# IRRIGATION WATER MANAGEMENT SIMULATION MODEL FOR LOWLAND RICE PRODUCTION

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## ABSTRACT

**An irrigation water management computer simulation model for lowland rice production was developed using the concept of rotation irrigation. It was designed so that the number of rotation areas and interval of irrigation could be varied within the program. Input parameters included maximum irrigable area, variety of rice which determined the period of irrigation, kind of soil and efficiency of the irrigation system. To run the computer simulation model, data on rainfall, pan evaporation and stream flow were necessary. The model can be used to determine the appropriate time of planting rice and to solve problems in water management.**

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**KEY WORDS:** Water management. Simulation model. Mathematical model. Rotation irrigation. Rice.

## INTRODUCTION

Irrigation water management is one of the strategic areas for research and development in the Philippines. Common efforts used to augment farm income cannot be effective without proper irrigation water management. Hagan and Houston (1968) stated that improved management of irrigation water can probably do more to increase food supplies, raise agricultural income and improve rural living conditions than any other single agricultural practice in rice-growing regions. However, irrigation water management is affected by stochastic events.

The popularity and use of the computer in irrigation water management were demonstrated by a number of workers. Howell and Hiler (1975) presented the response of grain sorghum to a water deficit occurring in 3 growth periods as derived from a controlled experiment. The result of the experiment was then used in a stochastic dynamic programming procedure to maximize the yield of sorghum subjected to an irrigation water availability constraint (Howell, Hiler and Redell, 1975). The results showed the proper irrigation decisions for each period when the soil water content and amount of irrigation water at the start of the period were known.

Optimal allocation studies of water supply were often related to storage water as the source of irrigation water over the growing season. Dudley and co-workers made a comprehensive study on the optimization of limited water allocation under a stochastic rainfall and water requirement regime for corn (Dudley, 1970; Dudley, Howell and Musgrave, 1971a, 1971b, 1972). In rice production, an attempt was made to optimize the water supply from river diversion irrigation systems through water management and scheduling of crop planting. Angeles (1975) studied the area that can be sufficiently supplied with irrigation water with the minimum river flow, minimum rainfall and maximum evaporation within a weekly period.

Considering the complexity of the problems in water management and the power of the computer, an irrigation water management simulation model was developed for use in water management studies for rice production.

## MATERIALS AND METHODS

*Simulation Model.* — The simulation process started by providing water for land preparation. Water was applied to the field in rotation among rotation areas. Since farmers were usually in the field during land preparation, any excess water from one rotation area could be diverted immediately to the next rotation area. When the whole irrigable area had been supplied with the needed water for land preparation, the model checked whether or not irrigation was needed in the first rotation area. Any extra water from land preparation was applied to the first rotation area if the number of days after land preparation was 7 days or more; otherwise, the extra water was not used.

The relationship of the irrigation processes to stages of plant development and rotation areas is shown in Fig. 1. The pre-irrigation period included the time needed to provide water requirement for land preparation in each rotation area. It was assumed that land preparation and rice planting was completed after supplying adequate water. A period of plant recovery which was 7 days without irrigation water was required to stabilize the plants. A 90-day irrigation period for medium-maturing variety of rice began after the 7-day plant recovery period. A drained period before harvest, when the plants did not need water, was provided to facilitate harvesting.

At the start of the irrigation period, the period of diverting water from the stream for irrigation pur-

