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The Landing of Parachuted Technology: Appropriation of Centralised Drip Irrigation Systems by Irrigation Communities in the Region of Valencia (Spain)

Noemí Poblador

CIRAD, Montpellier, France; noepoblador@hotmail.com

Carles Sanchis-Ibor

Centro Valenciano de Estudios del Riego, Universitat Politècnica de València, Valencia; csanchis@upv.es

Marcel Kuper

CIRAD, University of Montpellier, UMR G-Eau; marcel.kuper@cirad.fr

ABSTRACT: Drip irrigation technology in existing collective surface irrigation schemes is frequently implemented through top-down policies and black box projects, causing significant changes in agricultural water management, uneven effects on local practices and organisations, and very different reactions in the social structures of irrigation. In this paper, we analyse the institutional co-production of technological change in the case of irrigation for fruit production in the Region of Valencia (Spain) following the implementation of drip irrigation systems in two irrigation communities. The State conceived public subsidy schemes promoting drip irrigation that had to be implemented rapidly. The private sector designed and implemented the new subsidised standardised infrastructure with a logic that was disconnected from collective-action principles. Farmers' representatives opted for a centralised fertigation model that introduced significant rigidity into the irrigation system, hindering the development of polyculture and organic farming. Irrigation communities were then obliged to redesign the irrigation system to make it compatible with their needs and to recover social control over drip irrigation. Our results highlight the importance of human capital and social control in processes of technological change in collective irrigation institutions.

KEYWORDS: Drip irrigation, water users associations, adaptation, centralised fertigation, organic farming, Valencia, Spain

INTRODUCTION

Drip irrigation has emerged as part of a massive, worldwide and globally shared strategy for reducing the agricultural use of water. Government agencies, companies and NGOs have used public and private funds to promote the dissemination of drip irrigation under the umbrella of favourable regulatory frameworks (World Bank, 2006; OECD, 2017). This support has been based mainly on a strong conviction as to the water-saving capacity of the technology, which has been experimentally proven in numerous agricultural contexts since the publication of the seminal works of Goldberg and Shmueli (1971) and Berstein and Francois (1973). The recent critical review of the paradigm of drip irrigation efficiency (Ward and Pulido-Velazquez, 2008; van Halsema and Vincent, 2012; van der Kooij et al.; 2013; Scott et al.; 2014; Perry and Steduto, 2017; Berbel et al.; 2018; Grafton et al.; 2018; Grafton and Wheeler, 2018) and the observed rise in energy costs after irrigation system pressurisation (Rodríguez-Díaz et al.; 2011; Jackson et al.; 2010; García-Mollá et al.; 2014) have not tempered the interest of public and private actors in the technology.

Drip irrigation continues to expand, sustained by other valuable outcomes such as reduced labour requirements, increased production and productivity (Gleick, 2002; Venot et al.; 2014), reduced exports of nitrates and salts from the irrigated land (Playán and Mateos, 2006; Isidoro et al., 2006a, 2006b; Lecina et al.; 2010), and social benefits (Kumar and Palanisami, 2011).

The dissemination of drip irrigation technology has followed a top-down approach in many nations, where the massive subsidisation of water-saving technologies is replacing investment in the exploitation of water resources by large-scale waterworks; this is, in effect, shaping a second hydraulic mission (Sanchis-Ibor et al.; 2020). National plans and programmes have allocated generous subsidies to individual farmers or water users associations (WUAs) who had no previous expertise in the technique (Venot et al.; 2014, 2017; Yao et al.; 2017; Molle and Tanouti, 2017; Khadra and Sagardoy, 2019; Molle and Sanchis-Ibor, 2019). In arid or semi-arid regions around the world, private companies, regional administrations, or NGOs have provided technical support for the implementation of drip irrigation infrastructure, providing industrially standardised devices and often reproducing installation designs that replicate pilot projects. What is more, drip irrigation was time and again delivered to farmers and WUAs as a black box standard kit, regardless of the specificities of the different local contexts (Benouniche et al.; 2014a; Garb and Friedlander, 2014). In many cases, farmers had to use this 'parachuted' technology with little or no dialogue on the technical choices made and no accompanying training (Ortega-Reig et al.; 2017b).

The arrival of a standardised technological solution has produced varied and contrasting results in different settings (Errahj and van der Ploeg, 2017; Sanchis-Ibor et al.; 2017b); these results are often very different from the outcomes expected by promoters. Unforeseen effects of drip irrigation implementation have been reported in many regions of the world. One unforeseen effect is the stigmatisation of certain categories of farmers who are considered to be 'reluctant' to change and resistant to the wider modernisation process (Henriquez et al.; 2017). Another reported effect has been the increased competition for water which has occurred with the extension of entrepreneurial or capitalistic farming; this competition is a product of the complex interaction between the technology and the socio-ecological systems into which it has been introduced (López-Gunn et al.; 2012). Moreover, farmers' objectives (and needs) may differ from the aims of public policies; while public administrations generally pursue water-saving goals, farmers often prioritise increasing productivity and reducing labour and costs (Ortega-Reig et al.; 2017b; Ferrández, 2017; Loubier et al.; 2019), a situation which obviously hinders the achievement of policy objectives. Due to diverging objectives and diversity of geographical and agricultural environments, numerous local farm-scale adaptations of drip irrigation schemes and projects have been developed; in some cases, the disassembling of the standardised projects and redesigning of their hardware through a process of 'bricolage' has yielded important innovations (Benouniche et al.; 2014b; Naouri et al.; 2020).

An analysis of these processes of technological change reveals the complexity of the institutional co-production that takes place in irrigation systems (Lam, 1996; Joshi and Moore, 2004; Goodwin, 2019). This can involve the public sector subsidising the technology, private companies designing and implementing the infrastructure, collective management institutions being in charge of making the drip irrigation systems work, and individual irrigators using and modifying the drip irrigation systems. Between the design of public irrigation policies and the on-farm use of drip irrigation, many interactions take place among these various agents; their different visions and interests have rarely been taken into consideration despite their critical influence on the development of future irrigation systems.

In this paper, we focus on irrigation for fruit production in the Region of Valencia (Spain), an area where drip irrigation was massively introduced after a complex process that involved regional and national governmental departments, private companies, irrigation communities (ICs), and farmers. We analyse how the state and the agricultural sector introduced this 'modern' technology, how its introduction affected local irrigation management practices, and how farmers and water users associations have been obliged, through a controversial process, to redesign the new (and often considered rigid) irrigation system to make it compatible with their needs and goals. After presenting the methodology used, the paper describes the process of drip irrigation implementation at the regional scale and then analyses the two IC case studies in order to highlight findings that are relevant for the implementation of future irrigation modernisation policies.

