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Rainfall characteristics and rainwater management strategy for crop production

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सार — 2000 मि.मी. से अधिक 1000 से 2000 मि.मी. और 500 से 1000 मि.मी. की श्रेणी की वर्षा वाले तीन क्षेत्रों में वर्षा की विशेषताओं का पता लगाने के लिए, 10 स्टेशनों के वर्षा आंकड़ों की बारम्बारता का विश्लेषण किया गया है। इस प्रकार से उत्पन्न किए गए आंकड़ों से पता चला है कि तीन समूहों में स्थित अधिकत्तर स्टेशनों में, फसल के मौसम में अधिक वर्षा और कम वर्षा दोनों ही प्रकार की अवधियां हो सकती हैं। जब दापोली में एक दिन की तूफान वाली वर्षा अधिकत्तम है तो लुधियाना में यह न्यूनत्तम है। फिर भी प्रत्येक स्टेशन में अल्पावधि अधिक वर्षा होती है। जिसके दौरान जल को पुनः चक्रण के लिए एकत्रित किया जा सकता है। दो प्रमुख फसलों, जैसे चावल और गेहूं की फसल की विशेषताओं पर विचार विमर्श किया गया जिससे यह भी पता चलता है कि दोनों मामलों में जल की अधिकता और कमी फसल को प्रभावित कर सकती है। चावल के न्यूनत्तम उत्पादन का पता 1000-2000 मि.मी. श्रेणी वाले स्टेशनों से चला है जहां पर जल की कमी की अवधियों के साथ-साथ जल की अधिकता संकटपूर्ण समयों में हो सकती है और वह फसल को प्रभावित करती है। यद्यपि कृत्रिम सिंचाई कुछ हद तक मजबूती दे सकती है किन्तु रबी के मौसम के दौरान अंशतः और मानसून के दौरान जल की आपूर्ति में अनिश्चितता, जल की अधिकता से संबंधित समस्याओं को नियंत्रण रखने में सहायता नहीं करती है। फार्म/समुदाय तालाब पर आधारित भंडारन और पुनःचक्रण की तकनीक का सुझाव दिया गया है। यह तकनीक उपयुक्त है और विशेषकर उप-आर्द्र और आर्द्र क्षेत्रों में कृत्रिम सिंचाई के लिए सही विकल्प के रूप में तर्कसंगत है और यह अपेक्षाकृत सस्ती होती है। आरम्भिक विश्लेषण और परिणाम यह सुझाव देने के लिए काफी प्रोत्साहक है कि इस तकनीक का प्रयोग और मूल्यांकन और अधिक स्टेशनों पर किया जा सकता है।

ABSTRACT. Frequency analysis of rainfall data for 10 stations is carried out to identify rainfall characteristics in three regions with rainfall greater than 2000 mm, rainfall in the 1000-2000 mm range and rainfall in the range group of 500-1000 mm. The data thus generated indicated that both excess and deficit rainfall periods could occur within a cropping season at most stations located in the three groups. While one day storm rainfall is maximum at Dapoli, it is minimum at Ludhiana. However, short period excess rainfall occurs at each station during which water could be harvested for recycling. Crop characteristics of two major crops, *i.e.*, rice and wheat are discussed which also indicate that in both cases excess and deficit of water could affect yield. The minimum yield of rice is reported from stations in the 1000-2000 mm range group where periods of water stress as well as excess water occur during critical periods and affect the yield. Although conventional irrigation could firm up, to some extent, the uncertainty in supply of water during monsoon and partly during rabi season, it does not help to overcome problems related to excess water. A farm/community pond based storage and recycling technology is suggested. The technology is feasible and justifiably a better alternative to conventional irrigation, particularly in sub-humid and humid regions, and is relatively cheaper. Preliminary analysis and results are encouraging enough to suggest that the technology could be tried and evaluated at more stations.

