical tariffs

Irrigation method	Before 2009		2009		2010	
	ha	%	ha	%	ha	%
Surfae	1,973,336	59	1,064,248	31.1	1,043,704	30.6
Sprinkler	802,712	24	765,400	22.4	735,544	21.6
Drip	568,588	17	1,591,616	46.5	1,628,705	47.8
Total	3,344,636	100	3,421,304	100.0	3,407,953	100.0

Within this framework, what can we do when energy becomes a key factor in pressurized irrigation? Improve energy efficiency? Reduce energy cost?

The energy efficiency regards with the reduction in energy consumption while economic efficiency deals with the lowest energy cost for the same energy consumption. The first might improve by enhancing the design, operation and management of the irrigation systems network. The second might improve by enhancing the energy terms in the farmers' contract with the electrical supplier.

The Spanish Ministry of Industry through the Regional Agencies of the Energy, has implemented a group of measurements dealing with the improvement of the energy efficiency in irrigable areas (IDAE 2008). Regional Energy Agencies develop audits for the improvement of the energy efficiency in irrigated areas http://www.idae.es/index.php/mod.pags/mem.detalle/relcategoria.1034/id.93/relmenu.55).

The energy audits in Water Users Associations in Spain pursue the following goals:

✓ Assess the energy efficiency (adequacy in the design of the pumping system components and their management).

✓ Give a grade to the Water Users Associations assessing its energy efficiency.

✓ Propose measures to reduce the energy consumption and, therefore the operation cost in collective irrigation networks.

The measures adopted by the audits can be classified into two groups: measures affecting the performance of energy consumer equipment (pumps, engines, filters, variable speed drives), and measures affecting the design and management of the network, such as sectoring, design of new pipelines or reservoirs.

Among the measures adopted to reduce energy consumption, it is mentioned the division of water distribution networks in sectors of similar energy requirements hence, hydrants will be grouped regarding a similar energy demand and irrigation will be arranged as a given schedule. Also, the analysis and control of critical points is another alternative to improve network operation by saving energy. On the other hand, the power term in the farmers' contract with the electrical supplier, could be set by considering the real demanded irrigation requirements.

Although energy audits have been conducted in irrigation networks managed by Water Users' Associations, the implementation of the proposed energy conservation measures has not been always successful. However, the implementation of the measures proposed in a Strategy for Efficient Energy Management, specific for each WUAs, in a southeast Spain irrigation district, has increased the average energy efficiency (Rocamora et al. 2012).

3 CHALLENGES

The above sections aimed at summarizing the key issues of pressurized irrigation in Spain. The modernization of irrigation techniques has improved water use efficiency but it has also highlighted the concern about the feasibility of irrigated agriculture in a scenario of high energy prices. Other countries would have to learn from this experience when dealing with irrigation strategies.

Even though in recent decades irrigation technology and management of irrigation systems have been highly improved, there are still some gaps to meet the challenges derived from population growth and human development in the next decades. Research is still needed to assess the impact on basin-level water use of irrigation modernization and optimization of collective pressure networks. Likewise, the effects on the socio-economic sustainability of agricultural communities and on water quality in the river basin will have to be also evaluated.

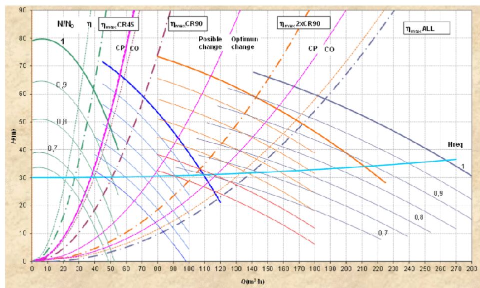
In the short term, challenges would be in the following issues:

1. Optimization in the design, operation and regulation of pumping systems

There is a need to develop criteria for a proper design, operation and regulation of pumps in pumping stations taking into account energy efficiency (Figure 10).

A.

B.



Figures 10 (A) Pumping station on an irrigation district and (B) Diagram with the pumping operation curves

2. Proper operation, regulation and maintenance of hydraulic valves (Figure 11).
3. Management of pressurized irrigation networks.

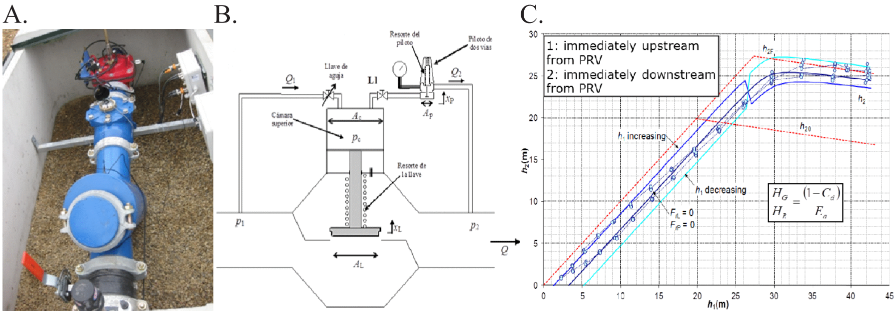
➢ Optimize water and energy by grouping the irrigation sectors attending to: the network topology and monthly water demand. The number and arrangement of operating sectors would change during the irrigation season according to water demand variability (Figure 12).

✓ Accurate estimation of crop water demands and irrigation practices

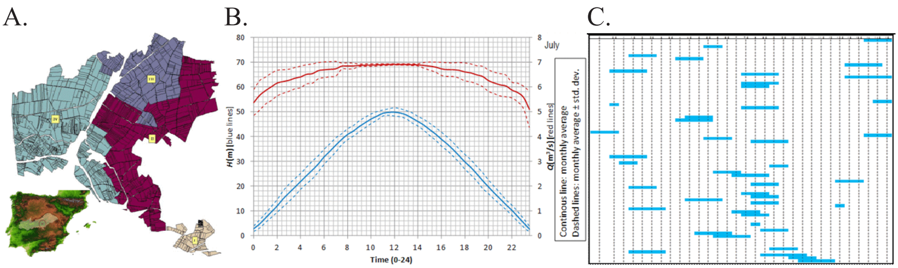
➢ Water orders allocated and executed for optimizing water productivity and energy cost by application of procedures such as genetic algorithms, dynamic programming etc.

➢ Simulation of different global (cropping patterns, irrigation operation,...) strategies performance on energy balance in irrigated districts.

➢ Determination of key factors for improving energy balance.



Figures 11 (A): Elements of a field hydrant; (B): Sketch of a flow regulator valve and (C): Diagram showing the operation of a flow regulator valve. (Source: Sánchez et al., 2012 a)



Figures 12 (A): Localization of irrigation district; (B): Water demand estimated by dynamic programming and (C): 24 hour period simulation of operation for on-demand hydrants (blue=open). (Source: Sánchez et al., 2012b).

4. Participatory irrigation management

➢ Public participatory policies with the participation on debates on water allocation, operation and management of irrigation networks of water users from the same basin.

➢ Building the basis of a sustainability framework incorporating indicators and indicator selection, reporting guidelines and evaluation within a participatory approach between irrigation researchers and industry/organisation stakeholders. This will allow delivery of triple-bottom-line reporting in an irrigation context that is integrated with the broader catchment.

5. Training and capacity building of farmers and managers

➢ Periodical training of technicians and irrigators in the operation, assessment and maintenance of pressurized irrigation systems.

6. Use of renewable energy sources

➢ Solar panels, windmills (Figure 13).

7. Development of precision pressurized irrigation systems

➢ System for remote sensing crop assessment.

A. B.

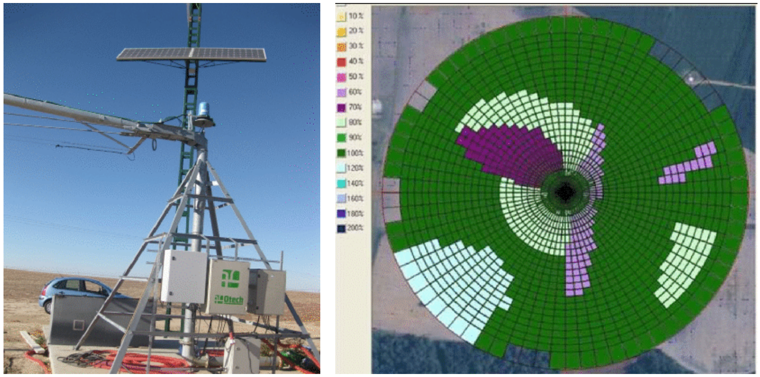


Figure 13 Center pivot irrigation: (A) solar panel and (B) water distribution in the soil

- System for digital management of water application for irrigation in the field.
- Wireless soil water content monitoring and groundwater system.
- Spatial decision support system.

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Measurement of the Dirtiness of Irrigation Water for Micro Irrigation Filters

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1 INTRODUCTION

In the 80's the Institute for Agricultural Engineering (in Afrikaans: Die Instituut vir Landbou-Ingenieurswese, or ILI as we are generally known) embarked on the development of a test method for micro irrigation filters. The main reasons why ILI tests agricultural equipment are:

- To get to know the products better.
- To find out what their performances are and
- To draw comparisons between products of the same kind.

The first point is obvious: one only gets to know a product if you work with it. The second point is also straight forward and many standard test methods are usually available for such tests. When it come to micro irrigation filters we found that the third point was far from easy to achieve.

The first thing that we have tried was to compare all the filters one on one with a "standard filter" (Figure 1). We found though that many filters clogged much faster than the "standard filter" and also the other way round.

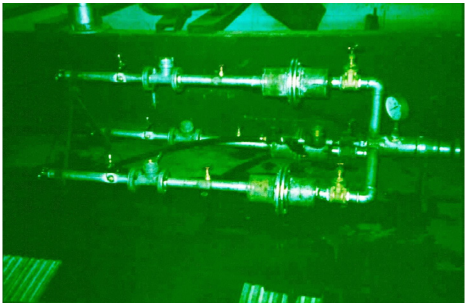

Figure 1 The small black (circled) filter in the centre was used as "standard filter"

Because of the fact that the test water gets cleaner when it is filtered (all water is re-circulated in our tests) the different filters did not work under the same conditions and therefore the test results could not be compared.

After that all the filters were connected to a common manifold and tested with water from a huge reservoir (Figure 2).

Even though the reservoir was so big, the clogging times amongst the filters differed so much that the same problem was experienced of test results that were obtained under differing test conditions. It became clear that a bare comparative test would not work and that we would have to move to a quantitative test method to be able to compare the filters with each other.

