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Effects of drip irrigation promotion policies on water use and irrigation costs in Valencia, Spain

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Abstract

The aim of this study is to conduct an ex post analysis of the generalized implementation of drip irrigation in the last two decades in the Valencia Region (Spain). Due to the important role played by water users' associations (WUAs) in this socio-technological change in the region, this research was based on 77 interviews with different WUAs that provided information prior and subsequent to modernization. Firstly, we review the published studies concerning the effects generated by this technological change and describe the drip irrigation promotion policies implemented by national and regional governments. Subsequently, we analyse the consequences for irrigation associations, including effects on water use and irrigation costs. The reduction of water withdrawals has been generally significant. This was possible because the regional contextual factors prevented, in most cases, crop intensification and areal expansion. Nevertheless, due to the enormous investment effort and the resulting maintenance costs, the technological change has increased irrigation costs, generating some uncertainties concerning the financial sustainability of some WUAs. In conclusion, a thorough assessment of contextual factors and accompanying measures such as technical assistance and monitoring appear to be indispensable to avoid unforeseen effects and to achieve the potential goals of conversion to drip technologies.

Keywords: Drip irrigation; Irrigation tariffs and costs; Spain; Subsidies; Water consumption; Water policy

1. Introduction

Drip irrigation generalization is a socio-technological change with no historical precedent in the Mediterranean region. Over the last two millennia, farmers have guided water along open air channels, flooding their fields through geometric furrows or inundating their plots by sheet flow. The ancient gravity-driven schemes started to be replaced shortly after 1965, when the drip irrigation systems developed by Blass (1973) were commercialized. Drip irrigation was subsequently disseminated all over the world. This technological change has induced important transformations in agricultural processes, farming practices, social and institutional architectures, water policies and related ecosystems.

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In Spain, the dimensions and speed of this technical shift have been impressive. In 1978 drip irrigation was only installed in 3,500 hectares (Medina, 1988), whereas in 2011 1,658,317 hectares had drip networks installed, equivalent to 47.7% of the total irrigated land (Ministry of Agriculture, Food and Environment, 2002-2013). It is the third largest area in the world irrigated with drip or other micro-irrigation systems, behind China and India (International Commission on Irrigation and Drainage (ICID), 2015). In the early stages of this technological dissemination, large landowners were leading the introduction of drip systems in Spain, which mainly took place in dynamic and well capitalized agricultural holdings. However, since the mid-1990s, consecutive national and regional Spanish governments have been committed to the promotion of drip irrigation through various programmes. Governments opted for a policy of technological change in the hope that it would lead to a significant increase in the efficiency of water use and agricultural productivity. It was also an option which was perceived to stimulate the construction industry, produce no obvious losers, create more competitive employment in agriculture, and improve the quality of life in rural areas (Playán & Mateos, 2006).

Recently, however, different studies have questioned the validity of this technology as a means of achieving increased irrigation efficiency (López-Gunn *et al.*, 2012a, 2012b; Van der Kooij *et al.*, 2013; Scott *et al.*, 2014). For this reason, in Spain, like in other countries subsidizing the adoption of drip systems, it is essential to assess how effective the investments have been, as well as to estimate if farmers are capable of supporting the increase in irrigation costs frequently derived from the implementation of drip irrigation and the subsequent use and maintenance of these systems.

Numerous works have explored the effects of water saving measures through analytical or mathematical models, but according to Berbel *et al.* (2015) only a limited number of publications have examined the situation before and after water-saving investments. The aim of this study is to conduct an ex post analysis of the impact of drip irrigation on water use and irrigation costs in the last two decades in the Valencia Region (Spain), based on 77 interviews with different water users' associations (WUAs) prior to and subsequent to modernization. We firstly review the published studies concerning the effects generated by the technological change and briefly describe the drip irrigation promotion policies implemented by national and regional governments. Then, we analyse the consequences for irrigation associations, with regard to the effects on water use and economic factors.

2. Drip irrigation: intended and unintended effects

Saving water has been the principal objective of the introduction of pressurized irrigation technologies in numerous arid and semi-arid areas. The capacity of localized irrigation systems to reduce consumption on agricultural land without undermining the provision of the water requirements needed by the crops has been widely demonstrated under laboratory conditions and on experimental plots. From Swaziland sugarcane (Merry, 2003) to Turkish olive groves (Çetin *et al.*, 2004), from Uzbekistan cotton (Ibragimov *et al.*, 2007) to Sahel market gardens (Woltering *et al.*, 2011), the world is full of successful and promising examples of drip irrigation development.