1. Introduction

Water available in abundance in nature is, perhaps, the cheapest and is of course the most essential input for production of food and energy. Although, water in the form of precipitation is available freely and right at the side where it is to be used: yet so tenuous and delicate is the balance between the demand for water by crops and its supply by precipitation, that even short term deficit periods often reduce the production significantly. Even in areas where rainfall is ample, it is unevenly distributed affecting crop yields due to excess water at one time and due to water stress at the other. Therefore, natural occurrence of rainfall both in time frame as also space has to be managed and evened out to correspond to agricultural needs. While in some areas it can be done by providing irrigation, yet in other areas particularly sub-humid and humid regions, it can be achieved through storage so that surplus in one period can be effectively utilized in meeting the deficit in other period.

In a major effort to reduce weather based fluctuations in crop yield, a common strategy of providing irrigation has been adopted in the country. The water for irrigation has been provided through major, medium or minor irrigation works. While major and medium irrigation projects are either diversion canal or storage-dam based canal irrigation system : the minor projects are largely ground water based and include to a small extent the tank storage projects. Experiences with these projects have been mixed. It is now well known that agricultural production has been much more in areas commanded by minor irrigation works (particularly ground water based projects) compared to major or medium irrigation projects. Even amongst major and medium projects performance of some of them has been quite encouraging

TABLE 1

General characters of rainfall at gauging stations used in the study

Station	State	Average annual rainfall (mm)	Coefficient of variation	Water surplus during kharif season	Water deficit during kharif season (mm)	Husked grain yield (t/ha)	Soil type
Dapoli	Maharashtra	3372	22.0	2619	Nil	1.61	Lateritic sandy loam to clay loam
Chalakudy	Kerala	3096	16.8	1714	Nil	1.24	Loamy sand to sandy loam
Dehradun	Uttar Pradesh	2152	17.7	1211	Nil	1.16	Sandy loam to silty loam
Cuttack	Orissa	1514	20.6	503	Nil*	0.98	Sandy loam to sandy clay loam
Navsari	Gujarat	1465	21.7	758	Nil*	1.21	Clay with saline patches
Madhipura	Bihar	1368	33.8	491	Nil*	0.82	Loamy sand to loam
Bilaspur	Madhya Pradesh	1249	23.4	441	Nil*	0.78	Loamy sand to clay
Parbhani	Maharashtra	880	35.2	Nil	251	0.87	Medium to deep black clay
Karnal	Haryana	826	44.4	60	158	2.19	Sandy loam with large alkali patches
Ludhiana	Punjab	681	30.0	Nil	161	3.38	Loamy sand to sandy loam

*Although there are no seasonal deficit, yet short periods of deficit occur to affect yield

while in case of others it has been poor. Broadly speaking, performance of the projects has been poor in areas where average annual rainfall is more than 1000 mm. Therefore, execution of projects in areas above 1000 mm average annual rainfall is being debated and questioned. In such cases, management of rainwater within the watershed is being pleaded strongly.

The objective of the present paper is to identify and describe the climatic (rainfall) and crop characteristics in semi-arid, sub-humid and humid regions to devise a management strategy which allows management of rainwater for consistantly high yields. A management strategy devised for and tested in a semi-arid and humid region is described. It is opined that this strategy with site specific modifications could be tailored to suit many situations.

2. Material and methods

Ten stations covering average rainfall varying from 650 mm to 3300 mm have been chosen to work out rainfall characteristics in regions represented by these stations (Table 1). Daily rainfall data varying from 10 to 25 years were subjected to frequency analysis. It included estimates of coefficient of variation, storm rainfall of different durations, potential runoff generating storms and monthly and seasonal dry spells in the region. A period of 5 days or more with rainfall of less than 2.5 mm/day occurring in succession has been considered as dry spell for the purpose of rice growth as the experimental evidence indicates that no significant reduction in grain yield is observed if water is not ponded up to 5 days after the subsidence of ponded water (Rajput 1988). It was further assumed that break in dry spell occurred only if rainfall exceeded 10 mm in a period of at least two days. Average water surplus amount and its duration was computed using Thornthwaite and Mather's (1955) water balance technique considering average monthly rainfall and evapotranspiration.

