Chapter 5

Evaluating Irrigation Strategies in Study Area

5.1 General

Conventional irrigational practices cause over irrigation or moisture stress conditions, leading to decrease in yield, and water use efficiency. Objective is to evolve such strategies, which can be helpful to all stake holders, in decision making keeping in view different scenarios which are likely to prevail. To match the irrigation supply with demand; estimation of the evapotranspiration is required to be done with appropriate methods. Crop evapotranspiration (ET_c) measurement is not easy, and requires sophisticated, expensive equipment, and trained research personnel. Complexities involved in estimation of crop water requirements with different parameters to be considered have made it a challenging task. Advent of automatic weather stations (AWS) has enabled the availability of meteorological data on daily/ hourly basis, which can be used to precisely estimate reference evapotranspiration using FAO-56 P-M model. Comprehensive FAO-56 P-M model coupled with, dual crop coefficient (Kcb) approach, and soil moisture balance (SMB) model is incorporated in MABIA method of WEAP model, which is an excellent decision support tool, for evolving irrigation strategies under varied situations. The dual crop coefficient approach helps in computing, separately soil evaporation and transpiration under normal, and water stress condition. Sardar Sarovar Project command needs such decision support models, for suggesting best irrigation scheduling practices. Recent WEAP software combines ET estimation, and irrigation scheduling using MABIA method, which helps in evaluating various irrigation strategies.

5.2 Model Description

Water Evaluation and Planning System (WEAP) represents a new generation of water planning software. The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; demand-management capability; environmental assessment capability; and ease of-use (Seiber and Purkey, 2011). It has been applied primarily in a number of studies concerning: Agricultural systems, municipal systems, single catchments or complex trans-boundary river systems. MABIA method uses the dual crop coefficient approach (FAO-56), which is an improvement over CROPWAT which uses single crop coefficient approach.

WEAP- MABIA model tool provides facility to trigger irrigation, by the fixed interval, percent of readily available water (RAW), percent of total available water (TAW), fixed depletion, and their combinations. The irrigation amount is decided as per the selected options such as fixed depth, percent of RAW, percent of TAW, percent of depletion, and their combinations. For this study six varied irrigation strategies (scenarios/treatments) are considered using above mentioned methods for triggering irrigation, and deciding irrigation amount, depending upon kharif season, rabi season, sowing date, and crop.

5.3 Irrigation Strategies Employed

The following irrigation strategies are mainly used for all fourteen crops with slight modifications, where ever required depending upon crop: (i) Strategy S I depicts the conventional irrigation approach of irrigating at fixed interval with fixed amount of irrigation. (ii) In strategy S II, to prevent soil moisture stress, fixed amount of irrigation is applied at 100percent of RAW. (iii) Strategy S III caters to irrigating the crop under no moisture stress conditions (i.e.100percent RAW). Amount equivalent to soil moisture depletion is applied to prevent any water losses. (iv.) In case of dry year/unavailability of sufficient water, protective irrigation is tried, wherein irrigation of reduced fixed depth is applied at 80 percent of TAW. (v) To promote better yields/water savings, deficit irrigation is applied during a specific growth stage/s depending upon crop, and (vi) To achieve water saving and ease in implementation strategy S VI is devised with combination of one or two methods of triggering irrigation with reduced irrigation depths.

5.3.1 Modalities

Modalities worked out for irrigation scheduling and their effects: (1) Unless famine like situation prevails in region I and II; the policy of SSP authority is to provide canal irrigation only during November to April, to promote conjunctive use of surface water and groundwater (Pathak, 1989). Due to this policy the farmers have to resort to groundwater irrigation in the command area, if rains are temporally uneven during Kharif season. In view of the above policy, it is decided to provide groundwater irrigation from 1st July upto end of October, for crops grown in Kharif season. Canal irrigated water is provided from 1st of November upto end of April, for all crops in region I and II. (2) For all irrigation schedules, the date of the last irrigation cut off is decided according to crop literature, or as per practises followed locally. For e.g. "Cotton irrigation cut off is decided at least 20 days before harvesting since cotton lint quality is affected, when its moisture content at harvest is higher than 8 percent (Barker, 1982, 1996; Barker and Laird, 1993)". Crop irrigation cuts for various Kharif crops are as follows: Paddy, cotton, tobacco, ground nut no irrigation is given in last 15 days, while for jowar/bajra no irrigation is given in last 10 days. In case of castor and sugarcane no irrigation to be given in last 30 days (Pathak, 1989). Thus, last date of irrigation for cotton was taken 15 days before harvesting as per local practises. (3) The crops which are grown with the onset of monsoon are not applied irrigation water in initial vegetative period, except strategy S III, as per conventional practises to stop over irrigation. Mild yield reduction is expected due to this approach. This is done with a presumption that sufficient soil moisture is present. Impact of this approach is likely to be seen with little yield reduction in above selected strategies. (4) Generally the total irrigation depth for strategy S II would be more than strategy S III, but where the irrigation is applied post initial stage, and irrigation cut off is few days ahead of harvesting in strategy S II, the total irrigation depth could be less also. The Kharif crops, if not irrigated under less or delayed rainfall than their yield is affected. Various irrigation strategies suggested for irrigating Kharif crops utilize only groundwater, whereas canal water is used post Kharif season. Conjunctive use of surface and ground water in the area can withheld the rising trend of water table in certain pockets of the region.

Crop data, climate data, and soil data were procured from the various government agencies as discussed in chapter 4. As per the average rainfall for all blocks, 2004, 2005, 2007, 2008 were normal rainfall years with 915 mm, 890 mm, 908 mm, 752 mm rainfall respectively, while 2006 and 2009 were wet year and dry year respectively with 1311 mm and 447 mm rainfall. Rainfall is prolonged in all blocks for the dry year 2009. Due to availability of relevant data covering normal, wet, and dry years from monsoon point of view; period 2003 year onwards up to 2010 is specifically selected for the study purpose. Water year selected for this study begins from 1st June 2003, and ends on 31st May 2004; which is taken as base period, representing the current account for any of the selected strategy existing for that period. The current accounts are also assumed to be the starting year, for all the scenarios (various irrigation strategies S I to S VI). This is done to accurately reflect the observed operation of the system. WEAP-MABIA model is run from June 2003 to May 2010 year, for study period by taking year 2003 as base period, for major 14 crops grown in region I and II. Following precipitation or irrigation, the soil is considered at its field capacity. Therefore, initial depletion is taken as zero. Depth of surface layer thickness subject to drying by evaporation is an important component in dual crop coefficient method, which is taken as 100 mm. After starting of precipitation, part of precipitation (i.e. effective precipitation) enters into the root zone, which increases the soil moisture. SCS method is found to be useful in estimating effective precipitation for soil moisture balance model. Effective precipitation has been calculated by SCS curve number method, for differing available moisture conditions (AMC) for five day antecedent rainfall, crop specific land use, and hydrologic soil group conditions. Many types of irrigation system wet only a fraction of soil surface. For furrow irrigation method fraction wetted is taken as 0.6. The maximum potential yield (assuming an optimal supply of water) has been taken from available literature or local sources. Actual yields will be lower, if the crop under goes water stress conditions due to insufficient water (i.e. soil moisture depletion falls, below the Readily Available Water threshold). In MABIA method before the planting of the crop and after harvesting; the model runs for fallow conditions to estimate the soil moisture balance during the water year. Crop wise daily soil moisture balance, yield, Water use efficiency (WUE), Irrigation water use efficiency (IWUE), and water demand (ground water and/or canal water), under irrigation strategies S I to S VI for total 20 blocks in region I and II are worked out. Simulation results of various irrigation strategies obtained are for years 2004 to 2010. Amongst all strategies, the model determined no stress condition strategy would maximize yield, water use efficiency, and irrigation water use efficiency, with optimum quantity of irrigation water depth. Thus other strategies are compared with it to check their effectiveness, and suggest the best amongst the remaining ones.

5.4 Irrigation Scheduling Strategies for Rice

As paddy rice crop is grown under submerged conditions hence, the soil is considered at saturation capacity during sowing, transplanting, and immediate after significant rainfall or irrigation. The initial depletion is taken as zero for the base year 2003 for computing soil water balance. The potential yield of rice under pristine conditions is taken as 4500 Kg per hectare.

The various strategies employed for rice are illustrated in Table 5.1: (i) Strategy S I: In this strategy fixed irrigation depth of 200 mm is applied at fixed irrigation interval of 15 days post sowing. (ii) Strategy S II: In this strategy the soil moisture conditions are not allowed to go below the readily available water. So the irrigation water of 75 mm fixed depth is applied, as depletion level reaches 100 per cent of readily available water (RAW). (iii) Strategy S III: It is model decided, wherein no moisture stress condition is allowed upto last cut off irrigation i.e. 15 days prior to harvesting. The 100 per cent of depletion amount is applied as irrigation, when soil moisture level reaches equal to 1 per cent of readily available water, (iv) Strategy S IV: In case the crop is grown as a rainfed crop a protective irrigation is applied, if rains are delayed. In this strategy irrigation of 50 mm upto vegetative stage, and then 100 mm fixed depth is applied as protective irrigation, when soil moisture depletion equals 80 percent of total available water. (v) Strategy S V: Deficit irrigation strategy is implemented, wherein irrigation of 100 mm fixed depth is applied at a fixed interval of 20 days only, and (vi) Strategy S VI: In this conventional strategy the field is kept under saturated conditions throughout the growing season. So as to accomplish this, irrigation water is applied at 25 days fixed interval with 75 mm of fixed depth. And in order to meet the daily evapotranspiration requirement, a top up of 8mm water is applied daily, for keeping the soil under saturated conditions. Irrigation is cut off 15 days pre harvest i.e.23rd October. For each strategy (number of blocks * number of years) 114 simulations are carried out for rice crop. Irrigation scheduling for rice from date of sowing for strategies S I to S VI has been tabulated and shown in Table 5.1

Table 5.1: Irrigation scheduling strategies for rice crop

Case	Irrigation Strategy		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1,16,31,46,61,76, 91,106	200 mm	Irrigation of 200 mm depth is applied at a fixed interval of 15 days post sowing.
S II	1-115	75 mm	Irrigation of 75 mm depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-115	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 1 per cent of readily available water, to attain no moisture stress conditions.
S IV	1-30 31-130	50 mm, 100 mm	Irrigation of fixed depth of 50 mm is applied upto initial vegetative stage (30days), and then 100mm water is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S V	1,21,41,61, 81,101days	100 mm	Irrigation of 100 mm depth is applied at a fixed interval of 20 days.
S VI	1,26,50,75, 100 & 115	75mm, 8mm	Irrigation of 75 mm depth is applied at a fixed interval of 25 days, and to meet the daily evapotranspiration requirement, 8 mm depth of water is added daily. Last irrigation is cut off 15 days ahead of harvesting.

***** From date of sowing. (Date of sowing 1st July and harvesting 7th November).

5.4.1 Water Balance, Yield and Efficiencies for Rice

Daily soil moisture balance is computed, for all the blocks and all strategies for rice crop, the result helps in assessing the management policy to provide canal irrigation water only during November to April with different irrigation strategies. Averages of ET actual, precipitation, groundwater irrigation, surface runoff, and flow to groundwater, yield, WUE, and IWUE were simulated for years 2004-2009 for all six strategies and, for all 19 blocks, where rice crop was sown in base year 2003. For illustration purpose simulation for block 1 has been shown in the Table 5.2. Water Balance of the Root zone as per FAO- 56 for Table 5.2 is given as follows: $D_{r,i} - D_{r,i-1} = -P_i + SR_i - I_i - CR_i + ET_{a,i} + DP_i$, Where $D_{r,i} - D_{r,i-1}$ is Net decrease in soil moisture. Illustrative calculation example for average of Strategy S I (F.I. with F.D.) is given as: 24 = − 985+1694 −1600 − 0 +527+388, the value of $CR_i = 0$. The negative sign shown in Table for Runoff and Flow to groundwater is not to be considered during calculation. In this simulation the standing water over the ground is not considered, and hence the excess irrigation or rainfall after saturation of soil, generates surface run off. In actual practise such surface run off is prevented by constructing the bunds, and this reduces the requirement of daily irrigation. WUE is computed as yield per crop evapotranspiration, while IWUE is obtained from yield per irrigation water applied. WUE is a biological indicator, while IWUE is influenced by performance of irrigation system, and degree of losses beyond transpiration. The mean values of WUE decrease with reduction in irrigation water application, while the mean values of IWUE increase with decrease in irrigation water application due to greater utilization of stored soil water at higher deficits. In block 1 model determined no stress condition strategy S III had highest average values of ET actual (642 mm), WUE (6.77 kg/ha/mm), and IWUE (10.70 kg/ha/mm). Strategy S VI wherein crop was grown under fully saturated conditions indicated to be best choice amongst the available strategies with values of ET actual (641 mm), WUE (6.77 kg/ha/mm), and IWUE (3.23 kg/ha/mm). Strategy S II was the second best option with ET actual (637 mm), WUE (6.69 kg/ha/mm), and IWUE (1.68 kg/ha/mm) values. Other remaining strategies were less important if both objectives of increasing yield and water savings were to be achieved. However, they could be recommended in different scenarios. The understanding of the soil moisture deficit pattern with significant rainfall and irrigation, for various irrigation scheduling strategies enables to assess the strengths and limitations of the irrigation management strategies. In this context Figures 5.1 (a-f) have been discussed for rice crop for block 4B, specifically as certain irrigation strategies were sensitive to yield. In strategy S I the irrigation is applied at fixed interval, and it is observed that the soil moisture deficit is developed during the initial period and during mid season stage.

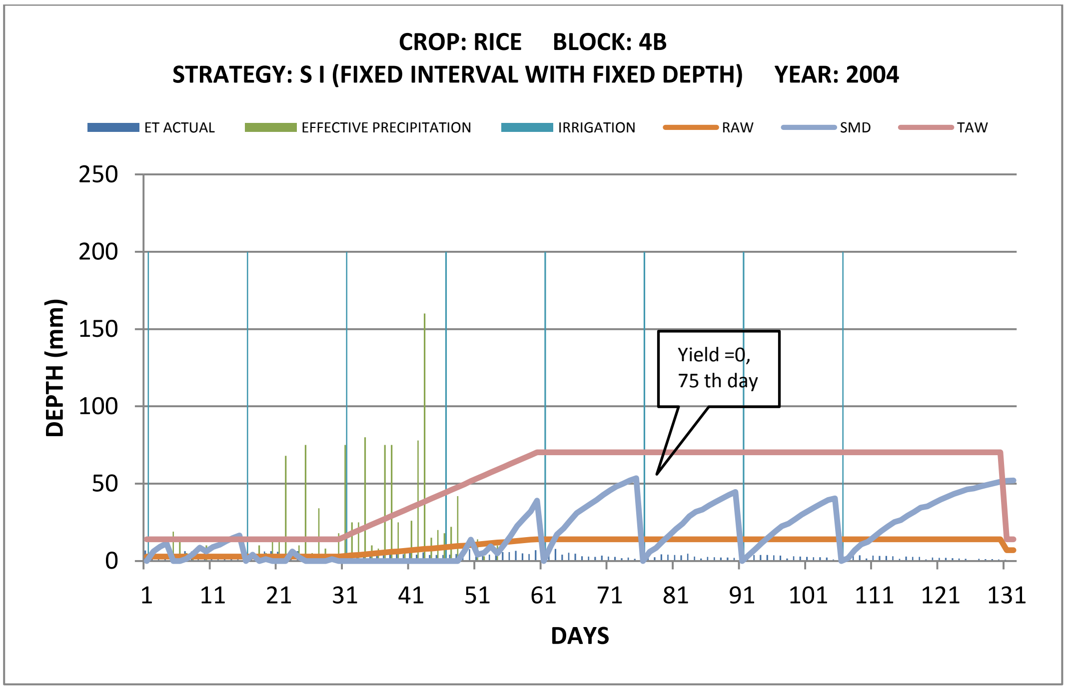
Table 5.2: Water balance, yield and efficiencies of rice crop in sandy clay (HSG – C) soil in block 1 (grown in 1.33 percent of CCA 9868 ha)

Irrigation Strategies for Rice	Year	ETc Actual	Effective Precipitation	GW Irrigation.	Net decrease in soil moisture	Flow to GW	Runoff	Yield	WUE	IWUE	GW demand
		mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha/mm	Kg/ha/mm	M. cum
		1	2	3	4	5	6	7	8	9	10
Strategy S I F.I. with F.D.	2004-2005	493	1068	1600	27	-430	-1773	2446	4.96	1.53	2.10
	2005-2006	448	655	1600	55	-353	-1508	2579	5.75	1.61	2.10
	2006-2007	663	1660	1600	21	-432	-2186	2986	4.51	1.87	2.10
	2007-2008	496	1050	1600	45	-399	-1800	3036	6.12	1.9	2.10
	2008-2009	500	966	1600	1	-462	-1604	2591	5.18	1.62	2.10
	2009-2010	561	508	1600	-5	-250	-1291	0	0	0	2.10
	Average	527	985	1600	24	-388	-1694	2273	4.42	1.42	2.10
Strategy S II 100% RAW with F.D.	2004-2005	580	1068	2400	17	-917	-1988	4324	7.46	1.8	3.15
	2005-2006	566	655	2700	46	-769	-2066	4218	7.46	1.56	3.54
	2006-2007	747	1660	2250	20	-892	-2290	4198	5.62	1.87	2.95
	2007-2008	565	1050	2175	33	-793	-1900	4289	7.6	1.97	2.85
	2008-2009	607	966	2400	3	-819	-1943	4044	6.66	1.69	3.15
	2009-2010	757	508	3450	-6	-1048	-2147	4049	5.35	1.17	4.53
	Average	637	985	2563	19	-873	-2056	4187	6.69	1.68	3.36
Strategy S III No Stress	2004-2005	582	1068	380	14	-368	-512	4370	7.51	11.49	0.50
	2005-2006	569	655	345	43	-238	-234	4295	7.54	12.44	0.45
	2006-2007	752	1660	443	19	-332	-1037	4279	5.69	9.67	0.58
	2007-2008	566	1050	324	31	-299	-540	4322	7.63	13.34	0.43
	2008-2009	616	966	402	1	-332	-421	4174	6.78	10.38	0.53
	2009-2010	764	508	603	-5	-190	-151	4157	5.44	6.9	0.79
	Average	642	985	416	17	-293	-483	4266	6.77	10.70	0.55
Strategy S IV Protective Irrigation	2004-2005	417	1068	400	22	-412	-661	2285	5.48	5.71	0.53
	2005-2006	351	655	300	37	-265	-375	2061	5.88	6.87	0.39
	2006-2007	509	1660	300	26	-313	-1163	2870	5.64	9.57	0.39
	2007-2008	401	1050	200	44	-304	-589	2881	7.19	14.4	0.26
	2008-2009	454	966	500	-30	-421	-562	2653	5.85	5.31	0.66
	2009-2010	421	508	500	1	-295	-293	1477	3.5	2.95	0.66
	Average	426	985	367	17	-335	-607	2371	5.59	7.47	0.48
Strategy S V Deficit Irrigation	2004-2005	388	1068	600	40	-434	-886	2226	5.73	3.71	0.79
	2005-2006	346	655	600	53	-340	-622	2517	7.28	4.19	0.79
	2006-2007	493	1660	600	28	-416	-1377	3111	6.3	5.18	0.79
	2007-2008	396	1050	600	54	-406	-903	3038	7.66	5.06	0.79
	2008-2009	407	966	600	0	-436	-723	2269	5.58	3.78	0.79
	2009-2010	384	508	600	-2	-253	-469	0	0	0	0.79
	Average	402	985	600	29	-381	-830	2194	5.43	3.65	0.79
Strategy SVI Combination Irrigation	2004-2005	582	1068	1322	14	-863	-959	4370	7.51	3.31	1.74
	2005-2006	569	655	1322	43	-837	-612	4295	7.54	3.25	1.74
	2006-2007	751	1660	1322	19	-793	-1457	4275	5.69	3.23	1.74
	2007-2008	566	1050	1322	31	-855	-982	4322	7.63	3.27	1.74
	2008-2009	616	966	1322	1	-890	-783	4174	6.78	3.16	1.74
	2009-2010	764	508	1322	-5	-587	-473	4157	5.44	3.14	1.74
	Average	641	985	1322	17	-804	-878	4266	6.77	3.23	1.74

Note: No. of rainy days for rice crop period in year 2004, 2005, 2006, 2007, 2008 and 2009 are 48, 46, 55, 55, 57 and 39 days respectively.

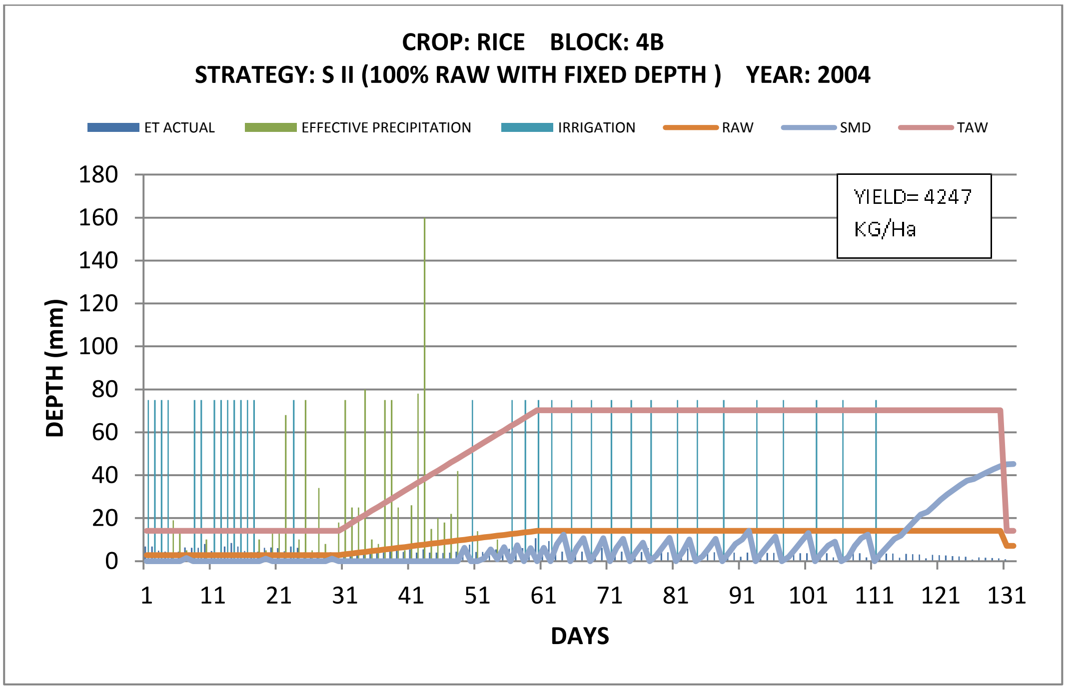
The crop faces no significant water stress in development stage. Yield is reduced to zero on 75th day just two days prior to irrigation in this block see Fig 5.1a. In case of irrigation strategies S II, S III, and S VI the rice crop is under no water stress condition, throughout its growth period, except 15 days prior to harvesting as water is drained off. This is in accordance to the prevailing practises to drain off the water 15 days before harvesting. The large amount of water is lost due to deep percolation in the initial and development stages in most of the strategies, except model determined strategy S III, where flow to groundwater is nil. Evapotranspiration rate and yield is significantly high in strategies S II, S III, and S VI. In strategies S IV (protective) and S V (deficit) the moisture stress is developed in initial and mid season stage. Due to this moisture stress, low yield or failure of crop is expected, which is also evident from the Fig 5.1d and Fig 5.1e.

It has been observed that in daily time step if daily yield fraction is zero, during any growing stage the yield is deduced to be zero during the season. Such instances were observed for rice in strategy S I in blocks 1, 2, 3A, 3B, and 4B having sandy clay soil, where climate data of Naswadi weather station were taken. In 2009 year, where 508 mm rainfall (below average) was noted, the rice crop failed just two days ahead of fixed irrigation interval in mid season stage. In case of strategy S IV (protective irrigation) yield deduced to zero just few days ahead of irrigation trigger for blocks 11A1, 12, and 6BR2, having soils silty clay loam, sandy loam, and silty clay respectively. In case of strategy S V (deficit irrigation) the crop failed to give yield in the year 2004, for blocks 3B,4B,,6A1,8, 11A2,13A, and 13B as the rains was delayed by 25 days in mid season stage, and irrigation had triggered just after two days of crop failure. While, in year 2009 very less rainfall of 282mm was noted in blocks 1, 2, 3A & 13B, and irrigation triggered after few days of the crop failure.



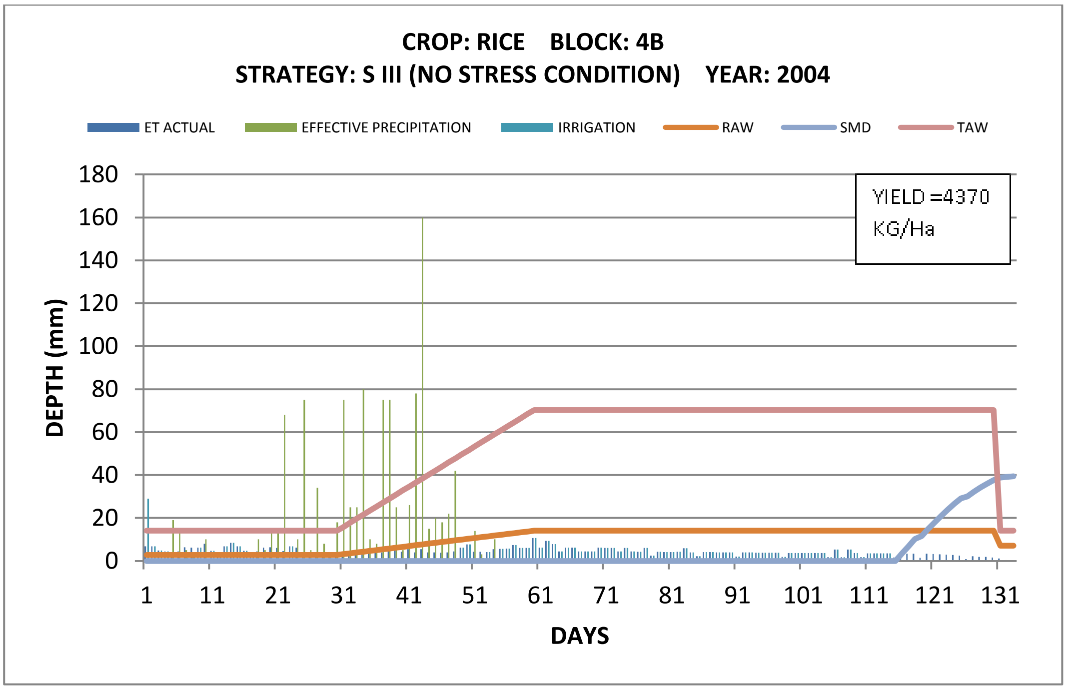
CROP: RICE BLOCK: 4B
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
250
200
150
100
50
0
Yield =0,
75 th day
1
11
21
31
41
51
61
71
81
91
101
111
121
131
DAYS

5.1 (a)



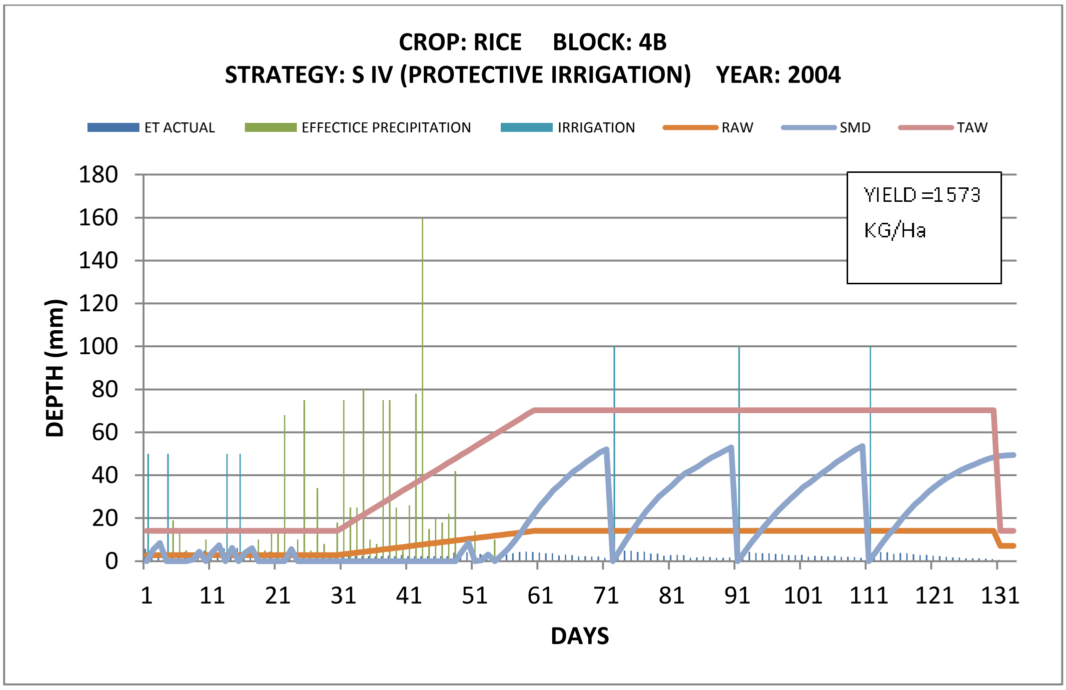
CROP: RICE BLOCK: 4B
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
180
160
140
120
100
80
60
40
20
0
YIELD= 4247
KG/Ha
1
11
21
31
41
51
61
71
81
91
101
111
121
131
DAYS

5.1 (b)



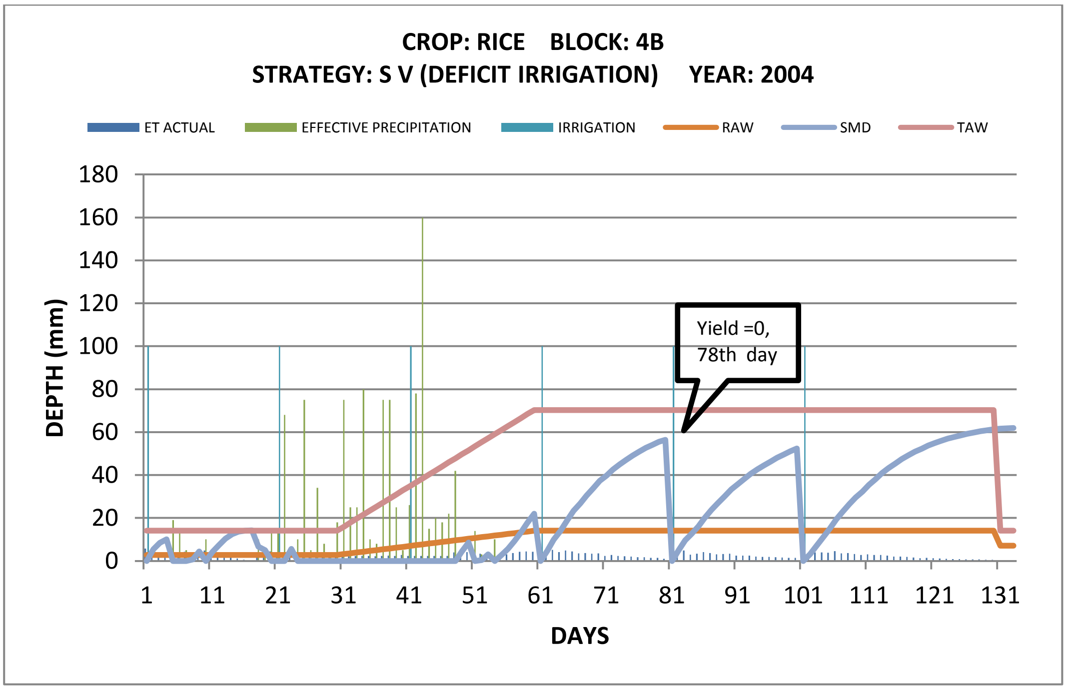
CROP: RICE BLOCK: 4B
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
YIELD =4370 KG/Ha
DEPTH (mm)
180
160
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
121
131
DAYS

5.1 (c)

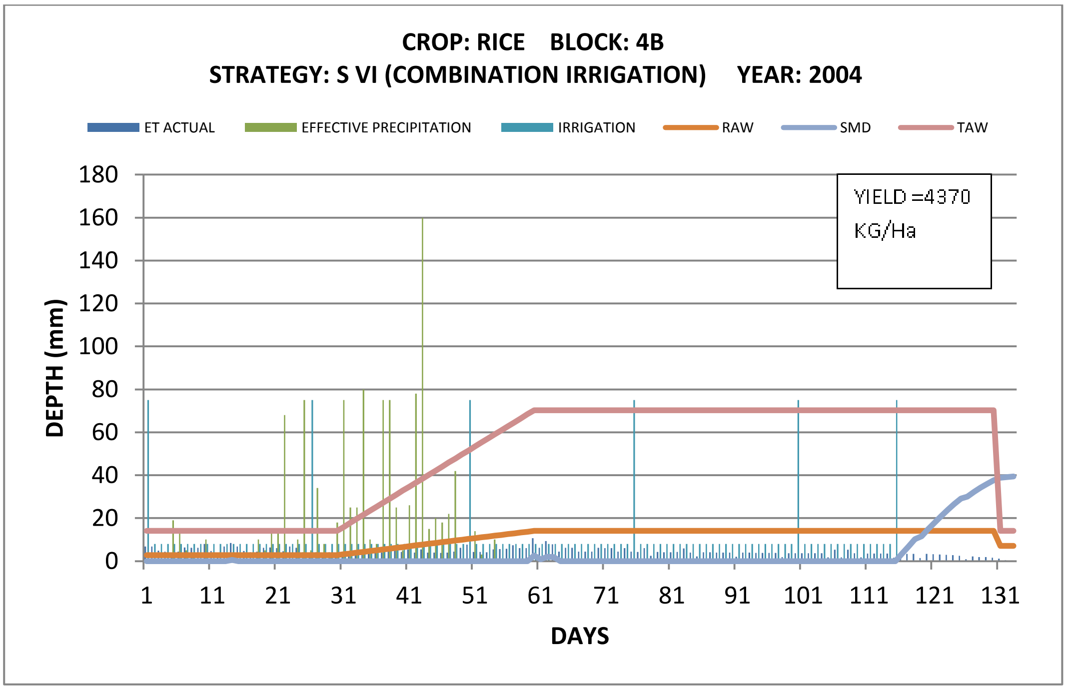


CROP: RICE BLOCK: 4B
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004
ET ACTUAL
EFFECTICE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
YIELD =1573 KG/Ha
DEPTH (mm)
180
160
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
121
131
DAYS

5.1 (d)



5.1 (e)



5.1 (f)

Fig 5.1(a-f): Soil moisture balance for irrigation strategies S I to S VI for rice crop year 2004

5.4.2 Effect of Soil Type on Rice Irrigation Depth

To study the impact of various soils on water usage, strategy S II was selected as reference strategy, because maximum amount of irrigation depth of water is used by various soils was in strategy S II. Mean blocks irrigation depth of water in strategy S II, were as follows (Fig 5.2) : sandy clay (10 blocks; 2506 mm), sandy clay loam (3 blocks; 1854 mm), sandy loam (2 blocks; 1494 mm), silty clay loam (2 blocks; 1400mm), silty clay (1 block; 1488 mm), and clay loam (1 block; 1475 mm) respectively. As sandy clay soil holds less rainwater, thus frequent irrigation resulted in high irrigation depth.