For this reason, but also for other motivations, such as a demonstrated increase in agricultural productivity or decrease in labour costs, several governments have developed actions to generalize drip irrigation adoption. Drip irrigation has been included in the Green Morocco Plan, in the Australian irrigated farm modernization programmes and in the projects developed by the Program of Provincial Agricultural Services (PROSAP) in Argentina. In other countries, such as in India, where the National Mission on

Micro-Irrigation heavily subsidizes drip irrigation, experts are also demanding an intensification of the public promotion of drip irrigation. Thus, Narayanamoorthy (2004), after obtaining considerable water savings and yield increases in a comparative analysis with gravity irrigation, has demanded target-oriented special programmes to generalize the use of drip irrigation. Sureshkumar & Palanisami (2010, 2014) specifically recommend a policy focus towards promotion of drip irrigation in regions where water and labour scarcities are critical, and also where the shift towards wider spaced crops has taken place (Sureshkumar, 2008). Moreover, various researchers, the Food and Agriculture Organization and non-governmental organizations have recommended the development of low-cost drip irrigation kits as a pivotal instrument to solve the water-food-poverty nexus (Postel *et al.*, 2001; Von Westarp *et al.*, 2004; Maisiri *et al.*, 2005; Ella, 2008).

Despite this wide support, in recent years some researchers have questioned the role played by drip irrigation in water-saving policies. These authors have warned of the danger of adopting a myopic view that fails to consider the impact of related factors or the required scale of analysis. This is due to the fact that many of the aforementioned works have been developed experimentally at plot level or from a technology-centred perspective, considering drip irrigation implementation as a black-box problem, frequently leaving out many influential factors (López-Gunn *et al.*, 2012b; Venot *et al.*, 2014). Similarly, after a critical and exhaustive literature review, Van der Kooij *et al.* (2013, p. 108) stated that 'there is no conclusive scientific evidence to support a general belief in drip irrigation as a water-saving device or as a tool to help solve the water crisis' and demanded caution against the massive installation of drip irrigation, because national or regional savings cannot be based on results only obtained at plot level. Even at a local scale, Benouniche *et al.* (2014) have shown cases in Morocco in which, after implementation of drip irrigation, some farmers applied the same volumes of water as was the case under gravity irrigation.

This gap between the policy objectives and final water consumption, based on the changing efficiency attained when technology is considered locally or from the point of view of integrated resource management, was initially described by Seckler (1996) and Perry (1999). According to these authors, the introduction of water-saving technologies can mean an increase in consumption at basin level when the local improvement in irrigation efficiency impedes use of return flows by other users, who will be forced to utilize new resources. This is the so-called rebound effect or Jevon's paradox, which states that the introduction of a new technology that improves the efficiency of using a natural resource does not necessarily lead to less consumption of this resource (Ward & Pulido, 2008; Hardy & Garrido, 2010; Dumont, *et al.*, 2014; Berbel *et al.*, 2015).

Studies such as Playán (2002), Playán & Mateos (2006), Perry *et al.* (2009), Lecina *et al.* (2010a), Cots (2011) and Fernández-García *et al.* (2014) have presented different scenarios in which the introduction of saving technologies have had implications that are contrary to the desired effect. Firstly, the modernization of irrigation systems can often be accompanied by crop intensification towards more productive varieties that have higher water requirements, which increases both evapotranspiration and water consumption (Lecina *et al.*, 2010a; Gutiérrez-Martín & Gómez, 2011; Fernández-García *et al.*, 2014). Secondly, water saved locally is frequently used for other purposes. Scott *et al.* (2014) have recently coined various terms to define these uses: *sectoral paradox* when water saved is used to satisfy new demands; *scale paradox* when it benefits attached ecosystems; and *efficiency paradox* when it is utilized to increase irrigated lands. In all these cases, basin consumption is not reduced, even though the use of water is optimized in economic terms.

Despite the fact that water saving is the main argument for the public promotion of drip irrigation, many other factors can call into question whether this policy meets its objectives or not. In the case of drip irrigation, electricity consumption emerges as an essential factor, because of its critical role in agricultural costs.

