IRRIGATION WATER MANAGEMENT STUDIES FOR RICE BY COMPUTER SIMULATION

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ABSTRACT

A computer simulation model developed using the concept of rotation irrigation was used to estimate the optimal irrigation time interval, determine the effects of subdividing the irrigable area into rotation areas on the yield of rice, estimate the maximum area that would give the highest yield and the optimal area that could be put under rice production for a river water source. The model was run using a 25-year data on rainfall, pan evaporation and stream flow. Results indicated that subdividing the irrigable area into rotation areas was not necessary when water supply was adequate. Rotation interval of 1 to 8 days did not significantly affect the yield of rice; however, an interval of more than 8 days considerably decreased the yield. For the irrigable area to be optimal, it was necessary to divide the area into 4 rotation areas which were irrigated at 4-day intervals. There was no significant difference between rotation irrigation and continuous irrigation schemes for small irrigable areas when water supply was adequate. However, rotation irrigation provided for a significantly greater optimal irrigable area. It also gave significantly higher production for large irrigable areas when water supply became inadequate.

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KEY WORDS: Rice irrigation. Irrigation simulation. Computer simulation model. Continuous irrigation. Rotation irrigation. Water management.

INTRODUCTION

Agriculture is the largest consumptive user of water. To control and wisely use water on the farms, farmers need to know better irrigation water management for maximum crop yield. This is important especially when cultivation of more land is impossible as in most countries in Asia.

Provision for an adequate water supply can be a controlling factor in increasing crop production. This was expressed by Pohjakas (1975) when he concluded that the lack of proper water management in many irrigation schemes was the bottleneck that prevented other agricultural inputs from being more effective. He stated that the use of improved plant varieties and fertilizers cannot be fully effective unless water management is favorable and economical.

Intermittent application of irrigation water and maintaining an appropriate amount of water in the soil can economize water use and increase water use efficiency. It can be accomplished by rotation irrigation which was found to decrease water use in Taiwan by 30 to 50% (De Datta et al., 1975b). However, the influence upon and the intention of rotation irrigation with other factors affecting better water management are not yet well understood. Studies conducted since 1973 indicated that rotation irrigation had no advantage over continuous method of irrigation. Wickham and Valera (1976) stated that no significant differences in any of the parameters studied were found between the 2 irrigation forms, with the exception of additional cost of the rotational model. Yet, some water management agencies in the Philippines are implementing rotation irrigation. Other studies showed that water use efficiency, as well as the yield of rice and soil moisture status, is significantly affected by the irrigation interval (De Datta et al., 1975b).

Julian (1975), realizing the importance of water management in crop production, encouraged studies to determine the optimal rotation interval based on soil and agronomic requirements. This task, which requires specification of an irrigation that maximizes the yield of crop and the area that can be supplied with a sufficient amount of irrigation water, is complex because of the influence of stochastic events. Since the problem is impractical to solve with the traditional methods of experimentation, this study was conducted by computer simulation. The objective was to define the number and size of rotation farm units and the interval of rotation irrigation necessary for proper utilization of water from the given run-of-the-river irrigation system.

MATERIALS AND METHODS

The effects of irrigation water management on the yield of rice were determined with the use of 4-, 8-, 12- and 16-day rotation intervals in combination with the following rotation areas:

NAC = 1, rotation irrigation without subdividing the given area into rotation areas;

NAC = 2, rotation irrigation between 2 rotation areas;

NAC = 3, rotation irrigation among 3 rotation areas;

NAC = 4, rotation irrigation among 4 rotation areas;

NAC = 5, rotation irrigation among 5 rotation areas.

Twenty water management combinations were possible. Considering the concept of rotation irrigation in which water is applied for at least 1 day, only water management combinations of rotation intervals greater than or equal to the number of rotation areas were considered. Each water management combination was utilized 25 times, since 25 years of input data were available. Only the data for the months of May to September each year were used since the cropping season in the United States starts about the first of May. Stream flow data obtained were from the records of Boyer river at Logan, Iowa (U.S. Geological Survey, 1954-1978), and rainfall and pan evaporation were obtained from the Weather Bureau stations at Logan and Castana, respectively (National Oceanic Atmospheric Administration, 1954-1978).

