Modelling irrigation scheduling to analyse water management at farm level, during water shortages

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Abstract

The area under irrigated corn has significantly increased in the Charente river basin during the last 10 years. Corn water requirements are maximum in the summer, the period with low water flows and highest environmental vulnerability. Periods of water shortage during which irrigation is temporarily forbidden occur frequently. To reduce water demand, specific water saving policies are required. This paper investigates irrigation management strategies at farm level during water shortages. A computer programme called IRMA is used to represent the farmer’s decision making process. The model was calibrated and validated using information collected through a detailed monitoring of irrigation and farming practices of three representative farms during two irrigation seasons. The accuracy of the model was good; the difference between measured and simulated cumulative water volume used was slightly less than 8.5%. Analysis of daily simulated water demand shows that farmers have adopted different strategies to deal with water shortages, depending on the physical and socio-economic characteristics of their farms. The application presented in this paper stresses the potential of the proposed approach, if used on a larger farm sample, to compare the expected impact of different water management policies on water demand and irrigation practices at the farm level. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Corn, Farm level, France, Irrigation scheduling, Modelling, Water demand

1. Introduction

In the Charente river basin, located in the central-western part of France, a total area of 8500 ha is irrigated with water drawn from the river and corn is grown in 90% of this area. Most of the 275 irrigated farms get water from small pumping stations which feed one to three farms each. Irrigation is on demand. Out of the 105 × 10^6 m^3 of water drawn annually in the Charente District1, the irrigation sector consumes the bulk of the 60 Mm^3 consumed during the period of low water flow and competes severely with the other sectors, such as domestic and industrial water use and leisure, as well as affecting aquatic life in the river.

In one year out of five, the total volume available for the irrigation season is below the 2000 m^3/ha required to meet 85% of crop needs at maximum evapotranspiration (MET). During water shortages, irrigation is partially restricted.
Pumping is temporarily forbidden, from one to seven days per week, depending on river flow levels. The days of the week when irrigation is forbidden also vary according to the location along the river in order to spread the demand for water between water users as evenly as possible.

The construction of a new reservoir on the Charente river is under way. However, the total water demand will still exceed the total available resource stored by this dam and short periods of water shortage are still likely to occur during the irrigation season. As no additional dams will be built and as new resources cannot be developed, the water crisis can only be solved by reducing the demand for irrigation during the summer, through water saving policies, such as water pricing or quota systems. The impact of such policies on cropping pattern and seasonal water use has already been analysed using micro-economic models (Montginoul et al., 1997). However, the seasonal time-step used in these models is too large to assess the impact of these policies on the daily organisation of irrigation events and the effective demand for water during shortage periods.

This paper presents a new approach which can be used to estimate the temporal distribution of the demand for irrigation water within the season and which assesses the impact of specific water saving policies on this demand. The approach is based on a day to day analysis and modelling of farmers’ irrigation decisions and practices. The results were obtained for three selected farmers facing irrigation restrictions. The characteristics of the water demand assessed are compared with a more classical soil–water balance approach, applied at the field level to estimate irrigation water requirements.

2. Methodology

2.1. General concepts

In this approach, we assume that farmers’ decisions related to irrigation result from two levels of decision. The first level concerns choice of strategy, which consists of long and medium term decisions related to the structure of the farm; the second level of decision covers implementation choices, defined as the sequence of actions taken to implement the strategy and to achieve production objectives.

- **A production strategy** is defined by: (i) the overall production objectives (for instance to achieve a certain yield while minimising risk); (ii) the acquisition of know-how and the choice of areas of specialisation (decisions related to crop specialisation); and (iii) the decisions which affect the structural characteristics of the farm (investment decisions).
- **The implementation tactic** is the translation of the production strategy into sub-objectives, decision rules and indicators for action (Girard et al., 1994). The implementation tactic defines how the production system will be managed during one cropping season, taking into account the variability of the environment (climate, water resource availability).

