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Assessment of Drip Irrigation in Morocco With Particular Emphasis on the Plain of Tadla

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Assessment of Drip Irrigation in Morocco
With Particular Emphasis on the Plain of Tadla

Research Grant Report

by

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Caution: Any error in the reporting or interpretation of the information included in this report is the sole responsibility of the author.

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Cover-page photo: Partial view of PIT from above the town of Afourer. Photo taken by Abdel Berrada on December 19, 2008.

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Abbreviations

ADS Maroc: Agence de Développement Social--http://www.adsmaroc.com/

AGR: Administration du Génie Rural

ABHOER: Agence du Bassin Hydraulique de l'Oum er R'bia

BIT : Bureau des Techniques d'Irrigation

CDA :	Centre de Développement Agricole
COSUMAR:	Companie de Sucres du Maroc
CRCA:	Caisse Régionale de Crédit Agricole
CRT:	Centre Régional de Tadla
DPA:	Direction Provinciale de l'Agriculture
DPAE :	Direction de la Programmation et des Affaires Economiques
INRA:	Institut National de la Recherche Agronomique
MADRPM:	Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes
ORMVA:	Office Régional de Mise en Valeur Agricole de: Doukkala (ORMVAD), Haouz (ORMVAH), and Tadla (ORMVAT)
PIT:	Périmètre Irrigué du Tadla
PNEEI:	Plan National de l'Economie d'Eau d'Irrigation
SCET-SCOM:	Société d'Ingénierie pluridisciplinaire-- (http://www.scet-scom.ma/Fr/Home.aspx?mod=0)

Abstract

Faced with chronic water shortages, the government of Morocco put forth an ambitious plan to equip 700,000 ha or 50% of the total irrigated land in Morocco with drip irrigation by the year 2022. Most of this hectarage would be achieved by converting from inefficient flood irrigation methods to drip irrigation. The main tool used to encourage growers to adopt drip irrigation is a government subsidy that covers 60% of the total initial investment cost. Approximately 163,000 ha were equipped with drip irrigation at the end of 2008. Most of this hectarage belonged to medium or large land owners and most of it was in horticultural crops, particularly fruit trees. Smaller farmers were less likely to convert to drip irrigation due to its high investment cost, the difficulty to obtain loans (the subsidy money is not disbursed until after project completion), or non-familiarity with drip irrigation. Other constraints include illiteracy, type of crops grown, and the subsidy approval process, which was lengthy and cumbersome. In order to reach its target, the government plans to convert 218,000 ha to drip irrigation on a collective basis, meaning that whole irrigation sectors would be converted to drip irrigation. The government will build the infrastructure to bring pressurized and filtered water to each farm but each farmer will be responsible to equip his/her land with drip irrigation and receive the 60% subsidy. Additional incentives (e.g., greater subsidy, trust funds to guarantee loans to small farmers, etc.) may be needed to convince farmers (mostly small land holders) to sign on the program. Many are not convinced that drip irrigation would work or be profitable for their crops such as wheat, barley, or alfalfa. All the drip irrigation installations I visited were surface drip irrigation systems whereby driplines were laid on the soil surface, which may interfere with field operations. Most were designed and installed by consultants or irrigation companies with little participation from growers. The average cost of a drip irrigation system in the Oum er R'bia river basin was $5,700[1]/ha and varied with farm size, crops grown, and degree of sophistication. Approximately 70% of the farms equipped with drip irrigation had a water storage reservoir. Water reservoirs allow growers to store their surface water allocation, which they receive every two to four weeks and thus be able to use it on a more frequent basis with their drip system. Even growers who only have access to ground water (most use both surface and ground water to meet crop demand) build water reservoirs to add flexibility to their operation and qualify for the maximum subsidy amount ($4,500/ha compared to $2,752/ha if a reservoir is not built). There is the concern that the development of drip irrigation on a large scale would further deplete ground water, which has been used extensively in the last 20 years to supplement surface water.

Drip irrigation is not a panacea but may be the best hope to conserve irrigation water in Morocco and maintain or enhance agricultural productivity (produce more with less water). It may not be feasible for every situation; therefore efforts to improve existing irrigation methods should be pursued. Moreover, Morocco should advance research and outreach programs to assist growers and consultants design and manage drip irrigation systems adapted to the social, economic, and agro-climatic conditions in the country.

[1] Dollar values in this report are derived by converting from Moroccan dirhams at an exchange rate of $1.0 = 8.0 dirhams.

Title: Assessment of Drip Irrigation in Morocco, with particular emphasis on the plain of Tadla

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Objectives:

1. Investigate and assess efforts to conserve irrigation water in Morocco, with particular emphasis on the plain of Tadla or PIT ('Périmètre Irriguè du Tadla').
2. Identify constraints to the adoption of drip irrigation.
3. Propose solutions to address some of these constraints.

Problem statement:

Morocco has a Mediterranean-type, semi-arid to arid climate with large variations in precipitation amount and timing. It has experienced frequent droughts, which, along with aging infrastructure, rapid population growth, and the expansion of its economic and industrial base has led to water shortages, some severe. Agriculture uses a large share (up to 85%) of the available water but in 2000-2006, only 55 to 60% (on average) of the demand for irrigation water was met from the main storage reservoirs (MADRPM-1, 2008). Still, there is the perception that agriculture "wastes" water. This perception is justified for several reasons: first, 15 to 20% of the water is lost during transit from the dam to the field. Second, approximately 80% of the hectarage in the large-scale irrigated perimeters is flood-irrigated using traditional methods such as the "Robta" (Fig. 1 & 2), which involves furrow flooding over a series of small basins (TRM, 1999). It is estimated that with the Robta, only about half of the water that enters the field is used by the crop. The other half goes unused mostly through deep percolation below the root zone. Several methods to increase flood-irrigation efficiency have been introduced but their adoption by farmers remains low due to factors such as the relatively high cost of land leveling.

Figure 1. Flood (furrow) irrigation in PIT

Figure 2. Typical Robta basins

Faced with chronic water shortages that are likely to increase in intensity if not addressed, the government of Morocco has studied several scenarios and taken steps to address the situation. Some of the options being considered or already in practice are desalinization of sea water, reuse of grey water, and water conservation. The latter is imperative for agriculture in order to maintain or improve land productivity.

In 2007, the government issued an ambitious plan ("Plan National de l'Economie d'Eau d'Irrigation" or PNEEI) to conserve in excess of 510 million cubic meters (Mm^3) of irrigation water per year (MADRPM-2, 2007). The main premise of PNEEI is that past and current measures to conserve water in agriculture such as the revamping of existing irrigation infrastructure and the introduction of improved irrigation methods (e.g., sprinkler irrigation) are not sufficient to address water shortages. The goal of PNEEI is to equip about 555,000 ha of irrigated land with drip irrigation[2] from 2008 through 2022. This would bring the total hectarage equipped with drip irrigation to 700,000 ha or 50% of the total irrigated land in Morocco. Most of this hectarage would be achieved by converting from flood- to drip irrigation. According to PNEEI, some of the benefits of drip irrigation would be:

- Water savings of 20 to 50% compared to existing irrigation practices
- Crop yield gains of 10 to 100%
- Increased farm revenue
- Reduced labor and,
- Protection of the soil and water resources e.g., by reducing leaching of salts, nitrates, and other pollutants into the groundwater.

The total cost of PNEEI was estimated at around $4.6 billion, of which $3.8 billion would be financed by the government, mostly in the form of subsidies (Belghiti, 2005). Subsidies were increased from 30% of the cost of some or all drip irrigation equipment and installation (plus the excavation of wells) in July 1986 to 60% in October 2006. Landowners who do not meet certain conditions may only receive the 30% (40% in dry regions) subsidy plus, since 1999, a bonus of $250 for each hectare of land equipped with drip irrigation (Belghiti, 2005; MADRPM-3, 2008). Payments at the 60% rate cannot exceed $4,500 per hectare ($/ha) if a water storage reservoir is built and $2,752/ha if it is not. Additional subsidies are provided for farm equipment, improved seeds and tree seedlings, etc. The procedure to apply for and obtain government subsidies has been simplified and streamlined.

Approximately 163,000 ha were equipped with drip irrigation through 2008 (MADRPM-4, 2008), most of which was done on an individual basis and outside the main irrigated perimeters. Consequently, the government plans to convert approximately 218,000 ha of land from mostly flood-irrigation to drip irrigation on a large scale in order to reach its target of 555,000 ha from 2008 through 2022. These so-called "projets de reconversion collectifs" or collective projects will group hundreds if not thousands of farmers in the zones administered by ORMVAs[3]. The government will build the infrastructure to bring pressurized water to the farms and each farmer will equip their land with drip irrigation and receive the 60% subsidy. Several such projects were being evaluated in 2008 and 2009.

To a non-specialist, the goal set by PNEEI to equip half of the irrigated land with drip irrigation is daunting but Morocco has a long history of developing and managing large-scale irrigation projects. I will discuss the rewards and challenges of such a program in the Oum er R'bia river basin, particularly the plain of Tadla.

[2] The term used in PNEEI is "irrigation localisée", which may not translate exactly to drip irrigation. A better French equivalent is: "goutte ā goutte".

[3] ORMVAs ('Office Régionaux de Mise en Valeur Agricole) are semi-autonomous agricultural agencies that oversee irrigation water infrastructure and management in nine irrigated plains in Morocco: Doukkala, Gharb, Haouz, Loukkos, Moulouya, Ouarzazate, Souss-Massa, Tadla, and Tafilelt.

Study methods:

This is a qualitative study in the sense that no new knowledge was generated e.g., via scientifically designed surveys or experiments. I based my analysis on information obtained through:

- A review of published reports and articles
- Meetings with key personnel at MADPM/AGR, ORMVAT, ORMVAD, ORMVAH, SCET-SCOM, ADS, and INRA/CRT
- Meetings with irrigation company representatives
- Meetings with farmers and farmers' representatives
- Visits to several farms equipped with drip irrigation. Of the 17 farms I visited, I only saw one drip irrigation system in operation. This was because of the unusually wet weather in the fall of 2008 and winter of 2009.

