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Comparative assessment of irrigation systems' performance: Case study in the Triffa agricultural district, NE Morocco

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ABSTRACT

Programs targeting conversion to irrigation techniques promoted as water-efficient, such as drip irrigation, are multiplying worldwide with the claimed objective to secure food production while alleviating the pressure on water resources. However, there is a persisting and widespread questioning about the actual impact when implementing the techniques in the real-world context, particularly in smallholder farms. We propose a framework to support an integrated assessment of the impact on farm holding performance resulting from the conversion towards a new irrigation technique. It is implemented for a 4030 ha agricultural district in the Triffa plain of NE Morocco where increasing number of farms are changing surface to drip irrigation. The indicators within the framework are calculated using survey data from a sample of 25 farm holdings collected in 2012 and 2013. The survey data are enriched with institutional data and data estimated from hydrologic modeling. The results indicate that, in the study area, farmers engaging with drip irrigation are mainly motivated by social factors, while most environmental and economic indicators are signaling a neutral or undesirable effect resulting from the conversion to drip irrigation. These results question the relevance of the water use reduction objective underlying the ongoing national plan "Plan Maroc Vert" (PMV) that aims converting up to 50% of irrigated agricultural land in drip irrigation, and call for a stronger appropriation of this water-saving objective by the farm holders. However, limited data availability and quality did not allow to firmly demonstrate the robustness of the findings. This severe data constraint revealed the difficulty to assess the socio-eco and environmental impact of such irrigation plan in the study area, and highlights the need for a data collection, centralization, and sharing effort. Conditioned to a strong reduction in data uncertainty, the framework methodology proposed in this study can serve as a practical reference for other studies seeking for an integrated assessment of irrigation management changes.

1. Introduction

Irrigated crops contribute to 21% of total agricultural area, anduse 69% of the withdrawn water resources worldwide (AQUASTAT), making the agricultural sector the biggest consumer of water. This use of water often leads to surface and groundwater resources depletion in irrigated perimeters, which harms ecosystems and prejudices water access and food security. Therefore, the sound management of water resources in irrigated agriculture is a key for sustainable development. The most widely used indices to assess the performance of irrigated systems are the engineers' irrigation efficiency (IE), defined as the ratio of water consumed by irrigated crops to water that is diverted (Boelens and Vos, 2012; Lankford, 2012a,b; Seckler, 1996), the agronomists' water productivity (WP), defined as the ratio of crop yield to water consumed by the irrigated crop (Zwart and Bastiaanssen, 2004), and the water use efficiency (WUE), defined as the ratio of yield to water applied (Stanhill, 1986). The use of these indicators has been repeatedly questioned and criticized as they are limited to the technical performance of the irrigation technology, hence disregarding the larger context into which it is applied (Pereira et al., 2012; Perry, 2008; Willardson et al. 1994). Yet, the spatial and temporal scale dependency of the performance is obvious. For example, studies have shown that IE values can go from very poor to very good if the computation considers the fraction of "lost" water that is re-used at another point in space or time (Clarck and Aniq, 1993; Guillet, 2006). These indicators have also been criticized for not only considering the technical aspects and not the socio-economic ones (Boelens and Vos, 2012; van Halsema and Vincent, 2012). Despite these limitations, these indicators remain

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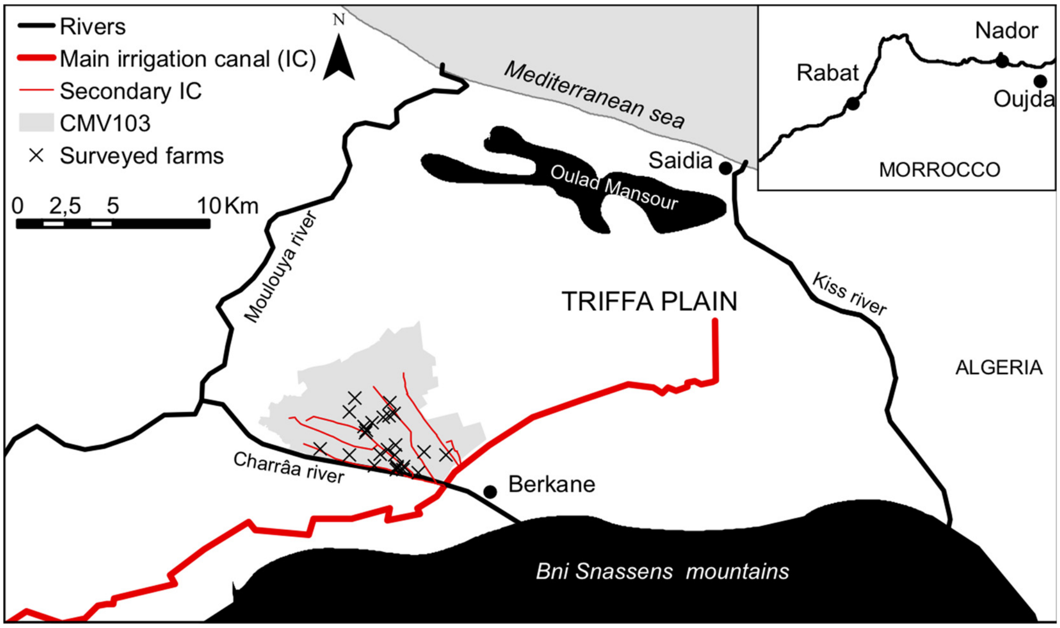

Fig. 1. Study area and localization of the surveyed exploitations.

widely used."

IE can be separated into conveyance efficiency (ec) and application efficiency (ea) (Bos and Nugteren, 1990; Tiercelin and Vidal, 2006; van Halsema and Vincent, 2012). Conveyance efficiency mainly depends on the design and state of the hydraulic infrastructure transporting water to the irrigated field, while application efficiency is usually expressed as a function of application technique. Given the significant financial investment needed to improve ec, ea is most often used as the actionable parameter when seeking to save water during irrigation practices (Boelens and Vos, 2012; Knox et al., 2012). As a result, irrigation water application techniques characterized by higher ea values such as micro-irrigation are increasingly being promoted to improve the performance of irrigated agriculture.

Micro-irrigation is indeed considered to be water efficient and to reduce the pressure on the water resources, thereby increasing yields and economic incomes (Chandran and Surendran, 2015; Darouich et al., 2012, 2014; Garb and Friedlander, 2014).