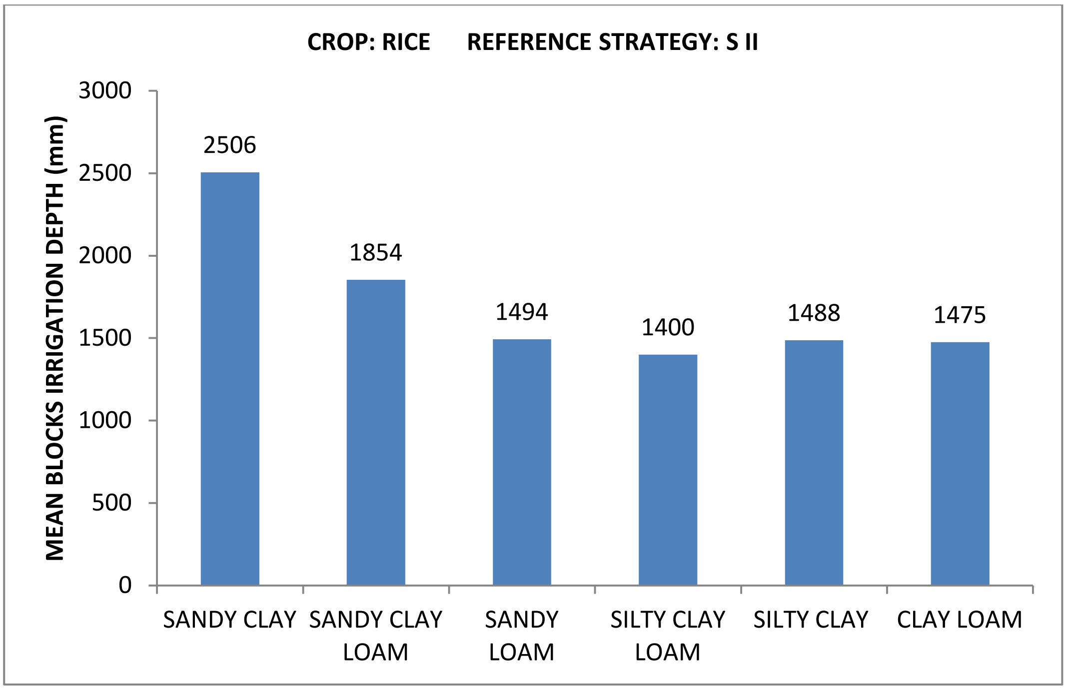


Fig 5.2: Effect of soil type on rice irrigation depth under strategy S II

5.4.3 Effect of Irrigation on Groundwater for Rice Crop

In the study area nine blocks, which are having large number of observation wells, or peizometers, for monitoring ground water table, and which are likely prone to water logging, or have high water table are selected, specifically to assess the impact of various strategies. Net withdrawals for rice crops have been shown in Table 5.3, for eight blocks 4B, 6A1, 8, 10, 11A2, 6BR2, 9A2R2, and 9B1R2. Rice crop is not sown in block 6A3R2. Strategies S II, S I and S VI can be recommended as net withdrawal of groundwater are high as observed from the soil moisture balance simulation. While, strategies S III, or S IV would not prevent the rise of groundwater table in such pockets having high groundwater table, especially in blocks

10, 6BR2, 9A2R2, and 9B1R2, but would increase the groundwater table in range of 40mm to 125 mm annually.

5.4.4 Irrigation Depth for Rice under Strategies S I to S VI

The irrigation depth range for rice crop under various strategies has been shown in Figure 5.3. The figure shows that strategy S II has wide range of irrigation depth. Irrigation depth in strategy S II is sensitive to soil, rainfall, and climatic conditions. The strategies for rice crop falling under the ambit of fixed irrigation depths are S I (1600 mm), S V (600 mm), and S VI (1322 mm). Other strategies, where type of soil, weather conditions influenced lower , upper range, and mean of irrigation depth are S II (minimum 900 mm to maximum 3450 mm, mean 2072 mm), S III (minimum 272 mm to maximum 603 mm and mean 384 mm), and S IV (minimum 100 mm to maximum 650 mm , mean 339 mm).

Table 5.3: Average net groundwater withdrawals (years 2004-2009) for strategies S I to S VI for rice crop period.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (years 2004-2009) for rice crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	1212	1658	109	34	224	498
6A1	Sc	1 to 15	1182	1490	42	72	234	452
8	Scl	0.5to 6.5	1229	1659	112	171	282	512
10	Scl	1.5 to 18	973	646	-43	-73	90	215
11A2	Sc	3 to >30	1195	1484	55	106	249	461
6BR2	Sic	1.2to>30	1117	764	22	-48	192	364
9A2R2	Sicl	1 to >30	1022	488	-40	-118	141	244
9B1R2	Cl	0.5 to 23	971	549	-63	-125	105	192

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Rice crop is not sown in block 6A3R2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation.

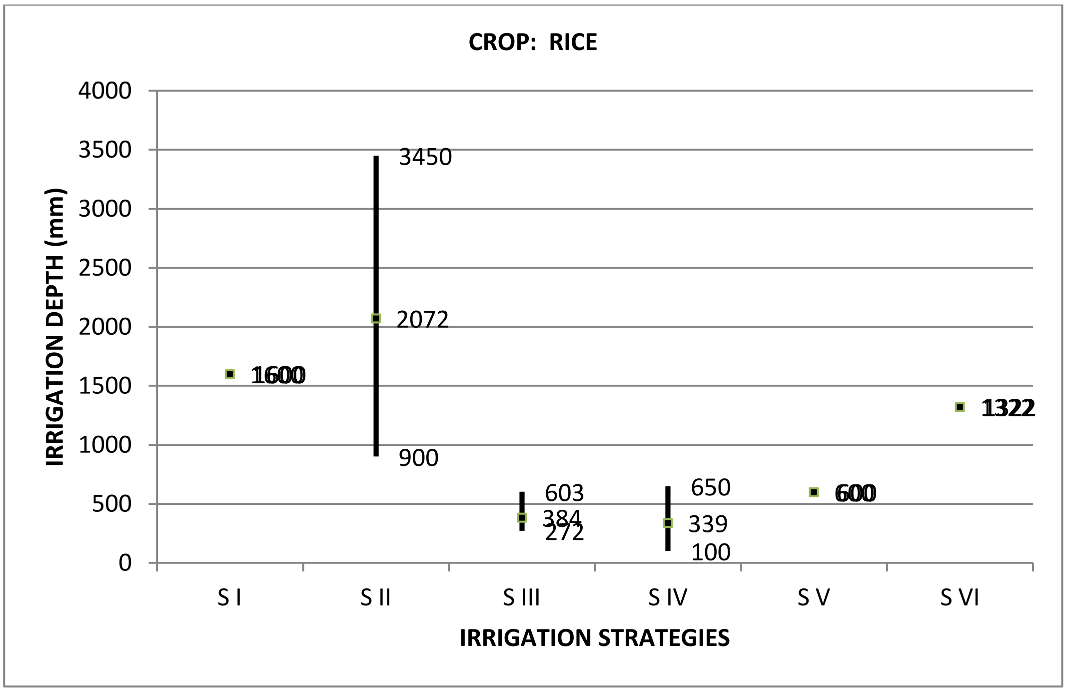


Fig 5.3: Irrigation depth range for rice crop for strategies S I to S VI

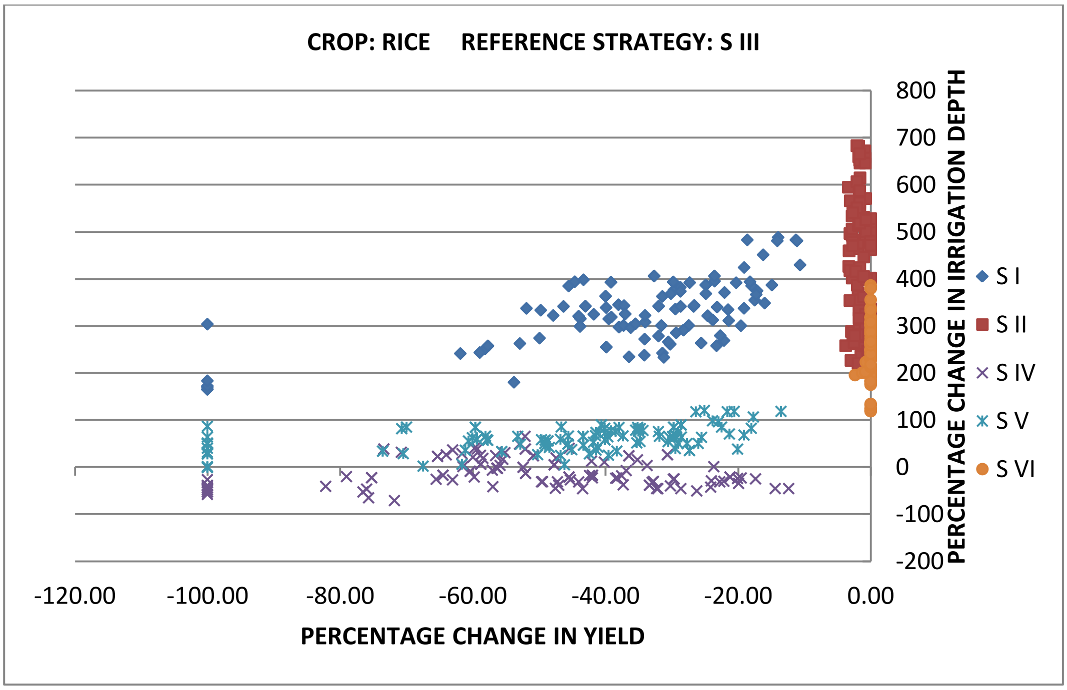


Fig 5.4: Percentage change in yield versus percentage change in irrigation depth for rice crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions).

5.4.5 Evaluating Irrigation Strategies for Rice Crop

A relation between percentage change in yield and percentage change in irrigation depth with respect to no moisture stress condition is shown in Figure 5.4, for all the blocks, and strategies during study period.

The averages reduction in yield of all blocks obtained through simulation for strategies S I, S II, S IV, S V, and S VI are 35.87 percent, 1.57 percent, 51.28 percent, 46.81 percent, and 0.05 percent respectively, while increase in irrigation depth with respect to strategy S III, for strategies S I, S II, S V, and S VI are 328 percent, 441 percent, 61 percent and 254 percent respectively. The decrease in irrigation depth of strategy S IV is 12 percent with respect to strategy S III. It is observed that strategies S III and S VI are best suited, for rice crop in the region I and II. It shows that strategy S VI attains second highest yield with 254 percent more water being applied in comparison to no moisture stress condition strategy S III, as under irrigation strategy S VI the soil is in saturated conditions throughout the growth period. Strategy S II gives third highest yield with 441 percent more water application, as irrigation of fixed depth is triggered at 100 percent of readily available water. In fixed irrigation interval irrigation scheduling strategy the crop on many instances could come under moisture stress before the application of fixed amount of water. Due to this reason strategy S I give 36 percent less yield, than the potential condition with 328 percent of more water applied for irrigation. As rice crop, gives optimum yield under saturated conditions, strategy S V (deficit irrigation) gives 47 percent less yield with 61 percent of more usage of water, while strategy IV (protective irrigation) gives at an average 51 percent less yield with 12 percent less usage of water in comparison to no stress (model determined) conditions. Under deficit irrigation, rice shows comparatively more reduction in yield due to its sensitivity to moisture deficit. The strategies S IV and S V could only be recommended to farmers not owning their open wells/ tube-wells, for groundwater irrigation during dry years. Strategies S IV and S V could be advised during years having less rainfall than average, or rainfall is unevenly distributed. The total average yield of all blocks estimated for strategies S I, S II, S III, S IV, S V, and S VI are 2800, 4283,4351,2116,2321, and 4349 $Kg.hectare^{-1}$ respectively. Strategies best suited, and recommended in order of merit, for attaining significant yield and water savings simultaneously for Rice are S III, followed by S VI, S II, and S I.

5.5 Irrigation Scheduling Strategies for Wheat

Wheat is a Rabi crop sown in 22nd November, and harvested in 11th march with 110 days of crop seasonal length. Maximum potential yield for wheat, taken as input data is 4000 $Kg.Ha^{-1}$ Different irrigation scheduling strategies adopted for wheat crop have been shown in the Table 5.4. The conventional irrigation strategy as practised by farmers is to irrigate the crop at fixed interval with fixed depth which is selected as strategy S I. In strategy S II it is decided to irrigate the crop with fixed depth, when moisture depletion reaches equivalent to 100 percent of RAW. The model determined no moisture stress condition strategy is selected as strategy S III. To irrigate the crop at 80 percent of TAW has been selected as protective irrigation strategy S IV. In case of dry year, or early withdrawal of monsoon deficit irrigation strategy S V could be suggested, wherein four irrigations of 60 mm depth are given, in case there is shortage of canal irrigation water. In strategy S VI irrigation scheduling selected is of fixed interval and fixed depth, wherein second irrigation is given seven days post sowing, while last irrigation is cut off 20 days prior to harvesting to obtain good grain.

Table 5.4: Irrigation scheduling strategies for wheat crop

Case	Irrigation Strategy for Wheat		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1,18,35,50,65,75, 90,103	70 mm	Irrigation of 70 mm fixed depth is applied at a fixed interval of 17, 15, 10, and 13 days subsequently post date of sowing 22nd Nov.
S II	Varying	70 mm	Irrigation of 70 mm depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	Varying	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	Varying	50 mm, 70 mm	Irrigation of fixed depth of 50 mm is applied upto initial vegetative stage (15days), and then 70mm water is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S V	1,26,56 & 80 days	60 mm	Irrigation of 60 mm fixed depth is applied subsequently from date of sowing.
S VI	1,7,21,42,65,81& 90	70 mm	Irrigation of 70 mm fixed depth is applied at a fixed interval from date of sowing

***** From date of sowing. Date of sowing 22nd November and Harvesting on 10th March.

5.5.1 Water Balance, Yield and Efficiencies for Wheat

Wheat yield, components of soil moisture balance under six irrigation strategies, for all the 20 blocks were estimated for the study period. WUE and IWUE were also computed from the above results. In order to derive a specific conclusion, it was decided to discuss the results of block 1only, which is shown in tabular form in Table 5.5, due to large (20 blocks × 6 irrigation strategies) simulation results. This approach would give an insight to study the impact of water stress on ET actual, Yield, WUE and IWUE; as their results would be nearly on similar lines across other 19 blocks with slight variations, due to soil and climate conditions. For illustration purpose simulation for block 1 has been shown in the Table 5.5. Water Balance of the Root zone as per FAO- 56 for Table 5.5 is given as follows:

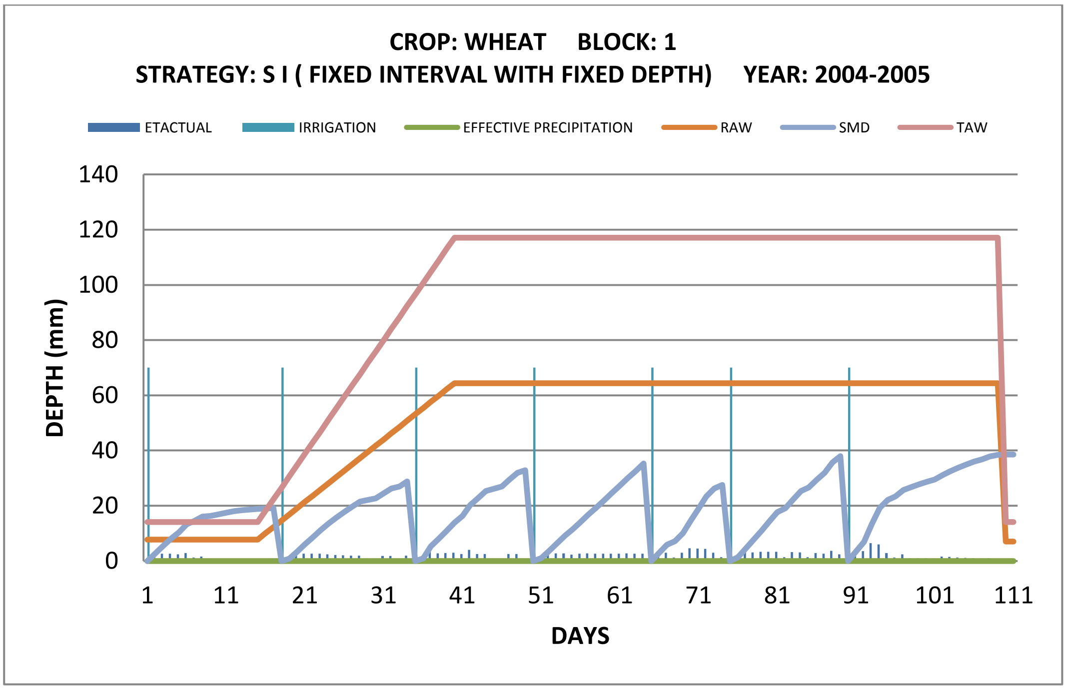
$D_{r,i} - D_{r,i-1} = -P_i + SR_i - I_i - CR_i + ET_{a,i} + DP_i$, Where $D_{r,i} - D_{r,i-1}$ is Net decrease in soil moisture. Illustrative calculation example for average of Strategy S I (F.I. with F.D.) is given as: 24 = −1+81 − 502 − 0 +323+123, the value of $CR_i = 0$. The negative sign shown in Table for Runoff and Flow to groundwater is not to be considered during calculation. It is observed that averages for study period, for strategies S II and S III had same ET actual, yield, and WUE, but there was significant difference in IWUE. Strategy S VI was slightly better edged over the strategy S I, although strategy S VI and strategy S I had marginal difference in values for yield, WUE, and IWUE. Both strategies S IV and S V showed lesser values of crop water use, but with enhanced values of WUE and IWUE in comparison to all other strategies.

Crop water use and irrigation amount varied greatly with seasonal climatic conditions and frequency of irrigations. Simulations show that strategies S I and S VI, wherein irrigation is given on the basis of growth stages show stress in initial stages refer Fig 5.5(a) & 5.5(f). Results of strategies (S II and S III) suggested that irrigation need to be scheduled based on the soil water status, and not on the basis of growth stages strategies (S VI and S I). From the Figure 5.5 c it can be said that irrigation of smaller depth (25 mm), if applied frequently (3-4), during the initial stage would enhance yield, WUE, and IWUE, rather than infrequent and large quantity irrigations, which is also reported by Timsina et al. (2008).

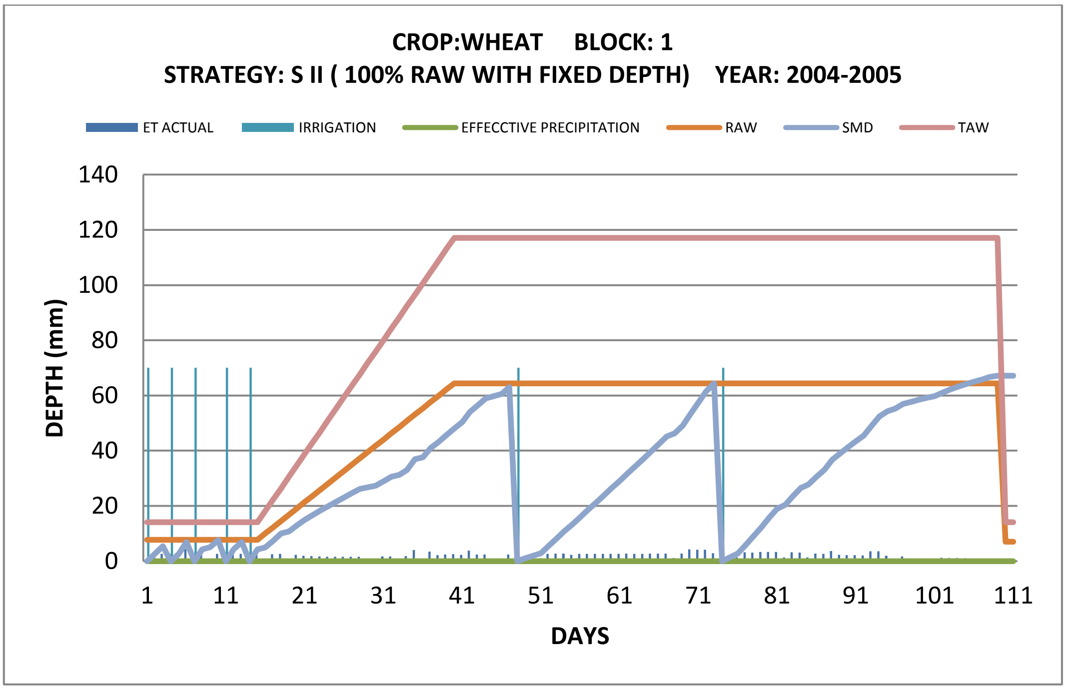
Table 5.5: Water balance, yield and efficiencies of wheat crop in sandy clay (HSG – C) soil in block 1 (grown in 1.27 percent of CCA 9868 ha)

Irrigation strategies for Wheat	Year	ETc act	Effective Precipitation	Canal Irrigation.	Net Decrease in Soil Moisture	Flow to GW	Runoff	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha/ mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10
Strategy S I F.I with F.D.	2004-2005	232	0	490	20	-196	-82	3646	15.71	7.44	0.614
	2005-2006	269	6	490	24	-170	-82	3596	13.39	7.34	0.614
	2006-2007	313	0	490	27	-122	-82	3595	11.48	7.34	0.614
	2007-2008	331	0	560	3	-149	-83	3859	11.66	6.89	0.702
	2008-2009	378	0	490	33	-64	-81	3418	9.04	6.97	0.614
	2009-2010	414	0	490	37	-35	-78	3398	8.22	6.94	0.614
	Average	323	1	502	24	-123	-81	3585	11.58	7.15	0.629
Strategy S II 100% RAW with F.D.	2004-2005	236	0	490	49	-43	-261	3995	16.96	8.15	0.614
	2005-2006	292	6	630	21	-50	-315	4000	13.69	6.35	0.790
	2006-2007	341	0	700	14	-57	-317	4000	11.75	5.71	0.877
	2007-2008	327	0	560	15	-44	-204	4000	12.22	7.14	0.702
	2008-2009	441	0	980	21	-94	-466	4000	9.07	4.08	1.228
	2009-2010	487	0	1050	7	-107	-463	4000	8.22	3.81	1.316
	Average	354	1	735	21	-66	-337	3999	11.98	5.87	0.921
Strategy S III No Stress	2004-2005	236	0	187	49	0	0	3995	16.96	21.38	0.234
	2005-2006	292	6	265	21	0	0	4000	13.69	15.10	0.332
	2006-2007	341	0	326	14	0	0	4000	11.75	12.25	0.409
	2007-2008	327	0	312	15	0	0	4000	12.22	12.81	0.391
	2008-2009	441	0	420	21	0	0	4000	9.07	9.51	0.527
	2009-2010	487	0	480	7	0	0	4000	8.22	8.34	0.601
	Average	354	1	332	21	0	0	3999	11.98	13.23	0.416
Strategy S IV Protective Irrigation	2004-2005	252	0	340	56	-27	-117	3534	14.05	10.39	0.426
	2005-2006	271	6	340	68	-27	-116	3425	12.62	10.07	0.426
	2006-2007	269	0	340	73	-27	-117	3333	12.39	9.80	0.426
	2007-2008	246	0	340	53	-27	-120	3580	14.53	10.53	0.426
	2008-2009	294	0	410	28	-27	-116	3428	11.64	8.36	0.514
	2009-2010	328	0	480	50	-35	-167	3544	10.81	7.38	0.602
	Average	277	1	375	55	-28	-126	3474	12.67	9.42	0.470
Strategy S V Deficit Irrigation	2004-2005	233	0	240	66	-35	-38	3291	14.11	13.71	0.301
	2005-2006	244	6	240	74	-38	-37	3060	12.51	12.75	0.301
	2006-2007	245	0	240	77	-35	-37	2953	12.04	12.30	0.301
	2007-2008	233	0	240	65	-35	-37	3410	14.62	14.21	0.301
	2008-2009	247	0	240	79	-35	-37	2860	11.56	11.92	0.301
	2009-2010	250	0	240	83	-35	-37	2554	10.20	10.64	0.301
	Average	242	1	240	74	-35	-37	3021	12.51	12.59	0.301
Strategy S VI Combination	2004-2005	244	0	490	20	-142	-124	3859	15.82	7.87	0.614
	2005-2006	280	6	490	24	-118	-123	3748	13.41	7.65	0.614
	2006-2007	324	0	490	27	-71	-122	3793	11.71	7.74	0.614
	2007-2008	315	0	490	24	-66	-133	3814	12.12	7.78	0.614
	2008-2009	368	0	490	33	-37	-118	3387	9.19	6.91	0.614
	2009-2010	383	0	490	39	-32	-115	3213	8.39	6.56	0.614
	Average	319	1	490	28	-78	-122	3635	11.77	7.42	0.614

Note: No. of rainy days for wheat crop period in years 2004, 2005, 2006,2007,2008 and 2009 are 0,1,0,0,0 and 0 days respectively. Water Balance of the Root zone as per FAO- 56 is given as: $D_{r,i} - D_{r,i-1} = -P_i + SR_i - I_i - CR_i + ET_{a,i} + DP_i$, Where $D_{r,i} - D_{r,i-1}$ is Net decrease in soil moisture. Illustrative example for average of Strategy S I (F.I. with F.D.) is given as: $24 = -1+81-502-0+323+123$, the value of $CR_i = 0$. The negative sign shown in Table for Runoff and Flow to groundwater is not to be considered during calculation.


CROP: WHEAT BLOCK: 1
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004-2005
ETACTUAL
IRRIGATION
EFFECTIVE PRECIPITATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
DAYS

5.5 (a)


CROP:WHEAT BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
IRRIGATION
EFFECCTIVE PRECIPITATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1
11
21
31
41
51
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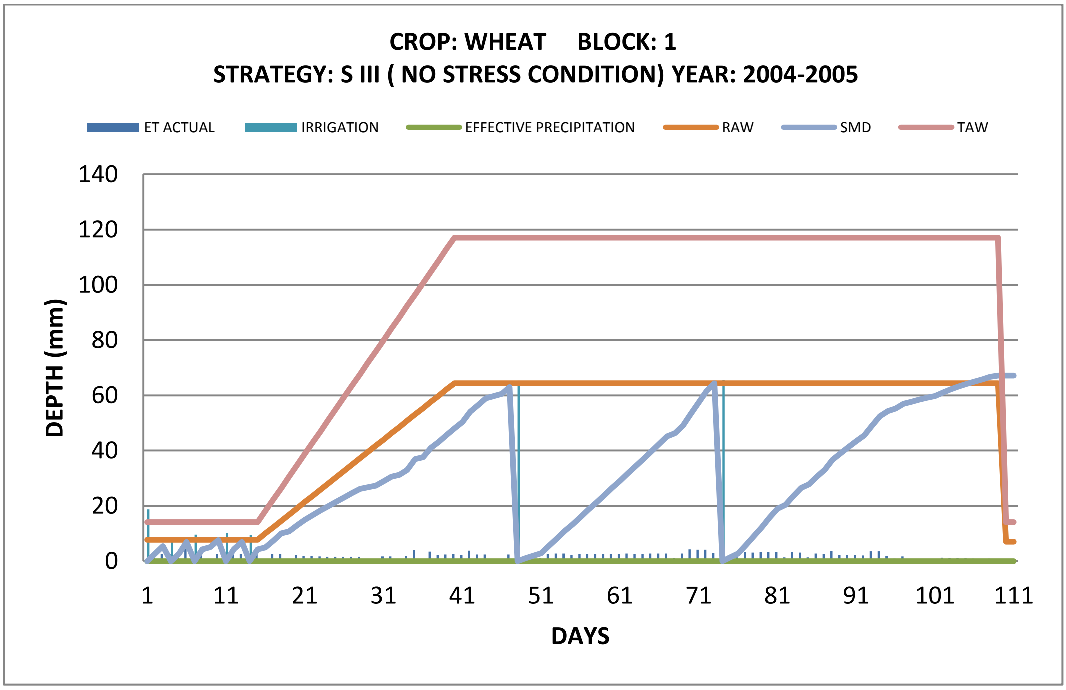
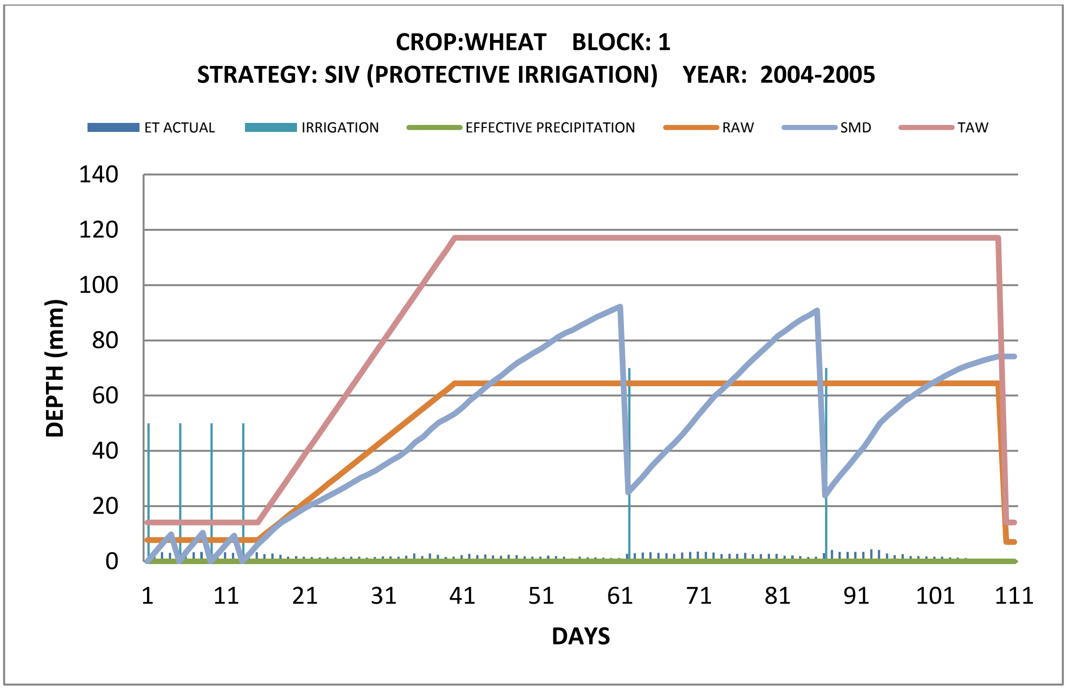
81
91
101
111
DAYS

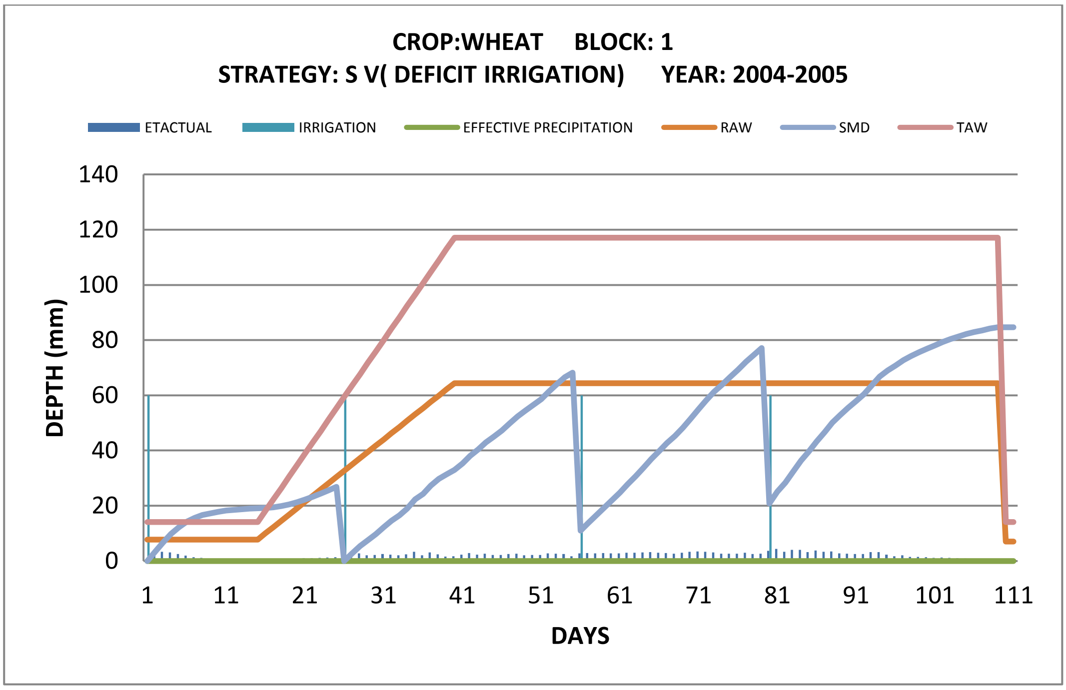
5.5 (b)


CROP: WHEAT BLOCK: 1
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
IRRIGATION
EFFECTIVE PRECIPITATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
DAYS

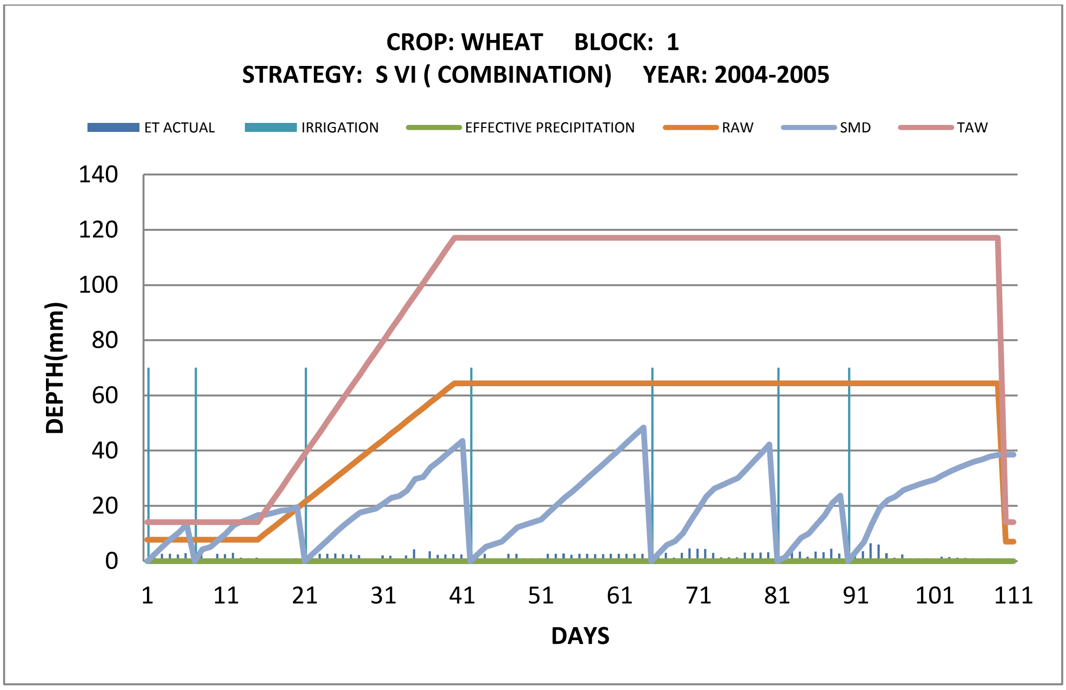
5.5 (c)


CROP:WHEAT BLOCK: 1
STRATEGY: SIV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
IRRIGATION
EFFECTIVE PRECIPITATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
DAYS

5.5 (d)



5.5 (e)



5.5 (f)

Fig 5.5 (a-f): Soil moisture balance for irrigation strategies S I - SVI under wheat crop for year 2004-2005

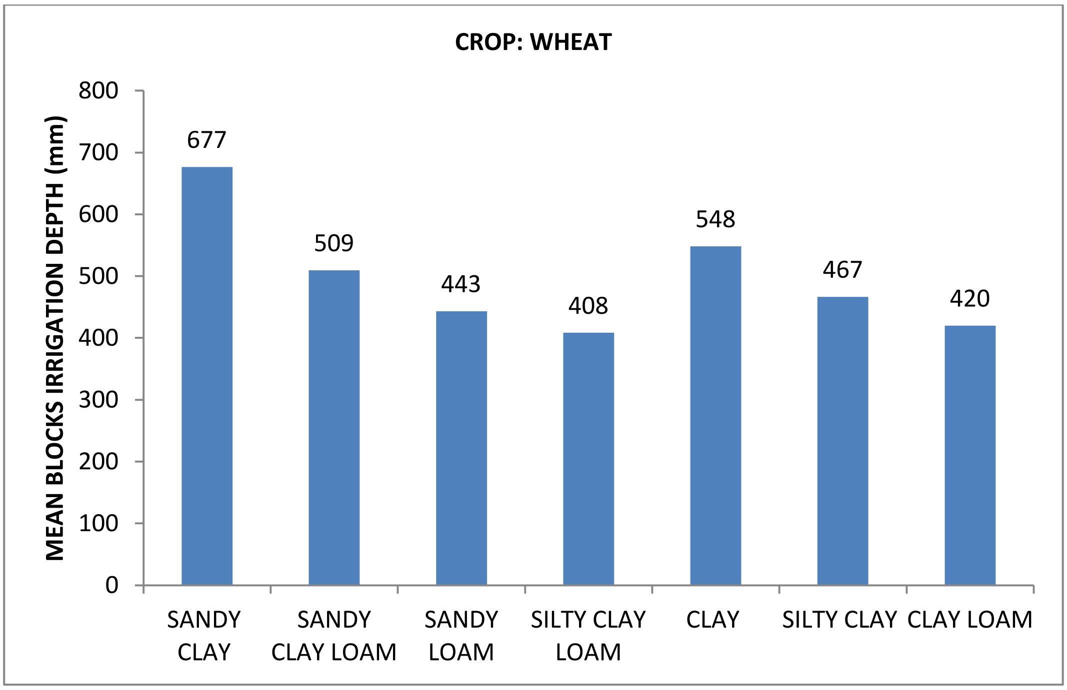


Fig 5.6: Effect of soil type on wheat irrigation depth under strategy S II

5.5.2 Effect of Soil Type on Wheat Irrigation Depth

The effect of soil type on wheat irrigation depth was analysed, and simulation results indicated that strategy S II required highest irrigation water depth, thus it was selected to study the relation between soil type, and irrigation depth. The Figure 5.6 showed that amongst the available soils selected in 20 blocks, mean blocks irrigation depth for sandy clay (10 blocks; 677 mm), clay (1 block; 548 mm), and sandy clay loam (3 blocks; 509 mm) required more than 500 mm amount of irrigation water. Mean blocks irrigation depth for soils silty clay loam (2 blocks; 408 mm), sandy loam (2 blocks; 443 mm), and clay loam (1block; 420 mm) required irrigation water between 400 mm to 500 mm.

