Water Harvesting and Recycling Technology for Sustainable Agriculture in Vertisols with High Rainfall

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Nearly a billion people in the world do not have access to clean drinking water. If we don=t care, then the number of those who would be badly in need of potable water could swell to a mind- boggling 2.5 billion in just 25 years and more shockingly, the majority of these people would be in India the center and states alone can-not expected to tackle the problem which calls for people=s Participation in tackling water scarcity. India receives about 4000 billion cubic meters (bcm) of rainfall every year of which 1869 bcm flows off as average annual runoff in the various rivers of the country. Due to geographical limitations only about 890 bcm of surface water can be utilized in addition to 423 bcm of replenishable ground water.

Madhya Pradesh in spite of all its sources remains a state of developmental paradoxes of a gross cropped area of 26.126 (1998-99) million ha of agricultural land only 4.918 million ha have any kind of assured irrigation of a net cropped area of 19.954 (1998-99) million ha only 6.172 (1998-99) million ha are actually double cropped. Yet the state remains the source for all the major river systems of central India receiving on average rainfall of 1150 mm annually. With most agriculture falling in rain fed category the incidence of drought has become a more or less perpetual feature. During the last two decades, droughts have occurred almost every year in one part or other in India, of them widespread are 1965-66, 1972-73, 1979-80, 1985-86 and 2000-01. As many as 14 districts of the state are classified as semi arid and another 21 as dry sub-humid while almost as much as 80 per sent of total cropped area is classifiable as belonging to the rain fed category always leading to the possibility of vide and unpredictable variations in the agricultural production from year to year. Added to this in the relentless and rapid depletion of the natural resource base in the form of ground water, soil and vegetative cover as the pressure on them mounts.

Need for Improved Technology

Unplanned plundering, thoughtless pillage ravenous devastating destruction and ruinous selfish exploitation of natural resources degraded the lands, dwindled the availability of water resources and erased the greenery. The gloomy status coupled with drought conditions, have their interactive, negative influence on environment. The crisis in India is more due to the misuse of natural resources like soil, water and forests, than industrialization. Present pace in progress, specially in growing greenery with watershed concept is insufficient to yield enough corrective results as the annual area brought under greening is less than the area eroded. It is definitely high time to stall the impending famine with determination.

Immediate hastening of the efforts is warranted for preserving the meager dense greens, maintaining good lands, improving bad conditions and restoring green foliage through scientific, integrated management. Watershed management concept, implemented on war footing, should help the country in not only reversing the trends but also reviving the good environment through modern but simple, technical, appropriate economical and feasible measures.

A major part of Indian agriculture mainly depends upon rainfall, which is both inadequate and uncertain. The agro-climatic regions and crop zones in Madhya Pradesh is given in table-1 indicates that the rainfall varies from 800 to1600mm per annum and there is very good potential for rainwater harvesting and recycling for stable agricultural production. However the total food grain production. is 1097kg/ha as (1999-2000) compared to all India production of 1620 kg/ha. Madhya Pradesh being blessed with very good resources of land and water holds very good potential for increasing the productivity of land through water harvesting and recycling. The state is having shallow & medium black soils on 3.06 m.ha (6.91%) deep medium black soils on 16.21 m.ha (36.53%) and mixed red & black soils area 8.11 m.ha (18.30%).The water harvesting technology developed at CIAE Bhopal will be suitable for deep medium black soils of Madhya Pradesh. However Soil & Water conservation technology are highly location specific a guideline will give details of analysis to be carried out for particular region.

Soils

The blackish clayed soils of CIAE Farm are dark coloured vertisolic silty clays to clays with depth greater than one metre. Three soil series namely Nabi Bagh - 1 (49.1 ha) Nabi Bagh-2 (4.4 ha) and Lambakheda (10.5 ha) have been identified and physico-chemical properties of these soils have been studied.

The textural classification of gravel (7.12%), sand (14.79%), coarse (1.84%), fine (12.95%), silt (30.51%) and clay (54.70%). The structure classification of soil is sub angular blocky. Bulk density is 1.84g/cc and bearing capacity of soil is 11 t/m^2. (2.4 m depth). Field capacity is 30.86% and wilting point 19.22%. The available water is 21 cm/100 cm of soil depth. Average infiltration rate on prolonged wetting is 10 mm/h. The hydraulic conductivity of soil is 22.73 cm/day at 0 to 40 cm depth and its value is 1.27 cm/day at 0 to 180 cm depth. Drainable porosity is 6.88%. The peculiar trend of hydraulic conductivity and low value of drainable porosity poses drainage problems in this soils. The pH of soil is 7.94 (slightly alkaline). Organic carbon is 0.48%. Exchangeable cations of Ca, Mg, Na, K are 31.23, 8.39, 0.864 and 0.511 Meq/100 gm of soil respectively and cation exchange capacity of soil is 49 meq/100 gm.