In this paper, we focus on the representation of farmers’ implementation tactics. The model presented below attempts to represent the sequence of decisions taken by farmers during one cropping season to implement the strategic choice and to achieve their production objectives.

Farmers’ implementation tactics rely upon a simplified representation of the complex system they operate.

- **Farmers** have a provisional schedule that divides the year into finalised periods and defines the sequence of operations to be conducted during each of these periods (e.g. a water turn between irrigated fields).
- **Just as time is divided into finalised periods, space is divided into areas with specific production objectives** (i.e. irrigation management units, for example).

In addition, farmers have a set of adaptive rules that are used on a daily basis, depending on farm indicators. An acceptable degree of flexibility is kept for unpredictable events (climate, resource shortage, breakdowns, etc.). This flexibility is translated into a set of rules for daily irrigation decision making (Réau, 1993; Balas and Deumier, 1993; Leroy and Jacquin, 1994). The management logic is based on synchrony (rules for choosing between fields and crops) and
2.2. Structure of the model

The model consists of three components (Fig. 1): (I) the decision context which describes farm characteristics; (II) the decision model which consists of a set of rules; and (III) the simulator engine which reproduces the decision sequence of the farmer. The model takes as input climatic scenario and gives as output an irrigation schedule for all the plots of the farm. The irrigation schedule is used by an agro-economic sub-model to assess the yields and margins obtained. The model is specified for each farm. This model is implemented using the IRMA software developed by Leroy et al. (1996).

The variables describing the decision context are based upon medium and long term farmers’ decisions, concerning conditions required to achieve general objectives:

- water resources — seasonal irrigation volume, flow rate and its evolution through the season;
- irrigation network — a succession of pipes, their capacity and connections to water resources;
- one or several general objectives that define the final goal towards which farmers’ decisions converge (for example, to achieve a target yield on irrigated crops);
- a provisional schedule that set key moments when the farm status is assessed and compared with intermediate objectives, using specific indicators (for example, vegetative state or soil condition);
- a set of rules that defines, for each finalised period, the type of decisions to be made under specific conditions, and a set of substitute solutions when expected goals cannot be achieved.

![Fig. 1. Structure of the IRMA software (adapted from Leroy et al., 1996).](image-url)
• irrigation equipment — type, flow rate, time needed to move it;
• labour — number of available hours per day;
• fields — area, soil, seasonal cropping pattern (crop and planting date), type and number of irrigation sets;
• irrigation blocks — bundling fields depending on a given flow availability influenced by water delivery constraints within the farm (water resource, equipment).

The decision model consists of all the rules used by the farmer to implement irrigation, which can be classified into four categories.

1. Rules to define irrigation units, in order to simplify irrigation scheduling, for a given irrigation campaign.

2. Irrigation blocks are shared between irrigation management units, i.e. aggregating fields with the same crop, irrigated in a certain sequence with the same equipment, with a specific order of priority during a water turn within the farm (often 7 and sometimes 10 days in the cases studied).

3. Fields are divided into irrigation positions depending on the type of watering equipment used (sets of irrigation sprinklers watering simultaneously, lane spacing for a movable rain-gun, sectors watered by a central pivot, etc.).

4. Irrigation blocks are shared between irrigation units.

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Fig. 2 presents an example of a sample farm which consists of two blocks, divided into several irrigation units.

1. Rules for starting irrigation are described per crop. These rules are applied separately for each irrigation management unit. They are either recursive [AS LONG AS (condition 1 is true), IF (condition 2 is true) THEN (irrigate)], or simultaneous [AS SOON AS (condition 1 is true) THEN (irrigate)]. Irrigation is defined either as an applied depth or as an irrigation duration. Indicators used in 'conditions' are functions of climate (rainfall, temperature, ETP, wind), soil (ASW), crop (development stage, water stress), water resource
(volume already used, volume remaining), and calendar (irrigation frequency, date).