The rainwater storage, harvesting and recycling technology developed at Karnal (Gupta and Dhruva Narayana 1972) was taken as the base for discussion in the light of rainfall characteristics in various regions. From topographical characters of the areas some alternatives are suggested to make it a viable, cost effective and appealing technology. In all discussions, rice and wheat have been taken as the main crops, although with known characteristics of other crops, technology could be modified to suit them.

3. General characteristics of rainfall

Management system for the conjunctive use of rainfall and irrigation water or for rainfall alone can be developed only with an understanding of the general characters of the rainfall in a region. Average annual rainfall in India estimated at 1190 mm shows wide spatial and temporal variation. Most of the coastal and interior areas receive precipitation exceeding 1000 mm annually with several stations receiving more than 3000 mm rainfall. Only the northwestern parts of the country such as Punjab, Haryana and parts of Rajasthan and Uttar Pradesh receive between 500 and 800 mm rainfall. Some parts of Rajasthan and Gujarat, in west, receive 200-400 mm rain. Similarly on the time scale, in general, more than 80 per cent of the rainfall is received in few months of the monsoon season. Usually this season extends from June to September, yet in some humid regions, there may be some variations. In other months, even in areas receiving more than 3000 mm rain/precipitation is so meagre that rainwater is negligible. Rainfall is highly variable and skewed. The variability increases with decreasing duration considered for analysis. In fact on weekly basis, the rainfall is extremely variable and, therefore, poses problems for planning agricultural operations. The introduction of irrigation in areas with above 1000 mm rainfall is based on the premise that it will firm up the water supply during

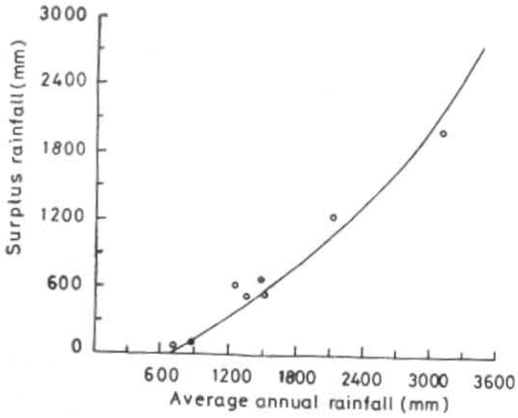

Fig. 1. Average rainfall *versus* surplus rainfall curve for the gauging stations used in the study

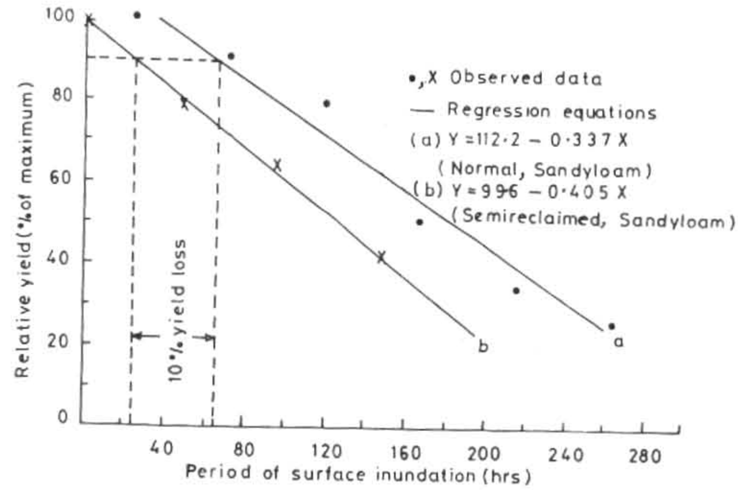

Fig. 2. Effect of water stagnation period on wheat yield in normal and semi-reclaimed alkali lands

frequent periods of low rainfall. The characterization of uncertainty, drainage and irrigation requirements, therefore, must start with an analysis of historical data.