Drip irrigation, the most widespread micro-irrigation technique, is characterized by a high uniformity of the water distribution and the capability to deliver the water directly to the root zone of the plant at a controlled timing (Goldberg and Shmueli, 1970; Tiercelin, 2006), hence theoretically minimizing evaporation and deep drainage (van der Kooij et al., 2013a). These technical specificities translate into a high potential irrigation efficiency (IE) – the ratio between the irrigation water used by the plant and applied – of drip irrigation, ranging between 70 to 95% (Fader et al., 2016; Hassanli et al., 2010; Tiercelin and Vidal, 2006; van Halsema and Vincent, 2012). These IE values outperform those of surface irrigation for which IE ranges normally between 40 and 75%. However, such a high efficiency is calculated under controlled conditions and is only achieved if the system is well designed and taken care of, and if the irrigation scheme is appropriately managed (Fader et al., 2016; Tiercelin and Vidal, 2006). Such conditions are rarely met when implemented in practical, real-world conditions (Lankford, 2012a). Additionally, adaptation of the farming practice by, for instance, increasing the irrigated land area and cropping intensity, and harvesting different crops often ensue from the modernisation of irrigated perimeters, and may result in a higher water consumption (Batchelor et al., 2014; Berbel and Mateos, 2014; Fishman et al., 2015; Lopez-Gunn et al., 2012; Olmstead, 2010; Ward and Pulido-Velazquez, 2008). Such adaptation may at end counterbalance the envisioned water saving effect of the modernization programme. Therefore, although many scientists, politics, and actors in the agricultural sector are promoting and justifying the conversion to drip irrigation as an effective strategy to tackle the water scarcity issue (e.g. Berbel and Mateos, 2014; Chandran and Surendran, 2015; Cooley et al., 2009; Evans and Sadler, 2008; Friedlander et al., 2013; Johnson et al., 2001; Khan et al., 2008; Lopez-Gunn et al., 2012; Monaghan et al., 2013; Negri and Hanchar, 1989; Olmstead, 2010), others draw attention to the divergence often existing between the potential IE obtained experimentally under controlled conditions, and the real IE once it is calculated beyond the scale of the experimental field (Lankford, 2012b; van Halsema and Vincent, 2012), and once the technique is implemented in the context of the farm holding (Batchelor et al., 2014; Boelens and Vos, 2012; Lankford, 2012b; Perry, 2011; Peterson and Ding, 2005; Pfeiffer and Lin, 2014; van der Kooij et al., 2013b; Venot et al., 2014; Ward and Pulido-Velazquez, 2008). Some of these authors attribute this divergence issue to communication failure by making, among other, a confusing use of the IE concept (Boelens and Vos, 2012; Lankford, 2012a; Perry, 2011). Venot et al. (2014) go even further by supporting that the widespread positive image of drip irrigation has been actively sustained by a group of actors to fit their values, interests, and mission. Following up on this rational, authors recommend drip irrigation conversion programs to be implemented in conjunction with educational and politic measures to ensure that the conversion to drip irrigation actually results in the completion of the water conservation objectives, and an evaluation that takes into account the context into which it is implemented (Berbel and Mateos, 2014; Darouich et al., 2014; Lopez-Gunn et al., 2012; Rodrigues et al., 2013).

Following up on these recommendations and to allow the evaluation of the actual impact of the conversion to a new irrigation technique, this study proposed and tested a framework for an integrated assessment of irrigation performance at the farm scale. The objectives underlying the implementation of the framework are (i) to overcome the limitations linked with the concept of IE, WP and WUE. As such, the notion of *performance* refers here to the integrated aspect of the evaluation and is used instead of *efficiency and productivity*; and (ii) to identify the actual factors explaining the appropriation of the drip irrigation techniques by farmers. This framework implies the evaluation of a set of indicators, and is tested in the field for the CMV103 irrigation district case study. This 4040 ha case study is situated in the irrigated

Triffa plain, in the north eastern part of Morocco (Fig. 1). This case study is interesting as Morocco is undergoing a plan for irrigation water saving, i.e. the "Plan Maroc Vert" (PMV). Among other targets, this latter plan aims at converting 50% of the Moroccan irrigated agricultural land area by 2020 to drip irrigation through a national subsidy program. The framework is applied to compare farm holdings that are still using the traditional surface irrigation technique, and others that engaged with drip irrigation. Results are used to assess whether the actual factors driving the farmers to use drip irrigation, and the impacts of such conversion, are aligned with the PMV objectives, that are water saving and modernisation of agricultural sector.

2. Material and methods

2.1. Study area

The study focusses on the 4030 ha CMV103 administrative district in the Triffa agricultural plain, in the Oriental Region of Morocco (Fig. 1). The region is populated by 2,314,346 inhabitants, among which 35% live in rural area (MAMP, 2009). The region is drained by the Moulouya river whose basin forms one of the six largest Moroccan catchments. The Triffa plain is the most fertile and productive agricultural region of north-east Morocco. It elevation averages 75 m, and it is bordered by the Bni Snassens mountain in the south, by the Moulouya river and its affluent, the Charrâa in the west, by the hills of Oulad Mansour towards the Mediterranean sea in the north and by the Kiss river in the east.

It is bordered by the Bni Snassens mountain in the south, by the Moulouya river in the west, by the Kiss river in the east, and by the Ouled Mansour hills in the north (Fig. 1). Climate is semi-arid with a 0.23 precipitation and potential evapotranspiration ratio (FAO, 1992). Average temperatures alternate between 11 °C in winter, and 25 °C in summer (ORMVAM 2009 inventory and personal communication with ORMVAM officers). Average rainfall is 329 mm, mostly distributed from September to May with a high inter-annual variability. Annual mobilized freshwater resources in the Moulouya basin are estimated at 1610 Mm^3 from surface water and 512 Mm^3 from groundwater, which amounts to around 964 m^3 per capita (AQUASTAT, 2018). Water resources in the region are therefore below the commonly accepted 1000 m^3 water scarcity threshold.

The agricultural area in the CMV103 district covers 4030 ha and is cultivated by around 750 farmers. Farm size averages 5 ha, but is characterized by a high variability ranging from less than 1 ha to 400 ha. Sixty-six percent of the land is owned by farmers, while 17% is managed by private companies, and 17% belongs to the state and are managed by public institutions (ORMVAM 2009 census record and personal communications with ORMVAM officers).