5.5.3 Effect of Irrigation on Groundwater for Wheat

Water balance simulations carried out helped to analyse the impact of various irrigation strategies on selected nine blocks having high water table / monitored for rising water table. Average wheat seasonal net groundwater addition to water table obtained through simulation during years 2004-2010 is shown in the Table 5.6. Results indicated that strategies S II, S VI, and S I would be beneficial in sequence, when reduction in rise of groundwater table without compromising with yield reduction was to be considered. However, strategies S IV and S V would be much beneficial, when strategy was just to be selected to control the ground water table rise. Considering the SWL range in certain pockets of selected blocks significantly higher rise in ground water table is seen, when strategies S I and S VI were to be used. Thus it was necessary to be cautious, while choosing the appropriate strategy, where groundwater table showed rising trend in those pockets.

5.5.4 Irrigation Depth for Wheat under Strategies S I to S VI

The irrigation depth range for wheat crop under various strategies has been shown in Figure 5.7. On evaluating the various irrigation strategies it was noticed that strategy S II was best suited for higher yields however; there was a wide range in irrigation depth water (minimum 350 mm to maximum 1050 mm) depending upon wet , normal, and dry year in the region I and II . Strategy S VI which was next in higher yields required fixed irrigation depth of 490mm. Strategy S I required 490 mm (with exception of 560 mm, for year 2008) fixed depth of irrigation water. Strategy S III (no stress condition) and Strategy S IV (protective irrigation) strategies applied almost same amount of irrigation water depth in range of minimum 170 to maximum 481 mm across various 20 blocks.

Table 5.6: Average net groundwater withdrawals (years 2004-2009) for wheat crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for wheat crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-123	-66	0	-28	-35	-78
6A1	Sc	1 to 15	-148	-49	0	-27	-35	-88
8	Scl	0.5to 6.5	-148	-49	0	-27	-35	-88
10	Scl	1.5 to 18	-162	-48	0	-36	-42	-111
11A2	Sc	3 to >30	-148	-49	0	-27	-35	-88
6A3R2	C	>30	-162	-33	0	-21	-34	-105
6BR2	Sic	1.2to>30	-166	-34	0	-23	-33	-114
9A2R2	Sicl	1 to >30	-180	-36	0	-25	-34	-131
9B1R2	Cl	0.5 to 23	-186	-47	0	-28	-39	-139

Note: Sandy clay (Sc), Sandy clay loam (Scl), Clay (C), Silty clay(Sic), Silty clay loam(Sicl), Clay loam(Cl) . The negative sign indicates the groundwater recharge (due to rain and irrigation)

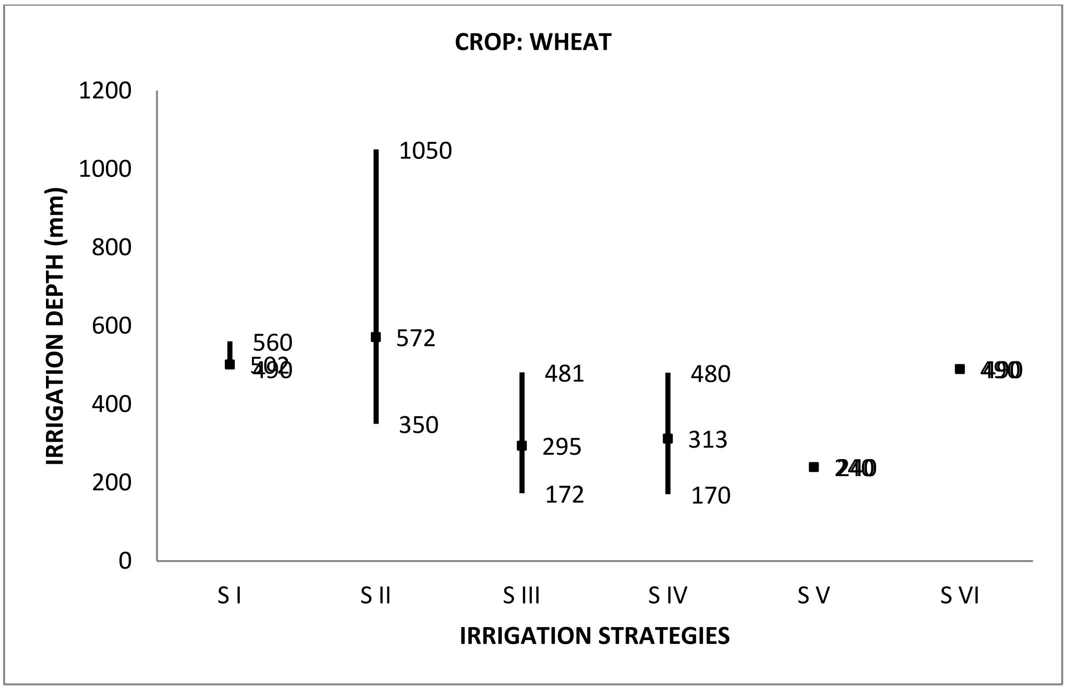


Fig 5.7: Irrigation depth range for wheat crop for strategies S I to S VI

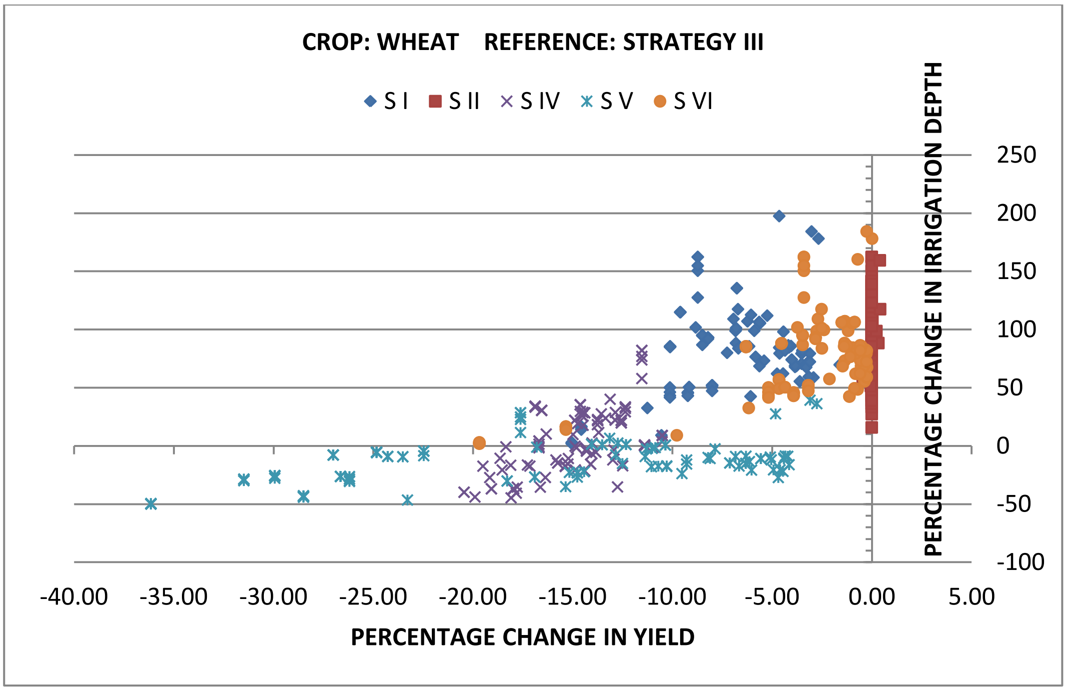


Fig 5.8: Percentage change in yield versus percentage change in irrigation depth for wheat crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.5.5 Evaluating Irrigation Strategies for Wheat

WEAP-MABIA model was run for study period 2004-2010 to obtain soil moisture balance and estimated yield for all twenty blocks and all six irrigation strategies. The relation of percentage change in yield to percentage change in irrigation depth, with respect to model determined no stress condition strategy (which would ideally give the maximum yield with optimum irrigation) was derived for all strategies. On comparing the various strategies the best strategy obtained was strategy S II, where there was no reduction in yield, however with more water usage ranging between16 percent to 162 percent, than the ideal no moisture stress condition. The strategy second to the best was strategy S VI with 0 to 20 percent yield reduction across all blocks, with more water usage range between 2 percent to 184 percent. Strategy S I gave yield reduction ranging between 2 percent to 15 percent however; used 2 percent to 197 percent more water. Strategy S IV (protective irrigation) had a yield reduction in range of 11 percent to 20 percent, with water usage ranging between-45 percent to 82 percent. Yield response factor for mid season stage in wheat is 0.5 thus it doesn't show sensitivity to moisture, and thus the yield reduction is not so significant. Strategy S V (deficit irrigation) showed yield reduction between3 percent to 36 percent, while water applied was in range of --50 percent to 39 percent in comparison to no moisture stress condition strategy S III. Thus, strategies S II, S VI, and S I can be recommended for wheat crop to attain higher yields, when there is no shortage of canal irrigation water. In case of earlier withdrawal of monsoon, or poor monsoon, when sufficient canal water is unavailable strategies S IV and S V can be recommended.

5.6 Irrigation Scheduling Strategies for Jowar

Jowar is grown in Kharif season with the onset of monsoon; the crop is sown in 1st July and harvested on 23rd October with 115 days of crop seasonal length. The initial depletion is taken as zero for the base year 2003, for computing the soil moisture balance. The maximum potential yield for the crop has been taken as 3000 Kg per hectare. The various irrigation scheduling strategies for the jowar crop tried are shown in Table 5.7. The four strategies are as follows: (i) Strategy S I: Fixed irrigation depth of 75 mm depth is applied at fixed days from date of sowing. (ii) Strategy S II: Fixed irrigation depth of 75 mm is applied post initial period of crop season stage, and the irrigation is triggered, when moisture depletion reaches 100 per cent of readily available water. (iii) Strategy S III: Irrigation depth equivalent to 100 per cent of moisture depletion is applied, and the irrigation is triggered at 100 per cent of readily available water. (iv.) Strategy S IV: Fixed irrigation depth of 40mm is applied post initial period of crop season stage onwards, when moisture depletion reaches 80 percent of total available water. Irrigation is cut off 10 days pre harvesting as per practises; except for no stress condition strategy S III. For all the four strategies (20 blocks ✖ 6 number of years) 120 simulations are carried out.

Table 5.7: Irrigation scheduling strategies for Jowar crop

Case	Irrigation Strategy for Jowar		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1,7,33,53,77 & 98	75mm	Irrigation of 75 mm fixed depth is applied at a fixed days from date of sowing.
S II	30-105 Varying	75 mm	After 30 days post sowing, irrigation of 75 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-115 Varying	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions
S IV	30-105 Varying	40 mm,	After 30 days post of sowing, irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water.

***** From date of sowing. Date of sowing 1st July and Harvesting on 23rd October.

5.6.1 Water Balance, Yield and Efficiencies for Jowar

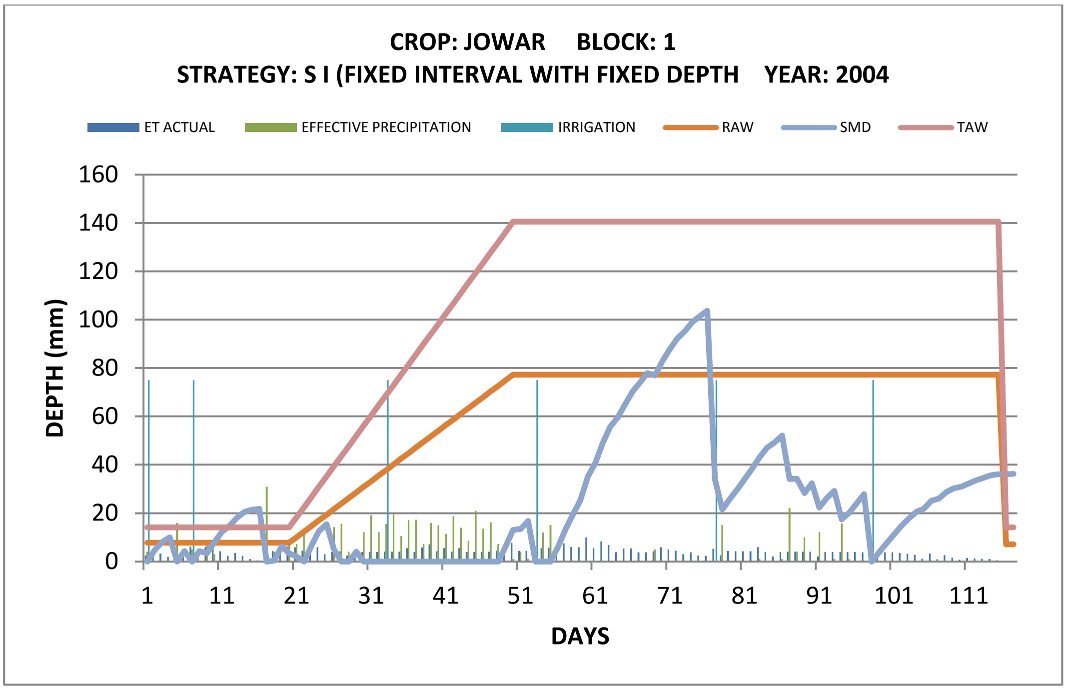
Daily soil moisture balance is estimated for all the blocks, and all four strategies for jowar crop. Averages of ET actual, effective precipitation, groundwater irrigation, surface runoff, groundwater flow, yield, WUE, and IWUE were simulated for years 2004-2009, for all four strategies, and for all 20 blocks where jowar was grown. Base year selected for simulation was 2003. Results of jowar crop sown in block 1 have been taken for illustration purposes refer Table 5.8. Mean over study period show that strategy S III has proven to be best strategy in terms of yield (3000 kg) followed by S I (2913 kg), S II (2825 kg), and S IV (2784 kg) respectively without much reduction in yield. Strategy S IV is found to be best suited in terms of WUE (7.68 kg/ha/mm) and IWUE (>109.20 kg/ha/mm) followed by S III, S II, and S I respectively with minor reductions in WUE, but with significant reductions in IWUE. Means over the study period show that strategy S IV, requires least groundwater for irrigation (4 mm) with less flow to ground water (126 mm), and surface runoff (524 mm). Strategy S IV is followed by strategy S II with mean 75 mm of ground water depth over study period, and requiring only one irrigation during normal monsoon, or two irrigations, if gap in rain interval is large (2006) however; in case of dry year (2009) it would require 4 irrigations. The flow to groundwater is minimal and surface runoff is also less in comparison to all other strategies. Strategy S I being the conventional one showed the highest groundwater irrigation depth with maximum flow to groundwater and surface runoff.

Table 5.8: Water balance, yield and efficiencies of jowar crop in sandy clay (HSG – C) soil in block 1 (grown in 0.70% of CCA 9868 ha)

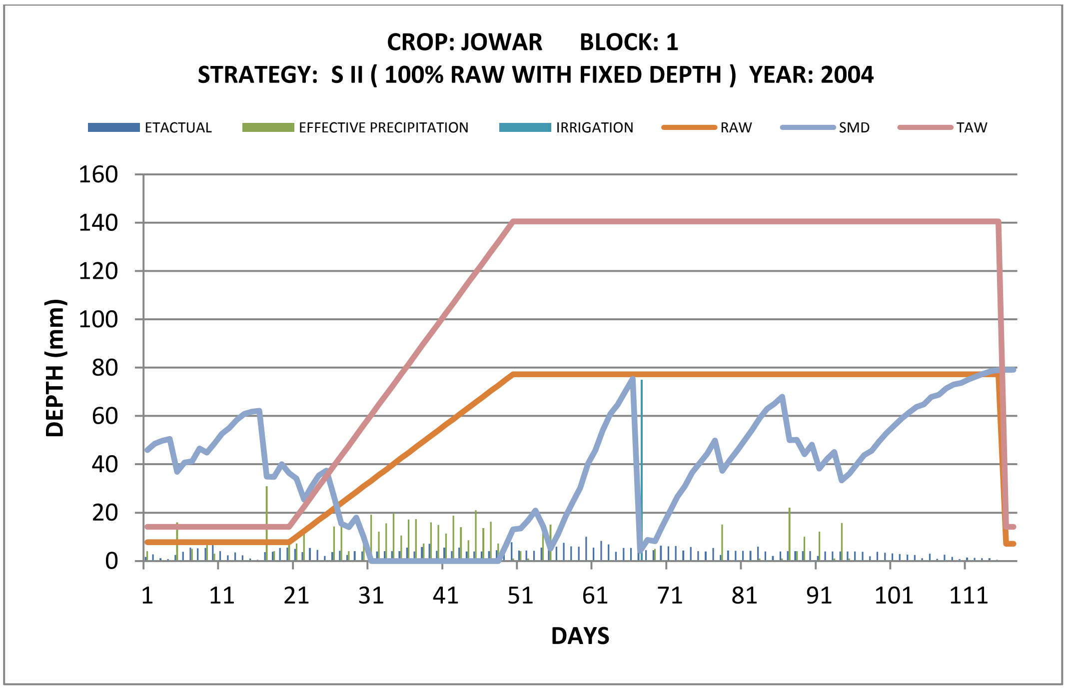
Irrigation strategies for Jowar	Year	ETc act	Eff. preci	GW Irrign.	Net Decrease in Soil moisture	Flow to GW	Runoff	Yield	WUE	IWUE
		mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha/ mm	Kg/ha/ mm
		1	2	3	4	5	6	7	8	9
Strategy S I F.I with F.D.	2004-2005	471	1068	270	54	-296	-625	2872	6.10	10.64
	2005-2006	438	655	270	75	-178	-384	2890	6.60	10.71
	2006-2007	626	1660	270	59	-212	-1150	2921	4.67	10.82
	2007-2008	475	1050	270	67	-216	-695	2931	6.17	10.85
	2008-2009	485	966	270	61	-243	-569	2915	6.01	10.80
	2009-2010	587	508	270	143	-88	-246	2949	5.02	10.92
	Average	514	984	270	77	-206	-612	2913	5.76	10.79
Strategy S II 100% RAW with F.D.	2004-2005	463	1068	45	61	-169	-542	2829	6.11	62.86
	2005-2006	422	655	45	93	-95	-275	2840	6.73	63.12
	2006-2007	610	1660	90	16	-100	-1056	2817	4.62	31.31
	2007-2008	467	1050	45	71	-111	-589	2920	6.26	64.89
	2008-2009	453	966	45	28	-86	-500	2711	5.99	60.24
	2009-2010	562	508	180	87	-20	-193	2832	5.04	15.74
	Average	496	984	75	59	-97	-526	2825	5.79	49.69
Strategy S III No Stress	2004-2005	379	1068	92	71	-292	-560	3000	7.91	32.58
	2005-2006	340	655	25	75	-119	-295	3000	8.81	121.15
	2006-2007	479	1660	74	47	-224	-1078	3000	6.26	40.77
	2007-2008	368	1050	39	50	-154	-618	3000	8.16	77.05
	2008-2009	417	966	128	27	-186	-517	3000	7.19	23.44
	2009-2010	404	508	169	92	-143	-221	3000	7.42	17.80
	Average	398	984	88	60	-186	-548	3000	7.63	52.13
Strategy S IV Protective Irrigation	2004-2005	343	1068	0	64	-247	-542	2691	7.84	NA
	2005-2006	323	655	0	36	-94	-273	2906	8.99	NA
	2006-2007	455	1660	0	-2	-147	-1056	2863	6.30	NA
	2007-2008	361	1050	0	24	-127	-587	2937	8.15	NA
	2008-2009	365	966	0	9	-115	-495	2684	7.36	NA
	2009-2010	351	508	24	38	-27	-192	2621	7.46	109.20
	Average	366	984	4	28	-126	-524	2784	7.68	

No. of rainy days for Jowar crop period in year 2004, 2005, 2006, 2007, 2008 and 2009 are 48, 46, 55, 55, 57 and 39 days respectively.

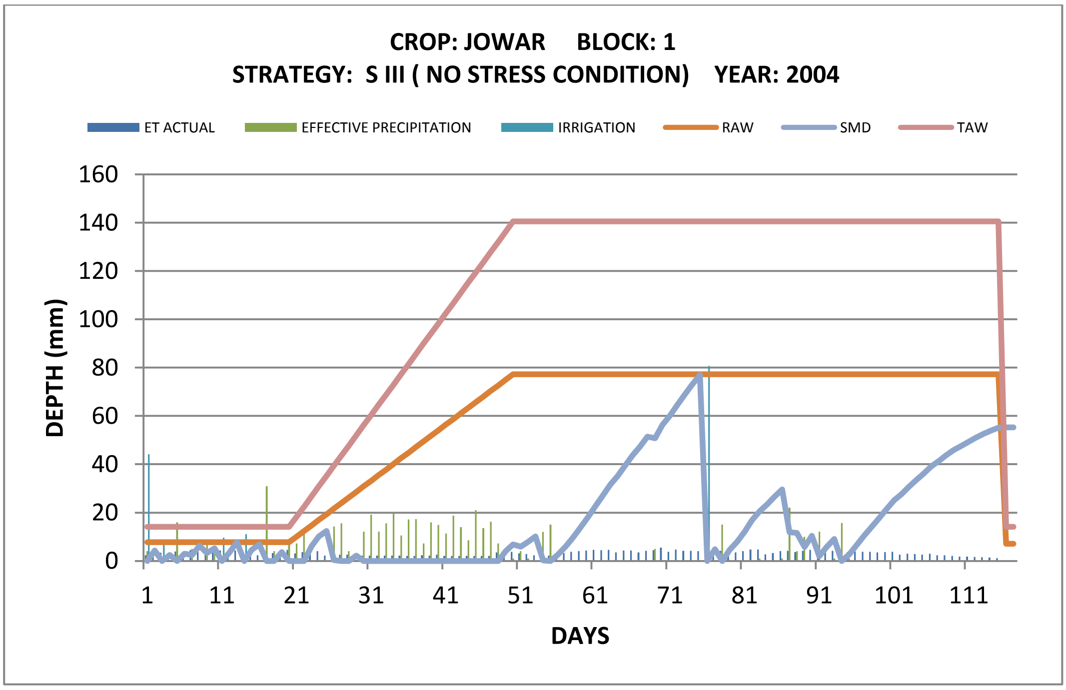
Actual crop evapotranspiration value is highest in strategy S I followed by S II, S III, and S IV respectively, this is because evapotranspiration rate is dependent on the quantity of water applied, which is evident from irrigation depth across various strategies. Method of irrigation applied here for Jowar is furrow, thus to obtain the total irrigation depth the values in the column 3 are required to be divided by fraction wetted 0.6 (for example, in strategy S I depth given in column 3 is 270 mm thus total irrigation applied is 270/0.6 = 450 mm).



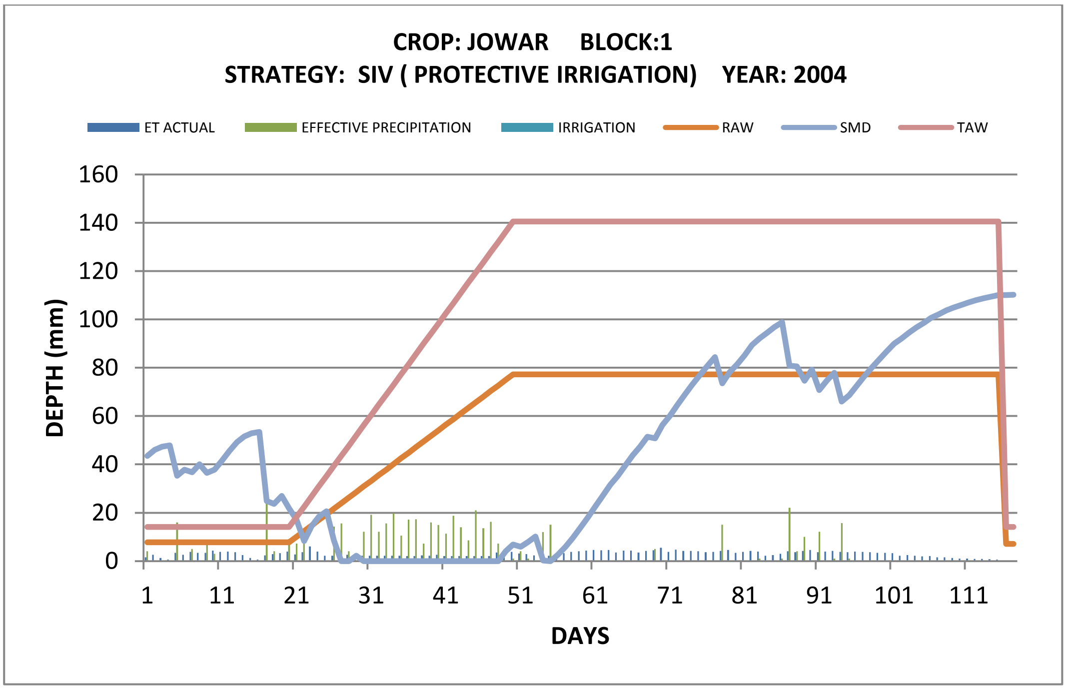
5.9 (a)



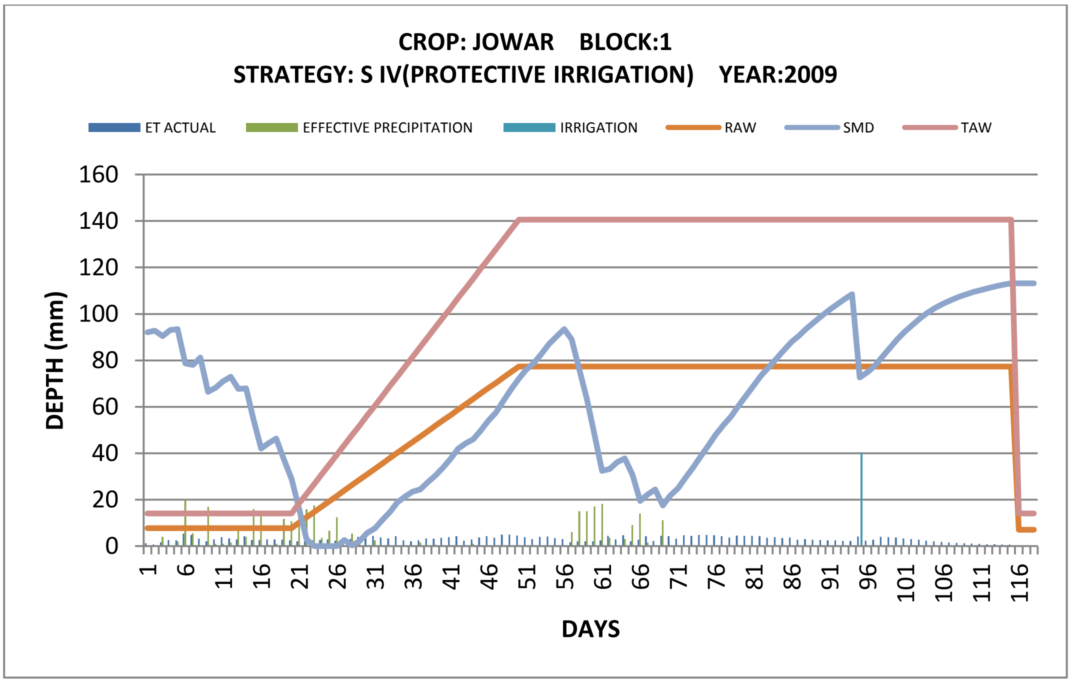
5.9 (b)


CROP: JOWAR BLOCK: 1
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
DAYS

5.9 (c)


CROP: JOWAR BLOCK:1
STRATEGY: SIV (PROTECTIVE IRRIGATION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1
11
21
31
41
51
61
71
81
91
101
111
DAYS

5.9 (d)



5.9 (e)

Fig 5.9(a-e): Soil moisture balance for irrigation strategies S I to S IV for jowar crop year 2004 and 2009

The soil moisture depletion in response to different irrigation strategies for jowar, during various crop growth stages, for irrigation strategies S I to S IV have been shown in Fig5.9, for block1 and results are summarized in Table 5.8. The irrigation is applied after the initial vegetative period in strategies S II and S IV. Crop water stress is observed, if interval between precipitation and / or irrigation is large. During initial vegetative period as the roots are not fully developed the crop would require frequent and small wettings, else crop water stress would be felt, which is also evident from figures of strategies S I, S II, and S IV, where the moisture stress is visible. Crop water stress is seen in strategies S I and S IV during mid season stage, and also in late stage in S IV. In dry year 2009, one protective irrigation is needed to be applied refer Figure 5.9 (e). The crop is more sensitive to moisture deficit during late mid season stage resulting in lesser yield, which is evident from strategy SIV (Table 5.8, yield=2691kg/ha in year 2004-2005).

5.6.2 Effect of Soil Type on Jowar Irrigation Depth

Impact of varied soils on groundwater irrigation usage by jowar crop has been shown in Fig 5.10. Mean blocks irrigation depth for study period for reference strategy S II, for jowar crop was highest in sandy clay soil (10 blocks; 64mm), followed by sandy clay loam(3blocks;

35mm) and clay (1 block; 30mm). Mean irrigation depth was in range of 15mm to 26mm, for clay loam(1block; 15mm), sandy loam (2blocks; 26mm), silty clay loam(2blocks; 26mm), and silty clay(1block; 23mm) respectively. As water retention in sandy clay soil is less, frequent irrigations are required leading to greater irrigation water depth.

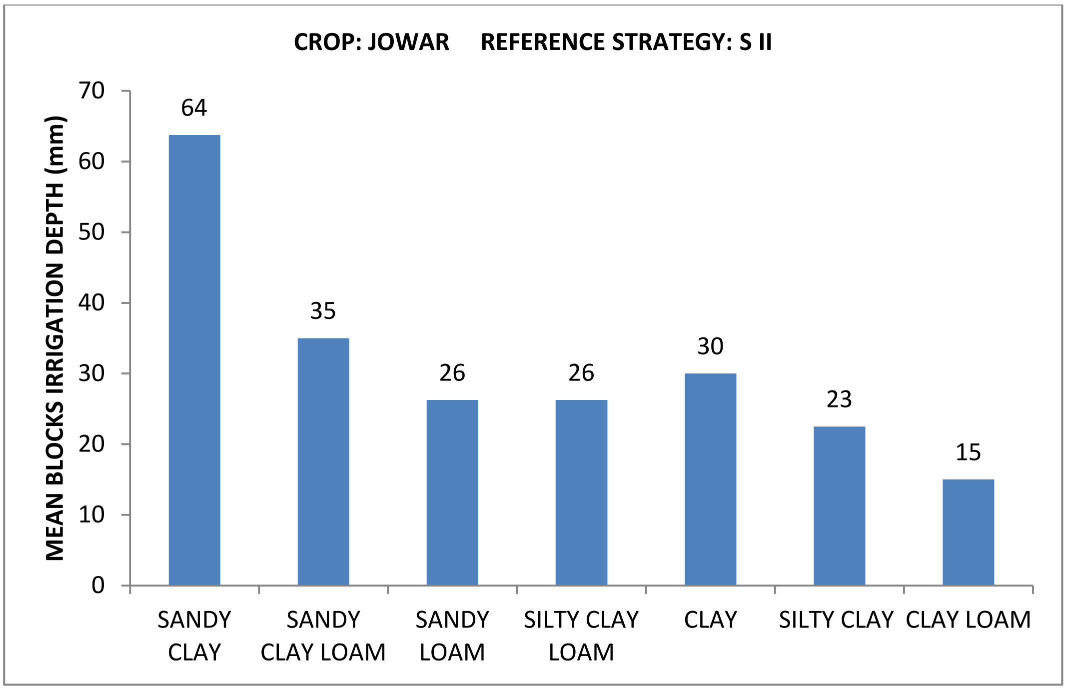


Fig 5.10: Effect of soil type on jowar irrigation depth under Strategy S II

5.6.3 Effect of Groundwater Withdrawal for Jowar Crop

Impact of the four irrigation strategies of jowar on ground water table rise on selected nine blocks was carried out and results is tabulated in Table 5.9. The results indicated that strategy S I was best suited, if groundwater table rise was to be restricted however; S I strategy would lead to further drawdown of water table in case of block 6A3R2, where static water table is already below 30m. Strategy S IV was unsuitable for regions having high water table as rise in water table would be between 56mm to 225mm annually. Strategy S II should not be recommended in blocks 4B, 6A1, 8, 10, and 9B1R2, as static water level was well within 25m range.

