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1.0 INTRODUCTION

Rapid expansion of irrigation facilities in India has raised the irrigation potential from 22.6 M ha since 1950-51 to 99 M ha by the end of 2003-04. This has resulted in substantial increase in agricultural production. In spite of this substantial gain, there is a growing concern that most of the large irrigation projects in India and Southeast Asia operate at a poor overall efficiency of about 30% to 35% (Bower and Hufschmidt, 1984; Sanmugnathan and Bolton, 1988). Poor distribution and management of irrigation water is the major factor responsible for this situation (Haque et al., 2004). In India, irrigation is the single largest user of water resources which accounts for about 84% of all withdrawals (Planning Commission, 2002). Due to increasing industrial and municipal needs, the share of water for irrigation is likely to go down. Surface irrigation systems (canals) are dominating source of irrigation in eastern India, but the use efficiency of water in most canal command areas is very low, often 30 per cent or less (Tanwar, 1998; Pandey and Reddy, 1988). In the major irrigation systems of Orissa, water is continuously supplied in the canals, which leads to water submergence of varying degree and duration in certain pockets of the command area. Thus, in future irrigation has to become efficient which stress the need for improved performance of the irrigation systems.

A number of computer aided models have been developed with the aim of improving water management scenario in large irrigation projects. A model based on water balance approach for low land paddy and soil moisture simulation approach for upland crops to estimate water deliveries at tertiary and secondary canal was developed by Kemachandra and Murty (1992). A multi-criteria mathematical model for irrigation canal scheduling with rotational distribution to enhance the performance of water distribution was suggested by Santhi and Pundarikanthan, 2000. Improved operation and management of the canal system through a better delivery schedule was found to enhance the overall system's performance and productivity of the command (Mishra et al., 2002; Haque et al., 2004). Saving in water use in optimum rotational irrigation schedule and yield reduction in longer rotational schedule was reported by Bhirud et al. (1990) in the semi arid region. Smout and Gorantiwar (2006) considered alternative schedules based on full or deficit irrigation within the framework of area proportionate water distribution for irrigation schemes in central and southern India.

The prevailing canal delivery schedule in most of the canal irrigation system of eastern India looks to be less efficient. Modification of the existing canal delivery schedule to maintain a better water regime in the command and to overcome the problem of low irrigation efficiency sounds to be an appropriate solution in improving the operation and management of the irrigation system. This will bridge the gap between the irrigation water supply and crop water demand and minimize the irrigation induced secondary problems such as water logging and salinization. Therefore, in this study, an attempt has been made in developing an alternative delivery schedule for both monsoon and dry seasons taking into account the prevailing cropping pattern, soil characteristics, climatic variation and canal capacity constraints. The new schedule will require considerable management coordination between farmers, who must adjust their planting and other agricultural operation schedules, and irrigation administrators, who must provide timely release of water (Barker et al., 2000).

2. CANAL DELIVERY SCHEDULING

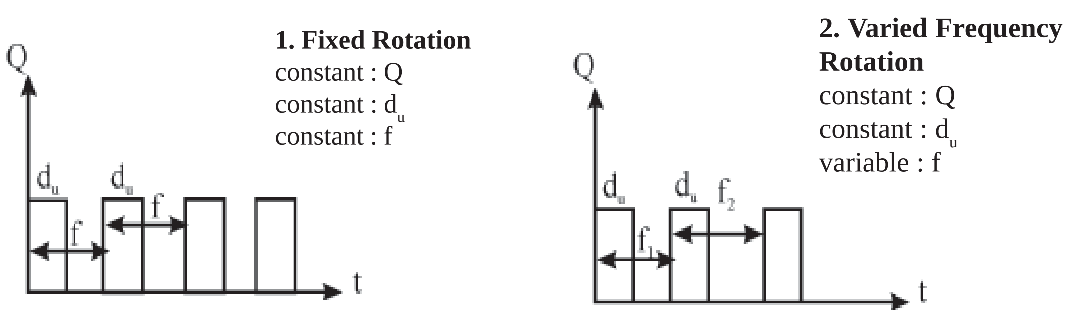
Scheduling is a function of flow rate, duration of irrigation and frequency of irrigation. Assuming that each of these components can be either constant or variable, a number of different types of irrigation schedules may be made. Broadly the scheduling can be categorized into three types.

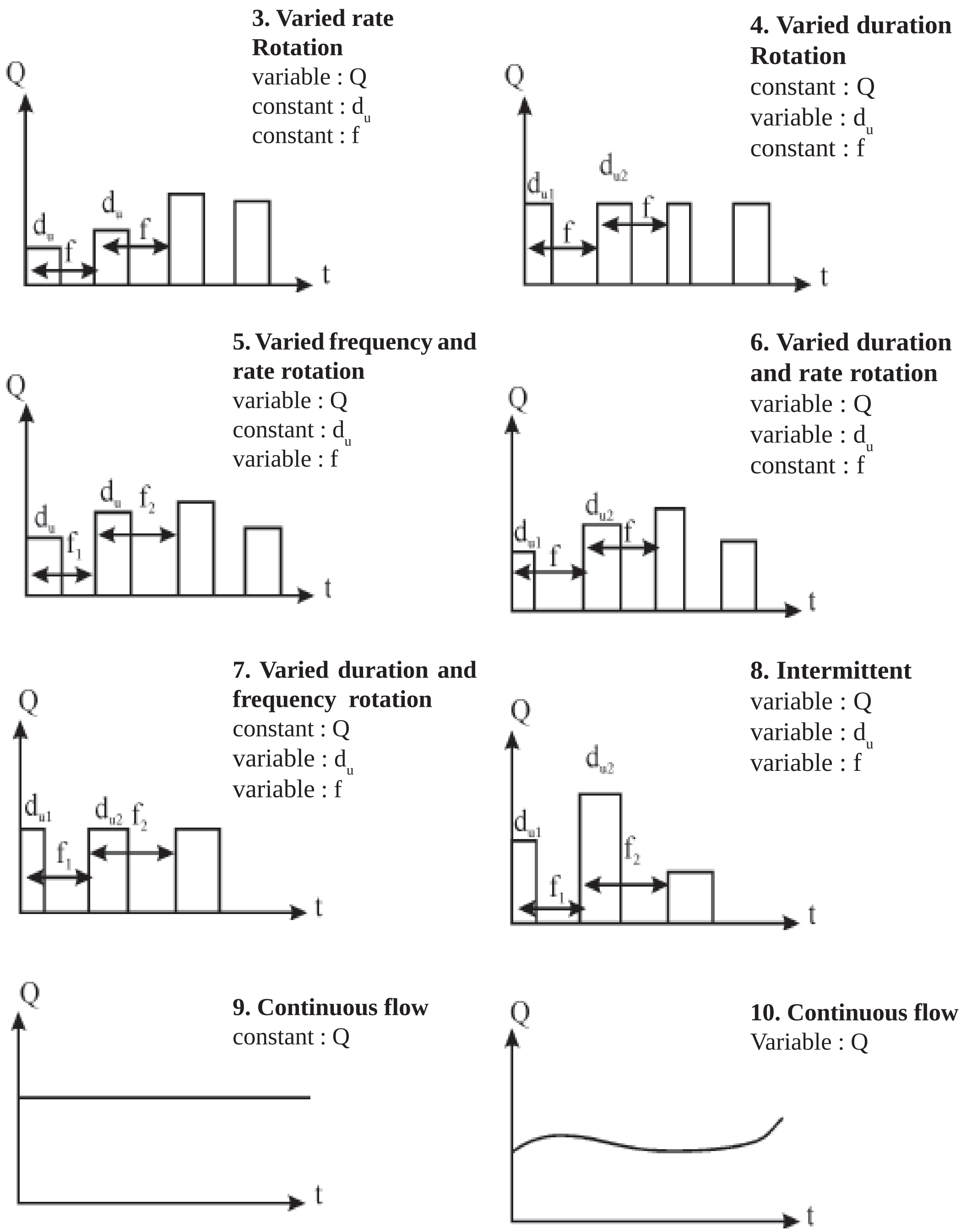
(i) Continuous: a constant or variable flow rate is maintained without interruption.

(ii) Rotational: a constant or variable flow rate is supplied intermittently with fixed or variable duration and frequency.

(iii) On Demand: Flow rate, duration and frequency are variable. Water is supplied according to demand.

Replogle (1986) presented a more systematic classification of irrigation schedule. He subdivided the multiplicity of irrigation schedules obtainable by permutation of the three above components in constant or variable form. He defined two extreme cases: the rigid schedule as fixed rotation and the flexible schedule as irrigation on demand. Between these two extremes he distinguished a number of transitional types of irrigation schedules. Murty et al. (1992) simulated the tertiary unit efficiencies with different cropping systems and water delivery patterns. They described the possible water delivery patterns to a tertiary unit (Fig.1). Herein 'Q' is the flow rate, 'f' is the frequency of supply and 'd' is the duration of flow. For determining the irrigation schedule, models based on water balance approach for lowland paddy and simulated soil moisture profile for upland crops were used.





Q=flow rate, f=frequency, du=duration and t=time

Fig. 1. Possible canal delivery scheduling patterns

3. STUDY AREA AND DATA COLLECTION

Phulnakhara distributary (Plate 1) of Puri Main Canal System (Plate 2) (a run-of-the-river scheme) located in the state of Orissa, India was selected as study distributary. The distributary off-takes from Kakatpur branch canal at 0.891 km relative distance (RD). The distributary has a design discharge of 6.045 m^3/sec at its head regulator. The designed cultivable command area (CCA) of the distributary is 5424.78 ha and actual CCA is 3864.14 ha. The length of the distributary is 21.528 km. It has 7 minors and 35 sub-minors. Head regulator of one of its minor located in the head reach is shown in Plate 3. Fig. 2 presents the index map of the Phulnakhara distributary and its command area. For flow measurement, few flumes are installed in the system. View of one of the flume installed in the Atala minor is shown in Plate 4.