Main features of the study area:

The area which I visited most frequently was the Tadla Irrigated Perimeter (PIT), which is one of nine large-scale agricultural irrigation districts developed by the government of Morocco as part of its so-called "one-million irrigated hectares" program. The Oum er R'bia river divides PIT into two independent hydraulic regions: the Beni Moussa (the larger of the two) on the south bank and the Beni-Amir on the north (Fig. 3). The Beni Moussa gets its surface water from the Bin el Ouidane reservoir and Beni Amir from Ahmed el Hansali reservoir[4]. Water flows from these reservoirs by gravity through approximately 3,000 km of open canals. The total gravity-fed irrigated area is 117,500 ha. Additional lands (at least 8,500 ha) are irrigated exclusively with well water. Surface water is allocated to farmers by ORMVAT based on available supplies and the crops grown. Priority is usually given to fruit trees, sugar beets, and forage crops. However, farmers are free to manage the water as they wish, within their property. Water is supplied on a priority-based system called "Tour d'Eau" every 2 to 4 weeks[5].

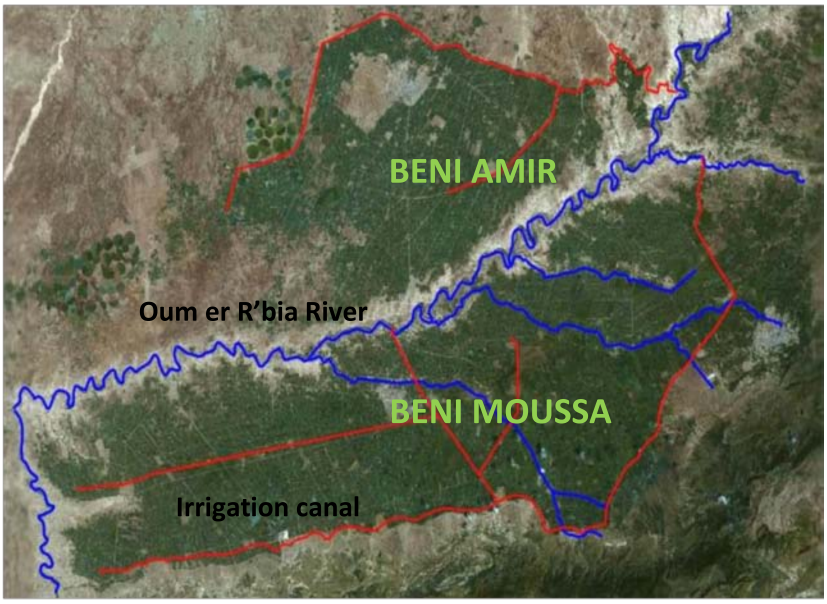


Figure 3. Satellite view of Beni-Amir and Beni Moussa (PIT). Source: ABHOER

[4] Ahmed el Hansali became operational in 2001. Before that, Beni Amir received water from a derivation dam near Kasba Tadla.

[5] For more information on irrigation water allocation at PIT visit: http://ormvatadla.com/site/exploitation-dgrid/ and: http://ormvatadla.com/site/service-de-leau/

The PIT has a semi-arid climate with mild temperatures from late fall (i.e., November) to early spring and generally hot and dry weather for the remainder of the year. The average monthly temperature is 18 °C with a maximum of 40 °C in August and a minimum of 3 °C in January. Annual precipitation (rainfall) averaged 268 mm from 1970 through 2007 with a downward trend (Fig. 4). Less than 50% of the water required to meet crop water demand was supplied from Bin el Ouidane or Ahmed el Hansali reservoirs in 1996-2008 (Fig. 5&6). The deficit is partly made up with groundwater, which has been tapped extensively in the last 20 years. Hammani et al. (2007) reported the existence of over 8,300 wells within PIT and over 4,500 wells outside the zone of action of ORMVAT. Some of these wells may not be in compliance with existing laws, which poses a threat to water supply and management in the Oum er R'bia river basin.

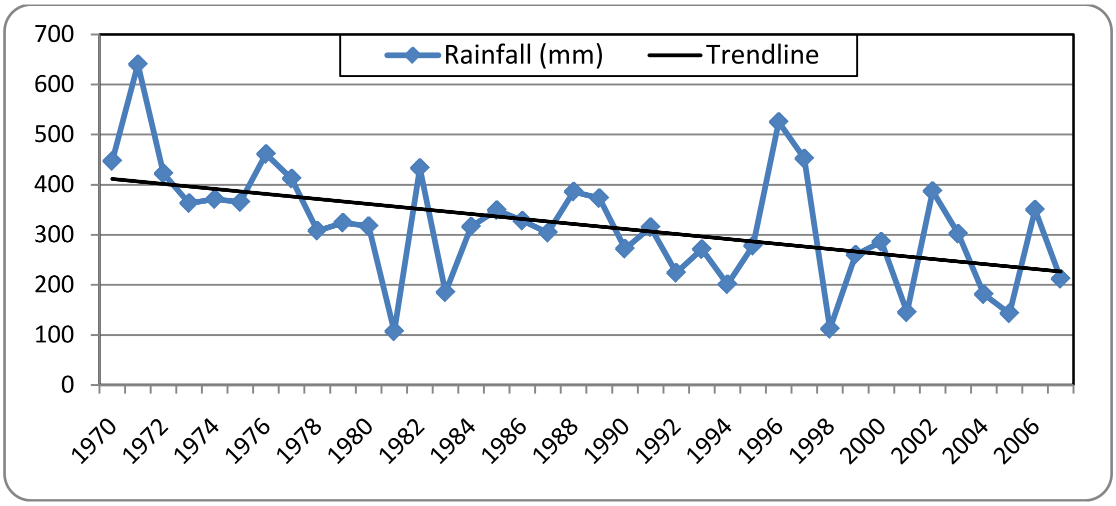
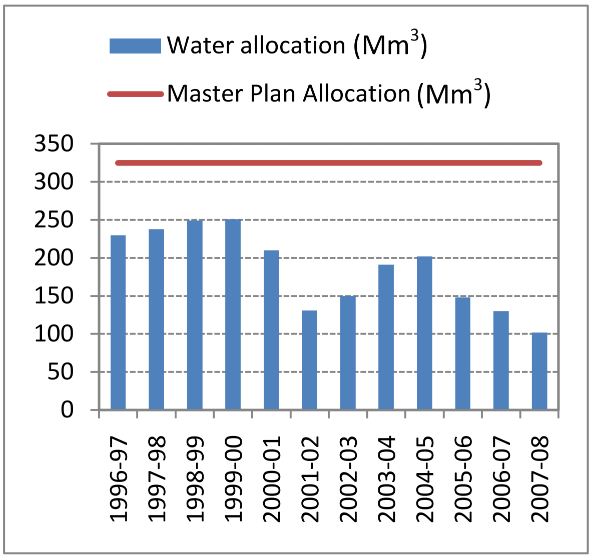
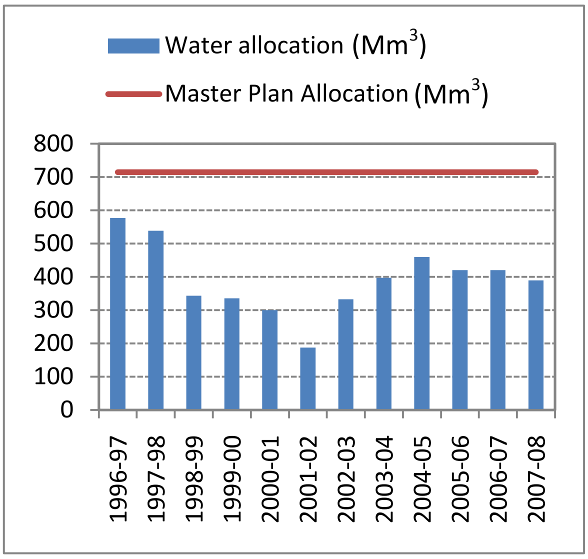


Figure 4. Annual rainfall at PIT-Ouled Gnaou. Source: ORMVAT



DEFICIT of 43%!

Figure 5. Water allocation for Beni Amir from 1996 to 2008 (Source: ORMVAT)



DEFICIT of 45%!

Figure 6. Water allocation for Beni Moussa from 1996 to 2008 (Source: ORMVAT)

PNEEI targets for the Oum er R'bia basin:

Table 1. Land to be converted to drip irrigation from 2008 to 2022

1. Irrigation perimeter or type	2. Total irrigated land (ha)	Land (ha) to be converted-- 3. Collectively	4. Individually	5. Total	5./2. (%)
Doukkala	96000	39500	37100	76600	80
Haouz	146000	57100	23500	80600	55
Tadla (PIT)	109000	49040	39700	88740	81
Subtotal	351000	145640	100300	245940	70
Total 'Grande Hydraulique'[6]	670430	217940	177150	395090	59
Private irrigation	441400	0	160000	160000	36
Grand total	1111830	217940	337150	555090	50

Source: PNEEI (2007)

The target for Doukkala, Haouz, and Tadla which are located within the Oum er R'bia watershed is 245,940 ha or 70% of the total irrigated land (Table 1). The total for PIT is almost 89,000 ha or 81% of the irrigated land, of which 49,000 ha would be converted to drip irrigation collectively, meaning that whole irrigation sectors would be converted at once. Preliminary studies put the number of hectares that can potentially be converted to drip irrigation collectively in PIT at about 53,000 ha, at a cost of 393 million dollars (Table 2). Collective projects are defined here as groups or clusters of fields or whole farms that share some components of the drip irrigation infrastructure such as common storage basins or water delivery systems.

Table 2. Irrigated land in PIT that can potentially be converted to drip irrigation collectively and investment cost.

