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ORIGINAL PAPER

Making the user visible: analysing irrigation practices and farmers' logic to explain actual drip irrigation performance

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Abstract The actual performance of drip irrigation (irrigation efficiency, distribution uniformity) in the field is often quite different from that obtained in experimental stations. We developed an approach to explain the actual irrigation performance of drip irrigation systems by linking measured performances to farmers' irrigation practices, and these practices to the underlying logic of farmers who operate these systems. This approach was applied to 22 farms in Morocco. Four sets of variables helped explain the gap between the actual irrigation performance and the performance obtained in experimental conditions: (1) farmers have agro-economic motivations or want to improve their social status, and for them, irrigation performance is at best an intermediate objective. (2) Irrigation performance is not a static value, but a rapidly evolving process, related to the (perceived) ability of farmers to change irrigation practices and renew irrigation equipment, but also to farmers' aspirations. (3) The social network of farmers, supporting the introduction and use of drip irrigation, determines how farmers may share experience, information and know-how related to drip irrigation. (4) Today, there is no social pressure to irrigate carefully to save water; only the state explicitly links the use of drip irrigation to saving water. Making the drip user visible in research and policy studies would lead to more realistic assessments of irrigation performance and draw the attention of policy makers to the actual conditions in which drip irrigation is used, and as a consequence help incorporate 'saving water' as an objective for drip irrigation users.

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Introduction

Drip irrigation is widely promoted as a way of improving water productivity (Luquet et al. 2005). This is based firstly on the assertion that drip irrigation is much more efficient than other irrigation techniques such as furrow or sprinkler irrigation. Less water is lost in conveyance, and water is applied directly in the immediate vicinity of the plant, thereby saving water. Secondly, drip irrigation allows more uniform distribution of water across the field (i.e. all plants receive almost the same quantity of water) and facilitates the application of water (ease of use, higher irrigation frequency), thereby improving crop yields (Wu and Gitlin 1983; Wang et al. 2013). Since drip irrigation is almost invariably associated with the application of nutrients (fertigation), these systems also allow better nutrient management. This led certain authors to claim that drip irrigation may double or triple the water productivity (Postel 2000; Gleick 2002). However, recent papers are more cautious about water efficiency claims of drip irrigation and pinpointed the fact that the claimed impacts of this technology are rarely compared with actual practice (Lankford 2012; van der Kooij et al. 2013). Other authors point to potentially negative effects of drip irrigation on the environment (salinization, groundwater pollution), when drip irrigation systems and irrigation practices are not tailored to their environment (Cote et al. 2003). Another line of criticism relates to the scale at which water productivity is measured. While drip irrigation systems may save water at the plot level, this may not be the case at the basin level, where water that is lost in one location is used in another (Molden et al. 2003; van Halsema and Vincent 2012). We argue in this paper that even at the plot level, the use of drip irrigation may not lead to water saving.

Generally, the 'goodness' of irrigation performance is related to two types of indicators: irrigation efficiency and the uniform distribution of water throughout the plot (Burt et al. 1997). Many indicators related to the two terms were developed to determine irrigation performance (Burt et al. 1997). These were mostly applied to irrigation systems in experimental stations to test the technical parameters of drip irrigation (e.g. hydraulic properties of drippers) (Camp et al. 1997; van der Kooij et al. 2013). However, in farmers' fields, irrigation performance depends not only on the technical standards of irrigation equipment but also on farmers' irrigation practices, as well as on the maintenance of the equipment (Tanji and Keyes 2002; Luquet et al. 2005). Wolf et al. (1995) demonstrated in Jordan that the efficiency of drip irrigation was even lower than the efficiency of surface irrigation due to poor maintenance, inadequate use of equipment and poor irrigation practices. Slatni et al. (2005) reported similar findings in the case of Tunisia. In this paper, we argue that irrigation practices depend, in turn, on the larger objectives and constraints of farmers. This may explain the wide range of hydraulic performance reported in the rare studies carried out in real-life settings (Wolf et al. 1995; Vidal et al. 2001). The actual irrigation performance of drip irrigation systems is an important issue, as it will determine both the real water savings and the final agricultural production that will ultimately be obtained.

Leeuwis and van den Ban (2004) proposed a model to understand the social nature and the logic underlying farmers' (technical) practices. This logic is determined by variables related to the perceived (technical, economic, social) consequences of changing practices and their assessment by individual farmers, farmers' perceived ability to carry out these (changes in) practices in the long run, the wider social environment that will support (or not) such practices, and perceived social relationships and pressure. This model was applied to different case studies, one example being soil fertility management practices (Adjei-Nsiah et al. 2004).

We hypothesized that the indicators proposed in the literature are useful to qualify the performance of drip irrigation, but insufficient to analyse the reasons for the differences and dynamics in the actual irrigation performance in the field. In the present study, we developed and tested an approach to explain the performance of drip irrigation systems observed in the field, by linking measured performances to farmers' actual irrigation practices, and to the underlying logic of farmers who own and/or operate these systems. This work answers calls of different authors, who advocated applying multidisciplinary approaches for a sound comprehension of irrigation performance (van Schilfgaarde 1994; Tanji and Keyes 2002; van der Kooij et al. 2013).

Methodology

Study area

The study area is located in the Saiss plain between the cities of Meknes and Fes in northwest Morocco, which is a rich agricultural area (Berriane 2002). The farms are located in the vicinity of the small town of Ain Taoujdat. In the past, the farming systems in the Saiss were characterized by rain-fed agriculture (cereals, vineyards) and by some irrigated crops (tobacco, orchards, horticulture) in a number of small irrigation schemes irrigated by springs. Due to the droughts that occurred in the 1980s and the arrival of investors, farmers progressively but massively turned to the use of groundwater through individual wells and tube wells. The river basin agency estimates the current irrigated area to be 37,000 ha, of which 25,000 ha are irrigated by groundwater through more than 12,000 individual (tube)wells, most of which are not officially registered. Access to groundwater led to a sharp increase in the area under orchards (42 % of the irrigated area) and horticulture (35 %). According to the river basin agency, a little over half of the irrigated area is now irrigated by drip irrigation. This figure probably applies only to the area irrigated by groundwater, as so far, drip irrigation is not used on a large scale in the small-scale gravity irrigation schemes. There is an increasing pressure on groundwater resources in the Saiss, and it is often claimed that drip irrigation may reduce the volume of water used for agriculture through higher irrigation efficiency at the plot level. This prompted us to investigate the irrigation performance of drip irrigation systems in farmer's fields.

We conducted our study in the 2011 irrigation season (March–October) on 22 drip irrigation systems in horticultural plots on 22 Moroccan farms, representative of the diversity of horticultural farms in the area. We first conducted an exploratory study on the different farm types and drip irrigation systems in the area. We then used different criteria to select the farms and plots, using a stratified random sample approach (Table 1). Firstly, only horticultural plots were selected (onion, potatoes and seed potatoes), so we would be able to compare irrigation practices; irrigation of fruit orchards is different (larger plots, year-round irrigation), and so we excluded orchards from this study. Secondly, we selected a wide range of farms, in terms of