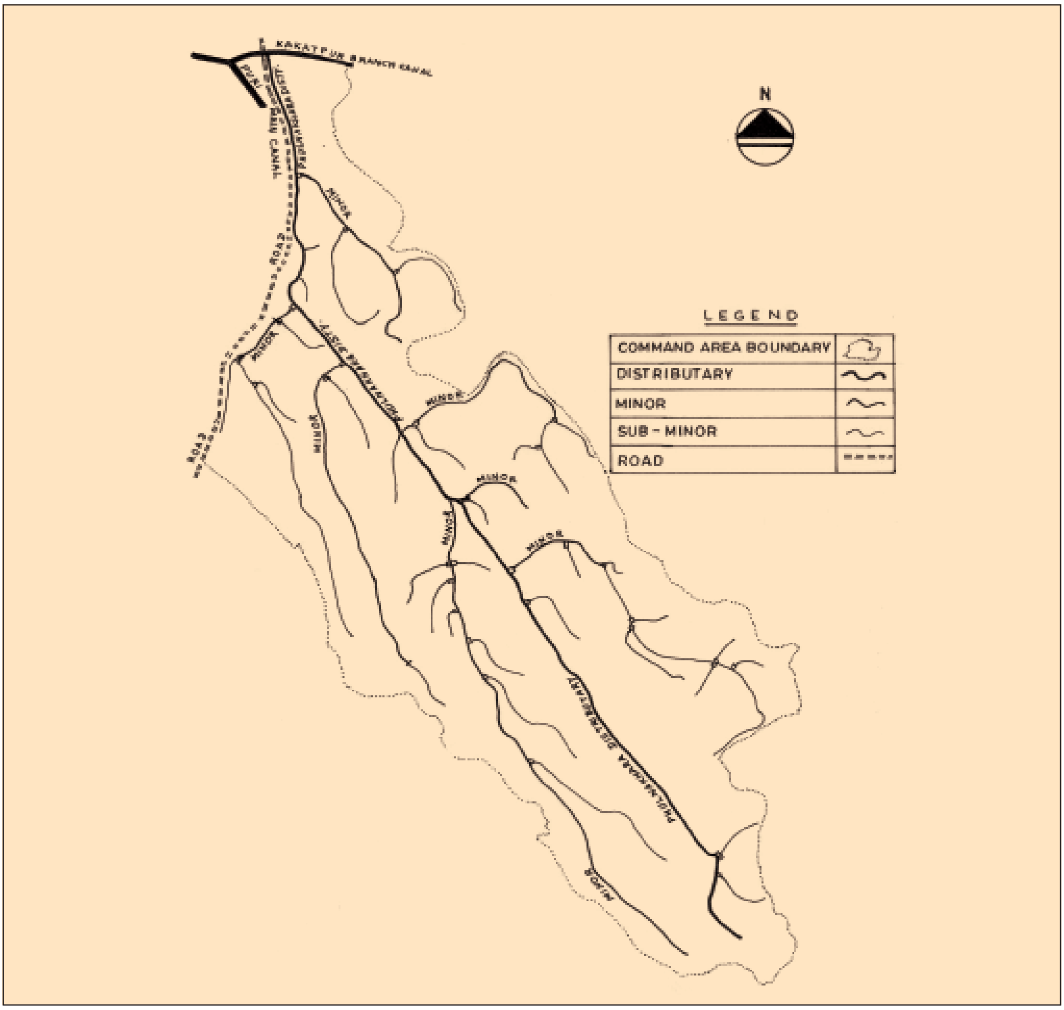


Fig. 2. Index map of the Phulnakhara distributary

Plate 1. Head regulator of Phulnakhara distributary (off-taking from Kakatpur branch canal)

Plate 2. Puri main canal system

Plate 3. Atala Minor (in the head reach) off-taking from Phulnakhara distributary

Plate 4. A flume for measurement of flow in the Atala Minor.

Daily discharge at the head regulator of the Phulnakhara distributary for dry season (December to May) was collected for 25 years (1977-2001) from the office of the Assistant Engineer, Department of Water Resources, Pratap Nagari, Cuttack, Govt. of Orissa. Soil samples in the head, middle and tail reaches of the study distributary were collected for determining their physical properties (Table 1). The command area of the distributary is dominated by clay loam soil at its middle and tail reaches. The soils of the head reach are relatively heavier than middle and tail reaches. Bulk density of soil ranged between 1.42 to 1.64 gm/cm^3. The soils of the middle reach are highly porous. Saturated vertical hydraulic conductivity ranged between 0.253 to 1.024 cm/hr and horizontal hydraulic conductivity between 0.133 to 0.896 cm/hr. The ranges of the soil properties given in the Table 1 apply to the predominant soils in the command area. The average annual rainfall of the study area is 1573 mm.

To estimate the irrigation water requirement, the prevailing cropping pattern of the command during dry season was collected for 12 years period (1988 to 2000) from the office of the Deputy Director of Agriculture, Cuttack, Government of Orissa. The average value of the crop coverage data is presented in Table 2. It is observed that about 91% of the command is covered by various crops during dry season and the remaining 9% of the command area remained fallow. On an average, Pulses such as green gram and black gram; Vegetables such as potato, tomato, cauli flower, cabbages and brinjal; Cereals such as winter paddy; Oil seeds such as groundnut and sunflower were grown in about 31%, 29%, 15% and 15% of the command area, respectively. Thus, the major crops grown during dry season are green gram, black gram, vegetables,

Table 1. Physical properties of soils of Phulnakhara distributary

Depth, cm	Textural class	Bulk density, gm/cm^3	Saturated vertical hydraulic conductivity, cm/hr	Saturated horizontal hydraulic conductivity, cm/hr	Moisture content at saturation, cm^3/cm^3	Moisture content at field capacity, cm^3/cm^3	Moisture content at wilting point, cm^3/cm^3
Head reach							
0-15	CL	1.556	0.262	0.235	0.535	0.335	0.190
15-30	CL	1.572	0.301	0.262	0.514	0.308	0.165
30-45	CL	1.625	0.288	0.229	0.527	0.320	0.180
45-60	CL	1.638	0.253	0.237	0.521	0.316	0.177
Middle reach							
0-15	SL	1.423	0.522	0.328	0.428	0.181	0.081
15-30	SCL	1.455	0.976	0.339	0.401	0.183	0.086
30-45	SCL	1.503	0.599	0.302	0.435	0.185	0.103
45-60	SCL	1.569	1.024	0.896	0.404	0.184	0.099
Tail reach							
0-15	SCL	1.420	0.470	0.133	0.437	0.228	0.110
15-30	SCL	1.542	0.310	0.162	0.478	0.260	0.155
30-45	SCL	1.562	0.521	0.320	0.462	0.250	0.142
45-60	SCL	1.551	0.503	0.355	0.411	0.215	0.108

Note: CL = Clay loam, SL = Sandy loam, and SCL = Sandy clay loam.

groundnut, potato, etc. In both the seasons the canal runs continuously with a variable flow rate. This continuous flow is provided to each distributary, each minor, each sub-minor and each farmer. The flow changes in the distributary are supposed to be distributed proportionately. However, due to lack of adequate control structures the flow changes are not translated proportionately as a result of which the tail-end farmers suffer maximum.

Table 2. Crop coverage in the distributary command during dry season (12 years average)

Crop	Area covered, ha	Percentage of command area, %
Paddy	531.48	13.75
Wheat	15.97	0.41
Maize	7.03	0.18
Ragi	15.80	0.41
Gram	2.64	0.07
Green gram	365.73	9.46
Black gram	397.11	10.28
Horse gram	421.66	10.91
Arhar	4.48	0.12
Other pulses	22.47	0.58
Groundnut	422.19	10.93

Til	108.81	2.82
Castor	3.65	0.09
Mustard	53.51	1.38
Linseed	5.06	0.13
Saf flower	0.53	0.01
Sunflower	0.07	0.001
potato	247.49	6.40
Sweet potato	15.52	0.40
Other vegetables	723.92	18.73
Onion	19.27	0.50
Chilly	66.34	1.72
Garlic	9.34	0.24
Coriander	15.45	0.40
Cotton	0.03	0.0008
Tobacco	0.84	0.02
Sugarcane	16.66	0.43
Other crops	15.33	0.40
Field pea	6.21	0.16
Cow pea	3.22	0.08
Total	3517.81	91.01

4. METHODOLOGY

4.1 Model Development for Modifying Delivery Schedule in Monsoon Season

$$ET_{ai} = ET_{oi} \cdot K_c \cdot Ks_i$$

Considering paddy as the main crop during rainy season, simple water balance approach of the rice field (in an irrigation unit) in the command (input-output = change in storage) is followed to decide the alternative schedule, which is be mathematically written as

$$W_i = W_{i-1} + RF_i - ET_{ai} - DP_i + IR_i - DR_i - RO_i \quad (1)$$

where, W_i = water level in the paddy field/ in an irrigation unit on the i[th] day in mm; RF_i = rainfall in the i[th] day in mm; ET_{ai} = actual crop evapotranspiration in the i[th] day in mm; DP_i = deep percolation and seepage loss in the paddy field on the i[th] day in mm; IR_i = irrigation water applied in the i[th] day in mm; DR = drainage on the i[th] day in mm; RO_i = runoff from adjacent upstream irrigation unit on the i[th] day in mm and subscript i represents the time in days.