(iii) Rules to split the season into finalised periods. Rules for changing from one period to the next are functions of calendar dates, or the first irrigation of a given irrigation unit. For each period, the sequence in which irrigation management units are irrigated is described as well as the rule in the case of rainfall and labour availability. Sequence defines priorities between fields.

(iv) Rules in case of rainfall are described, i.e. the amount of rainfall required to stop an irrigation session, and the number of days for which irrigation is postponed.

The simulator uses the variables of the decision context and the rules of the decision model to mimic the farmer’s decision making process concerning irrigation. A timetable is computed for each watering machine with a time step of 15 min. The irrigation schedule is given per day. Taking this irrigation schedule as an input, the agronomic sub-model assesses some indicators related to the crop status and the expected yield for every field. It is a classic water balance model coupled to a crop yield function.

- The soil is viewed as a reservoir characterised by a maximum available water storage (MAWS). MET is estimated from crop coefficient k depending on development stages of the crop and reference Penman evaporation (ET).
- Actual evapotranspiration (AET) is parameterised by the empirical function of Baier (1969). This relates AET to MET depending on the actual soil water content in the reservoir. When it becomes lower than an AET threshold value, it is reduced beneath MET. Drainage estimation is based on the filling of the reservoir, in relation to MAWS but without upward movement caused by capillary rise.
- The simulation of the development stages of the crop is obtained from threshold values of thermal time (TT) calculated from cumulative mean daily temperature over a base temperature as in Sepaskhah and Ilampour (1995). The yield is estimated by a relative yield, \( Y_Y / Y_m \), ratio of respectively obtained yield and maximum yield for a crop conducted at MET. It is a linear empirical function of the ratio of cumulative AET and MET during the sensitive period of water stress derived from Doorebos and Kassam (1987), with local calibration.

The water demand estimated with the IRMA model is then compared with demand assessed by a soil and water balance model used at field level (The PILOTE model) developed by Mailhol et al. (1997). This model is based on LAI simulation and considers three separate storage capacities along the soil profile, but does not take into account farm strategies and implementation constraints. It has been calibrated for corn (unpublished data).

3. Construction of the model

3.1. Data collection

Using information collected through a preliminary survey of 30 farmers (10% sample), five distinct types of farmer with different irrigation strategies were identified. They are characterised in Table 1. All the farms grow corn, but the importance of other crops and livestock activities varies from one farm to another. The main factors that explain the different types of irrigation practice are the land holding size and its ratio to the irrigated area, irrigation equipment, economic dependency on irrigated crops and farmer’s educational level (Chazalon, 1995). Based on this analysis, samples of three farms in 1996 and seven in 1997 were selected to monitor irrigation practices during the whole irrigation campaign. The cases of three of them with contrasting characteristics are presented here: a diversified cereal grower (G1), an intensive corn grower (G2), and a cattle breeder for whom irrigation remains a secondary activity (G4).

Detailed interviews on irrigation scheduling at the tactical level have been undertaken for each farmer to build their action model. More specifically, the interviews were based on:

- a field map, to define the irrigation management units according to the availability of water and labour resources, the irrigation equipment, and the type of crops;
- a calendar to define the predefined schedule of
Table 1

General characteristics of each farm type in the irrigated area (from a survey in 1995)