Table 1 Characteristics of the different groups of sample farms and sample plots

Group	Farm size (ha)	Number of (tube)wells	Crop on study plot	Plot size (ha)	Soil type	Year of installation of drip irrigation system
Large landholders (A)	120	3 W, 1T	Potato	2.5	Loam	2001
	100	3 W, 1T	Potato	2.5	Loam	2004
	120	4 W, 1T	Potato	2.0	Loam	2007
Reference farmers (B)	14	3	Potato	7.0	Loam	1999
	10	3	Onion	4.0	Loam	2003
	12	3	Potato	6.0	Loam	2003
Small innovators (C1)	1.0	1	Potato	1.0	Loam	2006
	3.0	4[a]	Potato	2.0	Loam	2008
Learners (C2)	2.5	1	Potato	2.5	Sandy loam	2006
	2.0	1	Potato	2.0	Loam	2006
Young horticultural farmers (D)	1.3	1	Onion	1.3	Sandy loam	2010
	6.8	1	Potato	4.0	Sandy loam	2008
	2.0	1	Potato	2.0	Loam	2008
	2.0	1	Potato	2.0	Sandy loam	2006
	4.0	1	Onion	4.0	Loam	2008
	5.4	1	Onion	1.5	Silt loam	2010
	6.0	1	Onion	4.0	Silt loam	2008
	2.0	1	Onion	2.0	Sandy loam	2008
	1.5	1	Potato	1.5	Sandy loam	2010
Part-time farmers (D′)	3	1	Onion	3.0	Loam	2005
	2.5	1	Onion	2.5	Loam	2000
	3.5	1	Onion	2.5	Sandy loam	2009

W = wells, T = tube well

[a] This farmer rented about 100 ha of land from other farmers, which explains the need for four wells

size (from 1 to 120 ha; Table 1), as we hypothesized that farm size had an impact on the choice and quality of the irrigation equipment (as large-scale farms have more financial means) and on irrigation practices (larger plots, fewer financial constraints for larger farms). Thirdly, we used the installation date to select irrigation equipment of different age, hypothesizing that older equipment would have a lower irrigation performance (Table 1). The access to water on the vast majority of farms is provided by wells of about 35–45 m depth. The flow rate of these wells ranges from 4 to 8 l/s. The cost of a fully equipped well (excavation cost, pump, engine) of 40 m ranged from 4,400 to 6,200 €. Only, the large-scale farmers in this area had tube wells of more than 85 m depth, generally with a flow rate of 7–8 l/s. The cost of a fully equipped tube well (drilling cost, pump, engine) with a depth of 100 m ranged from 5,000 to 9,600 €. The cost of a drip irrigation system ranged from 2,500 to 4,500 €/ha, depending on the quality of the installation and the components of a particular drip irrigation system (Ameur et al. 2013).

These costs can be compared with the gains obtained by farmers from, for instance, the production of onions. According to a recent economic study in the area on the onion sub-sector, the price at a nearby wholesale market ranged from 0.1 to 0.8 €/kg during the period 2008–2012 (Courilleau and Lejars 2013). Farmers share the gains with a large number of intermediaries, which take charge of the harvest and post-harvest handling. Depending on the price, but also the yields obtained (generally 80–120 t/ha), farmers obtain margins in the range of −10 to +100 €/ton (Courilleau and Lejars 2013). In theory, it takes thus one excellent cropping season (high yields, high prices) for a farmer to pay back his irrigation equipment. However, the risks are high, and farmers generally state 'one year we win, one year we lose'.

In a previous survey in Morocco, we had observed differences in equipment, such as the absence of filter systems (Benouniche et al. 2011). We, therefore, described the drip irrigation equipment in detail for each farm, as we hypothesized that these differences could explain part of the irrigation performance.

Research approach

Following the objectives of this study, we measured the irrigation performance at the plot level, observed the irrigation practices of farmers and labourers and finally, we analysed the underlying logic of farmers operating the drip irrigation systems.

We used two classic indicators to measure irrigation performance at the plot level: irrigation efficiency (IE) and the uniformity of water distribution (DU). We determined the irrigation efficiency, following Burt et al. (1997), who considered that 'at the heart of any consideration of irrigation performance is an irrigation water balance and determination of the fate of various fractions of the total irrigation water applied'. This indicator is, therefore, an interesting way of analysing farmers' irrigation practices. The distribution uniformity is a standard indicator for irrigation, and even more so for drip irrigation which aims specifically at attaining high distribution uniformity in a specific plot, i.e. greater than 90 % (Karmeli and Keller 1974; Burt et al. 1997). Karmeli and Keller (1974) specify that high distribution uniformity is achieved with 'precision manufacturing, sufficient filtering to eliminate clogging and uniform topography'. By inversing this argument, we argue that the measurement of the actual DU in field conditions—our hypothesis being that actual values of DU will be considerably different from the projected 90 %—will provide interesting information on the actual state of the equipment, and thus on operational and maintenance practice (e.g. cleaning of filters, renewing tubing), and on the design of the drip irrigation systems with respect to field conditions (e.g. topography).

Irrigation efficiency (IE) is generally linked to 'fractions of the irrigation water volume that are destined for certain functions', including transpiration, evaporation and infiltration. (Burt et al. 1997). But it is also important to establish the spatial scale at which IE is measured. In our case, IE was defined as the ratio between the volume delivered at the entry of the plot and the net irrigation water requirements (i.e. according to the FAO, the difference between crop evapotranspiration and effective precipitation), both expressed in mm. Evapotranspiration was calculated using the FAO CropWat package, and climatic data from weather stations located in the immediate vicinity of the farms (rainfall data came from Ain Taoujdate, and all the other parameters came from Meknes synoptic station). The exact sowing and harvesting dates were recorded for each plot, and the soil types were defined after analysis in a soil laboratory. The soils were generally medium-textured soils (Table 1). The volume of water delivered to the plots was determined by measuring the discharge during the irrigation season and by checking the irrigation calendar with the farmers during interviews. We cross-checked the information they gave us through regular visits to their plots during the irrigation season. This enabled us to detect exceptions to the (regular) irrigation schedule. We measured *the uniformity of water distribution* to the entire field through water distribution uniformity (DU), which Pereira et al. (2002) defined as the 'ratio among the average infiltrated depths in the low quarter of the field and in the entire field, both expressed in mm'. In each plot, we measured three times the discharge of 16 drippers equally spaced from head to tail along four different lateral lines (Karmeli and Keller 1974).

Regular visits to the plots enabled us to observe farmers' practices, both concerning irrigation itself and maintenance of the irrigation equipment. To this end, we used a checklist (who irrigates when? Who monitors the irrigation performance, and how? What maintenance is undertaken, by whom? etc.). While we took the utmost care to record the exact timing of irrigation for each plot in our sample, the (field) conditions of measurements were certainly not as good as in an experimental station. The crop yields were estimated based on interviews with the sample farmers and cross-checked with a broker in our study area, involved essentially in facilitating the selling and buying of onions and potatoes. These yields do not depend solely not only on irrigation practices but also on agricultural practices. However, we checked the impact of irrigation practices on water stress and consequently on crop yields for some selected farms using the CropWat package.

The logic underlying the choice and use of drip irrigation equipment (farmers' practices) was determined during semi-structured interviews using an analytical grid (decision and motivation for installing drip irrigation, how the equipment was installed, any adaptations made to the drip system, irrigation practices, maintenance, repairs, etc.) and cross-checked by direct field observations. This enabled us to identify categories of farmers with a different logic regarding the use of drip irrigation, by combining the measured performance of the irrigation systems with the insights obtained on irrigation practices through observations and interviews, using an iterative approach. This classification helped explain farmers' practices, and the wider logic of farmers concerning farming, but also the actual irrigation performance of drip irrigation systems.