Table 5.9: Average net groundwater withdrawals (years 2004-2009) for strategies S I to S IV for jowar crop period.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for jowar crop period			
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV
4B	Sc	7 to 22	-34	-130	-210	-225
6A1	Sc	1 to 15	-1	-100	-79	-115
8	Scl	0.5to 6.5	26	-62	-46	-68
10	Scl	1.5 to 18	-31	-90	-101	-102
11A2	Sc	3 to >30	4	-94	-75	-104
6A3R2	C	>30	36	-43	-32	-56
6BR2	Sic	1.2to>30	-7	-80	-75	-86
9A2R2	Sicl	1 to >30	-20	-89	-87	-104
9B1R2	Cl	0.5 to 23	-29	-98	-96	-106

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The negative sign indicates that groundwater recharge (due to rain) is more than groundwater pumping for irrigation

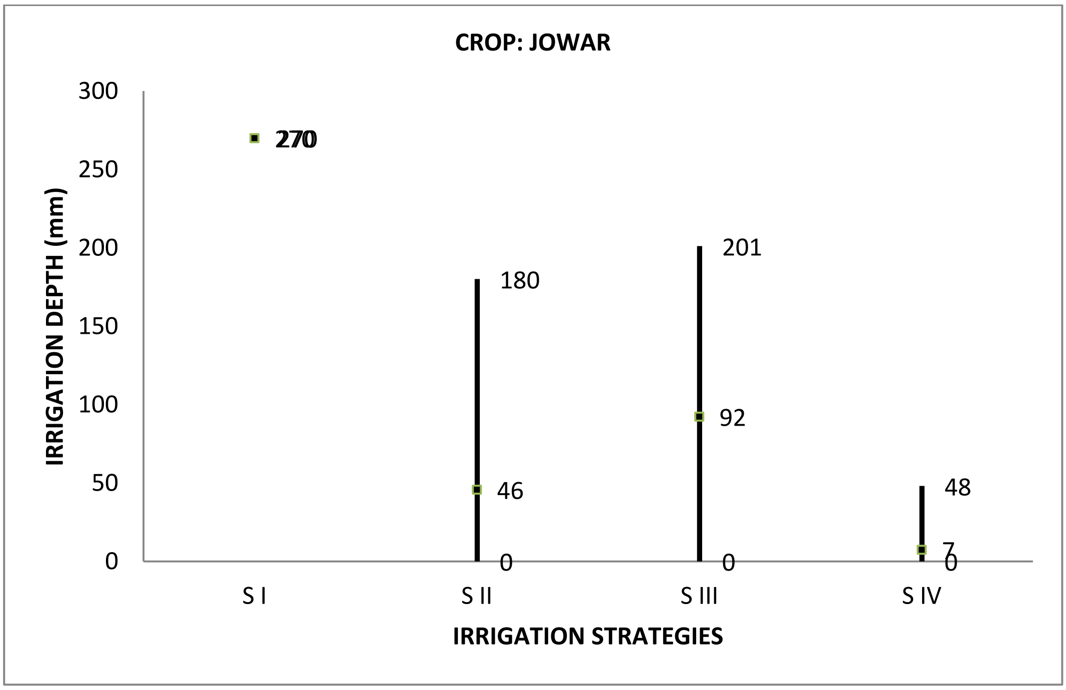


Fig 5.11: Irrigation depth range for jowar crop for strategies S I to S IV

5.6.4 Irrigation Depth Range for Jowar under Strategies S I to S VI

Irrigation depth range for jowar across various strategies has been shown in Figure 5.11. Strategy S I irrigates at fixed interval with fixed depth irrespective of the timing of rainfall, thus it has highest irrigation depth. The benefits of this strategy can be availed in certain pocket areas, where water table is high. The irrigation depth range is least in strategy S IV (protective) irrigation. In strategies S II and S III no irrigation is required, if normal monsoon is there however, in case of delay or poor monsoon maximum irrigation depth range for jowar crop is about 200mm. The irrigation depth range varies due to wet or dry year; in case of strategy S III maximum irrigation depth was noted for block 2 in 2009 dry year. Generally the total irrigation depth for strategy S II, would be more than strategy S III, but here it is less as the irrigation is applied post initial stage and irrigation cut off is few days ahead of harvesting. Method of irrigation applied here for Jowar is furrow, thus to obtain the total irrigation depth the values in the Figure 5.11 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth given in Figure 5.11 is 270 mm, thus total irrigation applied is 270/0.6 = 450 mm).

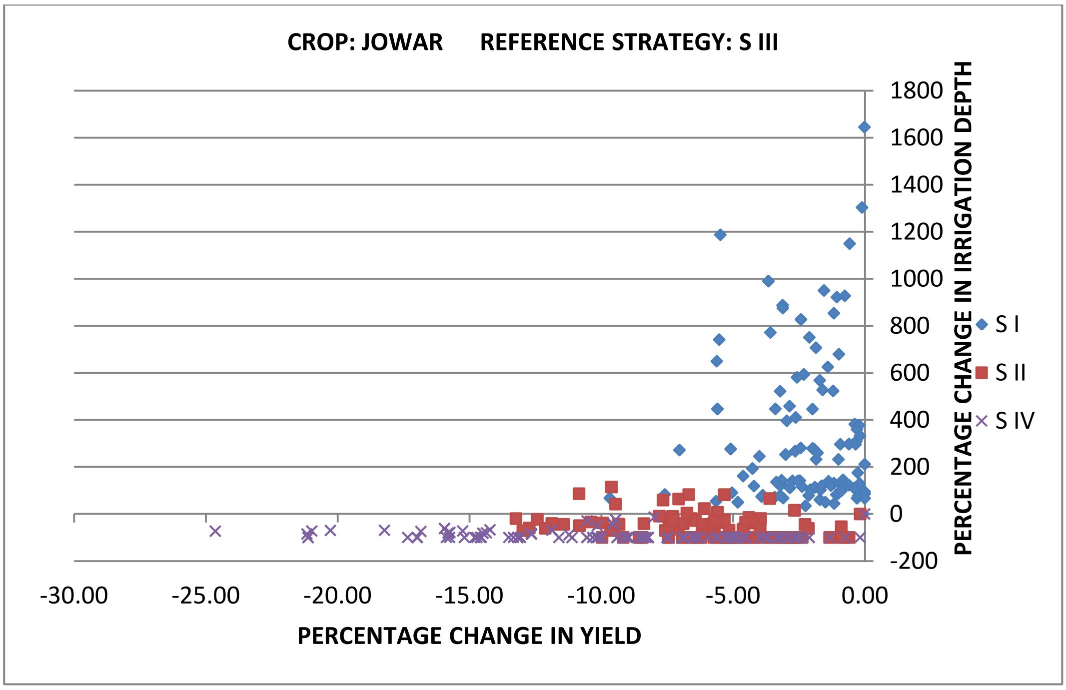


Fig 5.12: Percentage change in yield versus percentage change in irrigation depth for jowar crop under irrigation strategies S I, S II, and S IV with respect to strategy III (no moisture stress conditions).

5.6.5 Evaluating Irrigation Strategies for Jowar

The impact of various irrigation scheduling strategies on yield, and irrigation depth has been derived, by comparing all other strategies with no moisture stress condition (i.e. strategy S III). Strategy S III is designed to give maximum yield with optimum irrigation water. Relation between percentage change in yield and percentage change in irrigation depth with respect to no stress condition is shown in Figure 5.12, for all the blocks and strategies during study period for jowar crop. The average yield reduction, for all blocks obtained through simulations for strategies S I, S II, and S IV are 2 percent, 6 percent, and 9 percent respectively, while range of yield reduction are 0 to10 percent, 0 to13 percent, and 0 to 25 percent respectively, for the afore mentioned strategies. The average increase in irrigation depth for strategy S I is 333 percent, while average reduction in irrigation depth for strategies S II and S IV are 53 percent and 91 percent. The range of increase in irrigation depth of S I, S II, and S IV are 0 to 1645 percent, −100 to 115 percent, and −100 to 0 percent respectively (Note: The 0 value indicate irrigation depth equal to strategy S III, while −100 value indicate no irrigation is applied for that strategy). Strategy S II is best suited strategy, as it requires no or very less irrigation depth with good yield, followed by strategy S IV, where yield reduction is maximum upto 25 percent if no irrigation is applied. The total average yield for all blocks estimated for strategies S I, S II, S III, and S IV are 2930 kg, 2813 kg, 3000 kg, and 2718 kg respectively. Maximum potential yield with optimum irrigation water is attained with strategy S III, thus it is the best suited strategy. To irrigate with strategy S III is feasible, if irrigation requirement is triggered, according to soil moisture deficit with help of automated sensor installed to assess the soil moisture status. Strategy S II is second best, as with little or no irrigation, significant yield is attained with minimal reduction in yield. Strategy S IV gives significant yield with little or no irrigation thus can also be recommended if attaining maximum yield is not the only criteria. Strategy S I help in attaining high yield, though with excess usage of irrigation water than the requirement.

5.7 Irrigation Scheduling Strategies for Bajra

The pearl millet popularly known as bajra is a cereal sown in Kharif season with onset of monsoon. The crop seasonal length is 90 days with date of sowing, and harvesting selected are 1st July and 28th September respectively. The initial depletion is taken as zero for base year 2003, and soil water balance simulations are carried out up to 2010, taking the actual climatic data from the nearest weather stations, for all the blocks where bajra is grown. The maximum potential yield selected was 2000 kg per hectare.

The irrigation scheduling strategies chosen for bajra are shown in Table 5.10 which are as follows: (i) Strategy S I: Irrigation of 75 mm fixed depth is applied on the fixed interval days from date of sowing. (ii) Strategy S II: Irrigation of 75 mm fixed depth is applied, when soil moisture depletion reaches 100 percent of readily available water. (iii) Strategy S III: Irrigation depth equivalent to soil moisture depletion is applied, when moisture depletion reaches 100 percent of readily available water. (iv.) Strategy S IV: Irrigation of 40mm fixed depth is triggered post initial vegetative period, when moisture depletion reaches 80 percent of total available water. (v) Strategy S V: Irrigation of 75 mm fixed depth is applied at fixed 45 days from date of sowing. For every strategy (16 number of blocks ✖ 6 number of years) 96 simulations are carried out for bajra crop.

Table 5.10: Irrigation scheduling strategies for Bajra crop

Case	Irrigation Strategy for Bajra		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1,15, and 45	75mm	Irrigation of 75 mm fixed depth is applied at a fixed days from date of sowing.
S II	20-80 Varying	75 mm	After 20 days post sowing, irrigation of 75 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-90 Varying	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions
S IV	20-80 Varying	40 mm	After 20 days post of sowing, irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water.
S V	45	75mm	Irrigation of 75 mm fixed depth is applied at a fixed day from date of sowing.

***** From date of sowing. Date of sowing 1st July and Harvesting on 28th September.

5.7.1 Water Balance, Yield and Efficiencies for Bajra

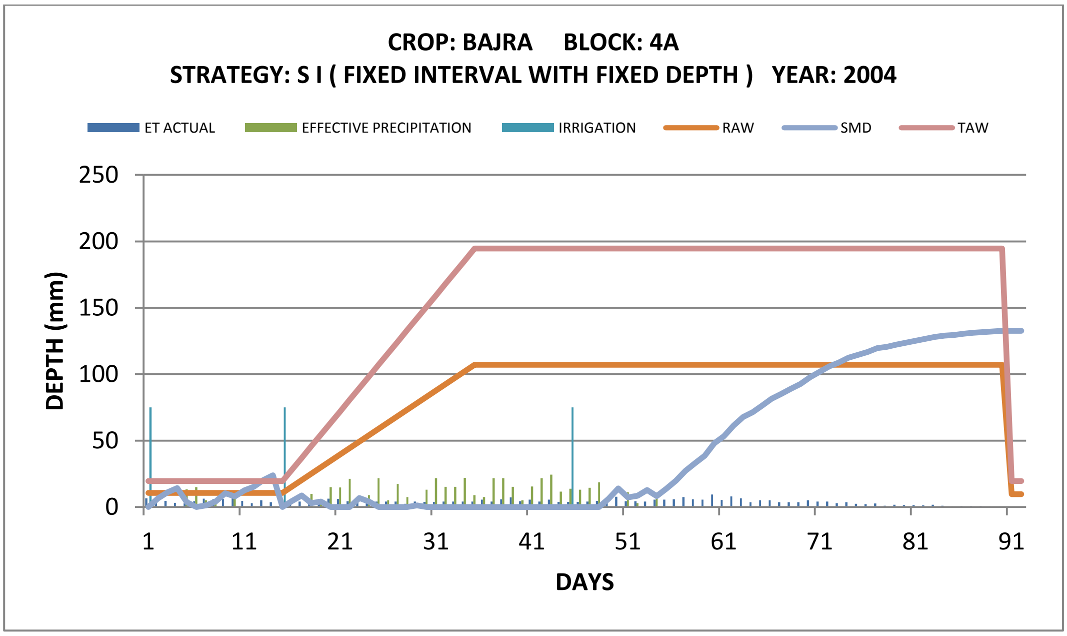
Daily soil moisture balance for all five strategies is simulated for 16 blocks for bajra crop. Averages of ET actual, effective precipitation, groundwater irrigation, surface runoff, groundwater flow, yield, WUE, and IWUE were simulated for years 2004-2009, for all five strategies, and for all 16 blocks where crop was grown. Base year selected for simulation was 2003. Results of bajra crop sown in block 4A have been taken for illustration purposes, refer Table 5.11. Mean over study period show that strategy S III is best strategy in terms of yield and WUE. Though strategy S I has high yield in comparison to other strategies, but values of IWUE is lower than others, due to excess usage of irrigation water. WUE for strategy S I is nearly similar to strategies S II and S V, while it is less in comparison to S III and S IV.

Table 5.11: Water balance, yield and efficiencies of bajra crop in sandy clay loam (HSG – C) soil in block 4A (grown in 1.28% of CCA 6831 ha)

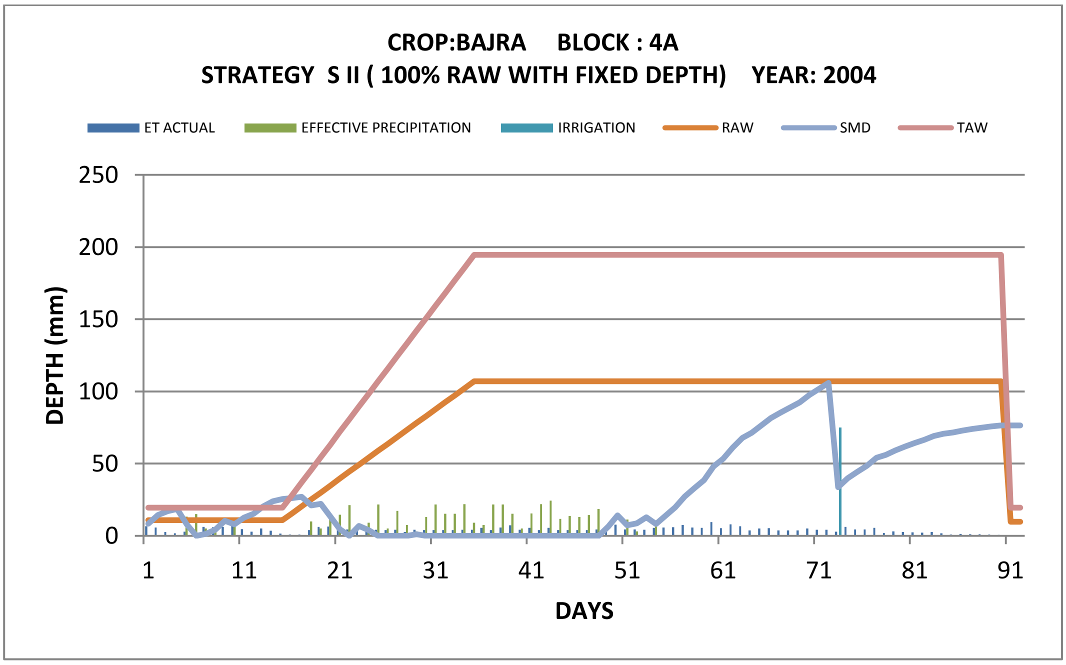
Irrigation strategies for bajra	Year	ETc actual	Eff. preci	GW Irrign.	Net Decrease in Soil moisture	Flow to GW	Runoff	Yield	WUE	IWUE
		mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha/mm	Kg/ha/mm
		1	2	3	4	5	6	7	8	9
Strategy SI F.I with F.D.	2004-2005	383	1129	225	131	-381	-721	1699	4.44	7.55
	2005-2006	388	591	225	-85	-108	-235	1868	4.82	8.30
	2006-2007	558	1541	225	38	-273	-973	1962	3.51	8.72
	2007-2008	427	937	225	-91	-239	-404	1999	4.68	8.88
	2008-2009	417	695	225	-37	-183	-283	1997	4.78	8.87
	2009-2010	462	466	225	48	-47	-230	1967	4.26	8.74
	Average	439	893	225	1	-205	-474	1915	4.41	8.51
Strategy SII 100% RAW with F.D.	2004-2005	389	1129	75	75	-260	-629	1891	4.86	25.22
	2005-2006	394	591	75	-9	-53	-210	1815	4.61	24.20
	2006-2007	535	1541	75	18	-183	-916	1759	3.29	23.45
	2007-2008	420	937	0	-91	-81	-345	1925	4.59	NA
	2008-2009	407	695	0	-37	-40	-211	1904	4.67	NA
	2009-2010	435	466	75	48	-6	-148	1628	3.75	21.71
	Average	430	893	50	1	-104	-410	1820	4.29	
Strategy S III No Stress	2004-2005	282	1129	38	106	-362	-629	2000	7.08	52.41
	2005-2006	300	591	105	-91	-95	-210	2000	6.67	19.00
	2006-2007	424	1541	42	9	-246	-922	2000	4.71	47.44
	2007-2008	304	937	0	-22	-253	-358	2000	6.58	NA
	2008-2009	333	695	60	-39	-171	-212	2000	6.01	33.12
	2009-2010	291	466	60	20	-105	-150	2000	6.87	33.24
	Average	322	893	51	-3	-205	-414	2000	6.32	
Strategy S IV Protective Irrigation	2004-2005	266	1129	0	106	-340	-629	1950	7.33	NA
	2005-2006	293	591	40	-91	-36	-210	1830	6.24	45.76
	2006-2007	405	1541	0	9	-227	-918	1943	4.80	NA
	2007-2008	304	937	0	-22	-253	-358	2000	6.58	NA
	2008-2009	322	695	0	-39	-123	-211	1890	5.87	NA
	2009-2010	263	466	0	20	-75	-148	1649	6.28	NA
	Average	309	893	7	-3	-176	-412	1877	6.18	
Strategy S V Deficit Irrigation	2004-2005	371	1129	75	131	-335	-629	1629	4.39	21.71
	2005-2006	366	591	75	-85	-5	-210	1433	3.92	19.11
	2006-2007	539	1541	75	38	-198	-916	1833	3.40	24.45
	2007-2008	420	937	75	-91	-156	-345	1925	4.59	25.67
	2008-2009	407	695	75	-37	-115	-211	1904	4.67	25.38
	2009-2010	435	466	75	48	-6	-148	1628	3.75	21.71
	Average	423	893	75	1	-136	-410	1725	4.12	23.01

No. of rainy days for bajra crop period in years 2004, 2005, 2006, 2007, 2008 and 2009 are 38, 51, 63, 54, 47, and 30 days respectively.

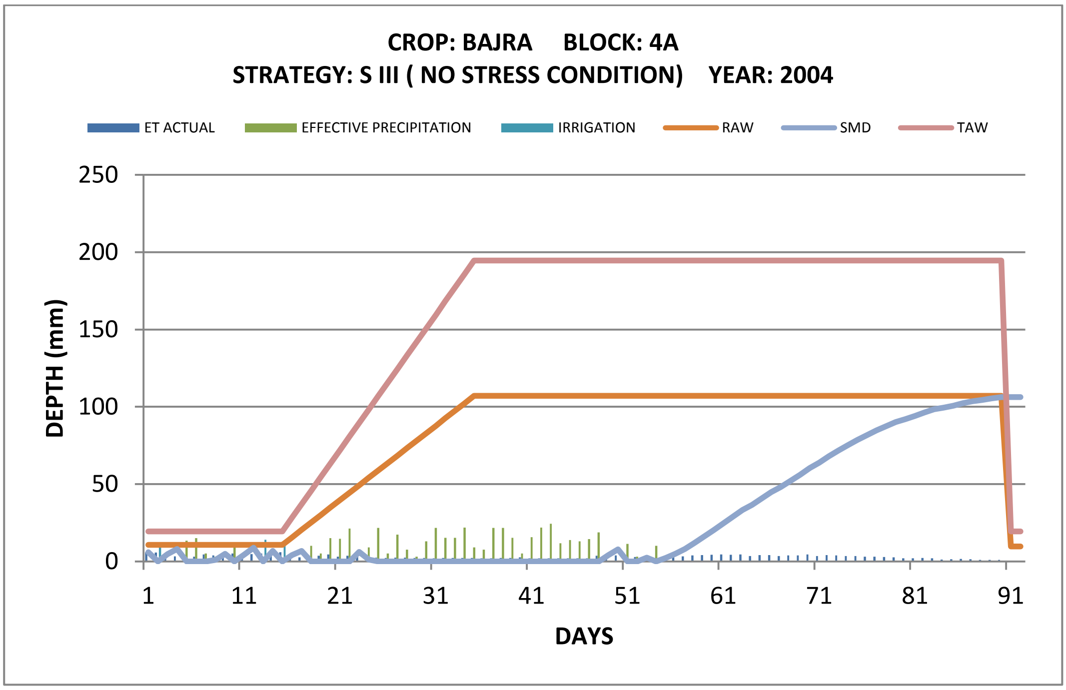
In strategies S II and S IV it is decided to irrigate during the same period, but at different depletion levels. Nearly similar yields are attained for strategies S II and S IV, but WUE and IWUE for strategy S IV is greater than strategy S II, but with lower actual crop evapotranspiration. Thus, aforementioned results confirm the characteristics of bajra crop being drought tolerant. S V strategy shows significant decrease in yield. Flow to groundwater is similar for strategies S I and S III, but runoff is higher in case of strategy S I. Flow to groundwater decreases in order of S IV, S V and S II, but surface runoff is nearly same.



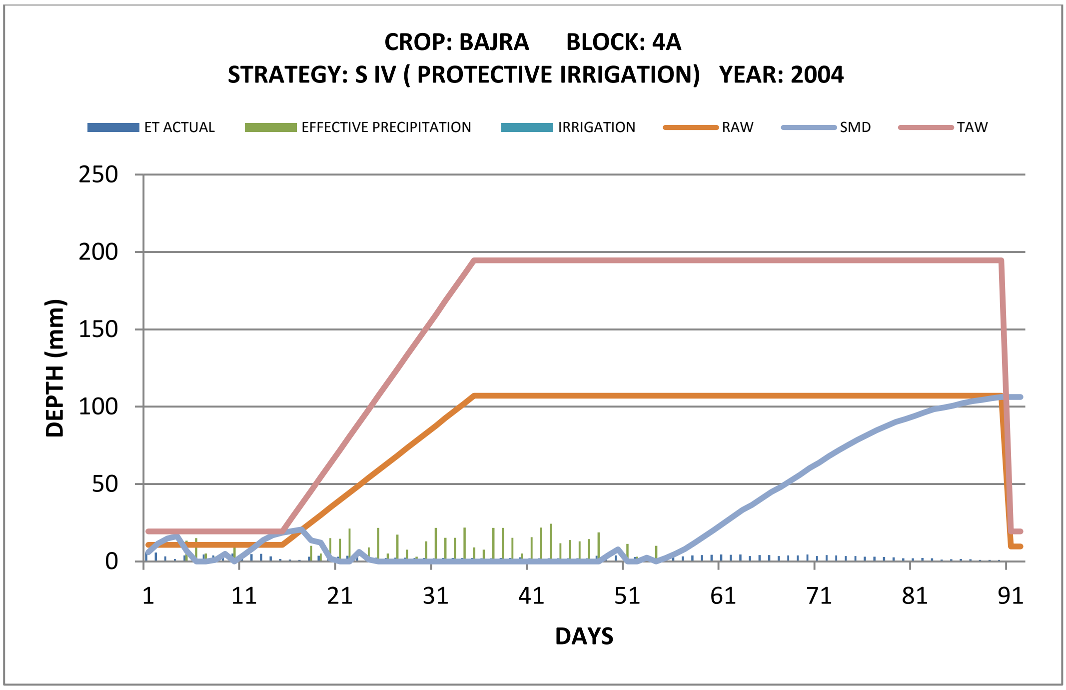
5.13 (a)



5.13 (b)


CROP: BAJRA BLOCK: 4A
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
250
200
150
100
50
0
1
11
21
31
41
51
61
71
81
91
DAYS

5.13 (c)


CROP: BAJRA BLOCK: 4A
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
250
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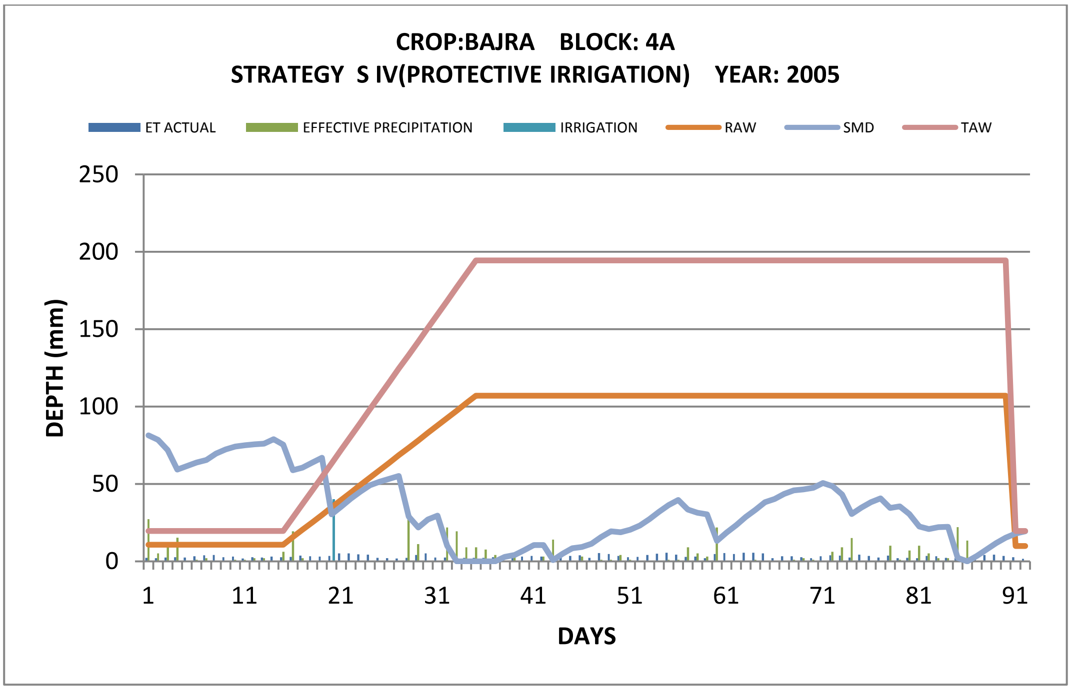
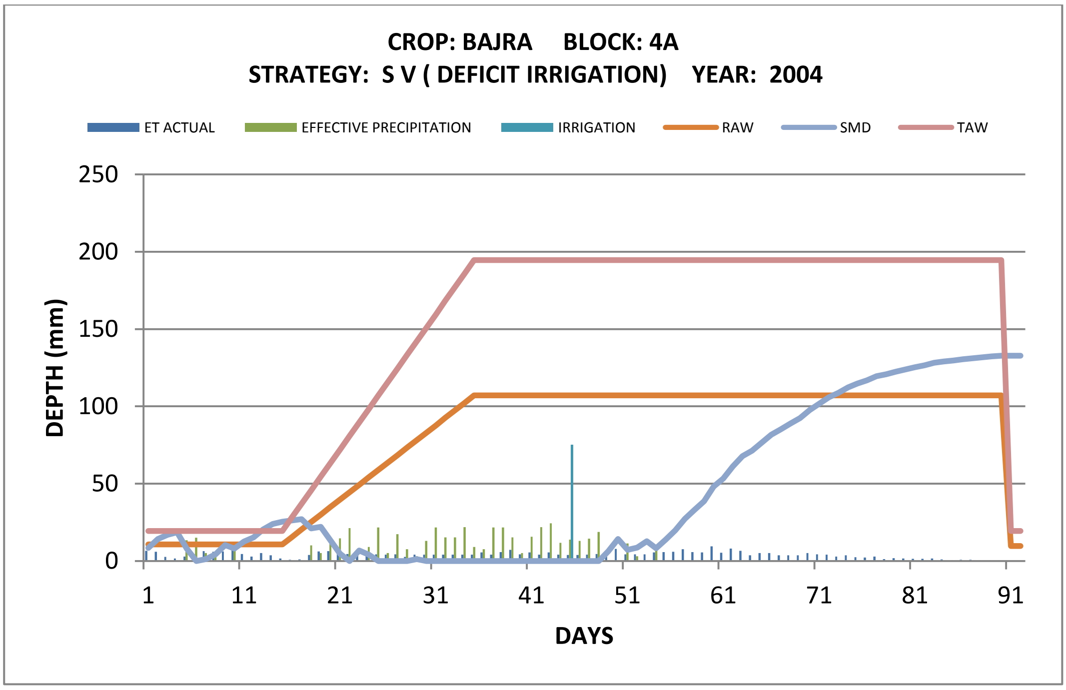
DAYS

5.13 (d)



5.13 (e)



5.13 (f)

Fig 5.13(a-f): Soil moisture balance for irrigation strategies S I to S V for bajra crop year 2004 and 2005

Average actual crop evapotranspiration is nearly same for S I, S II, and S V, but less in S III and S IV. Actual crop evapotranspiration for S I, S II, and S V is greater indicating that higher evapotranspiration is attained, due to excess application of irrigation water than required.

The soil moisture depletion in response to different irrigation strategies for bajra during various crop growth stages, for irrigation strategies S I to S V have been shown in Fig5.13 (a-f) for block4A, while the results are summarized in Table 5.11. In strategies S II and S IV the irrigation is applied post initial vegetative stage, while for strategy S V irrigation is applied in mid-season stage, thus soil moisture deficit is clearly visible during the late initial stage in these strategies. In strategy S I and S V soil moisture deficit is also seen during late mid season stage. The crop stress during the initial period can decrease yield significantly, which is evident from figure. One protective irrigation in year 2005 is applied in development stage as the soil moisture depletion was quite high indicating insufficient rain (due to late monsoon) till that period, while in year 2004 no irrigation was required due to significant rain till that period refer Fig 5.13 (d) &(e).

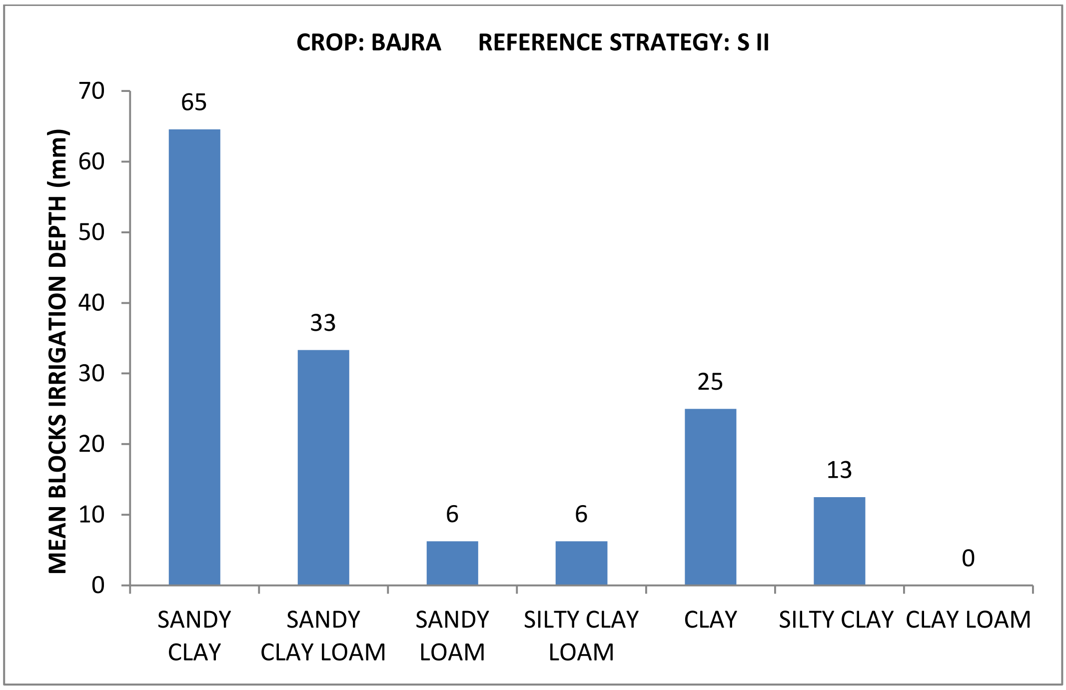


Fig 5.14: Effect of soil type on bajra irrigation depth under strategy S II

5.7.2 Effect of Soil Type on Bajra Irrigation Depth

The impact of soil type on bajra irrigation depth showed that as soil water retention for sandy clay is less it required maximum mean irrigation depth of 65mm for 7 blocks. Average irrigation depth for three blocks of sandy clay loam soil was 33 mm, while for one block of clay soil was 25 mm, showing minor difference of irrigation depth. Blocks with clay loam, sandy loam, silty clay loam, and silty clay either did not require irrigation water for bajra, or required very less amount of irrigation water, which can be seen in Fig 5.14.

