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EFFECTS OF DRIP IRRIGATION ON WATER CONSUMPTION AT BASIN SCALE (MIJARES RIVER, SPAIN)

EFFETS DE L'IRRIGATION GOUTE A GOUTE SUR LA CONSOMATION D'EAU A L'ECHELLE DU BASIN VERSANT (FLEUVE MIJARES, ESPAGNE)

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ABSTRACT

This paper carries out an ex-post analysis of the generalized implementation of drip irrigation in the last two decades in the Mijares River basin (Valencia Region, Spain), based on 15 semi-structured interviews with different water users' associations that provided information prior and subsequent to the modernization. In order to assess the impact of drip irrigation at the basin scale, a mathematical model was developed to simulate the situation before and after the implementation of the drip irrigation schemes. Discussion focuses on the analysis of the characteristics prevalent in Valencian agriculture that make unlikely an increase in demand after installing drip irrigation. Conclusions highlight the relevance of some contextual agricultural and water policy factors to block the appearance of the rebound effect.

RÉSUMÉ

Cet article développe une analyse ex-post de la mise en place de l'irrigation au goute à goute pendant les deux dernières décennies dans le bassin versant de la rivière Mijares (Région de Valence, Espagne). Le travail présenté repose sur les données issues de 15 entretiens semi-structurés réalisés avec différentes communautés d'irrigants qui ont facilité l'information antérieure et postérieure à la modernisation. Pour évaluer l'impact de l'irrigation au goute à goute à l'échèle du bassin versant, un modèle mathématique a été développé pour simuler la situation avant et après la mise en place des systèmes d'irrigation au goute à goute. La discussion est centrée sur l'analyse des caractéristiques propres à l'agriculture valencienne qui rendent impossible l'augmentation de la demande après le passage à l'irrigation au goute à goute. Les conclusions soulignent l'importance de ces facteurs propres à l'agriculture locale et à la politique hydraulique pour éviter l'apparition de l'effet rebond.

Keywords: Drip irrigation; rebound effect;models; water resources management; Spain.

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1. Introduction

Over the last 25 years, numerous governments have implemented a policy of promoting drip irrigation with the purpose of improving the efficiency of water use, something at the same time endorsed by international studies and reports. However, some recent research has questioned the usefulness of this technological change as a mean of achieving efficiency improvements(López-Gunn et al. 2012; Van der Kooij et al. 2013; Scott et al. 2014). The presence of negative effects on water and energy consumptionhas been particularly highlighted.

This gap between the policy objectives and final water consumption is due to the changing efficiency attained when technology is considered locally or from a point of view of integrated resource management (Ward and Pulido-Velazquez, 2008). Thus, recent works have focused on the so-called *rebound effect* or *Jevon's paradox*, which states that the introduction of a new technology that increases the efficiency of using a natural resource does not necessarily lead to less consumption of this resource (Berbel et al., 2014).

In this regard, the aim of this study is to carry out an ex-post analysis of the generalized implementation of drip irrigation in the last two decades in the Mijares River basin (Valencia Region, Spain). In order to understand the effects of this technological change at basin scale, a mathematical model has been implemented, simulating two scenarios, prior and subsequent to the adoption of drip irrigation.

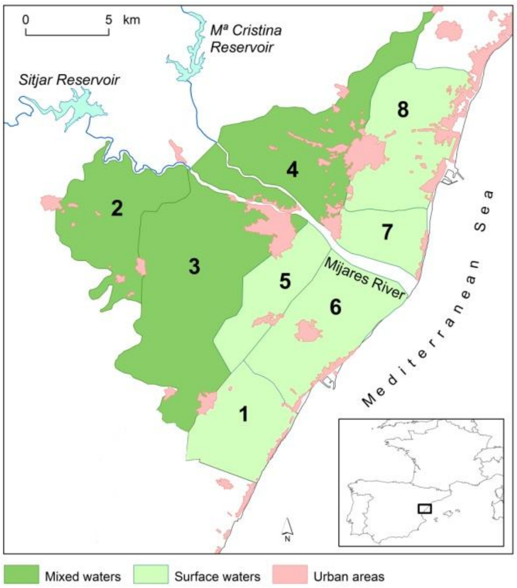

Figure 1.Mijares river district irrigated areas: 1.Nules-Mascarell-Fortuna, 2. Canal C220 3. Canal C100 4. MªCristina 5. Vila-real 6.Borriana 7. Almassora, 8. Castelló-Marjaleria

2. Materials and methods

Information on drip irrigation adoption and effects was obtained through 15 semi-structured interviews with different water users' associations that provided information prior and subsequent to the modernization. The total area of irrigable land of the associations that were interviewed covers more than 21.000 hectares, 47% of the total area of irrigable land in the Mijares River basin. Systematic information was collected, in addition to water use and consumption, regarding influential factors such as dimensions of the irrigated area and evolutionary trends, farm sizes, organization and institutional configuration, relationship with water authorities and other organizations, infrastructures state and development, financial situation, water costs and prices.

