Can medium range weather forecasts influence irrigation scheduling?

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Medium range weather forecasts (MRWF) are planned to be used in farm management and decision-making. A logical basis for the use of MRWF in irrigation scheduling is presented. The methodology is based on a daily soil water balance model to define the dynamic soil water state, and irrigation scheduling criteria based on soil moisture depletion. Historical rainfall data are used to examine the influence 3 to 5 days advance information of rainfall will have on irrigation scheduling of crops in the Jayakwadi Irrigation Project Area. For the deep soil, fixed irrigation depth scenario considered in this study, MRWF may not significantly influence irrigation decisions. The methodology can be extended to evaluate the impact of MRWF on other farm decisions and in other situations. Such studies can be used to develop guidelines for establishing agricultural advisory services.

MEDIUM range weather forecasts (MRWF) provide information about weather 3 to 10 days in advance[1]. Rainfall is an important weather variable influencing agricultural operations. At the present level of MRWF technology, the accuracy of rainfall forecasts is fair to marginal in 3- to 5-day range[2] in the monsoon season. The National Centre for Medium Range Weather Forecasting (NCMRWF) is establishing Agricultural Advisory Services to provide operational and reliable advice to farmers in India based on MRWF[1]. The services include advice on decisions relating to sowing, pesticide applications, irrigation, harvesting, etc. Irrigation scheduling advice is planned to be one of the important applications of MRWFs. Its basis is that taking account of the rainfall expected in the next few days when deciding whether or not to irrigate can save water through better utilization of rainfall. To what extent does this hold when we consider that irrigations are needed for many crops only in prolonged dry spells and are scheduled after the soil water storage is sufficiently depleted? No studies have been carried out so far to examine such questions and quantify the impact of the forecasts on farm level irrigation decisions.

In this paper, we present a methodology to examine the influence 3 to 5 days advance information of rainfall can have on irrigation decisions with respect to the quantities of water that can be saved and the timing of irrigation applications. This is done for a case study area, the Jayakwadi Irrigation Project in Maharashtra.

The area is characterized by a semi-arid climate with a mean rainfall of about 800 mm. Most of the rainfall (> 80%) is received in the monsoon season. There is a general scarcity of water in the region. These are typical conditions where application of MRWFs is expected to result in significant improvements in water conservation[1]. The analysis is done for 14 years and for 4 crops grown in the project area in the kharif (monsoon) season, sorghum, cotton, sugarcane and banana, to represent a wide range of cropping and irrigation conditions. Sorghum is harvested soon after the end of the monsoon season, cotton extends into the post monsoon rabi season, and sugarcane and banana are annual crops.

Conceptual basis

Before using MRWF in irrigation scheduling, a logical basis for their use needs to be developed. In general, forecasts can be integrated into real-time operational management of dynamic systems, such as irrigation systems, if the variables affecting the states of the system and decisions are identified, and provided; (i) The variable being forecast affects the state of the system; (ii) The influence of the forecast on the state of the system can be determined and the state of the system updated; (iii) The criteria for decision making can be defined with respect to the state of the system; (iv) The constraints on the decision variables are specified. Thus, the use of forecasts presupposes knowledge of the state of the system as it changes with time. But the state of the system can be influenced by many variables in addition to the one that is forecast. For irrigation scheduling decisions, the relevant state variable of the soil-plant system is the soil water content in the root zone. This is influenced by, in addition to rainfall (the forecast variable), evapotranspiration, depth of the root zone from which the plant water uptake occurs, the soil water storage available before rain occurs, percolation out of the root zone, etc. The soil water content is best estimated on a daily basis by a soil water balance model[3].

An irrigation decision is based on the state of the system (soil water content), that results from the simultaneous effects of all such variables and the constraints on the decision variables. Irrigation decisions are specified by the timings and quantities of irrigation. Results of field experiments have shown that irrigations should be timed when the soil water content in the root zone falls to a threshold level below which crop yields are reduced. The threshold level varies with crops and prevailing evaporation rates. The constraints on decisions are specified by the irrigation water conveyance and application systems. For example, in many irrigation projects, irrigation periods of 7 days or multiples thereof and fixed irrigation depths are preferred for practical reasons of operating large irrigation systems. Thus, real-time irrigation decisions are complex and include effects of several factors other than the forecast rainfall[4].