5.7.3 Effect of Irrigation on Groundwater for Bajra

The net groundwater withdrawals for bajra crop across the selected nine blocks exhibit (refer Table 5.12) that strategy S I was suited for blocks 4B and 8, where static water table rise is significant, thus it will help in reducing the ground water table rise; but not significantly suitable for block 6A3R2, where groundwater table is already below 30m depth, which would further let the water table go below. The other strategies S II, S IV, and S V indicate rising of water table for all the blocks, thus in these blocks 4B, 6A1, 8, 10, and 9B1R2 the irrigation strategies need to be cautiously used.

Table 5.12: Average net groundwater withdrawals (years 2004-2009) for strategies S I to S VI for bajra crop period.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for bajra crop period				
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V
4B	Sc	7 to 22	39	-35	-136	-166	-64
6A1	Sc	1 to 15	-20	-130	-102	-158	-143
8	Scl	0.5to 6.5	7	-103	-68	-134	-114
10	Scl	1.5 to 18	-60	-162	-118	-177	-168
11A2	Sc	3 to >30	-23	-135	-94	-170	-146
6A3R2	C	>30	13	-110	-81	-121	-100
6BR2	Sic	1.2to>30	-31	-145	-111	-147	-139
9A2R2	Sicl	1 to >30	-41	-158	-137	-158	-151
9B1R2	Cl	0.5 to 23	-47	-164	-144	-164	-158

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The negative sign indicates that groundwater recharge (due to rain) is more than groundwater pumping for irrigation

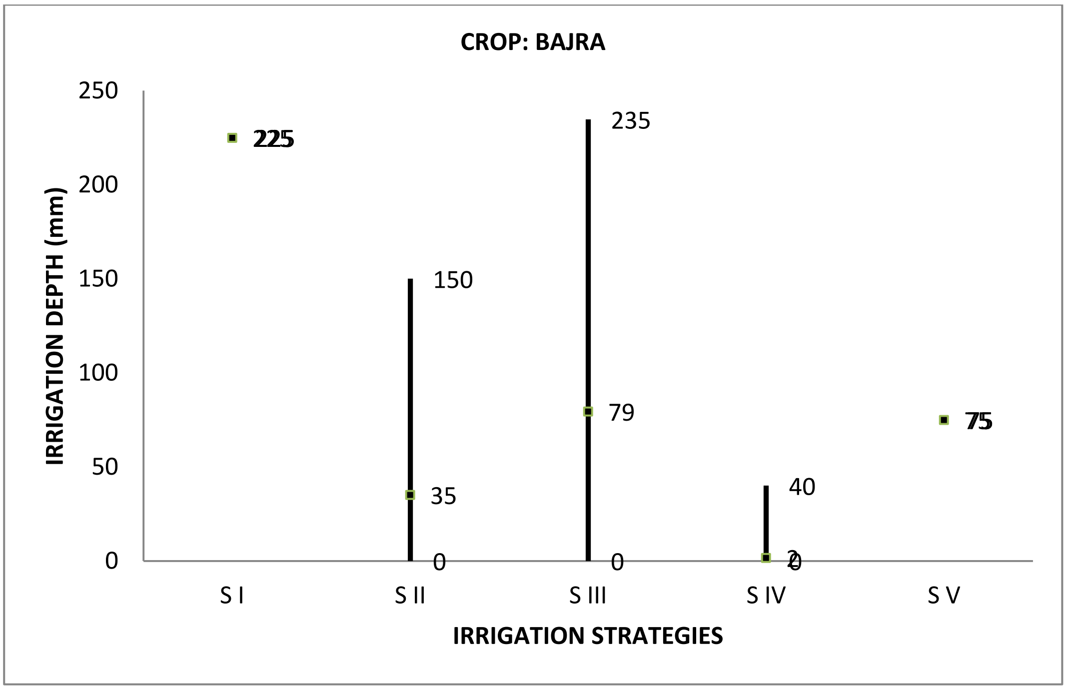


Fig 5.15: Irrigation depth range for bajra crop for strategies S I to S V

5.7.4 Irrigation Depth range for Bajra under Strategies S I to S VI

The irrigation depth range for all blocks and for all five strategies for bajra crop has been exhibited in Fig 5.15. Strategies S I and S II fall under the ambit of fixed irrigation depth. The other strategies S II, S III, and S IV have range between no irrigation to maximum irrigation depth of 150 mm, 235 mm, and 40 mm respectively. This indicates that bajra if grown in rainfed condition would give good yields, under normal monsoons and maximum upto three irrigations, under very dry scenarios. In strategy S III the maximum range for irrigation depth is due to dry year 2009 in block 13A. Normally the maximum range in irrigation depth for strategy S II is greater than strategy S III; provided irrigation is applied from day of sowing upto harvesting. Over here the irrigation for strategy S II and S IV is initiated post initial crop stage, and irrigation is cut off few days ahead of harvesting in order to stop over irrigation. Thus maximum range for strategy S III is more than strategy S II. The reason for post initial stage irrigation is done with a presumption that sufficient moisture would be available during Kharif season, for the crop which is sown with onset of monsoon.

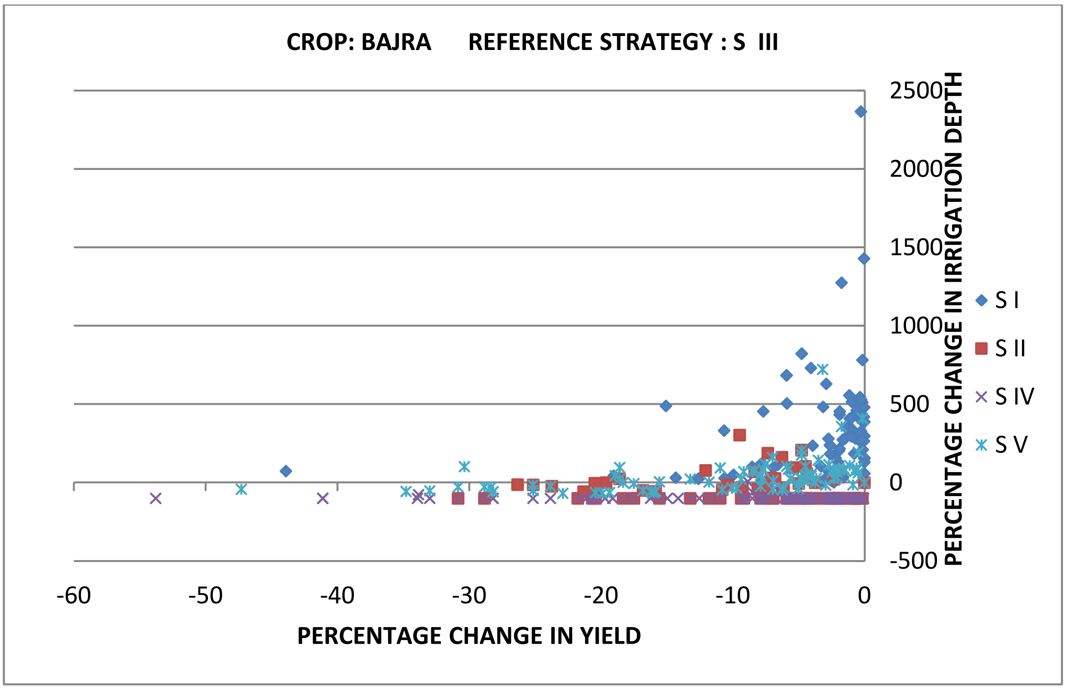


Fig 5.16: Percentage change in yield versus percentage change in irrigation depth for bajra crop under irrigation strategies S I, S II, S IV and S V with respect to strategy S III (no moisture stress conditions)

5.7.5 Evaluating Irrigation Strategies for Bajra

The assessment of various irrigation scheduling strategies on bajra yield, and irrigation depth has been obtained by comparing all other strategies with no stress condition strategy S III; this is done as it gives maximum yield with optimum irrigation water depth. Relation between percentage change in yield and percentage change in irrigation depth, with respect to strategy S III (no moisture stress condition) is shown in Figure 5.16. The reduction in yield in strategy S I range between 0 to 44 percent with an average reduction across all blocks, where bajra is grown is 3 percent indicating that potential yield is obtained with this strategy, and in case of delay in monsoon after first showers the reduction in yield could be high. The increase in average irrigation depth is as high as 327 percent in S I, showing that over irrigation is done with this strategy. Strategy S II indicates to be the best option for bajra as range in reduction of yield varies between 0 to 31 percent, with average reduction throughout all blocks is 9 percent. However; the irrigation depth range for strategy S II lies between nil to 304 percent with average being −48 percent, this is because irrigation is applied only after the initial stage, thus savings of water is obtained in comparison to no stress condition strategy SIII. The range of reduction in yield for both strategies S IV and S V is between nil to 54 percent and 47 percent respectively. The average irrigation depth for strategy S IV is nil mostly for all blocks, while for strategy S V average irrigation depth is 44 percent more than required, when compared with S III. These results exhibit that strategy S II and S IV can be recommended for bajra, where optimum yield can be obtained with no irrigation or very less irrigation, depending upon wet or dry scenarios.

5.8 Irrigation Scheduling Strategies for Maize

The maize crop is grown in Rabi season on 22nd October with crop seasonal length of 100 days. The base year selected for soil moisture computation is 2003 with initial depletion taken as zero. The potential yield for maize crop is taken as 3000 kg per hectare. The various irrigation strategies taken up for maize are shown in Table 5.13, which are: (i) Strategy S I: Fixed irrigation depth is applied at fixed interval of 15 days from date of sowing. (ii) Strategy S II: Fixed irrigation depth is applied, and the irrigation is triggered when soil moisture depletion reaches 100 per cent of readily available water.

Table 5.13: Irrigation scheduling strategies for maize crop

Case	Irrigation Strategy for Maize		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1, 16, 31, 46, 61, 76 & 91	75mm	Irrigation of 75 mm fixed depth is applied at a fixed interval of 15days subsequently post date of sowing 22nd Oct.
S II	1-91	75 mm	Irrigation of 75 mm depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-100	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	1-91	40 mm,	Irrigation of fixed depth of 40 mm is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S V	1, 21, 41, 61 & 81 days	60mm	Irrigation of 60 mm fixed depth is applied at fixed interval of 20 days subsequently from date of sowing.
S VI	1,11,21,30, 40, 50, 60, 70, 80 & 90	40mm	Irrigation of 40 mm fixed depth is applied at a fixed interval subsequently from date of sowing.

* From date of sowing. Date of sowing 22nd October and Harvesting on 29th January.

(iii) Strategy S III: Irrigation equivalent to soil moisture depletion is applied with the irrigation being triggered, when soil moisture depletion reaches 100 per cent readily available water. (iv.) Strategy S IV: Protective irrigation of fixed irrigation depth is applied, when moisture depletion reaches 80 per cent of total available water. (v) Strategy S V: Reduced fixed irrigation depth is applied at enhanced fixed irrigation interval, and (vi.) Strategy S VI: Fixed irrigation depth is applied at fixed intervals decided on basis of growth stages. Irrigation is cut off 9 days ahead of harvesting. For each strategy (number of blocks × number of years) 108 simulations are carried out for maize crop.

5.8.1 Water Balance, Yield and Efficiencies for Maize

Daily soil moisture balance is computed for all blocks and for all six strategies where maize is grown. The results of block1 has been shown in Table 5.14 and discussed over here. Method of irrigation applied here for Maize is furrow, thus to obtain the total irrigation depth the values in the column 3 and 4 of Table 5.14 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth given in column 3 and 4 is 45 mm and 270 mm, thus total irrigation applied is 315/0.6 = 525 mm). The simulations showed that strategy SIII was best suited in terms of yield, WUE, and IWUE as it gave highest value with nil run off on surface, and flow to groundwater. Strategy S VI was second best with higher WUE and IWUE, though with minor reduction in yield, when compared to strategy S II. Second highest yield was seen in strategy S II although with more surface run off, flow to groundwater, and consumption of water for irrigation, but with lesser value of WUE and IWUE. Strategy S V shows significant yield with higher values of WUE and IWUE, but with less surface run off and flow to groundwater, indicating that it could also be recommended, if yield was not the dominant criteria for evaluating the irrigation strategy.

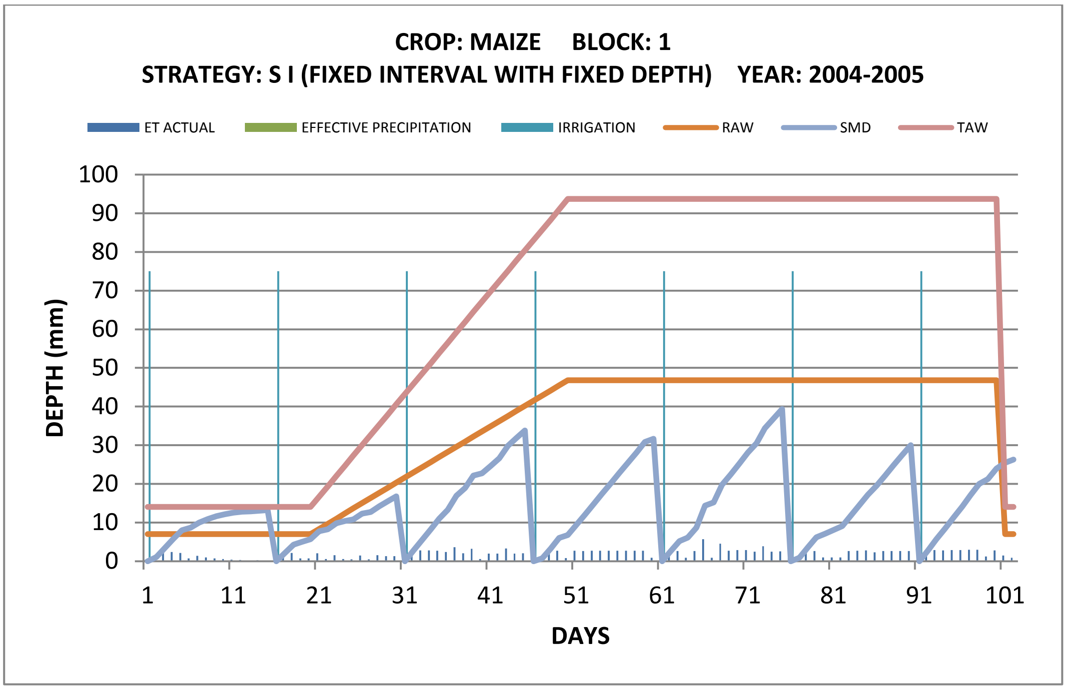
The soil moisture depletion in response to different irrigation strategies for maize, during various crop growth stages, for irrigation strategies S I to S VI have been shown in Fig5.17 (a-f) for block 1, while results are tabulated in Table 5.14. It is seen that maize crop is sensitive to moisture stress throughout is growth stage. Reduction in yield is noted, when moisture stress is felt during any growth stages. Moisture stress during initial vegetative stage results into yield reduction for strategies S I (2756 kg/ha), S V (2287 kg/ha), and S VI (2738 kg/ha). Moisture stress during initial, development, and mid season stages results into substantial decline in yield under strategy S IV (1510 kg/ha). In strategy S V (2287 kg/ha) mid stress during development and mid season stage has a slight effect in yield reduction.

Table 5.14: Water balance, yield and efficiencies of maize crop in sandy clay (HSG – C) soil in Block 1 (grown in 6.53% of CCA 9868 ha)

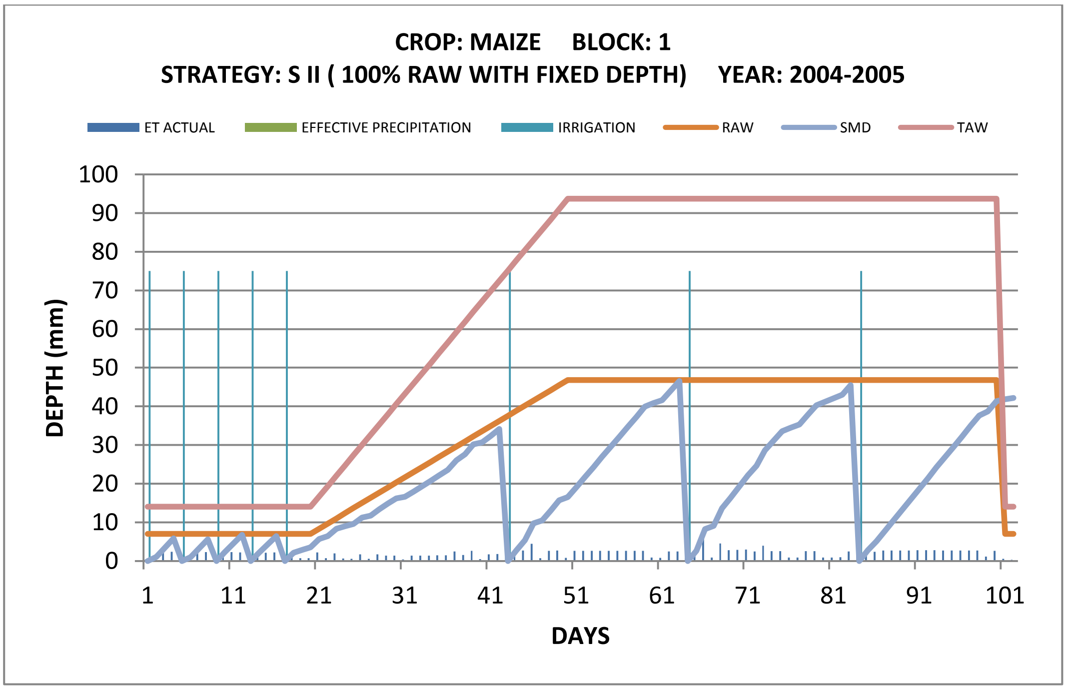
Irrigation strategies for Maize	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	Mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	198	0	45	270	83	-115	-85	2756	13.93	8.75	1.74
	2005-2006	239	6	45	270	97	-96	-83	2601	10.90	8.26	1.74
	2006-2007	270	0	45	270	118	-81	-82	2552	9.46	8.10	1.74
	2007-2008	257	0	45	270	113	-81	-91	2611	10.18	8.29	1.74
	2008-2009	334	0	45	270	149	-51	-79	2218	6.63	7.04	1.74
	2009-2010	353	0	45	270	159	-43	-77	2077	5.88	6.59	1.74
	Average	275	1	45	270	120	-78	-83	2469	9.50	7.84	1.74
Strategy S II 100% RAW with F.D.	2004-2005	206	0	135	225	96	-74	-176	3000	14.58	8.33	1.45
	2005-2006	266	6	180	315	111	-99	-247	3000	11.28	6.06	2.03
	2006-2007	302	0	180	360	150	-99	-289	2744	9.08	5.08	2.32
	2007-2008	281	0	135	360	123	-92	-245	3000	10.66	6.06	2.32
	2008-2009	406	0	225	540	193	-142	-410	2669	6.58	3.49	3.48
	2009-2010	442	0	225	585	198	-151	-415	2903	6.57	3.58	3.77
	Average	317	1	180	398	145	-110	-297	2886	9.79	5.43	2.56
Strategy S III No Stress	2004-2005	224	0	21	121	82	0	0	3000	13.37	21.11	0.78
	2005-2006	244	6	20	114	104	0	0	3000	12.28	22.32	0.73
	2006-2007	251	0	21	120	110	0	0	3000	11.95	21.30	0.77
	2007-2008	223	0	21	97	106	0	0	3000	13.45	25.51	0.62
	2008-2009	257	0	21	118	118	0	0	3000	11.65	21.48	0.76
	2009-2010	292	0	27	143	122	0	0	3000	10.26	17.59	0.92
	Average	249	1	22	119	107	0	0	3000	12.16	21.55	0.77
Strategy S IV Protective Irrigation	2004-2005	187	0	48	96	107	-16	-48	1510	8.08	10.49	0.62
	2005-2006	198	6	48	96	111	-17	-47	1387	7.02	9.63	0.62
	2006-2007	196	0	48	96	115	-16	-48	1313	6.71	9.12	0.62
	2007-2008	188	0	48	96	108	-16	-48	1520	8.07	10.55	0.62
	2008-2009	208	0	48	120	121	-21	-60	1305	6.27	7.77	0.77
	2009-2010	243	0	72	120	131	-20	-61	1547	6.38	8.06	0.77
	Average	203	1	52	104	116	-18	-52	1430	7.09	9.27	0.67
Strategy S V Deficit Irrigation	2004-2005	205	0	36	144	101	-33	-43	2287	11.18	12.71	0.93
	2005-2006	225	6	36	144	111	-29	-43	2389	10.62	13.27	0.93
	2006-2007	225	0	36	144	115	-27	-43	2177	9.69	12.09	0.93
	2007-2008	205	0	36	144	104	-36	-43	2257	11.02	12.54	0.93
	2008-2009	228	0	36	144	115	-24	-43	2151	9.45	11.95	0.93
	2009-2010	246	0	36	144	131	-22	-43	1793	7.29	9.96	0.93
	Average	222	1	36	144	113	-29	-43	2175	9.88	12.09	0.93
Strategy S VI Combination	2004-2005	233	0	24	216	100	-74	-33	2738	11.75	11.41	1.39
	2005-2006	255	6	24	216	108	-66	-33	2822	11.06	11.76	1.39
	2006-2007	257	0	24	216	113	-64	-32	2711	10.54	11.29	1.39
	2007-2008	232	0	24	216	100	-74	-33	2742	11.80	11.43	1.39
	2008-2009	261	0	24	216	114	-62	-31	2688	10.29	11.20	1.39
	2009-2010	293	0	24	216	133	-48	-32	2599	8.87	10.83	1.39
	Average	255	1	24	216	111	-65	-32	2717	10.72	11.32	1.39

Note: No. of rainy days for maize crop period in years 2004, 2005, 2006,2007, 2008 and 2009 are 0,1,0,0,0 and 0 days respectively.

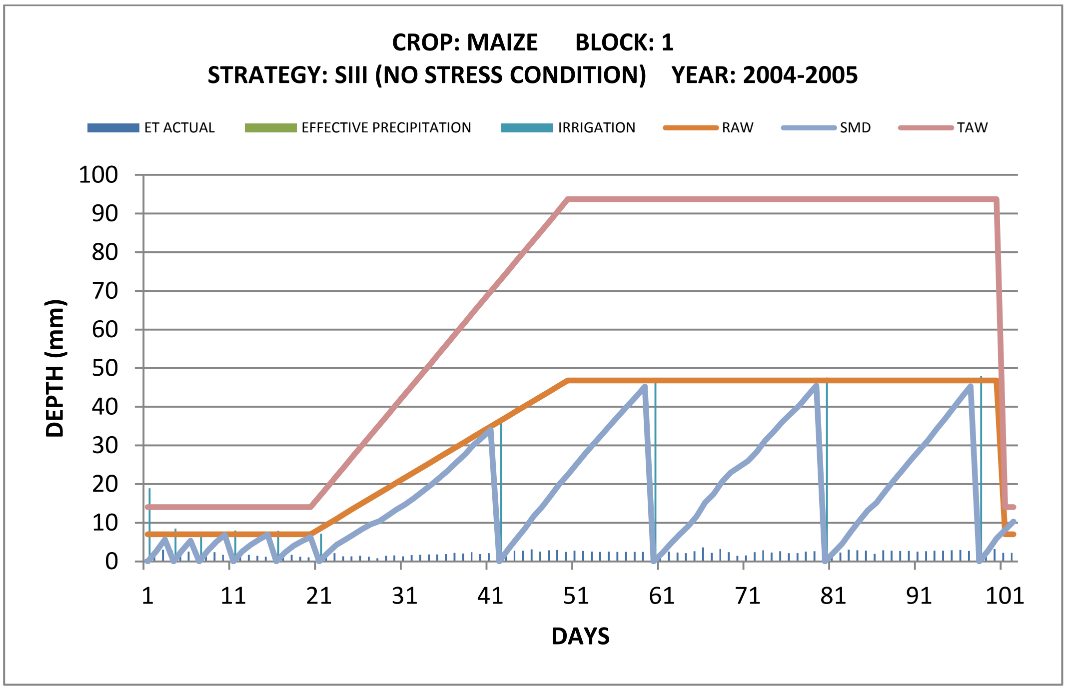
Frequent irrigations, during initial stage enhances yield, which is seen in strategies S II and S III, though proper utilization of water is seen only in strategy S III, wherein small depths of irrigation water equivalent to moisture stress is applied. Reduction of irrigation depth especially, for strategies S II and S VI in initial stages could help in water savings.



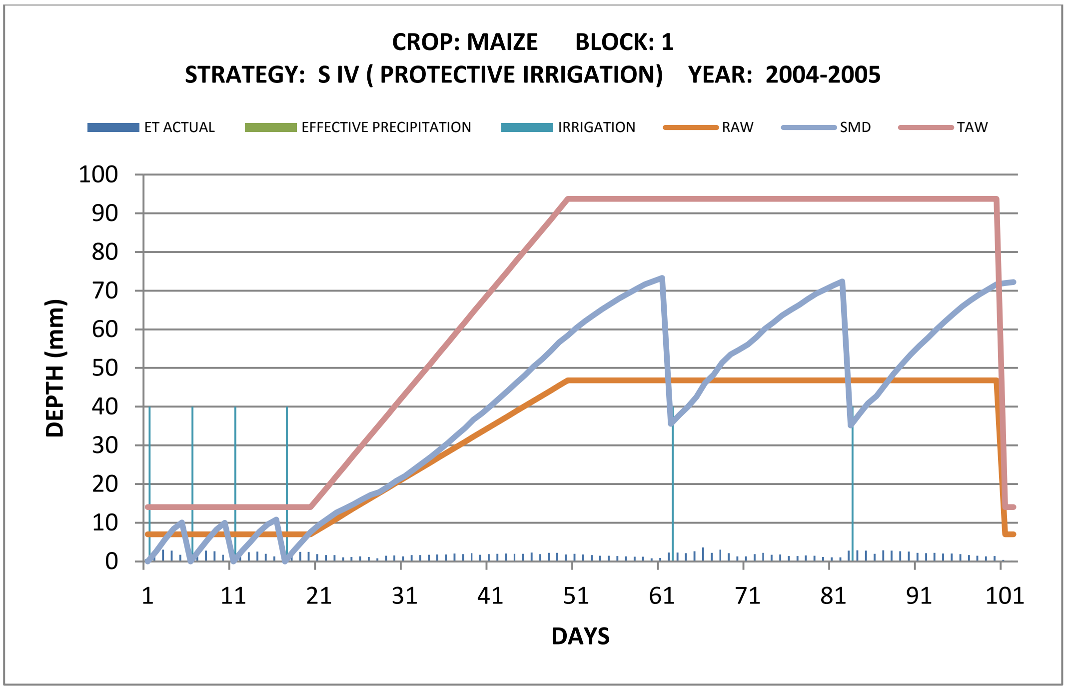
5.17 (a)



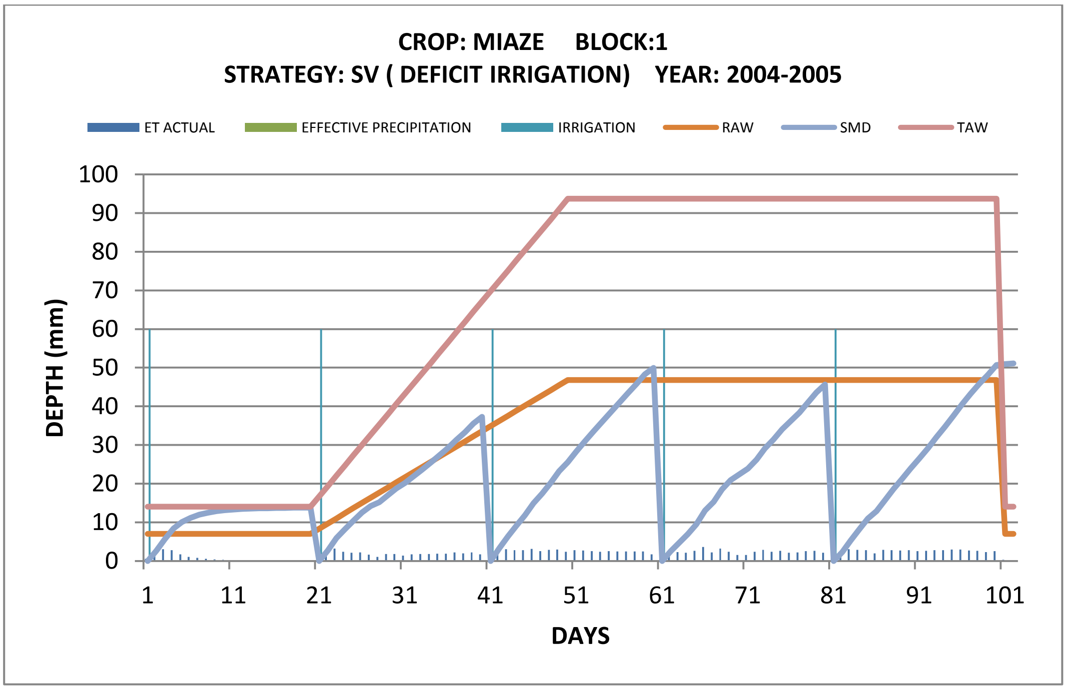
5.17 (b)


CROP: MAIZE BLOCK: 1
STRATEGY: SIII (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
100
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
DAYS

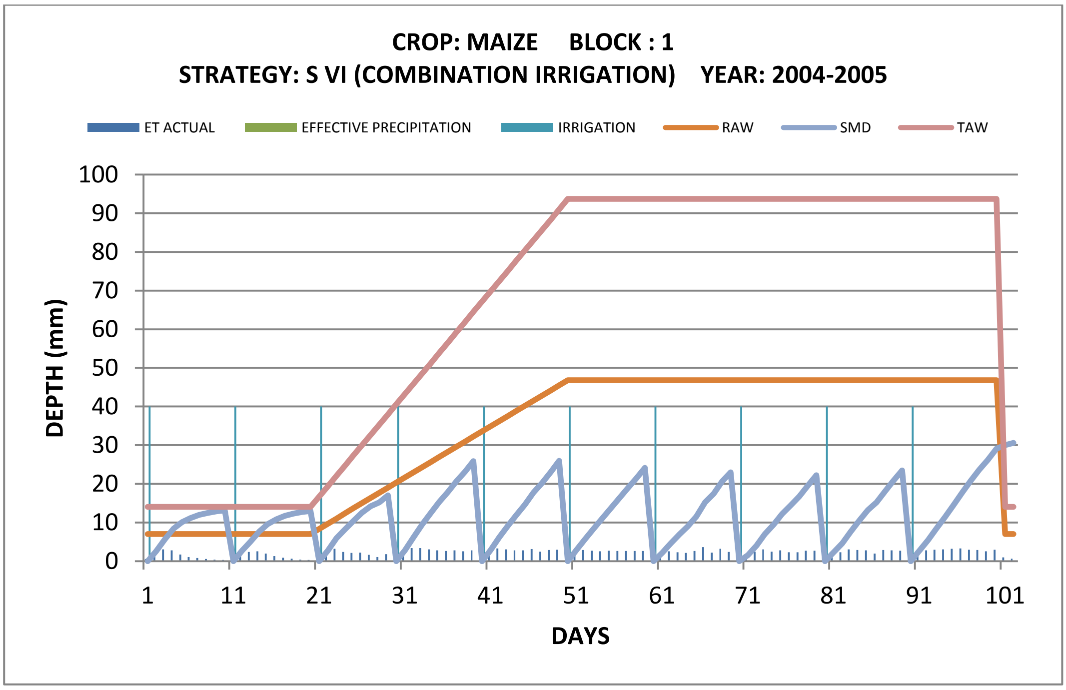
5.17 (c)


CROP: MAIZE BLOCK: 1
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
100
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
DAYS

5.17 (d)



5.17 (e)



5.17 (f)

Fig 5.17 (a-f): Soil moisture balance for irrigation strategies S I to S VI for maize crop year 2004-2005.

5.8.2 Effect of Soil Type on Maize Irrigation Depth

The impact of various soils on depth of irrigation water with strategy S II was done, as it utilized maximum amount of water for maize crop. Mean of irrigation depth for maize of all blocks, according to soil type was done and shown in Fig 5.18. The mean highest irrigation depth was in sandy clay (10 blocks; 540 mm), followed by sandy clay loam (3blocks; 343 mm). Sandy loam (2 blocks; 278 mm) and silty clay loam (1 block; 278 mm) had same irrigation depth, while silty clay and clay loam had 315 mm and 300 mm irrigation depths respectively.

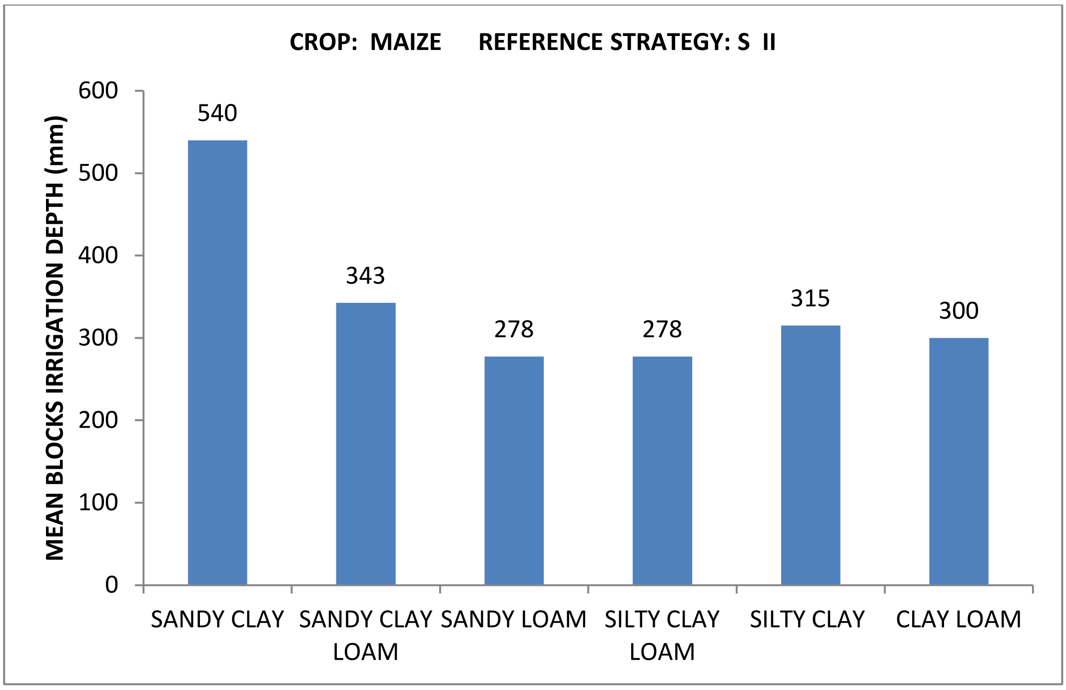


Fig 5.18: Effect of soil type on maize irrigation depth under strategy S II

5.8.3 Effect of Irrigation on Groundwater for Maize

On assessing the impact of irrigation strategies on maize net groundwater withdrawals, it is seen that strategies S I and S VI show slight rise of groundwater table in areas, where maize is grown for selected blocks, for monitoring groundwater table rise. Strategy S V does not have any significant impact on groundwater table. Strategies S II, S III, and S IV show slight falling in groundwater table across all the selected blocks for monitoring, which can be seen in Table 5.15.