We then regrouped the selected farmers in six groups, based on the results of the irrigation performance as measured, on the irrigation practices observed and on the logic of farmers. The first group (A) is composed of the large landholders in the region (three farmers in our sample). Their farms are more than 100 ha in size, and they practise four different farming systems: orchards, horticulture, livestock and cereals. In addition to the land they own, these farmers rent in several plots, which are then farmed by small-scale farmers on a tenant basis. The second group represents medium-sized farmers (10–15 ha; three in our sample), which we called reference farmers (B), as their agricultural and irrigation practices are keenly observed and followed by the majority of farmers (those from our sample, but more generally most farmers in the study area). This group of horticultural farmers specialize in the production of onions and potatoes. The third group represents the small innovators (C1) who may be owners or tenants (two farmers in our sample). This is a group of small-scale horticultural farmers (potatoes, onions), who were amongst the first to introduce drip irrigation on small-scale farms. The learners (C2) are composed of farmers who are either isolated or only recently started drip irrigation (two in our sample); they have <5 ha and grow onions and potatoes. This is basically a transitory group. The young small-scale horticultural farmers (D) may be owners, tenants or lessees; they have <10 ha (nine farmers in our sample) who grow potatoes and onions. This is certainly the largest group of farmers in the study area practising drip irrigation on horticulture, as drip irrigation is associated with 'modern' farming, and such farmers may obtain access to land through informal lease agreements. The last group represents the part-time small-scale horticultural farmers (D′), who have many off-farm activities (three in our sample). These farmers have <5 ha and grow onions and potatoes.

Results

We first looked at the irrigation performance at the plot level and then studied the irrigation practices of farmers in order to explain the wide range of performance observed. We then analysed the underlying logic of farmers who operate the drip irrigation systems. We used the classification of farmers' groups developed in the previous section for the presentation of the results.

Drip irrigation performance

We measured distribution uniformity and irrigation efficiency of drip irrigation systems in 22 plots for onions and potatoes (Table 2). The actual irrigation performance in farmers' fields, determined here through two indicators (irrigation efficiency and distribution uniformity), was shown to be very heterogeneous. We found a large variability in the irrigation performance with coefficients of variation of IE and DU of 34 and 37 %, respectively. This indicated a strong influence of farmers' practices on irrigation performance (Lorite et al. 2004). This was linked to quite generous irrigation supplies, contrasting with the water-saving image of drip irrigation, and to problems of bringing the same quantities of water across the farm plots, pointing to problems of design or maintenance of drip irrigation systems.

Irrigation efficiency

Perhaps surprisingly, the vast majority of the farmers over-irrigated their plots (Table 2). The farmers of groups C1 (small innovators) and C2 (learners) applied 2–4 times the amount of water required by the crop, but even the farmers of groups A (large landholders) and B (reference farmers) applied 25–75 % too much water. The farmers of group D were shown to irrigate the closest to the calculated irrigation water requirements. Five farmers were within 10 % of the required irrigation water requirements. There are two main reasons for the very high volumes applied. Firstly, some farmers were trying to compensate for the poor distribution uniformity of their irrigation systems by applying more water. This was especially the case for the large landholders and the learners. Secondly, some farmers who had drip irrigation systems with good distribution uniformity (for example, the reference farmers) applied more water in an effort to obtain good yields. They allowed a (large) safety margin because they wanted to be sure that whatever happened, their crop would not suffer from water stress. Their soils were well-drained, and while over-irrigation would not increase their yields, too much irrigation water would not affect their yields adversely either. Finally, among the farmers who aimed for high yields, but who had problems with their equipment (low DUs), two applied more water for the two above reasons combined.

Distribution uniformity

There was a wide range in the distribution uniformity measured (Table 2). Reference farmers (B) and young horticultural farmers (D) registered fairly good distribution uniformities, considering that they were measured for field conditions. Six irrigation systems of groups B and D had a DU of between 80 and 90 %, which can be considered as reasonably good; even though in this case, cleaning of the system is generally recommended as there may be problems of clogging (Pénadille 1998). These systems were installed between 1998 and 2008, but had been well maintained by farmers (daily maintenance, but also replacement of faulty equipment), as these farmers consider drip irrigation is a way to achieve good yields. Only one irrigation system had more than 90 % distribution uniformity, which is generally considered to be excellent (Karmeli and Keller 1974[1]). This was a recent system, installed in 2010 by a local fitter, who happened to be the uncle of the farmer concerned and is reputed in the region as a good fitter with a

[1] Official Moroccan standards (2007) also refer to these authors, when they advise that drip irrigation equipment should guarantee a DU of 90 %.

Table 2 Irrigation performance (irrigation efficiency, distribution uniformity) and yields obtained by different sample farmers on 22 plots, as compared to the irrigation practices and the characteristics of the drip irrigation systems of different farmers' groups

Groups	Practices	Drip irrigation system	Irrigation efficiency (%)	Distribution uniformity (%)	Yield (t/ha)
Large landholders (A)	Irrigation and maintenance done by labourers Weak maintenance, little renewal of irrigation equipment	Complete system[a]; damaged tubing	57 66 46	55 30 12	40 45 40
Reference farmers (B)	Irrigation and maintenance done by labourers; close monitoring by farmer Daily maintenance of irrigation equipment Frequent renewal of irrigation equipment	Complete system	51 61 57	88 89 73	70 90 60
Small innovators (C1)	Irrigation and maintenance done by farmer Cleaning of drip irrigation systems at beginning of season Little interest in daily maintenance and renewal of irrigation equipment	System with valves; no filter system, basic fertigation unit Mobile system[b] Damaged tubing	36 25	73 55	60 55
Learners (C2)	Irrigation and maintenance done by farmer Little experience in drip irrigation Cleaning of irrigation systems at beginning of season Very little interest in daily maintenance and renewal of irrigation equipment	System with valves; without filter system and fertigation unit Complete system; damaged tubing	31 39	43 44	50 56
Young horticultural farmers (D)	Irrigation and maintenance done by farmer Cleaning of drip irrigation systems at beginning of season Particular attention to daily maintenance of drip irrigation equipment (tubing, cleaning of filters) Frequent renewal of equipment Gradual upgrading of equipment	Complete system Incomplete system without filter system, and/or fertigation unit	90 94 92 97 80 78 80 65 107	93 88 86 82 86 78 72 73 77	60 40 45 50 50 55 70 60 45
Part-time farmers (D′)	Irrigation and maintenance done by farmer or labourers Very little interest in daily maintenance of drip irrigation equipment and renewal of equipment	Complete system; damaged tubing Incomplete system without filter system; damaged tubing	79 85 67	49 45 20	50 57 60

[a] A 'complete' drip irrigation system refers to a system having the following components: a pump, filters, fertigation unit, main line, laterals and drippers. None of the systems dispose of a water metre or a pressure regulator

[b] The second small innovator is a lessee and uses a mobile drip irrigation system. In case of a problem with the landowner, he can remove the system and fit it on another plot

great experience in installing drip irrigation. In addition, we observed that the farmer undertook maintenance daily (checking the condition of the drip tubing and cleaning the filters). The remaining 15 drip irrigation systems had a much poorer DU (average 51 %), registered for all the drip irrigation systems of the large landholders (A), as well as for the small innovators (C1), the learners (C2), the part-time farmers (D′), but also in a minority of the young horticultural farmers (D). Three systems even had a DU of between 12 and 30 %, two belonged to the large landholders and one to a part-time farmer. These systems were installed between 1999 and 2010 (Table 2). Consequently, the age of the systems is not decisive in explaining the differences in DU observed, contrary to our initial hypothesis.