To be able to do this it was necessary to be able to measure the dirtiness of the test water in a differentiating way as it is explained in the abstract. What we had to do was to measure the concentration of particles larger than a certain size in the test water and the way we tried to do this was as follows:

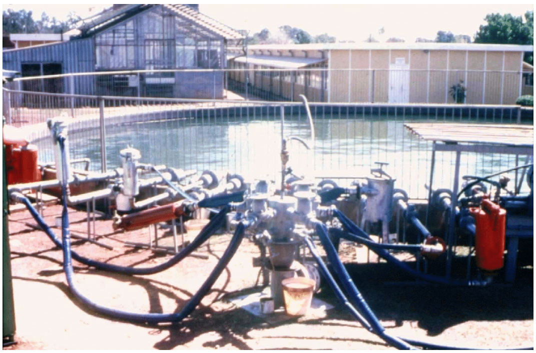

Figure 2 All filters were connected to a common manifold in an attempt to compare them with each other

A rain gauge was modified in the following way: the opening of the rain gauge was covered with a 200 µm screen for instance. An opening was made at the bottom and the test water was pumped into the rain gauge through it while a filter is tested. All particles larger than 200 µm would be held back by the screen but smaller particles will overflow together with the water and collected in a tank beneath the rain gauge (Figure 3). When a measurable amount of dirt has collected underneath the screen, the circulation will be stopped and the dirt allowed to settle in the bottom of the rain gauge. The height of the settled dirt would be measured and the gauge was calibrated to give the volume of the dirt in mL.

The overflow water in the tank is measured in L and converted to m^3 and the concentration of the dirt expressed in parts of dirt (mL) per million parts of water (m^3). Again did the problem arise that many filters got clogged long before enough dirt was collected to be measurable.

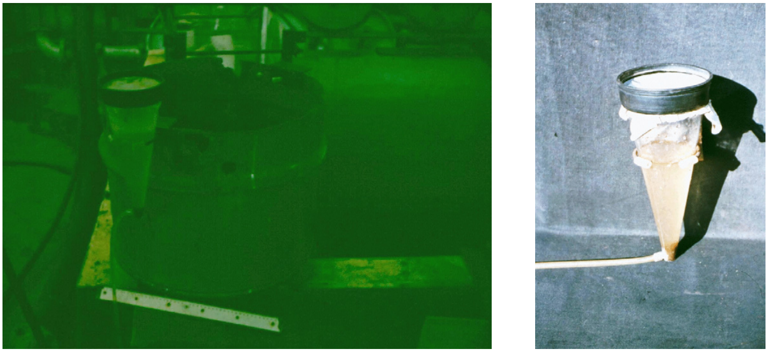

Figure 3 Measuring the concentration of dirt in the test water in ppm (volumetric)

While these tests were running, we also wanted to know what are the largest particles that got through the filters to establish what the actual filtering fineness of each filter was. This was done by drawing a sample of the filtered water through a small and very fine screen and to measure the sizes of the largest particles that have accumulated on it with a microscope (Figure 4). We found that these screens clogged very fast and that has put us onto the idea of using such screens to also measure the dirtiness of the test water.

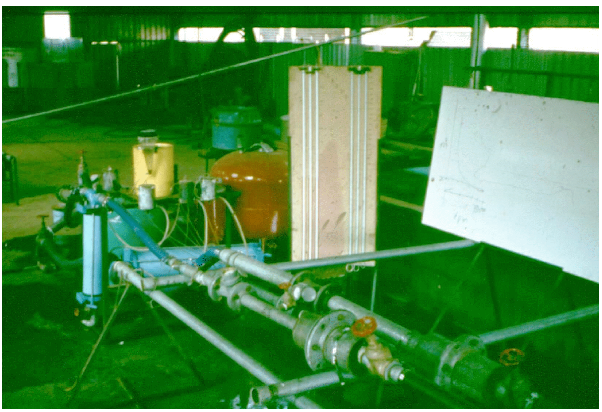

Figure 4 Drawing samples of the filtered water at the valve in the circle

2 THE DEVELOPMENT OF THE DIRTINESS INDEX METER (DIM)

On the strength of the last remark ILI set out on developing a device that could put this idea into practice:

2.1 Prerequisites for the DIM

The prerequisites that were set for a dirtiness meter were as follows:

- It should produce an increasing value for the dirtiness of the water when the dirtiness of the water increases.
- It should be capable of repeatable measurements.
- It should consider the fineness of the filter's element and still give about the same dirtiness value for the same water.
- It should be as fast, simple and cheap as possible.

2.2 Construction of the DIM

The DIM was assembled using 20 mm galvanized pipe fittings. The basic components of the meter were: a water meter that could measure low flow rates, e.g. a household municipality meter, with a small screen mounted on the inlet side, two brass gate valves, a 250 kPa pressure gauge and a 2000 L/h flow control valve. In Figure 5 detailed information is given on all the components and how they are assembled. The only component that must be manufactured, is the small screen in the water meter and this is done as follows:

Two brass washers, with a thickness of approximately 1,5 mm, and a 12 mm hole in each of them must be made in such a way that they fit neatly, though not too tightly, into the mounting nut of the water meter. A nylon screen of appropriate mesh size is cut to the same size as the washers and clamped between them with the mounting nut of the water meter.

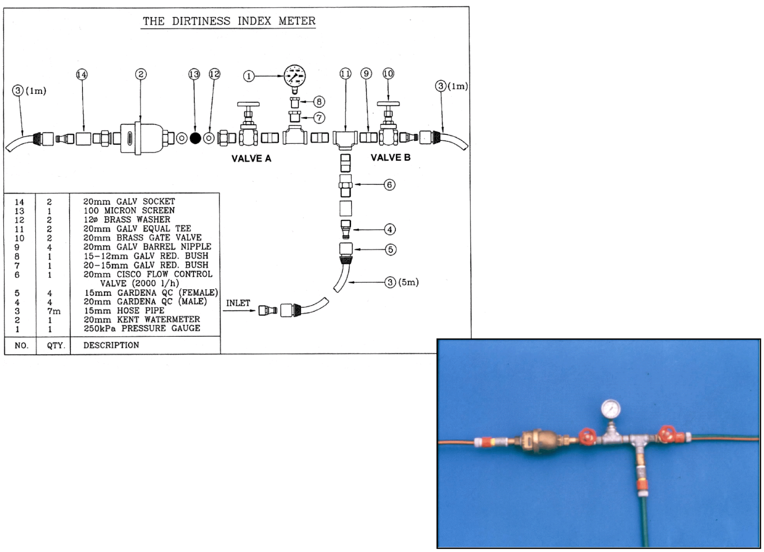

Figure 5 Construction of the Dirtiness Index Meter (Niekerk et al., 2006)

All components are screwed tightly together with sealing tape, except for the mounting nut on the inlet side of the water meter, which is only tightened by hand to enable easy access to the small screen (it is not critical if water leaks at this point).

2.3 Basic working principle of the DIM

The instrument works on the principle that an accelerated clogging test is done under controlled conditions on a screen similar to that of the filter for which the dirtiness of the water is measured. This is determined by measuring how many litres of water can be forced through the small screen by a pressure rise of 50 kPa against the screen as follows (Niekerk et al., 2006).

The DIM is prepared and operated in the following way: take the reading on the water meter (X), close valve A (Figure 5) and fully open bypass valve B. Install the right screen in the DIM, see that it is clean. Connect the DIM to a pump with a pressure of at least 200 kPa and slowly close valve B until the reading on the pressure gauge reaches 110 kPa. Open valve A fully. This will cause the pressure to drop to between 30 and 50 kPa (depending on which water meter is used). As the screen becomes clogged, the pressure will start rising again. When it reaches 100 kPa, close valve A and take the new reading on the water meter (Y). Subtract X from Y and this will give the amount of water that has clogged the screen in L.

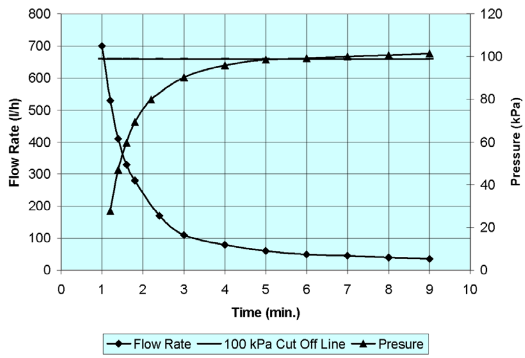

Figure 6 Flow rate and pressure build up characteristics of the Dirtiness Index Meter

The reason for setting the pressure at 110 kPa and taking the water meter reading at 100 kPa can be illustrated by Figure 6. This figure shows what happens in a DIM with a 100 μm screen and a DI of about 10 of the water during a DI measurement. When valve A is opened, the pressure drops to between 30 and 50 kPa and the initial flow rate through the water meter is 700 L/h. As the screen becomes clogged, figure 6 shows what happens with the flow rate and the pressure. The area under the flow rate curve is the volume measured by the water meter. In the beginning the DIM was left until the water meter stopped, but being a mechanical meter subject to vibration it would, for e.g. stop once after 6 minutes and then again after 10 minutes. This led to readings that could differ by 10% or even more from each other. Monitoring the pressure and taking the readings at 100 kPa made much more exact and repeatable readings possible.

2.4 Theory behind the DIM

Once a working device was developed there were still the prerequisites that were set for it to be met. There were two problems with the small screen:

- The more dirty the water is, the smaller the volume of water that cloggs the screen becomes.
- A 300 μm screen filters about ten times more water than a 100 μm screen before it gets clogged. (Although this was found in practice at first, it could be shown theoretically that an opening of 300 by 300 μm is almost ten times larger than an opening of 100 by 100 μm, which confirms the practical observation).

The first point implied that the more dirty the water is, the smaller the value would be that is given to the dirtiness of the water and that is just what we did not want to be. The second point on the other hand implied that if the same water is measured with a 300 μm screen it will give a value to the dirtiness of the water that is ten times larger than when it is measured with a 100 μm screen. Fortunately two solutions could be found:

- If the inverse is taken of the number of litres that clogged the screen, it produces an increasing value when the dirtiness of the water increases.
- If a factor is built into the dirtiness index formula that can be changed in accordance with the fineness of the screen in the meter, it can compensate for the variation in the volume of each screen. (The standard screen for the DIM was empirically taken as 100 μm with a screen factor of 100.)

From the two solutions just mentioned, equations (1) and (2) were empirically derived for the dirtiness index (DI) of the water (Niekerk et al., 2006):

$$\mathrm{DI} = \frac{1}{\mathrm{L}} \times \mathrm{F} \tag{1}$$

where:

DI - dirtiness index.
L - number of litres that clogged the screen.
F - screen factor (Table 1)

$$= 0.00632 \times \mathrm{M}^{2.1} \tag{2}$$

where:

M - micron size of the screen used in the meter

Table 1 F-factors for the most popular screen sizes (Niekerk et al., 2006)

Fineness of screen (μm)	Screen factor - F [1)]
50	23
100	100
200	430
300	1000

1) From equation (2)

Remark: If water is measured continuously over a period of time during which the dirtiness index varies substantially, then for the average DI it is not correct to take the numerical average of the calculated DI-values that were measured over that time, because lower values take longer to measure. To get the correct average DI over this time, it was found that if the average of all the volumes of the readings that were taken during this period is calculated, then the true average value for the DI is given when this average volume is used in the DI formula. This can be illustrated in Table 2 and Figure 8.

Table 2 The true DI over time with large variation in dirtiness

Measurement	Volume (L)	DI
1	10	10
2	8	13
3	4	25
4	2	50
5	8	13
Average DI:		22
Average volume:	6	16

This phenomenon is especially important when the filtration efficiencies of filters are measured. As will be seen later on, the DI measurements of the incoming water to a filter are quick because the water is dirty. On the other hand it is possible that one measurement of the DI of the outgoing water from the filter can take hours if it is a very effective filter that lets out very clean water. In this case the DI of the incoming water must be measured for the whole time that the measurement of the outgoing water takes and the average of the measurements before the filter must then be calculated in this way and used in the filtration efficiency formula that will be given later on.