Irrigation district*	Hectarage (ha)	Investment Cost (millions of $)
Beni Moussa West	15,421	116
Beni Moussa East (Zone 1&2)	32,045	240
Beni Moussa East (zone 3)	1,589	5
Beni Amir	4,244	32
Total	**53,299**	**393**

Source: ORMVAT (2008)
*The total irrigable land is 69,500 ha for Beni Moussa and 28,500 ha for Beni Amir.

Criteria for determining land that can be converted to drip irrigation include energy expenditure to pressurize water and groundwater availability and quality. Beni Amir for instance has deeper wells and saltier groundwater than Beni Moussa (ORMVAT, 2008).

Accomplishments at PIT:

Approximately 10,700 ha were equipped with drip irrigation in PIT from 1991 through 2008 (Fig. 7). The amount of land fitted with drip irrigation increased between 2003 and 2007 due to greater availability of government subsidies. It is worth noting that these figures do not include lands

[6] 'Zones de Grande Hydraulique' often refers to the nine irrigation projects/perimeters built by the government and managed by ORMVAs.

equipped with drip irrigation outside the zone of action of ORMVAT, which amounted to 3,800 ha in the Province of Beni Mellal at the end of 2007 (Messaadi, 2008). For ORMVA-Haouz, 10,794 ha were fitted with drip irrigation from 2002 through 2008 and 6,720 ha prior to 2002 (ORMVAH, Personal Communication, March 2009), which is well within reach of the target set by PNEEI for individual projects (Table 1). Not as many hectares (approximately 2,500 ha by the end of 2008) were equipped with drip irrigation in the plain of Doukkala, which has far fewer fruit tree orchards than the Haouz or Tadla. Doukkala also suffered greatly from recent droughts and the depletion of its groundwater whose quality is unsuitable for irrigation in some areas (ORMVAD, Personal Communication, March 2009).

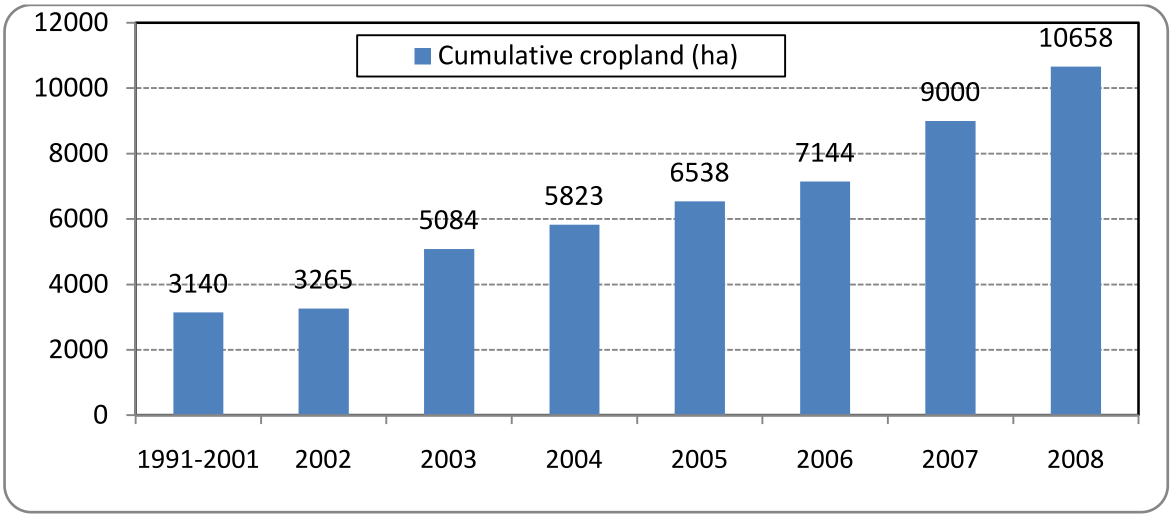


Figure 7. Cropland equipped with drip irrigation in PIT in 1991-2008. Source: ORMVAT

Unofficial ORMVAT data (Table 3) indicate that at least 80% of the hectarage approved to receive the drip irrigation subsidy from July 2002 through November 2008 was earmarked for fruit trees (mostly citrus). This makes sense for at least four reasons:

- Citrus fruits are among the most profitable crops in PIT (Daoudi, 2008)
- Drip irrigation is generally cheaper and easier to install and manage in orchards than for non-tree crops such as alfalfa or even sugar beets, partly because it does not require as many driplines.
- Growers who install new orchards or replace old trees with new ones get a subsidy of $975/ha. This is in addition to the drip-irrigation subsidy.
- Citrus orchards generally represent medium to large hectarages and generally belong to well-to-do and/or progressive landowners with a greater ability to finance their land improvement projects than smaller farmers.

Table 3. Drip-irrigation subsidy requests approved by ORMVAT from July 2002 through November 2008, sorted by crop. Source: ORMVAT

Crop	No. requests	Total SAU ha	SAU/request ha	Investment cost* $/ha	Subsidy $/ha	Subsidy/Cost %
Roses	5	147	29	4331	1826	42
Olive	24	670	28	4962	2862	58
Pomegranate	4	36	9	4991	2153	43
Citrus	218	3958	18	5721	2907	51
Field crops	3	45	15	6082	3649	60
Vegetables	44	547	12	6387	3352	52
Other	21	374	18	6494	3829	59
Vineyard	3	15	5	12016	3550	30
Total/w. average	**322**	**5791**	**18**	**5725**	**2979**	**52**

*One US dollar = 8.0 Moroccan dirhams

All other crops represented, individually, less than 1% of the number or hectarage of approved subsidy requests (Table 3).

Drip irrigation of field crops in PIT is still in its infancy as reflected by the low number of requests where 'Grandes Cultures' (field crops) or sugar beets were listed as the crop to be drip-irrigated. There were only three requests related to field crops and these most likely referred to sugar beets (Table 3). Bekkar et al. (2007) reported similar results, i.e., 83% of the drip-irrigated land surveyed consisted of citrus orchards. Only 8% had vegetable crops. The average size of the completed drip irrigation projects (sample size: 21 farms) was 12.8 ha. It was 18.0 ha when averaged over all the approved subsidy requests in 2002-2008 (Table 3). Fifty two per cent of the approved requests were for projects of 10 ha or less in size but represented only 16% of the total hectarage. In contrast, projects of 20 or more hectares in size represented 26% of the requests but accounted for 66% of the total hectarage (Table 4).

Table 4. Drip-irrigation subsidy requests approved by ORMVAT from July 2002 through November 2008, sorted by land size. Source: ORMVAT

Size category ha	No. requests	Total land ha	Hectares/ request	Investment cost* $/ha	Subsidy $/ha
Less than 10	169	915	5	6159	2921
10 - 19.9	71	1047	15	5578	2903
20-49.9	63	1878	30	5416	2723
Over 50	19	1951	103	5899	3293
Total/w. average	**322**	**5791**	**18**	**5725**	**2979**

The average estimated initial drip irrigation cost was around $5,725/ha, with large variations within and between years (Table 5), crops (Table 3), and individual requests. The cost per hectare generally decreased as the number of hectares increased but not always. The average subsidy was $2,979/ha and was lowest in 2002-2005 and highest in 2007 and 2008 as would be expected since the subsidy was increased to 60% in 2006. Kobry and Eliamani (2005) reported average estimated investment costs of $7,500/ha for approved drip irrigation projects of less than 5 ha, $6,750/ha for 5 to 10 ha, and around $3,950/ha for 10 ha or more. They did not distinguish between projects that had a water storage reservoir and those that did not. Daoudi (2008) reported the following initial investment costs for citrus orchards in PIT: 6,500 to $6,875/ha for orchards of 10 ha or less and around $5,000/ha for orchards greater than 10 ha in size. He estimated the net profit margin for an orchard in full production at $5,739/ha with drip irrigation compared to $3,053/ha with flood irrigation.

Table 5. Drip-irrigation subsidy requests approved by ORMVAT from July 2002 through November 2008, sorted by year. Source: ORMVAT

Year	No. requests	Total land ha	Hectares/ request	Investment cost $/ha	Subsidy $/ha	Subsidy/Cost %
2002	17	336	20	4081	1513	37
2003	59	767	13	5524	1977	36
2004	49	673	14	4901	1898	39
2005	12	302	25	5561	2434	44
2006	15	319	21	5278	2863	54
2007	92	1883	20	5767	3436	60
2008	78	1512	19	6634	3859	58
Total or average	**322**	**5791**	**18**	**5725**	**2979**	**52**

Examples of drip irrigation system component costs reported in recent (2008) subsidy requests are shown in Table 6. They ranged from approximately $3,700/ha to $8,800/ha. The head station and water delivery system accounted, on average, for 63% (45-65%) of the total system cost while the water storage facility represented about 20% (18-36%) of the cost.

Table 6. Estimated drip irrigation system component costs of five projects submitted to ORMVAT in 2008.

Project No.	**1**	**2**	**3**	**4**	**5**	**Cost/ha**	**% of total cost**
System component	**Estimated cost ($)**						
Head station & water delivery	92,088	82,500	148,833	18,660	514,255	**4,062**	**63%**
Storage reservoir	36,399	40,433	60,073	14,916	139,155	**1,380**	**21%**
Pumps	30,413	4,375	7,695	2,813	106,969	**722**	**11%**
Shelter for the head station	5,714	11,198	9,636	4,979	30,128	**292**	**5%**
Total cost	**164,614**	**138,505**	**226,237**	**41,367**	**790,507**	**6,457**	**100%**
Land Area (ha)	25.4	37.1	25.6	4.7	118	210.8	
Cost/ha	**6,481**	**3,733**	**8,837**	**8,801**	**6,699**		
Reservoir Capacity (m^3)	7500	7600	7200	1920	37000		
Crop	Citrus	Citrus	Sugar beets	Citrus*	Citrus**		

Projects 1 & 3 were designed by the same company.
*Citrus trees and vegetable crops
**Citrus trees and sugar beets

Most of the farms I visited had all the essential components of a modern drip irrigation system such as filtration, chemigation, flow meters, control valves, and the option to run the system automatically (Fig. 8).