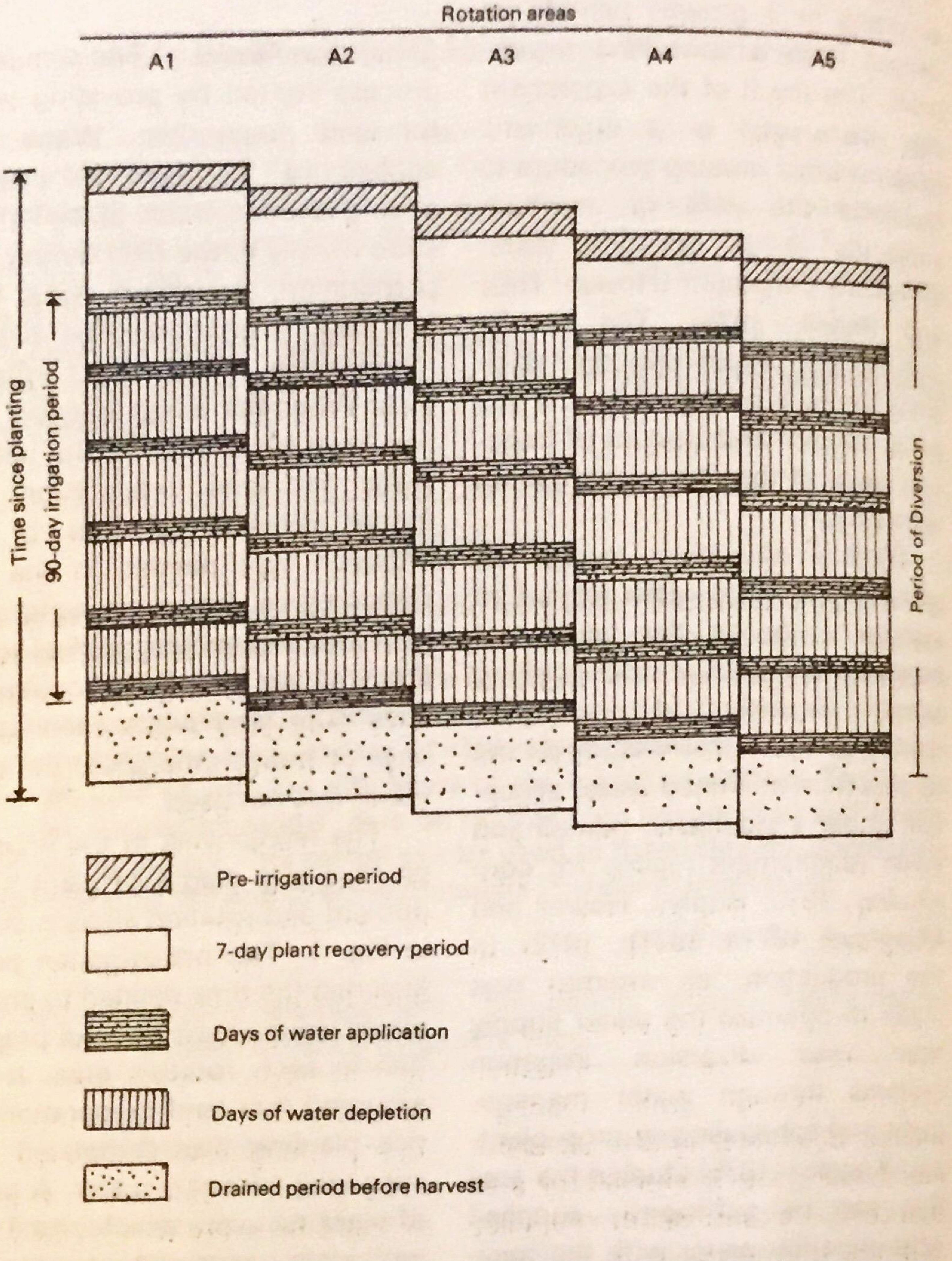

**Fig. 1.** Rotation irrigation process with five rotation areas and a 120-day maturing rice variety.

poses also started. It was equal to the irrigation period when the rotation unit was equal to 1, and increased when the number of rotation areas increased. This implies that more water was diverted for irrigation with a greater number of rotation areas. However, the number of days of water application and water depletion in the irrigation period depended upon the number of rotation areas and rotation interval. This restriction limited the period of diversion to the optimal number of rotation areas and rotation interval. The optimal number of rotation areas and rotation interval combination provided water management that supplied irrigation water without developing moisture stress to any rotation area. For all rotation areas to be irrigated, the maximum time of applying irrigation water to each rotation area was limited to the ratio between rotation interval and number of rotation areas. Water was diverted to the next rotation area when the application time was equal to or greater than the maximum application time, whether or not the water requirement was met. When all rotation areas were irrigated, the irrigation cycle was repeated throughout the irrigation period depending upon the rotation interval, number of rotation areas and the variety of rice which set the duration of the irrigation period. The simulation model is presented in Fig. 2.

*Mathematical Model.* — The simulation model was designed to calculate a number of dynamic variables. During the pre-irrigation period, it determined the number of delays of land preparation due to lack of water. Other calculations began on the first day of the irrigation period based on hydrologic data.

In both land preparation and irrigation loops, the simulation model modified the data of stream flow, pan evaporation and rainfall as input data. The stream flow data were modified to an allowable diversion which was no more than 50% of the flow above the required baseflow as determined by water policy. The allowable diversion was set to zero when it was less than or equal to zero. The expression was as follows:

$$QA(K) = (QS(J,K) - QL) \times FRACQ$$

where QA(K) = allowable diversion for day K, cu meter/min,
QS(J,K) = stream flow for year J and day K, cu meter/min,
QL = lowest flow in a given length of record, cu meter/min,
and
FRACQ = fraction above the required base flow, %.

The depth of daily water diversion (WIRQ) was computed by the use of the rational equation,

$$WIRQ = C \times QA(K) \times T \times EFF/AU$$

where EFF = conveyance efficiency, %,
AU = size of the rotation area, ha,
C = conversion constant = 14.40

T = 1 day, for a daily water application of stream flow.

Data on rainfall were modified following the assumption of Dudley (1970) that daily rainfall less than 0.10 cm is not effective, while 90%

