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RAINWATER HARVESTING IN PLATEAU REGION OF ORISSA - POTENTIAL, PROSPECTS AND TECHNOLOGY PACKAGE

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WATER TECHNOLOGY CENTRE FOR EASTERN REGION
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भाकृ अनुप
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FOREWORD

This Eastern region of India is bestowed with annual rainfall ranging from 1000mm in Eastern U.P., to 3000mm in the Sub-Himalayan region of Assam and West Bengal. Inspite of adequate amount of rainfall the crops of eastern region suffer from moisture stress due to erratic behaviour of the monsoon. Heavy downpour followed by prolonged dry spell causes unreliability in crop yield. Hence there is a dire need of rain water management to reduce the effect of moisture stresses in order to obtain sustainability in agricultural production. Runoff recycling is one such method to counter the unpredictable behaviour of the monsoon. Unfortunately very limited work has been done on this aspect for eastern region.

The institute initiated work on this aspect in 1994 and in a span of four years has come out with a technology package for rain water management. This bulletin is an effort to present the technology alongwith its potential for the state of Orissa.

I hope the bulletin will be helpful for dissemination of the technology among researchers, engineers and farmers.

(B.K. James)
Director (Actg.)

PREFACE

Although rainfall in plateau region of eastern India is sufficient to meet the crop water demand, its spatial and temporal distribution makes rainfed farming a risky proposition. Water harvesting can reduce the risk substantially by facilitating early planting of rice crop to take maximum advantage of the rainfall and insure the crop against rainfall aberrations in addition to providing irrigation in subsequent rabi crop. The information on potential and required technology is lacking. The WTCER has done significant work in this direction. This publication is an effort to compile this information for use of fellow researchers and practising engineers.

The author is grateful to Dr. S.R. Singh, Ex - Director, WTCER for his encouragement and providing facilities for the work. The author is thankful to Er. B.K. James, Director (Actg.), WTCER for encouraging to write this bulletin.

R.C. Srivastava

INTRODUCTION

In eastern India, the irrigated area is 43.5% in Bihar, 35.8% in West Bengal and 30.5% in Orissa. However, most of this irrigated area is located in plains of Ganga basin (Bihar and West Bengal) and Mahanadi delta (Orissa). The plateau area which has rolling topography, is mostly rainfed. A district-wise breakup of Orissa shows that out of 13 undivided districts, six are predominantly plains and seven are predominantly hilly. The total cultivated area of plain districts is 3334 thousand ha out of which 384 thousand ha is irrigated by public irrigation works (major and medium). The corresponding figures for districts having hilly terrain are 3215 thousand ha and 141 thousand ha respectively (Dalua & Nayak, 1991). This shows that hilly districts have only 1/3rd irrigated area to that in plain districts. Since the hilly districts have little ground water, the total irrigated area percentage will be much lower in hilly districts. Even this irrigated area is concentrated in valleys where few river projects like Kolab project in Koraput district are located. The high table lands which support a substantial portion of the population are rainfed. This population is predominantly scheduled tribe, the weakest segment of our society. The situation is similar in neighbouring areas of Bihar, West Bengal, and eastern M.P.

Rainfed agriculture in this large area of the plateau region has led to serious socio-economic consequences. Due to the poor agricultural performance in this region, the large segment of this population is below poverty line. Already as a state Orissa is on the lowest rung in terms of per capita income and had about 44.7 percent population below poverty line in 1987-88 as against 29.9 percent national average. Although district wise data on population below poverty line could not be found it can be said that percent of population below poverty line is much higher in these plateau districts. Owing to unstable yields and non availability of other employment opportunities, there is large scale migration of able bodied workers to other districts of state or outside of the state. In normal years, the migration percentage from these areas is about 30-40 percent and in drought year of 1996, this percentage has been around 70-80% (Times of India, October 1996).

The rainfall (40 years average) in these district ranges from 1378.2 mm in Kalahandi to 1648 mm in Sundergarh (state average 1482.2 mm) with average number of rainy days varying between 65.4 to 78.2. However, the yields are unstable due to erratic nature of rainfall and dry spells. In period 1961-1996, there were 13 drought years out of which five were severe drought years (Mohapatra, 1997), but the total average state rainfall was less than 1000 mm only in three years with the lowest average state rainfall being 950.7 mm in 1979. Thus, the farmers of rainfed areas suffer due to erratic nature of rainfall even when the total annual rainfall is around 1000 mm.

It is therefore necessary to bring these areas under irrigation to protect the resource poor farmers from the vagaries of the monsoon. Till now the route to irrigation development in this region has been through damming the rivers or minor irrigation projects, but due to topographical factors these projects have limited reach. Further, due to porous nature of laterite soils of this region, the losses in conveyance is very high and so the actual irrigated area is much less than the potential created. For example the Kangsabati project in West Bengal was designed to serve Bankura and Midnapore district, but due to heavy conveyance loss, the command area in Midnapore district rarely receive water.

It is evident from above that large irrigation projects do not benefit the scattered small farmers of the region. They have remained untouched by gigantic projects and the result is crop failure and starvation deaths in Western Orissa even when the monsoon rainfall is around 800 mm. Thus the need of the hour is to have very small scale water resource development around which a small tribal farmer can develop his farming within his limited risk taking capacity. The size of the project should be suitable to an individual farmer or a clan of tribals.

This water resource can be developed by small scale runoff recycling. Srivastava (1983, 1996 a), Srivastava & Rao (1993), and Bhatnagar et al. (1996) have shown that small scale runoff recycling can successfully alleviate moisture stress by providing supplementary irrigation to grow various field crops like rice, wheat etc., and vegetables on terraced fields of North Western Himalayas with yield level as good as under fully irrigated conditions. An optimal design of runoff recycling tanks in a series by overlapping command area of one tank with catchment of succeeding tank can minimise the catchment syndrome (Srivastava, 1996 b). Srivastava & Bhatnagar (1995) have also found that the yield of fodder grasses in pasture on slopes can be increased by 100 to 300% by providing supplementary irrigation. This is important for a hilly farmer, where crop livestock farming is a rule rather than exception, and a hill farmer has to grow fodder for his livestock as well food for his family. Although the state of Orissa has a large cattle population, this population is largely dependent upon crop residues and degraded pastures for its fodder requirement as there is no culture of cultivated fodder in the state.

In view of the above agricultural scenario, the runoff recycling based irrigation systems hold promise. These systems should be designed (i) to alleviate the moisture stress of rice during kharif season, (ii) to provide irrigation to low duty crops in rabi season, and (iii) to provide irrigation to improved pasture grasses to prolong their growth period. With this in view, studies were initiated at Water technology Centre for Eastern Region to develop technology for rain water harvesting system. A design of rain water harvesting system require information on runoff availability, seepage control and design of runoff recycling system to suit a cropping pattern. This bulletin is an effort to assess the potential of rainwater harvesting in Orissa and present the work done at WTCER in this respect.

RUNOFF AVAILABILITY

The optimal design of the runoff recycling requires the information on runoff availability both over the space and time. Since the observed data on runoff for sufficient long duration is not available, most of the water harvesting systems are designed on the basis of predicted runoff without any statistical backup. Thus, it is necessary that runoff predictions are made with the aid of statistical methods to ensure prediction of water resource availability with known probability levels. Srivastava and Rao (1993) have estimated daily runoff for number of years and grouped them in different months. This gave a time series of the expected runoff. Fitting these time series to different probability distributions, they have estimated the runoff for different probabilities. Using the similar methodology, daily runoff were estimated for terraced cultivated land having soil group B[1] hydrological soil cover complex for ten locations of Orissa. The curve number of this hydrological soil cover complex for AMC II condition was taken as 77. Vandersypen et al (1972) has presented following two formulae for different regions of India.

$$Q = (P - 0.3\ S)^2 / (P + 0.7\ S) \text{ for all regions}$$

and

$$Q = (P - 0.1\ S)^2 / (P + 0.9\ S) \text{ for black soil regions}$$

where

Q = daily runoff, mm

P = daily rainfall, mm

S = potential maximum retention, mm

= (25400 / CN)

CN = curve number

Daily runoff was estimated for ten locations of Orissa, for the time period of rainfall data availability. The time period ranged from 40 years to 15 years. The daily runoff was grouped in seven groups: May, June, July, August, September, October and total monsoon period, i.e., May to October. Runoff for the rest of months was negligible and therefore not considered.

For reliable estimation of hydrological parameters by probability distribution, the data series has to be of adequate length, random in nature, and should fit to some suitable probability distribution. To test the aforesaid criteria, the data series was subjected to three tests, viz., test for adequacy of length of record, test for randomness, and test for fitness to distribution. These tests are explained in following sections :

---

[1]*Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately course textures. These soils have a moderate rate of water transmission. The tentative soil hydrological grouping for most of Orissa area has been given B (Murty, 1982)*

Test for adequacy of length of record

Adequacy of the length of record was tested by Mockus's method which gives following equation to estimate the adequate length of record.

$$Y = (4.3\ t_{10}\ \log_{10} R)^2 + 6$$

where

Y = minimum acceptable of record, years

t = students's statistical level at 10 percent level of significance with (Y_t-6) degrees of freedom

R = ratio of magnitude of 100 year event to 2 year event

The magnitude of 100 year event and 2 year event are calculated using the following equation given by Chow (1964):

$$X_T = x^{-} . (1 + C_v . K_T)$$

where

X_T = computed mean of an event for a recurrence interval of T years, mm

x = mean of variate x_i (i=1,2....N)

C_v = coefficient of variation

K_T = frequency factor for a recurrence interval T years

= -2.45 . 10.577 + Ln {Ln T - Ln(T-1)} 1/3.1416

Test of randomness

The randomness of the data series were tested by using parametric test as proposed by Chow (1964). Serial correlation coefficient (r_K) for different legs was estimated as:

$$r_K = \sum_{t=1}^{N-K} \{(x_t - x^{-}) . (x^{-}_t + k - x^{-}_k)\} / \sum_{t=1}^{N} (x_k - x^{-})^2$$

where N is the length of record and x^{-} is the mean of variate. The confidence limit of r_k at 5 percent level of significance has been calculated with the help of following equation.

$$r_k = 1.69 . (N - 2) / (N - 1)^{32}$$

Clarke (1973) described that for all practical purposes, the value of r_k lying outside ±2/(N) indicate the presence of persistence of the data sequence. The limit of r_k for each station has been estimated accordingly. Regarding order of serial correlation coefficient, the value of serial correlation coefficient upto 3rd order has been considered.