Actual evapotranspiration is computed from the reference evapotranspiration.

$$ET_{ai} = ET_{oi} \cdot K_c \qquad \text{if } SMC_i \geq FC \quad (2)$$

$$\text{if } SMC_i < FC \quad (3)$$

where, SMC_i = soil moisture content for i[th] day, cm^3/cm^3; ET_{oi} = reference crop evapotranspiration on i[th] day, mm; FC = moisture content at field capacity, cm^3/cm^3; K_c = crop coefficient, and Ks_i = crop stress factor which is estimated as follows.

$$K_{Si} = \frac{\log\left[1+100\left(\frac{SMC_{i-1}}{AWC_i}\right)\right]}{\log(101)} \quad (4)$$

where, AWC_i = total available soil moisture storage capacity for i^{th} day, cm^3/cm^3.

Deep percolation loss from the paddy field is computed using Darcy's law (Paulo *et al*., 1995) as given below:

$$V_i = -K_v(\Delta H_i / \Delta Z) \quad (5)$$

where V_i = vertical flow velocity on i^{th} day (m/day); K_v = saturated vertical hydraulic conductivity (m/day); DH_i = difference in hydraulic head between two points in the vertical direction on i^{th} day (m), and DZ = vertical distance between the two points (m).

Assuming no spatial variability inside the paddy field (in an irrigation unit), the vertical seepage can be computed as:

$$Q_{vi} = -K_v \cdot A \cdot (\Delta H_i / \Delta Z) \quad (6)$$

where, Q_{vi} = vertical seepage from an irrigation unit on i^{th} day, m^3/day; and A = area of the irrigation unit, m^2.

The horizontal seepage from the paddy field is computed through Dupuit's approach (Walker and Rushton, 1984) as given below (Fig. 3):

$$Q_{hi} = \lambda(K_h / 2L)[(W_i + D_d)^2 - h_1^2] \quad (7)$$

where, Q_{hi} = total horizontal seepage flow along the bund (m^3/day) on i^{th} day; λ =length of the bund (m); K_h = horizontal saturated hydraulic conductivity (m/day); L = width of the bund (m); h_l = hydraulic head downstream (m), (the depth of the water in the drainage ditch); and D_d = depth of the drainage ditch (m)

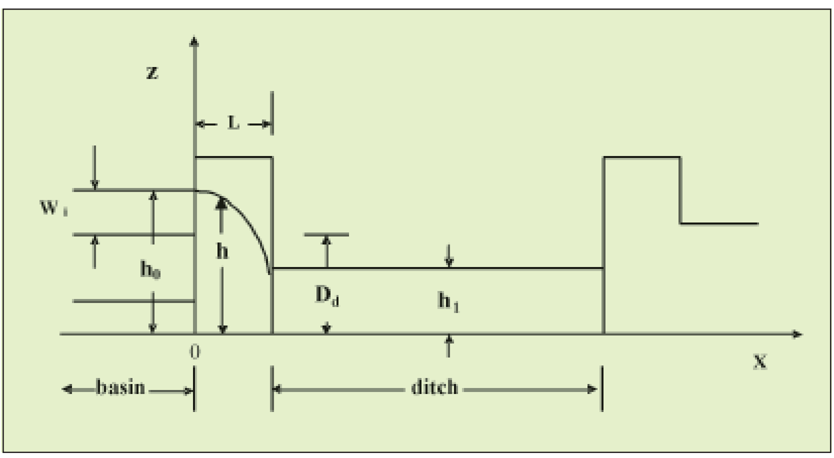


Fig. 3 Schematic diagram of an irrigation unit for estimation of horizontal seepage

In the rice field (irrigation unit), drainage occurs when the water level in the field (W_i) exceeds (W_{max}), the maximum allowable water level. The drainage amount (DR_i) can be calculated as $DR_i = W_i - W_{max.}$ Similarly, in an irrigation supply day if water level of the field (W_i) falls below the minimum water level (W_{min}), then irrigation (IR_i) is applied ($IR_i = W_{opt} - W_i$) where W_{opt} is the optimum water level in the field. Here, the value of W_{max}, W_{opt} and W_{min} are assumed as 15, 12 and 3 cm, respectively for simulation purpose (Fig. 4). The values of W_{opt} and W_{min} were decided by taking into account the conventional practice adopted by the farming community and the earlier work done by Kemachandra and Murty, 1992. A computer program was developed based on the above model.

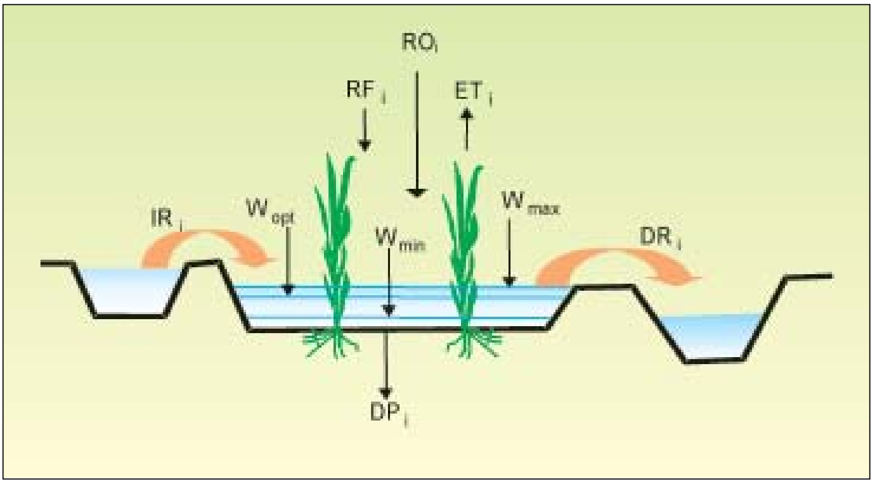


Fig. 4 Components of daily water balance in rice irrigation unit

For the purpose of modeling, the entire command of the distributary was divided into three reaches, viz., head, middle and tail. Each reach was further equally divided into four irrigation units. Thus, for the purpose of simulation, the entire command area was hypothetically divided into 12 irrigation units. In a particular irrigation unit, an uniform water depth has been considered in all the fields. The model computes the irrigation requirement at the field level. Conveyance loss of 20% in the field channel and water course and 15% in the minors and distributary was considered to arrive at the irrigation requirement at the head regulator of the distributary. Further, the spatial distribution of the area covered under different crops has been considered uniform in the three reaches within the command. Thus, the total area covered by a specific crop was equally divided into three parts for consideration under each reach.

Simulation was performed for the prevailing continuous schedule and four alternative rotational schedules for the rainy season. The alternatives considered are: (i) 7 days canal operation followed by 7 days canal closure (7_7), (ii) 10 days canal operation followed by 10 days canal closure (10_10), (iii) 15 days canal operation followed by 15 days canal closure (15_15), and (iv) 20 days canal operation followed by 20 days canal closure (20_20).

Simulation duration of 138 days beginning from 1st of July was considered. Simulation was performed for 17 years (1985-2001) period. For the simulation period, daily climatic parameters such as rainfall, pan evaporation, depth to ground water table from ground level; physical properties of soils such as saturated vertical and horizontal hydraulic conductivity, moisture content at saturation, field capacity, stage wise crop coefficient, etc. were used as input data sets for the model. The output from the model consisted of daily actual evapotranspiration, deep percolation, drainage, irrigation water applied and depth of standing water in each irrigation unit.

4.2 Model Development for Modifying Delivery Schedule in Dry Season

A model for modifying the delivery schedule during dry season was formulated as suggested by Tyagi *et al*. (1995). The model is based on the soil moisture balance simulation approach in the crop root zone of the command area. This model is used for simulating the moisture content in the root zone depth for crops other than paddy. The equation governing the daily soil moisture balance in crop root zone depth is as follows:

$${}_{i} = {}_{i-1} + IR_i + ERF_i - ETa_i - DP_i \quad (8)$$

For, ${}_{i-1} < SMS$

$$ERF_i = RF_i \quad \text{if} \quad RF_i < SMS - {}_{i-1} \quad (9)$$

$$ERF_i = SMS - {}_{i-1} \quad \text{if} \quad RF_i \quad SMS - {}_{i-1} \quad (10)$$

where, ${}_{i}$ = soil moisture content in the crop root zone on i^{th} day, mm; ${}_{i-1}$ = soil moisture content in the crop root zone on $(i-1)^{th}$ day, mm; RF_i = total rainfall on the i^{th} day, mm; ERF_i = effective rainfall on the i^{th} day, mm; IR_i = net irrigation water applied on the i^{th} day, mm; ETa_i = actual evapotranspiration on the i^{th} day, mm; DP_i = Deep percolation loss on the i^{th} day, mm; SMS = soil moisture content at saturation, mm; i = an index for days since crop growth i.e. 1, 2, 3,……….n; and n = total crop growth period, days.

Since the above basic governing equation is concerned with the daily soil moisture balance in the crop root zone, a linear root growth module is considered for determining the depth of root zone at any particular day. The equation considered is as follows:

$$RD_i = DS + (DM - DS)\frac{i}{m} \quad (11)$$

where, RD_i = depth of root zone on i^{th} day, mm; DM = maximum root zone depth, mm; DS = depth at which seed is sown, mm; and m = days after seeding when the maximum root zone depth is reached.