2.5 The DIM in practice

Once the DI concept and DIM were established it was time to see what it means in practice. The first thing was to establish what the relation between DI and ppm was. The successful tests with the modified rain gauge (see page with Figure 3 and 4) were repeated with the DIM and the relation in Figure 7 was found on grounds of

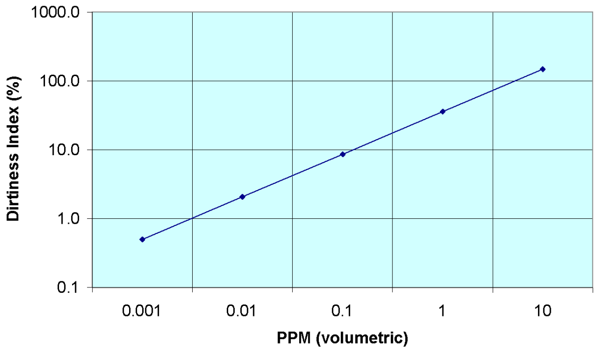

Figure 7 The relation between DI and ppm (volumetric)

similar performances of the filters, e.g. if a filter cleaned 10 m^3 of water at a ppm of 0,1 and a DI of 8,6 it would mean that 0,1 ppm = a DI of 8,6.

From Figure 7 it can clearly be seen that micro irrigation filters can not handle very dirty water. At a ppm of 1 most of the filters clogged within a very short time as Table 3 also illustrates:

The next step was to connect the DI to field conditions. A vast variety of irrigation water sources were measured as is illustrated in Figure 9:

Table 3 The DI and the clogging of filters (Niekerk et al., 2006)

Dirtiness index (%)	Classification of the irrigation water
< 1	Clean
> 1	Dirty
Approximately 5	Fairly dirty: Clogging of most filters within a day or two.
Approximately 30	Very dirty: Clogging of most filters within a few hours.
Approximately 60	Extremely dirty: Clogging of most filters within less than an hour.

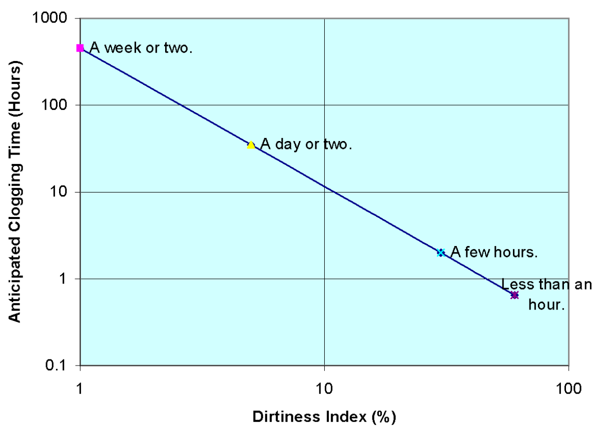

Figure 8 Graphic representation of Table 2

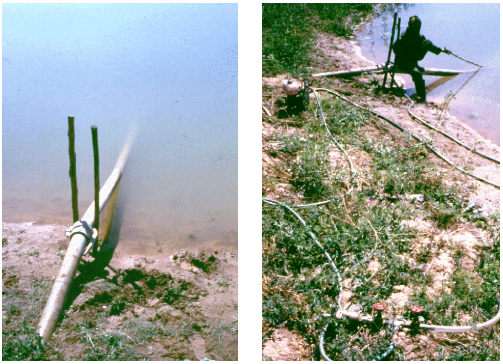

Figure 9 Measuring the DI of various irrigation sources

The dominant contaminant in this case was tiny larvae of some insect. They were about 200 µm in diameter and about 500 µm long. The DI of this water was measured as 12%.

It was found that a river in heavy flood (which is more or less the dirtiest condition that one would find in nature) produced a DI of 100 and therefore the DI can also be seen as a percentage scale for the dirtiness of irrigation water relative to the dirtiest condition one would normally encounter in the field. These measurements also showed that the average DI of irrigation water in nature is about 2%, but to get an even better feeling of the DI of irrigation water a typical irrigation water source was measured on a daily basis for the period of one year. These results are shown in Figure 10 (Niekerk et al., 2006).

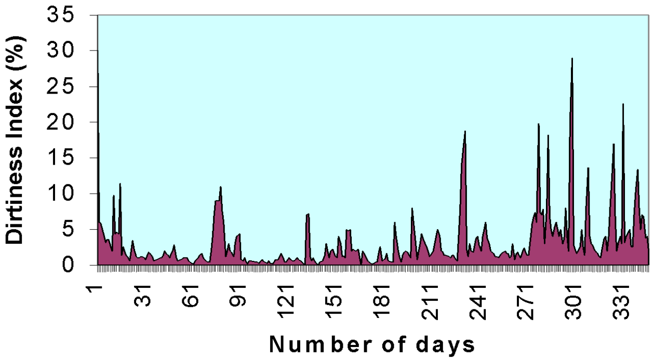

Figure 10 Yearly dirtiness indexes of an irrigation reservoir

The figure represents the measurements of a reservoir fed by a canal from a river in a summer rain area running from January to December. After every rain storm there is a sudden peak for a few days and then it reverts back to more or less the average DI for that point in time. When this data is analysed it is interesting to note that the height of these peaks are almost five times the average value of the DI at that time.

3 THE FILTRATION AND BACKWASH EFFICIENCY OF MICRO IRRIGATION FILTERS

The most elegant application of the DIM is in the tests on micro irrigation filters.

Before it could be used in the test lab the DIM had to be automated. Figure 11 shows what the automated DIM looked like. This was done by replacing the water meter with a meter that could produce high resolution pulses that are linear to the flow of the water through the meter which could be "read" by a PC. The pressure gauge was replaced by an electronic pressure sensor and four electro-hydraulic valves were also fixed to the DIM that could be opened and closed also by the PC. These valves are used to "backwash" the small screen everytime it became clogged and the PC has read the water meter. In this way the DI of the water could be monitored continuously.

Figure 11 The automated DIM

The "discovery" of the DIM has led to the development of a fully automated test bench for micro irrigation filters which can be seen in Figure 12. Water enters from the far end where the DI of the "incoming" water is measured. This DIM also assists the PC in controlling the DI of the test water that is pumped into the test bench through a series of control valves. Then follows the filter that is tested, an electronic water meter that measures the flow rate and volume of the filtered water, a second DIM that measures the dirtiness of the "outgoing" filtered water and finally a flow control valve that automatically controls the flow rate of the water through the test bench before the water returns to the pump reservoir. A separate pressure sensor measures the drop of pressure over the test filter.

3.1 The filtration efficiency of a micro irrigation filter

On the test bench a filter can be tested at different DI's. While a test is running the DI of the incoming water and the outgoing water is measured continuously. The filtration efficiency of the filter is defined by equation (3) (Niekerk et al., 2006):

Figure 12 The fully automated filter test bench in the Hydrolab of ILI

$$\text{Filtration efficiency} = \left(1 - \frac{\text{DI of the outgoing water}}{\text{DI of the incoming water}}\right) \times 100 \qquad (3)$$

As was discussed in the "remark" in paragraph 2.4 the true average of the DI measurements must be used in this formula. The more effective a filter is in removing a certain size of particle, the smaller the DI of the outgoing water will be which makes the quotient smaller and when that is subtracted from 1 the value in brackets gets closer to 1, times 100 gives a filtration efficiency value of close to 100%. Always bear in mind that the DIMs only measure the "concentration" of particles bigger than the screen size in them and therefore they measure the efficiency with which the filter removes that size and bigger particles. Figure 13 shows the results of a typical filtration efficiency test (Niekerk et al., 2006):

Figure 13 shows what happens "inside" a filter while it is clogging. The extend to which a filter is clogged is indicated by the extend to which the pressure differential (pressure drop) over the filter has increased. When one follows the light blue line (DI=30%) some interesting trends can be seen: a gradual fall in efficiency happens

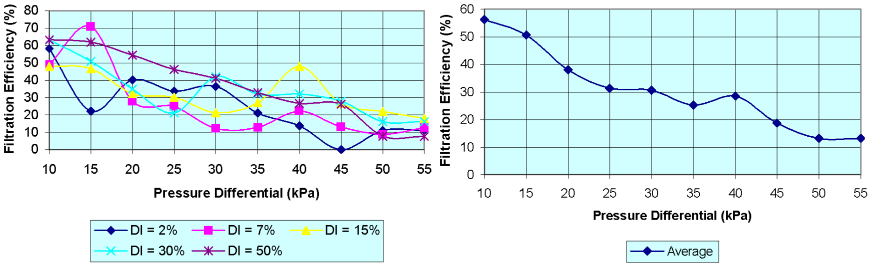

Figure 13 Filtration efficiency test results

till a pressure differential of 25 kPa is reached. This is because of the fact that more and more dirt is forced through the element by the increasing pressure differential across the filter. Then a rise in efficiency can be seen. This is because of the fact that some dirt that was not forced through the element has started to build up against the element, forming a "natural filter" that is finer than the element of the filter and more smaller particles are held back, causing an increase in the filtration efficiency of the filter. When the pressure differential gets very high a fall in efficiency again happens. This is because of the fact that the pressure differential now is so high across the filter that the "natural filter element" is broken up by the very high pressure differential across it and more dirt is forced through the element of the filter again causing a drop in the filtration efficiency.

3.2 The backwash efficiency of a micro irrigation filter

In practice it is not practical to take out a filter's element to clean it everytime it has clogged. For that reason micro irrigation filters are built in such a way that the flow of water can be "reversed" through them, washing away the dirt that has accumulated on the element. Because of the different ways in which filter bodies are built this way of cleaning is not as effective for one filter than it is for another filter. The result is that the elements seldom get completely clean with this way of cleaning and there is always a part of the element that does not get cleaned and the effective filtration area of the element is thus decreased. The result is that the element clogs faster when it "goes back into action" again with the result that a smaller volume of water can be cleaned before the filter is clogged again.

The method of measuring the backwash efficiency is as follows: at first a series of clogging tests are done on the filter at different DI's, but before each test the element is thoroughly cleaned by hand. In this way a filtration capacity curve for the filter can be compiled. After this, the same series of tests are done on the filter, but this time the filter is only backwashed before every test. As was described in the first paragraph the clogging volumes of these tests will be smaller than when the element was hand-cleaned, depending on the efficiency of the backwash process on this filter. These tests produce a second "lower" filtration capacity curve for the same filter. In Figure 14 these two filtration capacity curves are compared (Niekerk et al., 2006):

The backwash efficiency of the filter is thus defined by equation (4) as follows (Niekerk et al., 2006):

$$\text{Backwash efficiency} = \frac{\text{Volume of water cleaned at } DI_n \text{ with backwashing}}{\text{Volume of water cleaned at } DI_n \text{ with hand-cleaning}} \qquad (4)$$

where:

DI_n - the DI at a specific value n, e.g. 10%

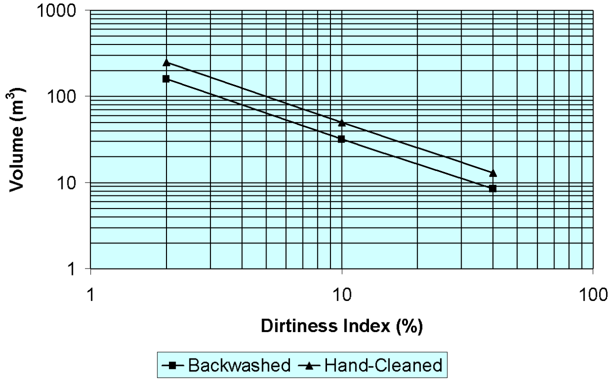

Figure 14 The two filtration capacity curves for a backwashed filter

This means that the volume that the filter has cleaned with backwashing must be compared with the volume that the filter has cleaned with hand-cleaning at the same DI, e.g. 10%.