Cultivated crop in the region are various and include mainly cereals and fodder, vegetable, and citrus, almonds, and oleaginous trees (MAMP, 2014). In the CMV103 district, main irrigated crops in 2009 were citrus (70.6% of irrigated agricultural land area), followed by potatoes (10.0%), cereals (6.2%), various fruit growing (4.6%), vegetable growing (2.8%), alfalfa (2.1%), and artichokes (1.5%). Other crops are grape vines, olive trees, forage, sugar beets, and beans (less than 1%) (ORMVAM 2009 inventory and personal communication with ORMVAM officers). Fig. 2 indicates the crop calendar for the main crops, the corresponding cultural coefficient (Kc), and the monthly rainfall and reference evapotranspiration. ET0 values are higher than rainfall during the entire year, thereby illustrating the need to complement with irrigation water, even when Kc values are low.

As a response, about a quarter of the agricultural land surface in the region is irrigated (MAMP, 2009). The water in the Moulouya basin is mostly withdrawn from two dams (556 Mm^3/year), and from flowing surface water (330 Mm^3/year) (Fig. 1). The dams were built in the late 1960′s in the context of a national strategy to develop large scale infrastructures for intensive irrigated agriculture. Most farmers also pump groundwater to complement surface water resources. Although the volume of groundwater withdrawn is less significant than surface water, it has been repeatedly claimed to lead to an overall decline in the water table elevation in the regional aquifers (SEE, 2017). Surface irrigation and sprinkle irrigation remain the main irrigation practices in Morocco with, in 2011, 72% and 9% of irrigated agricultural area respectively (AQUASTAT). However, areas in drip irrigation have been increasing considerably as a result of drip irrigation subsidy programs conducted under the NPIWS. The objective underlying these programs is to increase irrigated area under drip irrigation up to 550 Mha by 2020, which corresponds to 50% of the total irrigated agricultural land area in Morocco.

Irrigation water resources in Morocco are managed in accordance to the 36-15 Water Law and the National Program for Irrigation Water Saving (NPIWS) encompassed within the Green Morocco Plan (PMV for "Plan Maroc Vert"). Three ministries and agencies organize a sector-wide planning, and designated authorities oversee the cross-sectoral coordination. The main actors in charge of the irrigation sector are the hydraulic basin agencies (ABH for "Agences de Bassin Hydraulique") and the regional offices for the valorization of agriculture (ORMVA for "Office Régionale de Mise en Valeur Agricole").

2.2. Data collection

We conducted agricultural surveys within the CMV103 district (Fig. 1) in March 2012 and March 2013. We designed the farms sampling to have a representative sample of the region agricultural landscape (soil type and cultivated crops), and to have an equivalent number of farms using surface and drip irrigation. In total, we surveyed 25 agricultural holdings; 13 using surface irrigation and having 26 irrigated fields, and 12 using drip irrigation, and having 28 irrigated fields. Characteristics of the surveyed holdings are given in Tables 1 and 2. An important assumption underlying this study is that the holdings using surface irrigation are representative of the holdings using drip irrigation prior to their conversion. Collected data were to document the agricultural holders and labor force, farm land use (field number and areas, main crops and irrigation), agricultural and irrigation practices (technology, timing and water source and amount), and economic size and fluxes for the holdings. Surveys were carried out by the authors of the study, most of them accompanied with local ORMVAM officers to overcome language and cultural barriers. The survey encompassed a visit of the farm to reduce errors or farmer perception bias. During these visits, we corroborated the data collected about agricultural practices and irrigation management, and inquired additional information when necessary to deepen the understanding about irrigation practices.

In addition to the survey data, we collected census data about the land use and area, main crops, irrigated area and irrigation technology in the study area from the ORMVA of Moulouya (ORMVAM) data department. These were complemented with hydrologic data generated from a field-scale water budget model ran at a daily time step (Supplementary Material and Feltz et al., 2016).

2.3. Integrated performance assessment framework

In this study, we defined the integrated performance assessment as the quantification of the technical, agricultural, socio-economic and environmental components that are prone to change in a farm holding when implementing a new irrigation technique. As such, the concept of performance is broader than the concept of IE. In contrast to field experimentations conducted to quantify IE, performance aims for an integrated assessment of an irrigation technique at the scale of the farm holding.

We built the assessment framework from the Sustainability Assessment of Farming and the Environment (SAFE) framework (Van Cauwenbergh et al., 2007a) and complemented it by evaluation criteria

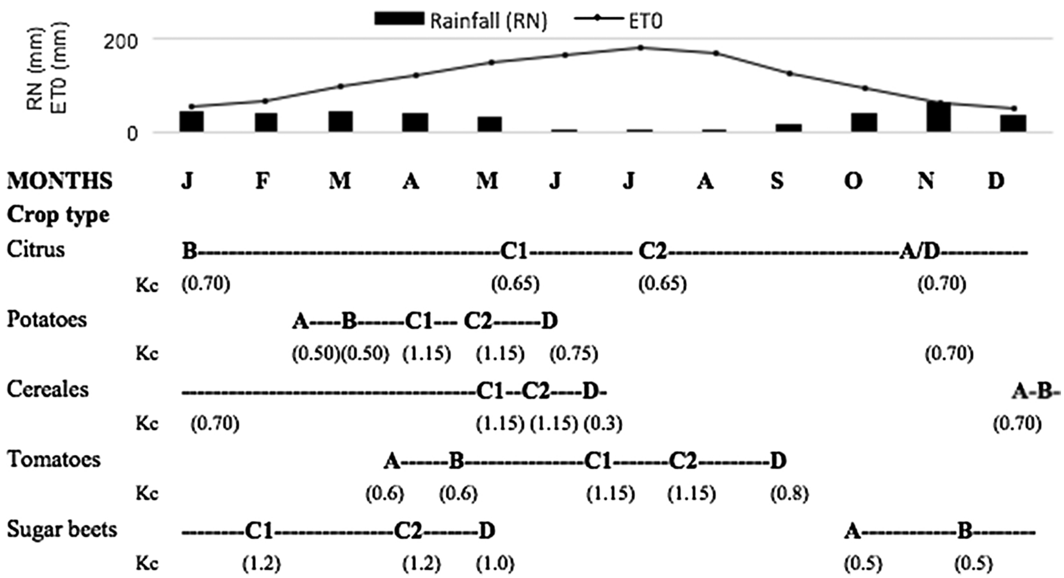

Fig. 2. Top: Average monthly rainfall and reference evapotranspiration for the study area. Bottom: Main crop types, crop calendar and corresponding Kc values for the study area. K_c are general values under typical irrigation management and soil wetting. A: sowing date/initial stage; B: Early growing stage; C1: Start full growth stage; C2: End full growth stage; D: Harvest/late season stage.