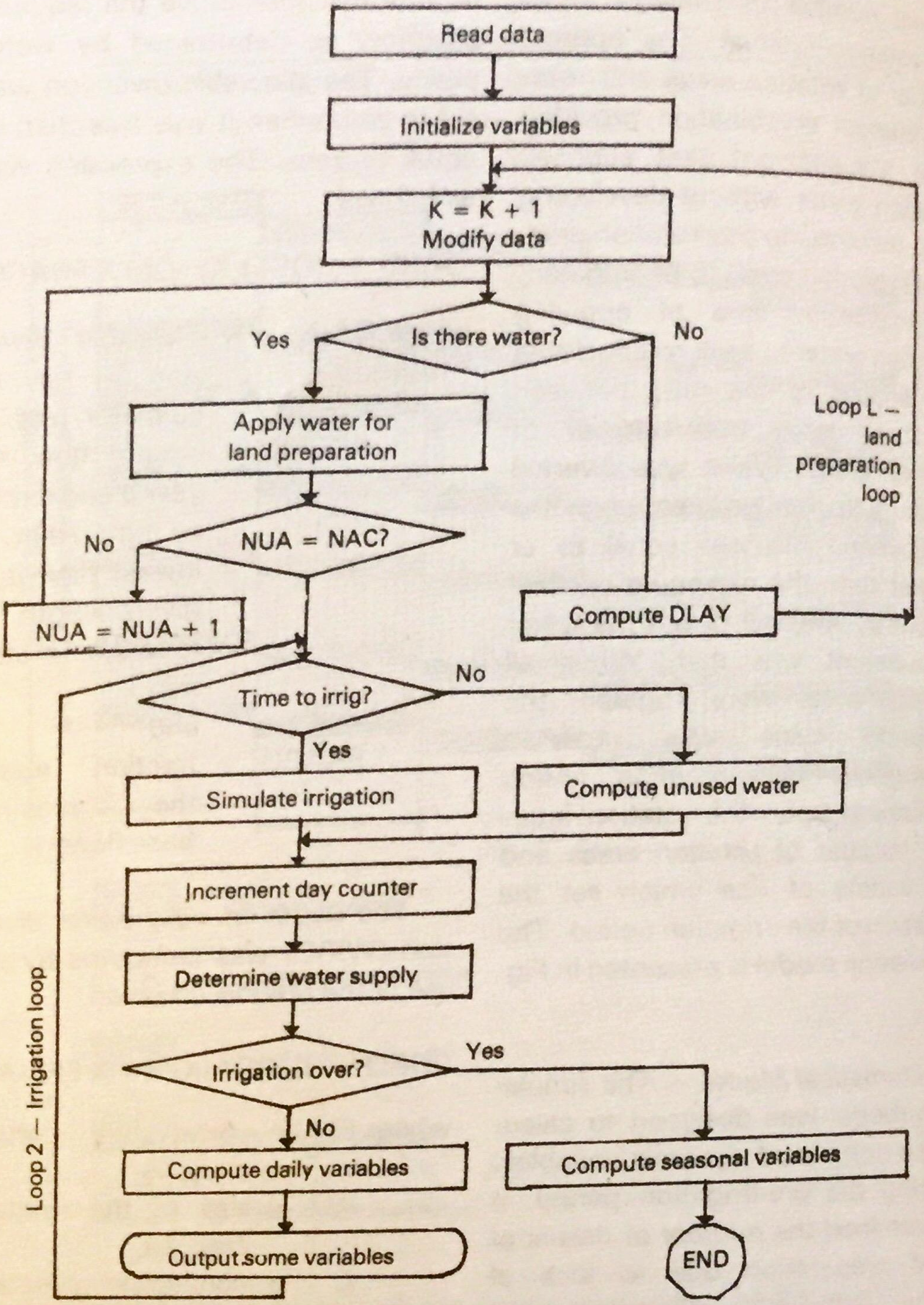

**Fig. 2.** Schematic diagram of the simulation model.

Legend:

K - day counter that read a new day throughout the season

DLAY - variable that gave the number of days for water application in a particular rotation area for land preparation

NUA - counter of rotation area

NAC - number of rotation areas

Loop 1 - land preparation loop - provided enough water for land preparation

Loop 2 - irrigation loop - provided water for irrigation of the daily rainfall greater than 0.10 cm is effective. The effective rainfall was then calculated by using the following equation which provides 10% for foliage interception:

$$ERN(K) = RN(J,K) - 0.10 \times RN(J,K)$$

where ERN(K) = effective rainfall for day K, cm, and
RN(J,K) = recorded daily rainfall greater than 0.10 cm for year J, and day K, cm.

Pan evaporation data were modified to represent the potential evapotranspiration with the use of the regression equation developed by Saxton, Johnson and Shaw (1974). The regression equation is rewritten as:

$$ET(K) = 0.01 + 0.83 \times PEV(J,K)$$

where ET(K) = potential evapotranspiration for day K, in, and
PEV(J,K) = pan evaporation for year J and day K, in.
1 in = 2.54 cm.

The actual evapotranspiration was equal to the potential evapotranspiration for saturated soil conditions. This was true for rice production in which,

$$DW(K) = ET(K) + PERC$$

where DW(K) = daily moisture depletion, cm and
PERC = daily percolation, cm

The cumulative moisture depletion after full irrigation was then calculated as,

$$\begin{aligned} TDW(NUA) &= \overset{n}{\underset{i=1}{\Sigma}} \; DW(K) \\ i &= \end{aligned}$$

where TDW(NUA) = cumulative moisture depletion after full irrigation for a given area unit, cm,
n = number of days after full irrigation, and
i = 1, first day after full irrigation.

The cumulative moisture depletion is called water depletion. It was set to zero when the depth of water was maximum. When soil moisture fell below saturation point, water depletion and depth of water in the field were corrected by disregarding percolation and considering the effects of the soil factor on evapotranspiration.

Since rice fields were provided with storage which became full after every adequate irrigation, water consumption could be estimated by the change of available storage after each day. The procedure measured water consumption in terms of the amount of water added into the storage. The available storage and water consumption were computed based on the depth of water in the field. First, the available storage was computed before the application of water for each rotation area. Then the average available storage was calculated. After the application of water for the day, the available storage for each rotation area and the average were again computed. The difference between the average available storage before and after the application of water was the water consumption during the day. Water consumption during the season was the accumulation of daily water consumption. The expressions used were as follows:

$$\mathrm{WS(NUA)} = \mathrm{WRI} - \mathrm{DEPTH\ (NUA)}$$

$$\mathrm{WS1} = (\mathrm{WS})(1)_1 + \dots + \mathrm{WS(NAC)}_1)/\mathrm{NAC}$$

$$\mathrm{WS2} = (\mathrm{WS}(1)_2 + \dots + \mathrm{WS(NAC)}_2)/\mathrm{NAC}$$

$$\mathrm{DWS} = \mathrm{WS1} - \mathrm{WS2}$$

$$\mathrm{SDWi} + 1 = \mathrm{SDWi} + \mathrm{DWS}$$

where

WS(NUA) = available storage for a given area unit, cm,

DEPTH(NUA) = depth of water for a given area unit, cm,

WRI = depth of spillway, cm,

WSI = average available storage at the start of the day, cm,

WS2 = average available storage at the end of the day, cm,

NAC = rotation unit used,

WS(NAC)1 = available storage for 1, 2, ..., NAC area unit at the start of the day, cm,

WS(NAC)2 = available storage for 1, 2, ..., NAC area unit at the end of the day, cm,

DWS = change of available storage, equivalent to the daily water consumption, cm,

SDWi = cumulative water consumption of previous day, cm and

SDWi = cumulative water consumption of present day, cm.

Depth of water was computed by adding rainfall and water from the stream every day throughout the time of application. Excess water or runoff was estimated by subtracting the depth of spillway from the total depth of water applied. The relationship used in the model were expressed as follows:

$$\mathrm{DEPTH(NUA)} = \sum_{i=1}^{\mathrm{TA}} (\mathrm{WIRR} + \mathrm{WIRQ})$$

$$\mathrm{RNAU(NUA)} = \mathrm{DEPTH(NUA)} - \mathrm{WRI}$$

where

DEPTH(NUA) = depth of water for a given area unit, cm,

RNAU(NUA) = depth of run off for a given area unit, cm,
WIRR = depth of rainfall, cm,
WIRQ = depth of water diversion, cm,
TA = time of applying irrigation water, days, and
$i$ = 1, ..., TA.

Total amount of runoff and total amount of water applied for the whole season were calculated by the use of the following expressions:

$$\begin{aligned}
\text{OVER} &= (\text{RNAU}(1) + \ldots + \text{RNAU}(\text{NAC}))/\text{NAC} \\
\text{TRNO}_{i+1} &= \text{TRNO}_i + \text{OVER} \\
\text{AIR} &= \text{WIRRA}(1) + \ldots + \text{WIRRA}(\text{NAC}))/\text{NAC} \\
\text{SAIR} &= \text{AIR} + \text{WIRR} \\
\text{CUIRR}_{i+1} &= \text{CUIRR}_i + \text{SAIR}
\end{aligned}$$

where

OVER = average runoff for a given rotation unit, cm,
RNAU(NAC) = amount of runoff for area 1, 2, ..., NAC, cm,
$\text{TRNO}_i$ = cumulative runoff of previous day, cm,
$\text{TRNO}_{i+1}$ = cumulative runoff of present day, cm,
AIR = average diversion for a given rotation unit, cm,
WIRRA(NAC) = irrigation water applied for area unit 1, 2, NAC, cm,
SAIR = sum of average diversion and rainfall, cm,
$\text{CUIRR}_i$ = cumulative amount of water applied of previous day, cm and
$\text{CUIRR}_{i+1}$ = cumulative amount of water applied of present day, cm.