STUDY AREA AND METHODS

The Region of Valencia is the largest citrus production area of Europe; covering 182,000 hectares (ha), it produces 3.1 million tons of fruit per year, mainly for export. The citrus production area has decreased slightly in the last two decades due to the expansion of kaki (persimmon) fruit, the ageing of farmers, and urbanisation. As case studies, we selected two representative irrigation communities (ICs) in this 'orange belt': Vila-real and Acequia Real del Júcar (ARJ). The first represents the situation of a traditional IC at municipal scale, while the second represents the situation of large-scale irrigation schemes; it encompasses 21 municipalities governed by a single institution for collective irrigation management.

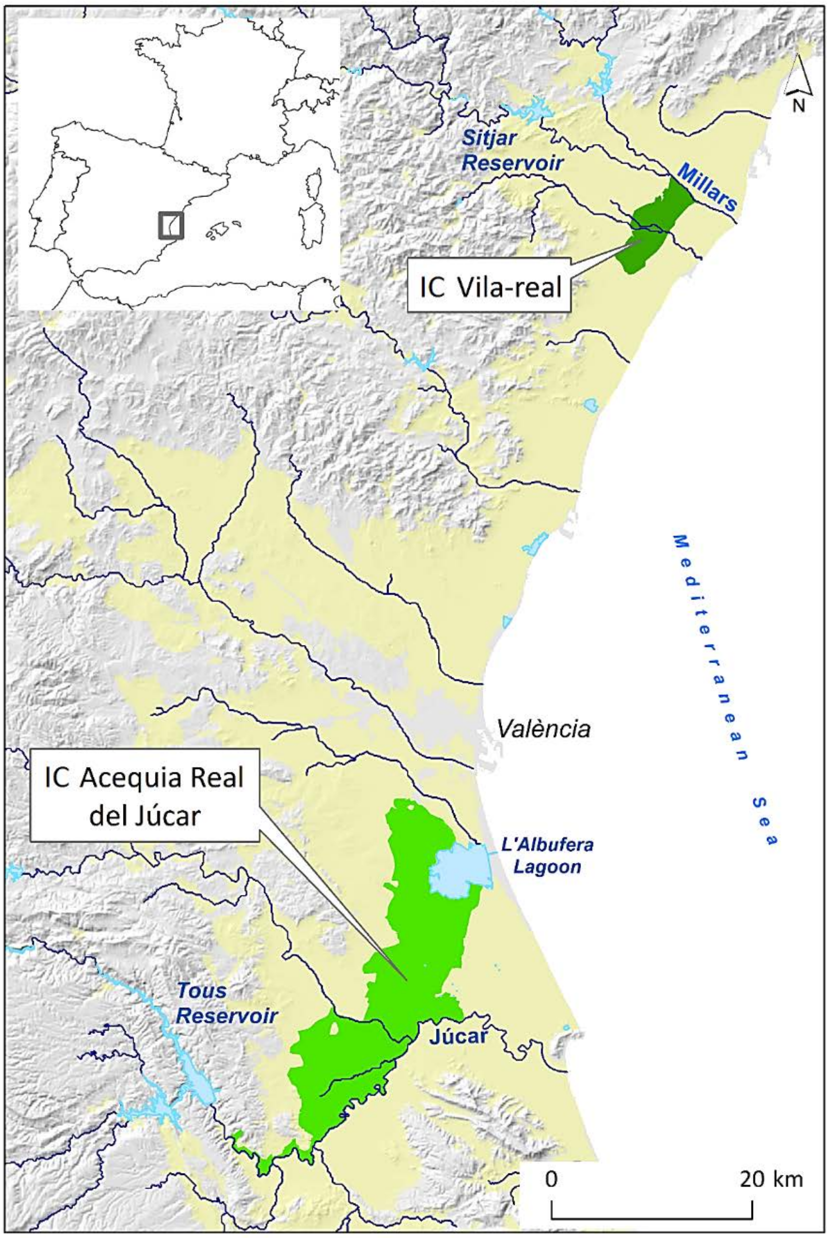
ICs are heirs to a long tradition of collective irrigation management as recognised by the water laws of 1866, 1879 and 1985 (Del Campo, 2018). The IC is managed by a governing board that is elected regularly by the IC's General Assembly, which is the sovereign body of the community. ICs hire technical and administrative staff for the operation and maintenance (O&M) of their irrigation system. The governing boards are the representatives of the ICs vis-à-vis the River Basin Authority (RBA) and other public institutions. They are members of the bodies of the RBAs that are most relevant for water planning and management (Water Council, General Assembly, Exploitation Board, Reservoirs Committee, etc). For these reasons, these governing boards are an essential link in the transmission chain of agricultural water management in Spain.

The study was carried out in two distinct irrigation systems (Figure 1). The irrigated area of Vila-real was created in the thirteenth century shortly after the foundation of the city of the same name by Christian conquerors. The irrigated area was managed by the city council until the creation of the IC in 1869. Today the IC covers 1700 ha divided into 11,100 plots, which are owned by 4600 farmers. Part-time farming is predominant, and only 12 farmers practise organic farming. Citrus orchards occupy 98% of the cultivated area, and other fruits and vegetables the remaining 2%. The cost of water has increased from 368 €/ha to 1140 €/ha, a rise similar to what has been documented by Sanchis-Ibor et al. (2017b) in other areas of the region that use surface water resources; however, if we also consider that since modernisation farmers' fertigation costs have been covered by the IC, the increase induced by modernisation only amounts to 252 €/ha. The IC has the right to divert 6879 m^3/ha/year from the Millars or Mijares River; in practice, however, only 4300 m^3/ha/year are regularly used at plot scale. This volume was significantly higher before modernisation (8400 m^3/ha/year). This decrease in water diversions has given more security of supply to all the users of the Sitjar reservoir (Figure 1). The expected drop in groundwater recharge after modernisation did not take place because the irrigated area decreased in the same period and because groundwater withdrawal also decreased in other ICs of the conjunctive use system of the Millars River (Sanchis-Ibor et al.; 2017b).

The Acequia Real del Júcar was built in 1258. The channel, significantly enlarged in the eighteenth century, irrigates 20,000 ha with water from the Júcar River. The IC has 29,400 members and the mean farm size is 0.7 ha, with part-time farming predominating. Paddy rice occupies 4500 ha, vegetables 2000 ha, and fruit orchards (citrus and kakis) 13,500 ha. Drip irrigation has only been introduced in parts of the fruit production sectors (6500 ha) but is planned for the rest of the fruit and vegetables area (9000 ha). The cropping pattern has not significantly changed during the modernisation process; water use, however, has decreased by 61 million cubic metres (Mm^3), from a yearly average of 275 Mm^3 between 1995 and 2004 to a yearly average of 214 Mm^3 between 2009 and 2018. If we only consider the years during which there were no drought restrictions, the difference increases to 133 Mm^3. As a consequence of this drop in water use and of the growing pressure on water within the Júcar Basin, the River Basin

Authority has updated their water rights, from 392 Mm^3/year (1998) to 214.2 Mm^3/year, matching water rights and water uses. According to the RBA, water savings generated by modernisation before 2015 were used to compensate for the water deficit of the Júcar Basin system, which also encompasses other smaller river basins (CHJ, 2020). Part of that savings (up to 15 Mm^3) has been allocated to users in the neighbouring Vinalopó Basin through a transfer project that aimed to maintain agricultural activity in an over-exploited groundwater system. Subsequently, water savings generated by the modernisation of the irrigation sectors in the Acequia Real del Júcar after 2015 are being periodically removed from the Acequia Real water rights and allocated to the Albufera wetland, in order to compensate for surface and groundwater discharge reduction.