and indicators extracted from an in-depth review of irrigation performance assessment studies (Bos and Nugteren, 1990; Dembélé et al., 2001; Fekete and Stakhiv, 2014; Kristensen and Pirc-Velkavrh, 2003; Lofgren et al., 1999; Margat, 2005; Molden et al., 1998; Muller, 2009; Rao, 1993; Skaggs and Samani, 2005; UN-TFIMR, 2009; UN-WWAP, 2009; Van Cauwenbergh et al., 2007b). The SAFE framework was designed to support an integrated and systematic assessment of the sustainability of Belgian agricultural systems, and is well-recognized in the scientific community (e.g. Binder et al., 2010; Gómez-Limón and Sanchez-Fernandez, 2010; Ripoll-Bosch et al., 2012). The SAFE framework was designed to assess a range of spatial scales, from field to regional or country scale, and embodies three hierarchical assessment levels: principles, criteria, and indicators (PC&I). Principles and criteria are related to the multiple functions of the agro-ecosystem. They go beyond the production function and include the three pillars of sustainability: the environmental, economic and social. The principles aim to list the general ecosystem functions that contribute to the achievement of sustainability (e.g. the water supply function), while the criteria indicate for the resulting state when the corresponding principle is respected (e.g. adequate amount of soil moisture is provided). The indicators are quantitative or qualitative variables that can be used to assess the sustainability of the agro-ecosystems in relation to each criterion. The holistic approach embodied by the SAFE framework presents various advantages for our study. Firstly, it enables the evaluation of multiple aspects of agrosystems once irrigation is implemented in the real-world context, which differs from the technical experimentation in controlled conditions. Secondly, it allows this evaluation to be done at

Table 2
Summary of socio-economic data collected from 25 agricultural surveys in March 2012 and March 2013. Units are indicated between brackets. Nb: number.

	Surface irrigation	Drip irrigation
Market (Nb of fields)		
Local	17	6
International	11	22
No data	0	0
Estate status (Nb of holdings)		
Owner	8	4
Renter (long-term)	1	2
Heir	4	6
No data	0	0
Education level of farm manager (Nb of farmers)		
No higher-level education	0	0
Vocational education	10	4
Higher education	0	2
No data	3	6
Workers besides farm holder (Nb of holdings)		
None	5	1
Family	2	0
External workers	3	5
No data	3	6
Economic data (average ± std dev, [min-max]		
Production (t/ha)	11.4 ± 11.6 [1-36]	28.2 ± 30.8 [5-100]
Sale price (10 Dh/ha)	29.3 ± 29.2 [3-100]	32.7 ± 16.8 [11-86.7]
Production costs (10 Dh/ha)	18.4 ± 16.2 [1.5 - 60]	24.8 ± 13.7 [6.5 - 50]

Table 1
Statistics about the agricultural landscape for the CMV103 administrative district and for the surveyed holdings.

	CMV103	Surveyed holdings	
		Surface irrigation	Drip irrigation
Nb of holdings	750	13	12
Nb of fields	NA	28	28
Farmland area (ha; mean ± std dev); [min-max])	6	3.4 ± 1.9 [0.15–5.7]	43.2 ± 113.9 [1.45–400.0]
Harvested farmland area (ha; mean ± std dev; [min-max])	4.9	2.7 ± 1.7 [0.1–5.3]	36.1 ± 99.4 [0.8–349.2.0]
Area harvested with citrus (% total area; mean ± std dev; [min-max])	70.6	64.7 ± 38.9 [0–100]	82.5 ± 38.6 [0–100]
Nb of holdings growing cirtus only (−)	NA	3	9
Nb of holdings not growing citrus (−)	NA	3	2

NA: not available; Nb: number; std dev: standart deviation.

the farm holding scale and from the farmer's perspective. This is important since studies on irrigated systems around the world have reported that the decision factors for the conversion to another irrigation practices are variable, but most often linked to practical considerations related to the farmers' holdings (Benouniche et al., 2011; van der Kooij, 2009, 2013). Thirdly, a holistic evaluation framework allows investigating agrosystem performance without formulating uni-dimensional or unduly constraining hypotheses about the objectives that motivated the farmers to follow a given farming strategy.

We adapted the SAFE framework by applying a six-rule screening procedure to all the PC&I in the SAFE framework successively:

1) Every PC&I must be prone to be impacted when converting a farm holding irrigation scheme to a new technology. To apply this rule, we first compiled a comprehensive list of the socio-economic and environmental variables that are subject to be impacted using the reference irrigation book "Traité d'irrigation" (Tiercelin and Vidal, 2006) (Table 2). We excluded any principle, criteria or indicator that was not related with any of the listed variables.
2) Every PC&I must be relevant for the study agricultural district (in this case, the CMV103 perimeter). This rule was applied because irrigation performance is dependent on the specificity of the study area (Rao, 1993). We applied this rule on the basis of our conceptual understanding of the socio-economic and environmental context in the study area, its issues and challenges.
3) Every indicator must have implications at the farm holding scale. This rule is to comply with the study objective that is to evaluate performance from the farmer's standpoint. It assumes that the farmer's evaluation of the performance doesn't expand beyond the boundaries of the farm holding. As such, this rule involves the systematic elimination of all SAFE indicators for which the application scale was the landscape, region, watershed, ecosystem, and country.
4) It must be possible to calculate every indicator based on existing data or knowledge, since one of the fundamental property of an indicator is the possibility to be calculated and quantified (Bell and Morse, 2004; Fekete and Stakhiv, 2014; Reed et al., 2006).
5) All criteria or indicators nested under a principle or criterion that was eliminated was also eliminated. Additionally, all principles and criteria for which all the nested criteria and/or indicators were ruled out were eliminated. Prior to eliminating a criterion based on this rule, possible alternative indicators listed from the literature body for this criterion were reviewed and any indicator suitable to quantify the orphan criterion was retained.
6) PC&I related to pollution aspects must be excluded because this study focusses on the quantitative aspect of the resources.

Finally, we compared the indicator list resulting from this screening procedure to the indicators listed from the literature review and added the indicators that did not have an equivalent in the SAFE framework. In such case, we revised the definitions of the selected indicators to fit the study case.