Four main problems may explain the poor DUs. Firstly, some of the irrigation systems had design problems, especially in the case of undulating land, leading to differences in pressure in the system. In the absence of pressure-compensating drippers, these pressure differences would lead to differences in discharge. Some farmers (1 small innovator, 1 learner) installed systems with multiple valves for different irrigation blocks in order to deal with this problem. However, the measured values of DU remain poor (73 and 43 %, respectively; Table 2). Secondly, in some of these systems (3), the filter system was incomplete (Table 2). Either there was only a sand filter, but no disc filter, or there was no filter at all, leading to clogging of emitters. The absence of filters can be explained by the lack of means of some small-scale farmers, but most often by the fact that some farmers simply do not see the point of having such filter systems, mostly in the case of learners. When the farmers become aware of clogging of emitters, they try to remedy the problem with acid, but also evolve gradually towards more complete drip irrigation systems, especially the young horticultural farmers (Table 2). Thirdly, there was a general problem to adequately maintain the drip irrigation systems. Either the owner was occupied elsewhere (the case of the part-time farmers) or irrigation was performed by labourers (for instance in the case of the large landholders; Table 2), for whom daily maintenance may be tedious, especially on large farms, and lack of maintenance does not necessarily have immediate (visible) consequences, but can gradually reduce distribution uniformity. Fourthly, a small number of farmers did not replace faulty equipment (perforated tubing, filter systems) in time (Table 2). This was mostly the case of bigger landlords, who received subsidies for the purchase of their equipment, or farmers who are mostly absent (part-time farmers; Table 2) or may even envisage abandoning a particular plot.

Farmers' irrigation practices

The premise of the paper is that farmers' irrigation practices do not necessarily target 'perfect' irrigation in the sense hoped by engineers. Overall, most farmers over-irrigated, but on many plots, we observed periods of under-irrigation (water stress), which suggests that the irrigation schedules have scope for improvement to better match crop water demand and water application. Our observations revealed that the farmers' irrigation practices were linked to (1) the way farmers perceive the impact of irrigation on yields, (2) the quality of the irrigation equipment and (3) constraints on access to water.

Over-irrigation to achieve optimal yields

The reference farmers (B) aimed to achieve optimal horticultural yields and generally over-irrigated to ensure the plants would not suffer from water stress. Table 2 shows that these farmers obtained the best yields of the sample farmers, i.e. 60–70 t/ha for potatoes and up to 90 t/ha for onions. In the study area, it is generally considered that the maximum yield for potatoes is around 80 t/ha and for onions up to 120 t/ha. The reference farmers invested in several wells and had sufficient capacity to deliver water to all their plots, even during summer. They installed drip irrigation to be able to supply enough water to all their plants. For such farmers, the cost of irrigation is relatively low compared to the revenues generated by horticulture, and they did not consider it a problem to provide 2–3 times the volume of water required, as long as problems of drainage would not affect their agricultural production.

This was the case for Fatima, who grew horticultural crops on her 10 ha farm and had three inter-connected wells. Her objective was clearly to obtain excellent yields, as confirmed by the labourer in charge of irrigation on her farm: 'To be competitive on the market, you need to have very good yields, and most of all, good quality products. To achieve this, you need to irrigate well. From the month of June onwards, we increase the irrigation volume to be sure of obtaining good calibre vegetables and excellent yields' (Mohamed, 30 years old, 2011). This is how Fatima obtained a yield of 90 t/ha on the sample plot (onions), which was the highest yield obtained amongst the sample farmers (Table 2).

Since there were no water constraints on her farm and Fatima's equipment was well maintained (DU = 89 %), in June, irrigation frequency was increased from once a week to every second day, and the volume increased from 10.7 to 64 mm/week. On one plot of onions, a total volume of 757 mm was applied, representing 1.64 times net water requirements (Fig. 1).

Over-irrigation to compensate for poor-quality installations

To obtain reasonable yields, the large landholders (A), small innovators (C1), learners (C2) and part-time farmers (D′) compensate for poor-quality equipment (see Table 2) by over-irrigating. Contrary to our expectations, this generally did not concern only the small-scale farmers, our hypothesis being that they would lack the means to invest in good-quality equipment. Instead it concerned mainly the large landholders, which delegated irrigation and maintenance to labourers, and were rarely present in the field to monitor irrigation performance. This was the case of Yacine, whose equipment had very poor distribution uniformity (12 %), and who applied 217 % of net irrigation water requirements in order to ensure a yield of 40 t/ha of potato, which is considered half of the maximum yield recorded in the region (Table 2).

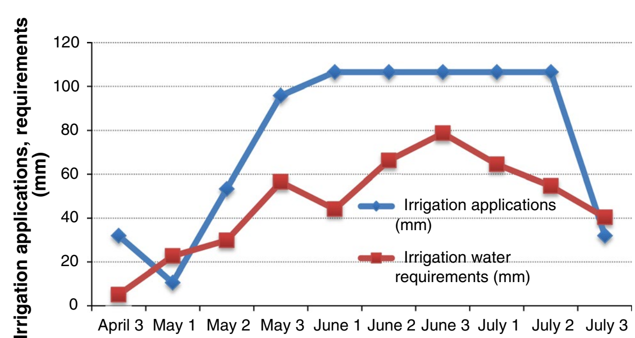

Fig. 1 Irrigation volumes compared to net irrigation water requirements (both in mm) on a plot of onions on Fatima's farm

However, we observed periods of under-irrigation

Even though, when we checked the total irrigation volumes over an agricultural season, we noted that almost all of the farmers over-irrigated, our observations also revealed the existence of periods when farmers underestimated irrigation requirements. This was the case for most of the young horticultural farmers (D) and the part-time farmers (D′). In the case of onions, these farmers obtained 50–70 t/ha (with an average of 58 t/ha), which was 25–45 % less than the best yield obtained by one of the reference farmers (Table 2). However, even the reference farmers (B) were shown to under-irrigate at times. In the case of Fatima (Fig. 1), we calculated a very mild water stress in the development stage of the crop, leading to a calculated yield reduction of 0.7 % on the sample plot (loam).

For most farmers of the other categories, these periods of under-irrigation were even more pronounced. Monim, one of the young horticultural farmers (D), applied a total volume of 713 mm to his onion crop, 25 % more than irrigation water requirements on his sample plot (loam). However, in April–May, he under-irrigated (compared to net irrigation water requirements), as he believed the onion plants did not yet require much water (Fig. 2). He attributed this both to the size of the (young) plants and to the climatic conditions (relatively cold). For Monim, the true irrigation season had not yet started. However, a comparison with the net water requirements revealed that insufficient irrigation water was applied at times, leading to water stress in the development and mid-stages of the crop, and in turn, to a calculated yield reduction of 11.5 %.

This phenomenon concerned most farmers. They underestimated irrigation water requirements at the beginning of the season. From May, they increased irrigation frequency

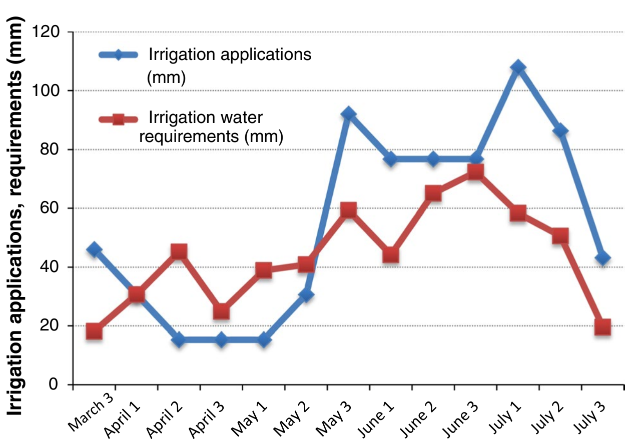

Fig. 2 Irrigation applications compared to net irrigation water requirements (both in mm) on a plot of onions on Monim's farm

and volumes in order to obtain good yields, but also to compensate for the problems they had with the hydraulic performance of their drip systems (poor DUs).

In some cases, the irrigation practices were constrained by access to water

Even in the case of groundwater irrigation with private wells, it is important to take water availability into account to explain irrigation practices. Five farms had water constrains, and farmers could not irrigate the entire plot according to the crop water requirements, especially during the summer months during peak crop water requirements. These farmers (all large landholders and two farms belonging to young horticultural farmers) had a problem of well capacity. At these farms, the continuous flow, based on the number of wells, well capacity and surface of irrigated land, ranged from 0.20 to 1.00 l/s/ha. Considering a peak demand of 8 mm/day and a potential irrigation efficiency of 90 %, the peak demand should be at least 1,03 l/s/ha. These five farmers had simply not enough water for their plots and accepted sub-optimal yields rather than diminishing the irrigated area.