Water balance for the whole irrigation season was expressed in terms of amount of water applied, water consumption and runoff, as follows:

$$\text{CUIRR} = \text{TRNO} + \text{SDW}$$

The depth of water in the field, DEPTH(NUA), was used as the basis for determining the water depletion correction when soil moisture fell below the saturation point. It was also the basis for computing the number of moisture-stress days. The number of moisture-stress days was counted beginning 3 days after the depth of water in the field became zero within the irrigation period. The yield of rice was then computed based on the regression equation developed from data given by Wickham and Valera (1976). The equation was expressed as:

$$\text{Y(NUA)} = 6.0 - 0.143 \text{ X } \text{NSTSS(NUA)}$$

where

Y(NUA) = rice grain yield for a given area unit,

tons/ha
NSTSS(NUA) = Do-3 = number of moisture stress days, where
Do = number of days when DEPTH (NUA) was less than or equal to zero.

The model was designed to print out values of seasonal variables if needed after each season. For a long-term simulation, the model accumulates the values of the seasonal variables and after the number of years of record, the average values of the seasonal variables are computed for each combination of number of rotation areas and rotation interval, henceforth called water management combination. Since each water management combination is run one at a time for the same irrigable area through the length of input record, the model can search during the process of simulation for the maximum average yield. The water management combination that has the highest average yield can then be recorded as optimal water management combination for a particular irrigable area. The model uses the maximum yield to compute the total rice production with the equation,

PROD = AC X YA

where

PROD = total rice population, tons,
AC = size of the irrigable area, ha, and
YA = maximum yield attained by an optimal water management combination, tons/ha.

The model was also designed to compute the profit of producing rice on a particular rice land by the use of the expressions,

PROFIT = ANCOME - XPENSE

where

ANCOME = PROD X PRICE
XPENSE = AC X COST, and
PROFIT = difference between income and expenses, $,
ANCOME = income, which is the product of total production and price of rice per ton, $,
PRICE = price per ton of rice, $/ton,
XPENSE = cost of rice production, $,
AC = irrigation area, ha, and
COST = expense of producing rice per unit area, $/ha.

## RESULTS AND DISCUSSION

The simulation model was run to determine the daily depth of water in the field, moisture depletion and runoff using a 6-day irrigation interval and 3 rotation areas. The measurements were plotted and evaluated for abundant and scarce water supplies.

*Depth of Water in the Field.*

Fig. 3, which is a portion of the 1954 irrigation period used in the study, represents the daily variations of depths of water on each rotation area with abundant water supply. At no time was the depth of water at or below the soil surface. The 3 rotation areas were regularly irrigated at 6-day intervals. The depth of water reached the maximum of 7.62 cm in only 1 day each time the irrigation water was applied. It could be observed that the depths of water in the field decreased as the time after water application increased. Exceptions could be observed when significant amount of rainfall occurred. At these times (days 23, 28, 31, 32, 33, 40, 46 and 51), the depths of water on all rotation areas increased. The season with scarce water supply in 1957 is presented in Fig. 4. Because of the scarcity of water supply for land preparation, planting time was delayed for 20 days. Irrigation was not possible until the 28th day of the season. At the start of irrigation, the first rotation area was fully irrigated. The second and third rotation areas were irrigated for a maximum of 2 days each but water supply was not sufficient to replenish water depletion. Hence, the depths of water over the rotation areas continued to decrease below the soil saturation point. At day 37, there was rainfall. Consequently, the depths of water for all rotation areas increased.