The simulation model estimated the optimal water management combination for any given irrigable area. The model also estimated the optimal production for any given area. To estimate the area with maximum yield and optimal production, a simulation run was made for several hectarage. For selection of maximum yield area, areas from 40 to 400 ha were used at intervals of 40 ha. The maximum areas with the highest yield for 25 years of input data were selected as irrigable areas that could be supplied with irrigation water from the given run-of-the-river irrigation system without moisture stress. For areas with maximum total production, larger areas up to 7,285 ha were used. The area that gave the maximum profit was chosen as that area which could be put into irrigated rice production for similar environmental conditions and assumptions.

Several parameters could be varied in the simulation model to determine their effects on optimal production. However, only irrigation efficiency, height of spillway and types of soil were tried. To determine their effects, 40, 60 and 80% irrigation efficiency, 7.62 and 12.7 cm height of spillway, and 0.27 and 0.018 cm per day percolation rates were used.

The water management studies were carried out on a long-term run using the 25-year records of rainfall, pan evaporation and stream flow obtained in West Central Iowa. The summary flow diagram of the simulation is presented in Fig. 1.

RESULTS AND DISCUSSION

Optimal Water Management Combination.

Optimal water management combination was the combination of the number of rotation areas and the rotation interval that gave the highest yield (Table 1). When 2 or more combinations had the same yield, the combination with the