Methodology

A two-layer daily soil water balance model[5] was used to determine the soil water states at the end of each day of the growing season for each crop in the study area. The model is based on well-established principles of crop water use[6], a dynamic root growth model[7], and a runoff model[8]. The applicability of the general principles and assumptions of the model for semiarid regions of India is well established[9–11]. Irrigations are of a fixed depth of 75 mm. Fourteen years daily rainfall data, 15-year average weekly reference evapotranspiration data, crop factors, and dates of sowing and harvesting of crops were the input data of the soil water balance model. Irrigations were scheduled in these 14 years whenever the average available soil moisture content in the root zone (mm/cm depth of soil) was below a threshold moisture level AS^* (mm/cm). AS^* was determined for each crop and daily potential evapotranspiration (PET) rate using a soil water depletion factor[5,9–11].

To examine the influence of advance knowledge of rainfall on irrigation decisions, the daily soil water balance model was run for 14 years for the growing seasons of 4 crops in the study area (sorghum, cotton, sugarcane, banana) under the following conditions:

(i) *No forecast*: The water balance model identifies the day (t) on which the soil moisture in the root zone (ASt) becomes less than or equal to AS^*. A fixed depth of irrigation of 75 mm is applied the next day, that is on day (t+1). The standard week of the year which includes (t+1) is identified as the irrigation week. The soil moisture content is updated after irrigation on day (t+1), and the model run is continued till the next day when $AS \leq AS^*$. The procedure is repeated daily to the end of the growing season.

(ii) *Perfect 3-day forecast*: The model is run as in case (i) above till day t when $ASt \leq AS^*$. Before irrigating on the following day, rainfall and daily PET of the following 3 days (t+1, t+2, t+3) are scanned. Let the total rainfall on these 3 days be TR and the total potential evapotranspiration TPET. Further, the incremental soil moisture (ISM) available because of root growth is estimated from the root growth model. If DT is the root depth on day t and DT3 is the root depth on day (t+3), then an irrigation of 75 mm depth is scheduled on day (t+1) if:

$$TR - TPET + ASM \leq AS^* . DT3$$

in which,

$$ASM = ASt \times DT + ISM.$$

Otherwise, irrigation is withheld on day (t+1) and the model advances through successive daily time steps till once again $AS \leq AS^*$. At this stage, the process of scanning for the rainfall on next 3 days, etc, is repeated and the need for irrigation confirmed with the above two equations. The standard week corresponding to the day of each irrigation is identified.

(iii) *Perfect 5 day forecast*: The procedure adopted is similar to the case of the 3-day forecast in (ii) above with the difference that data of 5 days ahead values of rainfall, PET and ISM is considered in place of the 3-day values.

Results

The standard weeks of the monsoon season when irrigation is scheduled for various crops for the conditions (i), (ii), and (iii) above are given in Table 1. The number of years (out of 14) when 1, 2, etc, irrigat ons are saved for each crop with use of advance information of rainfall is given in Table 2. The corresponding changes in irrigation timings are given as 1 week, 2 week, etc, shifts in irrigation weeks compared to the no forecast case (Table 3).

Discussion

Influence of advance knowledge of rainfall on water conservation

For the 14 years daily rainfall data and the crops in the Jayakwadi Project Area, the number of irrigations that could be missed as a result of advance knowledge of 3- or 5-day rainfall did not exceed one in any year. This was true even for a frequently irrigated crop like banana (33 to 38 irrigations in a year). Even this saving of one irrigation occurred only once in 14 years for cotton. The maximum observed impact was for banana for which one irrigation was saved in 6 out of 14 years. This was the case when the weather forecasts were considered perfect (actual values of 3- or 5-day rainfall specified in advance from the historical data). Since the actual MRWF will be less than perfect, no decisive advantage appears to result from their use with respect to water conservation.

