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Exploring ways to improve agricultural water management in two Mediterranean irrigated systems: promises of wireless low-tech sensor networks

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Abstract. Unsustainable use of water resources and climate change will exacerbate the already existing tensions on resources, especially in the Mediterranean context. Despite investments in modern, economically and energetically costly equipment, the performance of irrigated agriculture remains below expectations, notably because of inappropriate irrigation practices, due to insufficient knowledge of irrigation actual need and limited use of decision support tools. Access to information at an unprecedented level, via easily accessible low-cost and low-tech sensors, may be a major lever for better identifying achievable performance gains, at different spatial and temporal scales, and for guiding stakeholders towards more sustainable practices. To explore this hypothesis, we have worked on the emergence of such technologies within two Mediterranean irrigated systems (Provence, France, and Cap Bon, Tunisia) facing major water use efficiency issues. Interviews were conducted on each site in order to identify main local needs and constraints that limit sustainable water management, and potential levers to improve irrigation performance. Innovative technological systems (water sensors, automation, Internet of Things networks) have been developed in response and tested in field through a participatory approach. The technologies were then designed to be low energy, low-tech and low-cost, based on the hypothesis that the lack of accessibility – investment and maintenance costs, system readability – of existing equipment was a brake to the dissemination of innovations in the agricultural sector. We believe that the adoption of such technologies could contribute to improve irrigated systems sustainability by playing on several dimensions: promote suitable and sparing water use by improving decision-making; help maintain agricultural production by decreasing input costs; improving water users' working conditions. Generally, accompanying the transition towards more sustainable practices, by providing to the stakeholders keys for better understanding of their system. The performance gains achievable with these innovations, heeding their inherent weaknesses (eg. lower robustness and accuracy), and the potential impacts of their adoption at a larger scale remain to be assessed in an integrated way.

Keywords. UPH 16; Irrigation; Mediterranean agriculture; Participatory design; IoT

1 Introduction

The challenge of food security in a context of climate change and demographic growth brings irrigated agriculture – leading consumer of fresh water and source of more than 40 % of the world's agricultural production – under the spotlight (FAO, 2020). Within irrigated territories, pressure on water resources may causes allocation conflicts between agricultural, ecological, industrial and domestic uses. Major investments have been made to improve the performance of irrigated systems, from plot level to catchment scale. Measuring equipment (flow meters, soil moisture probes, water level sensors ...) is among the solutions deployed to support decision-making or irrigation systems automation. However, these tools are still under-used, especially at farm scale and in the global South. The digital boom and recent development of new technologies such as on-board electronics and Internet of Things (IoT) expand the possibilities for better understanding and management of agricultural resources (OCDE, 2019). For irrigated agriculture, these advances offer the opportunity of real-time water flows measurements through wireless sensor networks (WSN) deployed within territories. Many studies have shown that irrigation monitoring is technically feasible by means of systems based on different kinds of sensors, measured parameters and communication networks (Hamami and Nassereddine, 2020). Work has been done on diverse agronomic conditions and some studies have shown that performance gains are achievable with the help of such tools (Liao et al., 2021; Bwambale et al., 2022). However, to the best of our knowledge few studies have gone beyond the purely conceptual and technological aspects and actually tried to match such innovations with agrarian contexts. This article describes first the paths that led to the development of technological innovations within two irrigated territories and second provides an insight of the innovations that were implemented.

2 Methods and study sites

2.1 Shaping innovation to match territories

The aim of the first phase of the process is to understand the agrarian contexts and identify main issues related to agricultural water management. An agrarian diagnosis is carried out on two irrigated territories. Data is collected through a field survey campaign. To understand the main trajectories of local agriculture, open interviews with key resource persons and retired farmers are conducted. Around thirty semi-directive technical and economic interviews are conducted with farmers on each case study site. Besides we performed interviews with network operators and heads of water user associations, institutions, producers' and environmental associations. The analysis of these survey data allows (i) to build a typology of the farming and cropping systems composing the irrigated territories; (ii) to identify the performance gaps; (iii) a first insight into the innovation potential in the area, i.e. the identification of practices or tools improving performances and the inclination of stakeholders for innovation (access to education, digital technology, awareness of the stakes, investment capacity, etc).