4. Frequency analysis

A record of daily rainfall forms the statistical record from the past which has been selected to identify the variation in rainfall distribution in three regions, *i.e.*, rainfall in the range of 500-1000 mm, 1000-2000 mm and more than 2000 mm. Rainfall characteristics of the selected stations are reported in Table 1. Due to large site specific spatial vairations and limited stations selected for this study, it is not claimed that data reported here will be applicable to all stations where rainfall is in these ranges. although general conclusions will be similar. The maximum rainfall is nearly 200 per cent of the average at Parbhani (Maharashtra) while minimum is 40 per cent of the average value at Bilaspur (M.P.) The coefficient of variation is larger usually for areas receiving less rainfall compared to those falling in the upper range group except for Madhipura (Bihar) In most cases more than 75 per cent of the average annual rainfall occurs during June-October. There is large surplus rainfall during the monsoon season and it increases with increasing rainfall (Fig. 1). Management of this surplus to cope up with the requirements of moisture deficit periods, short spells of which may also occur within the water surplus periods is, therefore, needed. As short term excess rainfall could cause sufficient runoff for harvesting, the daily rainfall data are used to work out the storm rainfall of short durations varying from 24 hours to 120 hours (1-5 days). The data presented in Table 2 for 3 stations in the 3 range groups indicate that while one day storm rainfall is almost similar at low probability (less than 25 per cent), there are significant differences in storm rainfall at higher probabilities and with increasing durations. The storm rainfall, particularly for higher durations, increases with increasing rainfall. Therefore, duration of rainfall to be considered

TABLE 2

Storm rainfall at different probabilities in the 4 representative raingauge stations

Station (rainfall in mm)	Duration (days)	Storm rainfall (mm) at probabilities (%)				
		10	25	50	75	90
Dapoli (3372)	1	363	309	227	166	140
	2	530	463	362	286	254
	3	623	555	452	376	342
	4	719	641	523	435	398
	5	778	700	581	492	455
Chalakudy (3096)	1	180	162	136	116	107
	2	266	239	197	167	154
	3	329	294	242	203	186
	4	392	350	286	239	219
	5	434	390	324	274	253
Ludhiana (681)	1	178	145	95	58	42
	2	220	179	116	69	50
	3	232	189	125	77	56
	4	237	195	132	85	66
	5	254	211	146	97	76
Cuttack (1514)	1	198	167	128	85	70
	2	275	229	173	109	87
	3	293	246	188	123	101
	4	312	264	205	138	115
	5	330	280	218	147	123

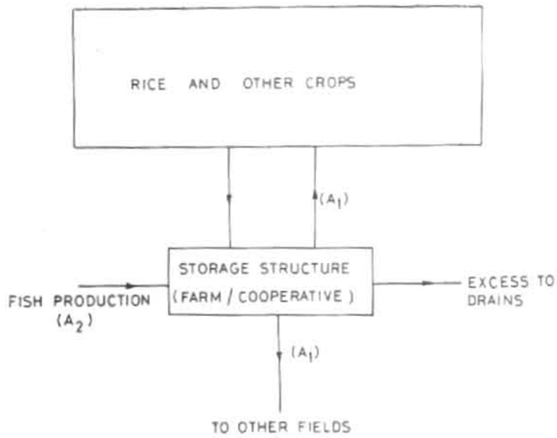

Fig. 3. Schematic view of management technology suggested for rainwater management serving dual purpose of (A_1) irrigation and drainage or (A_2) drainage and fish production

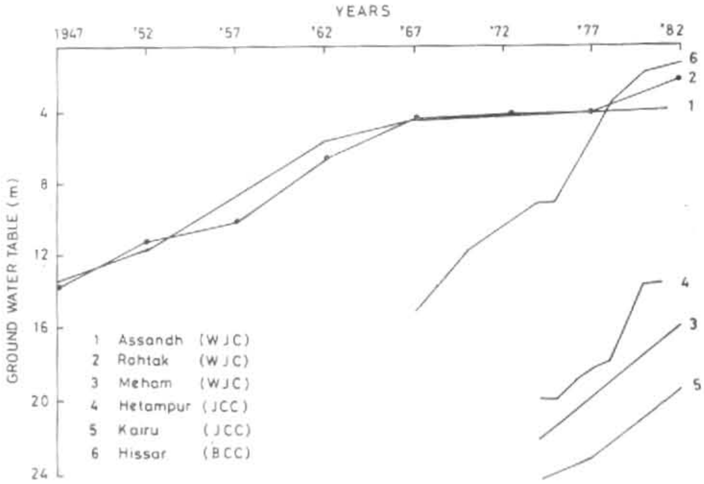

Fig. 4. Trend of watertable rise in irrigated areas in the State of Haryana

TABLE 3

Probability of one day storm exceeding 100 mm at three gauging stations

Gauging station	No. of storms in 25 yrs	Probability (%) in the month of					
		May	Jun	Jul	Aug	Sep	Oct
Chalakudy	45	28	36	48	4	4	8
Cuttack	27	0	8	27	31	15	15
Ludhiana	11	0	0	19	8	8	0