Further, the actual evapotranspiration for non paddy crops is computed from the reference evapotranspiration.

$$ETa_i = Kc \cdot Ks_i \cdot ETo_i \tag{12}$$

$$Ks_i = 1, \quad \text{if } \frac{AWR}{AW} \geq 0.75 \tag{13}$$

$$Ks_i = \frac{AWR}{0.75AW}, \quad \text{if } \frac{AWR}{AW} < 0.75 \tag{14}$$

where, Kc = crop coefficient which depends on crop growth stages; Ks_i = crop stress factor on the i^{th} day, which is a function of relative available soil moisture content in the field; ETo_i = reference crop evapotranspiration on i^{th} day; which is calculated by multiplying the pan evaporation data with pan coefficient. AWR = remaining available soil moisture, cm^3/cm^3; and AW = available soil moisture (field capacity-wilting point), cm^3/cm^3.

Here, while calculating the crop stress factor, it is considered that up to depletion of 25% of the available soil moisture, the actual evapotranspiration is equal to potential evapotranspiration and thus, there is no stress on the crop. The crop stress factor is considered to increase linearly when depletion level of available soil moisture increases above 25% (as suggested by Tyagi *et al*., 1995). Irrigation is applied to crops when both the following conditions exist *i.e.*, the available soil moisture reached a stage of 25% depletion level and the canal is in operation. The depth of application of irrigation is kept as the highest value between (field capacity - θ_i) and 6 cm.

For dry season paddy, simple water balance approach of the rice field in the command (input-output = change in storage) is followed, which is same as the modeling approach followed for monsoon rice and described under the sub-section 'model development for modifying delivery schedule in rainy season'.

Simulation was performed for the prevailing continuous schedule and five alternative rotational schedules. The alternatives considered are: (i) 7 days canal operation followed by 7 days canal closure (7_7), (ii) 10 days canal operation followed by 10 days canal closure (10_10), (iii) 15 days canal operation followed by 15 days canal closure (15_15), (iv) 10 days canal operation followed by 7 days canal closure (10_7) and (v) 15 days canal operation followed by 7 days canal closure (15_7). Based on the crop coverage data for past 12 years (1988 to 2000), the percentage of area to be covered under various crops in the command of the Phulnakhara distributary was decided. The major crops considered for simulation and the percentage of command area covered are winter rice (15%), groundnut (20%), potato (15%), tomato (5%), cabbage (5%), cauliflower (5%), brinjal (5%), green gram and black gram (30%) (Table 3). Considering that green gram and black gram can be grown with the residual soil moisture after harvest of paddy crop of rainy season or with a pre-sowing irrigation, the remaining seven crops covering 70% of the command area were taken into consideration for model simulation. Table 4 presents the month wise crop coefficient of the remaining seven crops considered. These monthly crop coefficient values were extracted through linear interpolation from the phenological stage-wise crop coefficient values of crops as prescribed by Doorenbos *et.al*., 1986 and Allen *et.al*.,1998. Simulation duration of 145 days beginning from 1st of December was considered. Simulation was performed for 15 years (1985-1986 to 1999-2000) period. For the simulation period, daily climatic parameters such as rainfall, pan evaporation, depth to ground water table; physical soil properties such as saturated vertical and horizontal hydraulic conductivity, initial soil moisture content, moisture content at saturation, field capacity and wilting point; and crop parameters as given in Table 3 and 4 were used as input data sets for the model. The output from the model includes crop wise daily actual evapotranspiration, irrigation requirement, daily depth of ponding in paddy field, daily soil moisture content in the root zone depth for other non-paddy crops etc.

Table 3. Input parameters for different crops

Sl. No.	Crop Name	Percentage of command area covered, %	Start date	Crop duration (days)	Maximum root zone depth (mm)	Depth at which seed is sown (mm)	Days on which maximum root zone is attended
1	Paddy	15	15th December	130	1000	50	90
2	Groundnut	20	15th December	125	1000	70	82
3	Potato	15	15th December	110	600	70	90
4	Tomato	5	1st December	120	1500	50	115
5	Cabbage	5	1st December	135	800	50	125
6	Cauliflower	5	1st December	120	700	50	105
7	Brinjal	5	1st December	130	1200	50	90
8	Greengram and Blackgram	30	1st December	90	1000	50	65

Table 4. Month wise crop coefficients for different crops

Sl. No.	Crop Name	Month 1	Month 2	Month 3	Month 4	Month 5
1	Paddy	1.10	1.10	1.10	0.95	0.95
2	Groundnut	0.40	0.70	0.95	0.75	0.55
3	Potato	0.40	0.70	1.05	0.85	0.70
4	Tomato	0.40	0.70	1.05	0.80	0.60
5	Cabbage	0.40	0.70	0.96	0.90	0.80
6	Cauliflower	0.40	0.70	0.96	0.90	0.80
7	Brinjal	0.75	0.80	1.00	0.95	0.85

4.3 Experimental Study

The experiment was conducted consecutively for three years during rainy season of 2002, 2003 and 2004 at the research farm of the Water Technology Centre for Eastern Region, Deras, Mendhasal, Khurda, Orissa. Five canal delivery schedules (four rotational schedules and one continuous schedule) and Control (no irrigation) were considered as treatments. They were (i) 7days canal operation followed by 7 days canal closure (T_1); (ii) 10 days canal operation followed by 10 days canal closure (T_2); (iii) 15 days canal operation followed by 15 days canal closure (T_3); (iv) 20 days canal operation followed by 20 days canal closure (T_4); (v) Continuous canal flow (T_5); and (vi) Control (C) – where no canal water was available and the crop was grown in rainfed condition. Each treatment had three replications. Thus, in total eighteen plots with size of 36 x 10 m each were laid out. Randomized block design was followed.

Two promising medium duration rice varieties were grown namely, *Surendra* (about 120 days duration) and *Swarna* (about 135 days duration). Half of each plot was transplanted with *Surendra* and the other half with *Swarna*. Rice was transplanted on 25th July, 20th July and 22nd July during 2002, 2003 and 2004 respectively with the spacing of 15 X 15 cm. Fertilizer dose of 80:40:40 kg/ha N: P_2O_5: K_2O was applied. Fifty per cent of N and full P and K were applied as basal and the remaining 50% of N was applied in two equal split doses during maximum tiller and panicle initiation stage.

Each plot was provided with a weir on its down-stream side (Plate 5). The crest level of the weir was kept at 15 cm height from the bed level of plot. Irrigation was given to a plot if the water level in it falls below 3 cm and the canal is in operation (on) for that plot. Irrigation is given in such a manner that the water level in the plot immediately after irrigation is brought to 12 cm height. Any water above 15 cm height used to spill over the weir and flows as runoff to the downstream fields. Different components of water balance were estimated for the experimental plots. The losses due to deep percolation was estimated using the empirical relationship developed by Mishra *et al.* (1998) for the same field which is as given below:

$$DP = -1.64 + 0.79\,D \quad (15)$$

Where, DP = Average loss of water due to deep percolation and seepage, mm/day and D = average depth of water ponded or stored in the rice field in a crop growing season in cm.

The effective rainfall was calculated as a fixed percentage (75%) of daily rainfall (Dastane, 1978). The potential evapotranspiration of rice was calculated by multiplying pan evaporation value with pan coefficient and crop coefficient at different stages. Water use efficiency (WUE) was estimated by dividing the grain yield with total crop water use (irrigation water + effective rainfall).

Plate 5. Experimental plot with surplus weir at the downstream side

Total rainfall of 931 mm, 951 mm and 775 mm was received during the crop growth period in the 2002, 2003 and 2004, respectively. The soil of the experimental site was sandy loam of alluvial origin. The pH of the soil is 7.1. The organic carbon, available N, P and K are 0.6%, 159.9 kg/ha, 10.42 kg/ha and 280.2 kg/ha, respectively.

5. RESULTS

5.1 Analysis of Historical Canal Flow

In order to understand prevailing delivery schedule of the study distributary, historical daily flow data at its head regulator was collected for 25 years period from the office of the Assistant Engineer, Department of Water Resources, Pratap Nagari, Cuttack, Govt. of Orissa and analyzed. The results of the analysis reveals that in a year, the canal runs in two spells i.e., the first spell in monsoon season and the second spell in the dry season. Fifteen years daily flow data at the head regulator of the distributary reveals that during rainy season the canal runs for about 99 days. On an average, the canal runs for 11, 22, 25, 27 and 14 days in the month of July, August, September, October and November, respectively. The average flow rate during July, August, September, October and November months are 2.65, 3.79, 4.03, 4.39 and 3.99 m^3/sec, respectively. Thus, during monsoon, in most of the time the canal flows at 2/3rd of its designed capacity. During the dry season (winter and summer), it is observed that out of 25 years, the canal had actually run for 15 years indicating a probability of 60% of canal operation during this season. Analyzing the 15 years of flow data for which the canal had actually run, it was observed that on an average the canal runs for about 90 days during this season (7, 23, 24, 25 and 11 days in the month of January, February, March, April and May, respectively). The observed mean flow rate during the month of January, February, March, April and May were 1.91, 2.96, 3.44, 3.90 and 3.10 m^3/sec, respectively against the design discharge of 6.045 m^3/sec (Table 5). Therefore, during the dry season, the canal runs almost at half of its capacity. Further, the prevailing flow delivery pattern of the chosen canal system may be categorized as "Continuous schedule with varying flow rate."