5.8.4 Irrigation Depth Range for Maize under Strategies S I to S VI

The irrigation depth range for maize crop for all six strategies across all the blocks is shown in Fig 5.19. The strategies S I, S V, and S VI fall under the ambit of fixed irrigation depth. In strategies S III and S IV the range of irrigation depth is less with average irrigation depth being 137 mm and 119 mm respectively. The strategy S II has a wide range of irrigation depth, exhibiting the sensitiveness towards soil, climatic conditions, and moisture retention post monsoon. Irrigation depth in strategy S II is large, due to over irrigation, especially during initial crop period, which can be reduced by providing lesser depth of irrigation. Method of irrigation applied here for Maize is furrow, thus to obtain the total irrigation depth, the values in the Figure 5.19 are required to be divided by fraction wetted 0.6 (for e.g. in S I, depth given in Figure 5.19 is 315 mm, thus total irrigation applied is 315/0.6 = 525 mm).

Table 5.15: Average net groundwater withdrawals (years 2004-2009) for strategies S I to S VI for maize crop period.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for maize crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-32	70	25	35	8	-40
6A1	Sc	1 to 15	-58	88	27	32	2	-46
8	Scl	0.5to 6.5	-58	88	25	31	2	-46
10	Scl	1.5 to 18	-74	80	23	11	-4	-57
11A2	Sc	3 to >30	-58	88	25	31	2	-46
6BR2	Sic	1.2to>30	-61	92	33	32	7	-45
9B1R2	Cl	0.5 to 23	-81	80	26	16	-7	-62

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Maize crop is not sown in block 6A3R2 and block 9A2R2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

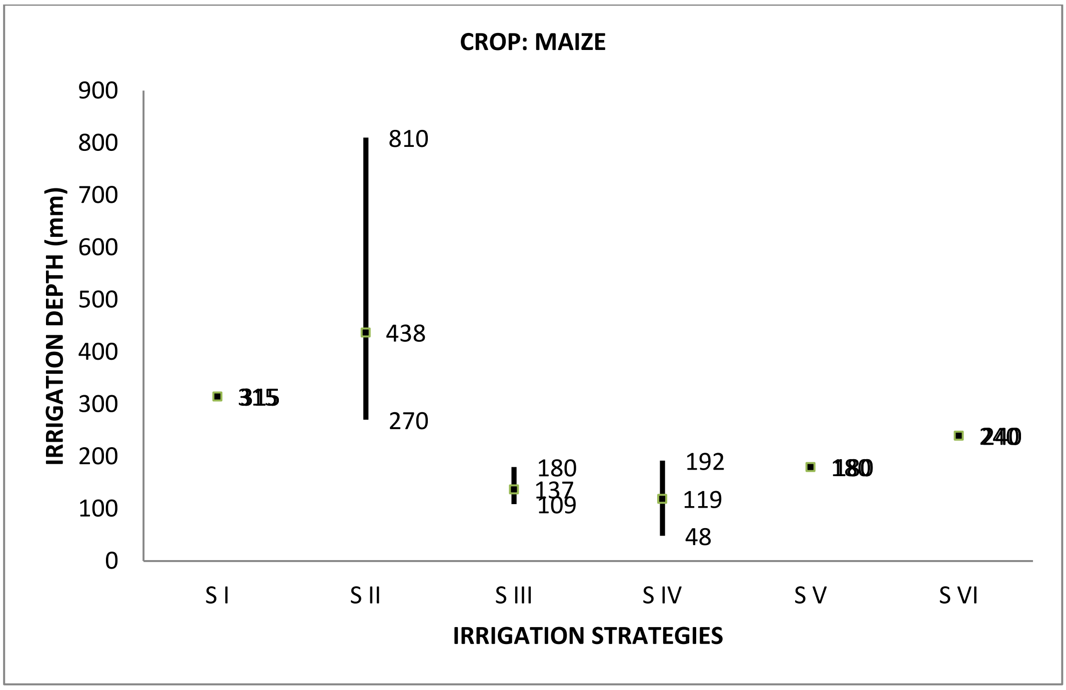


Fig 5.19: Irrigation depth range for maize crop for strategies S I to S VI

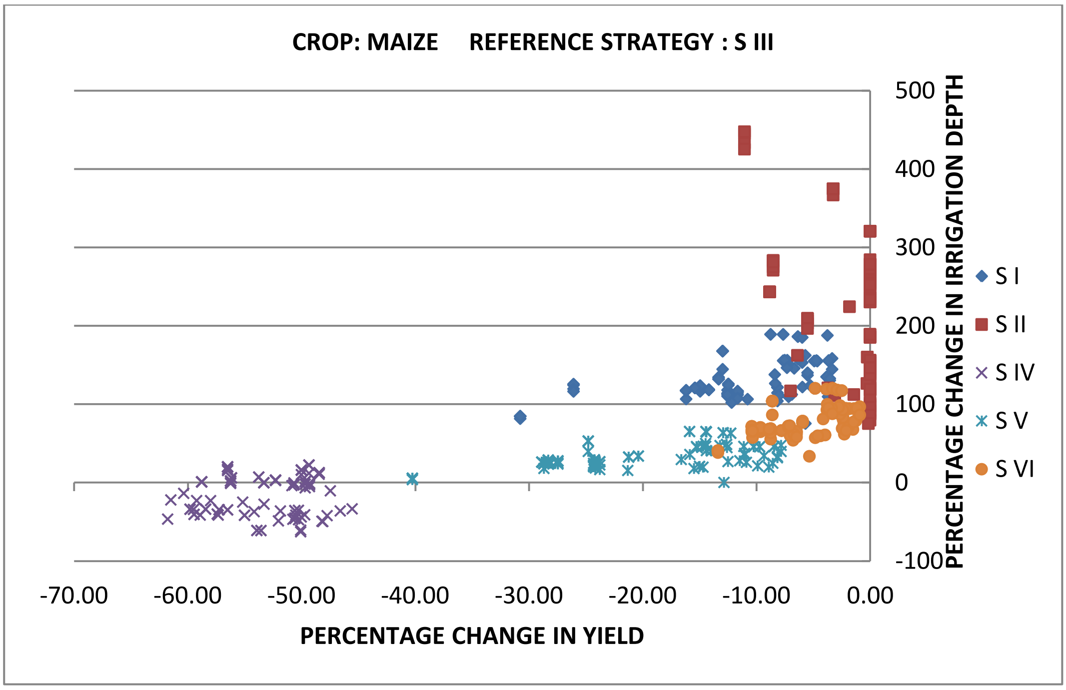


Fig 5.20: Percentage change in yield versus percentage change in irrigation depth for maize crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.8.5 Evaluating Irrigation Strategies for Maize

The maximum potential yield was attained with strategy S III (no stress condition) with optimum irrigation depth, thus it was taken as a reference strategy for comparing the performance of other irrigation strategies. Relationship of percentage change in yield versus percentage change in irrigation depth with reference to strategy S III was derived and exhibited in Figure 5.20. It was ample clear from results that strategy S II stood next to S III in terms of yield, with nil to maximum yield reduction of 11 percent although, with percentage increase in irrigation depth range between 75 percent to 448 percent, and with an average increase in irrigation depth of 216 percent, for all blocks. Less rainfall in October in blocks 1, 2, 3A, 3B, 4A, and 4B resulted into maximum increase in irrigation depth in year 2008, thereby increasing the irrigation depth value. The better results were availed with strategy S VI with minor average percentage yield reduction of 6 percent and average percentage increase in irrigation depth of 77 percent. For strategy S I percentage yield reduction range was between 3 percent to 31 percent, with average reduction in yield of 11 percent, and with average increase in irrigation depth of 132 percent, indicating that conventional methods of irrigation gave significant yield with moderately high irrigation depth. Percentage yield reduction range for strategy S V was high, with average yield reduction of 21 percent, although average increase in irrigation depth was 33 percent. Strategy S IV had very high average yield reduction of 53 percent with average 14 percent less amount of water usage, exhibiting that maize crop is sensitive to moisture stress, thus reducing irrigation below the optimum level has high yield reduction. The yield response factor for mid season stage in maize is 1.30 thus it shows sensitivity to moisture stress due to this there is a significant reduction in the yield. Strategies S II, S VI, and S I can be recommended in order of merit for maize to attain higher yields with significant water savings. In case of earlier withdrawal of monsoon or poor monsoon, when sufficient canal water is unavailable strategies S IV and S V can be recommended for maize. Maize crop is sensitive to moisture stress, thus reducing irrigation below the optimum level has high yield reduction.

5.9 Irrigation Scheduling Strategies for Tuver

Pigeon pea crop is a pulse which is popularly known as tuver in this region. The tuver crop is a two seasonal crop grown with onset of monsoon in Kharif season. The sowing for the crop is taken as 1st July with crop seasonal length of 160 days. The base year selected for soil moisture computation is 2003 with initial depletion taken as zero. The potential yield for tuver crop is taken as 1500 kg per hectare. The various irrigation strategies taken up for Tuver are elaborated in Table 5.16 which are as follows: (i) Strategy S I: Fixed irrigation depth is applied at fixed gap of 20days from post 40days of sowing. (ii) Strategy S II: Post 40 days of sowing, irrigation of fixed depth is given, when soil moisture available in root zone is equivalent to 100 per cent of readily available water. (iii) Strategy S III: To obtain no moisture stress conditions irrigation equivalent to 100 percent of readily available water is applied, as soil moisture depletion reaches cent percent of readily available water. (iv.) Strategy S IV: Post 40days of sowing, irrigation of reduced fixed depth is applied, when moisture available in root zone is equivalent to 20 per cent. (v) Strategy S V: Deficit irrigation is employed in two phases. In first phase, post 40 days of sowing up to 91days of sowing an irrigation of reduced fixed depth is applied, when the soil moisture available in root zone equals 20 per cent. In second phase, post 100days of sowing 3 irrigations of fixed irrigation depth is applied at a gap of 25 days, and (vi.) Strategy S VI: This strategy is employed in two phases. In first phase irrigation of fixed depth is applied post 40days upto 100days and irrigation is triggered, when the moisture depletion reaches cent per cent of readily available water. In second phase, irrigation of fixed depth is applied at fixed gap of 15 days post 105 days of sowing.

5.9.1 Water Balance, Yield and Efficiencies for Tuver

Daily water balance, yield and efficiencies were computed for Tuver crop for all blocks and for all irrigation strategies for the study period. The computed water balance for Tuver crop

Table 5.16: Irrigation scheduling strategies for tuver crop

Case	Irrigation Strategy for tuver		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	40, 60, 80, 100, 120 & 140	75mm	Irrigation of 75 mm fixed depth is applied at a fixed interval of 20days subsequently from 40 days post date of sowing i.e. 1st July.
S II	40- 150	75 mm	Irrigation of 75 mm depth is applied, as moisture level reaches at 100 percent of readily available water from 40 days post date of sowing.
S III	1-160	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	40- 150	40 mm,	Irrigation of fixed depth of 40 mm is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water from 40 days post date of sowing.
S V	40- 95 100, 125, & 150	60mm 75mm	Irrigation of fixed depth of 60 mm is applied, when moisture depletion reaches 80 percent of total available water from 40 days post date of sowing. Irrigation of 75 mm fixed depth is applied at fixed interval of 25 days subsequently from 100 days post date of sowing.
S VI	40- 100 105, 120, 135 & 150	75mm 75mm	Irrigation of fixed depth of 75 mm is applied, when moisture depletion reaches 100 percent of readily available water from 40 days post date of sowing. Irrigation of 75 mm fixed depth is applied at fixed interval of 15 days subsequently from 105 days post date of sowing.

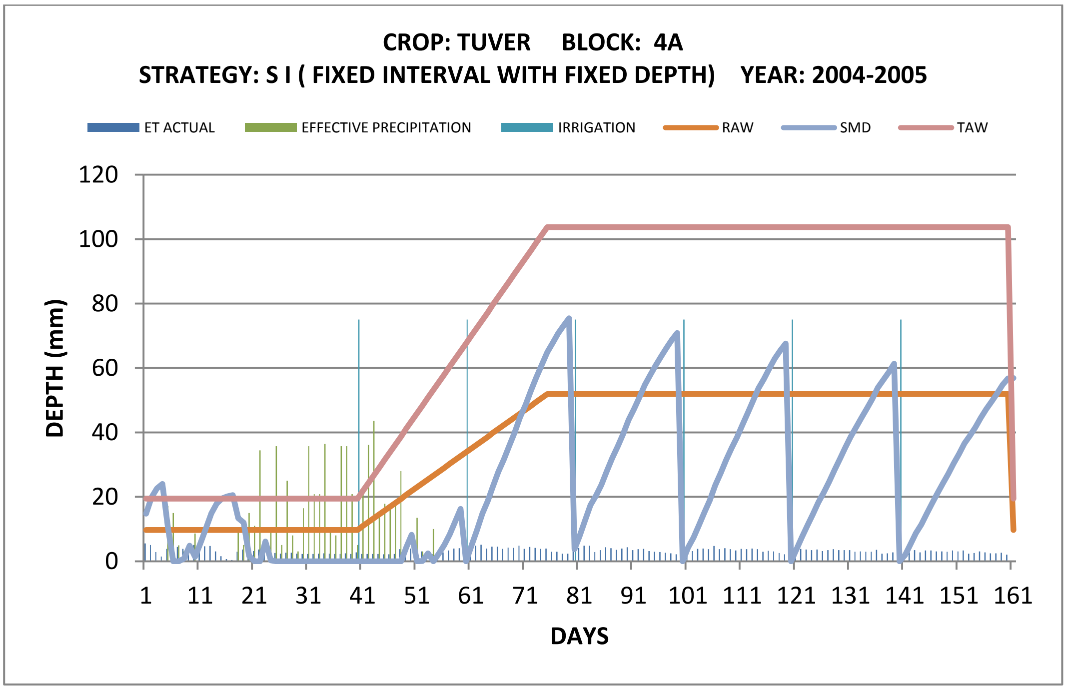
***** *From date of sowing. Date of sowing 1st July and Harvesting on 7th December.*

Table 5.17: Water balance, yield and efficiencies of tuver crop in sandy clay loam (HSG – C) soil in block 4A (grown in 8.12% of CCA 6831 ha)

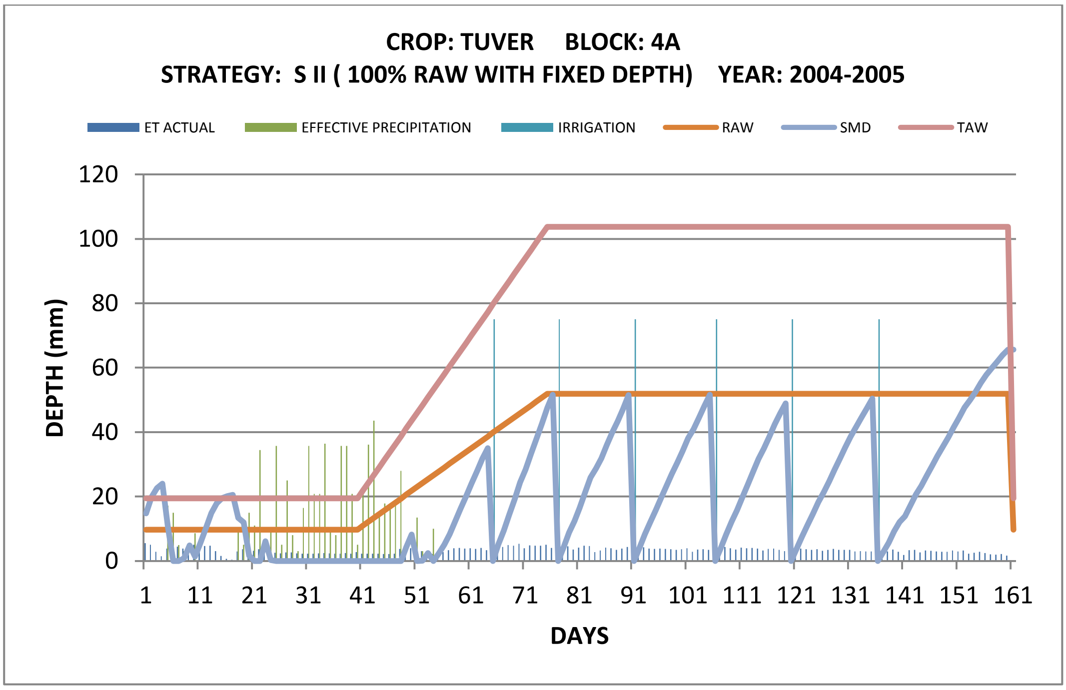
Irrigation Strategies for Tuver	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	Mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	524	1129	225	45	168	-335	-708	1334	2.55	4.94	0.25
	2005-2006	475	591	225	45	81	-220	-247	1423	3.00	5.27	0.25
	2006-2007	629	1544	225	45	99	-383	-900	1431	2.27	5.30	0.25
	2007-2008	536	964	225	45	70	-350	-418	1468	2.74	5.44	0.25
	2008-2009	545	730	225	45	59	-273	-240	1337	2.45	4.95	0.25
	2009-2010	515	610	225	45	74	-237	-201	1254	2.43	4.64	0.25
	Average	537	928	225	45	92	-300	-453	1375	2.57	5.09	0.25
Strategy S II 100% RAW with F.D.	2004-2005	541	1129	225	45	181	-379	-661	1441	2.66	5.34	0.25
	2005-2006	478	591	135	90	64	-155	-247	1447	3.03	6.43	0.50
	2006-2007	632	1544	135	45	101	-333	-860	1454	2.30	8.08	0.25
	2007-2008	540	964	45	90	62	-270	-351	1497	2.77	11.09	0.50
	2008-2009	558	730	135	90	63	-276	-183	1429	2.56	6.35	0.50
	2009-2010	545	610	270	45	133	-315	-197	1356	2.49	4.31	0.25
	Average	549	928	158	68	101	-288	-417	1437	2.64	6.93	0.37
Strategy S III No Stress	2004-2005	553	1129	177	64	169	-325	-661	1500	2.71	6.22	0.35
	2005-2006	501	591	83	94	97	-132	-232	1500	2.99	8.48	0.52
	2006-2007	652	1544	129	64	138	-313	-911	1500	2.30	7.77	0.36
	2007-2008	542	964	45	64	113	-263	-382	1500	2.77	13.76	0.35
	2008-2009	594	730	145	63	106	-247	-203	1500	2.52	7.21	0.35
	2009-2010	582	610	186	64	140	-264	-154	1500	2.58	6.00	0.36
	Average	571	928	127	69	127	-257	-424	1500	2.65	8.24	0.38
Strategy S IV Protective Irrigation	2004-2005	451	1129	96	24	159	-296	-661	702	1.56	5.85	0.13
	2005-2006	423	591	0	48	28	-55	-189	866	2.05	18.04	0.27
	2006-2007	589	1544	24	48	45	-220	-852	1004	1.71	13.95	0.27
	2007-2008	499	964	24	24	61	-231	-343	997	2.00	20.78	0.13
	2008-2009	503	730	24	48	18	-141	-176	955	1.90	13.26	0.27
	2009-2010	473	610	72	48	56	-170	-143	948	2.00	7.90	0.27
	Average	490	928	40	40	61	-186	-394	912	1.87	13.30	0.22
Strategy S V Deficit Irrigation	2004-2005	481	1129	81	90	138	-296	-661	987	2.05	5.77	0.50
	2005-2006	473	591	45	90	65	-109	-210	1347	2.85	9.98	0.50
	2006-2007	618	1544	45	90	85	-277	-868	1288	2.08	9.54	0.50
	2007-2008	527	964	45	90	75	-279	-368	1362	2.58	10.09	0.50
	2008-2009	531	730	45	90	56	-208	-182	1152	2.17	8.54	0.50
	2009-2010	482	610	117	90	84	-262	-157	999	2.07	4.83	0.50
	Average	519	928	63	90	84	-238	-408	1189	2.30	8.12	0.50
Strategy S VI Combination	2004-2005	546	1129	225	90	161	-399	-661	1482	2.72	4.71	0.50
	2005-2006	488	591	180	90	85	-200	-258	1465	3.00	5.42	0.50
	2006-2007	637	1544	135	90	104	-367	-868	1482	2.33	6.59	0.50
	2007-2008	541	964	90	90	84	-316	-371	1497	2.76	8.31	0.50
	2008-2009	560	730	135	90	74	-279	-189	1431	2.56	6.36	0.50
	2009-2010	552	610	270	90	117	-339	-197	1421	2.58	3.95	0.50
	Average	554	928	173	90	104	-317	-424	1463	2.66	5.89	0.50

Note: No. of rainy days for tuver crop period in years 2004, 2005, 2006,2007,2008 and 2009 are 38, 51, 65, 60, 54 and 38 days respectively.

in block 4A is summarized in Table 5.17. Method of irrigation applied here for Tuver is furrow, thus to obtain the total irrigation depth the values in the column 3 and 4 of Table 5.17 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth given in column 3 and 4 is 225 mm and 45mm, thus total irrigation applied is 270/0.6 = 450 mm). The data demonstrates that means of yields, WUE, and surface runoff value for strategies S III, S VI, and S II were not significantly different from each other, although the strategies could be recommended in stated order. Further, it is revealed through data that IWUE for strategies for S IV, S V, and S I decline in order stated however, their yields increase significantly, thus indicating decrease in yield is evident with rationing of water. On comparing the actual evapotranspiration values, it is evident that strategies S III, S VI, and S II, which use the water more optimally, have slightly higher values than others. The impact of irrigation strategies for tuver crop on soil moisture curve is shown in Fig 5.21 (a-f). The Fig 5.21 (a-f) and Table 5.17 demonstrate that the soil moisture stress only during the initial stage did not have a significant impact on yield, which is evident from (Fig 5.21 b and Fig 5.21 f). Tuver crop is slightly sensitive to moisture stress (Fig 5.21a), during initial mid season stage. The crop is significantly sensitive to moisture stress, during development and mid season stage (Fig 5.21d and Fig 5.21e)

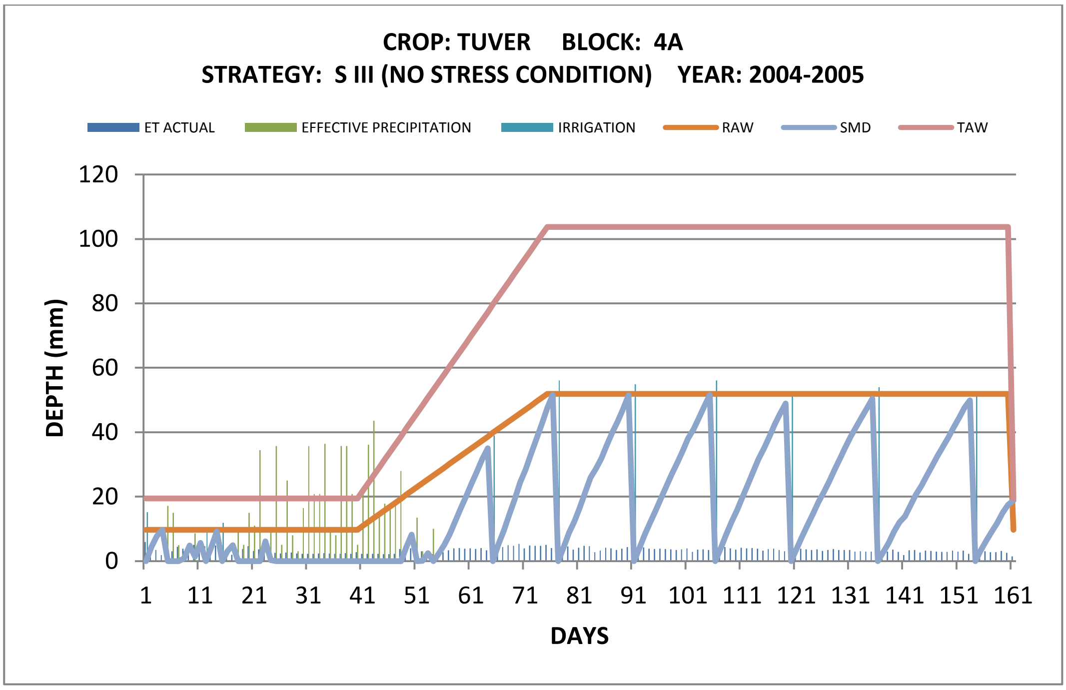


5.21(a)



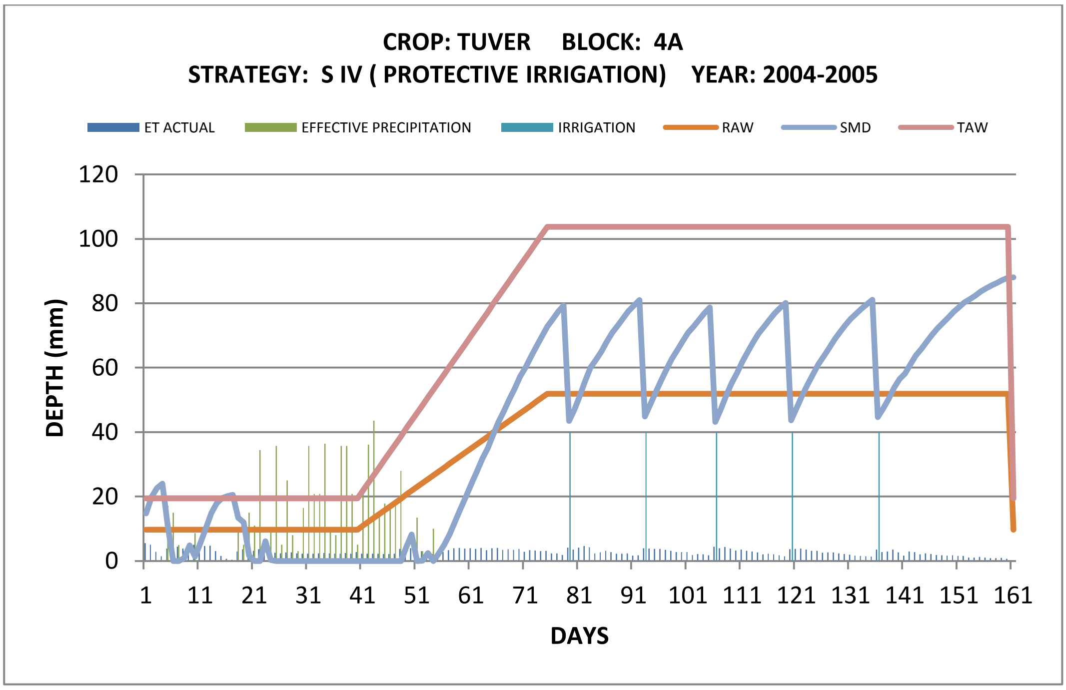
CROP: TUVER BLOCK: 4A
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

5.21 (b)

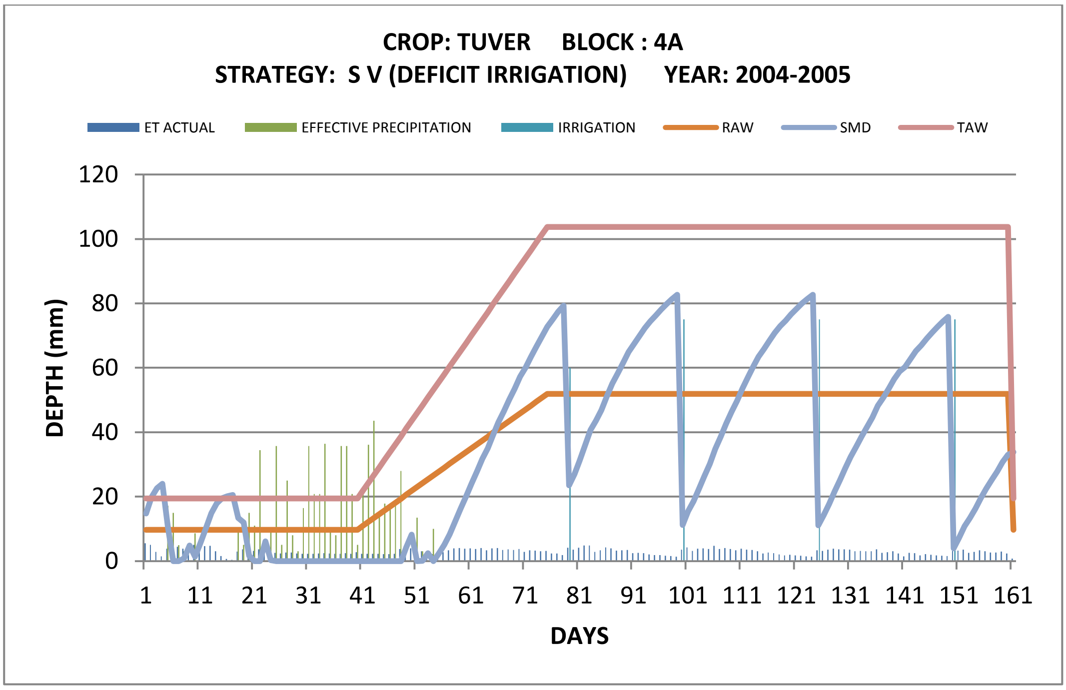


CROP: TUVER BLOCK: 4A
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

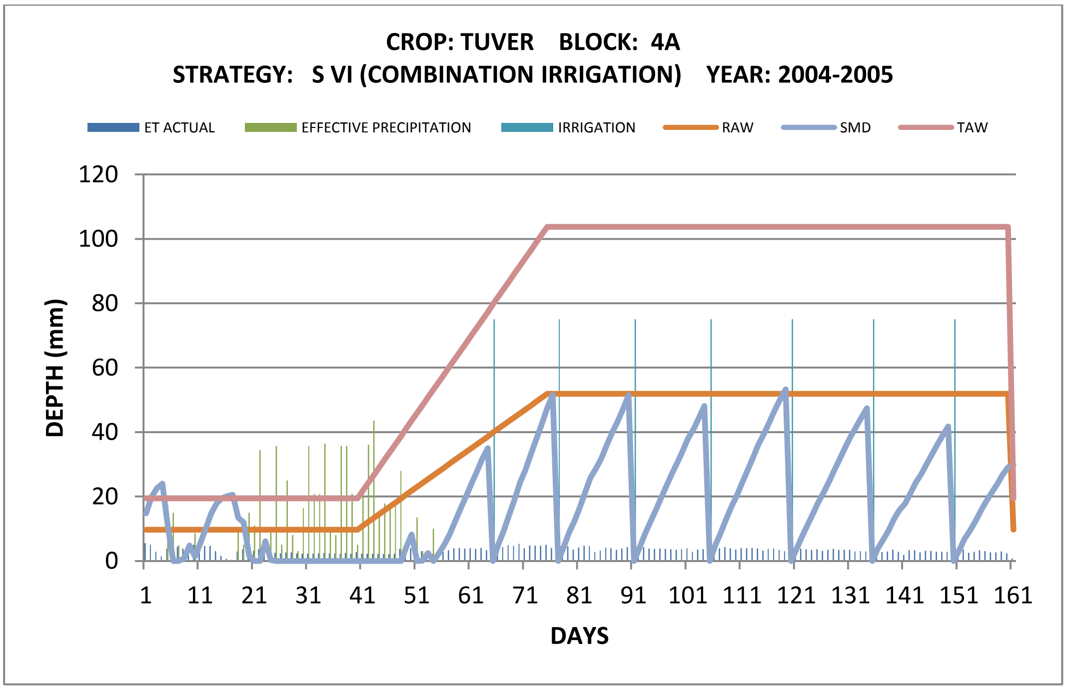
5.21 (c)


CROP: TUVER BLOCK: 4A
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

5.21 (d)


CROP: TUVER BLOCK : 4A
STRATEGY: S V (DEFICIT IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

5.21 (e)



5.21 (f)

Fig 5.21 (a-f): Soil moisture balance for irrigation strategies S I to S VI for tuver crop year 2004-2005

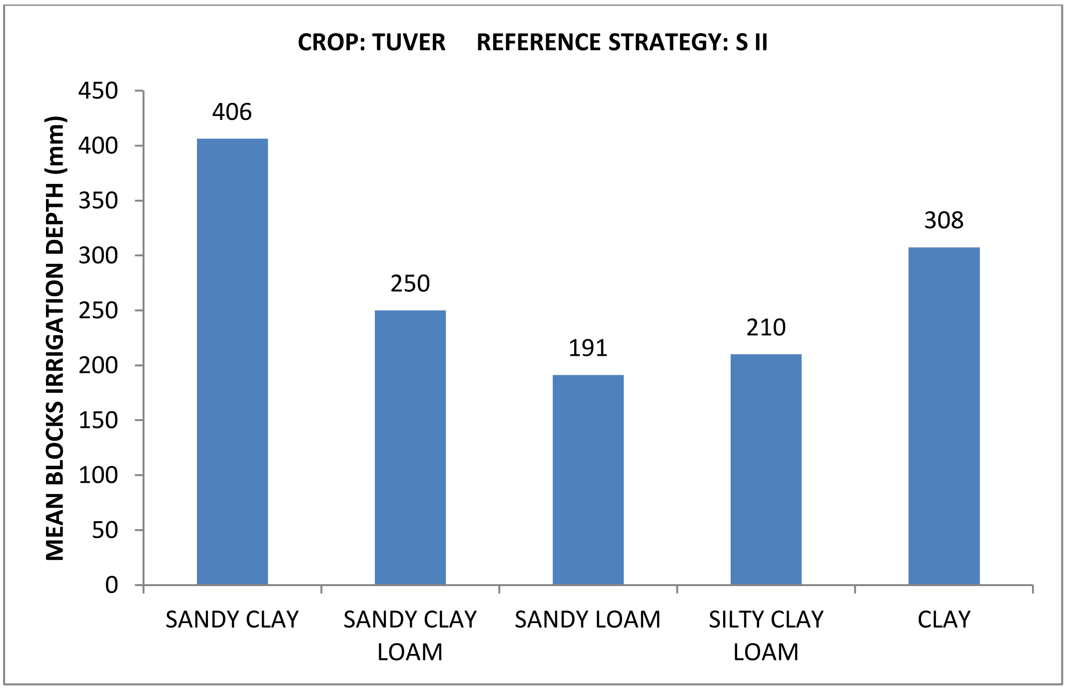


Fig 5.22: Effect of soil type on tuver irrigation depth under strategy S II

5.9.2 Effect of Soil Type on Tuver Irrigation Depth

The averages of six blocks having sandy clay soil estimated irrigation depth of 406 mm for reference strategy S II as revealed from Fig 5.22. All soils having content of loam such as sandy clay loam (3 blocks), sandy loam (2 blocks) and silty clay loam (2 blocks) did not have significant difference in values with an average irrigation depths of 250 mm, 191 mm, and 210 mm respectively. The clay soil block had irrigation depth of approximately 300mm. The impact of type of soil on irrigation depth was marginal for tuver crop.

5.9.3 Effect of Irrigation on Groundwater for Tuver

The average net groundwater withdrawals for the study period have been summarized in Table 5.18, for the blocks which have been selected for the purpose of groundwater table monitoring. The data revealed that strategy S V would result in water table rise in the all blocks, thus it could be recommended in block 6A3R2 and certain pockets, where the static water table was well below 20m causing no adverse affect in near future. All the other strategies except S I be refrained from using in block 4B due to rise in water table. Except strategy S V, any of the strategy could be used in block 8 as the water table further receded, which is very much required due to high static water level. In case of block 10 and 9A2R2 use of any of the strategy resulted in rise of water table.