Figure 1: Location of the study areas.



Note: Sandy-coloured areas are other irrigated areas in the region.

Due to the large size of the irrigated area, each municipality has its own local governing board elected by a local assembly; once a year, all the representatives of these 21 local councils attend a general assembly, from which the ten members of the main governing board of the IC are chosen (Carles-Genovés et al., 2008). This governing board is responsible for decision-making at the IC scale, while the local councils focus only on the municipal O&M. The local council and the IC both hire employees for O&M, at the municipal and community scales, respectively. Technological change due to the introduction of remote-control systems has stimulated the centralisation of decision-making around irrigation practices (Ortega-Reig et al.; 2017b).

Information was obtained through semi-structured interviews; a framework of themes (Galletta, 2012; Diefenbach, 2009; Longhurst, 2003) was used, the formulation of which was adapted to the professional and institutional profile of each interviewee. The purpose of the interviews was to obtain information on the characteristics of the ICs and the process of technological change (decision-making process, role played by the involved agents, results, effects, adaptation measures, and future perspectives). Table 1 summarises the professions of the interviewees and the organisations to which they belong. Interviews were held at the offices of the different institutions or in the fields that were part of the irrigation schemes. In all the ICs visited, one or more field visits took place after the interviews, guided by one or several members of the IC. Interviewees also kindly provided documents and internal reports from their institutions. After the first round of interviews, a number of follow-up interviews were conducted by phone with some interviewees in order to obtain more details on the topics discussed or to check information provided by documentary sources or other interviewees.

Table 1: Position of the interviewees, and the organisation to which they belong.

Interview No.	Profession	Organisation
1, 2	Farmers	Irrigation Community (IC) of Vila-real
3, 4	Managers	IC of Vila-real
5, 6	Technicians	IC of Vila-real
7, 8, 9	Technicians	IC of Acequia Real del Júcar
10, 11	Technicians	Other ICs within the region
12, 13,14	Farmers	Other ICs within the region
15	Manager	Other ICs within the region
16, 17	Technicians	Valencia Regional Government
18	Manager	Organic Farming Regional Committee
19	Lawyer	Regional Federation of Irrigation Communities
20, 21, 22, 23	Researchers	University
24, 25	Researchers	Regional Agronomic Research Institute
26	Manager	Water Users Association and Engineering Company
27	Manager	Engineering Company
28	Manager	Regional Association of Agronomy Engineers

DRIP IRRIGATION EXPANSION IN VALENCIA

A top-down water-saving policy leading to standardised and centralised drip irrigation systems

Drip irrigation has rapidly expanded in the Valencia region over the last three decades. In 1982, micro-irrigation systems had been installed on 5556 ha of farmland; by 2018, it was being used on 206,800 ha (ESYRCE, 2018). Before 1995, only some pioneers – mainly large landholdings using groundwater – had replaced the traditional gravity system with these pressurised networks; however, the severe drought of 1994/95, and the failure of the National Water Plan which was expected to transfer water from other peninsular basins to this region, triggered a redefinition of regional water policies (Sanchis-Ibor et al.; 2017b). The regional government developed and obtained approval for an Irrigation Modernisation Plan (IMP) to introduce drip irrigation as a water-saving strategy. Between 1995 and 2008, a total of €878 million was invested in subsidising the transformation process; this slowed down drastically after the financial crisis of 2009. Between 1995 and 2004, this IMP was adapted for use at the local scale by a series of work plans which were approved by the region's Department of Agriculture, and developed and implemented by its technicians.

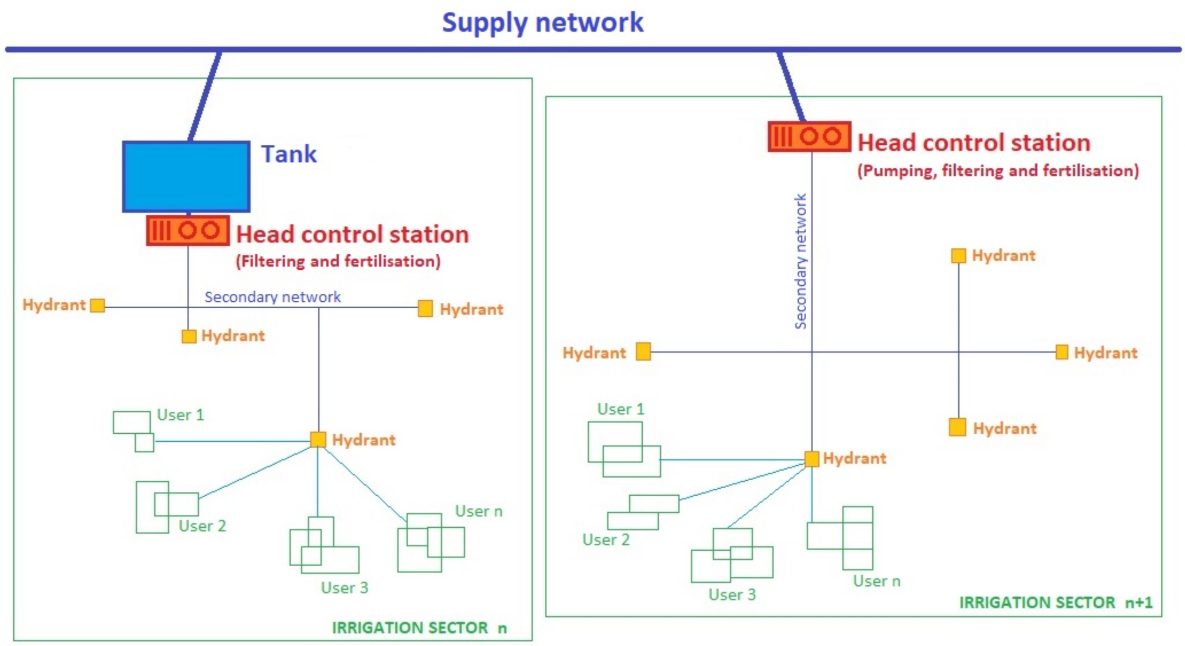
Between 1995 and 2008, the regional government established two financial support schemes: 1) subsidies for water works that were of 'general interest', which covered 100% of the cost of some selected infrastructure; and 2) subsidies for ICs' investments, which provided a 40% subsidy (increased to 50% in 2003) for those modernisation projects considered to be of local interest. The criteria for selecting the general interest subsidies were ambiguous enough to allow administrative arbitrarity (BOE, 2003), and often those subsidies were approved after a negotiation process with the ICs. The subsidies of ICs' investments were offered annually by the regional government through a public call. The ICs were required to submit a project plan that had been developed by a private engineering company, and the Department of Agriculture then decided on allocation of subsidies. Until 2008, the Department of Agriculture did not publish any detailed technical scale of assessment (DOGV, 2008). Both of the subsidy schemes – the general interest and the ICs' investments subsidies – were partially financed with resources from the European Agricultural Guidance and Guarantee Fund (EAGGF) Guidance section. The Central Government also contributed to subsidies of some drip irrigation projects in the region through the public company Sociedad Estatal de Infraestructuras Agrarias (SEIASA). This support was incompatible with the regional subsidies; however, if ICs were developing infrastructures in different sectors or elements of the irrigated area, they could obtain funds from both sources through different projects.