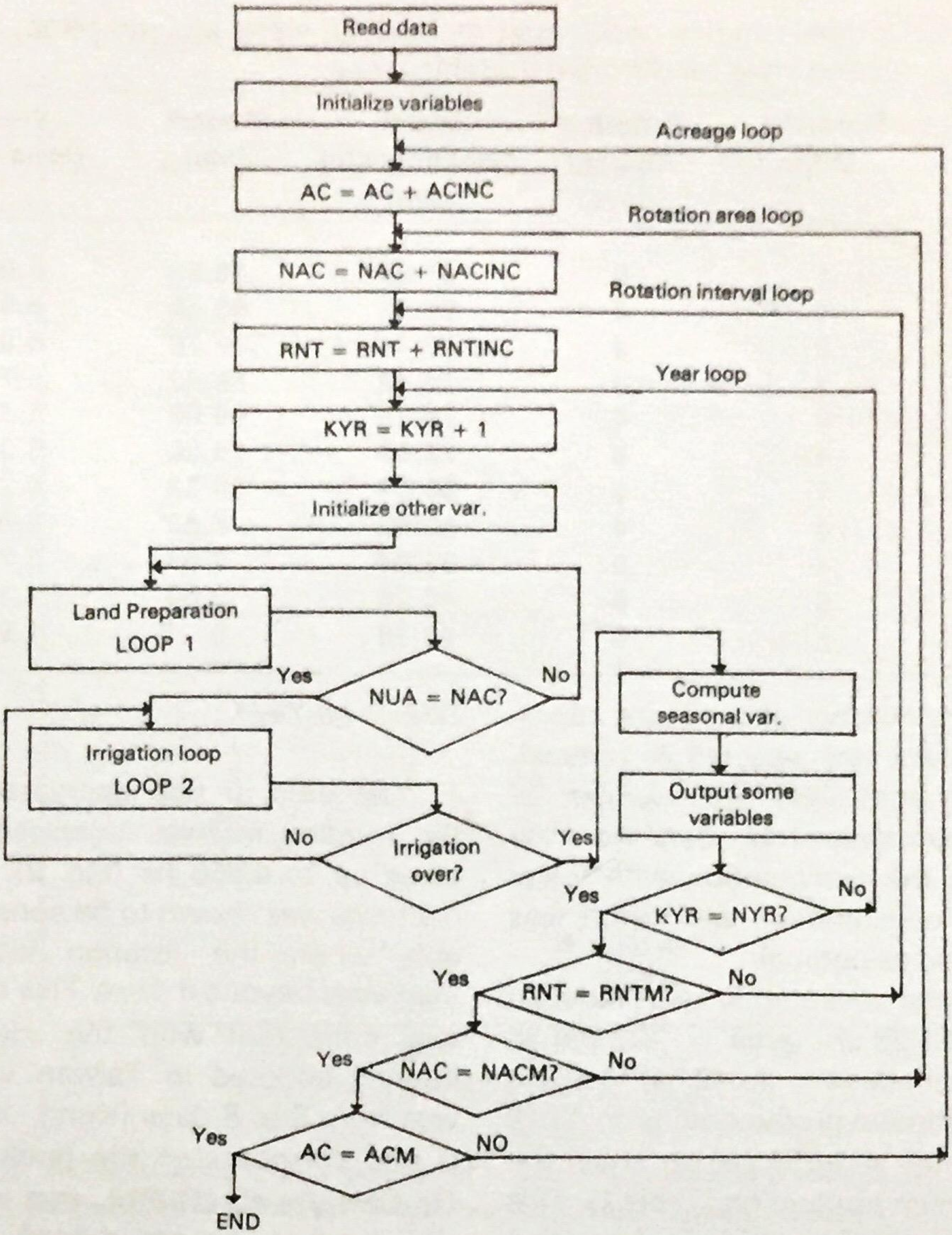

Fig. 1. Schematic diagram of major loops for the water management study.

LEGEND:

AC — size of irrigable area that may be divided into rotation areas,
ACINC — increment of irrigable area,
NAC — number of rotation areas,
NACINC — increment of the number of rotation areas,
RNT — rotation time interval,
RNTING — increment of rotation time interval,
KYR — year counter,
NUA — rotation area counter,
RNTM — maximum RNT
NACM — maximum NAC, and
ACM — maximum AC.

Table 1. Optimal rotation units, rotation interval, water consumption, runoff and yield for different irrigable areas.

Area (ha)	Rotation Unit	Rotation Interval (days)	Water Consumption (cm)	Runoff (cm)	Yield (tons/ha)
202	1	8	81.28	68.58	6.00
405	1	4	81.28	63.50	5.98
607	2	4	78.74	139.70	5.88
809	2	4	78.74	58.42	5.73
1,012	4	4	76.20	99.06	5.58
1,214	4	4	73.66	76.20	5.36
2,428	4	4	66.04	20.32	4.25
3,642	4	4	58.42	7.62	3.56
4,856	4	6	53.34	2.54	2.72
6,070	5	6	48.26	2.54	2.17
7,284	5	6	43.18	0	1.98

highest number of moisture stress-free years was selected as optimal. When both yield and number of moisture stress-free years were the same, the combination with lower water consumption and runoff was selected as optimal.

Water consumption was reduced from 81.28 cm (area = 202 ha) to 58.42 cm (area = 3,642 ha) to attain the optimum production, or to 43.18 cm (area = 7,284 ha) to attain the maximum production (Table 1). This reduction of water consumption was 28 to 47%, which was about 30 to 50% water saving by rotation irrigation as claimed by the researchers in Taiwan (De Datta, et al., 1975b). Water consumption for optimal profit production (3.56 tons/ha) was 58.42 cm, which was between the range of 57.71 and 66.42 cm, the average water requirement for rice plant development during wet and dry seasons in the Philippines, respectively (Lucero, 1976).

Effects on Yield.