The data series were tried to be fit to normal, pearson, and extreme distributions under untransformed, logtransformed and power transformed conditions. Fitness of the distribution were tested by method described by Srivastava & Rao (1993). Probable values of the runoff at different exceedance probability levels have been estimated by following formula :

$$X_p = x^{-} + \acute{o} \, . \, K_p$$

where

X_p = probable runoff at p probability level

x^{-} = mean

σ = standard deviation

K_p = frequency factor corresponding to probability level

With the above mentioned methodology, probable runoff for different monsoon months and total monsoon at exceedance probability of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% have been estimated and presented in Table 3. These data can be used both for designing drainage structures as well as runoff recycling structures. The Table shows that the runoff is expected from June to October even at 80% exceedance probability. Total seasonal runoff expected at Bhubaneswar at 80% exceedance probability is 143 mm. This is equivalent to the amount of water required for two irrigations (75 mm depth each) assuming no losses during storage. Thus, there is possibility of growing a low duty post monsoon crop like groundnut, mustard, etc. even at catchment command area ratio slightly more than 1.0.

Table 1 Probable runoff at different exceedance probabilities from terraced cultivated land having soil group B at different locations of Orissa

	Probable Runoff at different exceedance probability, mm								
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%
Location - Mayurbhanj									
May	23.59	15.42	12.09	8.71	5.12	3.19	0.75	0.0	0.0
June	122.94	86.17	69.29	51.56	33.97	22.39	11.24	0.0	0.0
July	104.44	74.30	58.98	45.15	32.94	4.87	16.0	9.48	3.2
Aug.	296.88	211.17	171.85	130.53	87.20	62.54	36.55	9.22	0.0
Sept.	333.62	151.41	84.77	51.93	33.12	21.12	14.01	7.24	3.2
Oct.	98.17	50.94	32.94	18.92	8.74	4.66	1.84	0.18	0.14
Monsoon	649.62	520.11	451.95	382.66	311.77	259.50	206.12	151.37	84.80
Location - Cuttuck									
May	23.59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	122.94	42.01	30.34	20.23	11.62	7.06	3.46	0.94	0.0
July	104.44	98.22	81.42	64.34	46.42	34.38	22.06	9.01	0.0
Aug.	296.88	116.96	93.61	75.88	60.84	47.39	34.49	21.58	8.39
Sept.	333.62	64.07	39.65	26.57	18.17	12.43	8.33	5.16	2.66
Oct.	98.17	31.51	22.00	13.86	7.22	3.93	1.51	0.14	0.42
Monsoon	649.62	329.77	294.39	258.40	221.07	190.57	159.46	126.76	82.84

Location - Bhubaneswar									
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	146.16	87.03	61.15	39.56	22.16	12.11	4.97	0.86	0.0
July	295.89	160.58	102.31	70.10	49.40	34.81	23.85	15.20	5.49
Aug.	227.82	165.99	138.32	110.39	81.26	66.15	50.58	33.91	8.39
Sept.	160.68	76.05	43.99	27.79	18.17	11.88	7.51	4.34	2.66
Oct.	0.0	0.0	0.0	0.0	0.0	6.00	0.0	0.0	0.42
Monsoon	597.58	467.83	385.83	324.95	274.63	229.78	187.15	143.63	82.84
Location - Angul									
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	63.59	43.69	61.15	22.80	16.0	10.4	5.70	1.98	0.0
July	107.24	68.69	102.31	38.75	26.38	19.56	13.63	8.58	4.44
Aug.	123.55	90.71	138.52	54.76	42.25	31.36	21.42	12.03	3.55
Sept.	94.47	56.23	43.99	26.40	15.36	9.15	4.44	1.36	1.0
Oct.	0.0	0.0	0.00	0.0	60.0	0.00	0.00	0.0	0.0
Monsoon	457.42	321.69	385.83	200.34	164.02	134.29	108.2	82.63	58.81

Location - Bhawanipatna									
May	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0
June	119.02	56.40	34.78	18.40	7.17	10.40	5.70	1.98	1.34
July	165.41	134.65	112.15	93.27	75.80	19.56	13.63	8.58	13.81
Aug.	120.25	118.96	75.79	51.93	36.59	31.36	21.42	12.03	6.08
Sept.	71.03	29.49	15.49	9.03	5.47	9.15	4.44	1.36	0.42
Oct.	24.92	18.02	12.96	8.73	4.80	0.00	0.00	0.00	0.0
Monsoon	384.40	330.41	290.90	257.77	227.1	134.29	108.20	82.63	69.80
Location - Bolangir									
May	1.38	0.82	0.53	0.34	0.21	0.13	0.06	0.1	0.0
June	75.68	37.52	23.63	13.48	6.64	3.48	1.44	0.38	0.1
July	225.90	165.37	136.42	109.83	85.30	68.39	53.23	39.33	24.68
Aug.	187.14	132.71	98.80	74.39	54.76	38.06	23.52	10.69	1.25
Sept.	112.14	72.93	54.16	37.94	24.20	14.97	7.78	2.85	0.1
Oct.	3.17	1.75	1.03	0.61	0.34	0.17	0.05	0.1	0.0
Monsoon	417.79	353.82	310.46	276.22	246.49	218.15	189.61	158.25	120.04

Location - Balasore

May	46.98	19.22	11.06	5.93	2.12	0.96	0.31	0.04	0.0
June	135.31	61.28	34.32	21.11	13.46	8.58	5.28	2.95	1.34
July	151.86	28.49	48.42	32.29	22.19	15.25	10.17	6.27	3.24
Aug.	267.74	145.47	92.57	63.43	44.70	31.50	21.58	13.73	7.42
Sept.	144.70	92.95	70.18	51.06	35.28	25.15	17.11	10.64	4.89
Oct.	133.24	80.37	52.15	34.33	21.95	12.97	6.47	2.12	0.12
Monsoon	663.41	487.55	389.16	322.14	270.42	127.03	187.91	149.99	110.23

Location - Phulbani

May	2.56	1.35	0.76	0.42	0.22	0.09	0.02	0.00	0.0
June	68.57	52.07	40.00	29.87	20.50	11.13	1.00	0.0	0.0
July	236.65	133.56	87.88	61.86	44.70	32.29	22.74	14.96	8.44
Aug.	130.56	100.18	84.19	67.94	51.31	39.05	26.53	13.68	1.94
Sept.	124.45	81.71	63.21	44.39	24.83	15.52	5.89	4.35	0.0
Oct.	9.73	6.05	3.92	2.48	1.44	0.68	0.18	0.0	0.0
Monsoon	321.12	281.92	253.23	229.17	206.90	184.62	160.56	131.87	92.67

Location - Gopalpur									
May	8.68	4.02	2.10	1.13	0.59	0.28	0.11	0.03	0.01
June	44.35	17.86	8.57	4.08	1.66	0.73	0.27	0.08	0.01
July	65.97	36.44	22.09	13.73	8.35	4.73	2.30	0.78	0.09
Aug.	70.39	39.69	27.56	17.55	9.42	5.33	2.39	0.53	0.03
Sept.	97.49	69.34	55.72	41.78	27.16	18.08	8.68	1.34	0.0
Oct.	246.58	163.77	128.16	91.95	54.31	76.38	17.86	1.85	0.0
Monsoon	401.89	307.90	262.43	220.11	167.06	136.74	105.36	71.85	37.59
Location - Dhenkanal									
May	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00
June	67.40	48.69	39.27	29.69	19.69	12.89	5.67	1.32	0.45
July	99.01	71.35	58.23	45.16	32.05	24.56	17.08	8.24	0.75
Aug.	141.96	102.65	83.68	54.39	44.80	32.67	20.23	7.04	5.95
Sept.	85.00	51.26	36.96	24.20	14.89	9.24	4.79	1.76	0.73
Oct.	26.55	10.40	5.86	2.93	1.24	0.61	0.25	0.07	0.0
Monsoon	323.42	261.58	227.98	193.81	158.38	131.05	103.14	73.98	36.85

The distribution of runoff over different months shows that there is possibility of some runoff in June and a good amount of runoff in July. This runoff could be utilised for supplementing the water requirement of rice during initial stage. This possibility has been discussed in subsequent sections.