A mathematical model has been developed to test the impact of drip irrigation in the Mijares River basin. It has been coded in the GAMS language (Brooke et al, 1998). Being depicted in Figure 2, it includes 2 reservoirs, 2 sub-basins, 1 aquifer, 13 streams (3 of them with minimum flow requirements) and 12 demands. Seepage losses in streams or reservoirs have been depicted using discontinuous lines. The information to build the model was obtained from the semi-structured interviews, as well as from the Jucar River Basin Authority Management Plan (CHJ, 2013). Moreover,irrigated area measurements were developed using ArcGIS TM 9.3 (ESRI, Redlands, California, 2009),through the interpretation of different aerial pictures dating from 1998 and 2009.

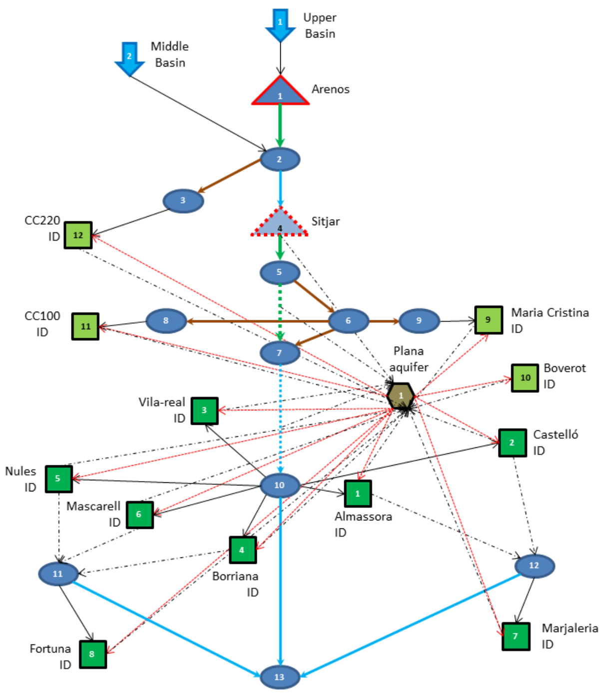

Figure 2. Demands, streams, reservoirs, sub-basins and connections considered by the mathematical model

The model allocates water according to the currently applied management rule, the 1970 Agreement (SCRM, 1974). The allocation system possesses four different types of demands: traditional, runoff, mixed and groundwater. Traditional demands use always surface water except during droughts. Runoff demands are allowed to employ the surface returned flows from the traditional ones, as well as boreholds. In mixed demands, supply is shared between the river and the aquifer. Groundwater demands require water pumping. All demands can pump from the Plana aquifer, which receives the seepage losses found in the Sitjar reservoir, the lower streams and the demands.

So as to test the impact of the drip irrigation, two scenarios were run: the 1998 one (before) and the 2009 one (after). Differences between scenarios consist of the different amount of water required by the demands, due to surface reduction and drip implementation; besidesmodifications in the demands' surface returns and seepage losses. The rest of the system was kept the same in both scenarios, which were run for the 1970-2009 period.

3. Drip irrigation implementation and induced changes

Before 1995, drip irrigation expansion in the Valencia Region was developed by farmers and water users associations. This process took place mainly in groundwater areas. However, after the drought of 1995, the administration became involved in the introduction of this water saving technology, in order to achieve a decrease in water uses in the region. The public sector took the initiative financing the installation of drip systems, particularly in areas supplied with surface wateror mixed waters (Avellá and García-Mollá, 2009).

In this context, at the beginning of the 2000 decade, the installation of drip irrigation infrastructures was financed in the River Mijares irrigation district by the regional government, the state corporations (SEIASA) and the water users' associations, using subsidies from both public administrations (regional and central). The total cost of the investment was between 4,000 and 13,000 € ha-1, with an average of 8,174 € ha-1. The financial public contribution facilitated the involvement of irrigators. Farmers, as well as water saving goals, positively assessed other benefits of this technology, such as the comfort provided by the decrease in duties and working hours.