At this stage, two cases may be encountered: innovation is existing on the territory, some "pilot" stakeholders (suppliers, farmers, managers) have developed expertise and tools to meet local needs. In this case, the objective is to support the existing innovation by asking why its adoption is limited for the moment, and by what means these solutions can be improved to encourage their dissemination. In the second case, the survey does not reveal any particular local innovation, despite the identification of strong water management issues. In this situation, the method consists of thinking up and designing new tools with the water users.

The design of innovations is based on a participatory approach, which aims to involve stakeholders throughout the process (Fig. 1). The development of the first prototype responds to a set of specifications dictated by the survey results, based on the needs and constraints formulated by the stakeholders. The tool is then introduced to potential users in the form of demonstration workshops, and then evolves regularly based on their feedback. Within the territories, work spaces for the design and maintenance of the systems (fablabs), also providing a place for interaction on the topic, are set up. Field trials carried out at "pilot" farmers' plots are an opportunity to test the technologies in real conditions, while user feedback contributes to the continuous improvement of the solutions developed.

2.2 Case-study sites

To explore our hypotheses, we experimented the envisaged method within territories known for the water management challenges they are facing (pressure on the water resource, agro-economic constraints). It was important that the study sites show a diversity of agrarian contexts (cropping and farming systems, access to the resource) while being representative of the key issues of irrigation in the Mediterranean basin.

2.2.1 The Crau plain, South of France

The Crau plain is located in the South-East of France, on the Mediterranean coast. The area has no natural river, but a network of irrigation canals developed over 500 years distributes the resource across the plain. The plain covers a vast groundwater table, the hydrodynamic functioning of which is highly dependent on anthropogenic activities (recharge and withdrawals). Water management in the Crau plain lies on a fragile balance between the different water uses. Three main

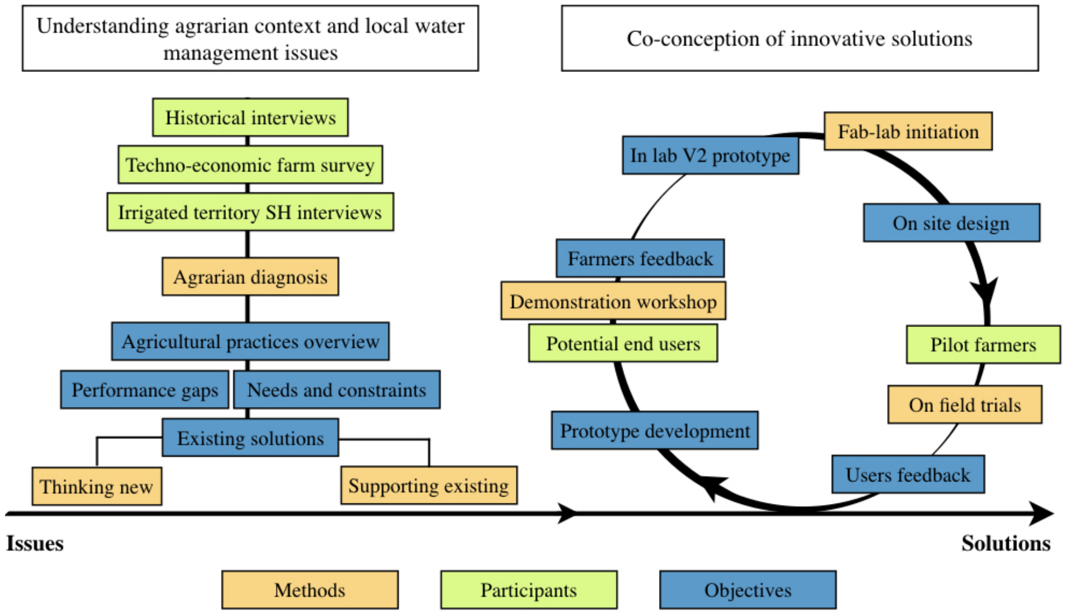

Figure 1. Shaping innovation to match territories. SH: stakeholders.

productions require irrigation in the area: Crau hay, whose gravity fed irrigation is supplied by the collectively managed surface network, arboriculture and market gardening, which mostly use groundwater to feed localized irrigation systems.