Approximately 70% of the subsidy requests approved by ORMVAT from July 2002 through November 2008 had storage reservoirs of varying sizes (Unpublished data). The rest either didn't have a water reservoir or the information was missing. Storage reservoirs are recommended even when the sole source of water is groundwater (wells). They provide a buffer in case of well pump malfunction or other unforeseen circumstances. Storage reservoirs are even more critical when surface water is the main or only source of irrigation water. This is because surface water (e.g., from Bin el Ouidane) is allocated every two weeks or longer, depending on availability, which can cause water stress even for flood-irrigated crops. With drip irrigation, water should be applied frequently (e.g., daily during peak demand) to meet crop demand.

The newer drip irrigation installations (e.g., since 2007) are likely to have a water reservoir due to the substantial subsidy (up to $4,500/ha) provided by the government. There was a significant correlation ($r^2 = 0.63$) between reservoir size and farm size at PIT (Unpublished data). Sizing of the water reservoir should be done based on the number of hectares to be irrigated and surface water availability (e.g., flow rate and tour d'eau). The following example was adapted from Benchokroun (2008):

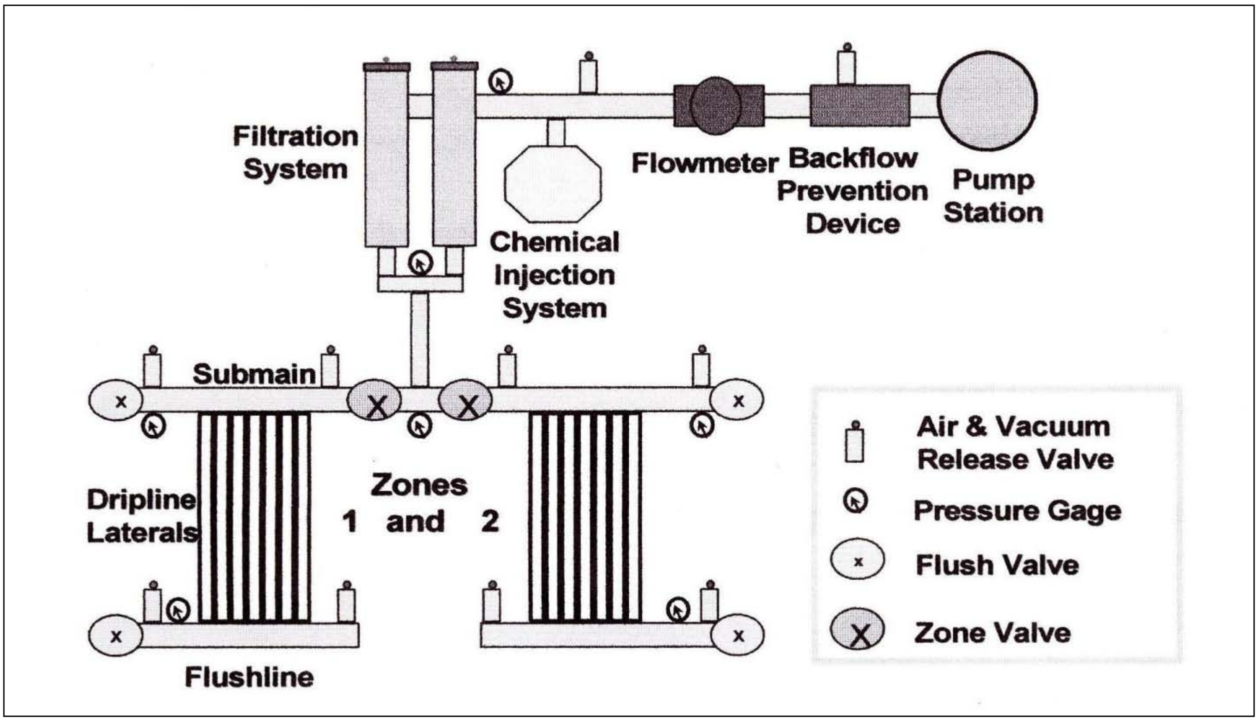


Figure 8. Typical drip irrigation system configuration (http://www.oznet.ksu.edu/sdi/)

- Irrigated land: 31 ha
- Water allocation: 7 hours/ha at 30 l/s, which would supply water for nine days (7 h/ha x 31 ha) / (24 h/d). Total allocated water is:
  $7\ h/ha \times 31\ ha \times 30\ l/s \times 3600\ s/h \times (m^3/1000\ l) = 23{,}436\ m^3$
- Assuming water is pumped out of the reservoir to provide 3 mm/day/ha of irrigation, then total outflow is :
  $3\ mm/d \times 9\ d \times (m/1000\ mm) \times 31\ ha \times (10000\ m^2/ha) = 8{,}370\ m^3$
- Consequently, the volume of the stored water is: 23,436 – 8,370 = 15,066 m^3 or 486 m^3/ha. This would provide enough water to drip-irrigate 31 ha for almost 16 days at 3mm/day or 10 days at 5 mm/day[7]. Daoudi (2008) recommended a storage capacity of 432 m^3/ha for citrus orchards in PIT based on a water allocation of 4 h/ha at 30 l/s or 6 h/ha at 20 l/s. Growers who rely heavily on surface water may want to build reservoirs with more storage capacity (≥500 m^3/ha).

[7] The PIT drip irrigation projects I reviewed used a peak ET value of 5 mm/day for citrus trees and 7 to 8 mm/day for annual crops. Most designs were based on water applications of 1-2 hours/day. In reality, one may irrigate for several hours one day and none the next day, depending on the initial soil water content and infiltration rate, weather condition, etc.

Most of the water reservoirs I visited had a rectangular shape and were 5 to 7 m deep, with earthen walls often raised 1-2 meters above ground level. The inside was lined with a polyethylene geomembrane (Fig. 9). Kobry and Eliamani (2005) reported that the cost of the geomembrane exceeded 50% (in three-quarters of the approved projects) of the total reservoir cost, which averaged \$6.4/m^3 in PIT. Daoudi (2008) reported reservoir costs of 4 to \$5/m^3 for citrus orchards.

Reservoirs not only provide a buffer so that crop water needs can be met on a timely manner but also allow sediments to settle down, thus reducing water filtration requirements. This was less of a concern than algae, which given enough sun and nutrients (e.g., N and P) multiplies rapidly and can plug up screens and cause pumps to fail. The most common control method seems to be an algae-eating fish called “carpe chinoise” (Chinese carp).

Most of the farms I visited had disk filters and all except one had chemigation equipment (Fig. 10). The larger farms had as many as four fertilizer tanks, plus a mixing tank and one tank for injecting acids to dissolve mineral deposits that can plug up drip emitters.

Figure 9. Water storage reservoir lined with a geomembrane. PIT, March 2009

Figure 10. Disk filters. PIT, March 2009

Approximately 42% of the drip irrigation subsidy requests approved in 2002-2008 at PIT listed groundwater (puit et/ou forage) as the sole source of water (Unpublished data). The majority of the drip-irrigated farms that have access to surface water probably also have wells. Only two of the farms I visited used well water sparingly, due to its high salt content. When they did, they mixed it with surface water.

Only one of the 17 farms I visited had flexible drip tubing, commonly referred to as drip tape in the USA. All the other farms had solid round drip tubing. None of the installations had buried drip tapes. This makes sense for tree crops such as oranges and olives because generally, the drip tubes are laid out along the tree rows and away from vehicular traffic[8]. For less permanent and more densely planted crops such as wheat, alfalfa, or sugar beets, laying the drip tubes on the soil surface will get in the way of field operations such as cultivation and harvest (Fig. 11). Thus the driplines may have to be moved to the side or rolled back every time one has to cut alfalfa for instance.

Citrus orchards usually have two driplines per tree row (one on each side of the tree), although some farmers do not install the second dripline until the trees are few years old (Fig. 12). The most

[8] Buried drip tapes are more prone to root intrusion and breakage in tree orchards than in non-tree crops.

common spacing between emitters is 0.75 m and the most common emitter flow rate is 3.9 l/h. Growing crops such as melons or sugar beets or even alfalfa between the citrus trees seems to be a common practice in new orchards equipped with drip irrigation. This is done to generate income until the trees start producing marketable fruits.

Figure 11. Hoeing of a sugar beet field fitted with drip tubes. Ouled Gnaou, December 2008

Figure 12. Drip-irrigated sugar beet in a young citrus orchard in PIT. January 2009

Intercropping may hinder tree growth, particularly when water is in short supply, and may not be profitable. It can, however provide nutrients to the trees and suppress weeds, although chemical weed control can be tricky since some herbicides may be labeled for the intercrop but not for the trees. I visited a new citrus orchard where the sugar beets grown between the trees had a poor stand, which the owner attributed to a poor seedbed. The spacing between driplines in sugar beet was 1.0 m and the spacing between emitters was 0.40 m. Emitter flow rate was 2.0 l/h. This appears to be the most common dripline configuration for sugar beets in PIT but dripline spacings of 0.8 to 1.2 m were reported.

Most of the drip irrigation system installations (in PIT) I looked at were designed based on the following assumptions:

- Drip irrigation efficiency: 90%
- Peak water demand (gross amount)—Fruit trees: 5 mm/day, other crops (e.g., vegetable crops): 7 to 8 mm/day

As much as 46% water can be saved due to drip irrigation (Table 7).