According to the interviewees, in most ICs the decision to adopt drip irrigation was made by their governing board. Participation in the general assemblies of ICs is often low and most farmers generally do not actively take part in the decision-making processes of the community; they instead transfer these responsibilities to a minority of entrepreneurs and more dynamic farmers. The boards brought the drip irrigation project plans to the General Assembly and, when put to the vote, most of them obtained wide support. Despite their limited knowledge of the new technology, the majority of farmers who attended the General Assembly trusted their representatives. At the beginning of the 2000s, the ICs did not have any technical staff able to design the new infrastructure, so their governing boards hired engineering companies that also prepared the necessary documentation to apply for public subsidies. During the interviews, farmers, managers, and the current technicians of the ICs pointed to the limitations of this process of technological change, which they felt to be mostly focused on the infrastructure. Prevailing modes of organisation of the existing irrigation systems were by and large ignored and the question of how farmers would get to know and use the system was not dealt with explicitly. As one of the managers said, "[having modernised the irrigation system,] what we need to do now is modernise the farmers" (Interview 26).

Moreover, as the interviewees from the engineering companies admitted, the process of designing and implementing the infrastructure had been too rapid; the farmers were not consulted and there was not enough reflection. As our case studies show, for financial reasons the companies maximised the number of projects implemented and, despite the variety of topographic, socio-economic, and agricultural conditions, applied similar technical solutions in different locations. In some cases, projects were clearly over-dimensioned in order to obtain bigger subsidies; in many others, inadequate technical solutions were introduced by the engineering companies. Once the subsidy had been provided and the infrastructure installed, however, the regional government made no ex post analysis of the project. No sanction has yet been imposed, and no demand for the return of a subsidy has till now taken place.

The vast majority of the new irrigation schemes in the citrus orchards of the region were designed according to a standardised model. The irrigation network consists of one main pipeline which replaced the historical irrigation canal and distributes water among one or several *cabezales* (head control units), introducing a centralised water distribution schedule. The water distribution schedule is decided by the governing board of the IC, while water distribution is operationalised by its technical staff. Varied automatisation software is used for remote water control and distribution. The old on-farm canals have been abandoned and are maintained in some areas for drainage reasons or to provide occasional gravity irrigation services for soil leaching; they are also sometimes used to irrigate sectors not yet transformed.

Figure 2. Regional collective fertigation scheme model.



The number of head control stations depends on the size and topography of the irrigated area. Each of these stations dominates a secondary network, controls the water allocated to each secondary pipeline, regulates the network pressure, and injects fertilisers through a nitrogen/phosphorus/ potassium (NPK) formula that is adapted to regular citrus production. Water and fertilisers reach all the hydrants from these stations and the hydrants then distribute the volume allocated to each plot through a tertiary network. This distribution can take place by turns or on demand, depending on the practices and agreements of each IC for water allocation. Centralised fertigation (combined distribution of water and fertilisers) was selected because it significantly reduces fertigation costs and because it was considered to be more comfortable for older and part-time farmers. As one interviewee stated, "70 year old men cannot be carrying sacks of fertilisers on their backs" (Interview 2).

The drip irrigation project in the irrigation community of Vila-real

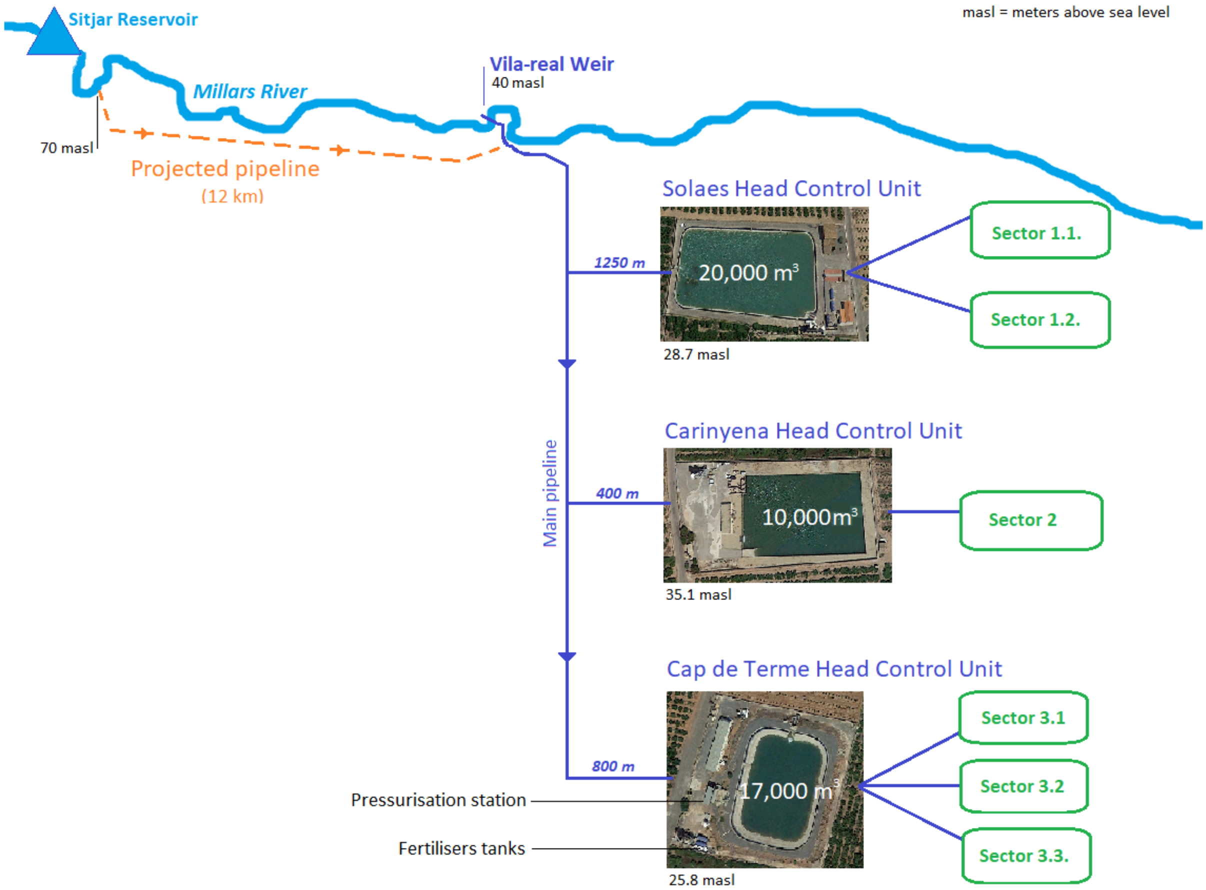
In the late 1990s, the governing board of the Irrigation Community of Vila-real proposed the introduction of drip irrigation systems to the General Assembly, with favourable public subsidies stimulating the discussion. Initially, according to the interviewees, most of the farmers were reluctant to accept this change; however, a minority of dynamic and influential farmers (larger landholders, representatives of agrarian trade unions, and bank employees) defended the initiative and progressively convinced most of the community members. Water security, personal comfort, and water productivity were argued to be the main reasons for adopting drip irrigation. In 1999, the General Assembly approved the modernisation project with 80% affirmative votes. Interviewees pointed out that most of the farmers were not properly informed of the implications of the change but trusted the opinion of the group of entrepreneur farmers. In 2000, the IC received financial support from the national government (SEIASA, with funds from the EAGGF Guidance section) as a part of the National Irrigation Plan, and in 2004 the pressurised irrigation network was completed.

