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Validation of farm pond size for irrigation during drought

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ABSTRACT

Field trials were conducted to validate farm pond sizes for supplemental irrigations during 2004-2011 at the Central Institute for Cotton Research, Nagpur ('21° 09' N, 79° 09' E.). Ten farm ponds 200 to 15,120 m^3 size resulted in a runoff storage of about 60, 75 and 28, 36, 58% (2007, 2010 and 2008, 2009, 2011) in normal and drought years at the end of August month. During actual drought the water availability was 0 and 18% only of the capacity designed in 2011 and 2008 July seedling droughts. Special recharging techniques like opening borewells/percolation tanks etc in under ground storages and using it with sprinkler irrigation during seedling droughts is the only option. Two supplemental irrigations at flowering stage along with application of deficient micronutrients on shallow and medium soils to Bt hybrid cotton (*G. hirsutum L.*) resulted in increased seed cotton yield by 50% and 44%, which was verified during 2008 and 2009 seasons in Yeotmal district. The minimum economical catchment was found to be 21 ha or 0.7 ha m pond size, with which 25% and 50% area could be irrigated by conventional and alternate furrow/sprinkler irrigation respectively, with a payback period (PBP) of 2 years in Bt hybrid cotton. Rotational soybean (*Glycine max* (L.) Merrill) could be irrigated to the extent of 16 and 33% catchment area with improved water use efficiency (WUE) from 250 to 500 kg/ha-cm for 1.5 and 3.5 years of pay back period (PBP) under conventional and sprinkler irrigation, respectively, during drought conditions. The same sprinkler and drip irrigation systems could also be used to irrigate subsequent wheat [*Triticum aestivum* (L.) emend. Fiori & Paol] crop with a gravitational well, covering 14 and 57% of catchment area with WUE of 180 kg/ha-cm with a PBP of 11 and 21 years.

Key words: Bt hybrid cotton based cropping systems, Economics, Methods of irrigation, Supplemental irrigations, Water harvesting in farm ponds.

Drought is defined as 51% of deficient rainfall in 20% area under consideration with a probability of 20% drought years in the last two centuries (NRSC, 2010). Severe droughts can occur in 40% of India's geographical area causing losses upto 25% in food grain production (Sharma and Smakhtin, 2004). This can be partly overcome by rain water harvesting in farm ponds (Kolavalli and Whitaker, 1996) for providing life saving irrigations. Crop water deficits are likely to be aggravated in future due to more aberrant climatic disturbances as experienced in the month of August 2008, 2009 and 2011. Bt hybrid cotton or soybean followed by chickpea or wheat is a popular cropping system in medium to deep *Vertisols* with supplemental irrigation. These soils are characterized with poor infiltration rates (about 1 cm/hr) and hydraulic conductivity (about 23 cm/day) resulting in impeded drainage in top 40–60 cm root zone and loss of precious top soil through sheet erosion (Bhandarkar, 2009). When the initial monsoon is week, early seedling drought occurs during July and soybean/Bt hybrid cotton crops need life saving irrigation which is not possible from current season harvested rain water due to limited or no runoff. Life saving irrigation is only possible using underground water. Recharging of underground aquifers is limited due to top heavy swelling type of clay (*Vertisols*). Limited underground storage in *Vertisols* permits only 1-2 hours of common three HP motor pumping unless exclusive recharging techniques are adopted like opening percolation tanks/borewells. However, surface storage reservoirs (farm ponds) are good avenues in *Vertisols* of humid tropics for supplemental irrigations where percolation losses are minimum, nevertheless limitations are seepage and evaporation losses during storage (Bhandarkar, 2009). The rainfall above 35-55 mm/day with intensity exceeding infiltration rate contribute to surface runoff in *Vertisols* (Rao *et al.,* 2010). On an average, it is estimated that 20% of total annual rainfall is lost as runoff in medium deep *Vertisols* that can be collected in dug out farm/percolation ponds at down stream or in a big size community pond (Sharda and Juyal, 2000; Rao *et al.,* 2010). Rivulets or short life