Some studies have detected cases of significant electricity savings after installing drip irrigation. Farmers supplied by groundwater sources and using obsolete irrigation networks achieve significant energy savings by transforming to drip irrigation and scheduling water extraction and pumping (Gómez Espín *et al.*, 2007). Hardy & Garrido (2010), however, argue that the modernization of irrigation in Spain has brought with it an increase in farm consumption of electricity, against a background of rising energy prices. Rodríguez-Díaz *et al.* (2011) have also observed an increase in energy costs, as the energy required for pressurizing the hydraulic network is much greater than for gravity propelled systems. Therefore, energy efficiency must be at the centre of any modernization policy.

The comparison of these results is not contradictory. Studies carried out in Australia (Jackson *et al.*, 2010) concluded that it is common to achieve a reduction in energy consumption in irrigation systems supplied by groundwater, while in those areas supplied by surface water, the pressurization process results in an increase in electricity costs and irrigation costs. In these cases, they recommend improving gravity propelled irrigation systems, thus avoiding pressurization of the network. Sese (2012) has also shown WUAs using mixed or groundwater sources which have experienced an increase in energy costs. In the present context of electricity prices, the development of a complete energy audit for the proposed transformation projects becomes essential, as Rodríguez-Díaz *et al.* (2010) suggest. In some cases, the increase in irrigation costs generated by energy can be counterbalanced at farm level by a reduction in fertilization costs, due to the benefits brought by fertigation systems. According to López-Gunn *et al.* (2012b), fertilization costs can be reduced by between 25% and 50%.

There are other economic effects associated with the implementation of drip irrigation technologies which have stimulated their widespread use. According to Gallego Bono (1996), improvement in water productivity is a more important consequence than water saving. The enhanced productivity gained by farms which adopt drip irrigation systems might justify the public promotion of this technological shift (Gómez Espín *et al.*, 2006; Gil Meseguer, 2010; Lecina *et al.*, 2010b). It is also true, however, that both studies warn of the risks from this investment, due to the significant levels of uncertainty over the future of many farms. This uncertainty is related to fluctuations in the agricultural markets and the price of electricity, and a lack of balance between water use and availability (López Fernández & Gómez Espín, 2008). These cases reveal the importance of developing technical and financial assistance in drip irrigation transformation projects to achieve water-saving goals and to control irrigation costs, something which has been highlighted by different studies (Gil Meseguer, 2010; Alarcón, 2011).

Many recent studies have highlighted the emergence of numerous unexpected consequences of policies promoting drip irrigation. In some cases, these studies come to apparently contradictory conclusions. The use of different methodologies, scales and goals explains much of this variance and some of the divergent results. However, a thorough review of these studies mainly reveals that the diversity of scenarios and influential factors such as design, type and origin of water resources, crops, age, state of conservation, water allocation policies, etc., are key determinants of policy success or failure. This fact has led some authors (Scheierling *et al.*, 2006; Huffaker, 2008) to discourage governmental programmes of subsidies for drip irrigation promotion.

3. The policies of modernization of irrigation systems in the Valencia Region

Governments and farmers' associations in Valencia have made a clear commitment to modernize irrigation infrastructures for the last three decades, due to the growing pressure on water resources. Despite strict regulation, by the 1980s the rivers could not supply enough water to many irrigation associations and several water resources were overexploited or had serious problems, such as seawater intrusion. It became necessary for national and regional governments to encourage reduction of the agricultural water use in Valencia.

The Valencia Regional Government Act 7/1986 for the Rational Use of Water in Irrigation Systems could be considered the initiation of this modernization process. Between 1987 and 1995, 611 modernization projects were financed, of which the vast majority (78%) were based on the renovation of the existing infrastructure, through concrete lining of channels or the replacement of channels with pipes. Only 39 works dedicated to the conversion to drip irrigation were carried out.

The drip irrigation trend accelerated after 1995, when the Valencian Regional Government approved the Plan for the Modernization of Irrigation. The Plan was the direct consequence of two events: the cathartic drought of 1994–1995 (García-Mollá *et al.*, 2013), which severely impacted on agricultural production, and the cancellation of the National Water Plan project of 1993, a plan that originally promised new water transfers to the Mediterranean coast from the larger peninsular basins. During the period 1997–2009, public investment in drip irrigation in the region was 560 M€, whereas the total investment (including WUAs' contribution) was approximately 1,000 M€ (calculated from Valencian Regional Government and State Society of Agricultural Infrastructures data). Since 2002, both the Central Government and the Regional Government have acted jointly through a Framework Cooperation Agreement resulting in the partial financing and subsidizing of collective irrigation networks. WUAs had a prominent role in the transformation process in this region and in other areas of Spain. In the majority of cases, WUAs directly applied for public subsidies after contracting a drip irrigation expert to design the new network. In a small number of areas, the public administration developed district modernization plans to cofinance the technological shift, but always after contacting the leaders of the WUAs to meet their demands.