<table>
<thead>
<tr>
<th>G1: diversified cereal grower</th>
<th>G2: specialised grower with an accurate strategy</th>
<th>G3: intensive corn grower</th>
<th>G4: breeder or small cereal grower</th>
<th>G5: diversified vine grower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface cultivated (ha)</td>
<td>125</td>
<td>140</td>
<td>105</td>
<td>80</td>
</tr>
<tr>
<td>Main irrigated crops (%)</td>
<td>R: 4%</td>
<td>R: 65%</td>
<td>R: 95%</td>
<td>R: 90%</td>
</tr>
<tr>
<td>Equipment (%)</td>
<td>R: 65%</td>
<td>R: 47%</td>
<td>R: 74%</td>
<td>R: 6%</td>
</tr>
<tr>
<td>Farmer age and initial formation level</td>
<td>58–68 years, low</td>
<td>35–50 years, medium</td>
<td>40–55 years, medium/low</td>
<td>25–35 years, medium</td>
</tr>
<tr>
<td>Economic impact of irrigated crop</td>
<td>medium high</td>
<td>high</td>
<td>medium/low</td>
<td>medium</td>
</tr>
</tbody>
</table>

* Mean value of the surface for the class.

A second series of interviews was conducted before the irrigation season in 1997, to identify possible changes in the decision context (i.e. the cropping pattern or irrigation equipment) that would require a change in the action model developed with the 1996 information. Then, the calendar of irrigation events and the volume consumed for the different management units were collected during the 1997 irrigation season. This information was used to validate the model.

The approach was used for two contrasting climatic contexts (1996 and 1997), compared with the average situation (see Table 2). The climatic context in 1996 was rather dry, and irrigation started in mid-June. On the other hand, 1997 was a rather wet year, and the rains in June postponed the beginning of the irrigation season to mid-July. In 1996, the arid conditions led to very low flows in the river and compulsory irrigation bans: two days per week from mid-June to the beginning of July, three days per week in July, and finally five days per week in August. In 1997, the high rainfall, late start of the irrigation season and releases from the dam limited the irrigation bans to one day per week (normal conditions for that time of year) till the end of July, when the bans were extended to two days per week.

3.2 Building the action model of sample farmers

Table 3 presents the decision context and the main decision rules for each sample farmer. Irrigated areas of the farms are spatially organised into one or two blocks that are composed of one to three management units depending on the irrigation equipment used and the water turn plan.

An indicator is computed for each farmer to estimate the level of irrigation constraint at the farm. This indicator is equal to the lowest of the following two ratios: the pump flow rate over the cultivated area, and the watering machine flow rate over the cultivated area.
Table 2
Climatic context, total depths from 1st April to 30th September

<table>
<thead>
<tr>
<th>Rain (mm)</th>
<th>Penman evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>259</td>
<td>438</td>
</tr>
</tbody>
</table>

Table 3
Characteristics of studied cases

<table>
<thead>
<tr>
<th>Blocks</th>
<th>Farmer 1</th>
<th>Farmer 2</th>
<th>Farmer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>Block 1</td>
<td>Block 2</td>
<td>Block 1</td>
</tr>
<tr>
<td>Decision context</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated area (ha)</td>
<td>32</td>
<td>15.4</td>
<td>29</td>
</tr>
<tr>
<td>Pumps (m³/h)</td>
<td>86</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>solid set (4 ha)</td>
<td>raingun (40 m³/h)</td>
<td>raingun (60 m³/h)</td>
</tr>
<tr>
<td>Constraint (m³/h/ha)</td>
<td>2.8</td>
<td>3.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Corn earliness</td>
<td>early</td>
<td>early</td>
<td>early and late</td>
</tr>
<tr>
<td>Decision model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal irrigation period</td>
<td>day and night</td>
<td>night (energy saving)</td>
<td>day and night</td>
</tr>
<tr>
<td>Management units definition</td>
<td>Unit 1: pivot</td>
<td>single unit; seven positions</td>
<td>Unit 1: raingun; seven positions</td>
</tr>
<tr>
<td>Unit 2: solid set</td>
<td>1 position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation scheduling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>first stress</td>
<td>8/10 leaves</td>
<td>2nd September</td>
</tr>
<tr>
<td>End</td>
<td>first water stress</td>
<td>8/10 leaves</td>
<td>2nd September</td>
</tr>
<tr>
<td>Irrigation depth (mm)</td>
<td>30</td>
<td>30–44</td>
<td>30–40</td>
</tr>
<tr>
<td>Normal duration of water turn (days)</td>
<td>7</td>
<td>7</td>
<td>1/10</td>
</tr>
<tr>
<td>Waiting after rain (day/mm)</td>
<td>1/5</td>
<td>1/5</td>
<td>1/10</td>
</tr>
<tr>
<td>Threshold rain (mm)</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Adaptations to ban of irrigations: 2 days/week</td>
<td>none</td>
<td>none</td>
<td>delay</td>
</tr>
<tr>
<td>3 days/week</td>
<td>none</td>
<td>watering night and day</td>
<td>delay</td>
</tr>
<tr>
<td>5 days/week</td>
<td>delay</td>
<td>watering night and day</td>
<td>missing out high MAWS fields</td>
</tr>
<tr>
<td>Strategy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance of irrigation</td>
<td>middle, diversified cereal grower</td>
<td>low, mainly stock breeder</td>
<td>high, main activity</td>
</tr>
<tr>
<td>Ratio: irrigated area/total area (%)</td>
<td>46</td>
<td>16</td>
<td>65</td>
</tr>
<tr>
<td>Objective corn yield (t/ha)</td>
<td>11.5</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