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streams can be diverted to feed gravitational wells/farm ponds through percolation to avoid siltation. Stored water can be used after the cessation of monsoon for improving the crop yields (Samra *et al.,* 2002). It is estimated that out of 20% of rainfall in the form of runoff about 50% of it can be harvested and recycled, which works out to be 150, 300 and 350 m^3 of water/ha/season in the experimental farm ponds of shallow gravelly, medium and deep clay loam soils, respectively (Bhaskar *et al*., 1998). Field experiments were conducted to estimate the net available irrigation water in experimental farm ponds at Nagpur. Scaling up and validation of farm ponds with other agro techniques for suitability of adoption by farming community were done in Nagpur and Yeotmal districts of Maharashtra state during 2007 through 2011. This paper provides the information on optimum farm pond size, net irrigation water availability during droughts and economics of its application in cotton based cropping system.

MATERIALS AND METHODS

Water harvesting: Theoretically possible runoff was calculated by deducting evaporation and maximum soil storage (assumed 200 mm) from rainfall of June to October (Table 1). Rainfall in the months (Table 3) were classified as deficit rainfall as per IMD standards i.e. 20-59% deviation from normal. Actual runoff was estimated by excavating variable size (200 to 15,120 m^2) farm ponds in different pre-identified watersheds at Central Institute for Cotton Research, Farm, Nagpur. Marked metal measuring scales were installed in these ponds for measuring stored water runoff levels. Silting was measured by depth of silt accumulated in farm ponds and average silting was measured by dividing it with the catchment area (Table 4).

Irrigation: Experimental ponds gave only runoff from a unit catchment area (Table 2) and calculations were made for irrigation water application. While validating big ponds, care was taken to account for seepage, evaporation, conveyance and application water losses along with economics for pumps, pipelines, electricity and depreciation etc. Pump sets of 5 HP motor were installed along with water pipe lines for irrigating cotton, soybean/ wheat. Irrigation water was given only from runoff harvested water in field experiments conducted in associated *Vertisols* (Lithic haplustrept) during August droughts of 2008, 2009 as crop life saving irrigations for Bt hybrid cotton and soybean followed by supplemental irrigations in post monsoon season for gram/wheat from the 2nd filling of farm ponds in the last week of August to 1st week of September rains. Season 2010 was a normal year, Bt cotton or soybean crops required no irrigation, but recharged water was used in 2011 June, July and August (Table 12) drought, where cotton could not germinate in June and soybean seedlings died after germination in July. The rain was revived in mid August and all farm ponds were filled to capacity (Table 12).

Economics: Crop response and profitability to harvested rain water as life saving and supplemental irrigations was studied. The cost of harvested rainwater was taken @ ₹15/m^3 with 20% of total cost of pond for construction of spillways, silt traps, grassy water ways, inlet drop structures, pitching of sides, planting of fruit trees on bunds were considered. The cost of irrigation systems and expected economic life for sprinkler and cluster planted drip irrigated cotton was taken as ₹15,000/unit/farm and ₹20,000/ha with a 15 year life span (two crops annually), respectively. The cost of 5 HP motor was ₹17,000/-, and the cost of pipelines was ₹13,000/- farm. Electricity charge was at ₹1,500/farm/year. Irrigation application charges were @ ₹100/day/ha/person. Labour requirement was 2, 2 and 1 persons/ha in conventional/alternate furrow, sprinkler and drip irrigation systems, respectively. The cost of zinc sulphate, magnesium sulphate and borax was ₹ 20, 10 and 40/kg, respectively. The mean selling prices of Bt hybrid cotton, soybean, gram and wheat were ₹ 30, 25, 25

Table 1. Month-wise rainfall, evaporation and calculated possible runoff as percent of total rainfall during experimentation.