The yield of rice decreased as the rotation interval increased for areas up to 4,856 ha (Fig. 2). The decrease was shown to be considerable when the rotation interval increased beyond 8 days. This result was consistent with the rotation interval adopted in Taiwan which was from 3 to 8 days (Kung, 1976). It also corroborated the finding of De Datta et al. (1975b), that irrigation intervals longer than 8 days reduced grain yield for a rotation irrigation system when rainfall did not provide supplemental water. For an area larger than the optimal irrigable area of 3,642 ha, rotation intervals of 6 to 8 days were preferable. This is logical because longer time is needed to apply more irrigation water to a larger hectarage.

Figure 3 depicts the effects of rotation units on the yield of rice. Rotation irrigation was not neces-

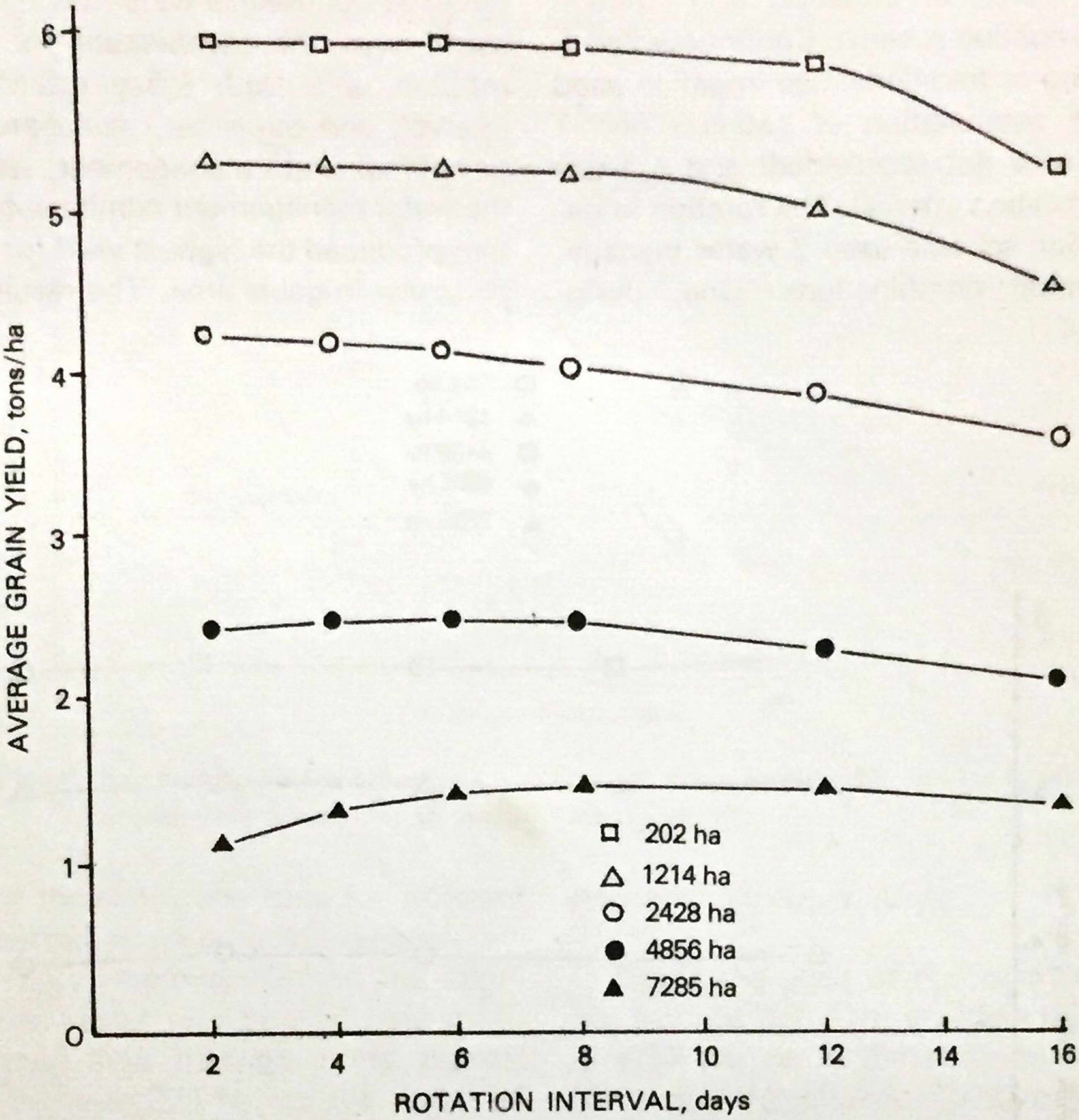

Fig. 2. Relationship of average grain yield of rice and rotation intervals for five irrigable areas for 25 years of rainfall, pan evaporation and stream flow data.

sary for small irrigable areas where water requirement was easily met. However when the area increased, water supply became inadequate, making rotation irrigation necessary. This is so because (1) the time needed to apply the required depth of water is short for smaller rotation areas, (2) water loss due to evapotranspiration and soil percolation is small when flooding time is short and the area being flooded is small, (3) only a given rotation area, not the whole large irrigable area, is subject to high soil percolation and potential evapotranspiration for only a short time, and (4) the number of rotation areas affects the period of diversion.

Area With Maximum Yield.

The area with maximum yield was estimated using the traditional method of irrigation and rotation irrigation scheme. Continuous flooding or traditional rice irrigation used a combination of rotation unit 1 (area not subdivided) and a 1-day rotation interval. The rotation irrigation scheme used 2 water management combinations. One, designated as nonoptimal water management, was the combination of 3 rotation units with 6-day rotation interval, and the other, designated as optimal water management, was the water management combination that produced the highest yield for a particular irrigable area. The results