Table 5. Flow delivery characteristics of Phulnakhara distributary during dry season

Month	Pooled mean flow rate, m^3/sec	Lower confidence interval of flow rate at 90% level, m^3/sec	Upper confidence interval of flow rate at 90% level, m^3/sec	Pooled standard deviation of flow rate, m^3/sec
January	1.91	1.72	2.11	1.00
February	2.96	2.87	3.04	0.80
March	3.44	3.35	3.52	0.83
April	3.90	3.82	3.98	0.77
May	3.10	2.93	3.28	1.15

5.2 Model Simulation for Monsoon Season

Simulation results of the existing schedule along with the four alternative rotational schedules indicate that irrigation water requirement is highest for continuous schedule and lowest for 20 days rotational schedule. The 17 years average value of irrigation water requirement was computed to be 17.56 M m^3 for continuous schedule and 14.86 M m^3 for 20 days rotational schedule. Fig. 3 presents the canal water supply and irrigation water requirement (demand) for existing continuous delivery schedule for different years. Perusal of the figure indicates that in all most all the years the supply is in excess than the demand. Therefore, the canal water supply needs to be matched with the irrigation water requirement to avoid an excess water situation in the

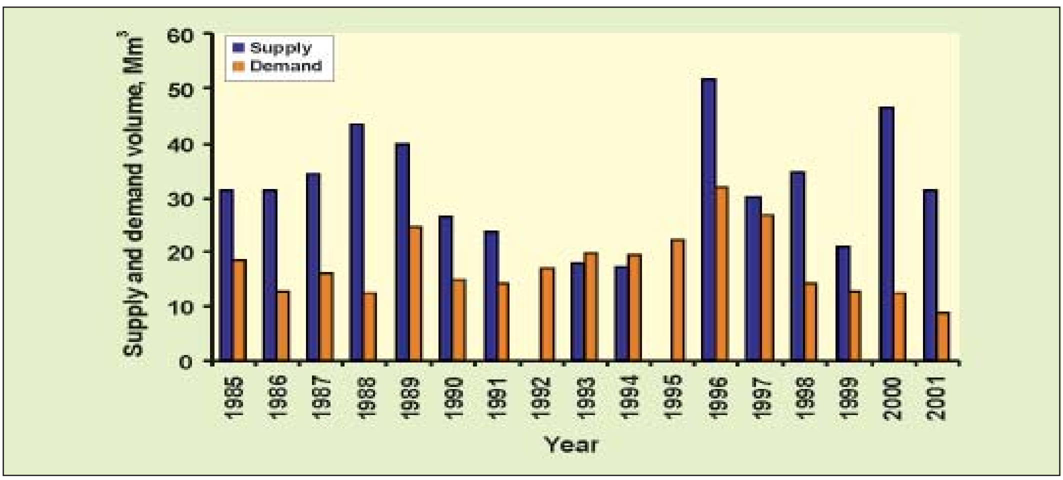


Fig. 3 Canal water supply and irrigation water demand of Phulnakhara distributary for the continuous delivery schedule during monsoon

command. Further, highest deep percolation (660.9 mm) and drainage (163.9 mm) losses were observed for continuous delivery schedule. Lowest deep percolation (628.1 mm) and drainage (135.1 mm) losses were observed for 20 days rotational schedule. Highest ET value of 451.2 mm was computed for existing schedule followed by 448.2 mm for 15 days rotational schedule (Fig. 4). Thus, amongst the four rotational schedules, 15 days rotation looks to be the best one due to highest value of ET, which is an indicator of the crop growth and yield. Average depth of ponding of 86.3, 76.5, 74.8, 73.6 and 70.1 mm were computed for continuous, 7 days rotation, 10 days rotation, 15 days rotation and 20 days rotation delivery schedule. Thus, 15 days rotational schedule looks to be a suitable alternative over the existing schedule for rainy season supply.

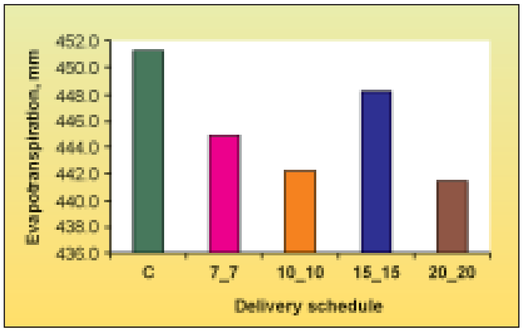


Fig. 4 Computed seasonal evapotranspiration of rice for different delivery schedules

5.3 Experimental Study during Monsoon

5.3.1. Crop growth and yield attributes

Plant height and tillers/hill at harvest are the two crop growth attributes, which were monitored during the study. Both these attributes were influenced significantly by different delivery schedules (Table 6 and 9). In the first year, the highest plant height (114 cm) was observed under the treatment 20 days rotational schedule followed by 15 days rotational schedule (110 cm) in rice variety *Swarna*. However, there was no significant increase in plant height in *Surendra* amongst the treatment. Relatively dwarf height and shorter duration of variety *Surendra* might be reasons for no significant difference in plant height. In the second year, the plant height was not significantly influenced by the treatments in both the varieties due to better availability of water in the initial period. However, there was a slight increase in plant height in the treatment of continuous water availability (T_5). Higher standing water level in the rice plots might have resulted in this slight increase. In the third year, the highest plant height was recorded in 15 days rotational schedule in *Swarna* variety. Pooled analysis of three years data showed that there was a significant difference in plant height amongst the treatments in case of *Swarna*. The highest plant height was recorded in the treatment T_3 (93 cm) and it was comparable with T_4 (91 cm). Lowest plant height was recorded in Control plots (C). In case of *Surendra*, pooled data showed that there was no significant difference in plant height amongst the treatments.

Both the rice varieties receiving irrigation under 15 and 20 days rotational schedules recorded higher tillers/hill and were at par with each other (Table 6 and 9). This trend was observed in all the three years for *Swarna* and two years for *Surendra*. Incase of 15 and 20 days rotational schedule, due to longer frequency of irrigation there was more chances of occurrence of intermittent unsaturated soil condition. This might have created a favourable water regime resulting in better soil aeration, root respiration and utilization of nutrients which in turn resulted in higher tiller production. Further, tiller numbers recorded in 10 days rotational schedule was also significantly higher compared to continuous irrigation due to the similar reasons. Prolonged water stress in control treatment resulted in lower tillers/hill.

Data presented in Table 7 and 10 showed that canal delivery schedules significantly increased yield attributes like, panicles/hill and number of filled grains/panicle. In case of *Swarna,* the highest panicles/hill was recorded in 20 days rotational schedule followed by 15 days rotational schedule and they were at par in all the three years. In case of *Surendra*, the highest panicles/hill was also recorded in 20 days rotational schedule for two years period. Pooled analysis showed that in both the varieties highest panicles/hill was recorded in 20 days rotational schedule and it was at par with 15 days rotational schedule.

Pooled analysis of filled grains/panicle showed that the highest number of filled grains per panicle was recorded in 15 days rotational schedule in both the varieties followed by 20 days rotational schedule. Slight moisture stress in 20 days rotational schedule compared to 15 days rotational schedule during grain filling stage might have caused lesser filled grains/panicle in 20 days rotational schedule compared to 15 days schedule. However, both the treatments were at par with each other. Even though there was no moisture stress in 7 days rotational schedule and continuous water supply, number of filled grains per panicle was significantly lesser compared to 20 days rotational schedule due to lesser panicle length resulted from unfavourable water regime. Though better panicles/hill was observed in control plots, the crop did not perform well with respect to number of grains/panicle due to dry spell and moisture stress at later part of crop growth. Similar effect of moisture stress during later stage on crop growth was also observed by Avil Kumar *et al*. (2006). The percentage of reduction was more in *Swarna* variety. It might be due to the longer crop growth duration of *Swarna* compared to *Surendra.* Due to less number of irrigation, it is expected

Table 6. Effect of treatments on growth attributes of rice variety, *Swarna*

Treatments	Plant height at harvest (cm)				Tillers/hill at harvest			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	100.83	75.11	80.13	84.71	9.70	7.86	9.93	9.17
T_2	100.45	72.80	83.27	87.17	9.90	9.50	9.97	9.80
T_3	109.67	70.49	99.75	93.30	10.60	11.00	11.53	11.04
T_4	114.35	74.00	84.00	90.73	11.70	11.90	10.83	11.05
T_5	106.13	75.75	92.77	91.63	10.50	8.43	7.40	8.70
C	102.86	73.70	75.70	84.01	10.30	8.40	7.20	8.62
CD(P=0.05)	10.04	NS	9.16	4.31	1.06	2.36	0.95	0.82

that there will be to lesser nutrient loss through leaching and runoff water in 15 and 20 days rotational scheduled plots. This has resulted in better utilization of nutrients and higher yield attributes.