On the other farms, farmers had theoretically sufficient discharge capacity of wells to increase the duration or the frequency of irrigation when water requirements increased (from June onwards). However, on some farms, the yield of wells, i.e. the ability to deliver the peak discharge over a longer period of time, constituted also a problem for some farmers, especially during the summer. Only farmers with sufficient means were able to install additional wells on the farm. Those farmers who did not have such means thus had to reorganize how water was distributed within the farm and even within a plot. These farmers used two main strategies.

Irrigating a plot in different turns during the day One of the farmers of the learners' group, who owns 3 ha with only one well (45 m in depth), did not have sufficient discharge during the summer and divided his plot into three irrigation blocks. His well would run dry after only a few hours of functioning. To solve this problem, he irrigated two blocks in the morning and one block in the afternoon. In this way, he compensated for the water shortage by increasing the duration of irrigation in the plot as a whole, and thus a longer presence in the field. He applied more water to the plot (224 % of the water requirements) than required. Interestingly, the water constraint did not seem to be sufficiently problematic for him to either deal with the yield problem of his well (e.g. digging a second well, increasing the discharge of the existing pump) or improving the poor irrigation performance of his irrigation system (DU of 43 %).

Increasing the frequency of irrigation Several farmers (young horticultural farmers, learners and part-time farmers) were not able to increase the volume of a single irrigation during the period of peak water requirements in summer, as their well ran dry. To deal with the problem, they increased the frequency of irrigation. Monim—one of young horticultural farmers—who cultivates 3 ha of onions started the irrigation season by irrigating every week. From the end of May, he increased the frequency, to every 2 days. In addition, he took great care of his irrigation equipment (installed in 2008) and had good distribution uniformity (85.6 %). It is interesting to note that this farmer, like many farmers in the area, used gravity irrigation (small basins) to 'establish' the crop. However, this initial application was not sufficient to avoid plant water stress, as he under-irrigated during the first part of the season (April to mid-May). Our observations of the total irrigation volume applied during the season revealed that he over-irrigated, despite the problems he faced with his well (IE of 80 %).

By reducing the duration of irrigation, the farmer 'saves' water

All farmers are well aware of the concept of saving water, which has been promoted by the state. However, in their mind, the concept is less linked to the volume of water used for irrigation, but rather to the duration of irrigation, which was dramatically reduced when drip irrigation was introduced:

> Drip irrigation is good. It is a water-saving technique. Before, I used to take four days to irrigate 1 ha; with drip irrigation, one day is sufficient to irrigate my plot (Mohamed, 26 years old, 2011).

Indeed, there were no water metres in 21 out of 22 drip irrigation systems, and none of the farmers knew how much water they applied or how much water they could save.

Logic behind farmers adopting and using drip irrigation

The results of the previous section showed that farmers' practices are a determining factor in the performance of drip irrigation systems (efficiency), along with the condition of the equipment (DU), which in turn depends on the design and maintenance of the system. However, it is necessary to go one step further in the analysis by understanding the social context and the logic behind the farmers' (technical) irrigation practices. In this section, we identify different categories of farmers based on their irrigation practices, as well as the logic behind their practices (Table 3; Fig. 3). We show that hydraulic performance reflects differences between farmers in how they conceive and practice agriculture.

Table 3 The underlying logic of different groups of farmers operating drip irrigation systems

Group	Prevailing logic of farmers with respect to drip irrigation
Large landholders (A)	'Landlord' status
	Increasing the size of the farm
Reference farmers (B)	Excellency
Small innovators (C1)	'Modern farmer' status
	Being a drip irrigation expert
Learners (C2)	Aiming for intensification
Young horticultural farmers (D)	Solving technical constraints
	Intensification
Part-time farmers (D′)	Ease of use

Large landholders: every new innovation is first adopted by these farmers (Group A)

The large landholders have a wide social and professional network, meaning they are always informed about the latest technology. They are generally office bearers in the farmers' organizations, for example, the regional dairy cooperative. In the mid-1980s, several companies from Casablanca (importers of drip equipment) came to the Saiss region and encouraged these large landholders to start drip irrigation on their farms on a trial basis. Often, the equipment was installed on small plots (1–2 ha) free of charge. For these landholders, being a 'big' farmer is an identity that requires them to stay informed about innovations and to be the first to adopt new technologies.

> At the time, a company from Casablanca came to see me to suggest drip irrigation. I remember that they installed it cost free on a 1 ha plot of plum trees. I could not refuse the offer, it was free of charge, it was an opportunity to discover drip irrigation (El Haj Driss, 80 years old, 2011).

When the farmers tested the innovation, they were impressed by the high yields obtained after the introduction of drip irrigation. They consequently progressively equipped the whole farm with drip irrigation. Later on, the government also started to show interest in the technology, and this group of farmers often managed to obtain government subsidies for their irrigation equipment. Today, all their plots are equipped. They even equip the plots they rent, requiring their tenants to adopt drip irrigation too. In so doing, they are no longer aiming to maintain their 'status', as today drip irrigation is now being used by a wide range of farmers and is thus no longer a distinguishing factor for such large landholders. Instead, their current aim is to increase crop yields, thereby 'rationalizing' their intentions, and to reduce labour requirements. However, they still want to be informed about innovation, and be the first to try new inventions (integrated automation systems for drip irrigation, for instance) and thus maintain their social status. To do so, they mobilize their professional networks, apply to state agencies for subsidies and invest their own money. This does not always guarantee success. In one case, the (fully automated) high-tech system turned out to be unsuitable in the local conditions:

> The first few days after the company had installed the automatic drip irrigation system, I found it very beautiful, and very sophisticated. But when I started to use it, I discovered how complicated it was. Especially the fertigation system, and the solenoid valves; when there is an electricity cut, you can't irrigate. After a week of use, I replaced the big fertilizer tub by smaller tubs to make it easier to measure the doses of fertilizer, and replaced the solenoid valves by manual valves (Driss, manager of a large-scale farm, 42 years old, 2011).

The performance of the equipment belonging to the farmers in this group was surprisingly low, with DUs ranging from 12 to 55 % (Fig. 3; Table 2). This can be explained by the fact that while these farmers are fascinated by the technology, they are not involved in the practical use of the equipment, which is handled by labourers or tenants. These workers do not spend much time on maintenance (renewing the tubes, cleaning the filters), as it has only a gradual (negative) impact on hydraulic performance. In addition, the plots are generally quite large, making it difficult to inspect all the drip tubes. Lastly, these farmers are clearly more interested in increasing the size of their farm, by renting in or purchasing land, than in intensifying the use of the land they already own. For all these reasons, the DUs of drip irrigation systems were very poor, which the farmers

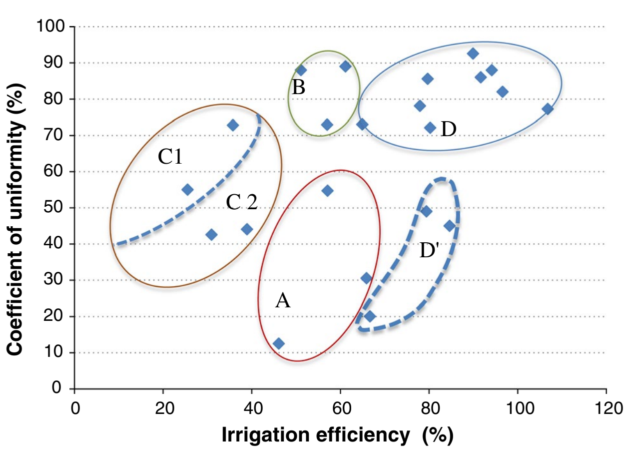

Fig. 3 Classification of groups of farmers based on the logic behind their irrigation practices to explain irrigation performances (irrigation efficiency and coefficient of distribution, both in %)

compensated for using large volumes of irrigation water (200 % of net irrigation water requirements, on average). Since these farmers have installed several often inter-connected wells, supplying sufficient water to compensate for technical deficiencies is not a problem.