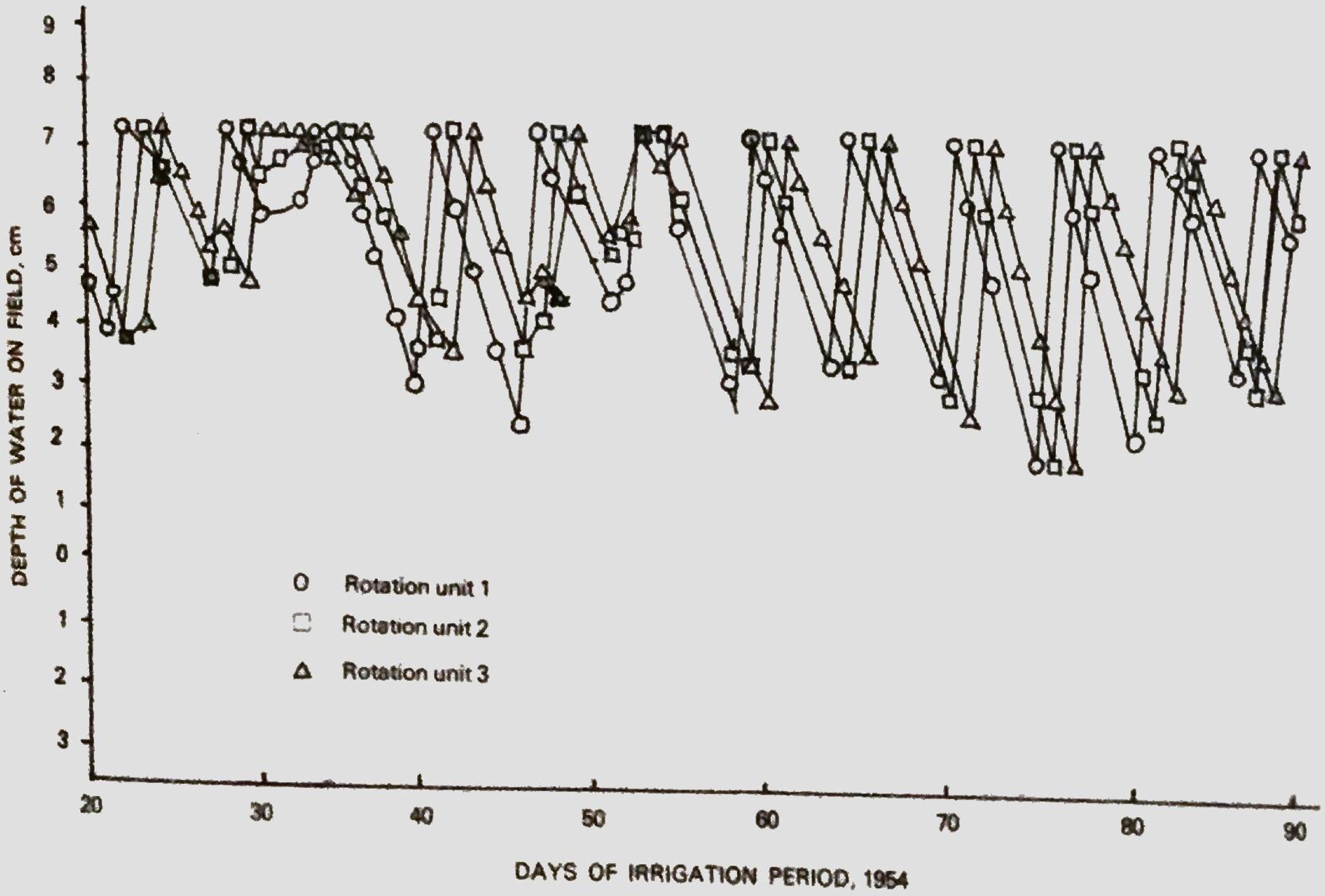

**Fig. 3.** Daily depths of water of a portion of the irrigation period for 3 rotation areas and 6-day rotation interval with an abundant water supply.

However, rainfall was not sufficient to bring the third rotation area to saturation point. Since no water supply was available for irrigation, the depths of water decreased again until the 44th day when rainfall increased the rate of flow for irrigation. Water supply was sufficient for the rest of the irrigation period. Fig. 4 also indicates the number of moisture-stress days. The model accumulated the number of moisture-stress days starting 10 days after the initiation of the irrigation period. With a 6-day rotation interval and 3 rotation units, the number of moisture-stress days for the first, second and third rotation areas were 0, 3 and 6 days, respectively.

### *Water Depletion.*

The model computed the daily and cumulative moisture depletions based on daily evapotranspiration and soil percolation. The percolation rate used was 0.27 cm per day, the average for all types of rice land soils with deep water table. Evapotranspiration calculations depended on the pan evaporation data.

Water depletion, which is the cumulative moisture depletion after full irrigation, is equivalent in magnitude to the storage available to hold the water applied. When the depth of water in the field was maximum, water depletion was zero and the field could not store more water. Any water added into the field was considered runoff.

The daily changes of field storage available to hold the water applied are shown in Figs. 5 and 6. Fig. 5 shows the changes of field storage for all rotation areas with abundant water supply, while Fig. 6 shows the changes of field storage for all rotation areas with scarce water supply. For an abundant water supply, the available storage was always zero which indicated that the depth of water was at the maximum. Plants were never under moisture stress. However, for the season with scarce water supply (Fig. 6), the diversion of water from the river was not sufficient to supply the water requirement throughout the irrigation period, incurring moisture-stress in plants. The rotation areas showed different degrees of water depletion. Rotation area 1 showed the least water depletion, while rotation area 3 showed the highest.

### *Adequacy of Irrigation Water Supply.*

Adequacy of irrigation water was determined based on the occurrence of runoff. The model computed among other variables, the depths of allowable diversion, runoff and effective water applied in a given area. A 324-ha irrigable area was divided into 3 rotation areas. For abundant water supply, runoff was high and occurred every single-day water application (Fig. 7). In contrast, water was applied often without runoff for the season with scarce water supply (Fig. 8). Water supply was either inadequate or not available for irrigation from day 34 to