TABLE 4

Probability of critical dry spells (≥ 10 days) at different stations

Station	Probability of critical dry spell (per cent) in the month of				
	Jun	Jul	Aug	Sep	Oct
Dapoli	27	0	4	54	88
Chalakudy	12	8	8	50	27
Dehradun	59	18	11	63	96
Cuttack	63	22	15	37	82
Madhipura	54	23	31	46	96
Bilaspur	81	24	9	57	95
Parbhani	69	46	54	69	92
Karnal	94	35	35	70	100
Ludhiana	88	15	15	81	100

in design will vary from one group to another. It may be 2 days for the first group while it should be 3 and 5 days for the other two groups, respectively. As pointed out earlier, even within a range group, there could be significant differences in the storm rainfall characteristics and it is particularly true for the humid regions (Table 2). The data indicate that while rainfall at Chalakudy (Kerala) is characteristics of the humid regions, it is not so for Dapoli (Maharashtra). Even the length of the monsoon season and water surplus periods for the two stations vary greatly.

The number of storms and probability of storms exceeding 100 mm in 24 hours for each station (for rice crop, assuming 10 cm storage, all storms exceeding 10 cm are considered to generate runoff) and for each month of the monsoon season were worked out for the three stations reported in Table 2 (Table 3). As expected, number of storms increase with increasing rainfall. Number of storms are 45, 27 and 11 for Chalakudy, Cuttack (Orissa) and Ludhiana respectively. However, their distribution as presented in Table 3 is interesting. While water harvesting could start right in the month of May at Chalakudy, it will not be possible till July at Ludhiana. Similarly, last harvesting (although at very low probability) could continue up to September at Ludhiana, it could be even in the month of October at Cuttack and Chalakudy. Thus, the water harvested in September/October could be saved for the rabi crop to give one or two life saving irrigations. Although at Chalakudy, runoff harvesting during May/June may not be useful as July and August have few dry days, the storage structures could be used for flood moderation at the tail end if necessary and for effective drainage.

Next in importance to devise a strategy for rainwater management is the dry spells. Dry spells of different durations occur within the season and in the crop growth period extending beyond the rainy season. Usually a spell equalling or exceeding 10 days is called a critical dry spell. Probability of critical dry spells is low at all the stations except Parbhani during the two months of July and August (Table 4). Once in two-year dry spells exceeding 10 days can occur in June, September and October for all stations except those in the 2000 - 3000 mm range. For two stations in this group (rainfall $\geqslant$3000 mm), critical dry spell could occur in the month of September at this probability and at Dapoli even in the month of October. At Madhipura and Cuttack probability of critical dry spell in the month of September are relatively less compared to even Dehradun (Uttar Pradesh) where average annual rainfall is significantly high.

A glance at the seasonal continuous dry spell also makes an interesting reading (Table 5). Continuous dry spell in the season at 50 per cent probability is maximum (35 days) at Ludhiana (minimum rainfall) and is minimum at Chalakudy (13 days). At Dapoli (the station with maximum rainfall) the value is 24 days following Chalakudy and Cuttack. However, the situation is quite different in respect of the winter season. The minimum continuous dry spell is at Ludhiana while it is maximum at Dapoli. Even at Chalakudy the value is almost equal to the stations with annual rainfall in the 1000-2000 mm range.

From this analysis it is apparent that periods of excess and deficit would occur at all places in semi-arid, subhumid and humid regions, though the quantum may vary amongst the three regions and within a region. Even in areas with no surplus rainfall on seasonal basis, storm rainfall is enough to generate runoff which could be harvested and recycled. Because of this variation, it is necessary to go in for site specific rainfall analysis for planning rainwater management.