	Rainfall (mm)						Evaporation (mm)						Runoff
	June	July	Aug	Sept	Oct	Total	June	July	Aug	Sept	Oct	Total	(%)
2004	159	207	251	41	8	658	213	140	98	121	150	219	33
2005	194	369	137	253	170	953	252	96	87	93	103	180	19
2006	99	418	257	169	9	943	185	108	89	97	129	186	20
2007	304	283	181	272	8	1040	145	107	75	92	108	167	16
2008	186	218	132	117	10	653	124	100	98	110	118	208	32
2009	104	329	241	83	229	757	182	106	120	120	112	240	32
2010	124	406	260	207	93.1	997	234	110	90.6	92.5	93.1	620	18
2011	134	71	305			510	181	112	100			393	20
Mean	187	273	228	161	67	849	209	118	95	101	117	524	26
Met.Normal	292	302	227	137	97	958							28

Soil storage was assumed at 200 mm

and ₹15/kg respectively. The research results were validated in farmer's fields in Yeotmal (AESR 6.4) and Nagpur (AESR 10.2) in Maharashtra state under Centrally sponsored Farm Ponds Schemes, where farmers opinion and irrigation response to both major and micronutrients was also gathered with different Bt cotton hybrids through a stratified sampling survey technique.

RESULTS AND DISCUSSION

Runoff storage in farm ponds affected by rainfall distribution

Possible monthly runoff after budgeting for the soil storage, evaporation and percolation losses was estimated during 2004-07 as potential runoff. About 125 mm of rain water can be harvested in a normal year of assured rainfall in *Vertisols.* As compared to this only 21 mm and 29 mm could be harvested during drought years of 2008 and 2009, respectively. In normal years (2004-2006) it was possible (calculated) to irrigate 15,52, 65% in shallow soils 33, 52, 65% in medium and 25, 54, 61% of the catchment area in deep *Vertisols* respectively in July, August and September months as evidenced from experimental farm ponds of 200 m^3 (Table 2). Runoff yield was limited in shallow black soils, which need more efficient irrigation, water conveyance and application methods. The effective rainfall for soil storage and runoff was 841 mm in 26 rainy days which was 95% of normal rainfall and resulted in 3 times pond filling on 30th July, 7th August and 4th September, 2007 in assured rainfall area of a normal year are required only for supplemental irrigation of Bt hybrid cotton in shallow soils or gram/wheat rotational crops in *Vertisols*. In a drought year 2008, which received

Table 2. Area (% of catchment area) that can be irrigated with experimental farm pond (200 m^3) (averaged over 3 years 2004-2006) in Nagpur.

Method of irrigation	July			August			September		
	Shallow*	Medium	Deep	Shallow	Medium	Deep	Shallow	Medium	Deep
Conventional irrigation	15	33	25	52	52	54	65	65	61
Alternate furrow	30	66	50	105	103	108	130	131	121
Sprinkler	27	61	46	96	95	99	119	120	111
Drip irrigation	85	188	143	298	293	308	370	372	345

*soil depth Shallow =<50 cm, Medium=90 cm, Deep=>90cm

Table 3. Rainfall above 5 mm/day, rainy days deviation from normal during 2007-2009.

	Normal year 2007			Drought year 2008			Drought year 2009		
	Rainfall (mm)	Rainy days	(%) Met. Normal	Rainfall (mm)	Rainy days	(%) Met. Normal	Rainfall (mm)	Rainy days	(%) Met. Normal
June	185	6	63	39	3	13	70	2	24
July	274	9	91	190	4	63	249	14	82
August	181	7	80	122	8	54	203	6	89
September	201	4	147	38	3	28	65	3	47
Average	210	7	95	97	5	40	147	6	61
Total	841	26		389	18		587	25	

Table 4. Siltation, availability and runoff water loss in different farm ponds 2007-2009.