Estimating the recent evolution of the surface area of drip irrigation in the region is complicated. Only the Land Use and Crop Yield Survey (ESYRCE) and the Agrarian Census offer data about the area irrigated by drip irrigation. According to the Agrarian Census in 1999, there were 283,565 hectares of irrigated land in the Valencia Region, of which 101,157 hectares had localized irrigation. In the Census of 2009, the figure for irrigated land went down to 267,870 hectares, while the drip irrigation area increased to 181,289 hectares. According to ESYRCE, in 2009 the total irrigated area was 322,639 hectares and the area irrigated by drip irrigation was 180,777 hectares. Despite the significant disparity in the figures for total irrigated land, the data related to drip irrigation appears relatively consistent.

Currently, irrigated lands are decreasing in the region. The Agrarian Census shows a reduction in total irrigated land between 1999 and 2009. The reasons behind this reduction are the decrease in profitability (low market prices and high cultivation costs in the case of some crops, particularly citrus and other fruits and vines), a lack of new generations to take over the farming (70% of Valencian farmers are older than 55, and 43% older than 65), urbanization, and expropriation for development of infrastructure.

4. Methodological issues

Management of water for irrigation is mostly carried out by associations and groups of farmers, due to the long historical tradition of collective management of irrigation in Spain (Glick, 1970). This study uses data from semi-structured interviews with 77 associations of varying types within the Valencia Region. At the time of the interviews, 60 of them had begun the process of changing to drip irrigation, while the other 17 were still using traditional gravity networks. The study compares recent interviews after modernization processes, with interviews carried out at the end of the 1990s (García-Mollá, 2000), prior to the modernization processes. As is shown in Table 1, the total area of irrigable land of the associations that were interviewed covers more than 143,000 hectares, 50% of the total irrigable land in the Valencia Region. The associations have been grouped together by water source. The following types of irrigation associations have been taken into account:

- Surface Water Associations. These are traditional associations of irrigators with sufficient concessions of surface water to irrigate in normal conditions that do not use groundwater or other sources, except in conditions of extreme drought. They irrigate large areas and, in general, have a greater guarantee of supply. Because of this these associations started modernization projects last.
- Groundwater Associations. Most of these associations are smaller and were created more recently than the traditional irrigation associations. Due to the high costs of pumped water, they were the pioneers of the modernization processes. All of them have installed drip systems.
- Transfer Water Associations. These associations supplement insufficient surface water with water from the Tajo-Segura transfer channel.
- Mixed Water Associations. These associations use both surface and groundwater supplies. Most of them are groundwater associations that incorporated surface water rights some decades ago, as a result of state plans for river regulation. The remainder are traditional irrigation associations that do not have sufficient surface water and also use groundwater in order to be able to irrigate the land in a normal year.

Interviews with WUA representatives were conducted by at least two researchers. During the interviews, systematic information prior and subsequent to modernization was collected, orally or through documentation given by farmers. Obtained data includes the dimensions and evolution of the irrigated area, water use and consumption, drip infrastructure development and maintenance and financial situation of the WUAs. Farmers were invited to express their personal view and assessment on the modernization process. This information was critical to understand the contextual framework in which transformation projects were developed.

Table 1. Associations interviewed (2009).

Irrigation system	Type of association	Number of associations	Irrigable area (ha)	Irrigated area (ha)	Drip area (ha)
Drip	Surface	11	14,499	10,458	9,586
	Transfer	2	36,208	20,057	8,323
	Mixed	17	20,427	16,565	14,698
	Groundwater	30	25,73	18,321	15,464
	Total	*60*	*96,864*	*65,401*	*48,071*
Gravity	Surface	8	45,87	43,528	
	Mixed	9	681	597	
	Total	*17*	*46,551*	*44,125*	
Total		*77*	*143,415*	*109,526*	*48,071*

The procedures of the WUAs to split costs among farmers are very varied. Therefore, information was specifically sought on subsidies, water costs and tariffs. This data was essential to facilitate the subsequent calculation of the financial impacts of the investments made and the induced changes in irrigation costs. In order to estimate the increase in tariffs and costs, we calculated the average of the differences between 1998 and 2009, and we updated 1998 values with the Consumer Price Index.