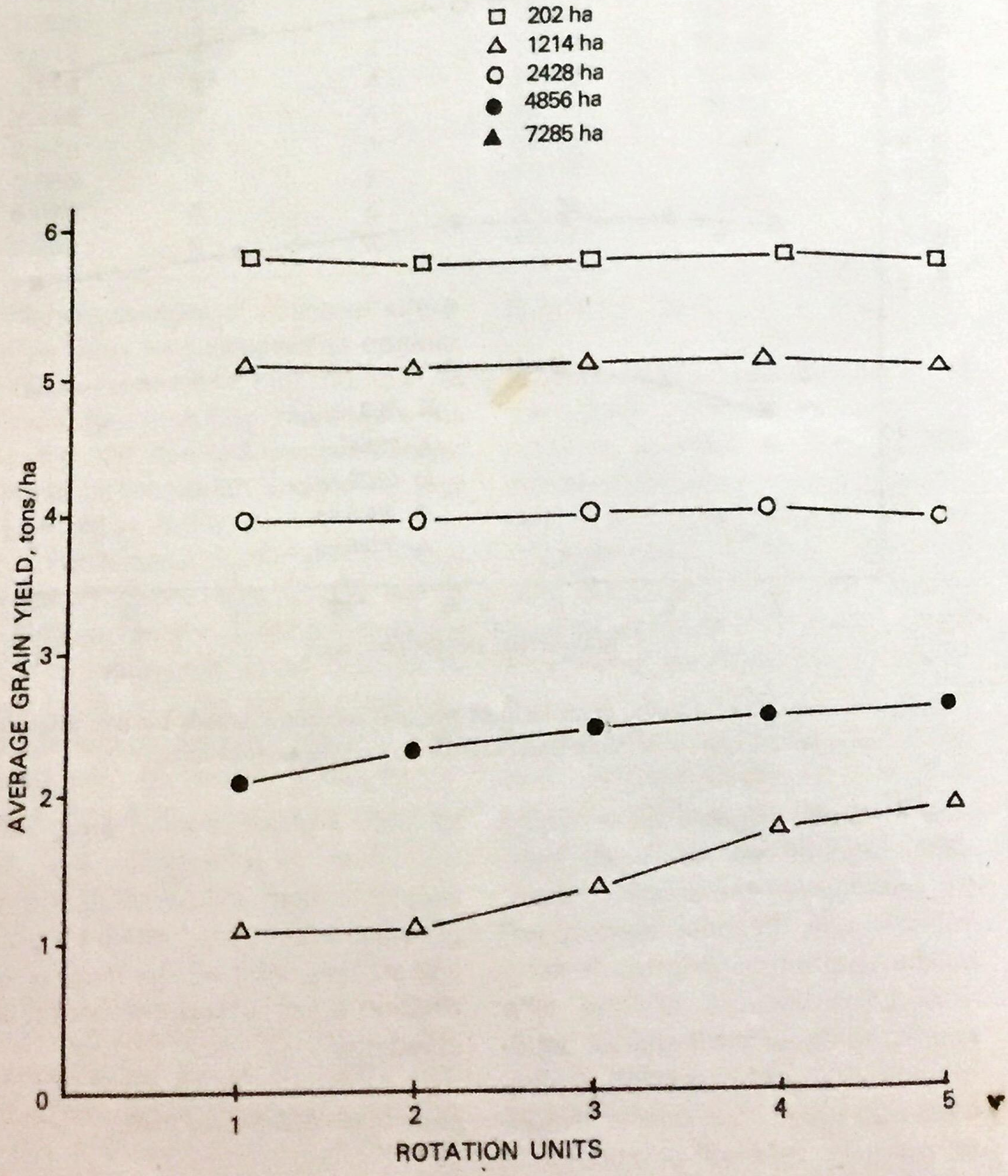

Fig. 3. Relationship of average grain yield of rice and rotation units for five irrigable areas for 25 years of rainfall, pan evaporation and stream flow data.