Pond No.	Storage Capacity (m^3)	Year of excavation	Soil loss (t/ha/yr)	Silting (%)	Available runoff water m^3 in September				Water lost (mm/day)		
					2007	2008	2009	2008*	Aug	Sept	Oct Nov
1	200	1987	4.65	2.13	90	0	49	0	12.6	0.02	0.01
2	675	1997	0.23	0.85	262	362	117	50	0.0	0.02	0.00
3	675	1997	0.23	0.82	262	0	100	0	0.0	0.02	0.00
4	2,002	2003	2.84	1.71	2,001	0	721	590	25.0	0.02	0.01
5	4,500	1996	0.12	0.1	3,671	1,100	984	0	1.6	0.04	0.00
6	6,885	2001	2.25	4.33	4,054	3,265	3,534	1,264	8.1	0.03	0.00
7	7,200	2001	2.41	0.64	7,096	3,325	2,093	1,891	4.0	0.02	0.02
8	11,600	2003	4.76	5.32	4,922	4,244	4,275	1,632	4.3	0.01	0.01
9	12,000	2007			9,279	5,116	7,092	5,417	6.4	0.02	0.02
10	15,120	2003	0.28	0.19	4,922	0	3,103	307	13.0	0.02	0.00

*August drought 2008

60% less rain with a dry spell of 19 days between 19th July to 10th August, 2008 with an effective rainfall 349 mm received in 18 rainy days seriously reduced the normal rainfed Bt hybrid cotton and soybean grain yields by 25% and 50% respectively in medium to deep *Vertisols* warranted for a life saving irrigations with only 18% farm pond storage (Table 3, 4). In the drought year 2009 also same duration of 19 days dry spell was observed between 1st to 19th, August, 2009 but the effective rainfall and runoff events were more and farm pond was filled twice on 9th July and 28th August, 2009 which made possible one life saving irrigation for Bt hybrid cotton, soybean and also supplemental irrigations for gram and wheat to a limited extent in bigger farm ponds (Table 3, 4). In the drought year 2011 a duration of 26 days dry spell was observed during 17th June to 14th August, 2011. The rains received between 15th to 30th August,2011 filled farm ponds and soil profile was saturated. Sharda and Juyal, (2000) and Rao *et al.,* (2010) reported similar findings on farm pond size and observed that in drought years farm pond size was less influential than the size of catchment and slope with which runoff quantity for storage is decided and often it was previous years recharge of ground water being used for seedling droughts for crop life saving, where as in normal year pond size matters as quantity of water decides supplemental irrigations for double cropping of winter crop production area and productivity.

Runoff availability in large farm ponds for supplemental irrigation

Rain water was stored only in water harvesting ponds above 4,500 m^3, during drought years with a provision to make one life saving irrigation with drip irrigation. The pond with siltation tanks etc was able to store 82% in normal year, 24% in drought year by mid September and only 18% of storage when the actual drought occured in July and August months (Table 4). Therefore, these ponds with higher permeability are effective for recharging the percolation/gravitational wells for supplemental irrigation of gram or terminal drought to soybean or drip irrigated cotton. The water lost by percolation was 24% in a period of 3.5 months storage in normal year. It was also observed in big water harvesting ponds in weekly water monitoring during 2008 and 2009 monsoon seasons, more water was lost from side slopes towards natural drainage unless compacted or impeded drainage compared to bottom where clay accumulates and water losses were minimal in more than 2 years old farm ponds. This may also partially be due to impact of waves which always keeps the soils of side slopes loose.

Catchment area that can be irrigated by harvested rain water

Shallow black soils responded to supplemental irrigations and deficient nutrient application with improved productivity and profitability by conventional irrigation

Table 5. Pooled (2004-07) supplemental irrigation response of Nbt hybrid NHH 44 cotton through conventional irrigation from harvested runoff water.

Station trial	Shallow black soils			Medium deep black soils		
Treatment	Yield (t/ha)	Cost of cultivation (10^3 ₹/ha)	B:C ratio	Yield (t/ha)	Cost of cultivation (10^3 ₹/ha)	B:C ratio
Rainfed cotton	0.88	9.7	2.48	1.0	10.1	2.81
Rainfed cotton with two supplemental irrigations (SI)	0.93	11.8	2.15	1.3	12.9	2.87
Rainfed cotton with two SI + Borox 3 kg ha/yr	1.08	12.4	2.39	1.6	13.7	3.22
SEm+	0.08			0.04		
CD (P=0.05)				0.09		

Table 6. Validation of supplemental irrigations from harvested rain water with Bt hybrid cotton in Sukhli village of Yeotmal district (M.S.) in drought year 2009.