As the members and technicians of the community at that time did not have the required technical skills, the IC hired an engineering company to design the new network. In order to obtain relevant information from the IC, the company established an operational link with the IC's governing board, which created a technical committee whose only function was to provide information requested by the company on water and agricultural requirements. This technical committee had no capacity to influence the technical decisions made during the design of the system.

Shortly after construction was completed, the IC identified some malfunctions that required readjustment of the design of the new pressurised network. According to the interviewees, the engineering company had built a system with three reservoirs and three head control units, which was not well adapted to the topographical conditions of the irrigated area. As a result, the system had low energy efficiency and irrigators had to readjust the pressure in numerous hydrants. Once the farmers and the IC technicians were familiar with the new infrastructure, they started to redesign the system. The most significant change was modifying the sectorisation of the irrigation system, increasing the number of sectors of the pressurised network from three to six; this change created groups of hydrants with similar pressure levels and energy requirements. Not surprisingly, the new sectorisation was very similar to the spatial distribution of the previous network of channels for gravity irrigation, which had been historically adjusted to the topography. Subsequently, in order to further reduce energy costs, technicians adapted the irrigation turns to optimise the electrical tariffs.

The three head control units and the reservoirs, however, should have been located at a higher place. Their unsatisfactory location hindered the full optimisation of the system: water had to be pumped twice, from the historical weir to the reservoirs and from the head control stations to the hydrants; the cost of reconstructing this infrastructure is currently beyond the capacity of the IC. As an alternative, the IC is now negotiating with the River Basin Authority to move the traditional intake of the IC (at the Vila-real weir at Millars River) to another weir located 12 kilometres upstream; this would enable the pressurisation of the main pipeline by gravity, thus eliminating the energy costs of pumping water from the historical weir to the three head control stations (Figure 3). Farmers hope to obtain a public subsidy for this project and they also want to involve some neighbouring ICs that could use the same infrastructure.

Figure 3. Sketch of the Vila-real irrigation scheme; it shows the six sectors that were created by the IC from three head control units, subdividing the three original sectors designed by the consultants.



Other malfunctions were also detected in the system: 1) the materials of some pipelines were too fragile for the working pressure, 2) some pipes were under-dimensioned (too narrow), and 3) the filtering systems required expensive maintenance and consumed too much water. The construction company engineers mentioned 'mistaken calculations' as the reason for the situation. According to the IC technicians, "the engineers of the company wanted the design and execution to go fast. The faster they were, the more projects they designed and implemented, and the more money they earned" (Interview 6). In other cases, the IC made adjustments to solve problems that would have been difficult for the construction company to foresee: first, the automatic devices failed during electrical storms, so the wire system had to be replaced by a radio control system; second, because the metal parts of the hydrants and valves were frequently stolen and the metal tended to degrade (thus increasing maintenance costs), metal was replaced by plastic.

Throughout this process of technological change, the IC hired technical staff trained for drip irrigation management, retiring the elderly *regadors* ('ditch riders') who had been managing the gravity irrigation systems. These engineers are now in charge of operating the system and adapting the drip irrigation infrastructure to the requirements of the IC. The technicians of the IC, for instance, recently introduced soil moisture sensors in the irrigated area; this has enabled them to reduce the amount of time spent supplying water to the plots from three to two hours per day. As the president of the IC proudly announced "Nowadays, we have the experience so we don't have to depend on outside engineering support and advice" (Interview 3). The IC, in other words, has taken over technical control of the system and uses outsiders only to supply equipment and chemical products, not to provide expert engineering advice. As Interviewee 5 commented, "We (ourselves) conceive the irrigation system projects"."

Fertigation has been the most contentious issue since the introduction of drip irrigation. After initially using an outside company to provide the fertigation application schedule, a specific internal committee now manages fertigation and carries out regular soil analytics. Because of the prominence of citrus orchards, the IC uses the same fertigation schedule for all users. The NPK formula injected in the three head control units is the same regardless of the crop, plant age, or farming practice. As a result, several problems have emerged: 1) in the irrigated area, 12 farms practise organic agriculture; centralised fertigation is a problem for them because the water that is distributed contains fertilisers that are not permitted in organic production; 2) centralised fertigation is also a problem for farmers who do not grow citrus fruits; some technicians of the community think that incorrect fertigation is the cause of some diseases detected in local kaki production. Organic farmers have complained about the situation and have argued for their right to receive 'clean water'. As one organic farmer stated, "I have no problem with drip irrigation, I really appreciate this new system as it is very 'convenient' (time efficient, requires less labour for weeding); my only serious problem is fertigation, because chemical fertiliser is imposed with the drip irrigation system" (Interview 1). As a temporary measure, the IC has opted to distribute 'clean' water on Saturdays and Sundays while maintaining fertigation during the rest of the week. During the first hours of the weekend, non-organic farmers who want some clean water can irrigate; at the end of their turn, the IC distributes water to the organic farmers. This solution does not satisfy organic farmers or those farmers who do not grow oranges. According to one interviewee, "I have different fruit trees with different nutritional needs, and I try to grow them organically. 'Clean water' one day a week is not the solution. This volume of water cannot meet my fruit orchard's needs and my agricultural choices" (Interview 2). In the future, the IC wants to "search for alternatives between a main menu and à la carte", re-sectorising fertigation (Interview 3); it is also planning to analyse chemical traces in the network and to model alternative scenarios for water distribution. This is increasingly an important issue, as the farmers engaged in conventional farming are an ageing population that is moving out of farming, while many young farmers want to use alternative ways of farming, including organic farming.