SEEPAGE CONTROL

One of the major constraint to development of runoff recycling irrigation system is high seepage losses from storage tanks. The seepage losses are quite high in laterite belt as the soil is of coarse texture and lower strata is made of fractured stones. Several investigations have reported that the gradual siltation and clogging of soil pores resulted in the development of layers of low hydraulic conductivity on the wetted perimeter. However, this is a very slow and long drawn process specially for small tanks and impedes the economic returns from the tank in early years. Few research workers concentrated on accelerating this process of creating layers of low hydraulic conductivity by adding artificial sediments particularly bentonite clay (Renfro, 1968) but not much success has been achieved. Asphalt and concrete lining has been tried but they are generally expensive and have maintenance problems (Laig, 1974). Many workers have used low density poly ethylene (LDPE) film for seepage control with varying degree of success. The major problem has been about the covering material to prevent mechanical damage and damage due to UV rays to the exposed film. IPCL (1980) suggested covering of film by soil at a side slope of 3.5:1. Rao et al. (1980) have suggested a 2:1 side slope with steps having film on bottom of side covered with soil. Srivastava (1988) used 15 cm thick soil layer at bottom and dry boulder pitching on sides having side slope 1:1. This design has been very popular and widely adopted by farmers in U.P. hills. However this design cannot be used as such in plateau region of Orissa due to non availability of river boulders. Rengasamy et al. (1996) has reported that dispersed clay with clay concentration more than 8 g L^{-1} seals the pores completely. They have also reported that the inoculation of algae reduces the seepage by 13 to 23%.

To develop design of inexpensive seepage proof tanks for Orissa conditions, studies were initiated. Housing and Urban Development Corporation (HUDCO) has developed design of machine to make compressed soil blocks. The studies were intitiated to evaluate feasibility of using these blocks as covering material over the LDPE film as well as for their use as replacement of klin burnt bricks which are costly and has to be transported from a great distance. The machine manufactures two soil blocks in one stroke. The size of block is 23.5 x 10.5 x 7.5 cm. According to the machine specifications, the compression strength of these blocks is 20 kg/cm^2, the maximum water absorption is 15 percent by weight, and the erodibility has been found negligible after water spray of 1.5 kg/cm^2. Texture range of the

Table 2 Texture range of soil to be used for making blocks as specified by manufacturers.

Type	Max %	Min %	Optimum %
Clay (<0.002 mm)	32	8	20
Silt (0.002 to 0.02 mm)	20	10	12
Fine sands (0.02 to 0.2 mm)	32	12	20
Coarse sand (0.2 to 2 mm)	20	18	30
Fine gravel (2 to 4 mm)	12	0	12
Coarse gravel (4 to 20 mm)	40	0	6

However, the above mentioned range may not be suitable for lining purposes, as in this case the prime concern is reduction in hydraulic conductivity.

To assess the feasibility of using these blocks for lining, two experiments, one on effect of submergence in water another on hydraulic conductivity were conducted. The results are presented below:

(i) Studies on effect of submergence in water on soil blocks with different percent of cement additives

Soil blocks with different levels of cement additives (0, 1, 2, 3, and 4 per cent) were manufactured and tested for effect of submergence as the soil blocks have to be under submerged conditions in a tank or channel. Four cover treatments, i.e., uncovered, cement plaster (1:3), cement plaster (1:6), and cement slurry coating were tested. The plaster/coating was done on three sides of a block made by joining three mud blocks with unplastered surface at bottom. The effect of submergence are presented in Table 3. It is evident from table that the plaster is essential for safety under submerged conditions. There is no effect of cement mortar ratio and 1:6 ratio can be used.

(ii) Studies on hydraulic conductivity of the compressed mud blocks having different levels of cement additives for two soils.

The soil blocks from two soils having different cement additives were tested in the hydraulic conductivity measuring instrument fabricated for this purpose. The texture of one soil was loamy sand while another was laterite soil. The textural analysis of both soils are presented in Table 4.

The cement additives used for block making varied from 1 to 5% in both soils. To assess the effect of lime on further decreasing the hydraulic conductivity, 3% lime was added in addition to 2% and 5% cement addition for both soils. The hydraulic conductivity of various blocks having different cement additives and kiln burnt brick is presented in figures 1 to 12.

Table 5 presents summary of the hydraulic conductivity of mud blocks made of two types of soils. It is evident from the table that the blocks made of both type of soils have hydraulic conductivity much less than kiln burnt bricks. While, the optimum amount of additive for loamy sand soil is 4%, it is more than 5% for laterite soil. When lime is added in addition to the cement, the effect is not uniform. It is evident from Table 5 that in loamy sand soil, the hydraulic conductivity reduced to 0.18 cm per day for 2% cement and 5% lime, but it has shown no reduction for 5% cement and 3% lime. For laterite soils, there is significant reduction in hydraulic conductivity by addition of lime (0.18 cm per day from 0.38 cm per day). This aspect need to be further investigated with more emphasis on size of pore space, particle size of cement and lime both normal and pulverized. The cost is also less than the cost of the kiln burnt brick. The added advantage is of no transportation cost which will be considerable in inaccessible areas. Further studies are underway to develop relationship between soil texture characteristics and optimum quantity of additives alongwith the effect of pulverization.

Table 3 Effect of submergence on soil blocks with different percent of cement additives

Cement Additive percent	With plaster of 1:3 cement mortar	With plaster of 1:6 cement mortar	Without plaster	Dipping in cement slurry
No additive	Slight erosion	Slight erosion	Dissolved	Dissolved
1% cement	No erosion	No erosion	Dissolved	Dissolved
2% cement	No erosion	No erosion	Dissolved	Dissolved
3% cement	No erosion	No erosion	Dissolved	Dissolved
4% cement	No erosion	No erosion	Dissolved	Dissolved

Table 4 Textural analysis of the soils used for block making

Particle diameter	Percent in Ist Soil	Percent in IInd Soil
> 2 mm	0.04	0.05
1.18 to 2.00 mm	0.89	1.50
0.6 to 1.18 mm	11.13	14.96
0.25 to 0.6 mm	45.81	47.33
0.075 to 0.25 mm	30.81	29.18
0.002 to 0.075 mm	4.65	3.78
<0.002 mm	6.60	3.18

Table 5 Hydraulic conductivity of compressed mud blocks with different level of cement additive

Sl. No.	Percent cement as additive and weight required per 1000 mud blocks	Percent lime as additive and weight required per 1000 mud blocks	Loamy sand soil	Laterite loamy s and soil	Cost of blocks per 1000 Rs
1.	0.5, 20 kg		0.41	0.60	400
2.	1.0, 40 kg		0.30	0.49	450
3.	2.0, 80 kg	0.0	0.24	0.48	550
		5.0, 150 kg	0.18	0.28	850
4.	3.0, 120 kg		0.20	0.47	650
5.	4.0, 160 kg		0.18	0.40	750
6.	5.0, 200 kg	0.0	0.18	0.38	850
		3.0, 90 kg	0.18	0.18	1030
7.	Kiln burnt brick		0.66		1800

(iii) Field evaluation of lining materials

An experiment was laid down to evaluate the lining material by comparing kiln burnt brick masonry lined, 4% cement additive mudblock masonry lined, and LDPE film overlain by zigzag mudblock (2% cement additive) pitching alongwith cement plaster (1:6) with unlined tank. The results of seepage loss for two months are presented in Fig. 1. The peak in curve around 17th January is due to rainfall. It is evident that both 4% cement additive mudblock masonry lined and LDPE film lined overlain by 2% cement additive mudblock pitching have performed better than brick masonry lined. The extra losses in LDPE film lined tank is due to flaws in construction, as the over lining of the film could not be completed in time and the film remained exposed for a quite some time. The further studies are underway.