Onfarm trial	Shallow soil			Medium deep soils		
Treatment	Yield (t/ha)	Cost of cultivation (10^3 ₹/ha)	B:C ratio	Yield (t/ha)	Cost of cultivation (10^3 ₹/ha)	B:C ratio
Rainfed cotton	1.0	10.0	2.75	1.6	11.5	3.83
Rainfed cotton with two supplemental irrigations (SI)	1.3	12.8	2.80	1.9	14.3	3.67
Rainfed cotton with two SI + Zn, Mg, B @ 10, 10, 3 kg ha/yr	1.5	13.4	3.07	2.3	15.4	4.10
SEm+	0.14			0.13		
CD (P=0.05)	0.44			0.32		

method (Table 5). With the sprinkler system of irrigation, 100% donor area can be irrigated in case of droughts in all soils/months except shallow soils in July, where only 27% area is irrigable (Table 2). Seed cotton yields were improved by supplemental irrigations by conventional flood method and with application of boron. Application of Borax @ 3 kg/ha/yr increased seed cotton yield by 23% in shallow soils and by 51% in medium deep soils during 2004-2007 (Table 5). There was an increase in seed cotton yield to the extent of 30%, 50% and 19%, 44%, respectively by two supplemental irrigations along with an application of micronutrients Zn, Mg, B in shallow red soils and medium deep silty clay loam soils of *Sukhli* village (AESR 6.2) in *Ralegaon* taluka of Yeotmal district Maharashtra state during 2009 with Bt hybrid cotton on farm trials conducted (Table 6).

Validation of viability of rain water harvesting ponds

Farm ponds of sizes *viz.,* 200 to 4,500 m^3 storage capacity required for sprinkler (SP), alternate furrow (AF) and conventional irrigation (CI) presently recommended could not reach to irrigate satisfactorily in normal and drought years (Table 4, 7, 10) for Bt hybrid cotton. These ponds were more helpful in recharging the ground water, rendered insufficient and uneconomical to bear cost of irrigation pumps, water pipeline grid system. In the same watershed, another big farm pond No.9 was dug with a capacity of 12,000 m^3 at downstream, inter connecting all other ponds with a natural stream can drain by gravity and store at lowest point of farm pond to avoid storage losses, which were otherwise non viable to irrigate in conventional system. As runoff was more, big farm pond of 12,000 m^3 filled 100% every year but held water 77% in normal year, 43% in drought years, 59% in mild drought years of designed capacity with more than 20 days dry spell with 10, 20, 60 ha area of catchment can be irrigated with a cost: benefit (C:B) ratio of 11, 20, 6 and pay back period (PBP) 1, 1 and 4 years by alternate furrow (AF), sprinkler (SP) and drip irrigation (DP) systems respectively for Bt hybrid cotton (Table 4, 7). The runoff stored in pond No.9 could give life saving irrigation 8, 14 and 45 ha of Bt hybrid cotton/soybean with 10, 19, 7 C:B ratio with a PBP 1-–3 years by alternate furrow, sprinkler and drip irrigation systems of irrigations respectively (Table 10, 11).

A farm pond No. 10 with a possibility of gravity irrigation to down stream crops, which acts as a drinking water source for farm animals was excavated at upstream with 21 ha catchment. However, it was unable to irrigate in drought year with only 12% storage found uneconomical without lining but able to recharge the gravitational well for drinking water to farm animals or life saving irrigation of crops (Table 7, 8). Pooled data of farm ponds of 6,885–15,100 m^3 locating downstream from a normal year of 2007 and July drought of 2008 or August dry spell of 2009 showed that farm pond No. 6 with a storage capacity of 6,885 m^3 and also a natural stream to fill when excess runoff is available, could hold 53% of design capacity on an average between 2007–09 and irrigated Bt hybrid cotton 5, 10 and 30 ha of catchment with a C:B ratio of 10, 18 and 6 and PBP of 1, 1 and 4 years with alternate furrow, sprinkler and drip irrigations respectively (Table 7). Farmer can also opt for irrigating soybean in mild dry spell years (fortnight) or gram in normal years with 7, 14 and 38 ha and C:B ratio of 5, 7, 8 and PBP of 1 year by alternate furrow, sprinkler and drip irrigation systems respectively (Table 8). However, as wheat production is relatively uneconomical for longer storage of runoff water in farm ponds, it is advised to restrict only by gravitational well for domestic consumption as it could reach only 5, 7, 27 ha area by alternate furrow, sprinkler and drip irrigation, the existing drip system is possible to irrigate with a C:B ratio of 3 and a PBP of 2 years (Table 9).