2.2.2 The Haouaria plain, North of Tunisia

The Haouaria plain is located at the northern tip of the Tunisian Cap Bon, governorate of Nabeul. The water resource of the plain is exclusively groundwater (agricultural, domestic and industrial water). The water tables, both deep and superficial, are heavily exploited by the numerous surface wells and boreholes. Access to agricultural water may organized within public irrigated schemes through water users' associations, or private through individual pumping. The main irrigation system is drip irrigation, both for tree crops (citrus, olive) and market gardening (potato, tomato, chilli, groundnut, etc.).

3 Results

3.1 Innovation pathways

In the Crau plain, the hay cropping system and the associated irrigation practices crystallise the issues and conflicts surrounding agricultural water management. Gravity irrigation is constraining in terms of workload and difficult to control. Many factors are at the root of performance gaps with strong consequences on the volumes withdrawn. Farmers and managers emphasise the lack of information that would be required to improve their practices (water advancement along the plot, irrigation events duration, water level in the canals, etc.). The search for solutions is active within the territory and several actors have contributed to the emergence of technological innovations (e.g. water gates controlled by timers, water detection systems). However, these innovations have not been widely disseminated throughout the territory, for technical and practical, economic or social reasons.

In the Haouaria plain, drip irrigation of vegetable crops on sandy and draining soils is problematic. Significant differences in water productivity are observed between users, who account for the high equipment cost without succeeding in reducing the volumes applied and the associated fees. The lack of information and the variable flow rates delivered by the network make irrigation monitoring complex. On citrus farming systems, the use of water tensiometers has been observed to adjust the irrigation schedule and reduce percolation losses, but the tool is hardly adopted due to its lack of technical (direct reading of the tension) and economic accessibility.

3.2 Overview of the innovation basket

The innovation process has led to the development of different kinds of technologies: (i) the "Pilowtech", a capacitive based soil moisture sensor for drip irrigation monitoring; (ii) the "WatAr sensor", which aims to provide information about surface water advancement for border irrigation and (iii) the "Flowter" sensor, for the monitoring of gravity based irrigation schedule (Fig. 2).

The technologies are designed to follow common properties, in response to common concerns raised on both study sites. They are low-tech, meaning easy to maintain and to reproduce by users. They are low-cost, so they may be

Figure 2. Example of innovations developed: WatAr sensor **(a)**, Flowter sensor **(b)**, Pilowtech sensor **(c)**.

used by any farming system. They are wireless and low-power, so they are autonomous without the need for regular visits. Developed systems are all based on open-source micro-controllers and LoRaWAN communication protocol. The data reading (historic and real-time) is made available to each user on an internet platform developed under Grafana cloud. A threshold-based alert system is set up through a smartphone messaging application. Besides collective features, the innovations differ relatively to the territories they have been designed for. The solutions developed in the Crau plain provide binary information about surface water flows. WatAr sensors localised downstream on the plot are alerting the farmer when time has come to operate the water gate and irrigate the next plot. Flowter sensors, placed in the tertiary channels, allow to monitor and record surface irrigation schedule (frequency and duration) at plot scale. On the other hand, the innovation that emerged from the plain of Haouaria allows double depth continuous soil moisture measurement and data is readable in various formats (moisture content percentage, graphic display of soil water storage level) both online and on-site.

4 Conclusions

The fieldwork carried out on the two study sites made it possible to identify needs relating to agricultural water management that are specific to each irrigated area. The methodology of the innovation process was adapted to the agrarian contexts. Regular exchanges with stakeholders led to the design of an innovation basket reflecting the inherent needs and constraints of the territories. The wireless water sensors developed meet common objectives and constraints for both irrigated systems: they represent technically and economically accessible means of real time and continuous flow measurement. The plasticity of on-board electronics and IoT systems then allows solutions to be adapted locally. Innovations are not static and continue to change as they are used in the field and feedback are made. Thus, recent technological advances in these fields presage progress in agricultural water management, provided that innovation is adapted to the territories and not the other way around. The impacts of these technologies adoption on the irrigated agriculture performances remain to be assessed. An integrated multi-criteria and multi-scale approach should help determine the achievable performance gains without neglecting potential undesirable effects. It would also be interesting to study the process of adoption of these tools in the longer term and on a larger scale: their re-appropriation by users, and the probable "bricolage" that would make them change over time.

Data availability. Data will be made available on request.

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