* Maximum available soil water.
Farmer 1 has the highest value for this indicator, i.e. 3.9 m$^3$/h/ha for the block irrigated by a raingun, and a lower value for the second block. However, the second block is irrigated by fixed irrigation equipment with greater flexibility and has the highest soil retention capacity. The mean value for the whole farm is 3.2 m$^3$/h/ha. As a result, satisfactory adaptability to the rainfall and irrigation bans is obtained, that leads to high corn yields despite the fact that corn cultivation is not the main activity of this sample farmer.

Despite adequate irrigation equipment, the indicator is lower for Farmer 2, due to a limited pumping capacity. With values of soil retention capacity between those of Farmer 1 and Farmer 3, and because of the secondary nature of irrigation on the farm, this farmer can afford to forego irrigation sessions for some fields if strict irrigation watering bans are in place. Also, in the case of water shortage, low priority is given to irrigation of areas under corn used for silage.

Farmer 3 has the most constraints from an irrigation point of view, as expressed by the low value of the indicator. The capacity of the irrigation equipment and pumping station is limited and only sufficient for the organisation of water turns during periods without shortage and bans. Also, the soil is rather shallow with a poor retention capacity. Thus, the only available option to adapt to irrigation bans is to delay water turns.

4. Results and discussion

4.1. Prediction of the irrigation calendar

For the blocks irrigated either by a raingun or by a solid set system, each water turn can be defined by a position or a sub-portion of the field irrigated during the irrigation event which lasts from 8 to 10 h. For the central pivot of Farmer 1, the irrigation calendar for any given location within the field is defined as the dates the sprinklers pass over this location. The predicted irrigation schedule was compared with the real irrigation dates.

Whatever the block and the equipment, the
Table 4
Calibration and validation results of IRMA on supplied volumes

<table>
<thead>
<tr>
<th></th>
<th>Calibration 1996</th>
<th>Validation 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean relative error (%)</td>
<td>Final error</td>
</tr>
<tr>
<td>Farmer 1, central pivot</td>
<td>13 %</td>
<td>*</td>
</tr>
<tr>
<td>Farmer 1, raingun</td>
<td>6.8 %</td>
<td>4.8</td>
</tr>
<tr>
<td>Farmer 2</td>
<td>7.1 %</td>
<td>8</td>
</tr>
<tr>
<td>Farmer 3</td>
<td>6.8 %</td>
<td>8.5</td>
</tr>
</tbody>
</table>

* The final measurement of this meter was not available.

The error between predicted and actual irrigation dates for the central pivot is one day on average for rainguns and solid set systems. It is 1.5 days for the central pivot system, as this equipment provides greater flexibility.