Table 7. Estimated water application and savings due to drip irrigation in PIT. Source: ORMVAT

Crop	Flood-irrigation	Drip irrigation	Water saved
	m^3/ha		%
Citrus	12000	7200	40
Olive	5000	2700	46
Sugar beets	8000	4800	40
Vegetable crops*	12000	7000	42

*Two crops/yr

Procedure for obtaining the government subsidy

In 2002, administrative units were created within ORMVAs and DPAs[9] to review subsidy requests and make sure that the drip irrigation projects were designed and installed properly. This was in response to abuses of the subsidy system or faulty irrigation system design by inexperienced, incompetent, or unscrupulous consultants or irrigation company representatives. Prior to 2002, the regional 'Credit Agricole' agencies (CRCA) not only provided loans and subsidy money to eligible farmers but also monitored the irrigation project execution. Since 2002, CRCA's role was restricted to that of a banker. The regional agricultural services (ORMVAs and DPAs), each within its 'zone d'action', review the subsidy request, which includes legal documents, the irrigation project design, equipment list and prices, and proof that the equipment meets the manufacturer's specifications. Subsidy seekers generally submit two documents, one to ORMVA or DPA, and the other to CRCA or to a private bank to request a loan to finance the project since the subsidy money is not disbursed until after the project is completed. A "Guichet Unique" or clearing house was created in 2008 within each ORMVA and DPA to streamline the application procedure for all the ag-related subsidies and speed up project review and approval. After receipt of the subsidy request ('dossier de demande de subvention'), Guichet Unique and other designated staff have a total of 30 days to complete the following steps. The allotted time (in days) for each step is shown in parenthesis.

1. Verify that the request includes all the required documents (3 d).
2. Verify the veracity and validity of the information submitted (8 to 10 d)[10]. Subsidy seekers are encouraged to work with local ORMVA and DPA staff to verify the project's location, water availability, and existing infrastructure before submitting the request to the Guichet Unique. A technical committee generally consisting of two to four technicians and engineers reviews and approves the project's design and cost estimates.
3. Inspect and certify that the project was installed as approved (15 d). ORMVA's technicians inspect the project at least twice: early to check that the irrigation pipes are of the right size and material before they are buried in the ground and, after project completion to verify that all other equipment and structures match the project specifications approved by the technical committee. This final inspection must be done by a committee of 4 to 5 designated members.
4. Notify CRCA of the project's completion and approval and the amount of subsidy to be disbursed to the applicant (2 d).
5. CRCA issues a check to the subsidy's beneficiary (2 d).

The review and approval process can be delayed due to missing or invalid information, faulty design, or other irregularities. The applicant is notified in writing of such problems and asked to address them. He or she cannot start installing the project until the subsidy request is duly approved. Growers have the option to request the subsidy after they install the drip irrigation system, in which case they are only entitled to 30% (40% in dry areas) of the system's cost plus a bonus of $250/ha. They may choose this option to avoid lengthy delays or for other reasons such as questionable land ownership or illegal use of groundwater. In the late 1990s landowners were given a grace period of three years to declare wells that were excavated before 1995 without proper authorization[11]. Apparently many did not due to ignorance or mistrust.

[9] DPAs or 'Directions Provinciales de l'Agriculture' are MADRPM's agricultural service agencies that promote, monitor, and regulate agricultural development in the regions not served by ORMVAs.

[10] Eight days if the grower applies for the subsidy after he/she installs drip irrigation. In this case the applicant is only entitled to the 30% (40% in dry areas) subsidy plus a bonus of $250/ha. He/she must formally request the subsidy, submit the legal documents that establish his identity and relationship to the land and the authorization to use the water, and commit to keeping the drip irrigation installation for at least five years. Growers who apply for the 60% subsidy must also submit a document that shows in great detail the project design. More information is available at: http://ormvatadla.com/site/procedure-doctroit-daide-financiere/

[11] Morocco has laws to regulate groundwater use but, apparently enforcement is lacking.

Constraints to the adoption of drip irrigation include: small farm size, multiple land owners or questionable ownership status (e.g., communal land), scattered fields, unauthorized wells, non-familiarity with drip irrigation, complicated water laws (e.g., in the Haouz), and debt which can greatly limit growers' ability to finance the irrigation project or get the subsidy.

Drip irrigation design and installation:

Most of the drip irrigation installations are designed by consultants who have their own companies or are affiliated with irrigation equipment dealers or manufacturers based in major Moroccan cities, particularly Casablanca. ORMVAT (and I assume other ORMVAs and DPAs) keeps a list of companies that specialize in drip irrigation system design and installation but does not advise growers on which companies to solicit.

Typically the consultant maps the land to be equipped with drip irrigation and gathers other relevant information (e.g., water supply, cropping system, etc.) his company uses to design the irrigation project. The consultant helps the property owner put together the subsidy request ('dossier de demande de subvention'). It contains legal information about the owner and his or her property, the irrigation system design data, layout, cost estimates, and equipment test results, etc. In order to facilitate the review process, ORMVAs and DPAs issue guidelines as to what type of information should be included and may even provide formulas for calculating crop water requirements, irrigation flow rates, pipe sizes, pump horsepower, etc. An example of guidelines issued by ORMVAH is shown in the appendix.

More often than not, the company that designs the system also installs it or subcontracts parts of it to other companies (turnkey projects). This could create a conflict of interest if, for example, the design company supplies its own equipment, which may not be as good or as affordable as other equipment available on the market. There did not seem to be much grower input in the project design and limited involvement in its installation even though some company representatives claim otherwise (Companies do provide training on how to use the system). In the farms I visited, some works (e.g., the trenches where the irrigation pipes are laid) and some structures such as the shelter that houses the head station or the fence around the storage reservoir were built by property owners or their hired hands.

Most of the specialized drip irrigation equipment such as disk filters and fertilizer and chemical injection and automation equipment is imported from overseas, mostly Spain, Israel, and Italy. However, as the market for drip irrigation expands, the number of system components manufactured locally would likely increase.

Collective projects:

Even if all the orchards, vineyards, and other suitable crops/lands[12] in the state-sponsored irrigated perimeters are equipped with or converted to drip irrigation on an individual basis, the goals set by PNEEI would likely not be met. Well aware of this reality, the government plans to convert approximately 218,000 ha collectively (Table 1). Of these, almost 146,000 ha are located in the Oum er R'bia basin. The World Bank financed several studies to convert up to 10,000 ha in each of Doukkala, Haouz, and Tadla to drip irrigation. I will briefly discuss the study conducted in the Beni Moussa irrigation sector of PIT.

The methodology used in Beni Moussa is supposedly (no official documentation was released to the public as of April 2009) similar to that used in Doukkala and Haouz. First, close to 50,000 ha deemed convertible to drip irrigation in the Beni Moussa (Table 2) were assessed (SCET-SCOM, Personal Communications, January and March 2008). Of this hectarage, approximately 20,000 ha

[12] In the sense that they are easier, cheaper, or more profitable to drip-irrigate than solid-seeded crops such as wheat or alfalfa.

were selected based on the fact that there was enough difference in elevation between the water source and the land, which would create enough pressure to operate the drip irrigation systems without additional energy input. The next phase of the study consisted of meeting with area farmers and potential partners to further narrow down the area to be equipped with drip irrigation. Potential partners include 'Centrale Laitière' (milk processing plant), COSUMAR, 'Crédit Agricole', and irrigation equipment suppliers. These partners would provide loans to farmers or pre-finance the drip irrigation system design, equipment, or installation at the field level. Discussions with farmers focused on selection criteria such as: groundwater availability and quality, farmers' motivation, and the condition of the existing irrigation infrastructure. Consequently, the project area was reduced to 10,000 ha and then to approximately 3,700 ha. This area was selected because of the high number of wells [13], good groundwater quality, and the apparent growers' enthusiasm for the project. Farm size was:

Farm size (ha)	< 5	5-20	> 20
Percent of Total Hectarage	50	40	10

Cropping systems were dominated by cereal (wheat and barley) crops, alfalfa, and sugar beets (Table 8). When this area is converted to drip-irrigation, it is expected that the hectarage in wheat, barley, and alfalfa will decrease while that of fruit trees (citrus and olive) and vegetable crops will increase and corn silage would be the forage crop of choice.

The projected cropping system would preserve PIT's vocation as a major milk and sugar producer but would enhance profitability by increasing the hectarage of horticultural crops. Crop water requirement (Table 9) was calculated using Penman-Monteith reference ET (ET_0) and crop coefficient estimates from FAO's Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

Table 8. Current (2008) and projected crop hectarage in the pilot project area.

	Current hectarage		**Projected**
Crop	**Ha**	**%**	**%**
Cereal crops	1312	32	25
Alfalfa	742	18	10
Corn silage	0	0	15
Sugar beets	667	16	18
Citrus [14]	317	8	15
Olives	252	6	15
Vegetable crops	152	4	10
Total (ha)	**3445**		
Cropping intensity (%)		**84**	**108** [15]

[13] There were 287 deep wells, 467 shallow wells, and 69 intermediate wells on 3,183 ha of land.
[14] 92 ha were drip-irrigated. The total drip-irrigated hectarage in the pilot project area was 111 ha in 2008.
[15] Most likely the total is over 100% because some land will be planted to more than one crop per year. Conversely, the current cropping intensity of 84% probably reflects the fact that some land is left idle (fallow land).

Table 9. Monthly drip irrigation water requirements (at the field) for the pilot project in PIT.

Cropping System	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
	Water requirement (m^3/ha)												
Current	323	143	85	14	54	142	337	514	642	509	460	431	3654
Projected	376	184	89	17	49	128	319	586	867	864	900	840	5219
Rain (mm)*	8.2	26.8	50.9	45.2	41.5	40.8	47.9	46.3	23.7	5.4	0.9	2.8	340

*Long-term monthly averages at the Ouled Gnaou Experimental Station. Source: ORMVAT

The annual drip irrigation water requirement for the projected cropping system was estimated at 5,219 m^3/ha at the field level and 7,223 m^3/ha at the distribution reservoir, which is about the average water allocation (7,163 m^3/ha) for Beni Moussa. This was based on the following efficiencies: From Bin el Ouidane to the distribution reservoir: 85%, open water channels: 85%, buried water pipes: 95%, field (drip irrigation): 90% (SCET-SCOM, Personal Communication, January 2009).

Before the government would start construction of the pilot projects in PIT, Doukkala, and Haouz, at least 70% of farm owners/managers must sign a commitment to convert to drip irrigation within two years of completion of the infrastructure (e.g., filtration and pumping stations and water delivery system) that would bring pressurized water to their properties. These projects would be partially funded by the World Bank. Other collaborative projects would be sponsored by the FAO, the European Union, and other partners.