IC of the Acequia Real del Júcar

At the end of the twentieth century, the increased competition for Júcar River resources led public administrations to prioritise the modernisation of the Lower Júcar Valley irrigation systems. The Júcar Basin Water Plan of 1998 and the National Irrigation Plan of 1995 set different deadlines for the modernisation of the irrigated lands of the ARJ and other traditional ICs of the Lower Júcar Valley. These documents, as well as other subsequent agreements between the regional and national governments and the ARJ, stipulated the commitment of the state to fully subsidise the construction of a drip irrigation network for the ARJ service area.

The decision to introduce drip irrigation in this large irrigated area was taken by the River Basin Authority; reducing the withdrawal and use of irrigation water would offer an opportunity to reallocate Júcar River water resources. Two goals were paramount: the transfer of water to the Vinalopó Basin (CHJ, 1998) and meeting other water demands within the Júcar Basin. The ARJ leaders perceived these agreements as an opportunity to obtain funds to finance a transformation that would increase the security of the irrigation water supply – proven to be necessary during the last drought cycles – and would consolidate the prioritisation of the Lower Júcar traditional irrigation systems over the other irrigation water rights holders in the basin. All these negotiations were carried out by the main representatives of the ARJ governing board; the resulting agreements on the introduction of drip irrigation were subsequently presented to the General Assembly of the IC.

The decision to adopt drip irrigation was not initially welcomed by most of the local governing boards of the ARJ; the governing board had to organise meetings to "convince" farmers village by village

(Interview 8). A member of a local governing board declared that "they trapped us", when mentioning these meetings with the engineers and representatives of the governing board. Other farmers who were interviewed said that these top-down decisions were easy to take because, "during the general assemblies the representatives of the local governing boards do as they are told" and "there is a lack of professionalism in the local governing boards. They are old and take everything on trust without question" (Interview 8). Some of the interviewees referred to the adoption of drip irrigation as an "imposed" decision, as was also documented by Ortega-Reig et et al. (2017b).

Because the IC had no technicians with experience in drip irrigation, the design of the new system was a challenge for the ARJ. It had to hire companies to design the new irrigation system, in a time when it was not easy to find companies with experience in this domain. The ARJ selected engineering companies for these projects solely on the basis of their reputation. According to the interviewees, these companies did not pay attention to the recommendations made by the IC. As one interviewee commented, "the suggestions from our managers and technicians were not taken into account, although [the engineering company's] design of the [drip irrigation] systems was questionable. Frequently, it was not right for what we need". These companies did not produce any empirical improvements, neither did they engage in an iterative process of implement – error – adjust – validation. Companies just did "a copy and paste of previous projects in other domains" and engineers were "desk engineers who had never implemented a project in real conditions" (Interview 8). The construction of the new main pipeline parallel to the historical irrigation canal caused no problems and, according to estimations made by the ARJ and the River Basin Authority, enabled 60 Mm^3 of water savings per year. This was possible because the pipeline is also used to distribute water to the gravity sector in winter, while the old canal is only used during the rice season (May to September); hence, when water demand substantially increases in the summer, the historical canal delivers water to the rice paddies of the Albufera wetland, while the pipeline, in parallel, supplies the modernised sectors growing citrus and kakis.

According to ARJ technicians, however, the design of the head control stations and the hydrants was clearly inappropriate. Design problems included: 1) at the head control stations, the engineering companies built three tanks for separate NPK fertigation even though commercially available fertilisers are already mixed and therefore only one tank is necessary; 2) the faucet for emptying the tank was set too high, causing solids to accumulate at the bottom; 3) the filters were badly designed and there were notable losses in pressure between the inflow and outflow of water, resulting in the operating pressure downstream being too low; 4) the automated components (solenoids) for centralised management were of poor quality and the airing structures in the head control station buildings were poorly designed; and 5) the designers located 16 to 18 intakes per hydrant in small concrete huts, which complicated maintenance.

The fertigation system was based on the centralised distribution of nutrients at head control stations. This was problematic in that the IC developed only two fertigation programmes, one specifically for citrus fruits and the other for kakis. The standardised design of the system thus prioritised the main crops to the detriment of all others, in that no special programmes were possible for other fruits grown in the area (peaches, apricots) and no alternatives were planned for organic farming. In some areas, the gravity network was preserved; it is sporadically used to leach soils or to meet the demands of old trees with wide root systems.

After 2011, the financial crisis put a stop to investments in drip irrigation and the ARJ went through a process of staff renewal to improve the management of the new system. The ARJ technicians, who were by then more experienced and better trained, took over management of the new network. Since 2015, ARJ technicians have also produced designs for the transformation of the hydraulic projects for the new sectors into drip irrigation; outside consultants are only called in to check designs when it is considered necessary, and the ARJ technicians take the final decisions concerning the projects. ICs have also financed R&D to improve soil moisture control or fertiliser traceability when they deem it necessary. Changes they have made to the irrigation system have resulted in a 50% reduction in maintenance costs. Today, the initial scepticism about drip irrigation has vanished and most of the farmers and local governing boards express their satisfaction with the new irrigation system. As the technicians of the ARJ said, "Before, we had to convince the local government boards, now they phone to tell us to hurry to install drip irrigation in their sectors" (Interview 8).

Centralised fertigation, nevertheless, is still a problem. Organic farmers have complained about the situation; however, although a few more are now changing to organic farming, they represent only 17 ha out of 20,000 ha. Originally, the IC offered them no solution to their problem; some farmers, at their own expense (€12,000), decided to build an individual pipeline that would allow them to take water from the main distribution network, upstream of the connection with the head control station where the fertiliser is injected. The IC allowed them to do so and has recommended this solution to other farmers as the only alternative. ARJ technicians are sceptical about the use of alternative irrigation turns with fertilised versus 'clean' water; they believe that the best solution would be to group organic farming fields in specific sectors of the irrigated area.