In the traditional irrigation areas, almost exclusively provided with surface water, some communities totally transformed irrigation systems to drip irrigation (Vila-real, Almassora) during the last decade, whereas others only executed partial transformations (Castelló), and some (such as Borriana and Nules) still use gravity systems in 2009. In the area supplied by mixed waters, the transformation projects have been fully developed in the communities of Maria Cristina and Cota 220, whereas in the community of Canal Cota 100only the 61% of the total surface was transformed to drip irrigation.

As a result of the modernisation process, water uses have considerably decreased. The reduction of withdrawals has been particularly significant in the mixed irrigated areas, where water use decrease from 8.100 m^3/ha in 1998 to 3.251 m^3/ha in 2009 (60%), whereas in the traditional surface water users' associationsdecreased in 55%, from 8.467 m^3/ha to 3.845 m^3/ha. However, we have to consider that in the not modernized areas of the mixed water users associations a decrease in 20% was also observed.

Several authors have recently highlighted the risk of increasing the irrigated lands or crop intensification (López Gunn et al., 2012), both resulting in an increase in consumption, after the technological shift. However, we have observed different trends in this district, where drip has not stimulated expansion and neither intensification. Citrus is almost the only crop in the area before and after modernization and instead increasing, irrigated lands have substantially decreased (between 7% and 20%)in a context of falling agricultural prices and aged farmers.

Decrease in water consumption generated by drip installation has modified the distribution of water resources used. This change, that we could denominate resources diversion effect, takes place in water users' associations using both surface water and groundwater. Here, we have observed how the drop in consumption –due to drip systems but sometimes also to the reduction in the irrigated area–, has led to a fall in the percentage of groundwater used for irrigation and an increase in the use of –cheaper– surface water. In the case of Maria Cristina irrigated area, this situation has led to the complete abandonment of groundwater resources, because the current water demand is fully met with surface water.

4. Model results

The results obtained were reservoir storage, aquifer levels and recharge values, and demands' supply by source. Regarding the reservoir storage, the 2009 scenario reflects a slight increase in the average amount of water stored, caused exclusively by the traditional irrigation demands' reduction. The mixed areas demands reduction does not cause a decrease in the surface water required, but in the pumped water, since those demands have legal rights upon surface waters that must be respected.

Despite the storage increase, the negative effect of the major droughts suffered in the Mijares river still appears in the reservoir levels (although less severe).With respect the aquifer state, the 2009 scenario shows an increase in the net recharge value caused by the pumping reduction. However, the effect of the drip irrigation implementation (and decrease in irrigated area) in the aquifer level is almost inexistent, as noticed in the recorded piezometric heads. The reason beyond this is the discharge mechanisms of the aquifer (mainly flow to the sea), that increase the groundwater discharge in response to the recharge increase. Due to that, the aquifer balance remains stable but with increased recharge and discharge values.

The most important effect of drip irrigation implementation is the significant reduction noticed in the aquifer overexploitation during droughts: in the 2009 scenario the aquifer level reduction due to temporary overdraft is distinctly lower than in the 1998.When considering demands, the higher impacts of drip irrigation are found in the mixed agricultural water users' association. There is even a demand, the Maria Cristina ID one, whose reduction allows it to be entirely supplied using surface water, in accordance with the information obtained from the farmers.

The impact of drip irrigation in the traditional demands is less significant, being the most important benefit the system robustness increase due to the higher reservoir levels, which reduces the amount of emergency pumping required by those water uses. In contrast with the previous situation, the drip irrigation causes a negative impact in the runoff demands, since they use the return flows of the traditional ones, needing to pump water to replace the lower returns associated to the drip irrigation. Although the Fortuna demand suffers no impact (neither the Borriana nor Nules nor Mascarell demands have drip irrigation at this moment), the Marjaleria one increases its water pumping to confront the reduction in the return flows of the Castellon and Almassora demands. This should be considered in the current modernization projects of the Nules area, because there is other irrigation sector (Fortuna) mainly provided with return flows.

5. Conclusions

Drip irrigation has been developed in parallel to an important decrease in water withdrawalsin the Mijares district. This has been possible because some contextual factors prevent, in most cases, from crop intensification and areal expansion. The mathematical model shows that the rebound effect seems to be not relevant or at least not enough to cause a global rise of agricultural water demands in the area. Water storage slightly increases in this period whereas groundwater levels achieve stability.The model also arises the impact of modernization on the not modernized water users' associations using return flow, which are forced to increase pumping.

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