Table 7. Effect of treatments on yield attributes of rice variety, *Swarna*

Treatments	Panicle/hill				Filled grains/panicle			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	7.86	6.67	7.33	7.21	92.20	79.93	85.67	85.91
T_2	7.66	7.00	7.23	7.36	84.70	76.80	95.00	85.80
T_3	8.66	8.67	8.83	8.70	108.60	94.47	109.50	104.21
T_4	9.66	8.90	9.27	9.28	113.40	90.20	95.17	99.61
T_5	7.93	6.87	7.07	7.28	99.30	61.53	83.67	81.64
C	8.20	7.13	6.67	7.31	86.70	60.05	69.67	72.15
CD(P=0.05	0.96	1.74	1.21	0.70	25.40	29.41	12.84	12.53

Table 8. Effect of treatments grain yield, straw yield and harvest index of rice variety, *Swarna*

Treatments	Grain yield (t/ha)				Straw yield (t/ha)				Harvest Index			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	4.14	3.35	3.66	3.82	5.90	3.83	4.81	4.88	0.70	0.87	0.83	0.80
T_2	3.91	3.49	3.88	3.87	5.72	5.12	5.19	5.34	0.68	0.68	0.81	0.72
T_3	4.81	4.83	5.12	4.92	6.62	5.50	5.64	5.92	0.72	0.87	0.90	0.83
T_4	5.36	4.94	4.27	4.85	6.81	5.17	5.25	5.74	0.78	0.95	0.78	0.83
T_5	4.06	3.15	3.51	3.67	5.85	4.12	4.83	4.93	0.69	0.76	0.78	0.74
CCD	4.20	3.27	3.16	3.49	6.08	3.83	3.89	4.60	0.69	0.87	0.62	0.72
(P=0.05)	0.31	1.24	0.59	0.43	1.34	0.97	0.96	0.45				

Table 9. Effect of treatments on growth attributes of rice variety, *Surendra*

Treatments	Plant height at harvest (cm)				Tillers/hill at harvest			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	98.80	82.21	88.15	88.15	10.20	9.53	9.70	9.81
T_2	93.50	84.96	89.28	90.86	10.40	9.60	10.50	10.19
T_3	98.33	85.87	83.03	80.25	9.96	11.53	11.53	11.19
T_4	93.73	79.45	88.78	86.98	11.40	11.20	10.57	11.03
T_5	94.43	81.96	89.49	89.86	10.63	8.66	8.53	9.28
C	95.26	76.55	84.53	86.25	11.23	9.33	7.97	9.53
CD(P=0.05)	NS	NS	NS	NS	0.80	1.72	2.45	0.98

Table 10. Effect of treatments yield attributes of rice variety, *Surendra*

Treatments	Panicle/hill				Filled grains/panicle			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	8.53	7.40	7.47	8.10	86.70	62.00	87.27	74.84
T_2	8.93	7.83	8.40	8.60	90.00	57.00	92.40	79.80
T_3	8.40	9.73	9.27	9.14	94.11	69.93	102.37	88.60
T_4	10.30	9.27	9.39	9.55	100.85	68.13	96.83	88.60
T_5	9.10	7.67	8.00	8.07	86.42	53.86	74.17	71.46
C	9.53	7.87	6.27	7.88	89.27	50.60	69.33	69.73
CD(P=0.05)	1.84	1.71	1.15	0.84	19.55	13.10	13.64	8.35

Table 11. Effect of treatments on grain yield, straw yield and harvest index of rice variety *Surendra*

Treatments	Grain yield (t/ha)				Straw yield (t/ha)				Harvest Index			
	2002	2003	2004	Pooled	2002	2003	2004	Pooled	2002	2003	2004	Pooled
T_1	3.73	3.26	4.09	3.55	5.66	3.62	4.62	4.63	0.65	0.70	0.79	0.71
T_2	4.01	3.25	4.31	3.71	5.76	3.72	4.65	4.71	0.69	0.68	0.83	0.73
T_3	4.18	4.39	4.81	4.46	5.60	4.57	5.24	5.20	0.74	0.83	0.88	0.82
T_4	4.72	4.51	3.66	4.40	5.90	4.72	5.09	5.15	0.80	0.85	0.83	0.83
T_5	3.66	3.37	3.65	3.51	5.47	3.65	4.51	4.54	0.66	0.74	0.79	0.73
C	3.90	3.37	3.58	3.47	5.85	3.55	4.08	4.49	0.66	0.71	0.77	0.71
CD(P=0.05)	1.08	0.90	0.36	0.47	0.99	0.36	0.83	0.45				

5.3.2 Yield and water use

The grain yield and straw yield (Table 8 & 11) was significantly influenced by the treatments. Maximum grain yields of 5.36 t/ha and 4.94 t/ha in case of *Swarna* and 4.72 t/ha and 4.51 t/ha in case of *Surendra* was obtained during first and second year of experiment respectively under 20 days rotational schedule and they were at par with 15 days rotational schedule. This trend was different in third year as the highest grain yield was recorded in 15 days rotational schedule plots for both the varieties. Less rainfall in third year of experiment might be reason for this difference. The lowest grain yield was recorded in control in both the varieties as moisture stress during later period severely affected grain filling. Increase in yield in 15 and 20 days rotational schedules compared to continuous water supply (T_5) ranged from 6.61 to 8.44 percent. The maximum grain yield obtained in 15 and 20 days rotational schedules may be due to favourable field water depth over all other treatments, which resulted in higher tillers/hill, panicles/hill and filled grains/panicle. Higher straw yield and harvest index was also observed in 15 and 20 days rotational schedules. Lower harvest index recorded in continuous water supply (T_5) was due to higher straw yield and low grain yield recorded in that treatment.

Fig. 5 presents the average (three years average) depth of ponding in various treatments. As evident, Continuous schedule plots registered highest ponding water depth and control plots registered lowest depth of ponding. Using the pan evaporation value the potential evapotranspiration for rice crop during the crop growth period was estimated as 343 mm. The amount of irrigation water applied was higher in continuous water supply (121 cm) and lowest in 20 days rotational schedule (42 cm). Saving in irrigation water due to rotational schedule compared to continuous water supply ranged from 18 to 65 percent (Table 12). Highest deep percolation loss was observed in continuous water supply due to higher ponding water depth. Lowest deep percolation loss was noticed in control plots. Water use efficiency was the highest in control treatment (*rainfed* condition) as there no irrigation water was applied. There was an increase in WUE of 22 to 66 % in rotational schedules

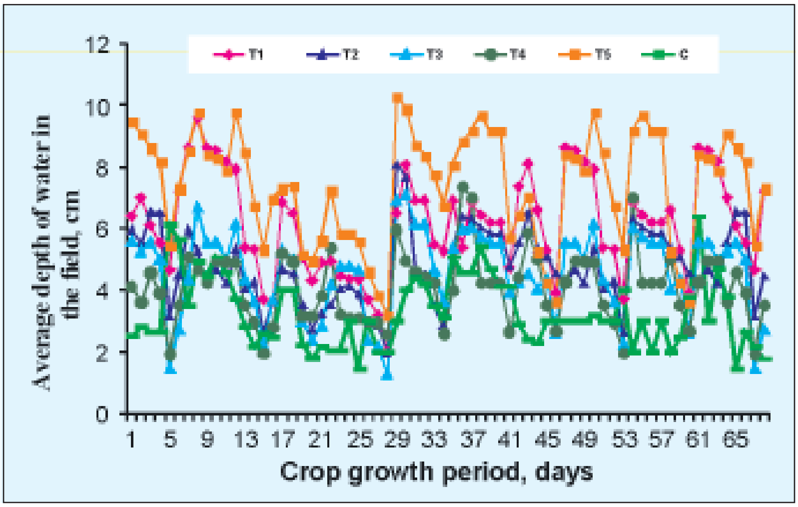


Fig. 5 Average depth of ponding in the experimental fields during crop growth period.

Table 12. Effect of rotational delivery schedule on water use efficiency

Treatment	Total depth of irrigation water applied (cm)	Water saving (%)*	Effective rainfall during crop growth period (cm)	Total deep percolation loss(mm)	WUE (kg/ ha- cm)	
					Swarna	*Surendra*
T_1	87.2	18	66.3	392	24.9	23.1
T_2	79.8	34	66.3	275	26.5	25.4
T_3	74.0	39	66.3	260	35.1	31.8
T_4	42.1	65	66.3	221	44.7	40.6
T_5	121.0	–	66.3	501	19.6	18.7
C	-	–	66.3	194	52.9	52.8

* *compared to continuous water supply*

plots over continuous schedule. Increase in yield and water use efficiency due to rotational water supply compared to continuous canal flow and other water saving methods in rice was reported by Palanisami (2002) in *Cauvery* delta. Here, amongst the rotational schedule, the highest WUE was recorded in 20 days rotational schedule followed by 15 days rotational schedule. However, 15 days rotational schedule registered maximum grain yield. Thus, considering both yield and WUE as the criteria to choose the best alternate schedule, 15 days rotational schedule is recommended over the continuous schedule.

5.4 Model Simulation for Dry Season

5.4.1. Computation of actual evapotranspiration

Actual evapotranspiraton (ETa) during the entire season is an indicator of crop growth and yield (Doorenbos *et al*., 1986). Table 13 presents the model computed seasonal actual evapotranspiration of dry season crops grown under different delivery schedules. The area weighted average of seasonal ETa was calculated by adding the products of seasonal ETa of individual crops with their respective area of coverage and then dividing by total cropped area. The highest seasonal ETa was observed under continuous schedule. Among the alternatives considered, schedule 7_7, 10_7 and 15_7 computed almost same seasonal ETa. There is about 18 mm reduction in seasonal ETa (area weighted average of all crops) in 15_15 schedule than that of continuous schedule. Similarly, there is about 13 mm reduction in average seasonal ETa in 10_10 schedule than that of continuous schedule. Thus, a reduction of 18 mm (about 5% of total season ETa) in case of 15_15 schedule and 13 mm (about 3.5% of total seasonal ETa) in case of 10_10 schedule narrows down the prospects of these two rotational canal delivery schedules from the list of alternatives considered.