One disturbing result that was found is that the backwash efficiency of disc filters is about 33%. For sand filters the backwash efficiency is about 90%.

4 CONCLUSIONS

The ARC-Institute for Agricultural Engineering has succeeded in developing a measuring device and method for measuring the dirtiness index of irrigation water for micro irrigation filters. The instrument that was developed is called the Dirtiness Index Meter (DIM) and it has proved to be the ultimate solution for this purpose and it has fulfilled all the prerequisites that were set for it.

The DIM has enabled ILI to do filtration and backwash efficiency tests on micro irrigation filters, making us the only test station in the world that can perform these tests.

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Los Servicios de Asesoramiento en la Gestión y Uso del Agua y la Energía en el Regadío

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1 Introducción
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18 Los Servicios de Asesoramiento en la Gestión y Uso del Agua y la Energía en el Regadío

1 INTRODUCCIÓN

El regadío es el principal consumidor de agua en el mundo. En algunas regiones, como es el caso de España, el regadío supone más del 80 % de los usos totales de agua, jugando un papel fundamental para garantizar la producción de alimentos. Este hecho, unido a los condicionantes legales (Directiva Marco del Agua DMA–2000/60/CE), ambientales, sociales y económicos, obliga a realizar una adecuada gestión de los recursos hídricos para conseguir un uso sostenible de los mismos. En estas condiciones, y sobre todo en las regiones con escasez de agua, situación que desafortunadamente es cada vez más frecuente y extendida, la sostenibilidad del regadío obliga a encontrar soluciones tecnológicas en el diseño, manejo y gestión de los sistemas de riego que permitan maximizar la productividad por unidad de volumen de agua consumida.

La competencia creciente por el agua, consecuencia de un aumento de la demanda para distintos usos, conduce a un incremento de su coste y a una creciente limitación de su disponibilidad para uso en la agricultura. Si a todo esto se le añade que las orientaciones de las políticas agrarias comunitarias apuntan a que el regante vaya haciendo frente a los costes asociados al uso del agua y a la reducir el posible impacto ambiental ocasionado con su uso, se pone de manifiesto la necesidad de ayudarles a realizar un uso eficiente del agua para ser competitivos en un mercado mundial cada vez más globalizado.

Ante esta situación, muchas Administraciones Públicas han propuesto un conjunto de medidas para maximizar el potencial social, económico y ecológico de los recursos hídricos disponibles, asegurar y potenciar el complejo agroalimentario y, en un contexto de equilibrio del balance hídrico, mejorar y modernizar los regadíos existentes e incluso incrementar la superficie de los mismos allí donde sea posible. En este marco, y en colaboración con Universidades y empresas públicas o privadas, los gobiernos de muchas regiones, donde el regadío juega un papel fundamental en su economía, han diseñado, y están desarrollando, los Servicios de Asesoramiento al Regante (SAR) como el que tenemos en Castilla-la Mancha denominado SIAR (Servicio Integral de Asesoramiento al Regante) (http://crea.uclm.es/siar/).

La iniciativa pretende ser el hilo conductor para la transferencia de tecnología a la agricultura, permitiendo a los agricultores ir conociendo y aplicando los avances tecnológicos ligados a la agronomía e ingeniería del riego en su sistema productivo.

2 OBJETIVOS Y ACTUACIONES DEL SAR

El objetivo del SAR es ayudar a los agricultores a conseguir un uso eficiente y racional de los medios de producción, y especialmente el agua, los fertilizantes y la energía, suministrándoles un adecuado apoyo científico y técnico para optimizar su manejo, contribuyendo a que la agricultura sea una actividad sostenible. Esto llevará asociados beneficios de índole económico (reducción de los costes de producción) y medioambientales (disminución del consumo energético, conservación de los recursos hídricos y reducción del impacto ambiental en las aguas y suelos). Para ello es necesario actuar de forma coordinada con el agricultor, haciéndole partícipe de las soluciones ofrecidas y suministrándole una información útil, así como complementar la formación de los agricultores, de modo que dispongan de herramientas para tomar las decisiones como empresarios responsables de la gestión de sus explotaciones.

Las principales actividades a desarrollar serán pues ayuda a los agricultores para:

- La programación del riego (PR) y manejo de los cultivos.
- Optimizar el diseño y manejo de los sistemas de distribución y aplicación del agua en la parcela.
- Planificación de cultivos en explotaciones agrícolas con limitaciones en la disponibilidad de agua y de otros medios de producción, mediante la utilización de modelos de ayuda a la toma de decisiones como MOPECO (Ortega et al 2004; López-Mata et al., 2010; Domínguez et al., 2011; Domínguez et al., 2012) que buscan el manejo del riego que conduce al óptimo económico en una agricultura sostenible.
- Asesoramiento sobre el uso eficiente de la energía, incluyendo auditorias energéticas que pongan de manifiesto los posibles problemas, así como las soluciones que sean económicamente viables (Moreno et al., 2010b).
- Asesoramiento sobre la fertilización de los cultivos, así como la elaboración y la divulgación de programas de abonado.
- Divulgación de la información y formación de técnicos y regantes.

3 NECESIDADES DEL SAR

La implantación del SAR exige, además de contar con los medios humanos necesarios (equipo científico y técnico multidisciplinar que abarque desde los campos de la agronomía y la ingeniería agraria, hasta la hidrogeología, la electrónica o la informática), el disponer de los correspondientes equipos y metodologías de trabajo, y conocer en profundidad el entorno agronómico en que va a desarrollar sus actividades, pudiendo concretarse en los siguientes aspectos:

- El clima local y las condiciones climáticas de la campaña agrícola. Para ello es fundamental disponer de una red de estaciones meteorológicas automáticas que abarque la mayor parte de la superficie donde realizar el asesoramiento.
- La naturaleza de los suelos de la zona, de las explotaciones piloto y de las parcelas de los agricultores colaboradores.
- El origen, la disponibilidad y la calidad del agua de riego.
- Los sistemas de producción, con sus sistemas de cultivo e itinerarios técnicos.
- Los sistemas de riego utilizados: materiales, características, condiciones de funcionamiento, etc., así como los programas de mantenimiento y conservación de las infraestructuras de riego.
- Las necesidades de los agricultores y problemas en el manejo del riego: estado de las instalaciones de riego, criterios de programación de riegos utilizados, relaciones con la Comunidad de Regante, nivel de formación técnica de los regante, etc.

Con toda esta información, se puede realizar un diagnóstico general de las zonas de actuación, necesario para elaborar el plan inicial de funcionamiento, incluyendo: la elección de las instalaciones de riego donde actuar, metodología a seguir en las distintas actividades, forma de realizar la PR, informes a elaborar y resultados a difundir, entre otros.

4 TAREAS DEL SAR

Una de las primeras tareas a realizar en un SAR es seleccionar los agricultores colaboradores de entre los más innovadores de la zona, para que sirvan de demostración de la utilidad del servicio al resto, en las que se toman las decisiones de riego, junto con las demás prácticas de cultivo, de forma consensuada con el agricultor. Dentro de sus explotaciones se seleccionarán las parcelas piloto, sobre las que se realizará el seguimiento de los cultivos que servirán de base para la estimación del consumo de agua y las recomendaciones de la programación de riegos a nivel general. En la Figura 1 se representa un esquema de funcionamiento del SAR.

La evaluación de las instalaciones de riego es otra tarea fundamental de un SAR. Sirve, por una parte, para iniciar la relación con los agricultores, implicándoles directamente en la realización de las pruebas para que conozcan el funcionamiento de sus instalaciones, y por otra, suministran la información necesaria para poder aplicar la programación de riegos. Los resultados deberán poner de manifiesto las posibles deficiencias de diseño, funcionamiento y manejo de sus instalaciones, para tratar posteriormente de buscarles las soluciones más adecuadas según los condicionantes existentes.

Una actividad fundamental dentro del SAR es la difusión de la información, así como de los resultados y conclusiones que se van obteniendo. Son múltiples los

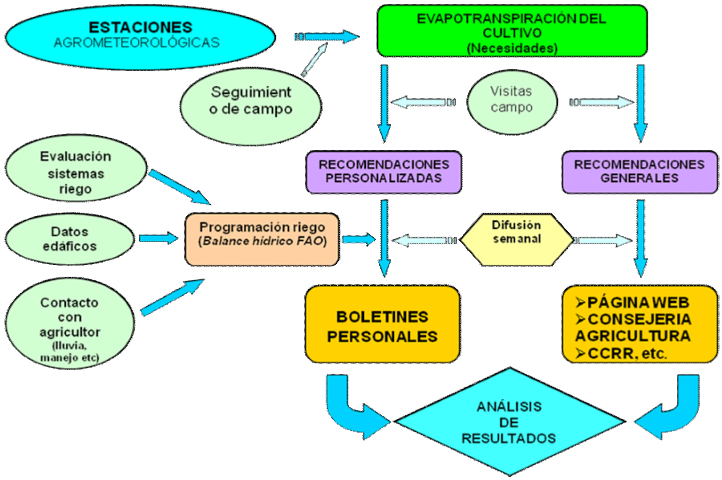

Figura 1 Esquema de funcionamiento del SAR

medios de difusión de la información que pueden utilizarse, entre los que pueden destacarse:

a) Los que transmiten la información de forma continua, o casi continua: Internet (http://crea.uclm.es/siar/, http://www.jccm.es) (Figura 2), boletines, medios de comunicación (prensa, radio, TV, etc.).

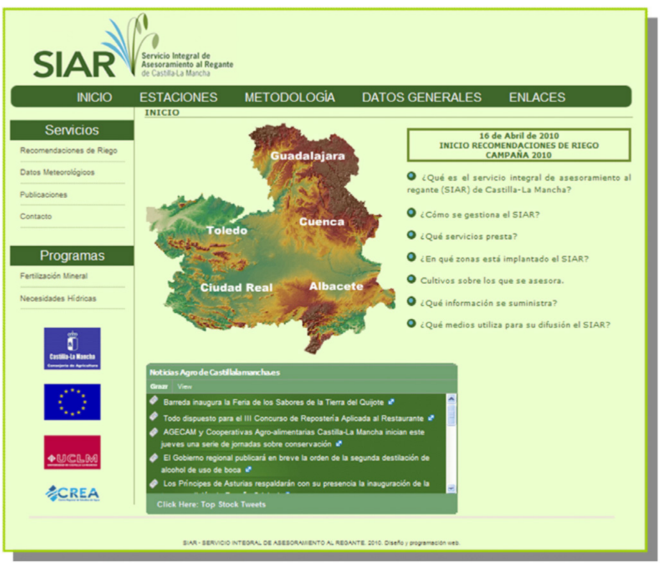

Figura 2 Ejemplo de la página Web del SIAR

b) Los de información periódica: hojas divulgativas, charlas, seminarios, cursos, etc.

c) Visitas a campo y transferencia del conocimiento ante problemas concretos.