Table 1. Standard weeks of the monsoon season when irrigations are required with (1) no forecast, (2) 3-day forecast, and (3) 5-day forecast of rainfall

Year	Case	Sorghum	Cotton	Sugarcane	Banana
(1)	(2)	(3)	(4)	(5)	(6)
1960	1	28, 34	27, 30, 34	23, 25, 30, 34, 36	27, 28, 35, 22
	2	28, 34	27, 30, 34	23, 26, 32, 34, –	27, 28, 35, 22
	3	28, 34	27, 30, 34	23, 25, 31, 34, –	27, 28, –, 22
1961	1	26	29, 38	23, 29, 37	27, 29, 22, 22, 24
	2	–	29, 38	23, 29, 37	27, 29, 22, 22, 24
	3	–	29, 38	23, 29, 37	28, –, 22, 22, 24
1962	1	25, 26	24, 30, 34	23, 25, 30, 34	27, 31, 22
	2	25, 26	24, 30, 34	23, 25, 30, 34	28, 31, 22
	3	25, –	24, 30, 34	23, 25, 30, 34	30, –, 22
1963	1	25, 30	29	25	27, 28, 30, 22, 23
	2	25, –	29	25	27, 28, –, 22, 23
	3	–, 29	29	25	27, 28, –, 22, 23
1964	1	–	–	22	28, 22, 22
	2	–	–	22	–, 22, 22
	3	–	–	22	–, 22, 22
1965	1	25, 33	27, 31, 37	22, 25, 31, 37	28, 31, 22, 23
	2	25, –	27, 31, 37	22, 25, 31, 37	28, 31, 22, 24
	3	25, –	27, 31, 38	22, 25, 31, 37	28, 31, 22, 24
1966	1	25, 26	27, 34	23, 26, 34	27, 22, 23
	2	25, 26	27, 34	23, 26, 34	27, 22, 23
	3	25, 26	27, 34	23, 26, 34	27, 22, 23
1967	1	37	23, 36	22, 24, 36	27, 28, 38, 22, 23
	2	37	23, 36	22, 24, 36	27, 28, –, 22, 23
	3	37	23, 36	22, 24, 36	27, 28, –, 22, 23
1968	1	25	23, 29, 34	22, 23, 25, 34	27, 28, 29, 22, 23
	2	25	24, 33, 36	22, 23, 26, 34	27, 28, –, 22, 23
	3	25	24, 33, 36	22, 23, 25, 34	27, 28, –, 22, 23
1969	1	25	23, 33	22, 24, 33	29, 23
	2	25	24, 33	22, 24, 33	–, 23
	3	25	24, 33	22, 24, 33	–, 23
1970	1	–	31	23, –	27, 29, 23, 24
	2	–	31	22, 31	27, –, 23, 24
	3	–	29	22, 30	–, –, 23, 24
1971	1	25, 27, 31	25, 28, 30, 33	23, 25, 28, 30, 34	27, 28, 29, 32, 22, 23
	2	26, 29, –	27, 28, 30, –	23, 25, 28, 30, –	27, 28, 29, 32, 22, 23
	3	26, 29, –	27, 28, 30, –	23, 25, 28, 30, –	27, 28, 29, 32, 22, 23
1972	1	29, 31	24, 29, 31, 34, 39	22, 24, 29, 31, 34, 39	27, 28, 29, 39, 22
	2	29, 32	25, 29, 31, 35, 39	22, 24, 29, 31, 34, 39	27, 28, 35, 22, 24
	3	29, 32	27, 29, 31, 38, –	22, 24, 29, 31, 34, 39	27, 28, 35, 22, 24
1973	1	25, 26	30, 38	22, 25, 37	22, 24, 30
	2	25, –	30, –	22, 25, 37	22, 24, 30
	3	25, –	30, –	22, 25, 37	22, 24, 30

Table 2. Number of years (out of 14) when the total number of irrigations for each crop over its entire growing season is reduced when compared to the 'no forecast' case by use of 3-day and 5-day forecasts of rainfall