Challenges:

Collective projects:

Getting farmers to agree to, help pay for, or manage shared irrigation structures can be a challenge. As one company representative put it,

"Farmers are individualistic and competitive by nature. They may copy a neighbor's innovation but they will fight over borders, status, and water!"

Supposedly, attempts to build common water storage reservoirs for drip irrigation have mostly failed in PIT[16]. This may not be the case in other irrigated perimeters such as Moulouya and Souss-Massa. For the PIT pilot project, water would be supplied on demand. No water reservoirs would be required at the farm level. Nonetheless, several concerns were raised at growers' meetings I attended during the week of January 26, 2009 or at other forums.

- The ability to finance the project at the farm level came up at every meeting. Some growers did not think they could afford or get loans to convert their land to drip irrigation. Others were not aware of the 60% subsidy the government may grant farmers who request it. A few outspoken farmers said that they would only sign on to the project if the government builds the entire infrastructure, inside and outside the farm, needed to use this new technology. They did not say if they would help pay for it. SCET-SCOM estimated the project cost at approximately $5,000/ha to bring pressurized water to each farm and another $3,750/ha (on average) to equip it with drip irrigation.
- In Doukkala, farmers worried about having to reimburse the government 40% of the cost of the external infrastructure as stipulated by the law[17]. Apparently, there is a proposal to lower farmers' contribution to 20%.

[16] There were plans to equip two growers' cooperatives totaling 265 ha with drip irrigation in 2008.

[17] Based on the 'Code des Investissements Agricoles', agricultural producers are supposed to help pay for the irrigation infrastructure and associated services provided by ORMVAs in two ways: (1) water use fees (in effect), and (2) construction fees to recover 40% of the initial investment to build the irrigation infrastructure. The latter is payable over 17 years at 6% interest with a grace period of four years.

- Several of the concerns voiced at the meetings relate to farm size and ownership status. Indeed, around 80% of the farms in PIT are smaller than 5 ha partly because of the inheritance laws in Morocco which lead to numerous land subdivisions (Abdallaoui et al., 2003). Co-owners may not agree on land improvements or be able to get a loan (e.g., insufficient collateral).
- Water allocation and pricing was a major topic of discussion at the meetings. Some participants worried that their water allocation would be reduced if they switched to drip irrigation. Others wondered what would happen to the saved water, if any. Would it go to cities? One grower outside the pilot project area, who already uses drip irrigation extensively, suggested trading the water he saves with well water he could use on his dryland in the zone "bour". Other comments were,

  "The government should guarantee us a water allocation of 7,000 m^3/ha."

  "We should get something in return if we commit to this project."

  In Doukkala, where water shortages have been more severe than in PIT (in some years surface water allocation was as little as 2,000 m^3/ha), farmers thought they should have an advantage (e.g. get more water) over those who use less efficient irrigation systems. According to ORMVAD officials, this was not an option.

  > "Each farmer will get the same allocation at the head gate. Those who use drip irrigation would incur fewer losses and consequently produce more per hectare and may save on their water bill in some years."

  Kobry and Eliamani (2005) reported that for the 2003/2004 irrigation season, PIT farmers who adopted drip irrigation were allotted 7,400 m^3/ha but they did not specify whether farmers who did not have drip irrigation received a lesser amount.

  Another common question was,

  "Would water price go up as a result of this project?"

  No one knew! In 2008, the water use fee at PIT was \$0.03/m^3, of which \$0.0025/m^3 went to ABHOER[18]. Pumping costs were estimated at \$0.06/m^3 at the storage reservoir and \$0.10/m^3 at the well (Daoudi, 2008). In Doukkala, surface water fees ranged from \$0.03/m^3 for gravity-fed systems to \$0.06/m^3 for pressurized (sprinkler irrigation) systems. At least one ORMVAT technician advocated an increase in water fees to recover the cost of the pilot project and/or encourage farmers to conserve water and optimize its use. This may be in lieu of the 40% grower contribution mentioned earlier. There have been attempts to structure water fees so that farmers who "waste" water are penalized but this has not been applied due to accounting difficulties, water shortages or other reasons. Increasing water fees by any significant amount after completion of the pilot projects is, in my view, unlikely since so much hope rides on these projects for future expansion of drip irrigation.

- Other questions and concerns were:
  - Would the existing secondary and tertiary irrigation canals be kept or maintained? Unlikely!
  - Would I be able to irrigate the way I do now or can I switch back to my old system (e.g., flood irrigation) if I don't like drip irrigation? Probably not since at

[18] 'Agence du Bassin Hydraulique de l'Oum er R'bia'. Agencies at each of the main watersheds were created in the late 1990s and early 2000s to coordinate water allocation among the various users, conduct studies, monitor and encourage (e.g., by promoting water conservation and enforcing the laws) equitable, judicious, and sustainable use of water supplies. They are equivalent to the Water Conservation Districts in the USA.

least 70% of the farmers have to sign on to the project before it can be built. Moreover, maintaining the "old" infrastructure would be too expensive!

- How well would drip irrigation work for alfalfa, wheat, or barley? (Farmers do not like the prospect of having to move drip tubes often!) The cost may be higher since there would be more driplines but with proper design (e.g., adequate system capacity and spacing between driplines) drip irrigation should work just as well for solid-seeded crops as for fruit trees.
- Will water be available all the time? Yes, although there may not be enough water in some years to grow summer crops. Coordination among farmers within irrigation units/blocks will be essential to making the system work.
- What happens when water in the canal or the reservoirs gets dirty? Siltation and turbidity are a concern with the existing irrigation system but should be taken care of with adequate filtration upstream of the secondary (buried pipes) water delivery system. Additional filters will be placed at the farm level.
- What happens if everyone starts growing vegetable crops (e.g., tomatoes?) Farmers may have to adjust their cropping systems e.g., grow more high-value crops than in the past but selling them at a profit can be tricky. This is an important question that is beyond the scope of this report.
- Can I still use my well water after I switch to drip irrigation? Yes!
- Potential for breakage or theft of the drip irrigation equipment!
- Would there be fewer weeds (forage for my animals not just on my land but also along irrigation canals) if flood irrigation is eliminated? Probably!
- There ought to be more demonstration plots to show us how drip irrigation works and more control of agricultural products such as pesticides and drip irrigation equipment. Farmers are weary of false claims and products such as defective (wrong active ingredient or formulation) pesticides.

Water conservation and environmental considerations:

The government considers drip irrigation as the best hope to bridge the gap between water supply and demand in agriculture. PNEEI predicts significant water savings, which would come from reduced runoff and deep percolation compared to flood-irrigation. However, unless rainy seasons like the fall'08-winter'09 occur more often, the main advantage of drip irrigation would be the optimization of available water (produce more with less!). Chohin-Kuper et al. (listed by Petitguyot et al., 2005) reported that in several Mediterranean countries, the adoption of micro-irrigation decreased water consumption per unit area but not at the farm level since the "saved" water was used to irrigate more land.

In PIT, there may not be much room for expanding the irrigated hectarage, so the potential for water savings with drip irrigation is real (Petitguyot et al., 2005). One concern however, is the impact drip irrigation would have on groundwater recharge and use. Indeed, an increasing number of agricultural producers have been using groundwater to supplement their surface water allocation. Hammani et al. (2005) estimated the number of 'puits et forages' [19] in PIT at around 10,000. Groundwater use accelerated in the 1990s due to drought and generous government subsidies. The majority of the drip-irrigated farms in PIT have wells.

It is estimated that (flood) irrigation return flows account for 80% of the aquifer recharge in the plain of Tadla (Hammani and Kuper, 2008). Thus, the more flood-irrigated land is converted to drip

[19] Hammani et al. (2005) distinguished three types of wells: (1) 'Puits' which are ≤ 35-m deep and have a diameter of 1.4 to 3 m, (2) 'Puits-Forages' with depths ranging from 31 to 117 m (These appear to be the most common in PIT), and (3) 'Forages' which can reach 160 m in depth. The deep wells have small diameters and are more cost effective ($23/linear m) than 'puits' ($250/m on average).

irrigation, the less water would be returned to the river and its aquifers, which could result in further groundwater depletion, increased pumping costs and could trigger more restrictions on groundwater use [20]. Another concern is groundwater quality given the relatively elevated salt concentrations in some areas such as the Beni Amir (ORMVAT, 2008). Drip irrigation would reduce leaching of salts to the groundwater but can result in salt accumulation in the root zone over time (Berrada et al., 2006). This could be alleviated by mixing groundwater with surface water which is generally not as salty as groundwater (e.g., in Beni Amir) or by flushing out the salts occasionally with large water applications.

One hope (beside more enforcement of existing laws) for minimizing the potentially adverse effects of drip irrigation is by supplying surface water on-demand (e.g., for the so-called 'projets collectifs'), which would reduce the need for groundwater. Nonetheless, the current government policies (e.g., subsidies for irrigation improvement or extension) seem to favor property owners who have access to groundwater.

When designed and operated properly, drip irrigation will save water compared to other irrigation systems. Results by Bouazzama and Bahri (2007) indicate that this may not always be the case [21]. They surveyed 23 citrus orchards in 2002 and found that the ratio of irrigation amount versus water requirements was: 0.7 to 1.5 in 39% of the orchards, 1.6 to 2.3 in 48%, and 2.6 to 2.9 in 13%. The water applied ranged from 4,420 m^3 to 18,610 m^3/ha (all orchards) and produced on average 3.6 kg of oranges/m^3 (4 orchards). Citrus tree water requirements were estimated using Penman Monteith to calculate evapotranspiration (ET_0) which was then multiplied by crop coefficients borrowed from FAO's Irrigation and Drainage Paper No. 36 (Listed in Bouazzama, 2004). There are unsubstantiated reports that some growers irrigate their orchards for long periods of time e.g., until the soil around the tree is saturated, while others flood-irrigate the trees occasionally to make sure that water reaches most of the tree roots. Mature trees can experience water stress in the first few years after being exposed to drip irrigation (Bouazzama, 2004). The drip system should be designed accordingly so that enough water can be applied until the trees adjust to the new irrigation system (e.g., smaller wetted volume than with flood irrigation).