In the same watershed another farm pond No. 8 was dug after two years with 11,600 m^3 at downstream inter connecting each other (6,885 m^3 and 15,120 m^3) as runoff was more which filled 100% every year but held water 39% of designed capacity with 11, 23, 64 ha of Bt hybrid cotton area can be irrigated with a C:B ratio of 6-8 and PBP <1year by alternate furrow, sprinkler and drip irrigation systems respectively (Table 7). It can also irrigate 11, 23, 64 ha of soybean-gram in normal years with a C:B ratio of 6, 7, 8 and PBP of <1 year by alternate furrow, sprinkler and drip irrigation systems, respectively (Table 8). Soybean-wheat crop can also be grown with a gravitational well 4, 5, 22 ha of catchment with the conventional, existing sprinkler and drip irrigation systems PBP of 3 years (Table 9). This pond can give life saving irrigation 2, 4 and 14 ha of Bt hybrid cotton/soybean 5, 9, 6 C:B ratio with a PBP 2–4 years by alternate furrow, sprinkler and drip irrigation systems respectively (Table 10, 11). This pond can hold water till end of January suitable for integrated fish farming between August to January.

A farm pond (No.7) of 7, 200 m^3 with a gravitational well in K.V.K., Nagpur was made for demonstration purpose which was already feeding 4 hectares of drip irrigated cotton and one hectare area with oranges, lemon, pomegranate, guava, papaya and seasonal vegetables. This pond was filled on an average 58% of designed capacity during 2007-09 and irrigated Bt hybrid cotton 6, 11 and 35 ha with a C:B ratio of 9, 17, 6 and PBP 1, 1, 4 years by alternate furrow, sprinkler and drip irrigation systems respectively (Table 7).

Table 7. Pooled economics of Bt hybrid cotton with supplemental irrigations from harvested rain water during September 2007-09.

Storage capacity m^3	Stored runoff (%)	Crop area covered ha			Additional seed cotton produced (in tonne)			Additional cost (10³ ₹)			B:C ratio			Net returns (10³ ₹)			Pay back period (years)		
		AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP
200	42	0.1	0.2	0.7	0.1	0.2	0.5	2	2	4	1.5	2.3	2.6	1	3	12	77.2	7.3	-1.4
675	37	0.4	0.7	2.0	0.3	0.5	1.6	2	3	10	3.6	5.6	4.9	6	13	39	7.8	5.2	4.5
675	18	0.2	0.3	1.0	0.1	0.3	0.8	2	2	6	1.9	2.9	2.9	2	5	18	2.6		
2,002	45	1.3	2.4	7.5	1.1	1.9	6.0	4	5	33	5.5	9.7	3.7	27	53	147			
4,500	25	1.6	3.0	9.2	1.3	2.4	7.4	6	6	40	6.4	11.1	5.6	33	65	182	2.8	2.0	3.9
6,885	53	5.3	9.6	29.9	4.2	7.7	23.9	13	13	122	9.9	18.3	5.9	113	219	596	1.2	0.9	3.5
7,200	58	6.1	11.1	34.5	4.9	8.9	27.6	14	14	140	9.7	18.1	5.9	131	253	687	1.4	1.0	3.6
11,600	39	6.5	11.9	37.0	5.2	9.6	29.6	17	17	152	9.2	17.2	5.9	139	270	737	1.5	1.0	3.6
12,000	60	10.4	19.1	59.2	8.3	15.3	47.4	23	22	241	10.7	20.3	6.0	227	436	1,180	1.0	0.8	3.5
15,120	12	2.6	2.6	2.6	2.0	2.0	2.0	11	9	9	4.6	5.8	5.8	50	52	52			

AF=Alternate furrow irrigation SP=Sprinkler irrigation DP=drip irrigation

Table 8. Pooled economics of soybean-gram supplemental irrigations from harvested rain water during September, 2007-09.