Reference farmers (group B)

Interestingly, the majority of farmers (those from our sample, but more generally most farmers in the study area) rarely refer to large landholders as a reference for their farming and (drip) irrigation practices. Instead, they turn to a small select group of medium-sized farmers, and we called 'reference farmers'. This group of horticultural farmers aims for excellence (calibre, quality of products, yields). These farmers are keen to know about any technological advances, but also pay a great deal of attention to new agricultural and irrigation practices. They often consult specialists for answers to specific questions related to technology and practices (fertigation, for example) and fix very clear targets for their production as they aim for specific markets. Like the large landholders, they hire labourers but they supervise them very closely and are present on their farm every day. Their daily presence in the field also means they interact more with farmers in other groups, who are keen to learn from these reference farmers.

> The first farmer to introduce drip irrigation in this village was 'big' Mohamed (group B, reference farmers). He is known to be a very competent farmer, he is a hard worker! He spends all his time on his farm! He has even installed a new crushing unit to make olive oil. He knows all the new techniques, and especially the best seed potatoes. He obtains excellent yields. Every year, before buying seed potatoes, I ask him for advice on which to buy (Taher, 31 years old, 2011, group C1).

This group of farmers introduced drip irrigation from 1996 onwards with the aim of intensification. They had observed drip irrigation on the large landholders' farms (group A) and were aware of its advantages. For them, drip irrigation is part of a larger intensive farming system. They adopted drip irrigation step-by-step. They first tried it out in a small plot not only to gain experience but also to reduce the cost of investment. Progressively, they equipped their whole farm. The first plots were equipped by companies in the vicinity, but later on, they purchased spare parts and installed drip irrigation in their plots themselves. Too busy on their farm to 'waste' their time negotiating with government administrations and convinced that their investment would quickly pay for itself, these farmers equipped their farm without applying for state subsidies.

These reference farmers consider maintaining the equipment and monitoring irrigation are very important. For them ‘good irrigation’ implies having excellent irrigation equipment (DU ranging from 73 to 89 %; Fig. 3; Table 2) and ensuring that their plants never undergo water stress, as they have a clear production objective and do not want to take any risks. They generally over-irrigate (164–196 % of net irrigation water requirements).

Small innovators (group C1) were amongst the first to introduce drip irrigation on small plots. They acquired know-how about drip irrigation while working as labourers on large farms. Once they were back on the family farm, they designed a drip irrigation system suited to their own requirements: simple to use, less expensive than high-tech installations. Taher, for example, worked on a large farm where drip irrigation was introduced in 2002. He was even involved in installing the irrigation equipment there. He wanted to understand how drip irrigation worked, as it was the first time in his life he has seen it. When he returned to his own family farm, and after an excellent agricultural campaign in 2005, he installed a simplified drip irrigation system on his own farm (small valves, simplified fertigation system).

…looking for social status

For this group of farmers, drip irrigation is a synonym for a high social status. It is about being a ‘modern farmer’. The main motivation for adopting drip irrigation in the first instance is to achieve this status. Taher used to be a labourer on a large farm. When he introduced drip irrigation on his family farm, his aim was not only to put himself on the same level as large-scale farmers but also to improve his status in his family environment. His uncle, with whom he was in conflict over land inheritance, had installed drip irrigation and had become a reference in the village: ‘the day I installed drip irrigation, I was proud of myself. I finally had drip irrigation, there was no longer any difference between me and my uncle’ (Taher, 31 years old, 2011).

The farmers in this group clearly regard reference farmers (group B) as an example to be followed. In turn, these small innovators have considerable influence on other small-scale farmers (group D, for instance). As Taher’s mother said: ‘the day my son installed drip irrigation, it was like a wedding party. I invited my neighbours, and I organized a small party. Oh yes, on that day I was happy, it felt right, now we had drip irrigation like the large-scale farmers. I showed the drip irrigation system to my neighbours. Afterwards, everybody wanted to install drip irrigation. Our neighbour Mounir, for example, came over next day and asked Taher to install drip irrigation on his farm’ (mother of Taher, 62 years old, 2011).

Today, Taher installs drip irrigation systems for farmers, gives advice to friends and neighbours on the type of equipment to install and advises his clients on which dealer or fitter to contact to purchase and install the equipment. This means that farmers in this group often do not have the time and the energy to spend sufficient time on their own farm. The performance of the drip systems is relatively poor (DU = 55–73), which they compensate for by over-irrigating, as they want to obtain the same yields as the reference farmers (IE = 25 and 36 %, respectively; Table 2).

The second example is Khalid, who worked as a labourer on some large-scale farms in France, where he discovered and used drip irrigation. When he returned to Morocco in 2006, he decided to install drip irrigation on the family farm:

> When I returned home from France, I immediately installed drip irrigation. At the time, drip irrigation was not very common in the village. It was a way to show the villagers that I came back with a certain know-how from France, and that this know-how related to something important: drip irrigation. I installed it myself. And since then, everybody talks about me as somebody who went abroad, and came back with something. He didn’t come back empty handed (Khalid, 60 years old, 2011).

In contrast to the first farmer, Khalid’s logic changed with time. While initially drip irrigation was mainly a status symbol, today, his aim is to increase his crop yields. This is also linked to the fact that his son (26 years old) has taken over most of the management of the farm. For example, unlike the first farmer, they renew their drip tubes and are very careful to maintain the equipment to ensure the irrigation system continues to function properly. Khalid is now part of group D (DU = 82 %; IE = 97 %).

The small-scale horticultural farmers: learners (C2), young horticultural farmers (D) and part-time farmers (D′)

These farmers have less than 5 ha and may be owners, tenants or lessees. They adopted drip irrigation from 2006 onwards. Adoption was facilitated by three concomitant phenomena: (1) they learned about drip irrigation as labourers on large- or medium-scale farms (groups A and B), (2) pioneer horticulturalists adopted drip irrigation on small-scale farms in their village, thus showing the feasibility of using drip irrigation on such farms (group C1) and (3) local expertise was developed concerning the sale and installation of drip irrigation equipment. This local support sector proposed cheaper equipment that was simpler to use and suitable for the specific requirements of the farms. For example, on undulating plots or farms with problems of well discharge, they proposed drip tubes with individual valves, enabling the farmer to adjust the pressure as required and irrigate line-by-line. Certain farmers initially hesitated, but were convinced by the results obtained by neighbouring farmers. These farmers were not only able to obtain good onion and potato yields but also gained in terms of the number of labourers required and the duration of irrigation.

> I installed drip irrigation when my neighbour Taher installed it on his plot. He explained what to do, and told me whom to contact. Finally, it is easy to have drip irrigation. When I installed it, I used it to grow onions, as everybody said that onions grow well with drip irrigation and give excellent yields (Mounir, 27 years old, 2011).