2.4. Indicator calculation

We provided a definition and calculation method for each selected indicator based on the definitions in the SAFE framework adjusted to fit with the study area and objective. We calculated the compiled list of indicators for each surveyed holding using the data from the surveys, census and a simplified hydrologic model. To assess the difference between farm using surface irrigation and the farms using drip irrigation, we calculated the aggregated statistics (mean, standard deviation, and ranges) of the indicators grouped by type of holding (surface and drip irrigation), and assessed the significance of the difference by conducting student t-tests statistical tests

Table 3
List of variables prone to change within a farm holding when conducting new irrigation technique. Compiled from the reference irrigation book "Traité d'irrigation" (Tiercelin and Vidal, 2006).

Variable list
Efficiency and homogeneity of water application
Technical complexity
Water recollection upstream
Water drainage
Sensitivity to topography
Sensitivity of irrigation technique to input water's quality
Pressure and discharge in irrigation system
Soil sensitivity to compaction/consolidation
Soil surface cluttering
Human labor
Adaptability to crop species
Control and precision of water application timing and volume
Fertilisation
Automatization
Crop species
Root system and plant sensititvity to drought
Farmland area
Phytosanitary issues
Weed growth control
Investment and management costs
Maintenance
Energy consumption

3. Results

3.1. Indicator selection

We selected seventeen indicators to support a performance assessment of the change in irrigation technique in the CMV103 district of the Triffa plain, Morocco. The final assessment framework is structured around the three sustainability pillars and encompasses eight principles, 13 criteria and 17 indicators (Table 3). This represents a sharp simplification of the initial SAFE framework that originally consisted of 18 principles, 48 criteria, and 96 indicators. We removed eight PC&Is because they were insensitive to a change in irrigation technique (Rule 1), 14 because they were not relevant for the study site (Rule 2), 14 because they reflected on a system property that was outside of the farmers' standpoint (Rule 3), 16 because of the lack of data (Rule 4), and the remaining were eliminated according to the fifth rule. Besides, we added four indicators identified in the literature because they had no equivalent in the SAFE framework or to support the assessment of criteria for which all indicators had been eliminated during the screening procedure. Detailed results from the selection procedure are given in the Supplementary Material (Table SM). Eigth of the selected indicators serve the assessment of the environmental pillar, four the economic pillar, and five the social pillar. Selected environmental indicators were related to water and energy aspects, while the indicators linked to biodiversity issues were excluded due to insufficient data. We kept all the principles and criteria in the economic pillar, but excluded seven indicators due to insufficient data. The scarcity of farm-scale economic data in public records was linked to the high sparsity and variability of reliable raw economic data, which hinders the compilation of such database in regional or national level. Besides, surveyed farm holders were not always participative in disclosing such data, even under the cover of anonymity. If the data had been available, PC&I for the economic pillar would be almost identical with the original SAFE framework. This correspondence regardless of the highly distinct agricultural context between Belgium and Morocco reflects the universality of the economic concerns in an agricultural project– both for decision makers and for farm holders. In contrast to the economic pillar, we removed the majority of PC&I for assessing the social pillar from the original SAFE framework, and included three additional indicators, which highlights the distinct social specificities between the two

Table 4
Principles (P), criteria (C) and indicators (I) selected for the assessment of performance of farm-holding using new irrigation technique. PC&I from the SAFE framework that were ruled out during the screening procedure and the justification are given in the SM Table 2.

Environmental pillar
P - Supply of water function
C - Adequate amount of soil moisture is supplied
I - Irrigation practice (Ind. 1)
I - Drougth stress (Ind. 2)
C - Adequate amount of ground water is supplied
I - Groundwater consumption (Ind. 3)
P - Supply of energy function
C - Adequate amount of energy is suppplied
I - Direct energy output (Ind. 4)
P - Energy flow buffering function
C - Energy flow is adequatly buffered
I - Direct energy input (Ind. 5)
I - Renewable direct energy iput (Ind. 6)
I - Energy balance (Ind. 7)
P - Stock of biotic resources function
C - Planned biodiversity is maintained or increased
I - Number of crop species (Ind. 8)
Economic pillar
P - Economic function
C - Farm income is ensured
I - Family farm income / family work unit / year (Ind. 9)
C - Agricultural activities are economically efficient
I - Total output from total input (total factor productivity) (Ind. 10)
C - Market activities are optimal
I - Diversity of agricultural income sources from (non-)production (Ind. 11)
I - Stable land tenure [a] (Ind. 12)
Social pillar
P - Production function
C - Diversity of food and raw material is maintained or increased
I - Diversity of main food types (Ind. 13)
C - Adequat amount of agricultural land is maintained
I - Percentage of irrigated agricultural area [a] (Ind. 14)
P - Physical well-being of the farmers community function
C - Labour conditions are optimal
I - Hire of farm workers for daily operations [a] (Ind. 15)
P - Psychological well-being of the farming community function
C - Education of farmers and farm workers is optimal
I - Education level of farm manager [a] (Ind. 16)
C - Farmer's feeling of independency is satisfactory
I - Farmer's feeling of contracts' independency (Ind. 17)

[a] Indicators added to complement the SAFE framework.

regions. The definitions of the selected indicators are given in Table 4, and additional information is in the Supplementary Material.

3.2. Comparative evaluation of performance in CMV103 district

Results indicate that conversion to drip irrigation in the CMV103 district has impact at the $p < 0.05$ significance level on five out of the 17 performance indicators (Table 5). Analysis of the direction and implications of the changes are detailed for each pillar of sustainability.

3.2.1. Environmental pillar

Almost all indicators exhibiting a significant change in the environmental pillar are changing in an undesirable direction.

The lower number of harvested species in farms using drip irrigation (Indicator 8, Table 5) indicates the higher specialization of these farms. A combination of factors might explain this higher specialization. The main one is that engaging with drip irrigation involves a significant conversion of the farmers practice. Hence, crops that are not suited to drip irrigation such as cereals are no longer cultivated. Another factor is that farmers using surface irrigation in cash crop orchards often take profit of the moist soil conditions prevailing in the tree inter-rows to grow other crops for personal use, agricultural input, or local market. This increases the diversity of harvested species. This diversification is no more possible in farms using drip irrigation as the moist soil conditions are restricted to the immediate proximity of the root system of the primarily harvested plant. However, some farmers using drip irrigation practice inter-row cropping on citrus tree fields when the trees are at young growing stages. Overall, conversion to drip irrigation is often embedded in a broader strategy towards a more intensive, cash crop oriented industrial agricultural practice. This implies a reduction of the diversity and an increase of the specialization level (Table 6).