We observed that Valencian WUAs frequently overestimated their irrigated lands. Thus, to more accurately reflect changes in water withdrawals, we directly asked WUAs for their water use per hectare and crop. We compared this data with information on the extension of the irrigated areas and WUA water withdrawals. In some cases, where irrigated land extension had been clearly overestimated by WUAs, additional calculation through the geographic information system was made to check and correct areal values.

5. Results and discussion

In Spain, WUAs are responsible for the management of irrigation, including the operation and maintenance of the system, and do so by hiring staff. The costs of management and amortization of the WUA investments are then split among all the members of the WUA. In the following subsections we analyse: (i) how WUAs have financed this technological shift; (ii) the impact of this change on water costs; (iii) changes in water withdrawals after drip irrigation implementation; and (iv) how contextual factors have affected water-saving purposes.

5.1. Investment, subsidies and financial problems

All the interviewed WUAs developed their transformation to drip irrigation after obtaining public subsidies from the public administration, mainly through grants covering between 40% and 100% of the total investment. Government loans were used to finance the technological shift only in a small number of cases. WUAs recouped the additional investment costs, not covered by grants, through annual fees charged to their members. These fees are usually proportioned to farm size, but instalments are different in each WUA. In order to make data comparable, we have considered the total amount invested and granted, with an amortization period of 25 years and zero real rate, divided by the drip irrigation area. The average investment required to change the irrigation system was 8,134 € per hectare, approximately 60% of which was financed by public funds. Table 2 shows the amounts that the participating WUAs invested per hectare in the transformation to a drip irrigation system and the subsidies received from differing public administrative bodies.

During the interviews some inconsistencies were detected in the financial plans for drip implementation of several WUAs. Some of them made an initial estimation of the projected transformation area that was far greater than the amount of land subsequently built on. This happened in some places where the irrigated area had a decreasing trend, either due to urban developments or to farming abandonment. There are also WUAs that deliberately oversized the irrigated surface area for the purposes of receiving more subsidies and/or seeing their water allocation reduced by less, so as to ease the reductions in times of drought or to prevent the effects of the growing pressure on water resources. The lack of external assessment and sound technical support facilitated these oversizing practices. The over-dimensioned projects resulted in higher financial costs.

Table 2. Investments in and subsidies for drip irrigation.

Type of association	Investments €/ha	Subsidies €/ha
Surface	7,991	3,877
Transfer	12,331	6,039
Mixed	7,902	4,837
Groundwater	6,569	4,704
Total	8,134	4,803

Another possible problem stemming from the modernization process can be observed in the associations whose projects were financed with long deferment periods (usually 25 years). Some WUAs have expressed concern over the problems they could have in the future to pay off the acquired debt. Both the oversizing of the projects and postponing the payment of a significant part of the financing could endanger the viability of the WUAs. Any future abandonment of farm holdings will have a detrimental feedback effect on those who remain working in the sector, as there will be fewer and fewer partners left in the association to assume the debt, which would be particularly dangerous in an unfavourable agricultural market context.

Using subsidies to encourage the employment of techniques to improve the efficiency of irrigation system leads to a lower percentage of cost recuperation. The cost recovery rate is the percentage of the total cost of irrigation which is paid for by the farmers. As Dono *et al.* (2012) point out, striving for high cost recovery percentages may not, on occasions, be compatible with the need to improve efficiency, both of which are objectives that must be achieved according to the European Water Framework Directive. This is of particular significance for the traditional irrigation associations that have enough surface water for irrigation in normal years, but have seen a considerable increase in the irrigation tariff after modernization due to investment and operating costs. In these cases, the transformation would have no appeal if it were not for government grants (García-Mollá *et al.*, 2014).

5.2. Changes in the tariffs and costs transferred to farmers

WUAs use water tariffs to split operating and investment costs among farmers. For this reason, in order to calculate changes in water costs, we have analysed the WUAs' annual irrigation tariffs per hectare and cubic metre. Three factors were considered: operating costs, irrigation tariffs and real costs of irrigation. Operating costs of drip irrigation include all the water management costs (maintenance, electricity, staff). In Surface and Mixed WUAs operating costs also include levies and public tariffs for surface water use. All the farmers belonging to the WUAs annually pay the irrigation tariff. It reflects the operating costs plus the part of the amortization of the infrastructure and modernization paid for by the WUAs (not covered by public grants). Finally, the real cost also includes the amount subsidized by the public administration. Farmers would pay this full cost if there were no public grants to promote drip irrigation installation.