5 BENEFICIOS A MEDIO Y LARGO PLAZO

Son diversos los beneficios que se derivan de la puesta en marcha de este tipo de servicios para los distintos sectores implicados, entre los que cabe citar:

- Para los agricultores: al ayudarles a optimizar los medios de producción, aumentando la rentabilidad de sus explotaciones e incluso mejorando la calidad de sus productos.

- Para las comunidades de regantes: al mejorar su capacidad de gestión, de manejo de información y la propia formación de sus miembros.

- Para las Universidades y los Centros de Investigación: al abordar con el sector agrario ligado al regadío los problemas de I+D+i que a éste se le plantean, mejorando las condiciones de la investigación y facilitando su transferencia a los propios usuarios, así como al ámbito científico-técnico y formativo.

- Para las Administraciones públicas: al poder disponer de herramientas de gestión y previsión de la demanda de agua, permitiéndoles además justificar la planificación y decisiones estratégicas ligadas a la gestión del agua y del medioambiente frente a los agricultores y comunidades de regantes.

6 EL SIAR DE CASTILLA-LA MANCA

La superficie regada en Castilla-La Mancha, extensa región semi-árida del Sureste de España, es superior a 450.000 ha distribuidas en toda la región (Fig. 3), representando el 11,5% de su superficie agrícola, aunque aporta más del 40% de la producción final agrícola de la región (JCCM, 2010). El 60% de los regadíos de Castilla-La Mancha se encuentran infradotados y el 65% emplean recursos hídricos subterráneos (PNR, 2002). Esta situación, donde dos grandes acuíferos se encuentran declarados sobreexplotados (Acuíferos 23 y 24), obliga a hacer un buen uso del agua, programando adecuadamente los riegos y recurriendo a sistemas de riego con alta eficiencia de aplicación, adecuadamente diseñados y manejados, y tender a cultivos poco consumidores de agua, de alto valor añadido y elevada productividad por volumen de agua consumido.

En estas condiciones, se justifica la necesidad de desarrollar servicios de apoyo y asesoramiento a la toma de decisiones de los agricultores (Ortega et al., 1997, Ortega et al., 2005).

Desde el año 2000, el SIAR se desarrolla desde el Centro Regional de Estudios del Agua (CREA) de la Universidad de Castilla-La Mancha en Albacete, bajo la dirección de la Consejería de Agricultura (Dirección General de Producción Agropecuaria), quien se encarga de marcar las directrices generales, favorecer el contacto con los

Figura 3 Distribución de los regadíos de Castilla-La Mancha

agricultores y suministrar los datos climáticos de base procedentes de las 44 estaciones agrometeorológicas actualmente en servicio por toda la Región (Fig. 4). Se trata de estaciones automatizadas, cuya información se almacena en un sistema de adquisición de datos y se descarga, por medio de telefonía móvil, en un ordenador central. El equipamiento disponible permite registros de: temperatura, humedad relativa, radiación solar global, velocidad y dirección de viento y precipitación con carácter semihorario. Los datos mostrados a los usuarios tienen carácter diario.

Entre los medios de difusión empleados por el SIAR, adquiere especial relevancia Internet, capaz de implicar a un número elevado de agricultores de cualquier zona de la Región. Así, la Página Web del SIAR (http://crea.uclm.es/siar/, http://www.jccm.es) se ha ido convirtiendo en un portal Web que ofrece servicios "on line", entre los que cabe destacar las aplicaciones de "Consulta diaria de los principales datos meteorológicos", "Cálculo de necesidades hídricas", "Balance de fertilización mineral (N-P-K)" o modelos de ATD como MOPECO (Modelo de OPtimización ECOnomica del regadío), modelo que permite seleccionar la alternativa de cultivo que consigue maximizar el margen bruto de la explotación en condiciones de limitada disponibilidad de agua, así como los riesgos asociados a la variabilidad climática, de precios de los productos, etc. En multitud de cultivos se demuestra que el volumen de agua necesario para la máxima producción no lleva asociada la máxima rentabilidad económica (Ortega et al., 2004, López et al., 2010, Domínguez et al., 2011). Además, este modelo permite calcular el calendario óptimo de riego deficitario controlado que se conduce el máximo rendimiento bajo diferentes condicionantes (agua salina, variación de precios de venta de la cosecha o de las condiciones climáticas, etc.) (Domínguez et al., 2012).

Figura 4 Red de estacionas agrometeorológicas empleadas en el SIAR

A título de ejemplo, en la Figura 5 se muestran los resultados de consultas anuales de la Web en los principales temas de interés, destacando las consultas a la estimación de las necesidades de agua de los principales cultivos regados en las veinte zonas de actuación y los datos climáticos, consultándose en menor media los programas disponibles para que cada agricultor pueda realizar su programación de riego o la fertilización de sus cultivos, así como la planificación de cultivos con MOPECO. Para la programación de riegos se utiliza el balance simplificado de agua en el suelo según la metodología FAO (Doorenboss & Pruitt, 1992; Allen et al., 1998), suministrándoles

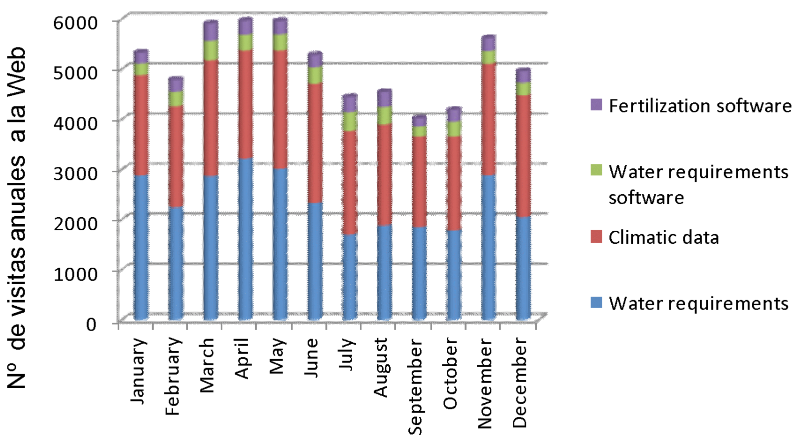

Figura 5 Resultados de consultas anuales de la Web en los principales temas de interés

el valor de ETo calcula por el método de Penman-Monteith (Pereira & Allen, 1999) y los valores de Kc de los principales cultivos de la zona, determinando su duración mediante visitas semanales a las parcelas piloto. Además, se tiene en cuenta la precipitación registrada por el agricultor en la propia parcela. La aplicación "on line" de fertilización solicita al agricultor información sobre el cultivo, suelo, abonado orgánico y entradas de agua a la parcela (precipitación, riego), realizando un balance de fertilización para cada elemento (N-P-K), estimando las extracciones del cultivo, la cantidad de elemento que aporta la mineralización del humus, el agua de riego, el abonado orgánico y el cultivo precedente, así como las pérdidas del elemento por lixiviación, retrogradación o fijación de arcillas.

7 SERVICIOS ADICIONALES SUMINISTRADOS POR EL SIAR

Parece interesante destacar además los servicios ligados al uso de la energía y al diseño de las instalaciones de riego, entre los que cabe citar:

- El análisis energético de las instalaciones de riego, incluyendo:
    - Sofware desarrollado para el análisis energético (Moreno et al. 2010b): Análisis de sondeos (AS) (Moreno et al. 2010a), Análisis de estaciones de bombeo (MAEEB) (Moreno et al., 2007) y análisis de redes colectivas de riego (Moreno et al., 2008).
    - Optimización del contrato con la compañía eléctrica suministradora.
    - Medida de parámetros hidráulicos, eléctricos y topográficos para calcular los indicadores de uso de la energía y proponer las acciones adecuadas para mejorar la eficiencia energética.
- Optimización del diseño y manejo de los sistemas de distribución y aplicación del agua de riego (aspersión y goteo) mediante el software PRESUD (Pressurized Subunit Design) para el diseño de subunidades de riego a presión.

8 INVESTIGACIÓN APLICADA QUE PUEDES SER TRANSFERIDA A TRAVÉS DEL SIAR EN UN FUTURO PRÓXIMO

La gestión óptima del riego implica la integración de muchos factores como el objetivo de producción que conducen al óptimo económico, las necesidades de agua de los cultivos, la interacción suelo-planta, el sistema de aplicación del agua de riego, las necesidades de fertilizantes y de energía, juntamente con los aspectos sociales, económicos y ambientales. La herramienta que se está desarrollando permite el control del crecimiento espacial de los cultivos y modelos de ATD alimentados por sensores remotos, interactuando en tiempo real con los usuarios a través de tecnologías Web-GIS. La teledetección permite obtener casi en tiempo real los datos espaciales respecto al tipo de cultivo, su crecimiento y desarrollo, el estado de disponibilidad de agua, e incluso la biomasa y la uniformidad de rendimiento de los cultivos a nivel de parcela y subparcela. Esta tecnología, a través de una plataforma Web, se puede utilizar para el seguimiento de la planificación de cultivos como estrategia para el control de los recursos hídricos, buscando una máxima eficiencia socio-económico y ambiental mediante modelos como MOPECO (Ortega et al., 2004), teniendo en cuenta el cambio climático, lo que conduce a una optimización de la eficiencia del uso del agua

Tanto la teledetección basada en satélites como en vehículos aéreos no tripulados (VANT) puede utilizarse con el objetivo de obtener índices de crecimiento y desarrollo de los cultivos tales como índice de área foliar (IAF), NDVI, biomasa y otros. Además, se puede obtener el índice de estrés hídrico de los cultivos a través de imágenes térmicas para determinar la programación óptima de los riegos deficitarios controlados (RDC). Las cámaras térmicas pueden proporcionar mediciones de alta precisión, al tiempo que permite amplias medidas espaciales, sobre todo si las cámaras están instaladas en vehículos aéreos. Los VANT representan una solución adecuada para la teledetección de propiedades térmicas, ya que la baja altura de vuelo permite evitar las interacciones atmosféricas. El uso de los VANT, con capacidades para el seguimiento de las condiciones de la vegetación debido a las altas resoluciones espaciales y espectrales utilizadas, que oscilan entre los 0,5 y 2 m de tamaño de pixel para diferentes anchos de banda, y las herramientas para el tratamiento masivo de datos, podrán permitir realizar una programación de riegos en tiempo real, que podrá alimentar a los sistemas de ATD a nivel de parcela y de Comunidad de Regantes para llevar a cabo una correcta gestión de las infraestructuras y, por tanto, para realizar un uso óptimo del agua y la energía.