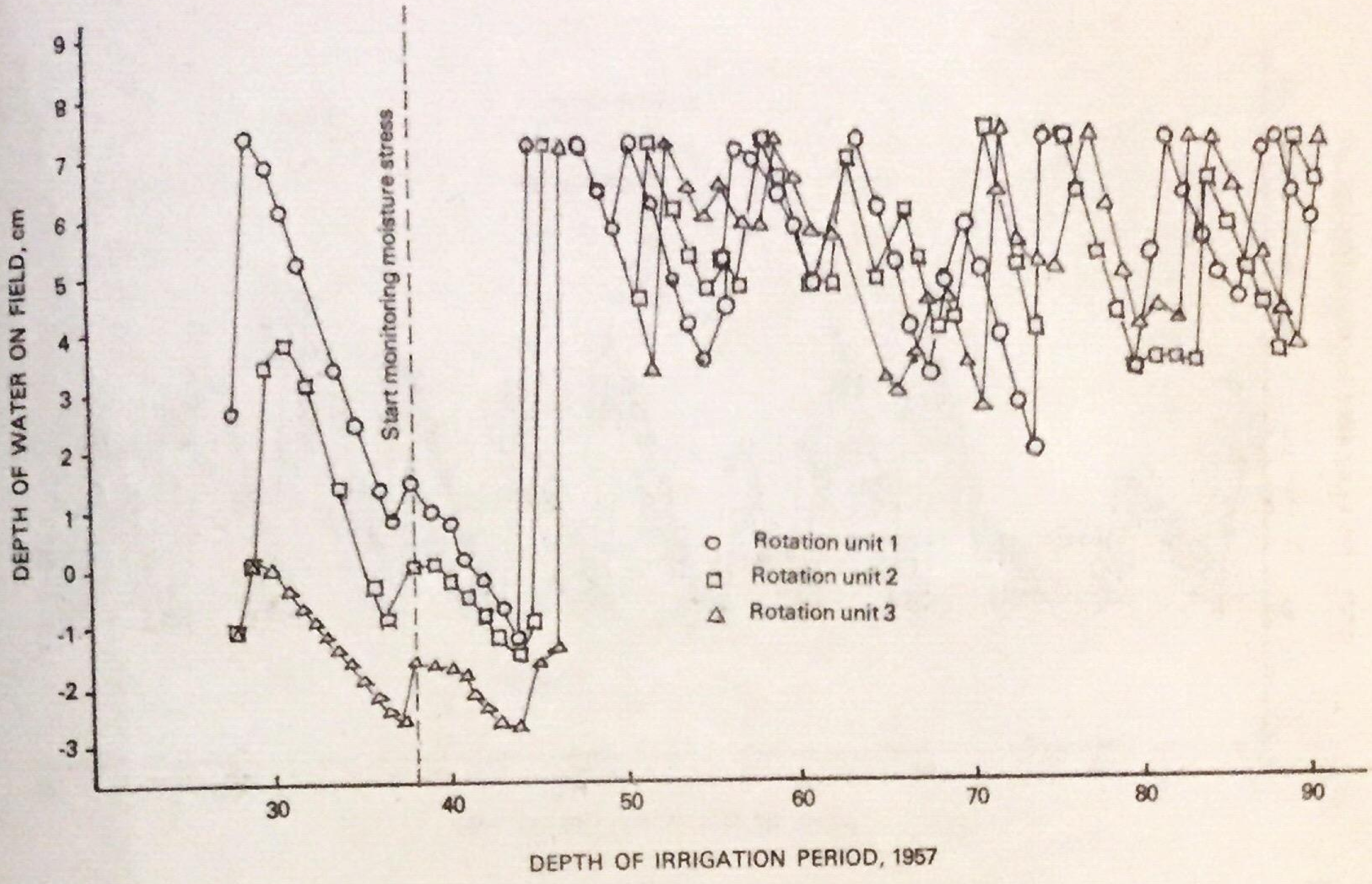

**Fig. 4.** Daily depths of water of a portion of the irrigation period for 3 rotation areas and 6-day rotation interval with a scarce water supply.

44. Oftentimes, a rotation area was irrigated for the maximum of 2 days, unlike the case of an abundant water supply when only 1 day was required to fill the available storage in each rotation area.

*Water Balance.*

The water balance for both seasons with abundant and scarce water supply was as follows:

| | Abundant water supply | Scarce water supply |
|---|---|---|
| Total water applied | 253 cm | 210 cm |
| Total water consumed | -89 cm | -78 cm |
| Total runoff | -164 cm | -132 cm |
| Error | 0 | 0 |
| Total | 0 | 0 |

It could be observed that the total amounts of water applied, water consumed and runoff were more for the season with abundant rather than with scarce water supply. This was expected because the actual evapotranspiration and percolation are usually high when the soil is always under saturated condition.

Since the rice field was provided with a spillway and drainage canals to convey runoff back to the river, the system permitted all the allowable diversion to be applied into the rice field regardless of demand. For a small irrigable area of 324 ha, this resulted in a large total runoff figure. However, the simulation model could be used to determine the maximum amount of diversion to obtain a minimum runoff for a given area if desired.

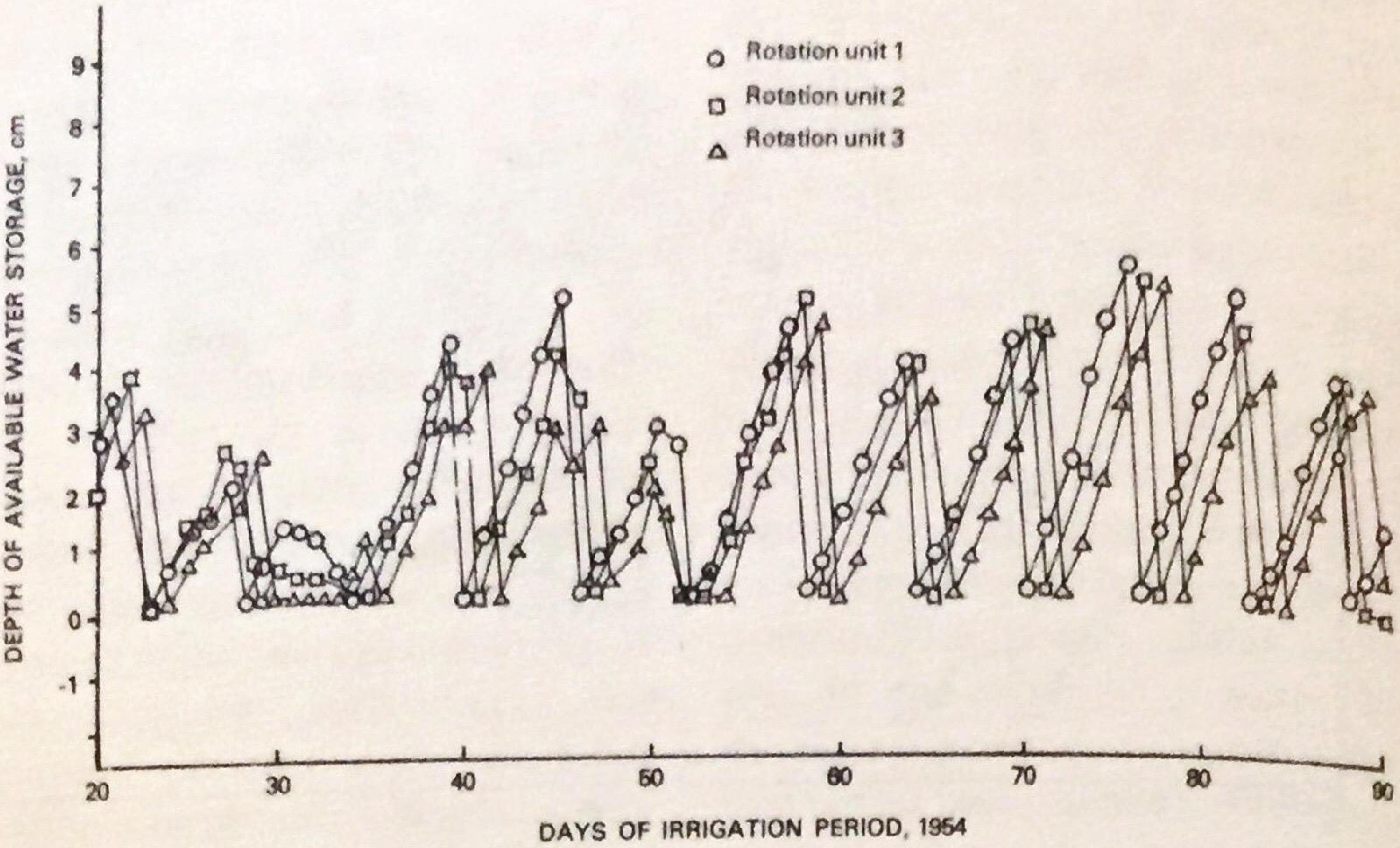

**Fig. 5.** Daily changes of field storage available to hold water applications for 3 rotation areas and 6-day rotation interval with an abundant water supply.