5.9.4 Irrigation Depth Range for Tuver under Strategies S I to S VI

Method of irrigation applied here for Tuver is furrow, thus to obtain the total irrigation depth the values in the Figure 5.23 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth the total irrigation applied is 270/0.6 = 450 mm). Figure 1.23 reveals that irrigation strategies S II and S VI have significant variation in irrigation depth, indicating the sensitiveness towards soil, rainfall, and climatic conditions. The strategies S III, S IV, and S V did not show any significant variation in irrigation depth within itself nevertheless, on comparing each other it showed that S IV required less water than strategies S III and S V.

Table 5.18: Average net groundwater withdrawals (years 2004-2009) for tuver crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for tuver crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-2	-20	-76	-104	-126	-68
6A1	Sc	1 to 15	-22	8	-29	-44	-84	8
8	Scl	0.5to 6.5	61	36	24	-5	-38	47
10	Scl	1.5 to 18	-63	-53	-66	-69	-94	-59
11A2	Sc	3 to >30	-27	7	-21	-46	-59	13
6A3R2	C	>30	14	29	0	-9	-37	21
9A2R2	Sicl	1 to >30	-53	-39	-56	-41	-80	-51

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Tuver crop is not sown in block 6BR2 and block 9B1R2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

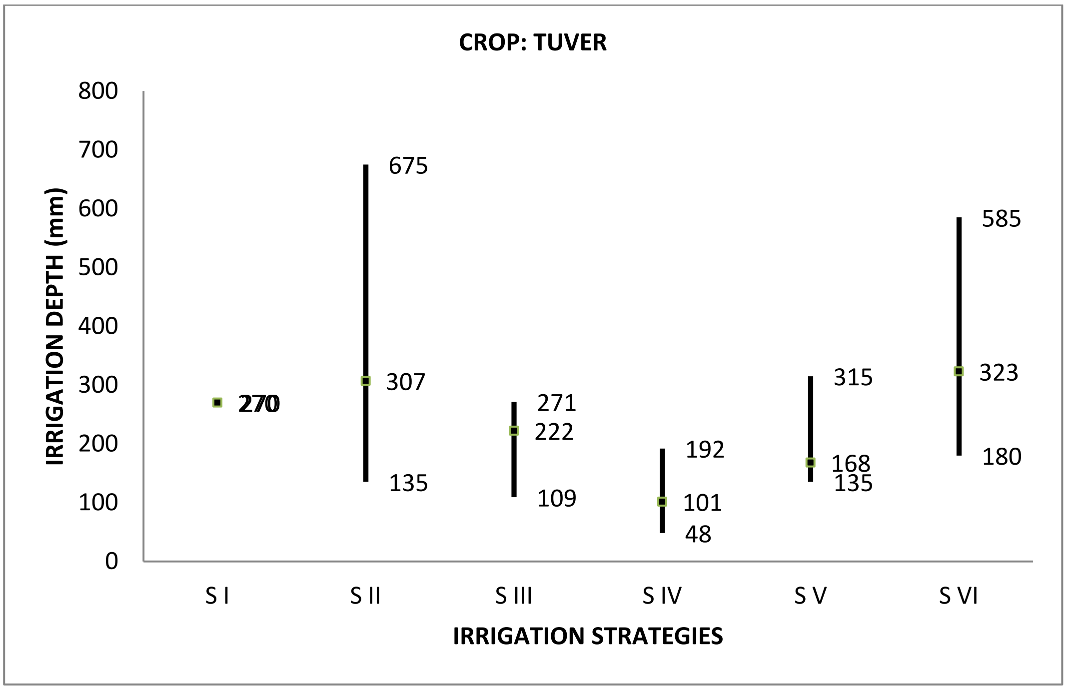


Fig 5.23: Irrigation depth range for tuver crop for Strategies S I to S VI

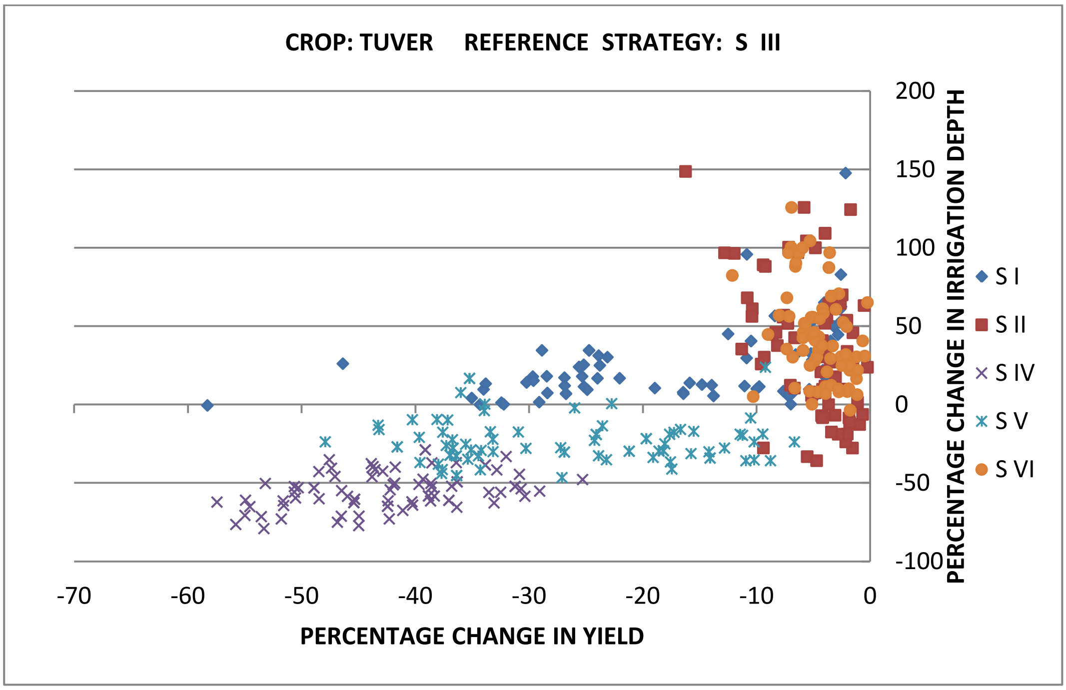


Fig 5.24: Percentage change in yield versus percentage change in irrigation depth for tuver crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.9.5 Evaluating Irrigation Strategies for Tuver

The relationship established between percentage change in yield and percentage change in irrigation depth, as revealed from Fig 5.24 demonstrate that there is not much significant reduction in average yield in strategies S VI (−4 percent) and S II (−5 percent), although former strategy uses 44 percent slightly more irrigation water depth, than later (36 percent) with respect to reference strategy S III. In spite of strategy S I using 25 percent of more water in comparison to S III, there is reduction in average yield by 17 percent, indicating the possible impact of delayed rainfall on the yield, as irrigation is applied post 40 days of sowing as part of strategy. The average reduction in yield for strategies S IV and S V are 43 percent, and 27 percent respectively with average reduction in irrigation depth by 55 percent and 24 percent respectively in comparison to reference strategy S III, making it clearly evident that with decrease in irrigation depth below optimum value the yield also significantly decreases. Little yield reduction is found in strategies S I, S II, and S VI, as irrigation is not applied in initial period as per conventional practises. Strategies best suited and recommended in order of merit for attaining significant yield and water savings simultaneously for tuver, are S III, followed by S VI, S II, and SI.

5.10 Irrigation Scheduling Strategies for Chana (Gram /Chick Pea)

Chick Pea or Gram is popularly known as chana which is grown in Rabi season in month of October or November. The sowing of crop is selected as 22nd October having 105 days of crop seasonal length. The initial depletion at starting of computation of soil water balance, for the study period is taken as zero. The maximum potential yield for chana is taken as 1600 kg per hectare. The six irrigation strategies that are employed for chana crop are elaborated in Table 5.19. (i) Strategy S I: Fixed irrigation depth is applied at fixed interval of 20 days from date of sowing. (ii) Strategy S II: Irrigation of fixed depth is given, whenever soil moisture depletion reaches 100 per cent of readily available up to 100 days of crop seasonal length.

Table 5.19: Irrigation scheduling strategies for chana crop

Case	Irrigation Strategy for chana		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1, 21, 41, 61, 81& 101	80mm	Irrigation of 80 mm fixed depth is applied at a fixed interval of 20days subsequently.
S II	1- 100	80 mm	Irrigation of 80 mm depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-105	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	1- 100	40 mm,	Irrigation of fixed depth of 40 mm is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S V	1, 29, 50, 71 & 92	60mm	Irrigation of 60 mm fixed depth is applied at fixed interval days subsequently.
S VI	1- 100	40mm	Irrigation of 40 mm fixed depth is applied at fixed interval of 14 days subsequently from date of sowing.

** From date of sowing. Date of sowing 22nd October and Harvesting on 3rd February.*

(iii) Strategy S III: During its entire crop seasonal length irrigation equivalent to soil moisture depletion is applied, when the soil moisture depletion equals 100 per cent of readily available water. (iv.) Strategy S IV: Protective irrigation of reduced fixed irrigation depth is given, when 20 percent per cent moisture is left in root zone. (v) Strategy S V: Fixed irrigation depth is applied on fixed days from date of sowing, keeping in mind the critical growth stages, where moisture stress could significantly lead to lesser yield, and (vi) Strategy S VI: Half of the normal irrigation depth is applied at interval of fortnight.

5.10.1 Water Balance, Yield and Efficiencies for Chana

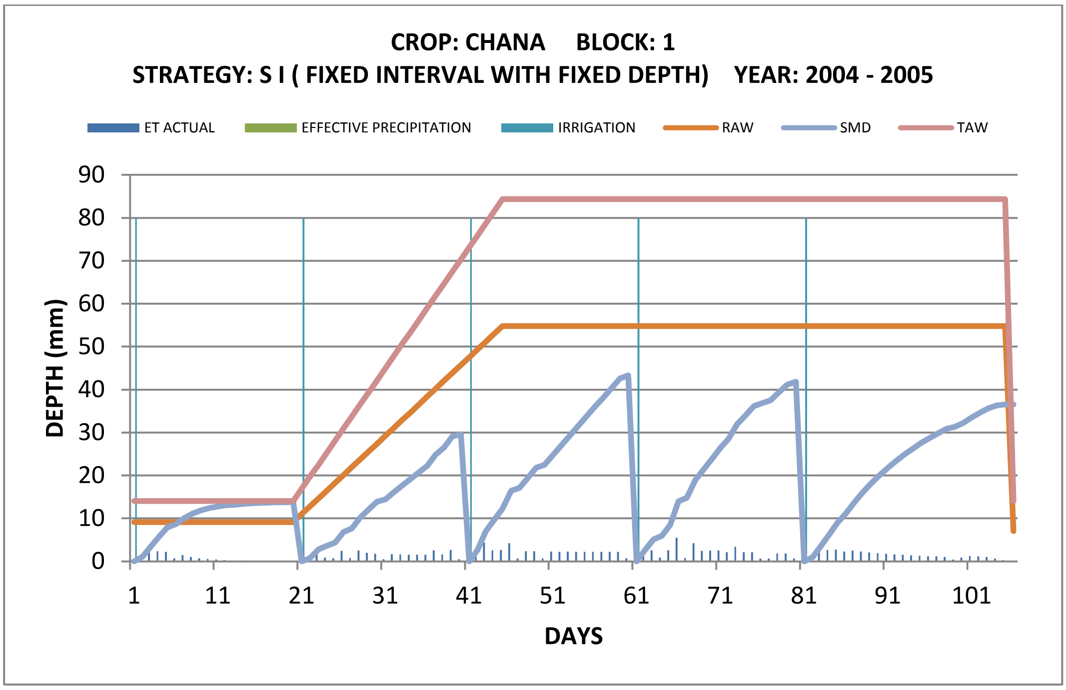
Table 5.20 data summarizes the soil water balance, yield and efficiencies for the chana crop for block1. Daily water balance was calculated, for all the blocks and all six irrigation strategies for the study period. As the results of all the blocks would be nearly on similar lines, although with minor difference, depending on soil, rainfall, and climatic conditions, results of only block1 has been illustrated, to give effect of the various strategies. Method of irrigation applied here for chana is furrow, thus to obtain the total irrigation depth the values in the column 3 and 4 of Table 5.20 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth given in column 3 and 4 is 48 mm and 192 mm, thus total irrigation applied is 240/0.6 = 400 mm). The tabular data revealed that strategy S III was with no doubt the best irrigation strategy in all terms of yield, efficiencies, and savings water. Strategy S II though maximized in potential yield, actual evapotranspiration, irrigation water, and losses due to run off and flow to groundwater stood far behind the other irrigation strategies, when IWUE and savings in water was considered, indicating better optimization of irrigation water was required. Strategy S VI though having slight reduction in yield compared to ideal no stress condition strategy, showed significantly better values for actual evapotranspiration, WUE, IWUE, losses due to surface runoff and flow to groundwater, thus it could be preferred over other strategies considering water savings with slight compromise with yield. The remaining strategies S I, S IV, and S V had nearly similar yields although, S V was slightly better placed than other two, when WUE, IWUE, water losses due to surface runoff and flow to ground water was to be considered. Further, it shows that strategy S IV could be preferred over strategy S I, when water savings was the prime objective.

The Fig 5.25 (a-f) clearly shows that no moisture stress is seen in strategies S III and S II in any stages of growth, thus it would give maximum potential yield (refer Table 5.20). Further, to note that in strategy S II if the irrigation depth in initial stages is reduced, the savings in water would be substantial. On looking at soil moisture depletion curve in Fig 5.25(a-f) for strategies S I, S IV, S V, and S VI the soil moisture stress is visible at different stages in initial stage for the mentioned strategies, although resulting into different yield reduction. This indicates that crop is more sensitive to water stress during late initial stage (Fig 5.25 f).

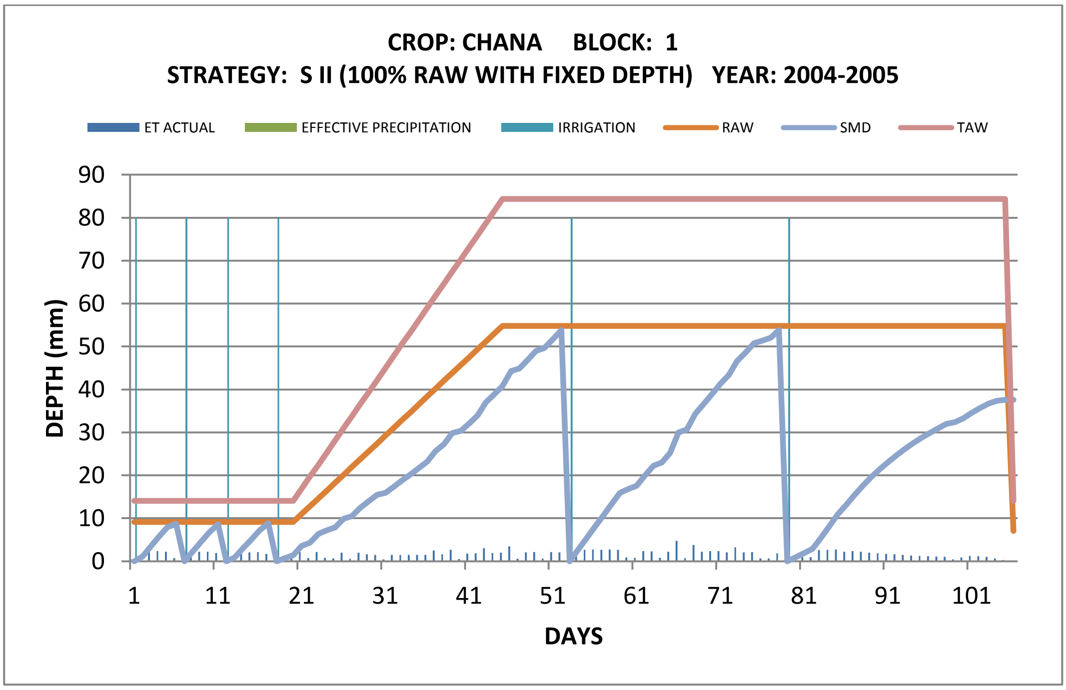
Table 5.20: Water balance, yield and efficiencies of chana crop in sandy clay (HSG – C) soil in block 1 (grown in 4.54% of CCA 9868 ha)

Irrigation Strategies for chana	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Runoff	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	169	0	48	192	79	-74	-76	1474	8.72	6.14	0.86
	2005-2006	203	6	48	192	90	-58	-74	1427	7.02	5.95	0.86
	2006-2007	219	0	48	192	107	-56	-71	1419	6.47	5.91	0.86
	2007-2008	205	0	48	192	103	-56	-81	1419	6.92	5.91	0.86
	2008-2009	269	0	48	192	131	-35	-67	1247	4.63	5.20	0.86
	2009-2010	277	0	48	192	137	-35	-64	1153	4.16	4.81	0.86
	Average	224	1	48	192	108	-52	-72	1357	6.32	5.65	0.86
Strategy S II 100% RAW with F.D.	2004-2005	180	0	96	192	84	-45	-146	1600	8.89	5.56	0.86
	2005-2006	227	6	144	240	85	-63	-185	1600	7.05	4.17	1.08
	2006-2007	256	0	144	288	114	-69	-221	1600	6.26	3.70	1.29
	2007-2008	235	0	96	288	98	-63	-184	1600	6.81	4.17	1.29
	2008-2009	343	0	192	384	138	-101	-270	1600	4.67	2.78	1.72
	2009-2010	359	0	192	384	152	-99	-270	1600	4.46	2.78	1.72
	Average	267	1	144	296	112	-73	-213	1600	6.35	3.86	1.33
Strategy S III No Stress	2004-2005	195	0	24	73	99	0	0	1600	8.18	16.56	0.33
	2005-2006	226	6	17	113	90	0	0	1600	7.08	12.28	0.51
	2006-2007	220	0	24	106	91	0	0	1600	7.26	12.35	0.47
	2007-2008	191	0	24	73	95	0	0	1600	8.36	16.58	0.33
	2008-2009	232	0	23	111	97	0	0	1600	6.91	11.93	0.50
	2009-2010	250	0	23	112	114	0	0	1600	6.40	11.80	0.50
	Average	219	1	22	98	98	0	0	1600	7.37	13.59	0.44
Strategy S IV Protective Irrigation	2004-2005	206	0	48	120	102	-16	-48	1338	6.49	7.96	0.54
	2005-2006	225	6	48	120	114	-17	-46	1349	5.99	8.03	0.54
	2006-2007	229	0	48	144	117	-21	-60	1337	5.84	6.96	0.65
	2007-2008	202	0	48	120	97	-16	-47	1355	6.71	8.07	0.54
	2008-2009	234	0	48	144	122	-21	-59	1325	5.65	6.90	0.65
	2009-2010	261	0	72	144	126	-20	-60	1376	5.27	6.37	0.65
	Average	226	1	52	132	113	-18	-53	1347	5.99	7.38	0.59
Strategy S V Deficit Irrigation	2004-2005	191	0	36	144	80	-37	-33	1386	7.26	7.70	0.65
	2005-2006	214	6	36	144	89	-29	-33	1433	6.71	7.96	0.65
	2006-2007	206	0	36	144	88	-30	-32	1384	6.73	7.69	0.65
	2007-2008	185	0	36	144	77	-39	-33	1386	7.47	7.70	0.65
	2008-2009	211	0	36	144	90	-27	-32	1376	6.52	7.65	0.65
	2009-2010	228	0	36	144	100	-19	-33	1351	5.92	7.50	0.65
	Average	206	1	36	144	87	-30	-33	1386	6.77	7.70	0.65
Strategy S VI Combination	2004-2005	218	0	24	168	85	-39	-20	1506	6.92	7.85	0.75
	2005-2006	238	6	24	168	92	-32	-20	1549	6.52	8.07	0.75
	2006-2007	234	0	24	168	92	-30	-20	1506	6.45	7.84	0.75
	2007-2008	212	0	24	168	82	-41	-21	1506	7.11	7.84	0.75
	2008-2009	239	0	24	168	95	-28	-20	1493	6.24	7.78	0.75
	2009-2010	257	0	24	168	106	-20	-20	1479	5.75	7.70	0.75
	Average	233	1	24	168	92	-32	-20	1507	6.50	7.85	0.75

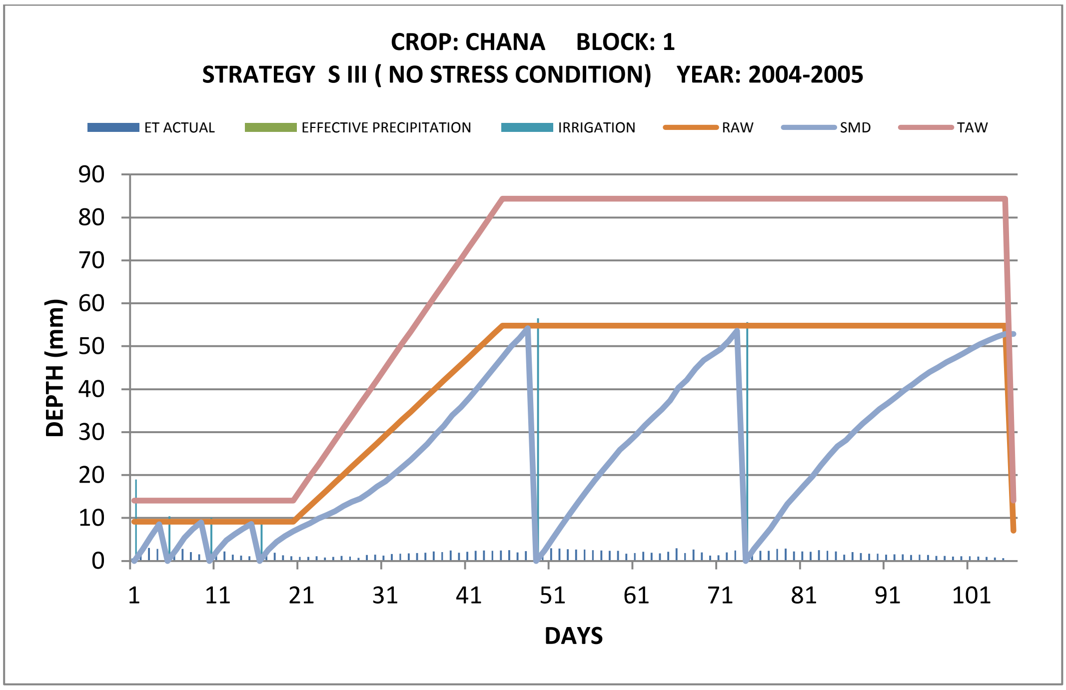
Note: No. of rainy days for tuver crop period in years 2004, 2005, 2006,2007,2008 and 2009 are 0, 1, 0, 0, 0 and 0 days respectively.


CROP: CHANA BLOCK: 1
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004 - 2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
DAYS

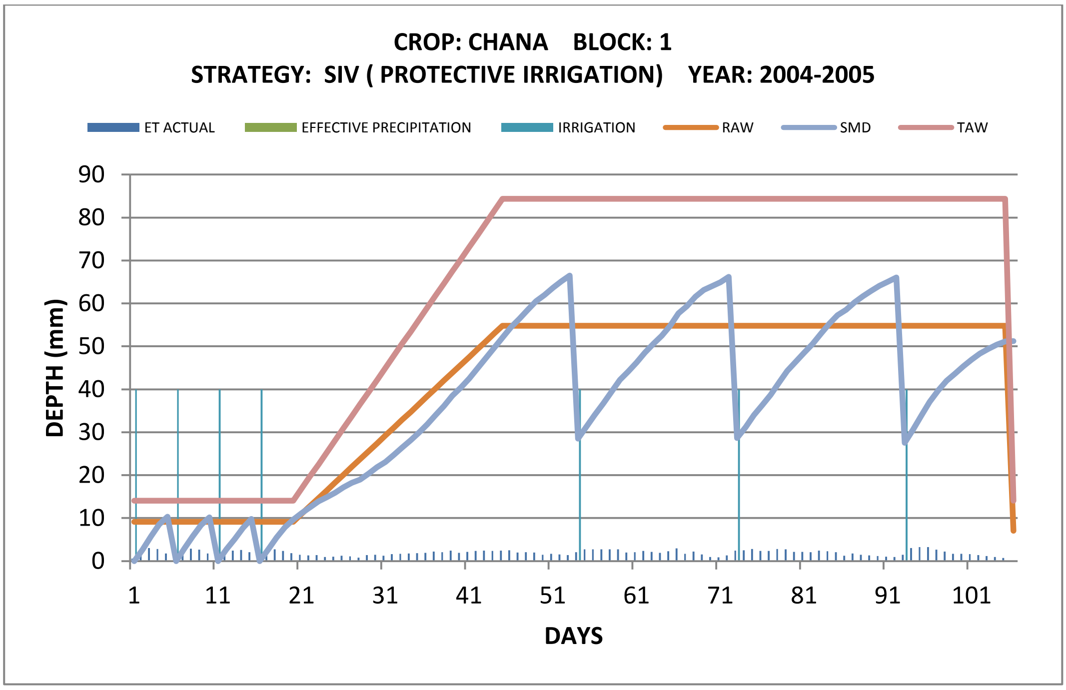
5.25 (a)


CROP: CHANA BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
DAYS

5.25 (b)


CROP: CHANA BLOCK: 1
STRATEGY S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS

5.25 (c)


CROP: CHANA BLOCK: 1
STRATEGY: SIV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
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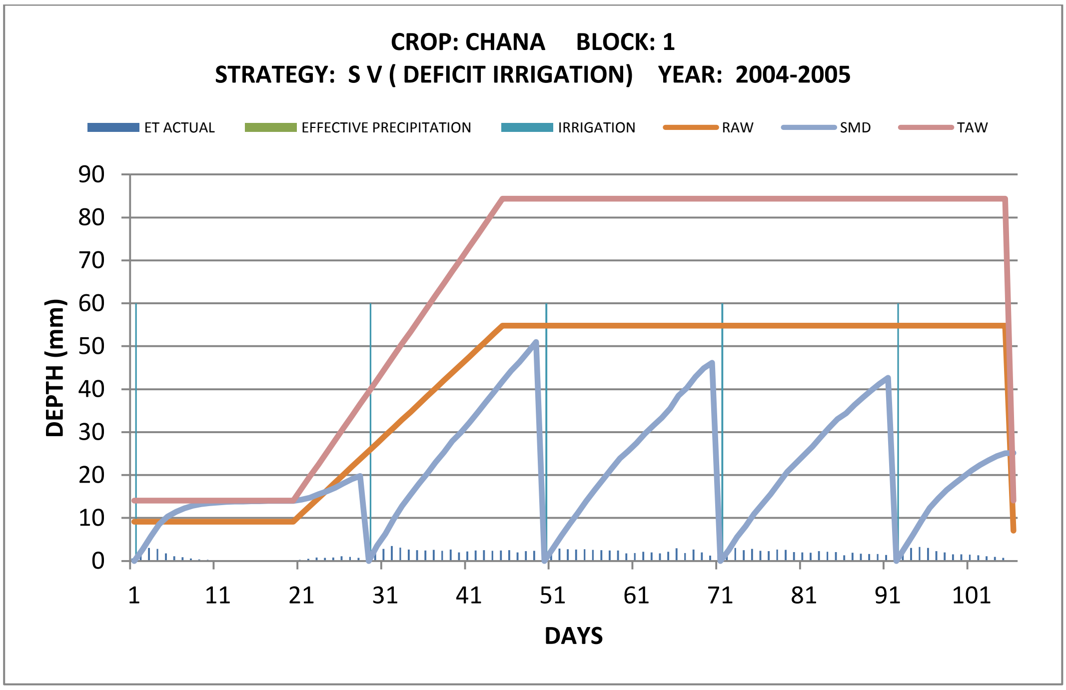
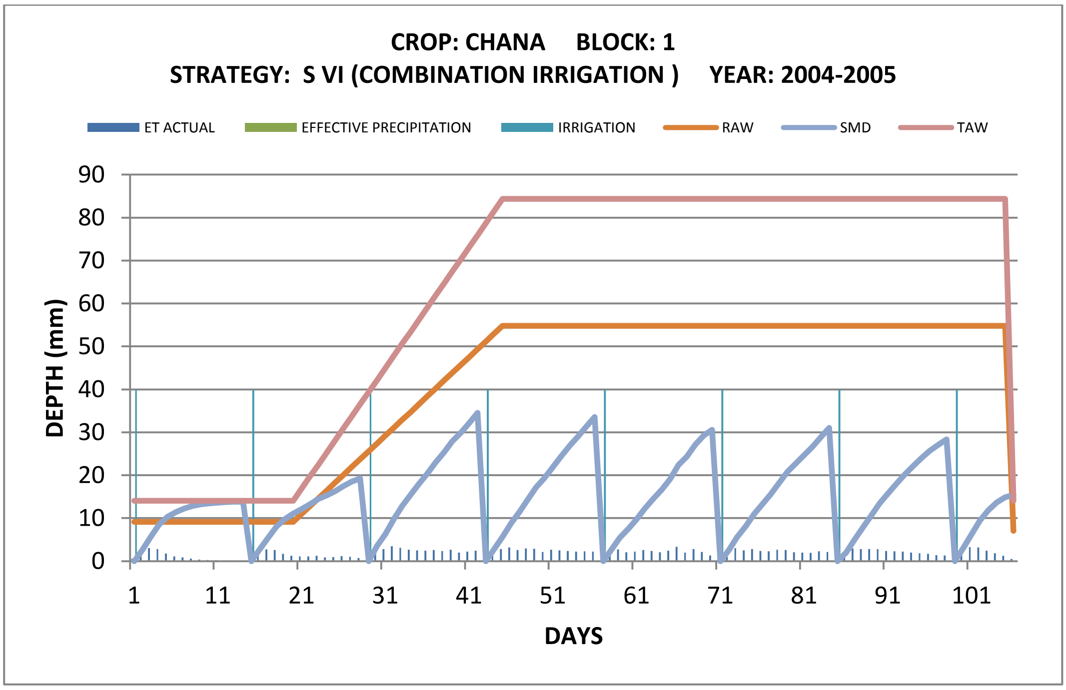
TAW
DEPTH (mm)
DAYS

5.25 (d)



5.25 (e)



5.25 (f)

Fig 5.25 (a-f): Soil moisture balance for irrigation strategies S I to S VI for chana crop year 2004-2005

It is evident from figure that in strategy S VI the crop is not facing moisture stress during late initial stage, thus yield is significantly higher than strategies S I, S IV, and S V. The crop is not much sensitive to moisture stress during mid season, which is evident from Fig 5.25 d. The moisture stress during mid season stage in strategy IV does not have significant reduction in yield, when compared with other strategies which show no moisture stress during mid season stage. It is clearly evident from Fig 5.25 and Table 5.20 that the reduction in yield is more in strategy S V than S I, due to prolonging of moisture stress even during initial development stage.

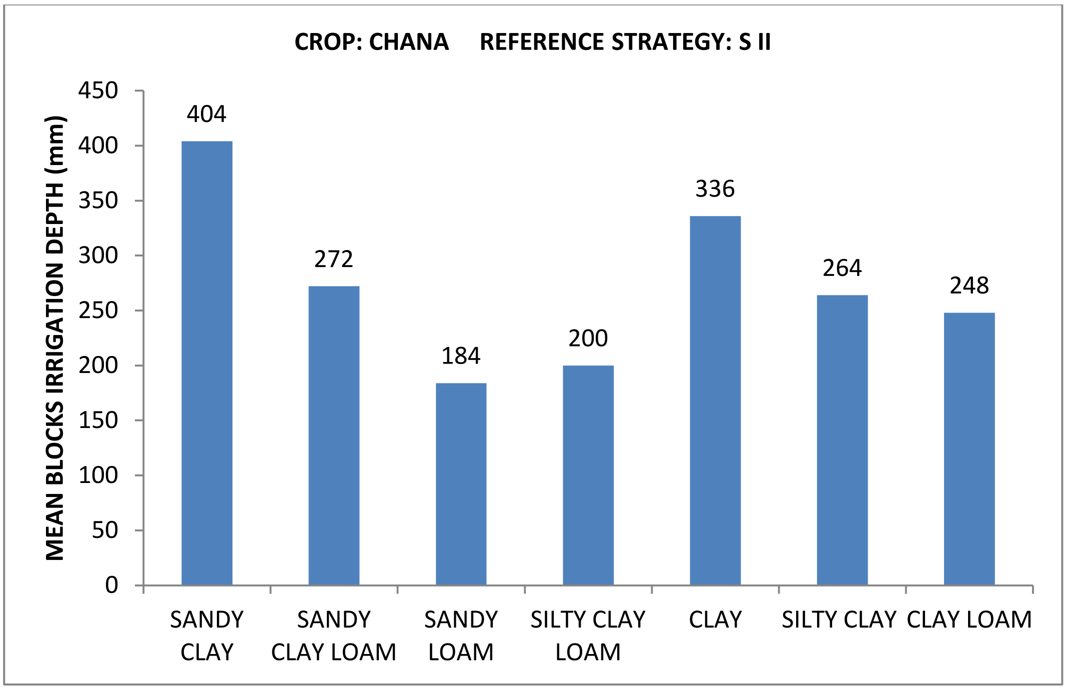


Fig 5.26: Effect of soil type on chana irrigation depth under strategy S II

5.10.2 Effect of Soil Type on Chana Irrigation Depth

The influence of soil type on irrigation depth was demonstrated by Fig 5.26 where strategy S II was taken as reference as it would give maximum potential yield with the maximum amount of water for particular type of soil without creating any moisture stress conditions. Fig 5.26 clearly show that average irrigation depth for 10 blocks of sandy clay soil required 400 mm of water. Average irrigation depth for three blocks of sandy clay loam, one block of silty clay and one block of clay loam required approximately same amount of irrigation depth of 270 mm with marginal reduction of 22 mm for clay loam. Both sandy loam and silty clay loam had negligible difference in irrigation depth which required approximately 200 mm amount of water for irrigation.

5.10.3 Effect of Irrigation on Groundwater for Chana

Table 5.21 data revealed the average net groundwater withdrawals for chana crop for the blocks selected with the purpose, of monitoring the groundwater scenario during the study period. It is found that strategies S I and S VI mildly influence the rise in the water table. Strategy S V does not contribute much in rise or fall of groundwater. Strategy S II helps in reduction in groundwater rise moderately, while strategies S III and SIV demonstrate very mild reduction in water table.

5.10.4 Irrigation Depth for Chana under Strategies S I to S VI

To study the impact of irrigation depth across various strategies Fig 5.27 has been shown. Method of irrigation applied here for chana is furrow, thus to obtain the total irrigation depth the values in the Figure 5.27 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth the total irrigation applied is 240/0.6 = 400 mm). Strategies S I, SV and S VI fall under the ambit of fixed depth. Higher variability in range of irrigation depth is seen in strategy S II indicating the significant influence of soil, rainfall and climatic conditions on the strategy. Strategies S III and S IV show low variability in irrigation depth, although strategy S IV requires slightly more irrigation than the no stress condition strategy S III.