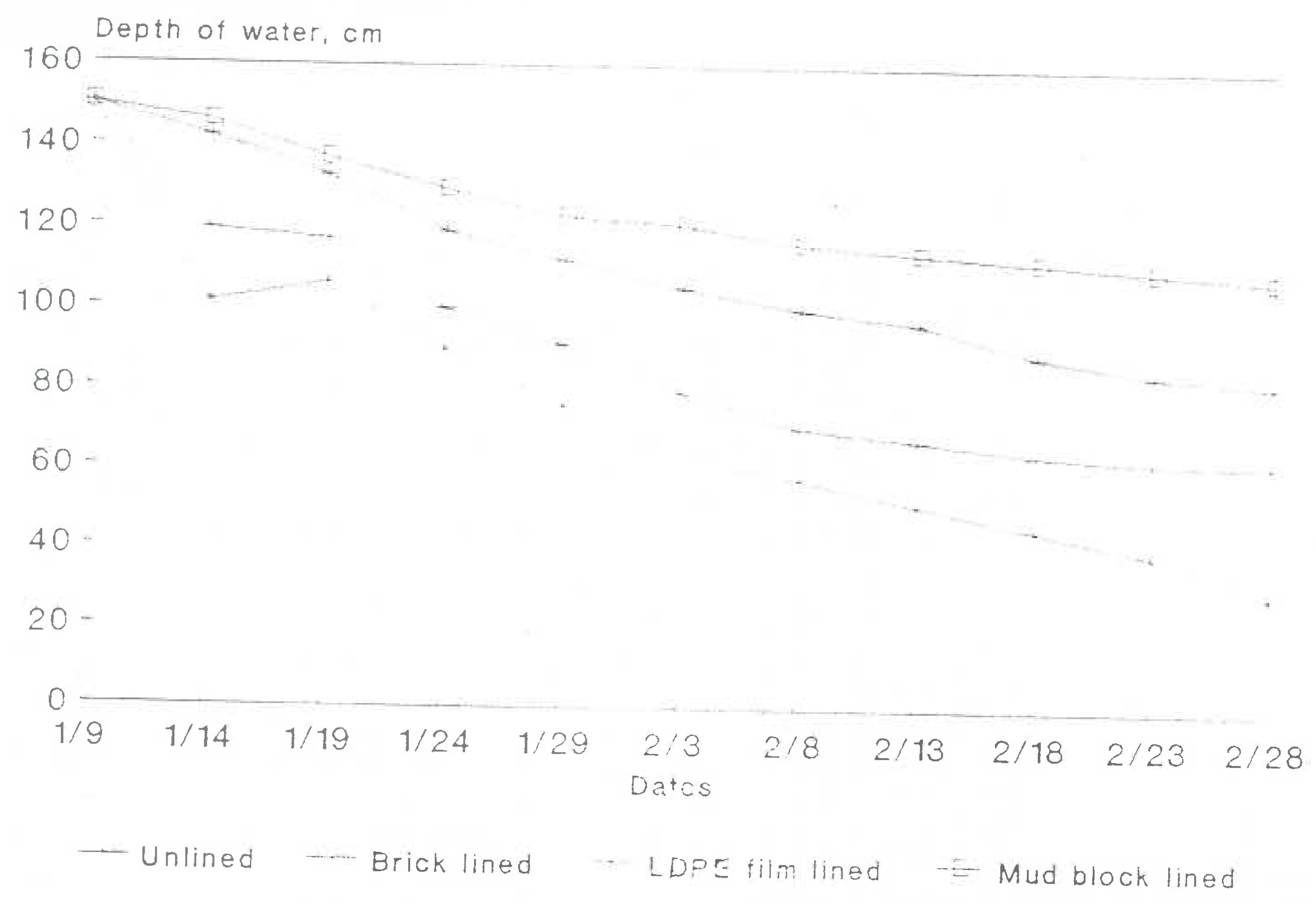

Fig. 1 Water level in tanks lined by different materials

DESIGN OF RUNOFF RECYCLING IRRIGATION SYSTEM

Water harvesting has been used for centuries and considerable work has been reported on farm scale reservoirs or farm ponds (Srivastava, 1992). However, application of modern mathematical tools for designing the water harvesting/runoff recycling systems is a recent phenomena (Sharma & Helweg, 1982). The role of water harvesting systems in semiarid and arid zone is to provide life saving irrigation to low duty crops in monsoon season and if possible one or two irrigations to raise another crop in following dry season (Helweg & Sharma, 1983; Verma & Sarma, 1990), but in subhumid/humid high rainfall regions, the runoff recycling should aim to provide sufficient water supply to rice in conjunction with rain during wet season and supplementary irrigation to a low duty crop in subsequent dry season. Jensen et al. (1993) and Bhatnagar et al. (1996) have reported feasibility of such system. Studying the cost effectiveness of such systems for Philippines conditions, Guerra et al. (1990) have reported that these systems have favourable benefit cost ratio.

Two methodologies have been used for design of such systems. Jensen et al. (1993) have estimated the total irrigation requirement at a particular probability and then designed the tank by estimating the water yield from catchment. Srivastava (1996) has used water balance simulation method which simultaneously simulates crop water balance and tank water balance for designing runoff recycling system for hilly terrains. He has assumed lined tanks and pipe conveyance with almost nil conveyance loss in view of very high seepage rate in tanks and small size of command area (0.1 ha). However, in plateau region of eastern India (comprises of western Orissa, eastern M.P., south Bihar and southern West Bengal) which receives rainfall between 1100 to 1500 mm, the design parameters should include decision on optimum command area of a single tank and feasibility/economics of lining of the tank in addition to the parameters of catchment command ratio, size of tank and suitable variety. While the feasibility/economics of the lining will be dependent upon rate of seepage loss from the tank, the optimum command area will be function of conveyance efficiency. In practice, the decision on location of tank will be based upon trade off between cost of construction of tank and conveyance efficiency.

In view of the above, a simulation model has been developed to suit the high rainfall conditions of eastern India and design parameters for a runoff recycling system has been obtained.

Methodology

A major constraint to realize the potential yield of rice in rainfed tracts of high rainfall areas of eastern India is late transplanting due to delay in obtaining ponded condition to facilitate puddling with rainfall alone. Even in canal commands, there is high yield difference between head and tail reach due to late availability of irrigation water in tail reach to facilitate transplanting in time. WTCER (1996) has reported a 40% reduction in yield of rice in canal irrigation project command when transplanting is not completed in July. Thus the first condition, which any irrigation system should satisfy, is that the transplanting should be completed by optimum time, i.e., 15th July. The other conditions to be satisfied are: there should be ponded water in the initial stage of transplanting for smooth recovery of plants; the soil moisture should not fall below field capacity and there should be sufficient water in the tank to meet the demand due to prolonged dry spells; and there should be sufficient water in the tank for providing at least two irrigations to succeeding dry season crop. The design parameters of a runoff recycling irrigation system are: minimum catchment command area ratio, size of the tank, and maximum affordable conveyance loss to meet up the objective of providing required amount of irrigation water at desired time. Since the parameters should be able to fulfill the objectives for a desired return period, a time series for these parameters is required. Besides the engineering design of the system, crop planning is also essential to realize the full potential of the irrigation system. The selection of the suitable variety is important in this regard. Since in this system the crop and tank are integrated, simultaneous simulation of the water balance of cropped area as well as the tank has been attempted to achieve the objectives.

The simulation has been done for a crop rotation of transplanted rice (July - October) - ground nut (November - March). The region gets premonsoon showers in May (the normal rainfall for Orissa during May is 40.36 mm) and thus it has been assumed that on 15th May, the soil is at permanent wilting point. Adequate drainage is assumed to prevail because of rolling topography. The ground water influence has not been accounted as the ground water depth during monsoon season is normally much below the root zone. Two varieties, a short duration IR -36 (110 days) and medium duration Mashuri (130 days) have been considered.

Water balance model

The daily water balance model used in this study has two parts: crop water balance simulation and tank water balance simulation. For crop water balance simulation, the model used by Srivastava (1996) has been modified. This has been done as due to high rainfall there is wide fluctuation in ponding depth. For tank water balance simulation, simple input output method has been used. The input is runoff, and output is evaporation, seepage loss and water used for irrigation. The integrated model has three components: A pre-transplanting model estimates the date of transplanting by accounting the soil moisture status and the runoff water stored in the tank, the second component estimates irrigation requirement for initial ponding period of one week to maintain 5 cm ponding for proper establishment of the plants, and the third component estimates the irrigation requirement to maintain the soil moisture above field capacity for the growth period upto physiological maturity. No irrigation has been proposed between period of physiological maturity to maturity as this period requires drainage. The simulation starts on 15th May and ends at the time of maturity i.e. 80 days for short duration variety IR 36 and 100 days for medium duration variety Mashuri from the date of transplanting. Any dependence of field duration on seedling age and time of transplanting is neglected here.

Pre-transplanting model

This phase of the model deals with the moisture balancing and tank water balancing for period from 15th May to the day of transplanting. During this period the soil moisture in top layer is generally below field capacity except for the time when there are heavy showers. There will be no percolation loss in this condition and it can be safely assumed to be negligible. The equivalent depth of soil moisture (SM_i) in the root zone at the end of day is calculated from

$$SM_i = SM_{i-1} + P_i - E_i \tag{1}$$

where P_i and E_i are daily rainfall and evaporation from bare soil, respectively. The initial value of soil moisture on 15th May has been taken at permanent wilting point. Evaporation from bare soil 'E' is estimated from the open pan evaporation (Eo) subject to the rainfall conditions of the days (Jensen et al., 1993; Srivastava, 1996 a).

The suitable date of transplanting will be a function of soil moisture status and irrigation water availability in the runoff tank. For proper utilization of rain water and minimizing the use of stored runoff water, the model stipulates two conditions to be fulfilled: (i) the soil moisture is above field capacity, (ii) sufficient water is available in the tank to provide irrigation for bringing soil moisture at saturation level, amount required for puddling and for ponding for at least two days (equal to seepage & percolation loss + evaporation). But this model does not take in account the age of nursery. To introduce this parameter, a condition has been incorporated that the transplanting will not be done before 1st July, by which time the nursery will be about 25 days old in normal conditions. Actually if this constraint is not put up, in few years of good rainfall in June the simulation will show transplanting before 1st July and the crop will suffer dry spell in early growth period. The water in the runoff tank on i^{th} day has been calculated as follows:

$$TV_i = TV_{i-1} + Q_i \, . \, A \, . \, R - LV_i \tag{2}$$

$$LV_i = V1_i - V2_i \tag{3}$$

$$V1_i = (W - 2H_i).(L - 2H_i).H_i - (W + L - 4H_i)\, H_i^2 + 1.33\, H_i^3 \tag{4}$$

$$V2_i = (W - 2H_i - 2LH_i).(L - 2H_i - 2LH_i).(H_i - LH_i) - (W + L - 4H_i - 4LH_i)\,(H_i - LH_i)^2 + 1.33\,(H_i - LH_i)^3 \tag{5}$$

$$LH_i = (ss_i + EP_i - P_i)/1000 \tag{6}$$

$$ss_i = m.H_i + c \tag{7}$$

$$EP_i = 0.7\, Eo_i \tag{8}$$

where

TV_i = runoff volume stored in the tank, litres

Q_i = runoff from catchment, mm

A = command area of tank, m^2

R = catchment command area ratio

LV_i = loss in volume of water due to seepage and evaporation on ith day, m^3

LH_i = loss in height due to seepage and evaporation on ith day, m

ss_i = seepage loss in tank on ith day, mm

EP_i = evaporation loss from tank surface on ith day, mm

Eo_i = open pan evaporation on ith day, mm

P_i = rainfall on ith day, mm

H_i = depth of water in tank on ith day, m

m,c = constants in relationship between seepage rate and depth of water in tank

Q_i has been calculated by SCS curve number method (Chow, 1964). The irrigation requirement for puddling (I_p) has been calculated as follows:

$$I_p = [30.0 + SAT - SM_{p-1} - P_{p-1} + Eo_{p-1} + SP_{p-1} + Eo_p + SP_p - P_p]/\text{ç} \qquad (9)$$

and

$$TV_p \geq I_p .A + 2(SP_{avg} + Eo_{avg}).A + 2\ (ss_{avg} + EP_{avg}).a \qquad (10)$$

where

p = date of transplanting

SAT = equivalent water depth at saturation, mm

P = rainfall, mm

Eo = open pan evaporation, mm

SP = seepage and percolation, mm

η = irrigation efficiency = conveyance efficiency x application efficiency

SP_{avg} = average value of daily seepage and percolation loss, mm

Eo_{avg} = average value of daily open pan evaporation, mm

ss_{avg} = average value of daily seepage loss from the tank, mm

EP_{avg} = average value of daily evaporation loss from tank, mm = 0.7 Eo_{avg}

a = average water area of the tank, m^2

The ponding depth at the time of transplanting has been assumed 30 mm. The eq. 10 explains the constraint of sufficient water availability in the tank to take care of irrigation requirement for next two days.