Some inaccuracies are due to unscheduled decisions. For instance, on June 19, Farmer 1 has irrigated two positions of Block 1 instead of one. IRMA takes into account the rain of June 21 and delays the fifth position, whereas the farmer delayed the sixth position (Fig. 3).

The gap between predicted and actual irrigation dates does not increase over time, because farmers repeatedly try to apply the predefined set of rules that has been used to calibrate the model. For example, Farmer 1 delays irrigation more than expected after the July 1 rainfall and the irrigation bans of July 3 and 4. However, the gap between predicted and real dates is greatly reduced two weeks later (Fig. 3).

4.2. Prediction of supplied volumes

Predicted volumes were compared with measured volumes delivered to each farm by pumping stations. Table 4 presents the results of calibration and validation with regard to volumes applied to irrigated fields.

The mean relative error was used to assess the ability of the model to simulate volumes supplied throughout the entire season. For 1996, the discrepancies remained below 7% for Farmer 2, Farmer 3 and for the raingun block of Farmer 1. The higher value for the central pivot of Farmer 1 (13%) is due to the high level of flexibility afforded by the central pivot system already mentioned above, thus making the decision rules more difficult to establish. For 1997, the errors are lower, as a result of the lower water shortage and reduction in the number of irrigation bans. The error in the total volume remains below 8.5% for 1996 and below 6.7% for 1997. Relating to the area irrigated and expressed in water depth (mm), the errors are smaller than the depth provided by a single irrigation position.

The simulation with the IRMA model provides an accurate aggregated demand for water on the farm for the season. Also, it computes the water demand for different time-steps. The accuracy of the model remains very good for time-steps of the same order of magnitude as the duration of a water turn, but decreases as the time-step is shortened.

4.3. Assessment of pumping at daily time-steps in water shortage periods

Because irrigation is banned on Sundays throughout the entire season, farmers spread their demand over the other days of the week. A reduction in the number of days when irrigation is authorised is expected to lead to adaptations of the irrigation scheduling. The time-step considered in the IRMA model allows an assessment of the
effect of irrigation bans on the demand for irrigation water.

Fig. 4 presents the daily water demand of the raingun block of Farmer 1 as predicted by the IRMA model. Under normal conditions, i.e. up to a weekly two day irrigation ban, the farmer can afford to rely on night irrigation only (water turns T1 and T2), and is irrigating at half his potential of 50 m³/ha/day. From July 7 onwards, irrigation is banned three days per week. Although the rainfall delays the adaptation of the irrigation schedule, irrigation is performed during three days (July 15, July 19 and July 22) to keep a constant duration of the water turns. To deal with the irrigation bans, the farmer intensifies the use of his irrigation equipment to maintain the same duration of water turns. As stressed in Fig. 4, T1, T2, T5 and T6 have an equivalent duration, while T3 and T4 have a shorter duration as there was no rainfall during these periods.

Similarly, Fig. 5 presents the demand for water of Farmer 3, with an equipment constraint of 2 m³/h/ha as compared with 3.9 m³/h/ha for the raingun of Farmer 1. Since the beginning of the irrigation season, Farmer 3 uses his equipment to its full capacity, and when irrigation ban periods occur, he cannot increase watering time during authorized days of irrigation. The only alternative available to deal with the restrictions is to delay water turns. As a result, the daily water draw demand of Farmer 3 presents a much lower variability over time than those modelled for Farmer 1. Four kinds of scheduling adaptation can be identified.

- The water turn is extended timewise, and the irrigation of one or more positions is delayed. This simple option is better suited to restrictions of short duration and good soils. However, it may be the only option available to the most constrained farmers.
- The equipment can be used more intensively, to avoid delaying the irrigation schedule and water stress.
- The irrigation depth can be reduced in all fields or for fields with deep soil. This adaptation is rarely implemented as it requires some adjustments of the irrigation equipment itself and modification in the irrigation timetable.
- Some fields or irrigation positions could be skipped, especially for fields with good soil storage capacity or when the final corn yield is of secondary importance because corn is used.