Rainfall Analysis

The area receives on average annual rainfall of 1200 mm(at Bhopal), 90 per cent of which is received during June through September as torrential monsoon showers. There is late onset of monsoon and recede early and the rabi crops are not sown in time. During winter the probability (at 75% chance) of getting rain is 33mm only which is meager. Analysis of the 50 years data shows that there is probability of drought year once in every 5 or 6 years.

The conclusion drawn based on analysis of 50 years of rainfall are : the probability of getting average annual rainfall (1210mm) is 40 per cent. Table 2 Shows probability of rainfall (mm) for the log normal distribution) onset and withdrawal of monsoon is on 25th and 37th weeks, respectively. The 24th and 25th weeks can safely be utilized for dry sowing and 25th and 26th weeks for normal sowing after the onset of monsoon. First inter-culture operation can be performed during 29th, 30th and 31st week and second during 33rd week. Waterlogging may occur during 32nd and 35th weeks. There is some risk in taking rabi crop after kharif harvest under rained condition. Rabi crops can be established in time with supplemental irrigation (recycling runoff water) if winter rains are delayed. The little rainfall received during January and February helps in the survival of rabi crops. Rainfall harvesting and recycling is of utmost importance during kharif for timely transplanting of rice and irrigating rice and soybean in latter stage of crops in case of early withdrawal of monsoon and pre-sowing irrigation and at least two irrigation one at crown root initiation and flowering stage for wheat to stabilize food production.

Runoff estimation

Binnie=s percentage of runoff as annual rainfall based on two river basin in Madhya Pradesh is given in Table-3. Binnie gave the percentage up to 1100 mm annual rainfall. Runoff was reported to be 63 percent (943mm) of monsoon rainfall (1488mm) or 57 percent of annual rainfall (1653mm) and same percentage was adopted here as shown in SI. No. 12. This is based on the report of Betwa Command Area (CGWB, 1981).

The average annual rainfall data of 50 years at Bairagarh/CIAE, Bhopal was classified into 14 groups and the runoff was estimated as shown in Table 3. The probability of occurrence of annual runoff was calculated using Weibull=s equation for different period and plotted in Fig. 1 which shows that probability of occurrence of 350 to 400mm runoff is 80 to 75 percent respectively. The runoff event mostly occurs during July and August on an average seven to eight rain storms occur during normal years, which can produce runoff.

The design and construction of farm pond

Two dugout farm ponds of 2.54 ha-m and 12 ha-m capacity were constructed at CIAE farm. The area of farm is 93 ha. The design of farm pond can be divided into: (i) design of pond capacity based on the total loss and gain basis (ii) Estimating the volume of an excavate pond,(iii) spillway design and inlet design . The relationship given as followed by Krimgold between the various hydrological factors and the dimensions obtained was used in the design of farm pond.

$$\frac{RA}{a} + P - \left(E + \frac{U}{a} + S \right) = d + \frac{W}{a}$$

Where

- A = the size of watershed area draining into pond, one to six hectare.
- R = total runoff from the contributing drainage area per ha during the period under consideration (July to Sept.) 0.3 ha-m (Fig.1)
- P = Precipitation falling on the reservoir during the period irrespective of whether or not it produces surface runoff from the drainage area, 0.92m (calculated from 10 years data of rainfall at 50% probability level for the period under consideration).
- U = amount of water used during the period under consideration, 0.2 ha-m per ha for rice crop (two irrigations or assumed to be nil)
- S = seepage during July to September, 0.3 m (based on observations at CIAE, Bhopal)
- E = evaporation from pond water surface (July to September) 0.29m(estimated from pan evaporation data at CIAE, Bhopal)
- d = depth of water in the pond, assumed 2,3 and 4 m.
- W = amount of water in excess of the capacity of the reservoir which is wasted over the spillway, ha-m. This factor was assumed to be nil, since pond is being designed for 75 to 80 percent expected runoff.

$$a = Lb + (bz + Lz)\, d^2 + (2z^2)\, d^2 \times 10^{-4}$$

Where

a = mean surface area of pond, ha

L = length at the bottom of pond, m

b = breadth at the bottom of pond , m

z = side slope of bund (u/s)

The Recycling of stored water in kharif and rabi season

When to irrigate

The monthly water deficits and surpluses were determined for better under standing of irrigation water requirement of crop (Fig.2). it was found that only three months in a year July, August and September, are with surpluses water and rest of the months are with deficit and irrigation water has to be supplied to meet the crop water demand during these months.