Storage capacity m^3	Stored runoff (%)	Crop area covered ha			Additional soybean produced (in tonne)			Additional cost (10³ ₹)			B:C ratio			Net returns (10³ ₹)			Pay back period (years)		
		AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP
200	42	0.2	0.5	1.3	0.4	0.9	2.4	3	3	8	5.0	9.6	10.2	8	19	53	7	3	1
675	37	0.7	1.4	3.7	1.1	2.3	6.4	29	32	46	3.2	4.6	6.7	-1	26	115	1	1	0.3
675	18	0.7	1.4	3.7	1.1	2.3	6.4	5	8	22	8.7	15.9	12.6	23	50	139	2	1	0.3
2,002	45	1.9	4.0	11.1	3.3	6.9	19.1	12	21	61	13.0	23.0	13.8	72	152	416	1	1	0.2
4,500	25	4.4	9.0	24.9	7.5	15.5	42.9	98	118	210	5.3	6.8	8.6	90	270	863	1.1	0.4	0.1
6,885	53	6.7	13.8	38.0	11.5	23.8	65.6	255	286	425	5.3	6.5	7.9	33	308	1,215	0.4	0.5	0.1
7,200	58	7.0	14.4	39.8	12.0	24.8	68.6	260	293	439	5.3	6.5	7.9	40	328	1,277	0.4	0.4	0.1
11,600	39	11.2	23.2	64.1	19.4	40.0	110.6	344	396	632	5.6	6.7	8.2	140	604	2,132		0.4	0.1
12,000	60	11.6	24.0	66.3	20.1	41.4	114.4	405	458	702	5.5	6.7	8.1	97	577	2,157	0.3	0.4	0.1
15,120	12	9.8	9.8	9.8	11.2	11.2	11.2	72	72	72	5.5	5.5	5.5	209	209	209			

AF=Alternate furrow irrigation SP=Sprinkler irrigation DP=drip irrigation

Table 9. Pooled economics of Soybean-wheat supplemental irrigations from harvested rain water during September, 2007-09.

Storage capacity m^3	Stored runoff (%)	Crop area covered ha			Additional wheat produced (in tonne)			Additional cost ($\times 10^3$ ₹)			B:C ratio			Net returns ($\times 10^3$ ₹)			Pay back period (years)		
		AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP
6,885	60	4.7	6.5	26.9	11.7	16.1	67.2	60	78	304	2.9	3.1	3.3	116	164	704	2.2	1.7	2.1
7,200	53	2.7	3.6	15.2	6.6	9.1	38.0	34	45	173	2.9	3.0	3.3	65	92	397	2.4	1.8	2.2
11,600	39	3.9	5.4	22.4	9.7	13.4	55.9	51	66	254	2.8	3.0	3.3	96	136	585	2.8	2.1	2.2
12,000	58	2.4	3.4	14.0	6.1	8.4	35.1	32	42	160	2.7	3.0	3.3	60	85	366	3.1	2.4	2.3

AF=Alternate furrow irrigation SP=Sprinkler irrigation DP=drip irrigation

Table 10. Economics of Bt hybrid cotton supplemental irrigations during August drought from harvested rain water during 2008