The design and operation of drip irrigation systems in Morocco have improved over the years due to, among other things, experience, generous government subsidies, which since 2002 have been tied to a rigorous review process; and possibly increased competition among drip irrigation services and supply companies. However, there is plenty of room for improvement! For example, Bouazzama and Bahri (2007) reported that 43% of the citrus orchards surveyed did not have soil or leaf test results on which to base their fertigation programs. Also, there did not seem to be much guidance in scheduling irrigations other than what the original design called for. Managing drip irrigation so that it produces the expected results (e.g., water conservation and an increase in crop yield and quality) requires experience and a departure from old habits (Burt and Styles, 1999) [22]. Well-to-do growers hire technicians, engineers, or consultants to run, manage, or guide their operations.

Research, demonstration, and outreach:

There are indications that several drip-irrigation related research and demonstration projects were conducted in the 1990s and early 2000s at PIT and other irrigated perimeters but the results are hard to come by. I visited PIT four times and Doukkala and Haouz once and I only saw one field

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[20] Laws to regulate groundwater use such as the requirement that users install flow meters at their wells and report the volume of water pumped have not been enforced. There are also indications that non-authorized excavations and use of well water still abound.

[21] Published reports or articles that document water savings with drip irrigation in Morocco are scarce or inaccessible.

[22] Unlike flood irrigation, drip irrigation requires frequent water applications (usually in small amounts); otherwise it would be difficult to catch up, i.e., meet crop water demand.

trial (at SEHA) whereby the test crop, sugar beets, was drip-irrigated. INRA's research center near Afourer appears to have the only consistent research program in the Oum er R'bia basin that addresses drip irrigation. A project started this season compares water use of alfalfa, berseem, and forage corn with drip (surface and sub-surface) and flood irrigation.

Subsurface drip irrigation or SDI, whereby the drip tapes are buried in the soil, is common in other parts of the world but does not seem to be practiced in Morocco or at least PIT. With SDI, drip tapes are usually buried 5 to 10 cm below ground for vegetable crops such as onions and cantaloupes, and 25 cm or more for field crops such as corn and alfalfa. Special tractor-mounted implements (e.g., injection shanks) are used to "inject" the drip tapes in the ground. Laser-guidance systems coupled with GPS are commonly used to keep the drip tape placement depth constant and record its location. The shallow-placed tapes may be replaced every 1-2 years while the deeper ones are usually kept in the ground for several years (e.g., over 18 years in on-going experiments at Colby, KS). With SDI, drip tapes should not interfere with field operations such as row cultivation. Another advantage is reduced water evaporation from the soil surface, the extent of which will vary depending on drip tape placement depth, irrigation depth (duration x flow rate), soil type, etc. With the proper design and irrigation scheduling, it is conceivable to be irrigating and performing some field operations (e.g., cutting or baling hay) at the same time. Adequate filtration and maintenance (e.g., flushing the driplines regularly and injecting acid to dissolve mineral deposits) will keep the system running for a long time. Leaks in the drip tapes can develop due to damage from tillage implements (e.g., if the drip tape is not deep enough) or from rodents and may be a challenge to fix. SDI would be ideal in Morocco for row crops such as corn and sugar beets and even solid-seeded crops such as alfalfa and wheat but would require more management skills than non-SDI systems. For example, growers would not have to move the drip tapes every time they need to plant or harvest a crop. SDI can be designed to accommodate several crops in rotation but research is needed to determine the optimum drip tape placement depth and lateral spacing, etc. More research and outreach are needed in Morocco to promote drip irrigation in general and address growers' concerns.

Other considerations:

ORMVA's ability to advise growers has diminished greatly due to reduced staff and more time spent on collecting data (e.g., ag statistics) and water fees, reviewing and approving subsidy requests, etc. For example, the unit at ORMVAT called "Bureau des Techniques d'Irrigation" had two technicians and one agronomist whose main mission was to promote efficient irrigation methods and technology. Instead, they spent most of their time processing subsidy requests for drip irrigation and making on-site visits to verify that the irrigation equipment and structures matched the approved project document. The head of BTI and two other engineers (the number varies from ORMVA to ORMVA) made up the technical committee that reviewed and approved the drip irrigation system design and investment cost. Additional ORMVAT staff can be mobilized to inspect the completed project, which adds checks and balances but complicates the approval process since there appears to be too many players and not enough coordination among them. Rigid requirements, top-heavy bureaucracy, staff reductions, and low morale put more strains on the system, especially since 2007 when the number of subsidy requests increased substantially. One committee member at an unnamed ORMVA said to me,

"There are not enough of us to review all the requests on time and do a good job of it. Of the requests I reviewed recently, only 10 to 20% were clean, meaning, they did not have problems such as faulty system design, excessive cost, or missing documents."

In the absence of accepted standards and references (e.g., yearly surveys of equipment prices), it is difficult for ORMVA's technicians to assess whether the costs listed in the subsidy requests are reasonable. Moreover, company fees are generally imbedded with other costs, which make it even harder to compare prices.

Conclusions and recommendations:

The 2008/2009 season brought much needed relief (in the form of snow and rain) to an otherwise bleak picture of meeting the demand for water in Morocco. Between 1994 and 2006, only 44% (on average) of the normal allocation for agricultural water was met nationally, due to drought and the increasing demand for Municipal and Industrial (M&I) water, among other factors. Nonetheless, agriculture still uses a large share (85%) of the available water and, by some accounts, "wastes" a good deal of it (Berrada, 2005). This is mainly because of inefficient flood-irrigation systems such as the 'Robta' that is predominant in the irrigated perimeters. Siltation of dams and aging infrastructure also contribute to water "waste".

To conserve water and optimize its usage – produce more with less, in other words – the government put forth an ambitious plan to deploy drip irrigation to about half of the total irrigated land by 2022. This would be achieved primarily through conversion of flood-irrigated land to modernized drip irrigated systems. The government provides a generous subsidy (up to $4,500/ha) to landowners who adopt this technology.

The estimated initial drip irrigation investment cost varied greatly among subsidy requests, which may be due to differences in land size, degree of sophistication or automation, crops grown, etc. There were no clear standards by which to compare prices, a lack of transparency (e.g., service fees are often embedded with materials costs) and possibly not enough warranties to ensure the system's longevity. Furthermore, there seemed to be little involvement of property owners in the design and installation of drip irrigation, which could negatively impact the system's cost and its operation and maintenance.

Nonetheless, the drip irrigation incentives program has made great strides, especially since 2007 when the subsidy was increased to 60% of the system's cost. Individual drip irrigation installations were on track to meet or exceed PNEEI targets, although the majority of these installations were for horticultural crops and appeared to benefit mostly medium and large landowners. Once most of the fruit orchards and vineyards for example are fitted with drip irrigation, the pace of adoption of this technology may slow down. Small farmers were generally not interested, not convinced, or not well informed about the advantages of drip irrigation (e.g., for cereal crops) or the subsidy program. They were less likely to secure loans to finance drip irrigation or even qualify for the subsidy. Furthermore, some structures such as water reservoirs may be cost prohibitive, unless they are shared by several farms or fields. There were reports of successful drip irrigation projects built by farmers' cooperatives in Souss Moussa and Moulouya but they represented a small fraction of the drip-irrigated hectarage in Morocco. These collaborative projects will be expanded considerably under PNEEI, to reach 218,000 ha by 2022.

Pilot projects currently under consideration would cut costs by taking advantage of free energy (PIT) or existing pumping stations (Doukkala). The government will build the infrastructure to bring pressurized (and filtered) water to the individual farms if enough property owners (≥70%) commit to installing drip irrigation on their properties. Participating farmers will be supplied surface water on-demand, which would reduce the need for groundwater, and may receive extra benefits or incentives beyond what the government currently offers to individual landowners. Challenges include the ability of small farmers to finance such projects, the feasibility of drip irrigation for low-value crops (e.g., wheat and barley), and marketing of vegetable and other high-value crops. Potential solutions proposed by various entities include the creation of a fund to guarantee loans for needy farmers or an increase in subsidy (e.g., to 80% of the initial investment cost) to farmers who participate in collective projects. I do not have enough details or expertise to assess these proposals (The 'Fond de Garantie' seems like a good idea!) but in my view, instead of increasing the subsidy, which is already substantial (e.g., in the US, typical drip irrigation installation with no water reservoir costs around $ 2,500/ha), the government should consider the following:

- Tie the subsidy amount to the drip-irrigation project's real cost and potential benefits. For example, the greater the hectarage to be equipped with drip irrigation, the lower the cost per acre and amount of subsidy per acre should be. However, some design companies or property owners may have a tendency to inflate the investment costs to secure the maximum subsidy allowed (e.g., $4,500/ha). Measures that can be taken to minimize abuses include,
    - Require the companies that design or install drip irrigation systems to report their fees separately from that of the equipment and other costs.
    - MADRPM (e.g., DPAE) should compile lists of drip irrigation equipment and their prices and update them at least once a year. These lists should be available to ORMVA and DPA technicians who review subsidy requests, and to property owners.
    - Standards should be developed and updated regularly. These should include minimum requirements and typical drip irrigation systems and their investment costs (average and range).
- Set a ceiling on the total amount of subsidies a property owner can receive in a given period of time (e.g. three to five years) to reduce inequities in the system. There is a range of subsidies offered to agricultural producers but not everyone knows about or benefits from them. This should be addressed through targeted advertising and information dissemination.