The modernization of irrigation practices has affected both the costs and the tariffs that the farmers pay for the water used for irrigation purposes (Tables 3 and 4). Operating costs now make up approximately 83% of the irrigation tariff, reaching 92% in groundwater WUAs, because of pumping costs. Tajo-Segura project tariffs increased the operating costs in Transfer WUAs. In general terms, even if

Table 3. Annual costs and irrigation tariffs (€/m^3) of drip irrigation.

	Drip irrigation (2009 averages)			Mean increase after modernization (%)		
	Operating costs	Irrigation tariff	Real cost of irrigation	Operating costs	Irrigation tariff	Real cost of irrigation
Surface	0.14	0.23	0.28	167	213	251
Transfer	0.29	0.37	0.46	55	101	145
Mixed	0.17	0.22	0.25	19	64	107
Groundwater	0.23	0.25	0.29	39	59	77
Average	0.20	0.24	0.28	54	87	117

Table 4. Annual costs and tariffs (€/ha) of drip irrigation.

	Drip irrigation (2009 averages)			Mean increase after modernization (%)		
	Operating costs	Price of irrigation	Real cost of irrigation	Operating costs	Irrigation tariff	Real cost of irrigation
Surface	475	788	954	33	62	81
Transfer	872	1,131	1,379	−2	27	54
Mixed	678	808	922	−45	−23	−1
Groundwater	733	813	924	−8	0	10
Average	666	805	927	−13	4	20

only the increase in operating costs is considered (resulting from pressurizing the irrigation network), it is evident that the implementation of drip irrigation has led to a rise in volumetric costs. Farmers have had to pay a variable share of the cost of the investment which, in turn, has led to a rise in costs.

The WUAs that use surface water have experienced the greatest increase in volumetric tariffs. The decrease in unit consumption has been a significant factor in this increase. The irrigation associations that use surface water have experienced a rise in the tariffs of irrigation per unit of area. Prior to modernization the tariffs of irrigation were lower, because the water could be obtained without incurring any significant electricity costs. Groundwater WUAs have not experienced significant changes in tariffs. Therefore, as Jackson *et al.* (2010) have observed, the impact of the shift to drip irrigation in surface water WUAs differs from that of groundwater WUAs. This should be considered when promoting drip irrigation transformation projects in traditional surface irrigation systems, because of the negative impact on farmers' incomes and agriculture viability.

Mixed WUAs have experienced a decrease in irrigation tariffs, which we attribute to a change of water source. Farmers of Mixed WUAs aim to conserve groundwater, and use surface water as a primary source, because groundwater is more expensive. With the introduction of drip irrigation, less water is used over all, decreasing the volume of groundwater needed to supplement the surface water. This result was consistent across most of the Mixed WUAs analysed. It has also been described in several sections of the Júcar-Turia Canal, which went from using 40–70% groundwater to 80–100% surface water (García-Mollá *et al.*, 2012). This change, that we have named resources substitution effect, allowed WUAs to achieve a considerably favourable (and in some cases unexpected) reduction of their irrigation costs. The impact of this effect on conjunctive use systems should be taken into account before promoting new conversions to drip irrigation.

In many WUAs some individuals have rejected the technological change or want to delay the installation of drip systems for several motivations (economic reasons, old trees with great root areas not properly covered by drip irrigation, organic farming against centralization of fertigation, etc.). WUAs respond to these situations in a number of ways. Some WUAs financially penalize the farmers who continue to use gravity irrigation, in an attempt to encourage them to adopt localized irrigation. For example, in Vila-real (Mijares basin) the tariff for gravity irrigation is 17% higher. Other WUAs allow the farmers a certain degree of freedom to continue using flood irrigation, as in Senyera and Sax (Júcar and Vinalopó basins). This variation in the application of tariffs reflects the social complexity of implementing a technological shift and also reflects some resistance to change.

5.3. Water use in WUAs

Reducing water withdrawals was the principal objective of the modernization policy for the public administration. The interviews revealed a significant decrease in water withdrawals across most WUAs. In Tables 5 and 6 annual means are shown for water withdrawals over irrigation surface area before and after the implementation of the modernization policies. The shift to drip irrigation led to a 53% decrease in the use of water across the WUAs interviewed. At the same time, WUAs that have

Table 5. Annual use of water for irrigation (means) by type of WUA (2009).