How much to irrigate

The studies on soil moisture regime indicates that at the top layer (0-15cm) soil moisture was below wilting point during critical growing period of rabi crop after harvest of kharif crops . The moisture is available below 30cm soil depth and there is no such equipment available to sow the crop in moist zone (listering) however the energy requirement will be very high. The only solution for timely establishment of rabi crops is to have pre-sowing irrigation. About 100 mm per month irrigation is required. Table-4 gives water requirement of crops and their Irrigation Needs.

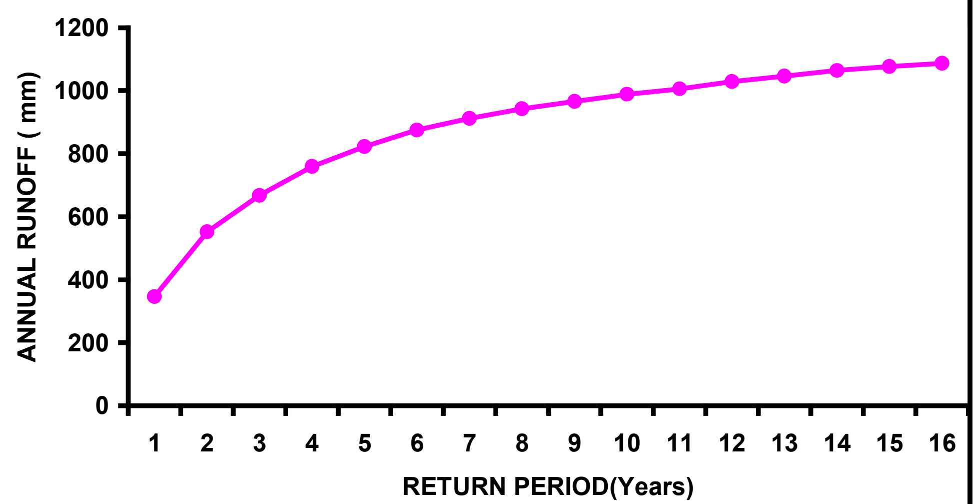

Fig. ANNUAL RUNOFF CURVE FOR BLACK SOIL OF BHOPAL

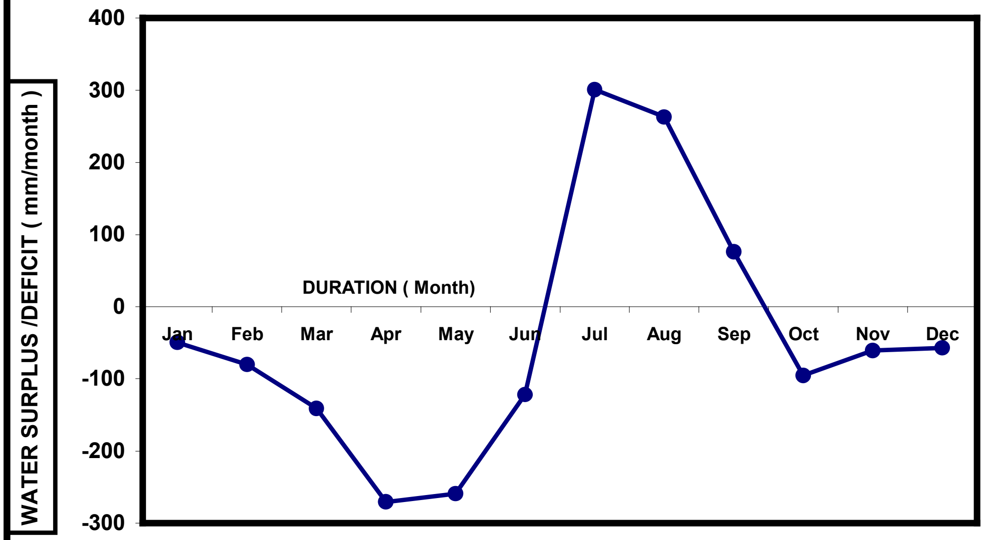

Fig. MONTHLY WATER DEFICIT AT BHOPAL

Water Utilization Studies

The maximum storage capacity of pond was 2.54 ha-m with water submergence area of 1.3 ha. Details of water harvesting ponds constructed at different locations are presented in Table-5. The maximum head of water was three m at full capacity of pond. The irrigation was given to kharif crop (rice) and rabi crop (wheat and chickpea) in the vicinity of pond. Table 6 shows the water utilization studies of dugout pond. The loss through evaporation and seepage varies from 38 to 68 percent of stored water depending on storage time of 3.5 to 6.5 months. Water which was utilized in kharif for transplanting of rice was refilled (36.16 to 8.4 percent of stored water) depending on rains. Water