Para cultivos de alta productividad, aún siendo relativamente caro el uso de este las técnicas disponibles, puede utilizarse la teledetección de muy alta resolución para determinar, de manera precisa, el crecimiento y desarrollo de los cultivos con cámaras de RGB y NDVI, el riego deficitario controlado con cámaras térmicas, e incluso la estimación de la biomasa con los modelos 3D obtenidos con técnicas de fotogrametría. Para ellos se están desarrollando software de planificación de vuelo, procedimientos para georreferenciación de imágenes, y software para un rápido procesamiento de las imágenes. Además se está desarrollando un software para predicción de ETo, llamado FORETo, basado en la predicción general de variables climáticas, junto con la determinación de la metodología más adecuada para identificar las temperaturas extremas para cada cultivo que permita calcular el tiempo térmico (grados-día).

9 CONCLUSIONES

- Es necesaria una adecuada planificación hidrológica.
- Para una buena gestión del los regadíos es necesario su adecuada planificación, así como actuaciones para su mejora, modernización y consolidación.
- El esfuerzo científico-técnico (investigación, formación, etc.) y económico (estaciones agroclimáticas, mantenimiento, etc.) es siempre necesario.

- Implicación de los regantes en la gestión de los recursos hídricos y la necesaria formación e información de estos en las nuevas tecnologías.

- Hay diferencias en la gestión del regadío entre las distintas zonas: por cultura de riego, disponibilidad y coste del agua, etc.

- Se presenta mayor grado de seguimiento de los SAR en cultivos de mayor rentabilidad y zonas con elevado coste del agua (>0,1 €/m^3).

- Es fundamental mantener una WEB como portal de servicios.

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Baixo Acaraú Irrigation Advisory Service: The First Results and the Quality of Water Use

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1 INTRODUCTION

Brazil is the country with the world's largest potential for expansion of irrigated area. Out of 30 million hectares capable of incorporating irrigation methods, only 5 million are in activities. These data demonstrate the importance of "More Irrigation" program, recently launched by the Ministry of Integration.

On the other hand, irrigation is the economic activity that most consumes water and is also the most granted use in Brazil, accounting for about 72% of all consumed water in local soil, as occurs worldwide, given that irrigated agriculture occupies only 15% of the total area identified as irrigable in the country. In other words, it is the activity with the highest consumption of water with significant potential growth and use nor always rational of the water resources.

Results of analyzes with farmers have shown that there is low efficiency in water use in irrigated agriculture of Ceará, causing losses by inadequate management. In general, there is not proper use of the methods of irrigation techniques. There are no plans for water conservation aiming at increasing efficiency and reducing waste. The supply of water is misused in irrigation with low use of technology in the sector. To modify their practices and existing behaviors, end users need to learn how to irrigate with less water to obtain high productivity, which is the ultimate goal of the Irrigation Advisory Service. It is necessary to develop a comprehensive training program to modify its practices or behaviors.

The first challenge to expand the irrigated area in Ceará, should establish policies to raise the capacity of the sources of water resources. Concerning the another issue, there are two situations: 1. There is not a structured system of technical assistance tailored to the needs of farmers; 2. There is a lack of technical knowledge from the farmers. There is a deficiency of the government institutes concerning to technological innovation to meet the multiple needs and peculiarities of the irrigated agriculture.

Despite significant efforts in many regions in the world, in the implementation of the Irrigation Advisory Services – IAS (SAI, the acronym in Portuguese) there are several limitations to the present and future development. The first experiments with SAI were held in the USA. According to (Lima et al., 2012). The first experiences with SAI were performed in the United States. The CIMIS (California Irrigation Management Information System), which is probably the best representative of the potential of the SAIs. It provides information to assist California farmers in managing their water resources.

The SAI aims to respond to technological demands of irrigators, or perform an advice on irrigation management. Other authors studied SAIs and demonstrate their importance for efficient irrigation (Ortega et al. 2005; González-Dugo et al. 2008; Córcoles et al. 2010; Lima et. al. 2010; Montoro et al . 2011; Car et al. 2012; Lorite et al. 2012; Lima et. Al. 2013).

However, all the SAIs used worldwide only gives as information the value of ETo, sent one at a time. S@I that was deployed by Inovagri in Baixo Acaraú Irrigation District – DIBAU), processes daily climatological data, the information on the system of irrigation on each farm and the current stage of each planting. Then, S@I sends SMS and e-email that guide more than 300 farmers from DIBAU, about when and how much to irrigate, aiming to maximize the relationship between water consumption and food production.

This paper presents the first results and the quality of water use of IAS (SAI) applied in the management of the Baixo Acaraú Irrigation District.

2 THE SAI PROJECT

The Inovagri Institute and the National Institute of Science and Technology in Irrigation Engineering (INCT-EI), based in ESALQ/USP, Luis de Queiroz Superior Agriculture School- São Paulo University have been performed since 2011, a project aiming to develop a model of the Irrigation Advisory Service - SAI. This project is funded by CNPq - National Scientific and Technological Development Council and by the Foundation for Research Support of the State of São Paulo - FAPESP.

The initial "laboratory" of observation and experimentation of the Irrigation Advisory Service - SAI had the Pilot irrigated area, in the Baixo Acaraú Irrigation District (DIBAU) in the state of Ceará, Brazil. This district has 8.335ha divided into 522 small plots, with farmers organized into a community. The plots are planted with fruit trees and vegetable crops, for home market and for exports (Fig.1) and the models of plots (Fig.2).

Among the activities that enabled the achievement of the objectives of that project, the following can be listed:

1) Develop a model of the Irrigation Advisory Service - SAI for deployment in Brazilian irrigated areas;

2) Conduct assessments on all irrigation systems and guidance on the right way to irrigate;

3) Calculate and inform the irrigation time for each farmer on "how", "when" and "how much" to irrigate via SMS, email and Web Service;

4) Conduct research to obtain concepts of quality of irrigation management for agribusiness and draft a protocol.

5) Develop System S@I (Irrigation Management Software).

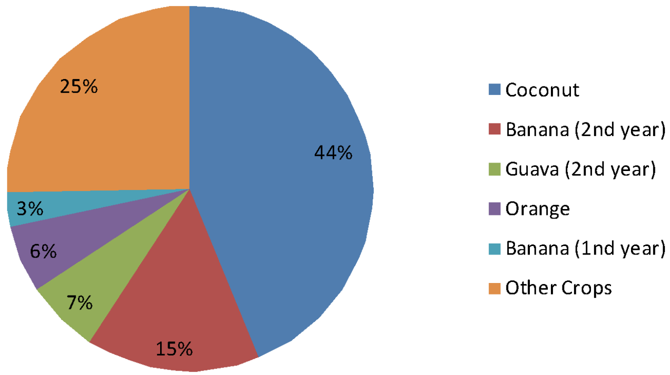

Figure 1 The division of the crops DIBAU (Data base from S@I – January/2014)

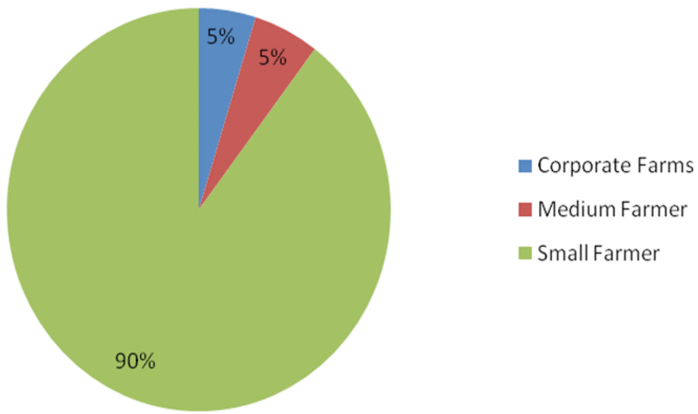

Figure 2 The division of the model of plots of DIBAU (Data base from S@I – January/2014)

In 2011 the development of irrigation management software have been started, the essential tool for SAI Project. A team composed of a System Analyst, a Programmer and a Web Designer has been assembled that, along with the team of Agronomists and Irrigation Technicians in the SAI, focused exclusively on the construction of the new software system titled Advisory System for Irrigators - S@I.

As an example, at SAI DIBAU initially technicians observed an inappropriate irrigation management that was being used in all sectors of DIBAU. After SAI has been deployed, there have been periodical evaluations of the irrigation systems. Moreover, the farmers have been aware of the need to adopt the technical recommendations taught by the technicians. Various sectors had their figures of uniformity emission of water improved after the corrections, changing their rating of "bad" (60%-70%) to "good" (80%-90%) and in some cases to Excellent (more than 90%). With that was possible to improve the functionality of the used irrigation system and the amount of water used in three main crops of DIBAU that was exceeded by 50%. In general, the farmer does not have minimal information about irrigation. He knows just how to turn on and off the system and uses the "visual aspect" of farming in order to make the decision. The process of sending the information for irrigators is shown in Fig. 3.

Figure 3 Flowchart of process of S@I System (Lima et al. 2013)

3 THE S@I SYSTEM

To carry out the irrigation management of the SAI in 2011 was developed specific software for the SAI. The computing system created is the System Advisory for Irrigators – S@I. The S@I System includes the DIBAU cadaster, the methodology for irrigation water requirements computation and communication module, is an exemplary Internet-based application that already provides useful service to the farmers in DIBAU, offers opportunities for research, and can easily become a model for many other collective irrigation districts in Brazil. Moreover, the S@I application has the potential to develop into a decision support system for the management of collective irrigation systems.

The S@I is a Web system (www.sistemasai.com.br) and the process of sending the information for irrigators is shown in Fig. 3. This tool has information about each user and their properties, related to property areas, number of sectors, crop, irrigation system, and water consumed, among others. The division of the crops DIBAU generated by S@I can be checked in Fig. 2.

As the software works without needing installation on computer, makes easier its use by farmers in several places of the country or the world, just by having the login and password.

The system S@I has an irrigation module that uses the irrigation database module integrated to an advisory automatic weather station to calculate and send messages via SMS or E-mail, the daily irrigation time of every plantation. This module also calculates the emission uniformity of the system with data collected by the technician, or even by irrigating feeding system.

The Advisory System for Irrigators-S@I is a software created to manage water use in irrigated areas, giving support to the Irrigation Advisory Service-SAI. S@I transfers the information to the farmer through SMS, email and web site. After registration conducted by the SAI with these data (farmer, crop, irrigation system and the application efficiency), S@I performs necessary calculations to send daily information on "when to irrigate" and "how much water to apply". The basic information to be sent to the farmer is the Irrigation Time (IT). The calculation procedure of IT follows this methodology: 1.The potential evapotranspiration (ETo) is computed by the Penman/Monteith method using the climatic data (Allen et al.1998); 2.Crop evapotranspiration (ETc) is calculated by multiplying ETo by the crop coefficient as follows: (ETc = KcETo). S@I has a database of "Kc" (Crop Coefficient); 3.The IT is obtained by combining the farmer information with the efficiency; 4.Then, S@I generates the information to be sent to each farmer via SMS and e-mail; 5.Each user has their own web page (S@I System) with their username and password.

4 RESULTS AND DISCUSSION

The implementation of the SAI Project was discussed by Santos Neto et al., 2011; Lira et al., 2011 and Lima et al., 2012. This fact used to lead irrigators to manage irrigation by total empiricism of other experiences, without considering local peculiarities.