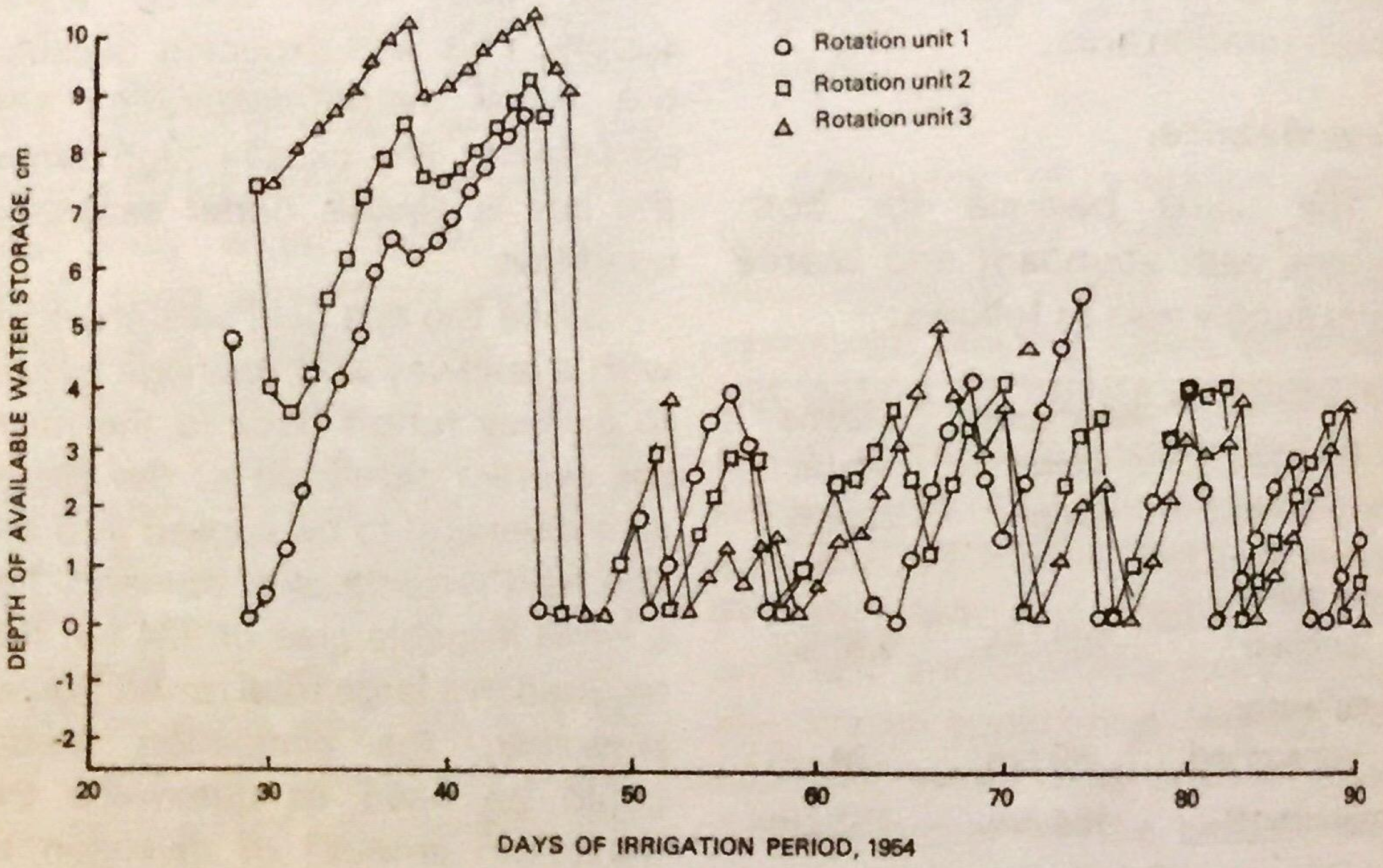

**Fig. 6.** Daily changes of field storage available to hold water application for 3 rotation areas and 6-day rotation interval with a scarce water supply.