	Gravity (m^3/ha)			Drip (m^3/ha)		
Type of WUA	Minimum	Average	Maximum	Minimum	Average	Maximum
Surface	7,000	7,842	8,500	2,850	3,468	4,675
Transfer	4,800	7,440	10,080	3,027	3,913	4,800
Mixed	4,500	8,236	12,000	3,000	3,673	4,933
Groundwater	3,300	5,212	9,000	2,321	3,796	6,744
Average		7,919			3,710	

Table 6. Use of water for irrigation (means) by crops in WUAs that installed drip irrigation after 1998 (Modernized) and WUAs still using gravity irrigation (Not modernized).

Irrigation system	Crops	1998 (m^3/ha)	2009 (m^3/ha)	Change (%) 1998–2009
Modernized (Drip irrigation)	Citrus	8,305	3,835	−54
	Citrus-Loquat	5,228	2,963	−43
	Mixed*	6,060	3,382	−44
	Table grapes	7,375	3,323	−55
	Average	7,919	3,710	−53
Not modernized (Gravity irrigation)	Citrus	10,673	7,576	−29
	Citrus-Loquat	10,715	8,148	−24
	Mixed	8,121	6,573	−19
	Average	10,225	7,433	−27

*Mixed refers to a pattern of citrus, pomegranates, palm trees and vegetables.

not adopted drip technology have also significantly decreased water withdrawals: a 20% decrease in mixed WUAs and 36% decrease in surface WUAs. Farmers and technicians attribute this change to the growing pressure on water resources, resulting in a reduction of water volumes distributed by the Basin Authority, due to the improvement of management and control systems and investments in the renovation of distribution networks (concrete lining or pipes construction).

Thus, comparing the average decrease in water use in modernized and not modernized WUAs (Table 6), the mean decrease in withdrawals that could be directly attributed to the introduction of drip irrigation is approximately 26%. In terms of absolute values, we also observe that the mean withdrawal in 2009 in gravity systems is significantly higher (namely double) than the mean withdrawal in drip irrigation systems in the region. This shows that the introduction of drip systems could still cause a significant decrease in withdrawals in these WUAs.

In general terms we can also observe that, where the supply of water was greater before modernization, a greater reduction in consumption is achieved now. This behaviour can be explained by the marked differences in the initial withdrawals, which depend on the particular edaphoclimatic characteristics of each district, and on design of the infrastructure and the management traditions (García-Mollá, 2000). Withdrawals were quite similar between users in the same district, while greater differences were observed between different districts. However, these marked differences prior to modernization reveal important past deficiencies in the network structure and the local management of water, particularly in some citrus irrigation systems provided with very generous allotments. This is, in most cases, the result of ad hoc construction and expansion over generations.

The new technology has replaced both efficient and inefficient gravity irrigation procedures, creating greater reductions in consumption in those systems that were originally less efficient. For instance, some WUAs in the Mijares and Palancia districts that had poorly designed networks consumed around 10,000 m^3/ha in the 1990s, whereas current withdrawals have decreased to 4,000 m^3/ha. However, in those districts with low initial withdrawals, mainly groundwater WUAs producing table grapes with high pumping costs in the Vinalopó Valley, the technological shift involved smaller variations. These farmers use around 3,600 m^3/ha in wet years and roughly 4,200 m^3/ha in dry years to irrigate the table grape crop, quantities which the modernization process has done almost nothing to change. This is consistent with the observation of slight improvements by Soto-García *et al*. (2013) in the intensive agriculture of Cartagena district (SE Spain), also with low initial withdrawals.

5.4. Drip irrigation paradoxes: the importance of contextual factors

In the Valencia Region, and in many other areas of the world, public administrations, WUAs and farmers have implemented conversion to drip irrigation systems en masse without properly analysing the user context. This limited consideration of the socio-technological change attached to drip irrigation implementation (López-Gunn *et al*., 2012b; Van der Kooij *et al*., 2013; Garb & Friedlander, 2014; Venot *et al*., 2014) has caused unforeseen effects for both users and planners, resulting in successful experiences in some cases and resounding failures in others.

Some authors believe that the installation of water-saving techniques may lead to a rise in irrigation water uses at the district or scheme scale. However, the current characteristics prevalent in Valencian agriculture make an increase in water withdrawals after installing drip irrigation unlikely for several reasons. Crop intensification, mentioned by Lecina *et al*. (2010a), Gutiérrez-Martín & Gómez (2011) and Fernández-García *et al.* (2014) as a possible cause of increasing water use after modernization, is highly improbable. In Valencia, the crops are mostly trees, which makes it difficult to change to other more productive crops in the short term, although it could be viable in the medium and long term. The recent and the expected crop trends in the region, in a context of poor markets for citrus, ageing of farmers, rising temperatures and decreasing water resources availability, suggests the continuation of the replacement of citrus (decreasing 11,392 ha between 1999 and 2009) by other woody crops with similar or lesser water requirements, such as persimmon (increasing 3,349 ha between 1999 and 2009) or pomegranates, or simply the abandonment of citrus orchards altogether due to the market crisis. We have also observed this trend in the WUAs interviewed, and no case of crop intensification has been detected.