The results achieved by the Pilot Project were: Number of farmers assisted by SAI: 396, number of SMS's sent: 136,920; volume of water consumed annually by

DIBAU: 13,377,488.35 m^3 (2012) - 36,514,096.40 m^3 (2013); total irrigated area: 3310ha; number of emails sent: 17,361.

The key or quantifiable metrics related to the implementation of this innovation in DIBAU are:

a) Total irrigated area: 3310ha

b) Volume of water used annually in m^3: 36,514,096.40 m^3 (2013);

c) Volume of water saved in m^3/ha/crop: on average 20%, or approximately 9 million of cubic meters of water saved in the District (estimated).

Decision Support Systems (DSS) for Irrigation scheduling have had a poor uptake despite proved usage benefits (Car et al. 2012). According this author, the use of the mobile phone Short Messaging Service (SMS) was trialed as an interface to overcome these difficulties.

The acceptance of SAI Project Pilot shows the following results about SMS: a) Of the farmers receiving Irrigation Time Information, approximately 97% understand the information; b) Of the farmers who received and understand the information, approximately 36% follow the time of irrigation recommendation and c) 25.64% of the farmers who follow the recommendations of irrigation perceived improvement in visual appearance of the plant.

Car et. al, 2012 in his study in Australia, working with the Irrigation system dripper run time scheduling advice, he sent daily to 72 Australian irrigators' mobile phones from a water balance system called IrriSatSMS. Then, 45 users (63%) found the SMS system was enough to use for the whole season and 80% of irrigators found the system useful. Additionally, high participation rates show that much model input data may be collected from irrigators via SMS so it can be used as a very cheap bi-directional communication channel.

About the S@I System, in Fig. 3 it is shown the screen with the irrigators view. The "Farm screen", is shown in the Fig.4, which is the division of property in areas with crops. The pixel black item shown on the picture below of the crops picture (see sector 1) represents the efficiency with the calculation methodology of the EU according Keller & Karmelli (1974).

The irrigation time, with every component of calculus, is shown in the Fig.5. After the completion of the analysis, it was made a new assessment of the lots and updated information.

Therefore, it is necessary to find ways to increase the water use efficiency in irrigated districts. The SAI Project was the innovation presented proposal and the S@I System is the smart tool to overcome this problem, performing calculations to send to the farmers and to teach them "when to irrigate" and "how much water to apply". Thus, we can characterize as an increase in the quality of irrigation of DIBAU with the performance of the SAI.

This importance is also reported by (Lima et. al., 2010; Car et al., 2012; Lorite et al., 2012), So, giving them a rational way to produce more food per hectare, or more food per cubic meter of water. Another important specific critical barrier that innovation

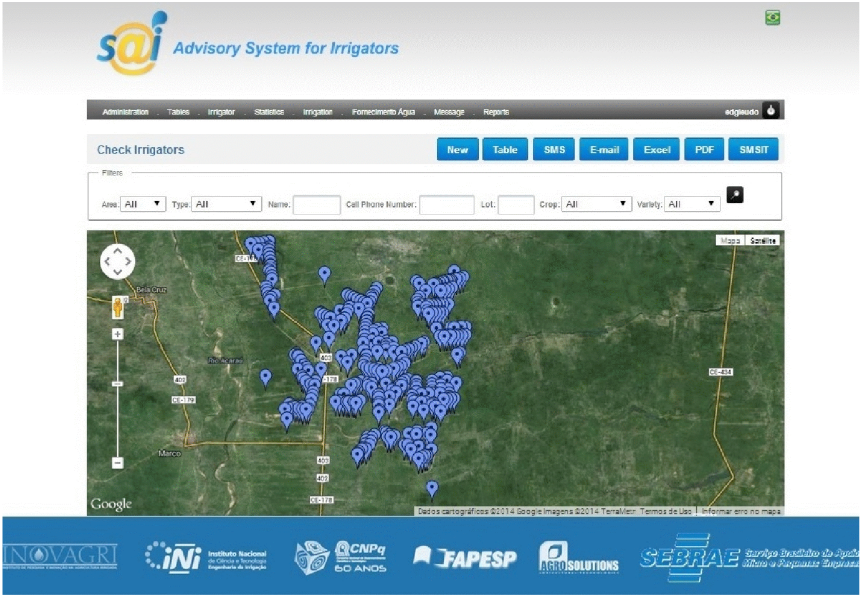

Figure 4 Irrigators view from the s@i System

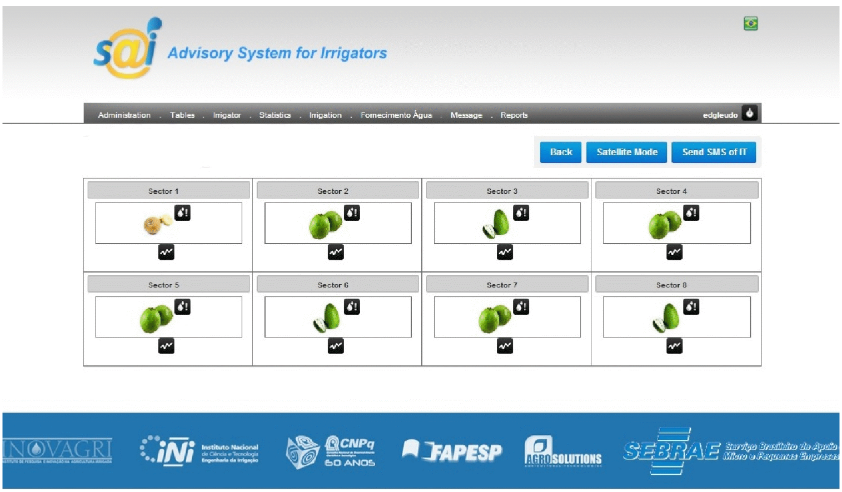

Figure 5 Farm Screen of the s@i System showing the crops

addresses is related to insufficient information and training to the farmers regarding how to use innovations. Because of that, the management of irrigation water has been inadequate. Water use efficiency has varied from 9% (Evaluated by the technicians of the SAI Service in 2011) to 90% (estimated) in the main public irrigation districts (Santos Neto et al., 2011; Lima et al., 2012).

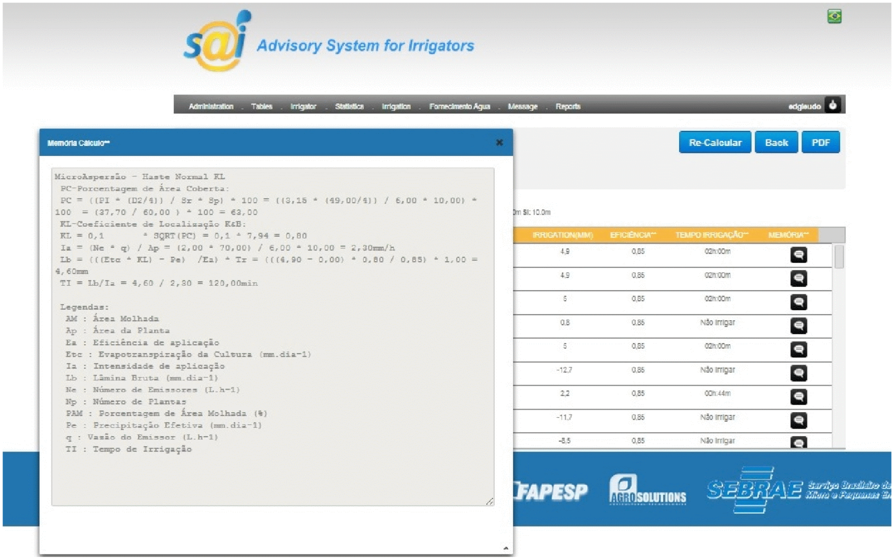

Figure 6 Irrigation time of the s@i System showing the memory calculation

It has been noted in the experience developed in the Pilot that the information management is complex, because it varies with the profile of the Assisted Farmer. For this, the system created, must be easy to adapt to various conditions. Another challenge to be faced is the lack of research in quantifying crop water requirements, which combined with the lack of technical assistance to the farmers result in the low technological level of irrigation.

5 CONCLUSIONS

Irrigation is an activity that strongly impacts on the environment and the S@I system may contribute to the rational use of water and natural resources of an Irrigation District, through the management of irrigated areas and the transfer of information to the farmers. The adoption of this innovation should be a technological breakthrough for the State agriculture also a contribution to the increase in the exports of tropical fruits.

It is noteworthy that Ceará is one of the states that do not have a State Organization and Agricultural Research. Therefore, S@I is critical. Public Irrigation Districts still suffer without help from the government, because they mostly do not have Irrigated Areas Management System. The S@I system aims to fill this gap, presenting itself as a participatory technological innovation, capable of contributing effectively to a more rational use of water in the semiarid of Ceará for food production.

This innovation is transformative because it leads to a new technology for irrigation control and application of water in irrigated agriculture and must produce an Irrigation Scheduling, resulting in less water and energy loss and increase of crop productivity.

6 ACKNOWLEDGEMENTS

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Using the Baixo Acarau Irrigation District as a Learning Laboratory

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20 Using the Baixo Acarau Irrigation District as a Learning Laboratory

1 INTRODUCTION

Irrigation in Brazil has experienced a spectacular development driven by the private sector and international manufacturers, with the support of the government, universities and public research organizations. The current irrigated area in Brazil is 4.5 million hectares. The Brazilian Irrigation Plan aims to double this area in the next 5 years. In spite of this success, the collective irrigation systems developed by the public institutions for providing a livelihood to small farmers has not produced the expected results in terms of productivity and area. Assessing the performance and productivity of existing collective irrigation systems, identifying their constraints and appropriate technology, and facilitating (through training and capacity building) the adaptation and adoption of these technologies are, therefore, rather timely.

Irrigation Advisory Services (SAI, the acronym in Portuguese) are vectors for the diffusion of scientific and technological innovation. Traditionally, these services have two main functions (Smith & Muñoz, 2002): providing farmers with relevant information for irrigation scheduling, and evaluating the irrigation systems in order to diagnose their performance and advise on their improvement. The three main elements of an SAI are: agro-meteorological stations, a laboratory for quality control of irrigation equipment, and mobile units for irrigation evaluation. Such a SAI has been implemented at the Baixo Acaraú Irrigation District (DIBAU, acronym of the name in Portuguese), in the north of the state of Ceará, Brazil.

In a broader sense, SAIs could also promote participatory irrigation management, irrigation management transfer, and action research. The approach to rural and agricultural development is slowly shifting from top-down to bottom-up, from centralized knowledge generation to recognition of local knowledge, diversity and learning processes (Chambers, 1994). Agricultural systems involve complex bio-physical, technical, and socio-economic relationships that demand appropriate and integrative frameworks for analysis and decision making. Participatory appraisal and action research methods may facilitate understanding between farmers, researchers and university faculty that results in multiple-way learning, integrative analysis, participatory planning, and effective action (Chambers, 1994).

The DIBAU, with its physical environment, farmers, infrastructure, IAS, and socio-economic and institutional context, can provide an invaluable and ideal "laboratory" for using participatory appraisal methods to both provide research opportunities for university faculty and students and to learn what works best, not only in terms of family-farm irrigation systems, but for their whole irrigated agricultural enterprise.