Crop	No. of years with 1 irrigation less		No. of years with 2 irrigations less		Total no. of irrigations (range in 14 years)
	3-day forecast	5-day forecast	3-day forecast	5-day forecast	
Sorghum	5	6	–	–	0–3
Cotton	1	2	–	–	1–6
Sugarcane	3	3	–	–	18–24
Banana	6	8	–	2	33–38

Table 3. Number of years (out of 14) when there is a shift in irrigation schedule by a week or more compared to 'no forecast' case, after use of 3-day and 5-day forecasts

Crop	No. of years with shift of 1 week		No. of years with shift > 1 week	
	3-day forecast	5-day forecast	3-day forecast	5-day forecast
Sorghum	2	2	1	2
Cotton	4	3	3	5
Sugarcane	3	2	1	–
Banana	2	1	1	2

Influence of advance knowledge of rainfall on irrigation timing

With respect to irrigation timing also, advance knowledge of rainfall did not lead to significant changes compared to the 'no forecast' case. A forward shift of one standard week in the timing of irrigation occurred in 1 year (for banana) to 3 years (for cotton) in 14 years for the 3-day forecasts.

Applicability of MRWF: From the above analysis, it appears that for the deep soil, fixed irrigation depth scenario of irrigation scheduling considered in this study, MRWF may not significantly influence irrigation scheduling decisions. This was primarily because irrigations were scheduled after the soil water reservoir was depleted sufficiently. The utility of MRWF in lighter soils and drier regions where frequent and shallow irrigations are the practice, and in rice fields which are irrigated frequently to maintain standing water conditions, needs to be examined. The relative costs of water and the method of water application may also have a role in determining the value of the forecasts in irrigation scheduling.

We recognize that the present irrigation practice in India at the farmer level is based more on heuristics and not on continual monitoring of the soil moisture status. But irrigation scheduling based on soil moisture and plant conditions is recommended by agronomists in India and is practiced in several advanced countries. The fact remains, however, that if MRWF are to be used in real time, the state of the system must be characterized, monitored and updated. Since soil moisture content is the relevant state variable for irrigation decisions, soil water balance models are required to monitor the current state of the system, if MRWFs are to be used. The paradox is, if irrigation scheduling is made scientific through monitoring the soil water balance, the forecasts themselves may have less influence on decision-making. This may be particularly true of deep-rooted crops in medium to heavy soils where sufficient soil water storage is feasible. On the other hand, the soil water balance based irrigation scheduling will by itself lead to significant water conservation and improved timing of irrigation.

Applicability of the methodology: The methodology for evaluating the influence of MRWFs on irrigation scheduling described in this paper does not use actual forecasts but the historical rainfall data. Thus, future rainfall at the beginning of each day is perfectly known. This knowledge could be used only if the present system state, its effect on decisions and the constraints on decisions were specified. The soil water balance model defined the state, agronomic experiments provided the criteria for irrigation scheduling decisions based on the state of the system, and the practical limitations of water conveyance systems provided the constraints on the decisions. The methodology can be extended to evaluate the use of MRWF in specific irrigation scheduling situations, for example, light soils, rice irrigation, different irrigation methods, etc.

The procedure can also be generalized and extended to evaluate how effective MRWF can be in other farm level decisions (sowing, pesticide applications, harvest, etc). What is required is a definition of the critical state variable affecting a decision, a mechanism to continually monitor this variable, the criteria for decision-making, and specification of any constraints on implementing decisions in the field. If these are available, the historical data can be used to examine the extent to which advance information of weather actually affects decisions. The agricultural advisory services of NCMRWF can then be developed accordingly for each region, for the category of advice most suited to the region.

It may be several years before MRWF are widely and accurately available. It is not necessary to wait for the availability of MRWFs before their impact is assessed. Historical weather records and records of decisions in those years can be examined to judge how the decisions would have been affected, if the weather was known in advance. Such studies will provide valuable guidelines for the development of agricultural advisory services in India.

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