utilized was 69 percent of the stored water about 1.5 ha was irrigated during kharif and six to seven ha during rabi.from pond-1 (2.54 ha m) and about 30 ha was irrigated twice during rabi from new pond(14 ha-m).A third pond of 5.5 ha-m was also constructed. Based on this study the area of submergence as affected by watershed area and pond depth is given in Fig. 3 . and command area of pond is given in Fig 4.

The results of the studies on water recycling:

The results of the studies on recycling of runoff water during kharif and rabi to various crops are enumerated in table 7. It was found that one and two irrigations at transplanting and transplanting and grain filling stage to rainfed rice increased the grain yield by 44 and 90 per cent respectively over no irrigation. For soybean, one life saving irrigation at grain filling stage in the years of early withdrawal of monsoon yield raised by 45 per cent and for wheat the yield was raised by 43, 78 and 100 per cent when, irrigated once at CRI, twice at pre-sowing + CRI and thrice at per-sowing + CRI+ flowering stage. Similarly grain yields of chickpea, linseed and safflower were increased by 90, 56 and 51 percent with two irrigations at pre -sowing is most essential to rabi crops in the event of early withdrawal of monsoon and insufficient storage of residual moisture in soil after the harvest of kharif crops and delayed winter rains.

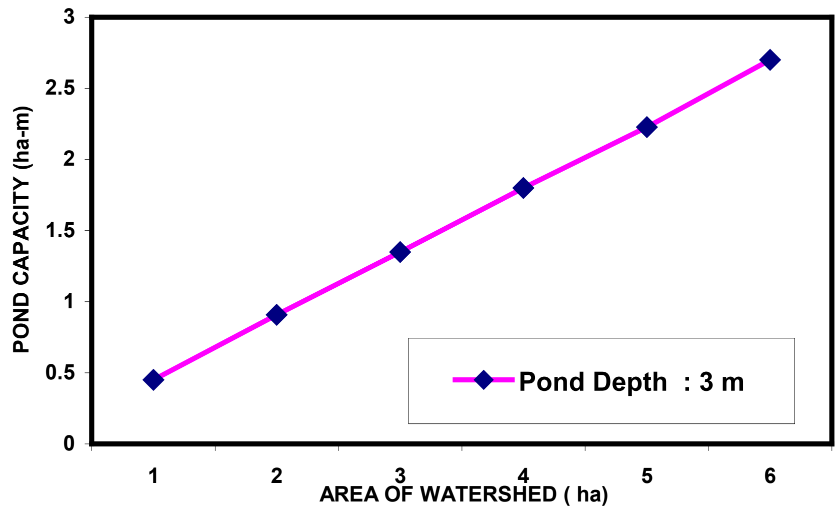

FIG. 3 CAPACITY OF POND (ha-m)