The drip irrigation subsidy program has had many benefits: water conservation, job creation, build up of skills and experience, and added value at the industry and farm levels. Water conservation at the field level is undeniable! Indeed, when designed and operated properly, drip irrigation will save around 40% water compared to flood irrigation. Proof that drip irrigation has resulted (or will result) in significant water savings at the farm, watershed, or national levels is hard to come by. Moreover, current research and outreach efforts do not match the enthusiasm and intensity with which Morocco is pursuing the goals set in PNEEI. Most of the basic information about drip irrigation comes from overseas, which is fine (why reinvent the wheel?) but there are specific needs that should be addressed. These include:

- Realistic estimates of drip irrigation efficiency and best management practices (BMPs) to maximize it. For example, most drip irrigation designs I examined were based on an efficiency of 90%, which may be too high for non-SDI systems since evaporation can be substantial during hot, dry, or windy periods.
- Develop crop coefficients for the major crops and climatic zones in Morocco. Most current estimates seem to come from FAO publications.
- Develop systems that are adapted to small farms/fields e.g., that offer flexibility and portability e.g., use layflat instead of buried PVC pipes!
- Develop simple monitoring tools for scheduling irrigation.
- Determine efficient and cost-effective fertigation programs and management tools.
- Develop design criteria (drip tape wall thickness, flow rate, placement depth and spacing, maintenance, etc.) adapted to the main non-tree crops and develop BMPs for SDI.
- Develop simple implements to bury the drip tapes, etc.
- Monitor salt accumulation under drip (e.g., in areas with relatively high salt concentrations) and develop BMPs to alleviate it.
- Develop strategies to address water shortages.
- Conduct regular surveys (e.g., every three to five years) to assess existing drip irrigation installations and their management.

There appeared to be plenty of competence for designing drip irrigation systems but not enough follow-up and outreach to assist farmers in managing these systems properly. The government should develop centers of excellence in research and education relating to drip irrigation. One center with promising research on drip irrigation is INRA's regional center in Tadla. In addition to research, regular outreach programs should be organized to enhance growers' knowledge of drip irrigation design, installation, and operation. Private companies play an important role in information dissemination but should not be a substitute for targeted government-sponsored programs in research and education.

The subsidy review process has helped build valuable experience and avoid costly mistakes in the design and installation of drip irrigation systems. However, the procedure is still cumbersome even though it was simplified and streamlined in 2008. Furthermore, the number of requests has increased substantially since 2007 with no matching increase in the number or quality of staff that process these requests. Potential solutions to unclog the system include:

- Computerize the system as much as possible and enhance communication among the interested parties (e.g., within and between ORMVA and CRCA) to speed up the process.
- Divide up the workload among the technical review committee members fairly.
- Only one or two people (e.g., one from BTI and one from Committee Technique) should inspect and certify the project's completion. Trying to assemble several (4-5) bureaucrats to accomplish this task can be challenging!
- Delegate more responsibility to field agents (e.g., at the CDA and 'Arrondissement' levels) for the early inspection of the system installation e.g., to verify pipe and water reservoir sizes.
- Require the subsidy applicant to only provide the essential information (e.g., water supply, system capacity, and a detailed diagram showing the system's layout and main features) needed to judge if the system is sound. Detailed equipment lists and the details of how flow rates, pump capacity, etc. were arrived at should not be required!
- Reduce the number of signatures required to approve the project or certify its completion. The signatures of the head of Guichet Unique and the head of BTI or their designees should suffice.
- Basic design criteria and methods should be made available to property owners, consultants, and the public in general via workshops, publications (e.g., fact sheets), and the Internet.

Drip irrigation is not a panacea but may be the best hope to conserve water and enhance agricultural productivity and sustainability. It may not work for every situation, thus it is prudent to continue efforts to improve existing irrigation methods. Similarly, it is prudent to start small (e.g., pilot projects) before investing too much in collective projects for these present formidable challenges. More importantly, property owners' and growers' associations should (be allowed and encouraged to) assume more responsibility in the design, installation, and management of drip irrigation projects. Growers' associations can play critical roles in promoting drip irrigation, guiding members in their choice of consultants and equipment, and securing funds. ORMVA's technicians or engineers could be 'loaned' to these associations (for large projects) to provide technical support.

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APPENDIX

Example of information included in the drip irrigation subsidy request[24]

1. **Basic information**

   a. **Geographic location of the property (farm/field) to be equipped with drip irrigation**

      i. Owner and property designation/name
      ii. Property location and how to get to it
      iii. Property's size (ha) and number of hectares under cultivation (cropland)
      iv. Is the property part of a government-sponsored irrigation perimeter/project? If so, how many hectares are allotted water from the project?

   b. **Soil and climatic data**

      The climate of the region where the property is located is characterized by[25]:

      - A low and erratic precipitation (240 mm/yr on average)
      - High summer temperatures (Average maximum temperature of 37°C)
      - Moderate to low winter temperatures (Average minimum temperature of 4°C)
      - Vey high evaporation (2,400 mm/yr)
      - Low (!) humidity: 70% in January and 40% in August

      The property's dominant soil type is: ________________________ (Specify). Attach available soil test results and/or specify soil texture, salinity, alkalinity, and pH.

      - Describe the property's layout (e.g., undulating terrain, % slope, etc.). Attach topographic map if available.

   c. **Available water resources**

      i. Water allocation per hectare and availability. Also how often do you get water and for how long?

      ii. Groundwater

         1. Existing wells and their characteristics:

            a. Total, hydrostatic, and hydrodynamic depths
            b. Well capacity and flow rate
            c. Water quality: pH, TDS, salinity, etc. Attach results of recent water analysis if available.

   d. Existing irrigation equipment and structures:
      i. Pumping station: Type, brand, horse power, etc.
      ii. Shelter: Size/dimensions
      iii. Water storage reservoir: Dimensions and storage capacity
      iv. Irrigation system (sprinkler or drip irrigation) and irrigated area (ha)

   e. Current cropping system
      i. Crops grown and hectarage
         1. Fruit trees: Species, spacing, age, and hectarage
         2. Intercrops: Species and hectarage

[24]This was translated by the author from an ORMVAH document written in French and entitled "DOSSIER DE DEMANDE DE SUBVENTIONS DES EQUIPEMENTS D'IRRIGATION LOCALISEE--Modèle de dossier technique". Some content was edited.
[25] The information given under (b) is specific to ORMVAH's geographic area.

3. Other: Species and hectarage

f. Current irrigation systems and their management

2. Drip irrigation project

a. Purpose

i. Crops and area (ha) to be equipped with drip irrigation

ii. Main project components: New and existing wells, pumping stations, shelters, storage reservoirs, irrigation pipes/conduits, etc.

b. Crop water requirements

Crop ET, ET_c (mm) = K_c x ET_0 where,

K_c is the crop coefficient for a given growth stage

ET_0 is the reference evapotranspiration (ET) in mm

Specify:

- Whole season water requirement for each crop
- Peak ET_c, daily and for the month with the highest ET_c
- Detailed accounting of how crop water requirements will be satisfied

3. Detailed description (type, technical specs, etc.) and listing of drip irrigation system components

a. Water distribution system (main, submain, and lateral)
b. Control valves
c. Air relief and/or pressure relief valves
d. Irrigation zones
e. Head station:
  i. Pumps
  ii. Filtration equipment
  iii. Injection equipment
  iv. Automation
  v. Other
f. Shelters
g. Water storage reservoirs
h. Other

Attach the results of equipment performance tests [26]

4. Hydraulic assessment of the drip irrigation installation

a. Divide the irrigated area into sections or zones: Reiterate the reason for dividing the project area into zones. Each irrigation zone is generally controlled by one valve. *It is important to have at least two zones, in anticipation of potential water shortages after project completion. Each zone can be operated separately or concurrently, depending on water availability.*

b. List the irrigation sections and blocs and their characteristics as shown in the table below:

[26] PVC pipes, drip tapes, etc. are to be tested by a certified laboratory.

Irrigation section no.	Blocs within each section	Number of ha	Number of trees (if orchard)	Flow rate (l/h)	Number of drip tubes	Tubing length (m)	Length of submain (m)	Notes

c. Determination of drip tubing diameter and flow rate

- Use the Christiansen rule within each irrigation zone: $\Delta Q/Q < 10\%$

  Q: Nominal emitter flow rate

  ΔQ: Variation of flow rate between emitters

- Use Blasius formula to calculate losses in water pressure:

  $J = 0.174 \times Q^{1.75} \times D^{-4.75} \times 1.1$

  Where,

  J: Pressure loss in m/m (increased by 10% to take into account 'singular' pressure losses)

  Q: Inlet flow rate in l/h

  D: Inside diameter in mm

- Show the results in a table format.

d. Main water conduit

- $0.5 < V < 2$ m/s (V : water velocity in m/s)
- Economic (inside) diameter: Deco = $Q^{1/2}$ with Q in m^3/s
- Use the Blasius formula above to calculate pressure loss
- Show the results in a table format

e. Pumping station

i. Flow rate

ii. Total Dynamic Head—Use the formula:

HTM $= P_{SD}+J_R+J_{PR}+J_{ST}+J_{CA}+J_{SP}+Hg+\Delta P$ where,

HMT : 'Hauteur manométrique totale' or total head, in m CE

P_{SD} : Required water pressure at the emitter

J_R+J_{PR} : Friction (pressure) loss in the submain and laterals in the least favorable bloc

J_{ST} : Pressure loss at the head station

J_{CA} : Total friction (pressure) loss in the water conduit for the farthest bloc

J_{SP} : Pressure (head) loss at the pump

Hg : Pumping depth—'Niveau hydrodynamique de l'eau'

ΔP : Elevation difference between the well and the emitter with the least pressure ('distributeur le plus défavorisé').

Make sure that new or existing pumping stations have enough power (lift) and capacity (flow rate) to meet the drip irrigation system requirements.

f. Shelter dimensions: Shelters must have enough space to house the head station equipment

g. Water storage reservoirs: Specify the reservoir capacity and calculation method.

5. System installation diagram

Show the system's installation diagram at the 1/2,000 to 1/1,000 scale and a map of the whole farm.

6. Cost estimates/quotes

List the costs of all the project (system) components and specify who (private company, property owner, etc.) would install/build what.