Table 13. Model computed seasonal actual evapotranspiration (15 years average) of dry season crops under different delivery schedules

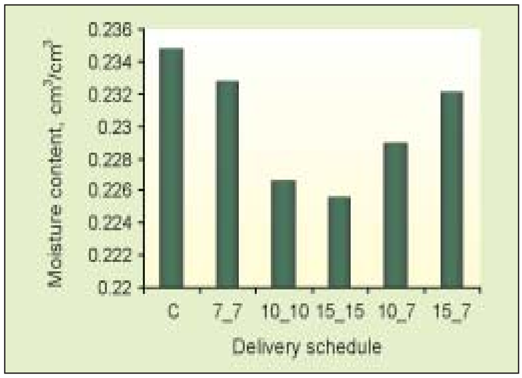
Delivery schedule	Seasonal actual evapotranspiration (mm)							
	Paddy	Ground -nut	Potato	Tomato	Cabbage	Cauli- flower	Brinjal	Area weighted average
C	494.20	322.29	304.23	298.11	363.61	302.09	389.18	359.80
7_7	492.08	319.82	295.43	293.60	353.11	293.07	380.53	354.44
10_10	488.99	311.78	283.49	289.32	342.61	289.13	370.99	346.90
15_15	483.44	313.24	275.37	285.21	332.82	273.91	368.62	342.14
10_7	491.06	316.50	291.47	294.18	350.59	291.52	383.00	352.35
15_7	492.31	319.45	295.95	293.88	353.18	293.59	384.82	354.86

5.4.2 Depth of ponding and soil moisture content

Fig. 6 shows the average depth of ponding in winter rice fields during the crop growth period under different delivery schedules. Schedule 15_15 and 10_10 registers a very low depth of ponding and hence looks to be unfavourable for winter rice. Average depth of moisture content for non-paddy crops are shown in Figs. 7a to 7f. The average moisture content of the command at field capacity and wilting point is determined as 0.262 cm^3/cm^3 and 0.133 cm^3/cm^3 respectively. Thus, at 25% depletion level of available soil moisture, the moisture content works out to be 0.229 cm^3/cm^3. Perusal of Figs. 7a to 7f indicates that for all the crops, schedule 7_7, 10_7 and 15_7 have average moisture content > 0.229 cm^3/cm^3. Schedule 10_10 and 15_15 have average moisture content value less than 0.229 cm^3/cm^3. Hence, there will be stress to crops if these two schedules (10_10 and 15_15) are practiced. In other words, during dry season, canal closure of more than 7 days will create moisture stress on crops. As the average water depth in rice field or the average moisture content of non-paddy crops really don't confirm periodical stress during entire crop growth period, it was decided to examine the water depth in rice field and moisture content in non-paddy crops throughout the crop growth period. For this purpose, a most dry year (1998) was chosen. Fig. 8 presents the daily depth of ponding in rice field and Figs. 9a to 9f presents the daily moisture content for non-paddy crops. As evident from Fig. 8 the water depth has fluctuated almost in the similar fashion for all three schedules. Schedule 7_7 looks to have a better edge over the other two schedules as in this case the water depth vanished from the soil surface for lesser number of days. For non-paddy crops, it is observed that in most of the time the moisture level remained within 32% of the depletion level of available soil moisture (moisture content of 0.22 cm^3/cm^3) for schedules 7_7, 10_7 and 15_7. Hence, these three schedules were further examined to select the best one.

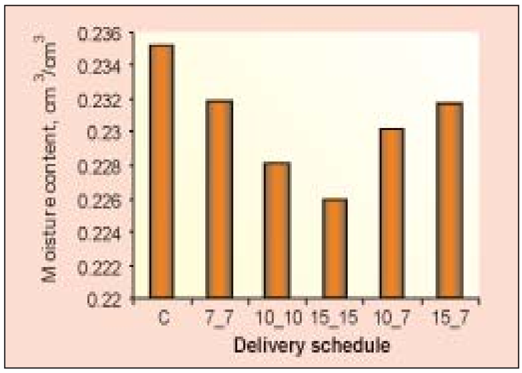
Fig. 6. Average depth of ponding in the paddy field at different delivery schedules

(a) Groundnut

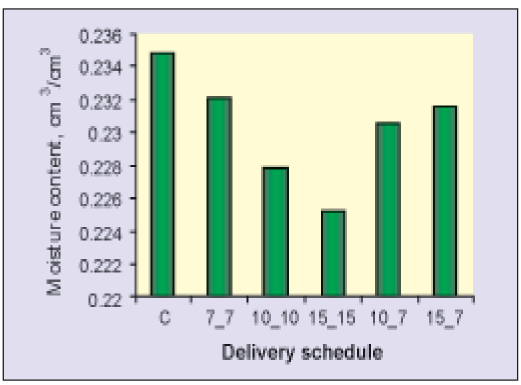


(b) Potato

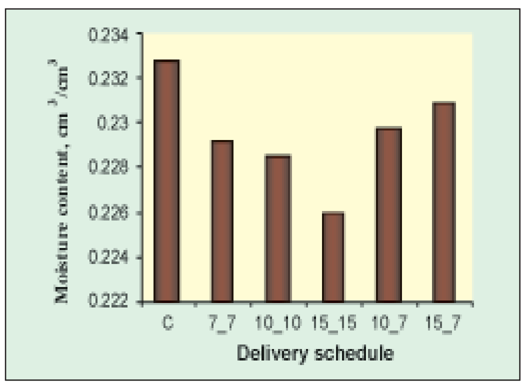
(c) Tomato



(d) Cabbage



(e) Cauliflower



(f) Brinjal

Fig. 7 (a-f). Average moisture content during the crop growth period for different delivery schedule

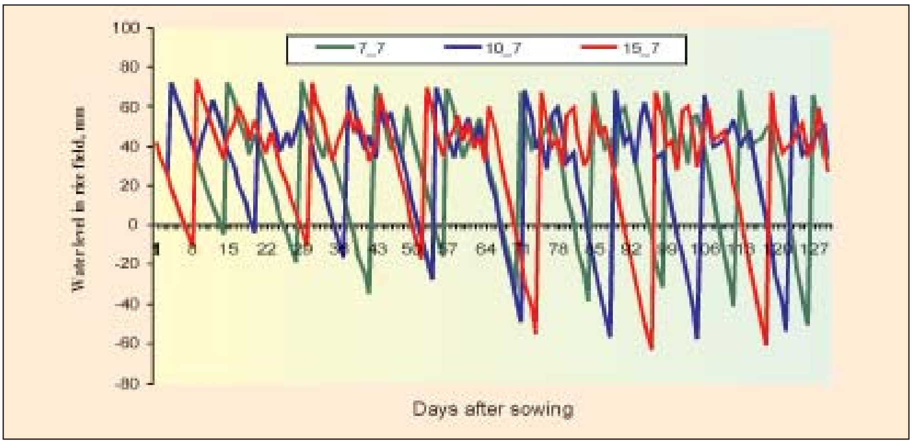


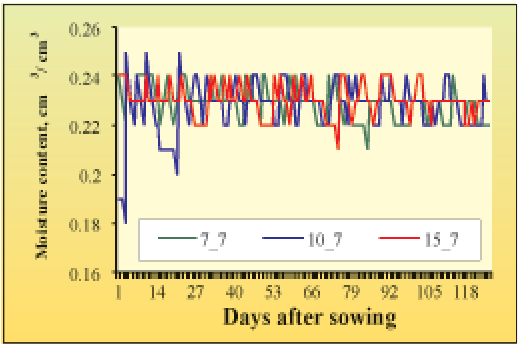
Fig. 8. Average depth of ponding in paddy fields in a most dry year (1998) for three different rotational schedules

5.4.3 Disappearance of water from paddy field

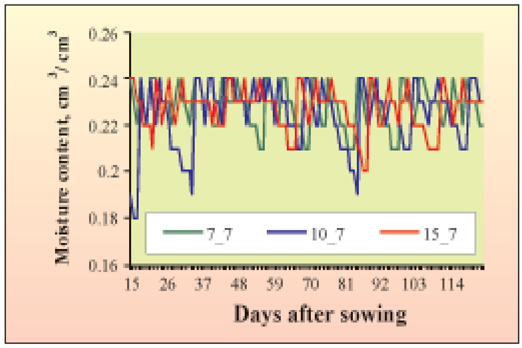
Table 14 presents the details of disappearance of water from paddy fields. Schedule 7_7 registered maximum of 4.4 4 days of disappearance of water. This value increased to 5.19 $\simeq$ 5 days and 5.5 $\simeq$ 6 days for 15_7 and 10_7 schedule, respectively. Results of the multi-locational experiment conducted under All India Coordinated Research Project on Water Management (Mishra *et al.*, 1999) reveals that in sandy clay loam to silt loam soil, disappearance of 3 to 5 days of water has not created any significant effect on crop growth and yield. Since the study distributary is dominated by sandy clay loam soil, it is expected that maximum disappearance of 4 days of water from paddy field will not bring any significant effect on crop growth and yield. Hence, 7_7 days schedule during dry season will have negligible moisture stress on winter rice amongst the alternative rotational schedules screened. Further, in this schedule the paddy field will have 8.5 times disappearance of water from its soil surface. It is expected that, this frequent wetting and drying of soil will enhance soil aeration and root respiration leading to better crop growth and yield. Thus, 7_7 rotational schedule is found to be the best alternate that suits to both paddy and non-paddy crops by maintaining a favourable water regime.