Energy input (Indicator 5) is significantly higher in drip irrigated farms. However, this result must be interpreted cautiously as the energy indicator is calculated based on theoretical assumption. In addition, it is not related to crop yield, although an increase in energy use per harvested land unit might be compensated by an increase in crop yield on that same unit, as found in other studies (e.g. Pergola et al. (2013)). No exact yield data are available to evaluate such indicator in this case study.

No renewable energy input was recorded in the surveyed farms (Indicator 6), although it has been recently observed in other farm holdings that farmers are starting to use solar panels as energy source for groundwater pumping, hence drastically reducing non-renewable energy consumption.

No significant difference is found for the hydric stress indicator (Indicator 2) when all fields are considered. Yet, previous study had shown that, when restricting the analysis to citrus fields, i.e. the dominant crop in the CMV103 district, the hydric stress indicator is higher (p-value = 0.06) for citrus irrigated with drip irrigation (annual number of days with hydric stress = 47), as compared to surface irrigation (annual number of days with hydric stress = 34) (Feltz and Vanclooster, 2013). This inability to cope with hydric stress suggests that the control of irrigation timing and quantity is not optimal, and that this management failure is exacerbated when using drip irrigation. In addition, although the statistical significance of the Indicator 3 is low (p-value = 0.1), it signals that the conversion to drip irrigation might not lead to the expected decrease in groundwater withdrawal. These results highlight the poor management of the irrigation technology and the risk of failure to meet the water saving objective targeted by the NPIWS. Based on our field observations and discussions during the agricultural surveys, very few farmers are using soil moisture sensor technologies to assess the need in irrigation water. Instead, many farm holders that engaged with drip irrigation keep making decisions about irrigation timing and quantity using the same decision criteria as when using surface irrigation. We observed instances of farmers in assessing crop water needs based on apparent observed soil dryness or wetness in drip irrigated fields. Although this practical assessment is valid for field in surface irrigation, it is misleading for fields in drip irrigation and likely triggers excess irrigation. In absence of rainfall, soil wetness status is indeed very low outside the dripper irrigation cone. These results highlight the gap between the theoretical and actual efficiency of the drip irrigation technique, and the importance of considering the context into which the technique is deployed when assessing performance. This also emphasizes the need to strengthen the technical training of the farmers when drip irrigation is implemented, and to implement real incentive programs to encourage famers to manage water as a scarce resource.

Despite indications that the conversion to drip irrigation could alleviate pressure on water resources, the environmental performance of the farms under drip irrigation as compared to surface are either identical or lower (more energy consumption, lower crop diversity, higher hydric stress). These findings suggest that, in the study area, the factors motivating the farmers to use drip irrigation are not directly related to environmental concerns.

3.2.2. Economic pillar

The conversion to drip irrigation does not appear to have a significant economic impact in the study area, except for a lower diversity of income sources (Indicator 11), which is in accordance with the

Table 5
Indicator definition for the evaluation of farm holding performance.

	Indicator	Definition	Unit	Data source
Environmental pillar				
1	Irrigation practice	Percentage of irrigated farmland area	%	- Irrigated area: farmer surveys - Total superficie: ORMVAM official records
2	Drought stress	Number of days a year during which plant is under hydric stress, i.e. during which the coefficient of hydric stress *Ks* as defined in Allen et al. (1998) is smaller than 1.	day/year	Ks values calculated with a hydrologic model with a daily time step, as detailed in Supplementary Material, Feltz (2013) and Feltz (2016).
3	Groundwater cunsumption	Total annual volume of groundwater withdrawn for irrigation / irrigated land area.	mm/year	Hydrologic model calibrated with institutional data and data from farmer surveys
4	Direct energy output	Energy produced directly (from methanisation, wind, or solar) or as bio-fuel.	10^6J/ha/year	Farmer surveys
5	Direct energy input - non renewable [a]	Energy used to withdraw and/or pressurize irrigation water. Detailed calculations in SM.	10^6J/ha/year	Standard values and farmer surveys
6	Direct energy input - renewable	Fuel, electricity and lubrificant from renewable sources used for agricultural production	10^6J/ha/year	Farmer surveys
7	Energy balance	Energy production-energy consumption (renewable and non-renewable)	10^6J/ha/year	Farmer surveys
8	Number of crop species	Number of species cultivated in the exploitation. This includes crops in irrigated and non-irrigated fields, for commercial and non-commercial purpose, and the inter-rows crops.	no unit	Farmer surveys
Economic pillar				
9	Net annual income [a]	Net farm income per ha and per year: difference between the farm income and the expenditures required for the agricultural production. Expenditures only include direct and indirect agricultural inputs, but exclude long-term investments.	Dh/ha/year	- Economic data: farmer surveys - Exploitation surface area: ORMVAM (2012)
10	Total factor productivity	Ratio total farm income / total expenses	no unit	Farmer surveys
11	Total factor productivity	Number of income generating activities. Includes agricultural sources (number of commercialized and non-commercialized crop types, and other by-products such as milk and animals) and indirect ones (management contract, farm equipment rental, agroturism[b], etc.), and activities external to agriultural exploitations.	no unit	Farmer surveysFarmer surveys
12	Longevity of estate status [a]	On a scale from 1 to 3. 1: unstable - typically caused by inheritance conflicts or disagreement; 2: intermediate - farmlands are rented, often to the state. 3: stable - farmers are also the owners.	no unit	Farmer surveys
Social pillar				
13	Diversity of main food types	Number of commercialized culture types	no unit	Farmer surveys
14	Percentage of irrigated agricultural area	Ratio surface area of irrigated land /total surface area of agricultural land	%	- Irrigated area: farmer surveys - Total superficie: ORMVAM official records
15	Hire of farm workers for daily operations [a]	Composite index accounting for the status of the farm manager and of the workers in charge of daily work. Evaluates (i) the status of the person(s) in charge of coordinating the work (hereafter referred to as the coordinator)? 1: farm owner or manager in the case of a corporation; 2: farm manager hired by farm owner; 3: team of workers. and (ii) the status of the person(s) in charge of executing the work on a daily basis (hereafter referred to as the workers)? This excluded the workers hired on a punctual basis. 0: the coordinator is also executing the work; 1: the coordinator helped by family members; 2: permanent workers. Final index is the sum of i and ii, and ranges between 1 to 5.	no unit	Farmer surveys
16	Education level of farm manager [a]	1 = no higher level education; 2 = vocational education; 3 = higher education	no unit	Farmer surveys
17	Farmer's feeling of contracts' independency [a]	0 = Fully independent, 100% of outputs sold at local market/ consumption at the farm; 2 = Fully dependant, 100% sold for exportation; 1 = Intermediary.	no unit	

[a] Adapted from the definition given in the SAFE framework.
[b] Educational or leisure activity that brings visitor to the farm against financial contribution.