Water balance for one week after transplanting

For the initial one week after transplanting, a ponding depth of 5$\pm$ 2 cm has to be maintained. The evapotranspiration during this period has been assumed equal to open pan evaporation as the crop factor (ET_{crop}/E_o) for initial stages of transplanted rice has been given 1.0 (Michael, 1978). The irrigation requirement for this period i.e. (p+1)th day to (p+7)th day will be

$$I_i = [50 - D_{i-1} + Eo_{i-1} + SP_{i-1} - P_{i-1}]/\eta \quad (11)$$

where

D_{i-1} is depth of ponding on i-1[th] day

Now this irrigation water will come from the tank and thus the water stored in the tank should be more than the requirement.

$$TV_i \geq I_i . A \quad (12)$$

and

$$TV_i = TV_{i-1} - I_{i-1} . A + Q_i . A.R - LV_i \quad (13)$$

where

$$TV_{p+1} = TV_p - I_p . A + Q_{p+1} .A. R - LV_{p+1} \quad (14)$$

Now in case the tank has run dry due to insufficient rainfall then

$$D_i = D_{i-1} - SP_i - Eo_i + P_i \quad (15)$$

Water balance for subsequent period

It has been assumed that irrigation will be given when the soil moisture goes below the field capacity upto physiological maturity stage. No irrigation has been sought between physiological maturity to maturity phase when the drainage is preferable. During this period, there can be three conditions of soil moisture. In first phase, there will be ponding due to sufficient rainfall to take care of seepage and percolation loss and evapotranspiration demand. The water balance equation will be

$$D_i = D_{i-1} - SP_i - Eo_i . Kc + P_i \quad (16)$$

where $Kc = ET_{crop}/Eo$, i.e., crop factor or pan coefficient. This phase will occur only where the following condition is satisfied.

$$D_{i-1} > SP_i + Eo_i . Kc - P_i \quad (17)$$

If condition expressed by eq (17) is not fulfilled the soil will go in moist phase and the water balance equation will be

$$SM_i = SM_{i-1} + P_i - Eo_i \, . \, Kc - SP_i \tag{18}$$

If the soil moisture is less than field capacity, it will need irrigation and irrigation required to bring a submergence level of 5 cm will be

$$I_i = [50 + SAT - SM_{i-1} - P_i + Eo_i \, . \, Kc]/\eta \tag{19}$$

At this point there will be two conditions: there will or not be sufficient water in the tank to take care of this irrigation requirement. In first case

$$TV_i > I_i \, . \, A \tag{20}$$

where

$$TV_i = TV_{i-1} - I_{i-1} \, . \, A + Q_{i-1} \, . \, A. \, R - LV_{i-1} \tag{21}$$

and thus $D_i = 50.0$ and $SM_i = SAT$

In other case, i.e., if $TV_i < I_i \, . \, A$, then

$$SM_i = SM_{i-1} + P_i - Eo_i \, . \, Kc \tag{22}$$

The further water balance will be computed by eq (22) and irrigation requirement will be calculated by eq (19) till the condition of eq (20) is not satisfied.

The estimation of crop evapotranspiration has been done by selecting values of pan coefficient for different crop stages and soil moisture conditions. While enough data are available for estimation of crop evapotranspiration of rice from open pan evaporation data for saturated or submerged conditions (Michael, 1978; FAO, 1977), the estimation of crop evapotranspiration for moist phase was done as per Srivastava (1996). The estimation of deep percolation is a tricky matter as it is an extremely variable parameter (Iwata et al., 1988) depending on soil and drainage conditions. Jensen et al. (1993) have taken percolation values of 1 mm d^{-1} for clayey soil and 3 mm d^{-1} for loamy soil, and on dry days they have assumed 50% reduction in percolation. Srivastava (1996) has reported two values of seepage and percolation loss, 15 mm d^{-1} under ponded conditions and 25 mm d^{-1} at the time of transition form moist to ponding phase (due to crack development after a dry period) for silty clay loam soil. However none of them have accounted for the effect of ponding depth on rate of deep percolation. The experimental data of WTCER, Bhubaneswar (WTCER,1994, 1995, 1996) showed that the deep percolation loss is a linear function of depth of ponding and therefore a relationship was developed between deep percolation loss and depth of ponding for use in this study. The relationship is

$$SP = 2.0786 + 0.0338 \, D \tag{23}$$

where SP is rate of deep percolation in mm d^{-1} and D is depth of ponding in mm.

The deep percolation rate at the time of puddling was taken as 5 mm d^{-1}. Another important parameter in water balance of rice is allowable maximum depth of ponding. Working on drainage requirement of the rice, Ghorai and Singh (1994) have reported that there is significant reduction in yield if the ponding depth is more than 12.5% of the height of the plant at the time of maturity. For varieties under consideration, this translates to 15 cm. Thus, a provision has been made in computer program that if ponding depth is more than 15 cm, it will be restricted to 15 cm. To take care of the requirement of the post monsoon crop (two irrigation of 75 mm each) a constraint of minimum tank capacity of 175 mm was included in the model.

A computer program was developed for this simulation and model was run for different catchment command area ratio (1.0 to 5.0), different irrigation efficiencies (1.0, 0.8, 0.6, 0.4), and three rates of seepage and percolation loss in tanks for both varieties for 16 climatological data (1980-1995) and time series for following parameters, (i) date of transplanting, (ii) days of ponding during three periods, viz., (a) transplanting to flowering, (b) flowering to physiological maturity, and (c) physiological maturity to maturity, (iii) required tank capacity, (iv) whether tank ran dry and was unable to supply water during first week of transplanting, (v) whether tank was unable to supply water in case of a prolonged dry spell, and (vi) whether the tank had sufficient water left to meet the demand of the post monsoon crop, were created for all the combinations of catchment command area ratio, irrigation efficiency, rates of seepage & percolation losses in the tank and varieties.

The numeric parameters obtained from the simulation were fitted to different distribution (normal, pearson, extreme, log normal, log pearson, and log extreme) with or without transformation to estimate the probable values as per methodology described by Srivastava and Rao (1993).

The effect of different variables on various parameters have been analyzed to get the optimum combination of the variables.

Fig. 2 shows the probable values of date of transplanting at exceedance probability levels of 50% and 80% for different catchment command area ratios. It is evident from figure that transplanting can be done earlier with higher catchment command area ratio[2] (CCR) with CCR $\geq$ 2.0 facilitating transplanting around 15th July at 50% probability which is optimum time of transplanting. But at 80% probability, the date of transplanting is around 29th July for CCR $\geq$ 2.0. Thus, in long run the design of the system with this CCR may lead to failure. With CCR $\geq$ 3.0, the date of transplanting at 50% and 80% probability is 11th and 20th July respectively. Thus, this CCR value can be termed safe as in only 20% cases the transplanting will be delayed beyond 20th July. Therefore to meet the first objective of irrigation, the catchment command area ratio should be 3.0 or more.

Fig. 3 presents the days of ponding during different growth periods for short duration variety as affected by catchment command area ratio at both probabilities. It shows that at 50% probability there is very little difference among values for CCR $\geq$ 2.0, but at 80% probability, this condition arises only for CCR $\geq$ 3.0. Thus from maintaining proper moisture environment throughout the growth period point of view, the minimum catchment command area ratio should be 3.0. At this CCR, the irrigation system did not fail to provide irrigation when required all through the growth period for any of the simulated year.

Fig. 4 presents the effect of duration of variety on moisture status of the crop during different crop growth periods at 50% probability. It is evident from figure that medium duration variety has slightly more percent days under ponding during transplanting to flowering phase but less during the other two phases. This is due to coincidence of most active monsoon period of July - mid September with first growth period. The last two growth periods of medium duration variety coincides with withdrawal phase of monsoon and therefore the days of ponding is lower than that of short duration variety whose second growth period partly overlap with active monsoon phase. The pattern is similar at 80% probability (Fig. 5) also. However, the difference between period of ponding is more for flowering to physiological period, the critical reproductive phase. Thus, although both varieties have sufficient period under ponding, the short duration variety will be preferable especially in case of small and marginal farmers having less risk taking capacity.