DISCUSSION

Re-engineering of state-implemented drip irrigation systems by irrigation communities

National and regional governments developed an effective policy for the promotion of drip irrigation, with undeniable results in terms of its expanded area. This modernisation programme, formulated and developed during an era when irrigation efficiency was only considered at the plot level (Grafton et al.; 2018), was conceived as a pivotal national water-saving mission. The policy was executed using a top-down strategy backed by generous subsidies, but it was also based on the active participation of the governing boards of ICs that applied for public funds. These boards took the initiative and then convinced other farmers to implement the project. The technological change was the result of a process of co-production that was planned by national and regional state administrations in close cooperation with the governing boards of the ICs. The transformation, however, could be completed only once the drip irrigation system was in place and after the ICs had assimilated it by adapting the infrastructure to their needs and reorganising its management. The existence of a strong, historically and legally consolidated structure of collective institutions for irrigation management was able to influence the actions of the state in its facilitation of the technological expansion while at the same time adapting the new hardware to its own goals and necessities. (Similar processes have recently been observed in Turkey; see Le Visage et al.; 2018). In Spain, the negotiation and cooperation between the governing boards of ICs and the state shaped the territorial expansion of the new techniques. The active role of the governing boards of these associations in the adoption of drip irrigation makes them the most critical agent in the process of technological change (Ortega-Reig et al.; 2017a).

The ICs hired private companies to design and implement the new irrigation systems. We have shown that despite the formal involvement of IC governing boards in the planning of drip irrigation, they – and even less so individual irrigators – were not consulted about technical choices in the drip irrigation projects. The reasons given for this lack of consultation were: 1) the irrigators' insufficient knowledge of the new technology; 2) the lack of experience in drip irrigation on the part of the technical staff in the communities; 3) the rapid pace of the transformation process; and 4) reductions in formal economic support for training of IC managers, IC technicians, and farmers. This lack of knowledge undermined the capabilities of the governing boards and farmers and temporarily weakened social control over the very technology that characterises collective irrigation management institutions (Anderies et al., 2004; Cifdaloz et al.; 2010).

There were differences in the main objectives of public administrations and of farmers in installing drip irrigation; public administrations prioritised saving water to deal with the basin's deficit, while the main concerns of farmers were reducing labour and increasing productivity. These different priorities were compatible in that they did not require significantly different infrastructure or technical procedures. The goal of the engineering companies in charge of the design of drip irrigation systems, however, was the maximisation of the profit of each construction project; this often limited the above-mentioned objectives and affected the economic and hydraulic efficiency of the systems. Some infrastructure was oversized and some was undersized; private companies did not take the subsequent maintenance tasks and costs into account, nor did they consider the critical observations made by the ICs and farmers during the design and construction process. ICs and farmers often described the engineering companies as being the owners of a scientific procedure in which the farmers' knowledge of the local requirements and the managers' experience of water distribution were ignored; this has also been documented in other regions of the world (Diemers and Slabbers, 1992; Gelles, 2000; Boelens and Vos, 2012). As some interviewees stated, no correction of the engineering projects by ICs was accepted because "accepting a modification meant that their engineering works were wrong. And that was unacceptable [to these engineers]" (Interview 8).

When the ICs left the design of the new networks in the hands of private companies, they became dependent on external decision-making processes. One of the consequences was that the companies did not adapt their designs to local conditions and, as we have shown, many problems in the design and implementation of the drip irrigation systems emerged once the systems were being operated by the ICs. In other cases, because the installing of hardware does not guarantee successful use of a new technology, copy-pasting or rescaling of drip irrigation projects caused malfunctions (Garb and Friedlander, 2014; Taylor and Zilberman, 2017). The generosity of the public subsidies and the process of their annual allocation probably acted as an important incentive, which contributed to an accentuation of the imperfections of the process of technological change. Companies lacked the incentive to learn from local knowledge or to improve the technical quality and adaptability of the new infrastructure.

There is a broad consensus in the literature that hardware, software and orgware (the institutional processes of adapting a new technology) shape complex sociotechnical systems (Callon, 1991; Latour, 1991; Law, 1999; Smits, 2002; Jansen and Vellema, 2011; Klerkx et al.; 2012); the successful uptake of drip irrigation therefore requires changing practices, updating knowledge, and recrafting institutions. Irrigation modernisation, like many other processes of technological change and innovation in agriculture, is a co-evolutionary process (Geels, 2002; Kilelu et al.; 2015); changes in the irrigation infrastructure are thus tightly interconnected with management and social transformations (van der Kooij et al.; 2015) which in turn often trigger new changes in infrastructure. In the case of the expansion of drip irrigation in California, Taylor and Zilberman (2017) observed that this co-evolution necessitates additional human capital to adapt the technology, requiring public or private extension services. In Spain, however, due to the weak support of extension services and the dysfunctions introduced by private engineering companies, the ICs underwent a process of internal reorganisation to improve their human capital, which regenerated knowledge, replaced the actors and practices, and renewed the institutions.

The advent of the new hardware led to two major changes in the irrigation communities. First, the ICs decided to strengthen their capacities by recruiting young technical staff who were capable of operating the drip irrigation systems; second, the technical staff who faced operational difficulties progressively changed the infrastructure of the drip irrigation systems by, for example, eliminating/adding head control units and combining secondary canals. The combined knowledge of how to operate the system and the adjustments made to the infrastructure then enabled the ICs to cater to further changes in the agricultural context, for example the emergence of organic farming. Farmers and IC technicians provided practical responses to drip irrigation dysfunctions, developing solutions that were halfway between engineering adaptations and bricolage (Benouniche et al.; 2014b). Similar processes of adaptation and bricolage have been observed in other contexts where state-led irrigation modernisation programmes have been implemented. In the Brazilian state of Ceará, local actors partially solved deficiencies in filtering systems that had been designed by engineers who had not accounted for the existing sediment load of pumped water; this local solution involved conceiving artisanal filters (Mateos et al.; 2018). In the

Tadla irrigation scheme in Morocco, engineers ignored the conjunctive use of surface and groundwater, catering solely to surface water when they designed the collective drip irrigation project (Boularbah et al.; 2019). Farmers then called on artisans to connect their tube-wells to the drip irrigation infrastructure, thereby recreating a conjunctive use environment. What sets apart the experience in Valencia, however, is how the process of bricolage was institutionalised in the existing ICs. This process proves that these ICs act as communities of practice, first through their capacity to improvise new understanding when external canonical knowledge proves to be inadequate (Brown and Duguid, 1991), and second because of their capacity to evolve as organisations based on common interests and shared experiences (Wenger, 1998; Cox, 2005).

Only after this sociotechnical change could the ICs entirely restore social control over the technology, completing a co-evolution that re-empowered the farmers. As the statements made by the interviewees show, the ICs now feel proud of their command of the drip system. It would nevertheless be an error to idealise the role of these institutions. Despite their well-known skills in the collective management of irrigation (Maass and Anderson, 1978; Ostrom, 1990), the participation of farmers in decision-making processes is often scant. The positive climate of confidence in most communities contrasts with the poor attendance at general assemblies; most farmers trust the members of the governing boards and consequently lack interest in some decisions that could be strategically important for their future.