5. Crop characteristics to excess and deficit water

For development of rainwater management strategy rice and wheat crops are considered in the context of this paper although similar information should be generated/ obtained if some other crop is to be grown in the region.

5.1. *Rice*

In India rice crop is grown in nearly 40 Mha. While in some areas rice is grown both in kharif and rabi, in others, it is grown only during the kharif season. Presently, water requirement for this crop is estimated to range between 1500 and 3500 mm (Randhawa and Rajput 1988). Nearly 70 per cent of this water is lost in deep percolation and only a small amount of water estimated at 15 per cent is actually transported through the plants. The variation in water requirement is due to soil type, rainfall, other climatic variables, management and the varietal differences. Although rice is a water loving crop and need submergence of water; both excess depths of submergence (particularly at the tiller formation stage) and deficit of water affect the crop yield. In low land rice, excess submergence depths could result in seedling mortality and poor tillering resulting in low yield. Thus in humid regions medium to tall varieties may be grown, which are more tolerant to flooding.

Effect of occasional excess submergence depths due to storm rainfall in semi-arid regions has been studied by Gupta and Pandey (1983). It was postulated that the effect of submergence could be better described by an excess submergence depth index which is calculated by adding additional submergence depths beyond a optimum value for a given variety. The effect of this index on rice yield (Var IR-8) indicate that in regions with an annual average rainfall of 750 mm, rainfall can be stored in the rice fields up to an index of 150. Once this value is crossed, there will be yield decline, such that 6.4 per cent yield reduction is expected at an index of 260. Such a high index could be achieved in semi-arid regions when rainfall is above normal and it equals or crosses 850 mm mark. Thus, rice crop in areas with more than 1000 mm of rain would require drainage, in the absence of which yield will be adversely affected.

Water deficit in all the 3 rainfall groups considered in this paper is experienced during the reproductive phase and for the rabi crop, it will be intermittent depending upon the adjustment of the planning schedule, rainfall and availability of irrigation water. It has been suggested that poor yields could be due to reduced number of panicles per unit area and a relatively high spikelet sterility (Murty 1977, Yoshida 1981). Matsumisha (1962) reported that a period of water stress, a few days before heading results in about 60 per cent spikelet sterility. Like many other crops, yields may also be reduced due to senescence of leaves which is hastened during a spell of water deficit (Hsiao 1973).

The data on rice yield for the districts in which stations covered in this paper lie, indicate that the husked grain yield vary from a low value of 0.78 t/ha at Bilaspur (M.P.) to a high value of 3.38 t/ha at Ludhiana which has provision of irrigations (Table 1). A significant observation, however, is that yield is comparatively low at stations in the range group of 1000-2000 mm compared to those in the 2000-3000 mm range group. This observation nicely fits in the earlier observations that while both excess and deficit water affect the yield in the second group, the deficit water stress is relatively less in the group with above 2000 mm rainfall (Table 1). It appears that a strategy which reduces ill effects of excess water and ensures water during deficit period would lead to better rice yield in such areas (1000-2000 mm range group).

5.2. *Wheat*

The second important crop following rice is the wheat. Most studies have shown that wheat requires 40-44 cm water for satisfactorily completing its growh cycle (Prihar and Sandhu 1988). Wheat which is the major crop in northwestern India, also suffers from submergence of water and is quite sensitive to water stress, particularly at crown root initiation, boot and flowering stage. Goel & Gupta (1986) and Sharma & Swarup (1988) reported that due to heavy showers received during winter season in northern parts, crop could suffer, if water is not removed within 24 - 66 hours (Fig. 2). The yield reduction could be about 10 per cent in a semi-reclaimed sandy loam soil [ESP, 250% (0-15 cm layer)] if water is not

TABLE 5

Expected duration of dry spells at different probabilities between June to October and November to March