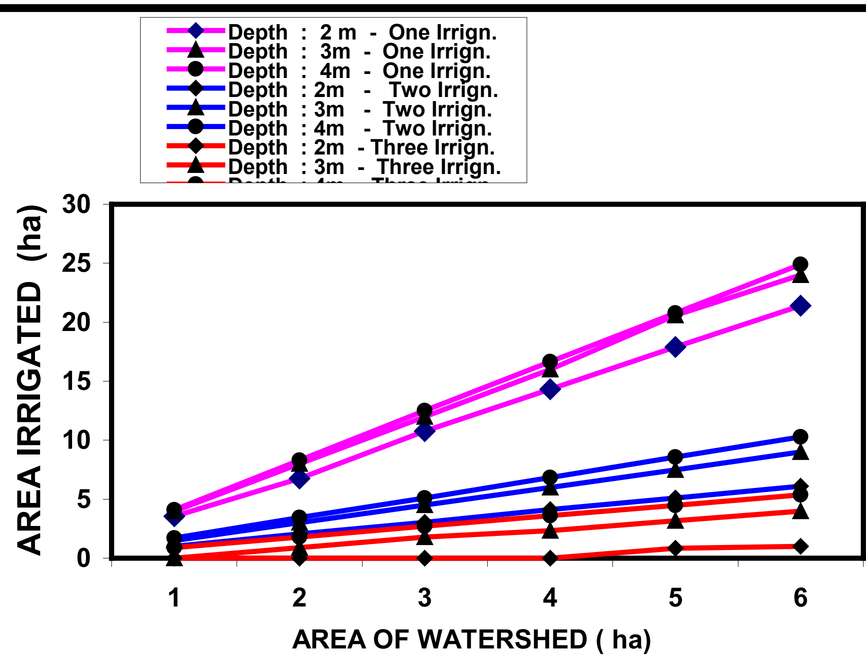

FIG. 4 COMMAND AREA AT DIFFERENT LEVELS OF IRRIGATION (ha)

It was further observed that the application of nitrogen fertilizer along with the life saving irrigation to crops like chickpea, linseed and safflower (Table 8&9) give a tremendous boost to the crop production in this area. The mean increment in grain yield of irrigated chickpea with 10 and 20kg.N/ha was 5.0 and 6.6 q/ha over no N. In linseed the response to N in the presence of irrigation at 40 and 80 kg. N/ha over control was 2.0 and 3.0 q/ha. The same in safflower was 2.6, 4.4 and 6.4 q/ha with 30, 60 and 90 kg N/ha, respectively over control. This showed that for harvesting maximum benefit from the limited irrigation potential, the N fertilization should be increased at matching rate in order to meet the increased nutritional demand of the crop.

Economics of Water Harvesting Pond

The economic analysis of pond has been carried out considering that irrigation water is used during kharif for paddy crop (30 ha) and Rabi wheat (24 ha) and chickpeas (16 ha) as cropping sequence. It is not possible to cultivate 30 ha of paddy in present situation, however, for general recommendation the growing of paddy under irrigated condition has been suggested under kharif season. The cost of pond including associated structures and irrigation grid system including pump house has been considered for calculation of benefit cost ratio. Considering additional benefit obtained through irrigation net benefit ratio works out to be 1.13. For project to be economical it should be greater than 1, therefore, the project is economical. The benefit cost ratio works out to be 2.03 considering total benefit and cost under irrigated condition. From the foregoing discussions, it can be concluded that the technology of water harvesting pond is feasible and economically viable in black soil areas with high rainfall for stabilizing the agricultural production.

Conclusions & Recommendations

•Water harvesting pond to be constructed in 10-12 percent of watershed area with 3m depths.

•The minimum runoff received is about 300 mm to fill up the pond every year.

•About 60 to 70% of stored water can be utilised for irrigating crops.

•Entire kharif and 50% of rabi crop (of the watershed area) can be irrigated twice with twofold increase in yield.

•Ground water recharge through pond is 0.8 to 1.2 ha –m/ ha

•Water harvesting is technically feasible and economically viable (Benefit cost 1.3 – 2.0) and socially acceptable.