Fig. 6 and 7 present the effect of conveyance efficiency on different parameters for catchment command area ratio of 3.0 at 50 and 80% exceedance probability for short duration variety. It is evident that the difference is very marginal between conveyance efficiency of 100% and 80% but the difference increases sharply if the conveyance efficiency drops below 80%. This becomes very critical for parameters such as date of transplanting and days of ponding during flowering to physiological maturity phase. Therefore the location of pond should be such that the conveyance efficiency could be maintained around 80% at an affordable cost. This becomes very important in laterite soil belt where the conveyance losses are very high. In water harvesting based irrigation systems, the number of irrigation required is low making higher cost on lining of conveyance system uneconomical (Srivastava and Bhatnagar, 1989). The conveyance efficiency also affects the required size of the tank (Fig. 8) although the difference is not very large as a minimum of 1750 m^3 storage requirement has been envisaged for one ha command area to provide 150 mm of irrigation to the post monsoon crop. Therefore the size of the command area under one tank should be selected so that the conveyance efficiency does not drop below 80%. An optimal location of the tank can be found by trading off between cost of efficient conveyance system and additional cost of construction of tank at a less economic location.

There is no effect of different rates of seepage and percolation loss in tank on various parameters. This may be due to the fact that in high rainfall areas, the total rainfall is much more than the seepage and percolation loss during monsoon period and therefore there is no effect on performance of system during monsoon period. However, the higher rate of loss will affect the water availability for the post monsoon crop and the decision on lining should be taken on that basis.

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[2] *A value of more than 31 means that the transplanting date is in August, but for sake of comparison the computed data have been presented.*