Prob. level (%)	Duration of dry spell (days)							
	Dapoli	Chalakudy	Madhipura	Dehradun	Cuttack	Bilaspur	Ludhiana	Parbhani
June-October								
10	41	21	39	47	27	43	51	53
25	34	18	34	40	24	36	45	42
50	24	13	25	28	19	30	35	32
75	15	10	19	21	16	25	27	24
90	12	8	16	17	14	21	24	18
November-March								
10	152	131	151	87	138	129	63	152
25	152	115	128	75	120	105	54	136
50	138	92	95	58	92	84	41	111
75	128	74	70	45	72	67	31	92
90	124	65	59	40	63	55	27	77

TABLE 6

Rainfall storm and duration of dry spells for different return periods at Karnal (Gauging station : CSSRI)

Particular Max. rainfall	Rainfall (mm) for return period (years)					
	1.11	2.33	5	10	25	50
1-day	52.4	103.0	136.0	162.9	196.8	222.0
2-day	66.2	123.5	160.9	191.4	229.9	258.4
3-day	70.4	134.3	176.0	209.9	252.8	284.6
4-day	73.3	146.3	193.9	232.7	281.7	318.0
5-day	77.7	162.5	217.7	262.7	319.6	361.7
Max. dry spell during monsoon season (days)	14	23	30	35	41	46

TABLE 7

Components of rainwater stored in a storage-recycling irrigation system at Karnal

Year	Jun-Sep rainfall (cm)	Runoff outside the area (cm)	Rain water retained in the catchment (Rice field & farm pond)	
			Total (cm)	% of rainfall
1972	69.5	12.1	57.4	82.5
1973	58.9	9.4	49.5	84.6
1974	37.4	0.5	36.9	98.7
1975	60.5	1.2	59.3	98.0
1976	74.3	6.0	68.3	91.9
1977	58.9	5.5	53.4	90.7

removed in 24 hours. In normal soils the periods could be around 66 hours. Thus, a farm level drainage is very essential as such storms are expected to occur once in 3 years even at Karnal which is a semi-arid station.

Response of crops to irrigation amply indicate the reduction in yield due to water stress. Experiments at Hoshiarpur (Kandy Project, Punjab), Dehradun, Agra (Uttar Pradesh) and Rewa (Madhya Pradesh) indicated that application of one irrigation to wheat resulted in an increase in yield by 25 per cent at Agra and 114 per cent at Hoshiarpur compared to dry land crop. The values at other places were in this range. Thus in a crop like wheat, if water for one irrigation could be managed through rainwater harvesting, tremendous increase in yield could be obtained. The exact quantum of increase, however, will depend upon climate, water holding capacity of the soil, time at which first irrigation is applied and other management support.

5.3. *Technology*

Characteristics of rainfall at each station indicate that a major portion of the rainfall is received in the form of heavy storms of short durations and thus generate enough runoff. This usually follow a dry spell or in other cases long dry period occur towards the end of the season. On the other hand, major crops suffer loss in yields both due to excess as well as deficit of water. Farm pond technology, therefore, offers excellent opportunities for conservation, storage and recycling for management of rainwater near to the place where it falls. Keeping in view the characteristics of the rainfall (Table 6) at Karnal (Haryana) and the high runoff generating capacity of the alkali lands in the area, a technology for rainwater management was conceived and tested at 40 ha farm of the Central Soil Salinity Research Institute, Karnal. The technology consists of the following three steps :

(*i*) To store as much rainwater in the cropland (rice fields) as is possible without affecting yield.

(*ii*) To harvest/channelize the excess rainfall and store it in a dugout farm pond of sufficient capacity for recycling during dry spells and for applying life saving irrigation to the wheat crop.

(*iii*) To channelise still excess runoff to natural/artificial drains.

A schematic set up of the storage structure is shown in Fig. 3. The technology has been successfully tried at the institute farm and as much as 90 per cent of the rainfall had been conserved within the farm area (Table 7).