Table 6
Statistics of the performance indicators for the farm holdings using surface and drip irrigation, and p-value of the *t*-test assessing the significance of the difference between the mean value of the two (H0: the means are following the same distribution).

	Indicator	Surface irrigation		Drip irrigation		p-value
		mean and std dev.	[min-max]	mean and std dev.	[min-max]	
Environmental pillar						
1	Irrigation practice (%)	79 ± 19	[33-100]	78 ± 21	[16-88]	0.83
2	Drought stress (day/year)	63 ± 82.4	[0-338]	42 ± 75	[0-326]	0.38
3	Groundwater cunsumption (mm/year)	1168 ± 1479	[0-4336]	2544 ± 2452	[37-7704]	0.1
4	Direct energy output (10^6J/ha/year)	0 ± 0	[0-0]	0 ± 0	[0-0]	1
5	Direct energy input - non renewable (10^6J/ha/year)	1.0 ± 1.2	[0-3.6]	5.8 ± 4.9	[0.5-16.2]	< 0.01
6	Direct energy input - renewable (10^6J/ha/year)	0 ± 0	[0-0]	0 ± 0	[0-0]	1
7	Energy balance (10^6J/ha/year)	434 ± 550	[0-1611]	2582 ± 2172	[225-7206]	
8	Number of crop species (-)	2.8 ± 1	[1-4]	1.8 ± 0.9	[1-3]	0.01
Economic pillar						
9	Net annual income (1000 Dh/ha/year)[a]	8.3 ± 13.0	[-9.7-31.1]	12.8 ± 15.2	[-10.3-45.8]	0.48
10	Total factor productivity (-)[a]	1.9 ± 1.1	[0.5-4]	1.8 ± 0.7	[0.7-3.0]	0.68
11	Diversity of agricultural income sources from (non-) production (-)	4.1 ± 1.4	[2-6]	2.6 ± 1.2	[1-4]	0.01
12	Longevity of estate status (-)	2.3 ± 0.9	[1-3]	1.8 ± 0.9	[1-3]	0.22
Social pillar						
13	Diversity of main food types (-)	2.1 ± 0.9	[1-4]	1.5 ± 0.7	[1-3]	0.1
14	Percentage of irrigated agricultural area (%)	79 ± 19	[33-100]	78 ± 21	[16-88]	0.83
15	Hire of farm workers for daily operations (-)[a]	2 ± 1.1	[1-4]	4 ± 1.7	[1-5]	0.01
16	Education level of farm manager (-)[a]	1 ± 0	[1-1]	1.7 ± 1	[1-3]	0.06
17	Farmer's feeling of contracts' independency (-)	1.2 ± 0.7	[0-2]	0.5 ± 0.7	[0-2]	0.02

[a] Statistics calculated on subset of the surveyed holdings, since some farmers have chosen not to disclose the data needed for the calculation.

higher level of specialization revealed in the environmental pillar (Indicator 8). This lower diversity of income sources and crop types might make the holdings less resilient to any market shock or crop harvest failure due for instance to crop diseases.

The absence of significant difference regarding the longevity of the estate status (Indicator 12) between the two types of holdings contrast with findings from several other studies (e.g. Burnham et al. (2014); Salhi et al. (2012)). The conversion to drip irrigation indeed supposedly requires heavy financial investments that starts being profitable only after a long period, and therefore requires stable conditions. The fact that this assumption does not hold true in the CMV103 district may be explained by the use of cheaper technologies by some farmers, among other through pumping water directly from the aquifer instead of building a reservoir. The resulting drastic cost reduction can justify a conversion towards drip irrigation even when the longevity of the holding is less secured. On another hand, the conversion towards drip irrigation is heavily subsidized which may explain that farm holders would take the risk to convert, even if case of lower stability.

Finally, results indicate that the conversion to drip irrigation does not change the annual income nor the economic balance. However, the results should be regarded cautiously since economic data are generally marred by high uncertainty. In addition, they were not disclosed by all the survey respondents.

3.2.3. Social pillar

Indicator 15 exhibits significant differences. Farms using drip irrigation hire more farm workers for daily operations. This is to be attributed to the generally bigger farmland area of the exploitations under drip irrigation, and the higher workload thereof, but also indicates a clear-cut difference in the daily management of the farm depending on the irrigation model. The farms using surface irrigation are generally smallholder family farms with external workers hired on a punctual basis, while the farms using drip irrigation tend to have a higher dependency on daily workers. This result also corroborates studies that reported that a frequent criterion motivating conversion to drip irrigation is the reduction of the time that the farm manager spends in the field (e.g. Foltz (2003); Salhi et al. (2012)).

The education level of farm managers (Indicator 16) is significantly higher in exploitations under drip irrigation: none of the 13 managers in farms using surface irrigation attended vocational nor higher education, while all the surveyed farm managers who received an education are practicing drip irrigation. Hence, higher education is most likely a favorable factor for the farm holder to question the traditional irrigation system and engage with the conversion. This result corroborates findings in Alcon et al. (2011) and Salhi et al. (2012) that educated farmers are more prone to decide for conversion to drip irrigation.

The dependency to commercial contract (Indicator 17) is significantly higher for farmers using drip irrigation. This is because the major part of their crops is citrus for exportation and sugar beets for sugar industry, both inherently dependent to contracts. The agricultural models in farmers using surface irrigation are more oriented towards local market and for the consumption at the farm level. Therefore, from a social standpoint, the performance of a farm using drip irrigation is weakened due to a higher dependency to contracts. In these farms, owner and manager most often have a professional education, land area is bigger, and there are several contracted workers.

The conversion to drip irrigation does not impact the performance criteria supported by the 12 other indicators. Hence, very similar percentage of irrigated farmland area (Indicator 14) for the two irrigation systems indicates that such land attribution is depending on decision factors that are independent from the type of irrigation practice used, and that the proportion of irrigated farmland is not an incentive for a farm manager to implement the conversion to drip irrigation.

Finally, the lesser significance of the difference for indicators 13 (number of commercialized crop types) and 8 (number of crop types, including non-commercialized crops, i.e. crops grown for household consumption) testifies for the more market-oriented model of holdings using drip irrigation.