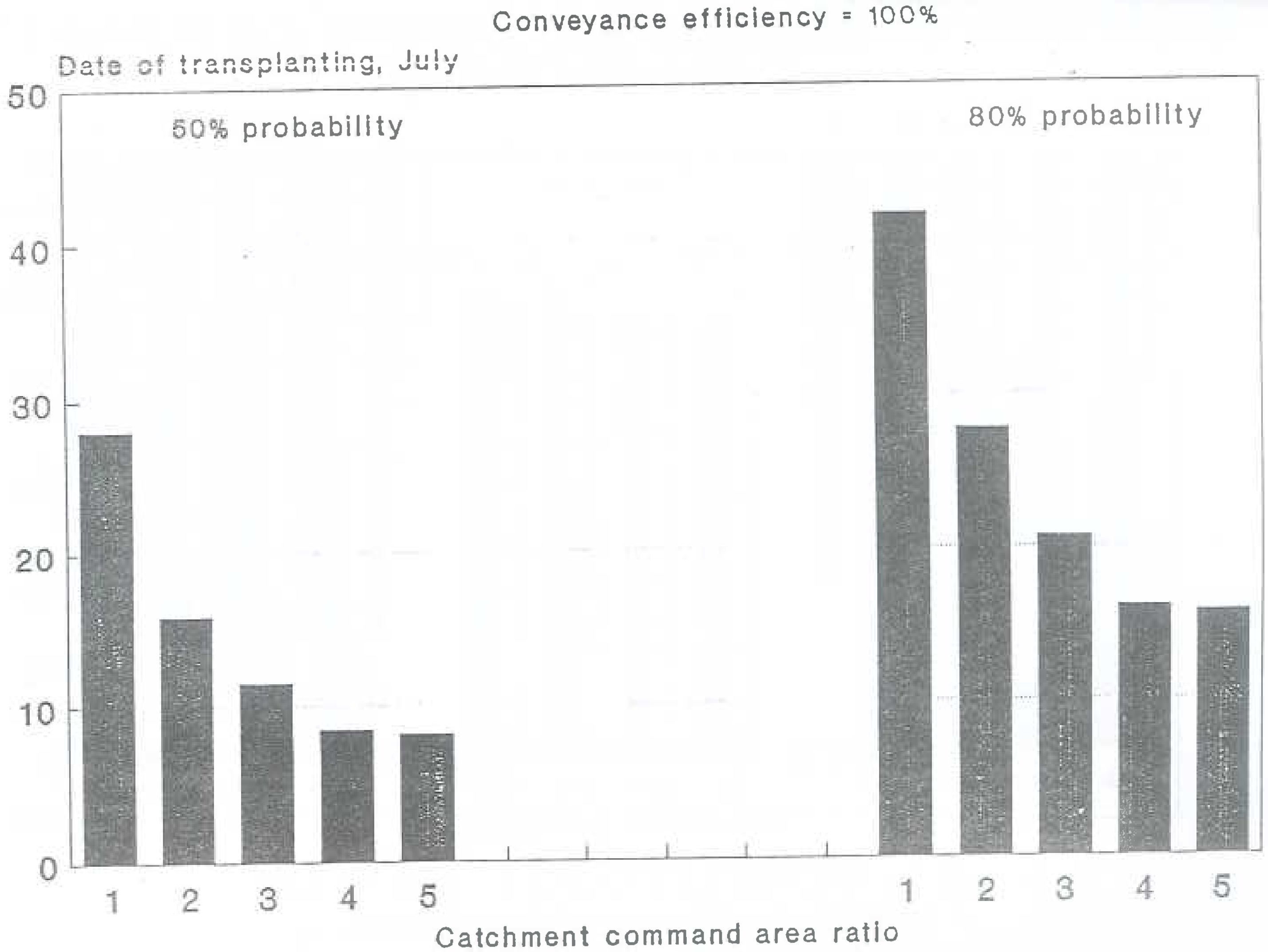

Fig. 2 Date of transplanting with different CCR at two probabilities

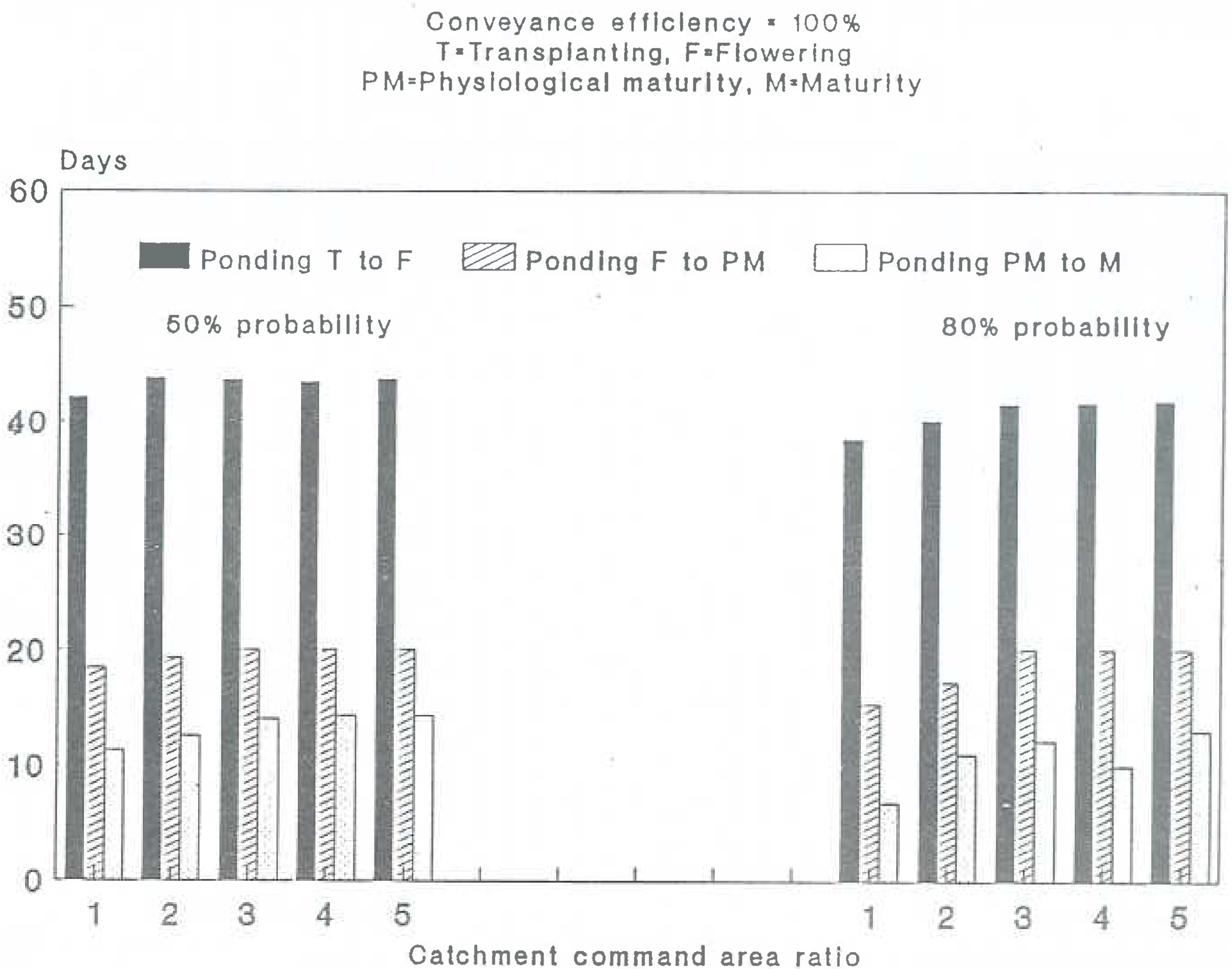

Fig. 3 Effect of CCR on days of ponding during different growth periods

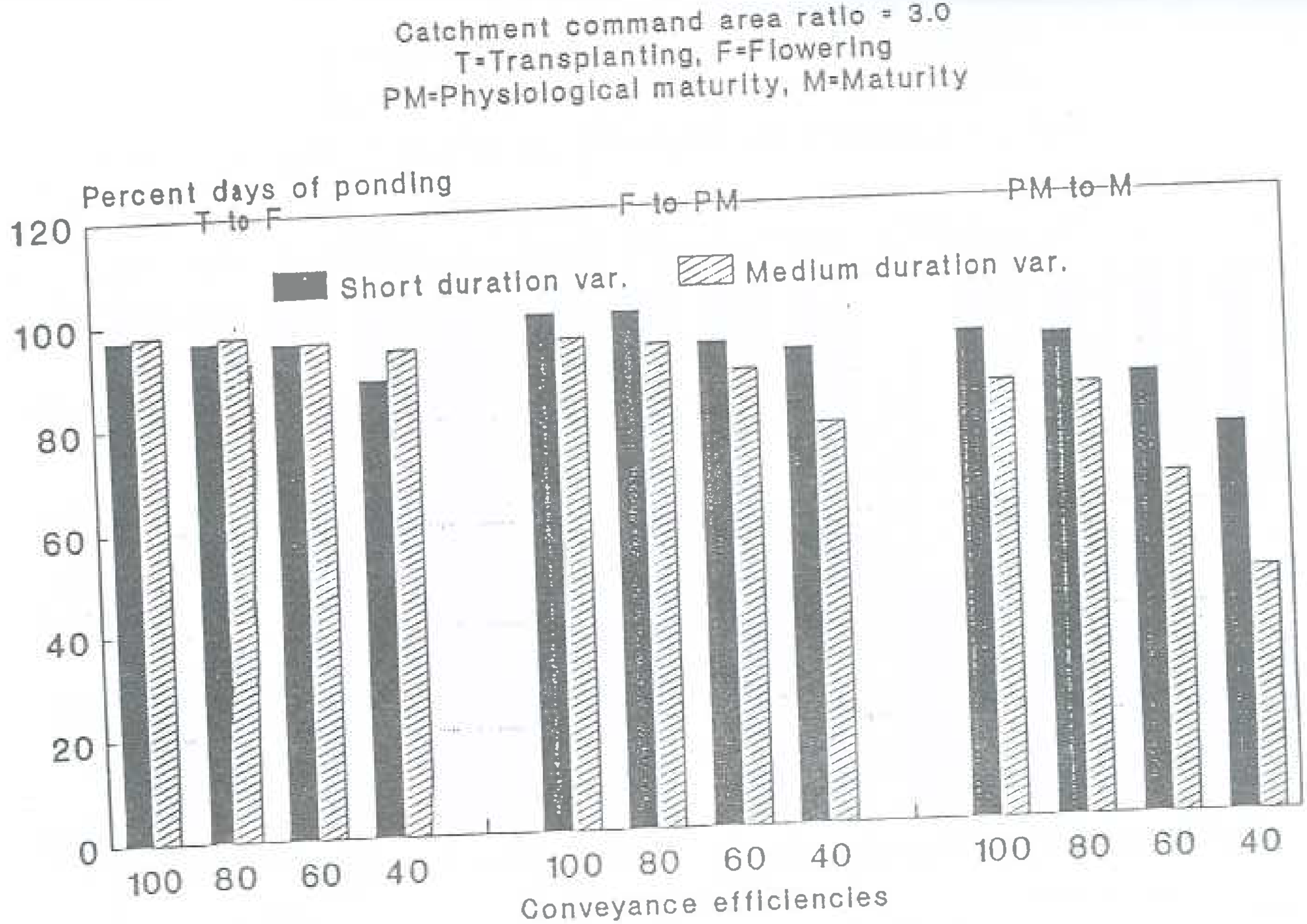

Fig. 4 Days of ponding as percent of th growth period for short and medium duration varieties at 50% probability

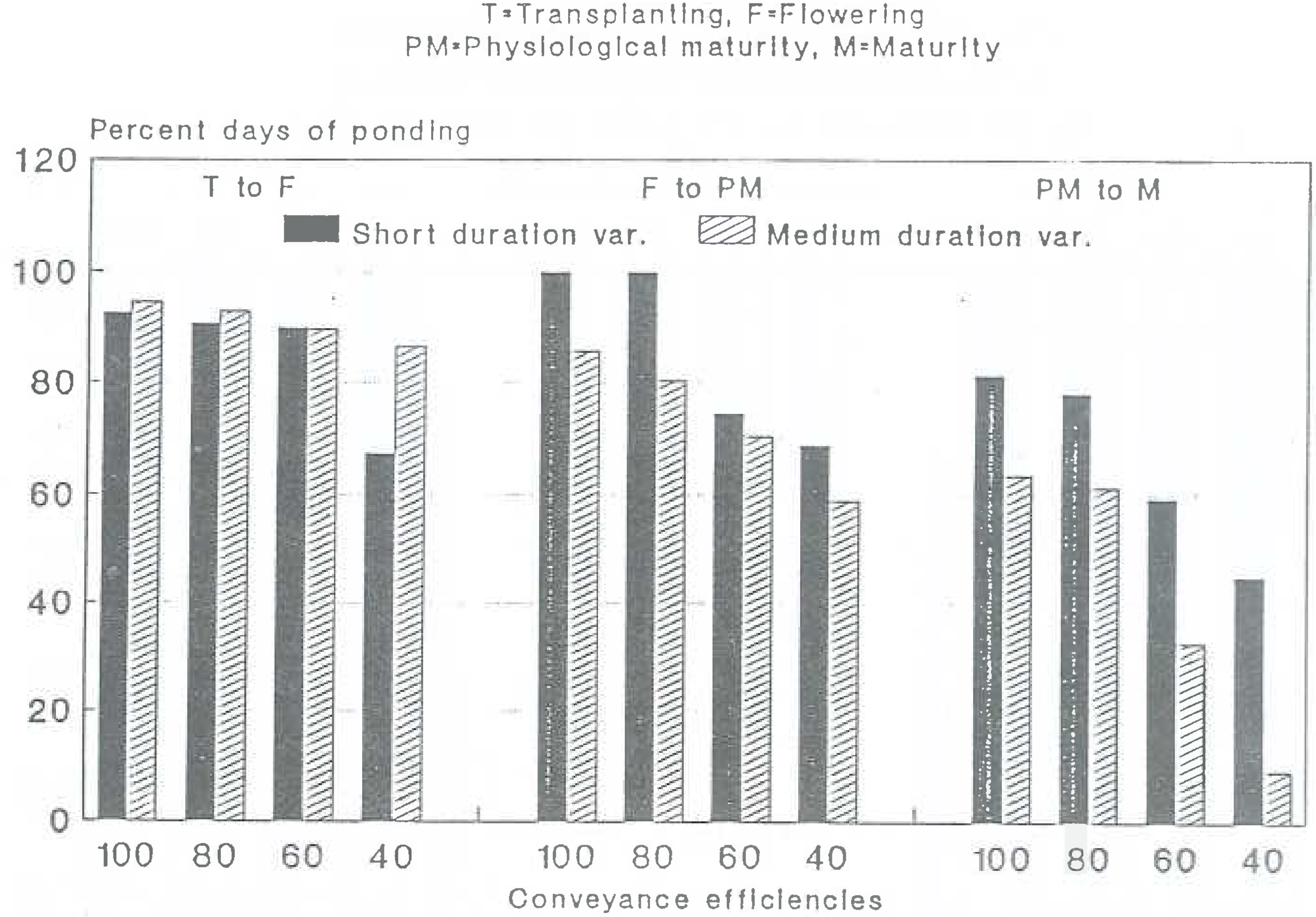

Fig. 5 Days of ponding as percent of the growth period for short and medium duration varieties at 80% probability