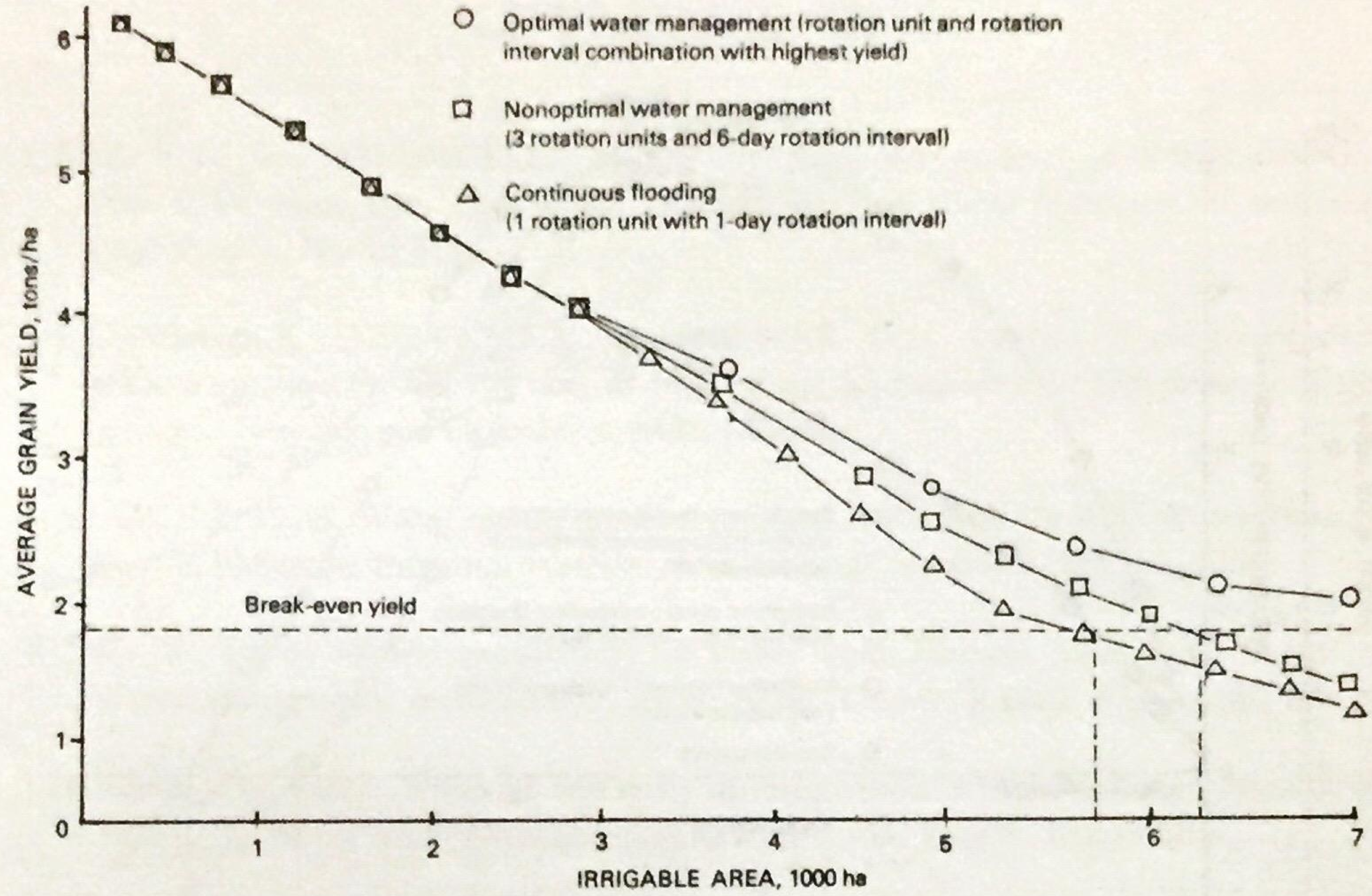

Fig. 4. Relationship between the average grain yield of rice and irrigable area for 3 water management schemes for 25 years of stream flow data.

of the simulation runs for different hectarage are reflected in Fig. 4.

By whatever method the irrigation water was applied, the maximum area that gave the highest yield was 223 ha for the entire 25 years of input data. A simulation run at 20-ha interval gave 223 ha to be the maximum irrigable area that can be supplied with irrigation water without moisture stress for the particular assumed systems.

There was no significant difference in yield up to the 1,619 ha irrigable area for the 3 irrigation water management schemes. When the area became larger, continuous irrigation method produced the lowest yield, optimal water management the highest, while the yield of nonoptimal water management was intermediate.

Area with Maximum Profit.

Using the price of rice of $150 per ton and the cost of production of $259 per ha in the early 1970s (Cruz and Malungkot, 1976), the profit from producing rice on a given area was determined.

There was no considerable difference between continuous irrigation and rotation irrigation both in total production and profit when the area put under irrigation was very much smaller than the optimal area (Fig. 5). The difference showed up significantly when water supply became inadequate to irrigate a large area. Consistently, nonoptimal water management was intermediate between continuous and optimal water management when the area was larger than the irrigable area of