The same technology with minor site specific modifications was considered for a humid region in Sunderbans (West Bengal) with an average annual rainfall of 1800 mm. The estimates of surplus rainfall for this region indicated that after meeting all the demands of the kharif season, as much as 450 mm of rainfall is surplus and can be stored in the dugout farm ponds. It was recommended that nearly 20 per cent of the farm land should be dug to 3 m depth to store excess rainwater which could be used to irrigate crops in the winter season (1.5 m) and to serve as fish pond (Yadav *et al.* 1981). It was also brought out that technology is feasible on regional scale; yet 25 cm high peripheral bunds should be constructed in the region to have field control of rainwater and to store atleast 15 cm of rainwater to smoothen out the water requirement during short dry spells. This technology has found favour and is being popularized. The success of the technology and the analysis of rain data reported for different stations firmly point out that this technology could be beneficially extended to other areas.

6. Storage places

One of the major items of cost in this technology is the cost of the storage structure in terms of land and to digging cost. Depending upon the site, some of the places/existing structures could be considered for reshaping into storage ponds. Only consideration should be high storage to earthwork ratio. Water from such ponds could be utilized by the community. Probable places of storage which can be explored are the following :

(*i*) Existing water tanks or ponds.

(*ii*) Low lands with minor reshaping.

(*iii*) Main drainage channels.

(*iv*) Dugout farm or co-operative ponds. Additionally, in deltaic or coastal regions, following places can also be considered :

(*a*) Coastal tidal lands

(*b*) Closed minor tidal creeks.

In hilly areas, embankment ponds could be used to store rainwater. The sites which offer adequate storage with least amount of earthfill, should be ideal spots.

7. Conventional irrigations *versus* recycling technology

Too frequently irrigation is introduced and water allowed to the farmers, before any assessment and understanding is conveyed to him to use the system in relation to crop culture on a particular soil under different climatic situations. Understandably, intricacies and importance of water management are not appreciated by him. Naturally, and coupled with inherent lacunae in the system, irrigation efficiency which is defined as the percentage of water utilized to meet evapotranspiration demand to water released at the diversion head is poor. It fluctuates from a very low value of 10 per cent during months with heavy rainfall to nearly 40 per cent during the peak demand period. Considering, high cost involved in harnessing the water, even the latter figure is low. Inadequate provision of storage of water in the irrigation system has been recognised as one of the major factors contributing to the low utilization of water resource, as it results in lack of flexibility and mismatch between the demand and the supply. For example, in most irrigation projects, supply is much more than the demand during kharif while water will not be commensurate with the demand during rabi and summer seasons. Infact, in areas where rainfall is more than 1000 mm, water supply in canals is at its maximum when the areas are in flood due to heavy rains and there are no takers of the water made available.

In spite of all the shortcomings, irrigation system does firm up to some extent the uncertainty in the supply of water, yet it does not, in any way, help to overcome problem of water excess. In fact in many cases, it has accentuated the problem of drainage. This could be due to regional rise in water table (Fig. 4) and also due to avoidable applications of irrigation water. Usually there is high runoff in irrigated than in unirrigated areas. Recently, provision of drainage is being made in the old and new irrigation projects, yet the drainage works as envisaged are limited to construction of main drains or in some cases, to collector drains. Rarely, field drainage is undertaken or encouraged. Thus, agricultural fields continue to suffer due to excess water during heavy storms. The storage and recycling system, blends these two interrelated problems and, therefore, should be more rewarding in terms of agricultural production.

Secondly, in a multi-purpose project, management alternatives are at variance for achieving different objectives. Usually, in such projects, flood control becomes the first casuality followed by irrigation. Coupled with heavy rainfall, flood problem is most acute at the tail end of the irrigation system. Therefore, a system which takes care of drainage and irrigation should be helpful in handling the flood problem to a greater extent.

A strong case to develop minor surface irrigation projects based on conservation of monsoon rainfall within the watershed and near to the point where it falls has been built up with ample justification. The system will provide greater flexibility and to a greater extent maintain ground water balance. Costwise also, there is ample justification to shift the emphasis to minor irrigation works. While cost of a major or medium irrigation project works out in the range of Rs. 20,000 - 30,000 per hectare, it could be less than Rs. 5000 per hectare for a farm pond storage/recycling irrigation project. It is expected that such storage works will provide water which will be at the command of the irrigator and will also provide much needed relief during periods of excess rainfall.

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