In these three groups, we were given a range of different reasons for introducing drip irrigation. These reasons did not (or rarely) relate to improving social status, but to specific technical objectives (increasing agricultural production, obtaining a better quality product), and in response to specific constraints. In a way, drip irrigation had been demystified. The constraints related to water shortage, the difficulty of finding labourers or the kind of topography that makes gravity irrigation difficult or even impossible. Drip irrigation thus allowed farmers to extend their irrigated area: 'I decided to install drip irrigation when I saw it at my neighbour's, who does not have sufficient water in his well. With drip irrigation, he could irrigate his entire plot. I contacted the son of a friend at the milk cooperative, who suggested I install a drip system with individual valves. This system was not very expensive, and was suitable for the conditions of my land; There is not enough water in my well, and my farm plot is on a small hill' (Younes, 62 years old, 2011).

Today, there is a clear distinction between the three different groups of small-scale horticultural farmers. The farmers in group C2 are 'learners'. Their equipment is generally of poor quality, and they face many problems in their agricultural and irrigation practices. They are either isolated (limited social network) or only recently started drip irrigation. Group C2 is thus a temporary category, which farmers will leave after 1–2 irrigation seasons, most likely for group D (or D′).

Group D comprises young farmers aiming for intensive horticultural production. For them, drip irrigation is part and parcel of 'modern' agriculture and an obvious choice that enables them to deal with specific constraints (labour, precise application of inputs, etc.). They closely observe the reference farmers (group B) and manage to closely follow their farming and irrigation practices. They also take advantage of the advice and support of local fitters. These (young) farmers manage the technology well (installation and maintenance). Once these small-scale farmers have used drip irrigation for 2–3 years, they may change their irrigation equipment in order to 'be more efficient and produce more', thereby also improving the distribution uniformity. Karim, for example, adopted drip irrigation to deal with the problem of insufficient water in his well. In 2010, he installed cheap, mobile equipment with individual valves, without fertigation or filter systems. Today, he is in the process of installing a complete drip irrigation package on his entire farm, in order to obtain better yields. He is about to change from group D to group B (Fig. 4).

The farmers in group D′ are only on their farm part of the time, as they have off-farm activities. Their limited presence in the field is reflected in the state of their drip irrigation systems, which are generally in bad condition (clogging, poor distribution uniformity; Table 2). While in their interviews they talked about having the same intensification objectives as the farmers in group B, in practice, their irrigation and agricultural performance never matched their ambitions. Drip irrigation is often a way for them to reduce their presence on the farm and a technology with a certain ease of use.

Interactions between logics and, groups, evolving logics

Our results show that the (prevailing) logic behind farmers' adoption and use of drip irrigation differs and that these differences have an impact on the quality of the irrigation equipment, the irrigation practices and the maintenance of the equipment and hence on irrigation performance itself. Of course, no farmer (nor any group) acts on only one logic, and there is often a combination of mutually reinforcing rationalities at play. However, our discussions with farmers, as well as our field observations, revealed that the prevailing logic differed significantly in the different categories of farmers. Interestingly, the farmers themselves identified different categories of irrigation practices and could easily relate to the categories we identified.

It was also interesting to note that the logic of farmers often changes once they start to use the drip irrigation system. Status is still relatively important, but less so since many farmers have adopted drip irrigation in the meantime. After 2–3 years of use, having improved their income, almost all farmers display economic logic, aiming to intensify their agricultural production. For small-scale farmers, this means intensifying production on their small plots. For large-scale farmers, this generally means increasing the size of the farm, while aiming at reasonably high yields, but without achieving the results of small-scale farmers. During this process, farmers often renew their irrigation equipment. While small-scale farmers at first buy cheap simple equipment (with a simplified filter system, for instance), after 2–3 years of use, they change to more complete

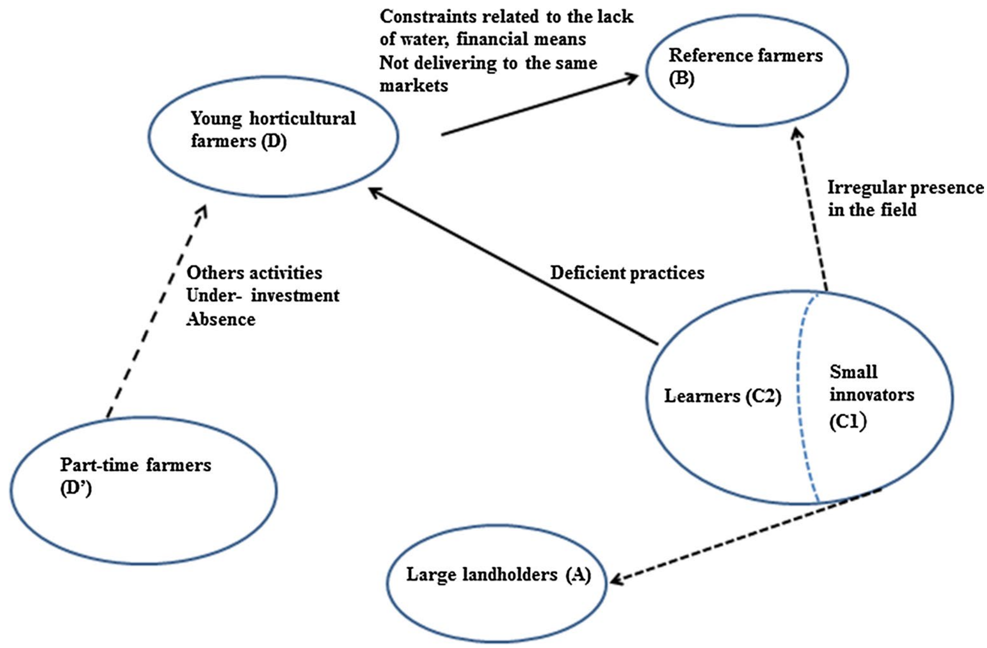

Fig. 4 Interactions between the different groups of farmers related to drip irrigation and agricultural practices

irrigation systems. They not only have obtained the means to invest but also their ambitions have also changed.

As mentioned above, there are many interactions between the different groups with exchanges of knowledge, know-how and practices, as farmers closely observed not only the farmers in their own group but also those in other groups (Fig. 4). These interactions influenced the logic of farmers and gave them ideas, which may lead to new investments in irrigation equipment and to changing practices. We present two types of interactions in Fig. 4. Firstly, farmers of a particular group observe farmers' practices of other groups, which thus serve as role models (dotted arrow). However, in some cases, these farmers could not implement such practices, due to insufficient means or other constraints, as mentioned in Fig. 4. This explains their current practices. Secondly, some farmers who observed certain practices of other farmers' groups adapted them to their situation and thus changed their practices (plain arrow).

Farmers may change category, but not all manage to catch up with other groups

The dynamics related to horticulture and drip irrigation can change rapidly. Farmers may move from one group to another as their logic changes or when they are able to invest more, for example in new equipment, or by improving their practices. In most cases, the farmers in group B (medium-sized farms) are the main reference, especially for those in group D, who are all small-scale farmers (Fig. 4). Group D farmers imitate the practices of the reference farmers, but their equipment is not as good (lower DU; Table 2), and they have less access to water, as they do not have the means to dig additional wells. This leads to lower yields, and thus lower revenues, and a continuing difference between these groups. 'There is no big difference between me and Mohamed (group B, reference farmers), I have got good equipment. But I do not have enough water, otherwise I would just be like him' (Monîm, 26 years, 2011). Interestingly, the vast majority of the small-scale farmers (C2, D) did not refer to the large landholders (group A) as a source of inspiration, even though some had worked on their farms and learned about drip irrigation there. The (poor) performance of the drip irrigation systems we observed on these big farms, along with erratic irrigation and maintenance, tended to confirm the views of these small-scale farmers. However, the small innovators (C1) continued to observe changes in irrigation equipment in the farms of large landholders. Through their close links with labourers and farm managers who work there, they obtained information more easily than on the farms of reference farmers.