This paper focuses on the training potential and knowledge that can be acquired by performing field level research on the DIBAU's 8-hectare family farm units.

2 THE IRRIGATION DISTRICT AND ITS SAI

DIBAU has an irrigable area of 8,335 ha within the municipal districts of Bela Cruz, Marco and Acaraú. The district is divided into 501 farm plots of varying sizes: small (4-8 ha), medium (16-18 ha) and large (80-200 ha). It has been designed to use micro-irrigation. DIBAU produces mainly fruit crops oriented to exportation: coconut 48%, banana 18%, guava 6%, orange trees 5%, papaya 4% (DIBAU's SAI database – July/2013). DIBAU is situated 160 km from the Pecém Sea Port, which allows reaching European and North American markets within one week. DIBAU is managed by a farmer's association integrated by all 501 DIBAU farm lot owners.

Among the irrigation districts in Ceará, DIBAU is the second in water demand. However, farmers did not have water management advise until the SAI was implemented (Santos Neto et al., 2011; Lira et al., 2011; Lima et al., 2012). Farmers used to manage irrigation based on their limited experience.

DIBAU's SAI aims to respond to technological demands of irrigators and advice on irrigation management (Lima et al., 2012). It has already developed a GIS including the irrigation distribution network, farm plot limits, cropping pattern, as well as a dynamic database containing on-farm water and energy use data. In 2011, a specific software for the SAI was developed (S@I). S@I is an exemplary Internet-based application that includes the DIBAU database, the methodology for irrigation water requirements computation and communication module (Fig. 1). It offers opportunities for research and can easily become a model for many other collective irrigation districts in Brazil. Moreover, the S@I application has the potential to develop into a decision support system for the management of collective irrigation systems.

A large number of farmers (366 in June 2013) have voluntarily accepted to include in the database relevant information that defines their profile. A first set of on-farm irrigation evaluations has been already conducted. S@I allows maintaining the SAI database updated and gives access to authorized users for consultation.

Performance indicators have been selected to define the irrigation performance baseline. Benchmarks, that are expected to be dynamic as the benefits of the SAI

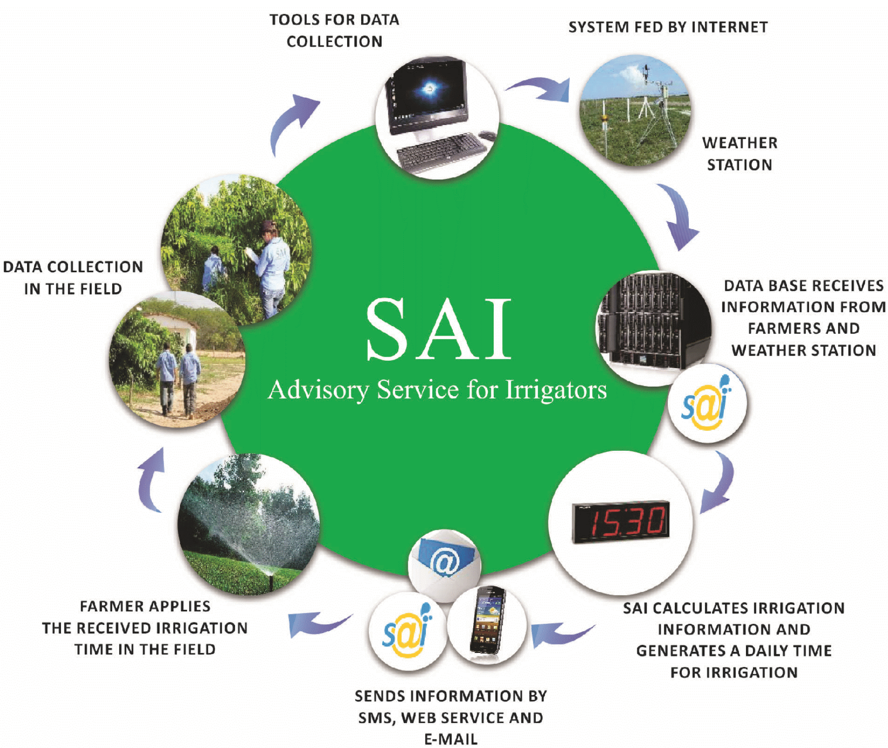

Figure 1 Flowchart of process of S@I System (Lima et al. 2013)

manifest, are established based on these performance indicators. The GIS and the database will be necessary to design the methodological approach that will allow the use of DIBAU as a learning laboratory; the baseline will be the reference to assess the progress derived from the learning and action research experience; and the farmers who have adopted the SAI will be the target group for participatory learning and action process.

3 THE PARTICIPATORY APPROACH

– Three main benefits of a participatory approach are envisioned:

– Provide valuable information for the development of new family-farm irrigation projects and the extension and/or rejuvenation of existing projects.

– Provide field training for university students in appraising irrigated farming operations.

– Provide action research opportunities for university faculty and students.

The proposed approach is to study all aspects of family-farm operations, from the standpoint of such things as intensity of farming, machinery availability and usage, availability of all types of agricultural inputs (including extension information), how family farmers cope with irrigation system repair and maintenance, income constraints and marketing. As state before, the general concept for doing this is:

- focuses on what is happening and assumes it is rational in the context of the local people and their social, economic, natural, and physical environment;
- searches for what is successful and takes a performance view, coaching stakeholders to expand success to improve performance, while learning from failure examples;
- uses an integrated framework that leads to interdisciplinary action.

4 THE LEARNING LABORATORY

The core group of actors involved in the learning and action research process will be: individual farmers, farmer's association and its management service, the IAS, the Universidade Federal do Ceará - Agrarian Science Center, and the Escola Superior de Agricultura "Luiz de Queiroz" (Universidade de São Paulo). This group will be opened to any other actor that could contribute or profit from the learning and action research process.

As stated here, the envisioned studies would require a multidisciplinary approach, involving irrigation engineers, agronomists, agricultural economists, and rural sociologists. The multidisciplinary teams would work together to develop interdisciplinary research. The Universidade Federal do Ceará – Centro de Ciências Agrárias with their eight related departments would be an ideal host for the envisioned program. The field studies would be carried out by student Teams. These Teams would have several members, each one supervised by the departments of Agricultural Engineering, Soil Science, Plant Science, Agricultural Economics, Rural Sociology, Animal Science, and Home Economics.

A hostel-like facility near DIBAU Headquarters would provide the students and their faculty advisers with a base of operations as well as classroom space for instructional purposes. Thus student teams would be able to spend a week or two at a time doing participatory rural appraisals of the DIBAU's family-farmers.

The learning and action research process will involve multiple rounds. The first round will focus on learning. It will have two phases. First, the SAI staff, board and managers of the farmer's association, and faculty of the involved university departments will discuss the approach to interact with farmers. Then SAI staff and university faculty will develop guidelines for semi-structured participatory interviews. Next, the student Teams will be trained for doing this interviews. A set of test interviews will be conducted by the student Teams accompanied by SAI staff and university faculty. Then, the guidelines and semi-structured questionnaires will be revised according to the experience derived from the test interviews. Then, the 1st Phase will begin properly. The types of questions to engage in during this 1st Phase will be, for example:

1. Regarding irrigation

a. How does one cope with repairs and maintenance of their micro irrigation system and where do they get their repair parts and what are the typical yearly costs of keeping the system in operation?

b. Are there additional micro irrigation technologies and components, such as: higher flow-rate drip emitters that were less prone to clogging; or different lateral take off and main control valves they would like to have available and access to?

c. Do they have any suggestions as to how their irrigation systems could be improved?

d. How do they determine when to irrigate and how much water to apply?

2. Regarding labor and mechanization

a. What access to mechanization or animal-traction do they have for the various crop husbandry needs (soil preparation, sowing, weeding, harvesting)?

b. Is additional labor available when they need it, and how much does additional labor cost?

3. Regarding productivity

a. How many years did it take them to develop and cultivate all of their 8-ha farm?

b. For the current year and previous year, which crops are cultivated, what surface and yield obtained?

c. What are their favorite crops and why?

d. How much (many hectares) of their land are they able to manage efficiently?

e. What are their main constraints to increasing productivity?

f. What is the variability of income they receive from their main crops?

4. Regarding crop operations

a. Are there guidelines – recommendations for all crops? Prepared by whom?

b. How do they manage weed control? Do they follow recommendations?

c. How do they manage the fertility of their crops and how much fertilizer do they use? Do they follow recommendations?

d. How do they go about learning how to cultivate new crops?

5. Regarding family-farm households:

a. What are the demographics?

b. Is time dedication and operations different according to gender?

c. Do they grow most of their own food or do they purchase it?

d. Do they raise small animals for part of their food supply?

e. What is the nutritional level of the family members?

f. What is their income distribution?

g. What is the range of net return to land and household labor per cubic meter of irrigation water delivered to the farm?

h. What is their return per hectare of irrigated land?

i. What is the educational status of the adults and of their children?

j. What are their experiences with financing their permanent crop establishment and irrigated farming operations?

6. Regarding farmer's organizations: Have any formal cooperative businesses or sharing efforts among farmers spontaneously developed:

a. For purchasing farm input supplies such as seed, pesticides, fertilizers, and irrigation equipment?

b. For mechanized services such as plowing?

c. For marketing produce?

The information result of the 1st Phase will be processed and reported by the student Teams supervised by SAI and faculty staff. The expected results after discussion with the target group of farmers, the farmer's association staff, and other stakeholders that may contribute to the discussion are:

An understand of farming practices and strategies in relation with broader agrarian, socio-economic, and institutional linkages

Means of adoption and adaptation of technologies

Identification of constraints and needs

Identification of appropriate technological innovations

Evaluation of progresses made through the IAS

An action agenda containing the guides for developing expansion plans for family-farmed irrigated agriculture in DIBAU, including priorities, will follow. This will be the beginning of the 2nd Phase that will include testing of innovations and reflexive analysis of strategic decisions and innovations, for each farmer type and crop. Farmers will be grouped in order to be operational, although the groups should be flexible and permeable. Farmers, SAI staff, and the student-faculty Teams will discuss the introduction of new practices, equipment, crops. The final decision will be of course made by each individual farmer.

The monitoring plan of the SAI will be intensified and strengthened in order to assess the progress in the learning process. The two phases described above will be repeated in a second (third and so on) round, thus the process becomes continuous.

The project leader will coordinate the elaboration of a report and an executive summary to be submitted to government decision makers. It is expected that the same experience could then be used for the development of new family-farm collective irrigation projects and the rejuvenation of existing projects in Brazil.

The Baixo Acaraú learning experience will be communicated in every of the coming INOVAGRI International Meetings and WINOTEC International Workshops on Innovations Technology in Irrigation. There the project will be discussed and

Figure 2 Visit of researches (in the picture: Jack Keller, Luciano Mateos, Helena Gomez-Macpherson and others) to DIBAU's SAI in 2012, during the INOVAGRI International Meeting and IV WINOTEC

critiqued by national and international experts. The communication in this forum will encourage the incorporation of more researchers and irrigation practitioners to this experience.

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