4. Discussion

Most indicators supporting environmental and economic performance assessment are signaling a neutral effect or undesirable alteration resulting from the conversion to drip irrigation. These results support the conclusions in Venot et al. (2014) that drip irrigation should not be framed as an effective practice for water saving and poverty alleviation without considering the context into which it is implemented. It also supports the conclusion by the same author that the conversion to drip irrigation has had little capability to improve smallholder farming. These neutral or negative effects on environmental and economic factors suggests that, in the study area, farmers engaging with drip irrigation are mainly motivated by social factors. Specifically, the difference in farm management highlighted by Indicator 15 suggests that the main drivers motivating farmers for using drip irrigation is the possibility to organize daily work tasks differently, therefore implying a higher convenience and comfort improvement. This has been repeatedly corroborated by discussions with the farmers, and it has also been highlighted in other studies led in Tunisian and Algerian irrigation districts exhibiting similar farm holding models and harvest crop schemes (Foltz, 2003; Salhi et al., 2012). Indeed, in the study region, surface irrigation requires substantial human labor for water application and distribution, which is typically executed by workers hired on a punctual basis and whose guidance and supervision is highly time-consuming for the farm manager. Inversely, drip irrigation is more automated and less labor intensive thereof, which supposedly eliminates the need for punctual workers hiring and training. Social and cultural reasons were also pointed by Alcon et al. (2011); Foltz (2003); Salhi et al. (2012) and Wanvoeke et al. (2016) as determinant motivators for engaging with drip irrigation technologies. Wanvoeke et al. (2016) indicated specifically that, in their Burkinabe study area, this engagement is primarily linked with advantages such as access to attractive credits, higher social prestige, and resulting opportunities to create new alliances. The higher dependency to contract for farms under drip irrigation revealed in this study aligns with many studies (e.g. Berbel and Mateos (2014); Boelens and Vos (2012); Lopez-Gunn et al. (2012); Olmstead (2010); van der Kooij et al. (2013a); van Halsema and Vincent (2012); Venot et al. (2014)). These studies showed that the conversion to drip irrigation is often used to modernize infrastructures and comply with export companies' requirements.

Overall, the findings in this study question the significance of the National Plan for Irrigation Water Saving (PNEEI) under the Plan Maroc Vert targeting the conversion of 50% of irrigated land to drip irrigation. It highlights that environmental concerns are not sufficient incentive for farmers to weight into their operational decisions. This stresses the need to complement the subsidy programs by real incentives, such as pricing measures to motivate farmers to conserve water, and training programs to support farmers for an optimal operation and management of the drip irrigation technology.

Several drawbacks limited the scope of this study, which calls for additional work on the topic. The first and major one is linked to data scarcity. Limited data caused the exclusion of numerous performance indicators, and compromised the reliability of some of the final indicators. Among others, all indicators related to quality concerns (water pollution, soil salinization, etc.) were excluded, although this component is crucial for a truly holistic assessment of irrigation practices. Causes of data scarcity were the limited pool of pre-existing data and the restriction to data access by institutional authorities, and the limited time and funding to deploy instrumentation network and grow the pool of agricultural surveys. Another drawback is that the study didn't incorporate the temporal dimension. Instead, to cope with the lack of data that would have allowed evaluating the performance of a farm holding prior and after the conversion to drip irrigation, the holdings that were still using surface irrigation were used as a proxy for the holding of the drip irrigation farms prior to their conversion. Although this simplification is acceptable to gain preliminary knowledge and understanding, results still need to be regarded with caution due to possible differences in farm typology and farmer profiles existing prior to the conversion. The problem of data scarcity is a common and widespread issue in agricultural studies in developing countries (e.g. Bastiaanssen et al. (2007); Hamid et al. (2011); Kharrou et al. (2013)). Therefore, this study is an additional instance highlighting the need for a data collection and storage program and strategy at the institutional level. Such program should include (i) the conduction of repeated agricultural census; (ii) the deployment of monitoring network to track the temporal evolution of key environmental variables and adapt management as needed; (iii) the cleaning and storage of historic and new data in a central database; (iv) a lift of the institutional barrier that make the data acquisition a very time and resources consuming, if not impossible, process. Lastly, no reference values were proposed to evaluate the absolute values taken by the indicators. Such references would have been difficult to determine because of their high dependency to the socio-economic and environmental specificities of the region under study. The comparative assessment between farms using surface irrigation and farms using drip irrigation allows to overcome this difficulty. It allows to measure the direction and amplitude of any possible change, while integrating the specificities of the region.

5. Conclusions

A framework to support a comparative integrated assessment of the performance of farm holdings using traditional surface irrigation and those that engaged with a new irrigation technique was defined and applied to the CMV103 irrigation district in the Triffa agricultural plain in Eastern Morocco. Results indicate that the conversion from surface to drip irrigation in the study area led to neutral or negative effects on environmental and economic aspects, while most significant beneficial effects were detected for the social pillar, as drip irrigation allows structural changes in the holding. The latter result suggests that the objectives pursued by the farm holders engaging with the drip irrigation technique are different from the objectives underlying the subsidy programs led under the Moroccan National Plan for Irrigation Water saving under the *Plan Maroc Vert*. Results indicate that farmers do not consider the need to reduce consumption when planning their irrigation scheme, and stress that environmental concerns are not sufficient incentive to motivate farmers for irrigation water saving. This divergence in the objectives might undermine the success of the plan in targeting water scarcity issue, and therefore calls for a more meaningful engagement and training of the farmers, along with raising awareness about the water scarcity issue prevailing in the region. More generally, results from the study are confirming that, despite the high theoretical water use efficiency of the drip irrigation technology, its performance when evaluated at the farm holding scale is far less obvious. Therefore, the decision to engage with that technique should be based on a multi-level criteria evaluation.

Despite the conduction of surveys with the farmers, the institutional and long-term monitoring data scarcity context into which this study was implemented was a major obstacle, and compromises the robustness of the results. This calls for the institutionalization of the data standardization, centralization, the release of the data in public database, along with the implementation of continuous monitoring programs to track and scrutinize the state of the natural resources and the agricultural activities.

Contributions

AA: work synthesis and writing of the manuscript; NF: project instigator, method development and application, conduction of the data collection and agricultural surveys, data analysis; MV: tutoring the work and revision of the manuscript; FG, MS: Expert guidance and revision of the manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agwat.2018.08.033.

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