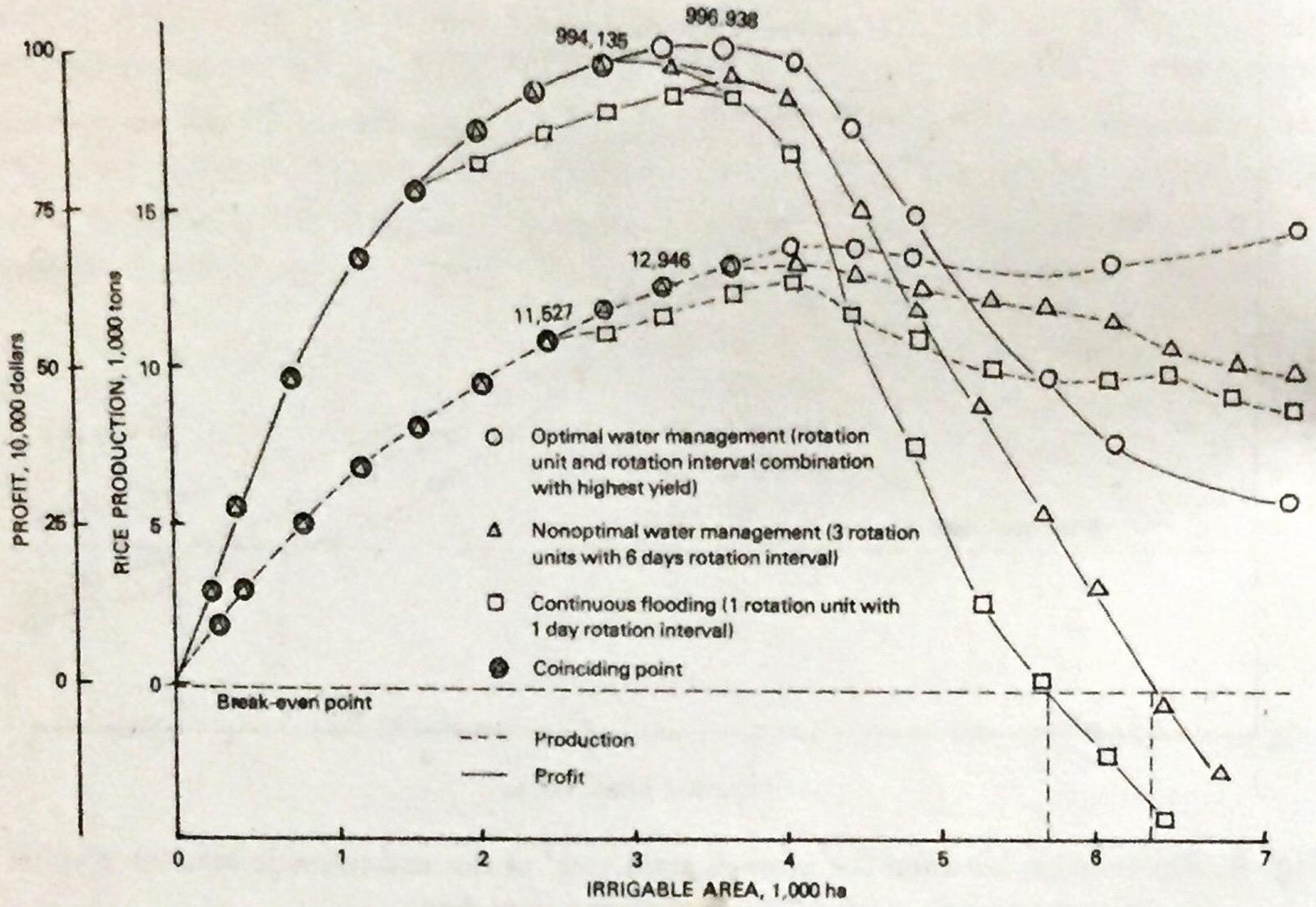

Fig. 5. Relationships of total production and profit with the irrigable area for 3 water management schemes.

maximum profit.

Continuous irrigation produced the maximum profit when the irrigable area was 2,833 ha. Both nonoptimal and optimal water management produced the maximum profit when the irrigable area was 3,642 ha. However, nonoptimal water management produced the lower profit beyond an area of 1,619 ha as compared with optimal water management. Optimal water management was always profitable. On the other hand, both continuous and nonoptimal water management became unprofitable beyond 5,666 and 6,374 ha, respectively. At these points, yield corresponded to the break-even yield.

A limitation in the use of the irrigation water management simulation model may be observed in Fig. 5. The irrigable area with the highest profit was 3,642 ha for both optimal and nonoptimal water management. For irrigable areas greater than 4,856 ha, rice production increased when the irrigable area was increased. A study of the sample output indicated that growing seasons were affected by the water supply for early planting. Inadequate water supply shortened the period of irrigation and decreased the number of moisture stress days. The less number of moisture stress days during a short growing season caused the increase in rice production, which was an error.

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