Table-1 Agro-Climatic Region & Crop Zones in M.P. including Chhattisgarh

Zone / Crop	Agro-climatic Regions	Soil Type	Rainfall Range, mm	Districts Covered	Partly Covered Districts
1 Rice	Chhattisgarh plains including Balaghat	Red & Yellow (Medium)	1200 to 1600	Raipur, Durg, Rajnandgaon, Bilaspur	Raigarh: Raigarh, Kharsia, Gharghoda, Leloonga & Sarangar Tehsils Kanker: Kanker & Narharpur Tehsisls
-do-	Baster Plateau	-do-	1400 to 1600	Entire Bastar District Except Kanker & Narharpur Tehsils.	
-do-	Northern Hill Region of Chhattisgarh	Red & Yellow Medium black & skeltal (Medium/light)	1200 to 1600	Surguja, Shahdol, Mandla, Jashpurnagar	Raigarh: Dharamjaigarh Tehsil. Sidhi:Singroli Tehsil (Bedhan),
2 Wheat - Rice	Kymore Plateau & Satpura Hills	Mixed red and black soils (Medium)	1000 to 1400	Rewa, Satna, Seoni, Sidhi (except Singroli tehsil of Jabalpur)	Panna, Katni Tehsil, Katni (except Katni Tehsil)
3 Wheat	Central Narmada Valley	Deep black (deep)	1200 to 1600	Narsinghpur, Hoshangabad	Sehore: Budni Tehsil. Raisen:Bareli Tehsil.
-do-	Vindhya Plateau	Medium black deep black (Medium/Heavy)	1200 to 1400	Bhopal, Sagar, Damoh, Vidisha, Raisen (except Bareli), Sehore Ashoknagar	Guna: Chanchoda, Raghogarh & Aron Tehsils
4 Wheat-Jowar	Gird Region	Alluvial (Light)	800 to 1000	Gwalior, Bhind, Morena, Sheopur-Kala, Shivpuri, (except Pirchore. Karera, Narwar, Khaniadana,)	

				Guna (except Aron. Raghogarh, Chachoda Tehsil)	
Wheat - Jowar	Bundelkhand	Mixed red and black (Medium)	800 to 1400	Chhattarpur, Datia, Tikamgarh Betul & Chhindwara	Shivpuri:Karera Pichhore, Narwar & Khaniadhana Tehsils, Panna
-do-	Satpura Plateau	Shallow black (Medium)	1000 to 1200	Betul & Chhindwara	
5 Cotton Jowar	Malwa Plateau	Medium black (Medium)	800 to 1200	Mandsaur, Ratlam, Ujjain, Dewas, Indore, Shajapur, Rajgarh	Dhar : Dhar, Badnawar & Sardarpur Tehsils. Jhabua:Petlawad Tehsil.
-do-	Nimar Plains	Medium black (Medium)	800 to 1100	Khandwa, Khargone	Dhar: Matlawar, Dhampuri & Gandhawani Tehsils
-do-	Jhabua Hills	Medium black skeletal (Light / Medium)	800-1000	Jhabua District. (except Petlawad Tehsil)	Dhar : Only Kukshi Tehsil.

Table-2: Probability of rainfall (mm) for log normal distributions

Recurrence interval (years)	Per cent chance	Rainfall (mm)
1.25	80	738.9
2.00	50	1075.8
2.5	40	1210.0
5.00	20	1600.0

Table 3: Annual rainfall and runoff Bairagarh + CIAE Bhopal based on Binnie=s percentage

Rainfall class value	Frequency in 50 years	Runoff Percent	Runoff mm	Weighted runoff mm
550	2	18	198.0	99.0
650	2	23	299.0	149.5
750	1	27	202.5	202.5
850	4	31	1054.0	263.3
950	4	36	1368.0	342.0
1050	7	39	2866.5	409.5
1150	5	42	2415.0	483.0
1250	4	45	2250.0	562.5
1350	7	48	4536.0	648.0
1450	5	51	3697.5	739.5
1550	3	54	2511.0	837.0
1650*	2	57	1881.0	940.5
1750	3	60	3150.0	1050.0
1850	1	63	1165.5	1165.5
Total	50		27594.0	551.81

* Binnie gave the percentage up to 1100 mm of annual rainfall. Runoff was reported to be 63 percent (943mm) of monsoon rainfall(1488mm) or 57 percent of annual rainfall (1653mm) and same percentage were adopted here as shown in SI.No. 12. This is based on the report of Betwa Command Area (CGWB,1981).

Table 4: Water Requirements (WR) of Crops and Their Irrigation Needs

Crop	Growing Period	WR (mm)	Including Pre-sowing Irrigation		Depth of Application (mm)	Irrigation at% ASM
			Irrigation require-ment,mm	No.of Irrigation		
Wheat	Oct-Feb. Nov.-Mar.	270 316	320 400	4 5	80 80	50
Gram	Oct. Feb.	-	160 240	2 3	80 80	25
Peas	Oct.-Jan. Nov.-Feb.	-	160 160	2 2	80 80	25
Sugarcane	Feb.-Jan.	1580	800 320	10 (Feb-Jan) 4 (Oct-Dec)	80 80	50
Rice Nursery Growing	June	200	300	4 to 5	4 to 6	2 to 3cm
Water requirement	July-Oct.	462	160	2	80	Ponding 50+20 mm
*Percolation	July-Oct.	9mm/ day	-	(July&Sept)	-	-
Banana	July-June	1440	960 240	24 (Feb-June) 6 (Mar-Apr)	50 50	75
Maize	June-Sept.	433	-	-	Irrigation not** required during kharif season	
Soybean	June-Oct.	446	-	-		
Sorghum	June-Sept.	375	-	-		

* Percolation at 5 + 2 cm water head

**Effective rainfall during Jule to October. 447 mm and June to September. 422mm (Based on 50 years rainfall data)

ASM - Available soil moisture.