Other small-scale farmers (C1, D) also aimed to reproduce the agricultural achievements of the reference farmers (group B). However, they faced two types of obstacles. Firstly, their equipment did not perform as well (Table 2, group C1). Secondly, some farmers had problems with their irrigation practices. Some may have had to face a general shortage of water in their well that limited their irrigation capacity, but more often, they had difficulty in correctly estimating the water requirements of the plants they cultivated. Similar problems affected their agricultural practices, which impacts on yields and on the quality of the products. As the horticultural market becomes more competitive, the agronomic performance (yields, product quality) is considered more and more important: 'this year, I sold my onions to Marjane (supermarket) in Casablanca for 6 dirhams/kg, better than Mohamed (group B, reference farmers), and next year, I hope to have the same yields as he has, so that I can sell all of it to Marjane' (Taher, 32 years old, 2012).

The irrigation practices of farmers in group C2 were problematic, mainly due to their lack of experience in the use of drip irrigation, while some lacked interest in their agricultural activities. With time, some of these farmers may reach the same hydraulic performance as those in group D, but many have structural problems that would be difficult to overcome. While they claimed their logic was the same logic as that of farmers in group D, many of them have off-farm activities and simply do not have the time or even the interest in improving their practices. For them, drip irrigation is a means to reduce labour requirements and thus the need for their presence on the plot.

Discussion: beyond water saving, putting drip irrigation performance in a wider perspective

In recent years, irrigation engineers have made a major effort to clarify the notion of irrigation performance and to define appropriate indicators (Burt et al. 1997). Our study showed that these indicators are relatively easy to apply, even though they require considerable effort to collect data, particularly field data on irrigation applications. These indicators were also helpful to distinguish between problems affecting irrigation equipment (DU) and irrigation practices (IE). However, our study also showed that farmers define irrigation performance in different ways, relating them to other objectives than 'just' water. Leeuwis and van den Ban (2004) provide four sets of variables to understand the logic underlying individual (irrigation) practices. Firstly, farmers rarely link the notion of 'good irrigation' with efficiency or uniformity of distribution, as saving water is simply not a priority in their evaluative frame of reference (Leeuwis and van den Ban 2004). Their aspirations to become 'drip irrigation farmers' may be agro-economic (increasing yields, producing high-quality products), improving social status or obtaining knowledge in order to play a role in the drip irrigation support sector (councillors, fitters, salesmen). In fact, the combination of these aspirations, which converge in individual farmers, may explain part of farmers' enthusiasm for drip irrigation (Zwarteveen et al. 2012). Irrigation performance, as engineers see it, is at best only an intermediary objective for most farmers. Certain farmers may be interested in achieving good distribution uniformity to ensure good yields, but if they can compensate for poor uniformity by increasing the volume of water they use for irrigation, with no adverse effects on yields, there may be no reason for them to improve irrigation performance.

Secondly, irrigation performance should be seen more as a process than as a static, unchanging value. This is related to the farmers' belief that they are not only able to change their practices when they adopt drip irrigation (Leeuwis and van den Ban 2004) but also their ability to improve their (drip irrigation) practices as they go along. This was the case of the farmers in the 'learners' group, who introduced drip irrigation, were not yet experts at all the practices, but were nevertheless confident they would learn them in a very short time, thereby probably improving their irrigation performance. From a more general point of view, the model proposed by Leeuwis and van den Ban (2004) is explicitly presented as a dynamic system in 'continuous motion', through which 'social actors connect their past, present and future'. These dynamics are not only the result of feedback mechanisms (learning, for instance) but are also related to changes in the social environment (local expertise of drip irrigation equipment manufacturers), or the aspirations of farmers or their perceived self-efficacy. Farmers may thus change category from one year to the next as they become more confident or less interested in agriculture; new categories may appear and others disappear, and drip equipment may be improved or deteriorate. From a research point of view, this means that irrigation performance should be monitored as a dynamic process, efficiency and uniformity should be measured and farmers' practices observed over a longer period of time.

Thirdly, we showed how the wider social environment, which facilitated the introduction and use of drip irrigation, was established progressively. Local expertise developed that facilitated the purchase of equipment, the design and installation of the system, its maintenance and irrigation practices. This allowed equipment to be designed for each particular situation. In addition, farmers had the support of strong social networks in the use of drip irrigation. They regularly met and discussed different practices related to drip irrigation with family members, neighbours and friends. The presence of a drip irrigation 'community' doubtless helped new farmers adopt drip irrigation, but likely also influenced practices, and consequently irrigation performance. For the time being, irrigation performance does not appear to be an important topic in these networks, since, as mentioned above, farmers' aspirations do not include performing well from a hydraulic point of view.

Fourthly, there appears to be no social pressure on irrigating carefully to save water. There is only one actor, the state, who explicitly links the use of drip irrigation with saving water. However, the water-saving objective is mixed with a water productivity objective (more crop per drop), which makes the message rather confusing for farmers. In addition, we almost never observed water metres on the drip systems, even on those that had been subsidized by the state. In other words, the water-saving message did not get through to those who use drip irrigation systems, which are promoted to help save water through greater efficiency and a uniformity of distribution. This leads generally to over-irrigation and added pressure on water resources. These results are in accordance with findings in India, where the adoption of drip irrigation led to increased pressure on groundwater (Namara et al. 2007).

These four sets of variables put the concept of irrigation performance in a wider perspective, thereby explaining the social nature of farmers' practices, and the wide range of hydraulic performance observed. Measuring hydraulic performance also helped identify the logic underlying farmers' practices. Frequently, the farmer's stated logic of irrigation corresponded to the logic of the 'reference' farmers with whom they identified. The difference in the irrigation performance of two farmers who claimed to belong to the same category prompted us to take a closer look at irrigation practices and pinpoint a mismatch between farmers' discourse and their actual practices. One of the farmers, who considered he belonged to the 'reference farmers' category, was seen to possess all the capacities required to be in this group, but was not sufficiently present in the field to direct irrigation practices and the maintenance of his equipment. This farmer can be considered more as a councillor than as a practitioner of drip irrigation. The field measurements also helped us to overcome our own previously biased view of the performance of drip irrigation when we discovered that the large landholders' expensive high-tech equipment had the lowest distribution uniformity.

Conclusion: putting the user at the heart of the irrigation performance debate

Drip irrigation is a common topic in the international literature and is often viewed as a technical innovation leading to more efficient irrigation and water saving. Our results show that the use of drip irrigation does not lead automatically to water saving, even at the plot level. Farmers' practices do not necessarily target 'perfect' irrigation in the sense hoped by engineers. Yet, the actors who install, use and maintain drip irrigation systems, and who consequently determine the actual irrigation performance of these systems, remain invisible to researchers and to the policy makers who subsidize drip irrigation equipment. As a result, the efficient performance of drip irrigation is a myth. Encouraging the introduction of drip irrigation is often considered sufficient to deal with problems of water scarcity. This means that little research is undertaken on how to improve actual irrigation performance. Putting the user first in research studies would probably lead to more modest assessments of actual irrigation performance, but could also draw the attention of policy makers to the actual conditions in which drip irrigation is implemented, and thus to including 'water saving' as an objective for individual farmers and for the 'drip irrigation community' as a whole. Our results also showed that farmers were able to improve irrigation practices over a relatively short time, for example to improve yields. This means that once water saving becomes part of their objectives, farmers will certainly be able to increase the irrigation efficiency.

From a methodological point of view, our approach combined the measurement of irrigation performance, the observation of irrigation practices and the analysis of the underlying logic of farmers who use drip irrigation. This approach enabled us to explain the diversity and dynamics of irrigation performances in the field. While this may initially appear to complicate the analysis of irrigation performance, we believe that putting the actors concerned at the heart of the debate on irrigation performance (i.e. making them visible) will make it possible to turn the myth of 'saving water' through drip irrigation into reality.

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