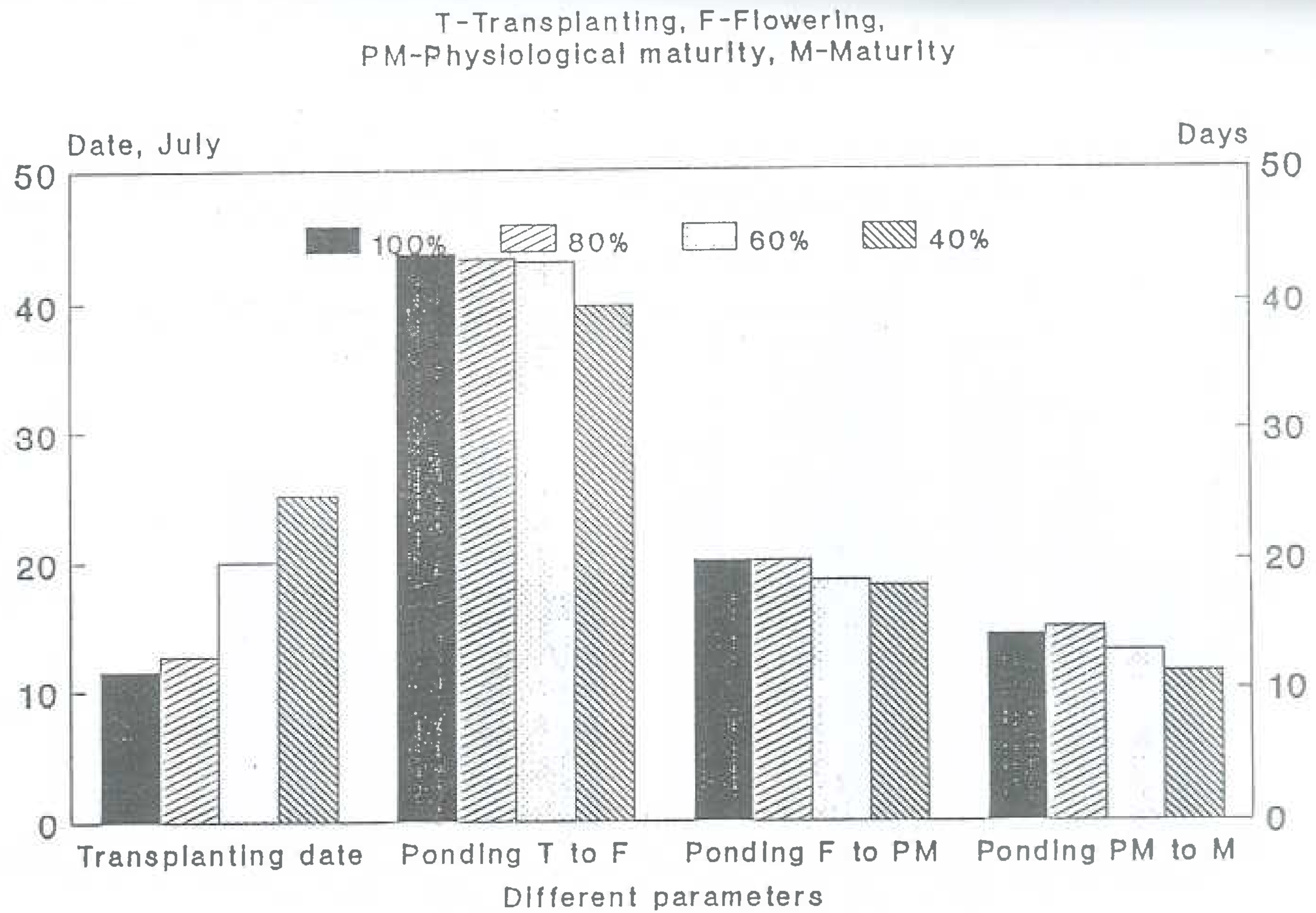

Fig. 6 Effect of conveyance efficiency on varoius parameters at 50% probability for short duration variety with CCR= 3.0

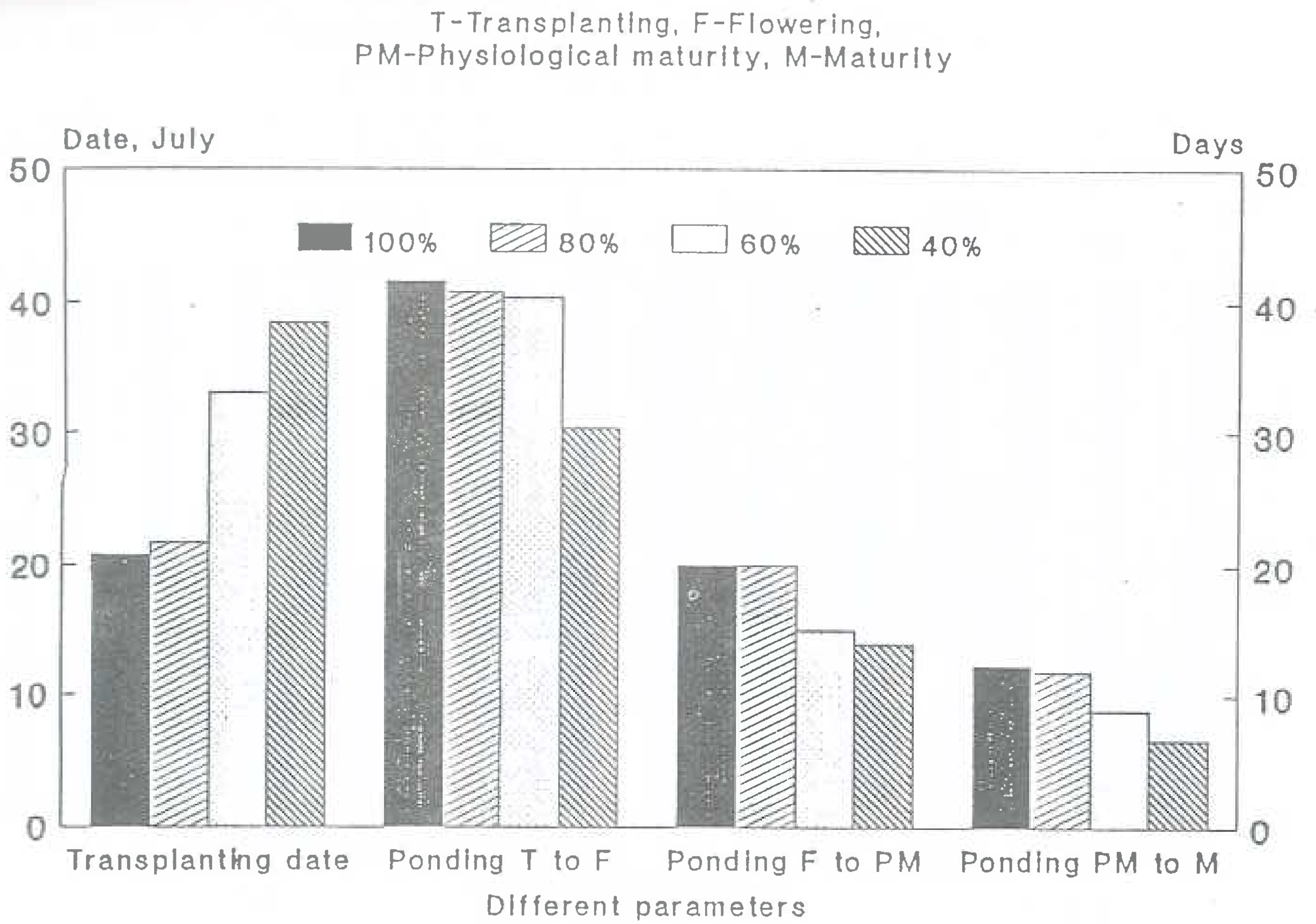

Fig. 7 Effect of conveyance efficiency on various parameters at 80% probability for short duration variety with CCR=3.0

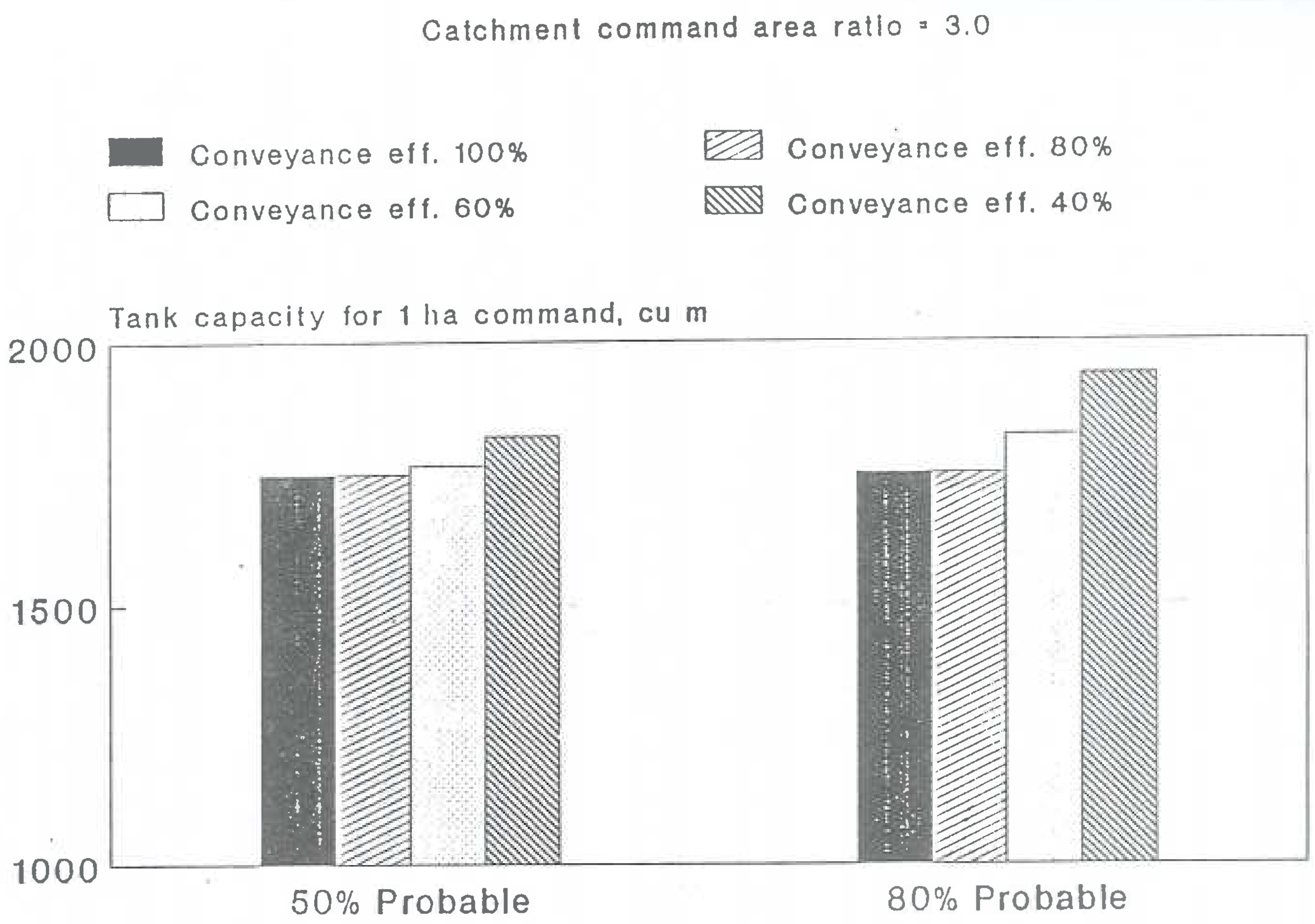

Fig. 8 Effect of conveyance efficiency on required tank capacity at different exceedance probabilities

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