Storage capacity m^3	Stored runoff (%)	Crop area covered ha			Additional seed cotton produced (in tonne)			Additional cost ($\times 10^3$ ₹)			B:C ratio			Net returns ($\times 10^3$ ₹)			Pay back period (years)		
		AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP
200	0																		
675	50	0.1	0.1	0.4	0.1	0.1	0.3	3	3	4	0.7	1.0	2.5	-1	0	6		423	10
675	0																		
2,002	590	0.9	1.6	4.9	0.7	1.3	3.9	4	5	20	4.6	7.8	5.7	16	33	97	3	2	4
4,500	0																		
6,885	1,264	1.8	3.4	10.4	1.5	2.7	8.4	8	9	43	5.3	9.4	5.9	36	72	208	4	2	4
7,200	1,891	2.7	5.0	15.6	2.2	4.0	12.5	10	10	61	6.7	12.0	6.2	56	111	314	2	1	4
11,600	1,632	2.4	4.4	13.5	1.9	3.5	10.8	12	12	56	4.9	8.9	5.8	45	93	268	4	2	4
12,000	5,417	7.9	14.4	44.8	6.3	11.6	35.8	20	19	166	9.5	17.8	6.5	169	327	908	1	1	3
15,120	307	0.4	0.4	0.4	0.4	0.4	0.4	8	8	8	1.3	1.3	1.3	2	2	2	101	107	112

AF=Alternate furrow irrigation SP=Sprinkler irrigation DP=drip irrigation

Table 11. Economics of soybean supplemental irrigations during August drought from harvested rain water during 2008.

Storage capacity m^3	Stored runoff (%)	Crop area covered ha			Additional soybean seed produced (tonne)			Additional cost (× 10^3 ₹)			B:C Ratio			Net returns (× 10^3 ₹)			Pay back period (years)		
		AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP	AF	SP	DP
200	0																		
675	50	0.1	0.1	0.4	0.1	0.1	0.4	3	3	4	0.7	1.1	2.6	-1	0	6		191	9
675	0																		
2,002	590	0.9	1.6	4.9	0.9	1.6	4.9	4	5	20	4.8	8.1	6.0	17	34	102	3	2	4
4,500	0																		
6,885	1,264	1.8	3.4	10.4	1.8	3.4	10.4	8	9	43	5.5	9.8	6.1	38	76	219	3	2	4
7,200	1,891	2.7	5.0	15.6	2.7	5.0	15.6	10	10	61	6.9	12.5	6.4	59	116	330	2	1	3
11,600	1,632	2.4	4.4	13.5	2.4	4.4	13.5	12	12	56	5.1	9.3	6.1	48	97	282	4	2	4
12,000	5,417	7.9	14.4	44.8	7.9	14.4	44.8	20	19	166	9.9	18.5	6.7	177	342	953	1	1	3
15,120	307	0.4	0.8	2.5	0.4	0.8	2.5	10	11	19	1.1	1.9	3.4	1	10	45	334	27	9

AF=Alternate furrow irrigation SP=Sprinkler irrigation DP=drip irrigation

Table 12. Rain water stored at the end of August month during 2010, 2011 years

Pond No	Farm Pond Capacity m^3	2010	2011
Pond No 4	2,002	1,125	470
Pond No 5	7,200	4,361	2,580
Pond No 6	12,000	6,917	8,702
Pond No 7	11,600	5,528	6,080
Pond No 8	9,885	9,112	6,916
Pond No 9	15,120	6,338	4,473
Total storage created	42,687	60%	47.3%

Option-1 is to give supplemental irrigation for soybean/gram in mild dry spell/normal years of 7, 14, 40 ha of catchment with C:B ratio 5–7 and PBP <1 years by alternate furrow, sprinkler and drip irrigation systems respectively (Table 8). Wheat crop can also be grown in 3, 4, 15 ha of catchment by alternate furrow and existing sprinkler and drip irrigation systems (Table 9) with a gravitational well as it can hold water in pond upto November month only. This pond can give life saving irrigation 3, 5, and 16 ha of Bt hybrid cotton/soybean in a drought year 2008 with a C:B ratio of 7, 12, 6 and with a PBP 2–4 years by alternate furrow, sprinkler and drip irrigation systems respectively (Table 10, 11).

Based on study the minimum economical pond size and catchment were found to be above 6,885 m^3 and 21 ha for direct pumping to face the challenge of severe drought in Bt hybrid cotton followed by soybean–gram/wheat cropping system. Farmers must opt to feed the farm ponds from the natural streams which can help if any droughts may occur. Recharging with borewells/percolation tanks to the under ground aquifers can help to over come both summer water shortages and seedling droughts.

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