Table 5: Details of ponds at different locations

Location	Year	Rs/m^3 Water Stored	Average Depth m	Loss cm/day	Capacity ha-m
CIAE	1980	3.4	2.9	0.9-1.0	2.54
Islamanagar	1989	3.1	2.1	0.901.0	7.14
Patti (Raisen)	1990	5.45	3.1	1.1-1.3	5.42
IISS	1992	6.6	2.5	-	4.5
IISS	1993	-	1.5	-	3.00
IISS	2000		1.3	-	1.90
CIAE	1995	10	2.2	0.5-1.0	14
CIAE	2004	10	2.8	0.9-1.0	5.5

Table 6 Water utilization studies of pond

SI.No	Particulars	Year of Study	
		First	**Second**
1	Maximum storage capacity cum	20125	23345
2	Dead storage, cum	20	412
3	Maximum storage depth m	2.8	3.0
4	I. Water lost, cum II As percentage of total storage	13596 67.62	8540 37.25
5	I Water pumped, cum II As percentage of total storage	13781 68.54	15905 69.35
6	Water refilled during kharif (As percentage of total storage)	36.16	8.4
7	Water storage Duration month	6.5	3.5
8	Water applied (a) Kharif, ha-m (b) Rabi, ha-m	32.8 105.0	62.25 96.80
9	Area irrigated (a) Kharif, ha, Rice (b) Rabi, ha , Wheat & chick pea	1.6 (twice) 6.5 (twice)	1.5 (four times) 7.0 (Once)

Table 7: Effect of supplementary irrigation on grain yield (q/ha) of rice, soybean and wheat

Stage of Irrigation	Rice	Soybean	Wheat
No Irrigation	17.6	16.2	15.8
Transplanting (T)	25.4	-	-
Grain filling	22.7	23.5	-
T+Grain filling	33.5	-	-
Pre-sowing (PS)	-	-	22.1
CRI	-	-	22.6
PS+CRI	-	-	28.2
CRI+Flowering(F)	-	-	26.5
PS+CRI+F	-	-	31.4
C.D. (5%)	2.9	2.22	3.12

Table 8: Effect of supplementary irrigation on grain yield (q/ha) of Chickpea, linseed and safflower

Stage of Irrigation	Chickpea	Linseed	Safflower
No Irrigation	13.0	8.7	11.1
Pre-sowing(PS)	21.3	10.2	15.2
PS+Flowering(F)	23.9	13.0	17.4
PS+Pod filling	24.6	13.6	16.7
PS+F+Pod filling	26.9	15.2	19.2
C.D.(5%)	1. 33	0.70	1.16

Table 9 Effect of supplementary irrigation and nitrogen on grain yield (q/ha)

Irrigation	**Chickpea**			**Linseed**			**Safflower**			
N(kg/ha	0	10	20	0	40	80	0	30	60	90
No Irrigation (control)	10.5	12.5	13.6	6.8	8.5	9.1	9.0	10.4	11.6	13.3
Pre-sowing irrigation only	15.7	18.7	19.9	7.9	9.5	10.7	12.4	14.4	16.2	17.8
Pre-sowing+Flowering	18.6	22.5	24.2	10.0	11.8	12.0	14.4	16.8	18.0	20.9
Pre-sowing +Pod filling	19.7	23.0	24.9	10.7	12.9	13.4	13.7	16.2	17.5	19.5
Pre-sowing +Flowering+Pod filling	20.8	25.6	27.6	11.3	14.1	16.2	14.7	17.8	20.9	23.3
Mean for irrigation	17.5	22.4	24.1	10.0	12.1	13.1	13.7	16.3	18.1	20.1
C.D.(5%)irrigation		1.33			0.70			1.16		
C.D.(5%)Nitrogen		1.42			0.34			0.54		
Irrigation X N		2.31			0.43			0.72		