Adapting the irrigation infrastructure to changing demand: The case of organic farming

During the design process, the governing boards of ICs, public administrations, and engineering companies agreed on the selection of centralised fertigation as the model of infrastructure to be installed throughout the citrus orchards. Centralised fertigation fulfilled the requirements of the main type of local farmer, primarily older men who grew fruit as a secondary economic activity or a 'traditional hobby', as orange-growing, practised by the majority, yielded extremely low profits. This technical choice meant that the farmers were relieved of some unwelcome tasks, but it also deprived them of decision-making power with regard to fertigation. By selecting this centralised model, the governing boards met the demands of the majority of the farmers, but introduced significant inflexibility into the irrigation system such that innovation and change were hindered.

There are at least three categories of farmers who particularly have problems with the rigidity of the new irrigation system. First, some citrus fruit growers produce early or late varieties which they can sell better on agricultural markets; these farmers do not require the same fertigation programme as most other farmers. Second, some farmers grow other fruits (peaches, apricots) which also require different fertigation schedules. Third, there are emerging farmer profiles, generally entrepreneurial young people, who are willing to adopt organic fruit growing as their only (or main) source of income, that is, as a 'real – not just part-time – profession'. This is particularly important in the context of the current crisis facing Mediterranean agriculture (Ortiz-Miranda et al.; 2013), as alternatives to traditional agricultural practices are being blocked, critically affecting organic farming. Perceived by young farmers to be an alternative to the traditional commercial channels – which are trapped in an orange market where prices have been stagnant or declining for the last three decades – organic farming is starting to expand in the region. Centralised fertigation makes organic farming certification impossible and hinders the option of changing from citrus to other fruit or vegetable crops. The study cases reveal different ways that organic farmers are adapting to this situation – the same options as those chosen in other ICs of the region. After receiving the demands from organic farmers, some ICs (including Vila-real) modified their orgware to allow these farmers to receive water in a different turn; others, including the ARJ, have modified the hardware by installing new pipelines that bypass the head control stations where the fertiliser is injected. Both solutions cause problems – possible remaining chemical traces, alteration of irrigation turns and economic cost – and create new dilemmas for the communities.

This situation raises at least two critical questions. Who should assume the financial costs of these adaptations? Should the communities be obliged to distribute clean water, or can they force all users to receive water plus fertilisers? The interviewees did not agree in their responses, and it is likely that in other national legal water frameworks we would obtain other legal answers. The crux of the matter is whether the access rights to clean water of a minority (innovating farmers) can alter or be an exception to what has been approved by the majority (General Assembly). The 'sufficient consensus' criteria has been considered in some approaches to ethics in rural innovation (Leeuwis, 2004; Leeuwisn and Aarts, 2011), while the political ecology perspective has frequently supported the rights of minorities in water conflicts, mainly regarding water grabbing and rights dispossession (Mehta et al.; 2012; Yacoub et al.; 2015; Birkenholtz, 2016). What we observed in these case studies, however, is that in order to cope with this dilemma ICs are searching for an equilibrium among the two groups of users through negotiation, offering some alternatives to the minority of organic farmers in order to preserve (and prioritise) social peace within the community. This is the same strategy that the Spanish ICs have used in the past to solve internal conflicts; it is also one of the critical elements that sustains community life and robustness (Maass and Anderson, 1978).

CONCLUSIONS

Processes of sociotechnical co-evolution are usually accompanied by tensions and difficulties that affect the outcomes of innovation (Kilelu et al.; 2013). The institutions involved in these processes can pursue different objectives or have different priorities, as we have seen in the case of drip irrigation in Spain (Ortega-Reig et al.; 2017a, 2017b). They can also have different knowledges, technical skills and financial capacities, which condition how the interaction among them takes place during the co-production process. In the Region of Valencia, we have observed two main factors that initially conditioned the process of adoption and implementation of drip irrigation: unwavering political and financial support from the national and regional governments, and the lack of a sound command of the new technology among both engineering companies and farmers.

During the last three decades, Spain has promoted an ambitious irrigation modernisation programme that has been based on generous subsidies of pressurised irrigation; there has been a lack of predefined criteria in the allocation of funding and no rigorous ex ante analysis or ex post assessment (López-Gunn et al.; 2012). This enormous financial support, which obviously facilitated a vast expansion of areas equipped with new irrigation technologies, established some perverse incentives that were irresistible to numerous engineering companies; they aimed to maximise the cost of the projects developed, design and build them as quickly as possible, and avoid coping with the complexities of local irrigation systems and farming traditions. A more well-designed framework of financial and technical support would presumably have led to farmers being consulted ex ante, but would surely have slowed down the speed of implementation. The landing of the parachuted technology was a challenge for the ICs; experiences in the adoption of drip irrigation show that, in many cases, the overcoming of the challenge of new technology requires outside support (Taylor and Zilberman, 2017). In the historical ICs analysed in this work, the possibility of outside technical support was not feasible or not considered by farmers. They lacked the training and the ability to design the new irrigation system and were quickly overwhelmed and outpaced by the conversion programme; as a result, the private sector monopolised the design of the new infrastructure, while the ICs were, in the process, rapidly marginalised. The private sector followed a logic that was disconnected from collective-action principles; this was also the case when private companies participated in irrigation management in the region (Sanchis-Ibor et al.; 2017a; García-Mollá et al.; 2020). Moreover, farmers' representatives opted for a centralised fertigation model that introduced significant rigidity into the irrigation system, blocking polyculture and organic farming.

Despite these limitations, we observed how the ICs reacted after some time, initiating the renewal of the managerial structure. Older technicians progressively acquired knowledge of drip irrigation systems and others were hired specifically to improve the technical capacity of the employees of the communities. These new teams detected the dysfunctions of the technology that had been parachuted in by the engineering companies; they enabled a process of appropriation and adaptation of hardware and organisational processes to the characteristics of the irrigated areas and the needs of the communities. In other words, the ICs evolved, and recovered social control over the infrastructure in a co-evolutionary process, thereby demonstrating significant resilience to external disturbances.

Local control is a basic component of socio-ecological systems that rely on irrigation, and it is critical to sustaining the robustness of collective action (Cifdaloz et al.; 2010). Collective-action values also underlie the process of developing alternative avenues for organic farming and polyculture through changes in hardware, software and orgware, in an attempt to balance the divergent interests of the different members of the community. The importance of these common values underlines the need to analyse these co-evolutionary processes of adoption of drip irrigation in a wider sample of socio-ecological systems. The well-known academic recognition of the Valencian ICs' collective-action values (Ostrom, 1990), and the robustness evidenced by the recovery of social control of the irrigation hardware, could lead to the consolidation of a myth around the role of these institutions (Garrido, 2011). We should nevertheless take into account that the lack of participation by farmers weakened the decision-making processes, that lack of training in new technologies delayed the reorganisation process (which has obviously had important economic costs for farmers), and that the solutions implemented for organic farming and polyculture are still precarious and have disadvantages and burdens for all categories of farmers.

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