Other authors, such as Playán & Mateos (2006) and Sese (2012) highlight the risk of increasing the irrigated lands after the technological shift, which is what Scott *et al.* (2014) call the efficiency paradox. This is impossible in Valencian traditional surface irrigation, because the service area of each WUA is completely confined between other WUA service areas (or urban areas), and only decreases are possible. Neither is it likely in other districts due to the increasing trend of agriculture abandonment. We have only observed an increase in the irrigated area in six of the 60 WUAs adopting drip irrigation, the remainder are stable or clearly decreasing. Three of these cases are small groundwater WUAs with slight increases, and only in two cases are there significant increases in the irrigated area. One is the San Rafael Irrigation Community, at the Sénia River basin, which has tripled the irrigated area mainly by transforming rain-fed olive groves into citrus seedlings for sale. The other case is the Beneixama Valley Irrigation Community, where the installation of drip irrigation on a lesser water-demanding crop (shift from fruit trees to olive groves) made it possible to enlarge the irrigated area without increasing the local water use or modifying their water rights. In both cases, drip irrigation was not the cause of the irrigation expansion, but the necessary vector to guarantee irrigation expansion based on groundwater resources.

The possible appearance of the rebound effect or Jevon's paradox at basin scale cannot be properly detected without a complete basin water budget, with particular examination of changes in evapotranspiration, groundwater recharge and return flows. However, information provided by the basin authority (Confederación Hidrográfica del Júcar, CHJ) suggests that this effect is not visible or has a very limited impact in most of the regional watersheds. The agricultural water use estimated by the CHJ between 1998 and 2013 (Avellá *et al.*, 2014) shows a decreasing trend in those basins, partly as a result of decreasing irrigated areas, such as Palancia or Mijares, where intensive modernization has taken place during the last two decades. In some cases, such as the Vall d'Uixó district (Mijares basin), reduction of consumption has brought about an improvement in the aquifers according to the information provided by WUAs.

6. Conclusions

In the Valencia Region, the political goal of reducing agricultural water use has been successfully achieved through drip irrigation promotion. We have observed an important decrease in water withdrawals after drip installation in different districts, far superior to those achieved in areas that were not modernized during the same period. This differential decrease, that we can attribute to drip irrigation, has been possible in most cases because the regional contextual factors prevent crop intensification and areal expansion. This highlights the importance of understanding and controlling the regional agricultural context to anticipate unforeseen effects.

To achieve this water saving goal, the public administration provided users with access to generous grants to modernize their systems. This was a clear bottom-up approach. Nevertheless, without sound technical assistance, this administrative procedure can cause negative impacts in WUAs. The lack of technical support and sound supervision is responsible for the oversizing practices detected in a small number of transformation projects, and also for the design of some inaccurate financial plans that have risked the viability of these WUAs.

Due to the costs of the installation of drip irrigation and the new electricity costs, the irrigation costs per cubic metre have increased in all the WUAs. A significant increase in cost per hectare in traditional surface irrigation was also detected. This rise should dissuade most of the traditional irrigation system users from adopting these technologies without a previous complete financial assessment. It could be also problematic given the tendency towards decreasing agricultural areas. As the irrigation cost per unit is likely to increase, the sustainability of these WUAs will be put at risk.

Other risks for water management emerge from the way in which the water-saving goals have been achieved. The decrease in water withdrawals induced by drip irrigation has caused an unexpected shift in the distribution of water resources used in mixed WUAs, the so-called resources substitution effect. This change can alter the traditional balance of the regional conjunctive use systems, improving aquifer levels but not releasing fluvial water resources. Water planning authorities should consider this in order to avoid the generation of dry water savings in future planning.

The significant water savings obtained by drip irrigation promotion policies in the Valencia Region have been achieved at the expense of some negative impacts on irrigation costs. This is a partial sample of the complexity of the socio-technological process attached to the shift to drip irrigation. For this reason, future public promotion of irrigation modernization in this region and in other irrigated lands must incorporate thorough prior and wider diagnosis of contextual factors, and include accompanying measures such as technical assistance and impact monitoring.

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