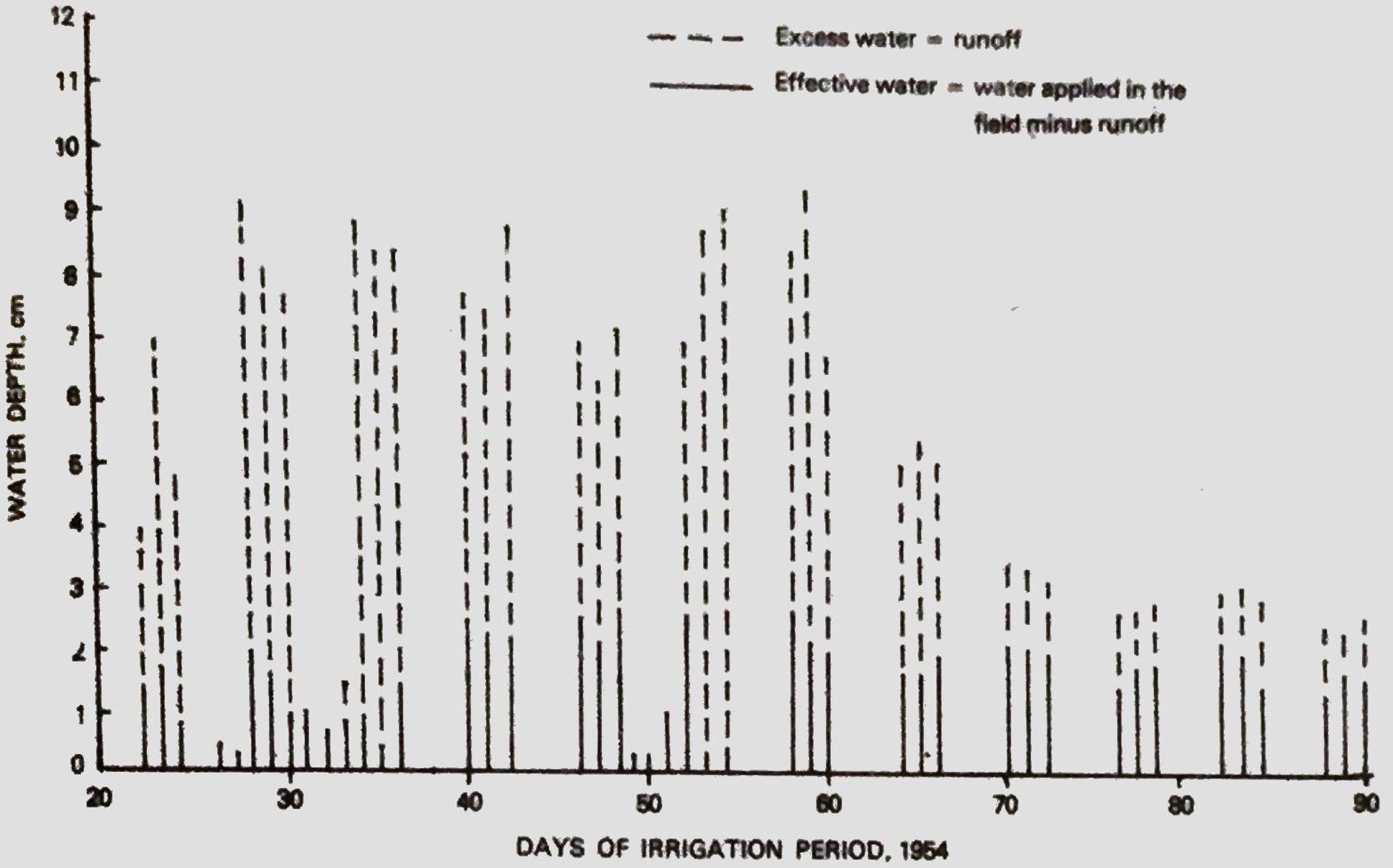

**Fig. 7.** Water adequacy at each irrigation for 3 rotation areas and 6-day rotation interval with an abundant water supply.

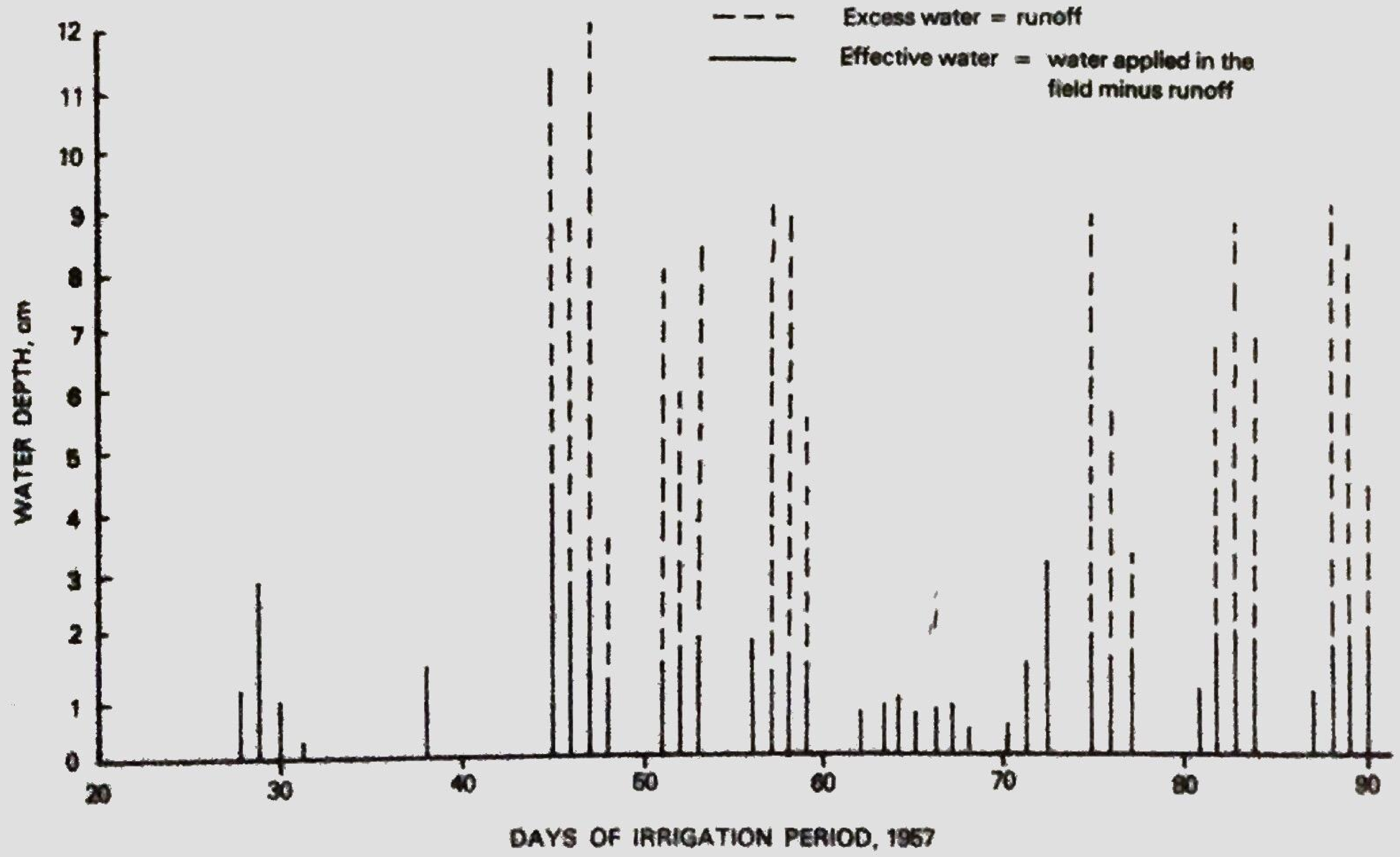

**Fig. 8.** Water adequacy at each irrigation for 3 rotation areas and 6-day rotation interval with a scarce water supply.

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