Fig. 4. Impact of bans on daily demand (Farmer 1, Block 2, year 1996).
as silage (see Farmer 2). This adaptation is more likely to be implemented late in the season once the period of highest stress sensitivity is over. Lengthening the water turn, reducing the irrigation depth or skipping irrigation sessions for some fields lead to water saving. However, increasing the use of the irrigation equipment, the option selected by Farmer 1, does not reduce the demand for irrigation water. It only transfers the demand to the authorised days. This kind of adaptation is justified as the irrigation scheduling already based on saving does not allow any reduction of supply without causing water stress events. Systematic overuse of equipment is then to be expected when faced with temporary irrigation bans.

4.4. Comparison between IRMA and PILOTE

Fig. 6 compares the water demands defined by the farmer and predicted with the IRMA model and the crop demand predicted with the water balance model PILOTE for the raingun block of Farmer 1. Overall, the water balance model over-predicted by 42% the water demand for the entire season. This overestimation is mainly due to an overprediction of the demand for irrigation events early in the season, because irrigation equipment constraints were not considered. Once the irrigation season has effectively started, the demand predicted by the two models follows the same trend. In fact, farmers’ irrigation scheduling rules, specified in the IRMA model, do not consider light falls of rain that reduce the crop water requirements and that are accounted for in the PILOTE model. However, this difference is levelled out by higher irrigation depths predicted by the IRMA model. From the end of July, as the frequency of irrigation bans increases, the gap between the cumulative demand predicted by the two models increases again.

When PILOTE is run with the irrigation depth and calendar used by the farmer, it shows that water stress occurs in one period in July and
Fig. 6. Comparison of measured and predicted demand. Farmer 1, Block 1.

during another one in August (results not presented here). Corn yields obtained by the farmer for the fields monitored range from 8.5 to 10.3 t/ha; values to be compared with the maximum yields of 14 t/ha measured in experimental plots. As no other factor was limiting crop production, this data confirms that crop water requirements have not been fully met. In high demand periods, the soil storage capacity remains at its critical threshold, due to a late start of the irrigation campaign. As a result, irrigation bans lead quickly to water stress events with an expected negative impact on crop yields.

5. Conclusions

The IRMA software that models the irrigation decision making process allows accurate prediction of the events of an irrigation season (dates and volumes of water applied) at the block or farm scale. The average discrepancy between predicted and observed irrigation dates is less than 1.5 day. The error in the cumulative volumes applied is below 8.5% for the calibration year and 6.7% for the validation year; the absolute value of error concerning volumes is smaller than the water applied in a single irrigation position.

The model was used to analyse the adaptation of scheduling rules to water shortage situations or temporary irrigation bans. Model simulations stress the gap between the demand for water at the farm and theoretical crop water requirements. The methodology developed provides an instrument to compare different tools used in water saving (bans, quotas, water pricing) which is complementary to the analysis undertaken with more traditional micro-economic models.

The prospects for practical application of the methodology are broad. The decision model calibrated and validated enables, for example, simulations under different climatic scenarios. The same decision model can be tested with 30 years of climatic data. As a given year is too marred by climatic particularities to provide general results, several years of simulations would allow the stochastic dimension of the phenomenon to be investigated.

To address the issue of water shortage at the scale of the Charente River Basin, a larger and representative sample of farmers should be selected to represent the socio-economic and physical diversity within the basin. Using this representative sample, a series of interviews and selected measurements of water flows and demand would be required to build action models for every represen-
tative farm and to calibrate and validate the model.
Aggregated at the scale of the basin, the results of
the simulation for the various representative farms
would provide a good estimate of the impact of
water saving measures. The results obtained should
then be translated into simple recommendations
for the management of dam releases and low
flow periods.

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