Table 14. Details of disappearance of water level from paddy field

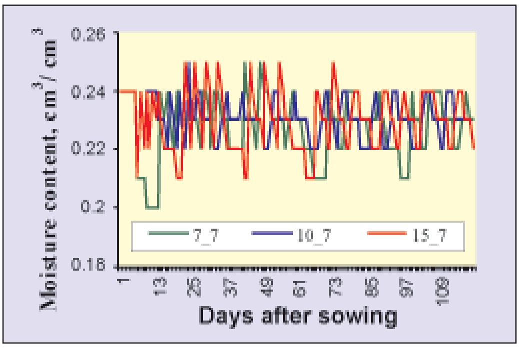
Disappearance of water level from rice basin	Delivery schedule		
	7_7	10_7	15_7
Maximum number of days of disappearance	4	6	5
Number of times for which maximum days of disappearance has taken place	2	1	1
Total number of times disappearance has taken place	9	6	6



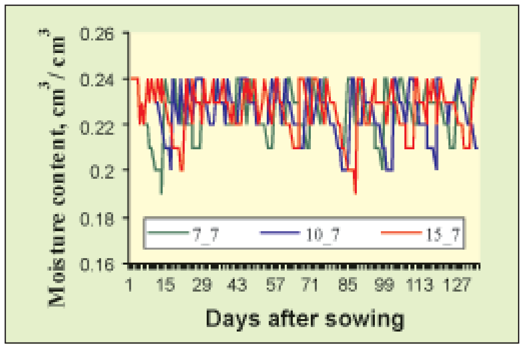
(a) Groundnut



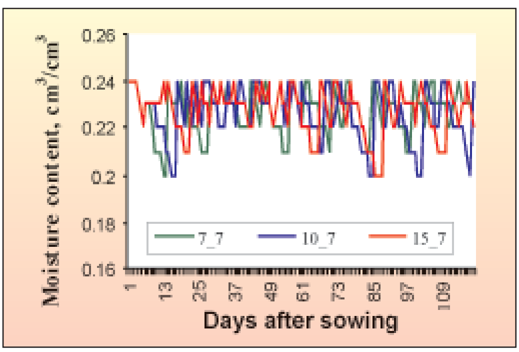
(b) Potato



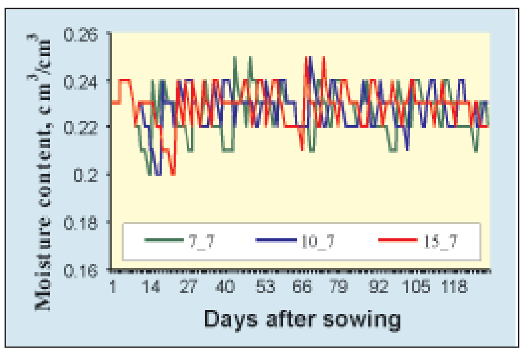
(c) Tomato



(d) Cabbage



(e) Cauliflower



(f) Brinjal

Fig.9 (a-f). Moisture content during the crop growth period in a most dry year (1998) for three different rotational schedules

5.4.4. Comparison of irrigation water supplies with crop water demands

The actual canal water supplied during the dry season and the model computed canal water required for irrigation under different delivery schedules at the head regulator of the distributary are presented in Table 15. In case of prevailing continuous schedule, the requirement is more than the actual water supplied. In case of rotational alternative schedules considered, the model computed water requirements were found to be less than the actual water supplied. Adopting 7 days rotational schedule (7_7) will save on an average about 10.31 % of irrigation water when compared with the actual irrigation water supplied. Thus, 7 days on followed by 7 days off rotational schedule will save considerable amount of irrigation water without bringing any moisture stress on the crops. In addition to the advantages of rotational schedule, adoption of this schedule will motivate farmers to upkeep and maintain the field channels, which were constructed by Command Area Development Authority. This schedule will discourage field to field irrigation. Fig. 10 presents the daily actual flow rate at the head regulator of the distributary and the model computed irrigation water requirement for 7_7 rotational schedule for the year 2000. During the canal operation periods for the suggested rotational schedule, it is observed that the canal flows mostly at its full supply level. This will improve the water delivery, reliability of irrigation water supply and equitable distribution. Thus, 7_7 rotational schedule can be safely applied to study system during dry season as an alternative to the prevailing continuous schedule.

Table 15. Comparisons of actual irrigation water supplied and model computed crop water demand

Year	Actual irrigation water supplied during dry season, Mm^3	Model computed canal water requirement during dry season under different delivery schedules, Mm^3					
		C	7_7	10_10	15_10	10_7	15_7
1985	26.26	31.42	24.75	24.37	22.63	26.05	27.20
1986	24.48	28.78	22.33	22.19	20.66	20.58	24.67
1987	37.06	31.92	25.45	24.95	23.76	23.26	27.84
1988	42.04	34.01	27.33	26.67	25.57	28.41	29.63
1989	34.22	27.42	21.07	20.63	19.60	22.00	23.30
1990	25.26	30.33	23.66	23.22	21.97	25.15	26.15
1991	0.00	29.00	22.87	22.35	21.02	23.98	25.16
1992	0.98	32.40	26.29	25.63	24.68	25.57	28.49
1993	0.00	31.32	24.93	24.18	23.12	26.41	27.30
1994	15.16	29.52	22.98	22.22	21.35	24.30	25.59
1995	0.00	30.50	23.99	23.22	22.01	25.05	26.24
1996	0.00	27.33	21.16	20.61	19.02	22.29	23.55
1997	29.14	25.18	18.66	18.28	17.14	19.87	21.02
1998	0.00	32.33	26.19	25.43	24.34	27.48	28.50
1999	19.18	31.57	25.35	24.56	23.55	26.24	27.12
2000	38.47	30.47	24.29	23.61	22.53	25.03	26.08
Average	26.57	30.21	23.83	23.26	22.06	24.48	26.11

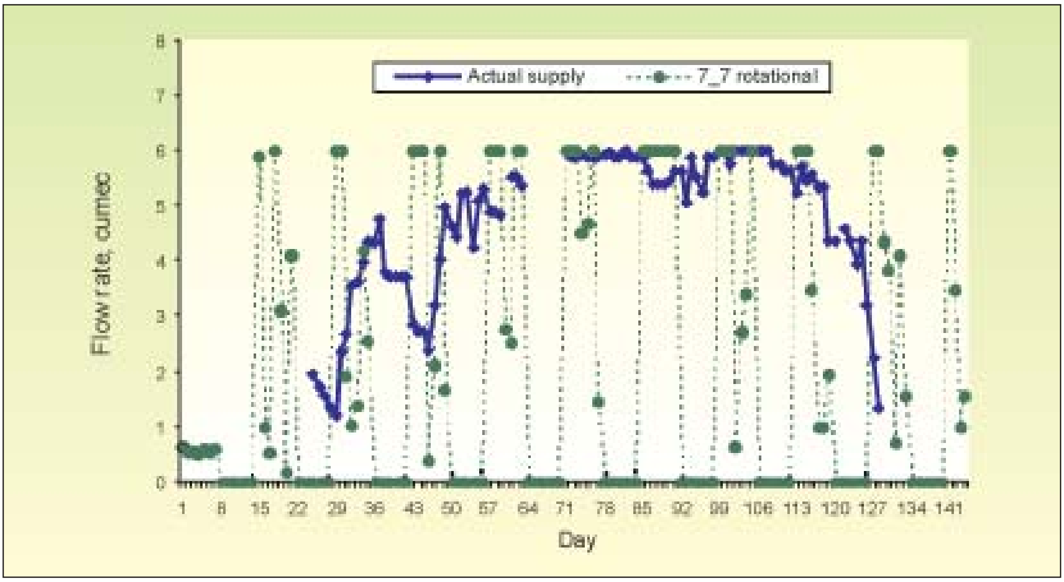


Fig. 10. Comparison of actual (prevailing schedule) and computed (7_7 rotational schedule) flow rate at the head regulator of the distributary during 2000

6. DISCUSSIONS

Rotational canal delivery schedule over the continuous delivery schedule has been observed beneficial for the Phulnakhara distributary. It is suggested to have 7 days rotation (7 days canal operation followed by 7 days canal closure) in the dry season and 15 days rotation (15 days canal operation followed by 15 days canal closure) during monsoon season. For better operation and distribution of irrigation water, all the distributaries of Puri main canal system may be grouped into two sets. The first set of distributary when supplied with the irrigation water, the second set will remain closed. After the first sets turn is over, they will be kept closed and the second set should run.

Further, it is also envisaged that water will take almost a day (average time) for traveling from head regulator to tail end point of the distributary. Therefore, the distribuary should run practically for eight days (one day travel time + seven days for irrigating the command) during dry season in each rotation and for sixteen days (one day travel time + fifteen days for irrigating the command) during monsoon in each rotation.

During the dry season (*rabi*) it is suggested to start the canal by 1st of December. This may not be acceptable always. If there is delayed monsoon and the command is not ready for the second crop after *kharif* rice, the supply can be delayed by 15 days at least. Therefore, the prevailing climatic and moisture scenario of the command needs to be taken into account while beginning the canal operation at the start of a season.

The above findings (suggested alternative delivery schedules) are the outcome of model simulation and an experimental study. A number of assumptions have been made while carrying out the model simulation which will vary in a large command. Therefore, the findings of this study need to be tested in the command of a distributary as a pilot study before making a general recommendation.

7. CONCLUSIONS

Models for modifying the existing canal delivery schedule during monsoon and dry season were formulated for a run-of-the-river canal system of Orissa, India. Model simulation study over a period of 17 years supported by field experimental study revealed that 15 days rotational schedule (15 days canal operation followed by 15 days canal closure) is the best alternate over the prevailing Continuous delivery schedule. The alternate schedule registers a better crop ET and yield. Similarly, during the dry season, model simulation results over a period of 15 years revealed that 7 days rotational schedule is the best alternate over existing schedule. This schedule creates a favourable water regime for both paddy and non-paddy crops and saves about 10.31% of irrigation water when compared to the existing continuous schedule.

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