Table 5.21: Average net groundwater withdrawals (years 2004-2009) for chana crop period under strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for chana crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-4	71	25	34	6	-7
6A1	Sc	1 to 15	-21	89	26	32	0	-12
8	Scl	0.5to 6.5	-21	89	24	31	0	-13
10	Scl	1.5 to 18	-33	68	22	16	-11	-18
11A2	Sc	3 to >30	-21	89	24	31	0	-13
6A3R2	C	>30	-18	95	28	32	6	-5
6BR2	Sic	1.2to>30	-21	76	30	31	2	-5
9B1R2	Cl	0.5 to 23	-34	67	24	19	-11	-18

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Chana crop is not sown in block 9A2R2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

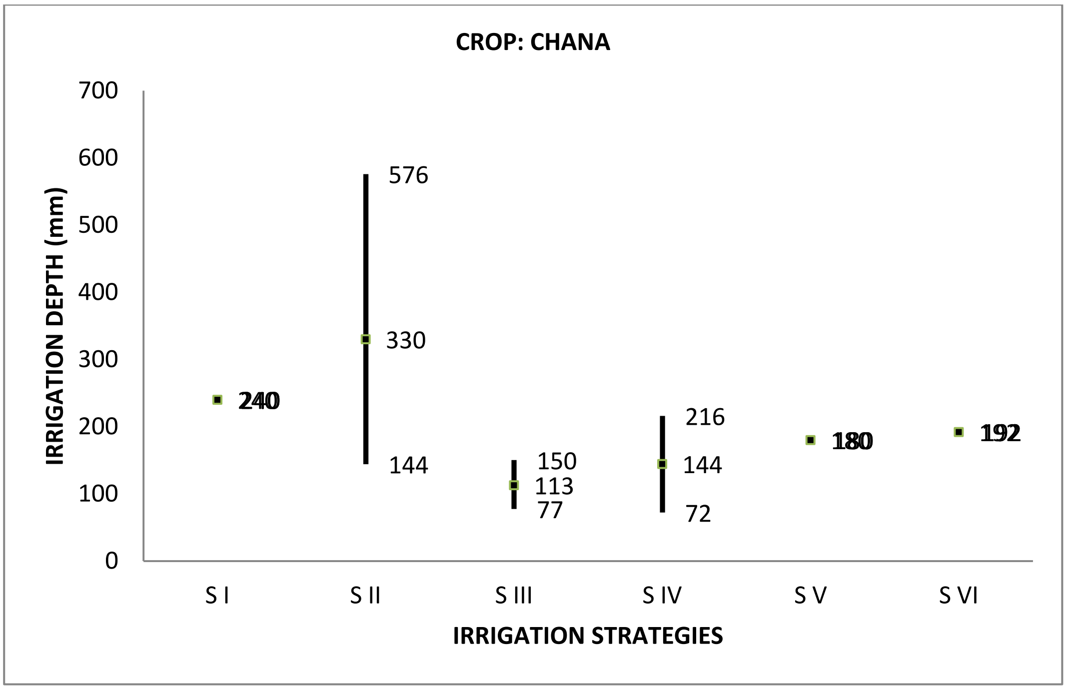


Fig 5.27: Irrigation depth range for chana crop for strategies S I to S VI

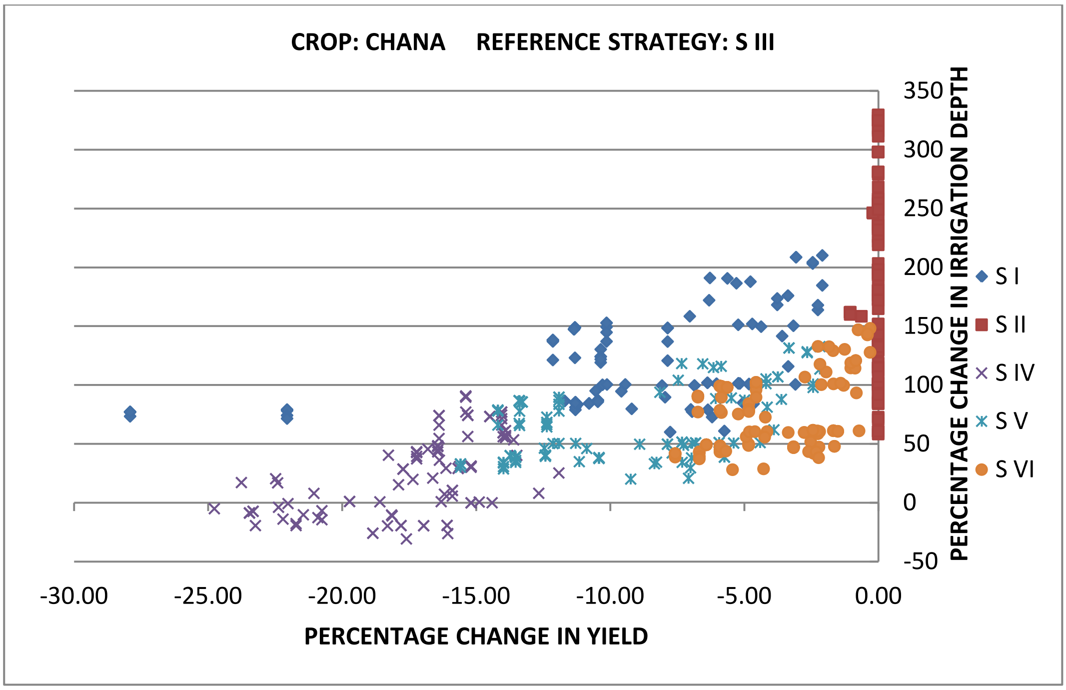


Fig 5.28: Percentage change in yield versus percentage change in irrigation depth for chana crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.10.5 Evaluating Irrigation Strategies for Chana

The relationship derived between percentage change in yield and percentage change in irrigation depth, with respect to ideal no moisture stress condition strategy S III show that strategy S II is best in terms of attaining potential yield nevertheless, with higher variability and increase in irrigation depth in range of 58 percent to 329 percent, with an average increase of irrigation depth of 191 percent. Strategy S VI has low variability in yield reduction with range 0 percent to 8 percent and average reduction in yield of 4 percent. On comparing with reference strategy S III, strategy S VI shows percentage increase in irrigation depth in range 28 percent to 148 percent, with average increase of 75 percent. Average yield reduction (10 percent) for strategy S I and S V is identical, although with slightly higher reduction in yield in some case is visible for strategy S I. This occurs during dry year 2009 in blocks 1, 2, 3A, 3B, 4A, and 4B probably due to higher soil moisture depletion because of early withdrawal of monsoon resulting in water stress. Strategy S I (119 percent) have slightly more average increase in irrigation depth than strategy S V (64 percent). Strategy S IV has average percentage reduction in yield of 17 percent and range of 12 percent to 25 percent reduction yield, although with range of percentage change in irrigation depth of -31 percent to 90 percent and average percentage increase of 29 percent. Strategies best suited, and recommended in order of merit for attaining significant yield and water savings simultaneously for chana, are S III, followed by S VI, S II, and SI.

5.11 Irrigation Scheduling Strategies for Sugarcane

Sugarcane is a perennial crop grown in different seasons. The crop selected here is a 10 month crop grown in 1st July having a crop seasonal length of 320 days. The initial depletion is taken as zero at the starting of computation of soil water balance for the study period. The maximum potential yield for the sugarcane crop is taken as 75000 kg per hectare. The irrigation strategies decided for sugarcane have been summarized in Table 5.22, which is as follows: (i) Strategy S I: Fixed irrigation depth is applied at gap of 15 days from sowing.

Table 5.22: Irrigation scheduling strategies for sugarcane crop

Case	Irrigation Strategy for sugarcane		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1-300	125 mm	Irrigation of 125 mm fixed depth is applied at a fixed interval of 15days subsequently
S II	30- 300	125 mm	Irrigation of 125 mm depth is applied, as moisture level reaches at 100 percent of readily available water from 30 days post date of sowing.
S III	1-320	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	1- 300	75 mm,	Irrigation of fixed depth of 75 mm is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S VI	30-105 110-260 270-300	125mm 125 mm 125 mm	Irrigation of 125 mm depth is applied, as moisture level reaches at 100 percent of readily available water. Irrigation of 125 mm fixed depth is applied at a fixed interval of 15days subsequently. Irrigation of 125 mm fixed depth is applied at a fixed interval of 10 days subsequently.

* From date of sowing. Date of sowing 1st July and Harvesting on 15th May.

(ii) Strategy S II: Irrigation of fixed depth is applied post initial crop growth stage upto 300 days of sowing, and irrigation is triggered, whenever moisture depletion reaches 100 per cent of readily available water. (iii) Strategy S III: Irrigation is triggered, whenever moisture depletion reaches 100 per cent of readily available water, and amount of irrigation applied is equivalent to soil moisture depletion. (iv.) Strategy S IV: Protective irrigation of reduced fixed depth is applied upto 300 days of sowing, and irrigation is triggered whenever soil moisture depletion reaches 80 percent of total available water. (v) Strategy S V: Deficit irrigation strategy for sugarcane is not employed. (vi.) Strategy SVI: In this strategy irrigation is applied differently for three phases. In first phase, from post initial stage to 105 days of sowing the irrigation equivalent to 100 per cent of readily available water is applied, when moisture depletion equals readily available water. In second phase, irrigation of fixed depth is applied at gap of 15 days from 110 days of sowing up to 260 days of sowing. In third phase, irrigations of fixed depth is applied at 10 day gap from 270 days of sowing. For each strategy (number of blocks ✖ number of years) 66 simulations are carried out for sugarcane crop.

5.11.1 Water Balance, Yield and Efficiencies for Sugarcane

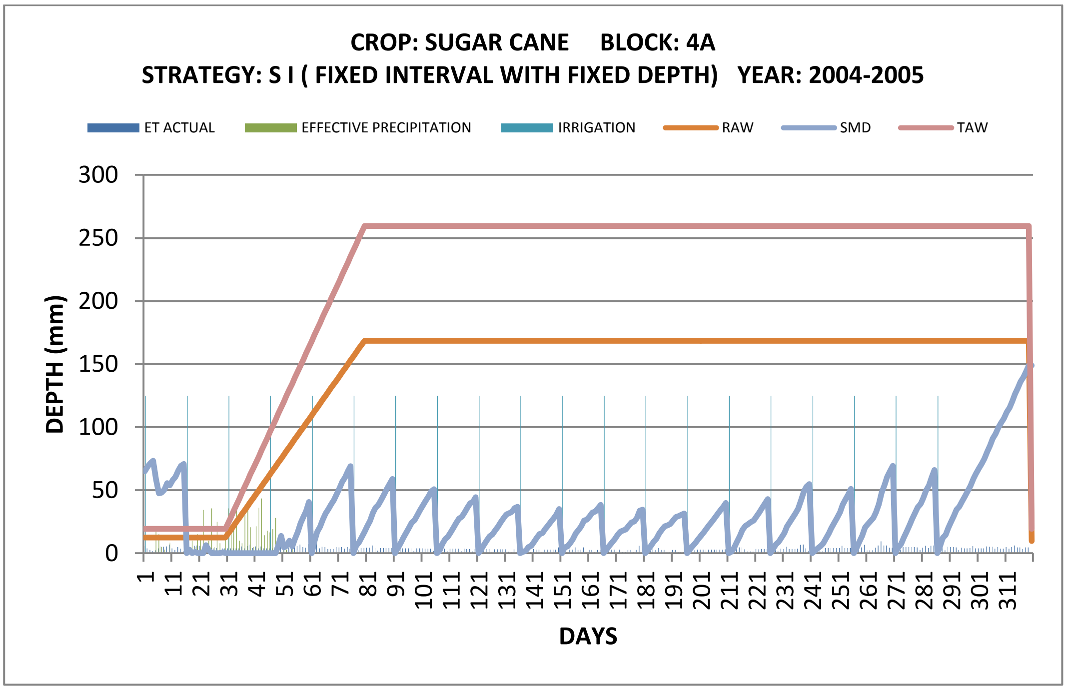
Daily soil moisture balance was calculated for all the treatments for study period in eleven blocks where sugarcane is grown. As it would be cumbersome to discuss the results for all the blocks only results of block4A has been summarized in Table 5.23. In sugarcane furrow irrigation method is applied, thus to obtain the total irrigation depth the values in the column 3 and 4 of Table 5.23 are required to be divided by fraction wetted 0.6 (for e.g. in strategy S I depth given in column 3 and 4 is 675 mm and 825 mm, thus total irrigation applied is 1500/0.6 = 2500 mm).The data of table demonstrate that Strategy S III was best suited with highest yield, WUE, and IWUE. It is also observed that yield was high at any instance, when amount of irrigation was large for e.g. strategies S I and S VI, except strategy S III, where irrigation is given equivalent to soil moisture stress conditions only at that point of time. Further, on comparing the average yields over strategies S II (yield=63511 kg/ha; irrigation=613mm), and S VI (yield=67331 kg/ha; irrigation=845mm), it is evident that relatively higher yield was obtained with larger amount of irrigation even though starting of irrigation and cut off period was same. As values of WUE and IWUE are dependent on irrigation applied we see that when rationing of water was not done, WUE increased and IWUE decreased, which is clearly evident from comparing the values of S VI and S II.

The influence of the irrigation strategies on soil moisture pattern has been shown in Fig 5.29 (a-e). At the same time the results data of block 4A is also given in Table 5.23. On studying both together it is clear that strategy S I had significantly high yield as moisture stress is visible only during the starting of initial stages. In strategy S II, as it was decided to irrigate only, after the initial stage presuming that sufficient moisture would be present in soil after sowing, this was done to reduce the number of irrigations. The moisture stress during initial stage has resulted in reducing the yield to certain extent. The yield obtained in strategy S III is maximized, as no stress was seen. The sugarcane was sensitive to moisture stress during mid season stage, which was reflected through yield reduction in strategy S IV. Relatively higher yield is attained with more frequent irrigations, were ratified while comparing SII and SVI.

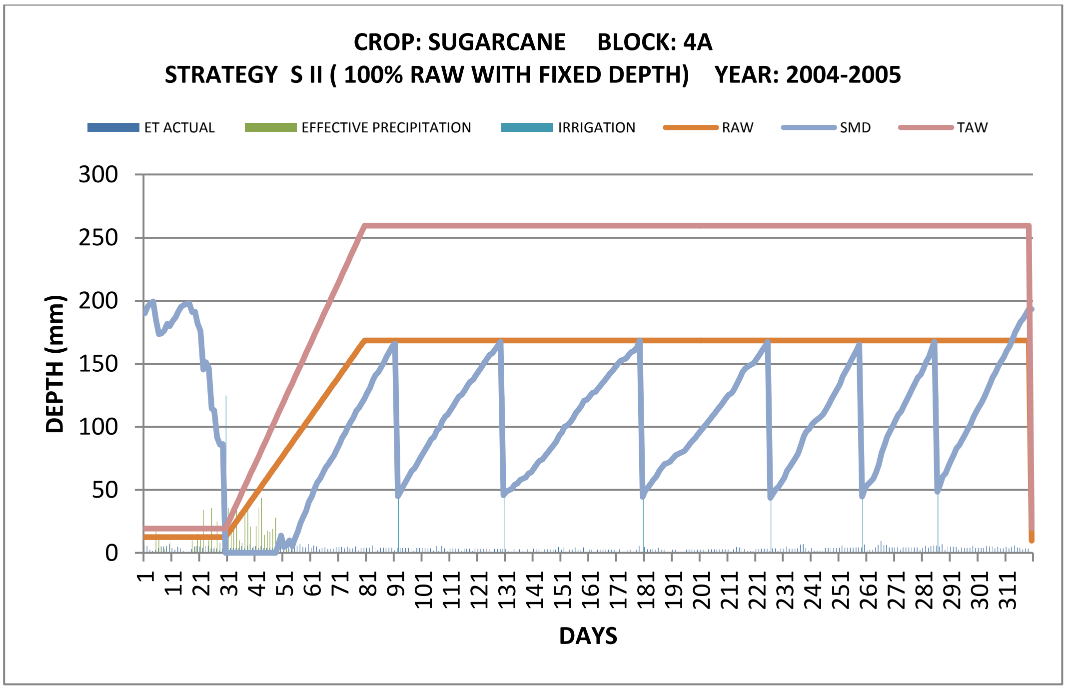
Table 5.23: Water balance, yield and efficiencies of sugarcane crop in sandy clay loam (HSG – C) soil in block 4A (grown in 1.83% of CCA 6831 ha)

Irrigation Strategies for Sugarcane	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	1205	1129	675	825	355	-1118	-661	72013	59.75	48.01	1.03
	2005-2006	1272	591	675	825	390	-854	-356	67179	52.83	44.79	1.03
	2006-2007	1583	1544	675	825	480	-1014	-927	73093	46.18	48.73	1.03
	2007-2008	1371	964	675	825	374	-968	-498	74431	54.28	49.62	1.03
	2008-2009	1650	730	675	825	496	-747	-328	61603	37.33	41.07	1.03
	2009-2010	1798	610	675	825	576	-633	-256	68025	37.84	45.35	1.03
	Average	1480	928	675	825	445	-889	-504	69391	48.03	46.26	1.03
Strategy S II 100% RAW with F.D.	2004-2005	1167	1129	150	375	339	-326	-500	67782	58.07	129.11	0.47
	2005-2006	1245	591	225	375	360	-62	-244	64265	51.60	107.11	0.47
	2006-2007	1535	1544	75	450	377	-211	-699	66265	43.16	126.22	0.56
	2007-2008	1352	964	75	450	291	-95	-333	70489	52.13	134.26	0.56
	2008-2009	1612	730	75	600	482	-117	-158	55517	34.44	82.25	0.75
	2009-2010	1730	610	225	600	501	-42	-164	56750	32.81	68.79	0.75
	Average	1440	928	138	475	392	-142	-350	63511	45.37	107.96	0.59
Strategy S III No Stress	2004-2005	1217	1129	322	409	339	-447	-535	75000	61.63	102.61	0.51
	2005-2006	1156	591	128	411	343	-112	-205	75000	64.88	139.27	0.51
	2006-2007	1387	1544	34	514	471	-356	-821	75000	54.08	136.72	0.64
	2007-2008	1181	964	41	406	372	-258	-345	75000	63.49	167.50	0.51
	2008-2009	1358	730	137	512	406	-242	-185	75000	55.21	115.53	0.64
	2009-2010	1407	610	217	614	386	-166	-152	75000	53.32	90.28	0.77
	Average	1284	928	147	478	386	-263	-374	75000	58.77	125.32	0.60
Strategy S IV Protective Irrigation	2004-2005	1077	1129	225	360	413	-471	-579	45382	42.12	77.58	0.45
	2005-2006	1046	591	225	315	306	-124	-268	47864	45.77	88.64	0.39
	2006-2007	1255	1544	225	360	360	-373	-862	46583	37.13	79.63	0.45
	2007-2008	1090	964	135	315	280	-259	-345	50977	46.75	113.28	0.39
	2008-2009	1243	730	270	405	364	-258	-268	50207	40.39	74.38	0.51
	2009-2010	1278	610	180	450	386	-173	-176	50404	39.45	80.01	0.56
	Average	1165	928	210	368	352	-276	-416	48569	41.93	85.59	0.46
Strategy S VI Combination	2004-2005	1210	1129	150	720	356	-647	-498	68572	56.67	78.82	0.90
	2005-2006	1147	591	150	720	324	-414	-224	66326	57.84	76.24	0.90
	2006-2007	1370	1544	60	720	370	-566	-757	69370	50.62	88.94	0.90
	2007-2008	1207	964	60	840	264	-631	-290	73093	60.55	81.21	1.05
	2008-2009	1343	730	105	720	416	-468	-160	63291	47.14	76.72	0.90
	2009-2010	1381	610	105	720	382	-299	-137	63332	45.87	76.77	0.90
	Average	1276	928	105	740	352	-504	-344	67331	53.11	79.78	0.93

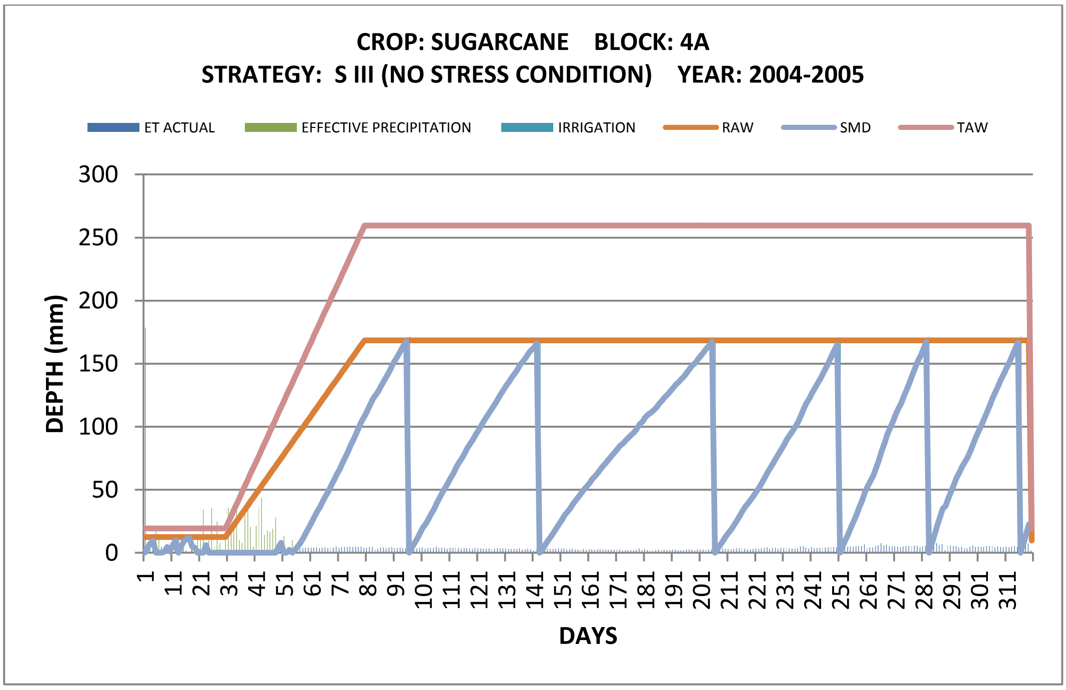
Note: No. of rainy days for sugarcane crop in year 2004, 2005, 2006,2007,2008 and 2009 are 38, 51, 66, 60, 54 and 38 days respectively.


CROP: SUGAR CANE BLOCK: 4A
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS

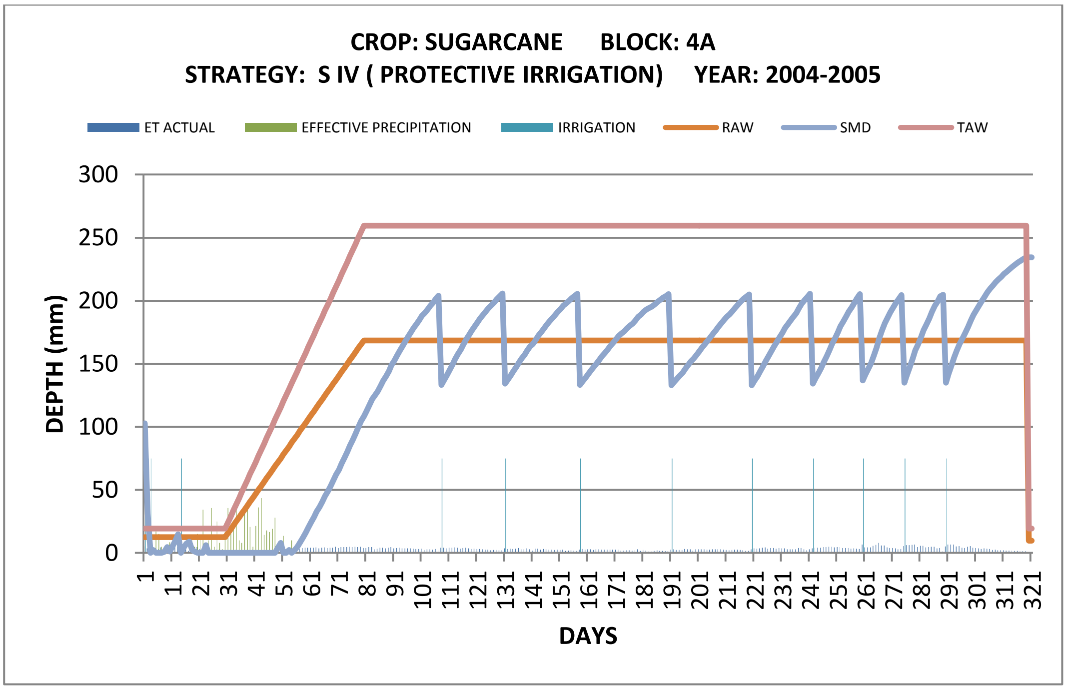
5.29 (a)


CROP: SUGARCANE BLOCK: 4A
STRATEGY S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS

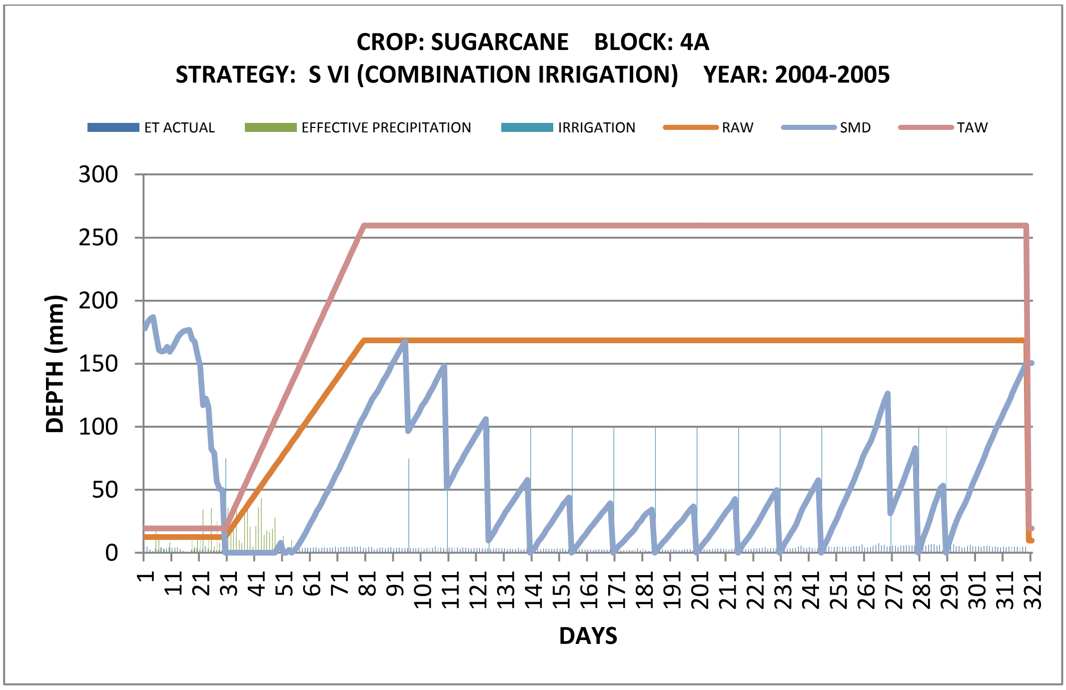
5.29 (b)


CROP: SUGARCANE BLOCK: 4A
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS

5.29 (c)


CROP: SUGARCANE BLOCK: 4A
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS

5.29 (d)



5.29 (e)

Fig 5.29(a-e): Soil moisture balance for irrigation strategies S I to S VI for sugarcane crop year 2004-2005

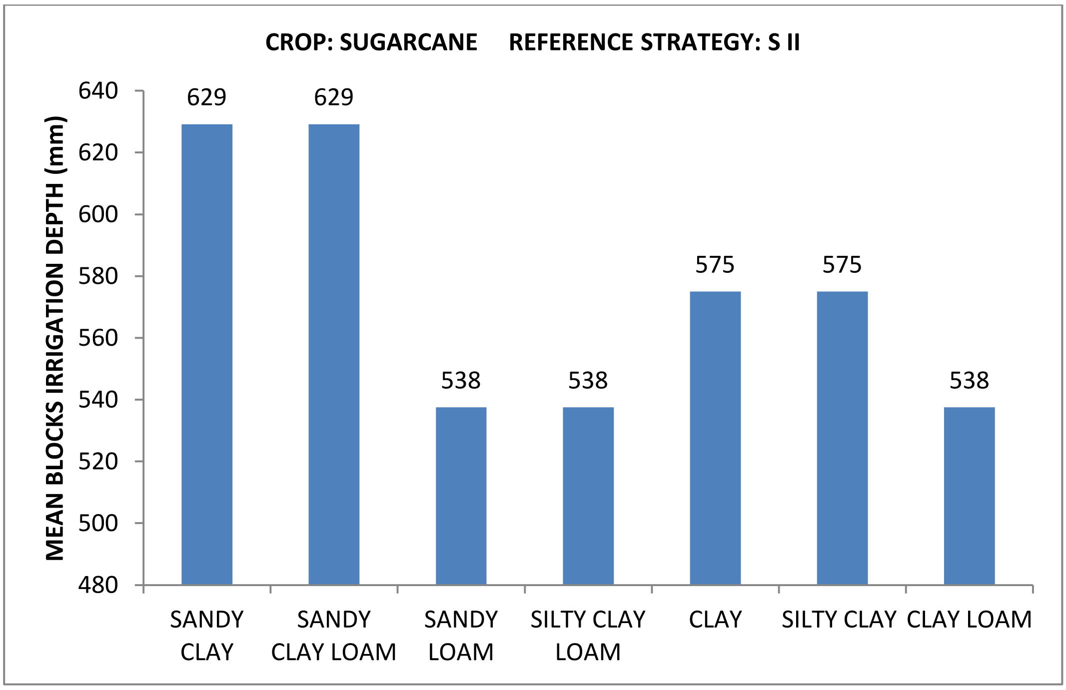


Fig 5.30: Effect of soil type on sugarcane irrigation depth under strategy S II

5.11.2 Effect of Soil Type on Sugarcane Irrigation Depth

The influence of soil type on irrigation depth under reference strategy S II was examined. The irrigation given for strategy S II was between post initial vegetative stage and 300 days of sowing. As irrigation is applied for furrow method the actual irrigation applied will be equal to irrigation depth / fraction wetted. The fraction wetted is taken as 0.6, so for illustration purpose if 629 mm is as irrigation depth than irrigation applied will be 629/0.6 = 1048mm. Fig 5.30 illustrates that variability in average irrigation depth between three blocks of sandy clay and three blocks of sandy clay loam was not seen and both had average irrigation depth of 629 mm. Similarly soils having one block each of sandy loam; silty clay loam and clay loam had similar irrigation depth of 538mm. One block of each clay and silty clay had irrigation depth of 575 mm. The impact of rainfall, climatic conditions is seen in the results.

5.11.3 Effect of Irrigation on Groundwater for Sugarcane

The impact of various irrigation treatments and their influence on groundwater table was examined for nine blocks, which are specially taken for groundwater monitoring, refer Table 5.24. Average net groundwater withdrawals for all the blocks under strategies S I and SVI show rising in water table moderately and substantially respectively. Strategy S II and S IV show receding in groundwater table. In case of strategy S III except block 4B, 10, and 9A2R2 all other blocks show receding in water table.

5.11.4 Irrigation Depth for Sugarcane under Strategies S I to S VI

Range of irrigation depth for various irrigation strategies/treatments for sugarcane is illustrated by Fig 5.31. As the crop is under furrow irrigation method; the irrigation depth needs to be divided by fraction wetted value of 0.6 to obtain the irrigation applied (for e.g. in strategy S I depth the total irrigation applied is 1500/0.6 = 2500 mm). Strategy SI falls under the ambit of fixed depth, and strategy S V is not tried for sugarcane. The variability in irrigation strategies is not so prominent. The lower range values for S II, S III, and S IV is around 450 mm. Strategy S VI though does not have much variability, but minimum and maximum values are at relatively higher side. This is possibly due to selection of combination strategy, where its partly fixed irrigation at later two phases and irrigation in first phase is of not much duration.

Table 5.24: Average net groundwater withdrawals (years 2004-2009) for sugarcane crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for sugarcane crop period				
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S VI
4B	Sc	7 to 22	-119	14	-62	9	-370
6A1	Sc	1 to 15	-116	32	47	113	-239
8	Scl	0.5to 6.5	-87	79	99	162	-203
10	Scl	1.5 to 18	-180	14	-7	48	-226
6A3R2	C	>30	-114	84	86	105	-241
6BR2	Sic	1.2to>30	-168	49	55	68	-245
9A2R2	Sicl	1 to >30	-252	19	-24	33	-305
9B1R2	Cl	0.5 to 23	-269	53	30	24	-316

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Sugarcane crop is not sown in block 11A2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

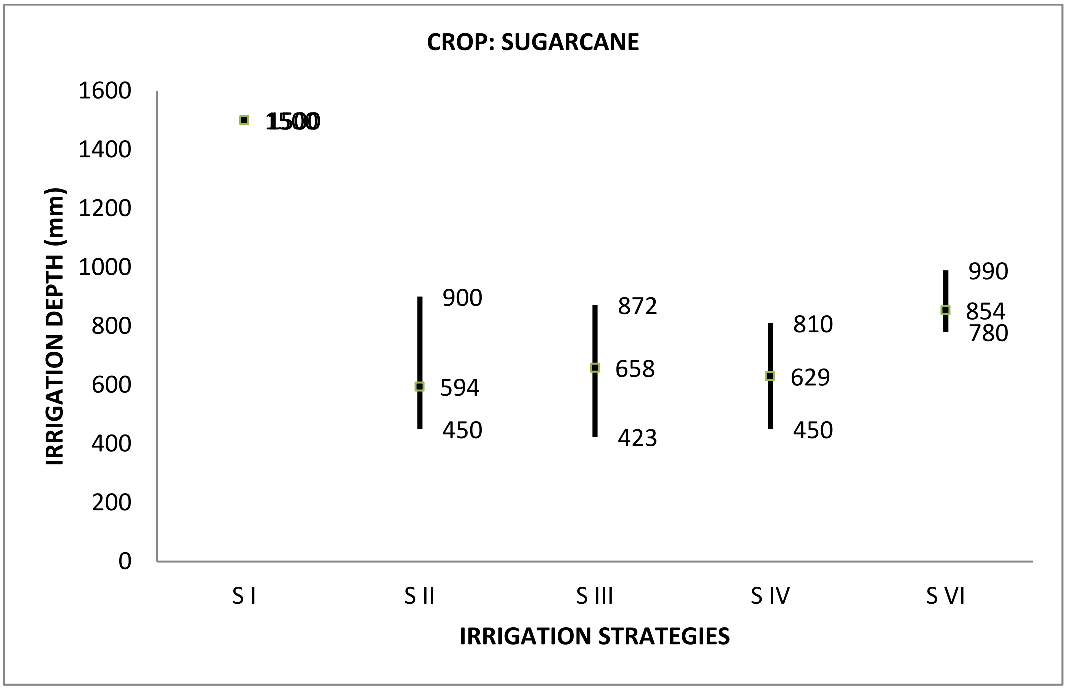


Fig 5.31: Irrigation depth range for sugarcane crop for strategies S I to S VI

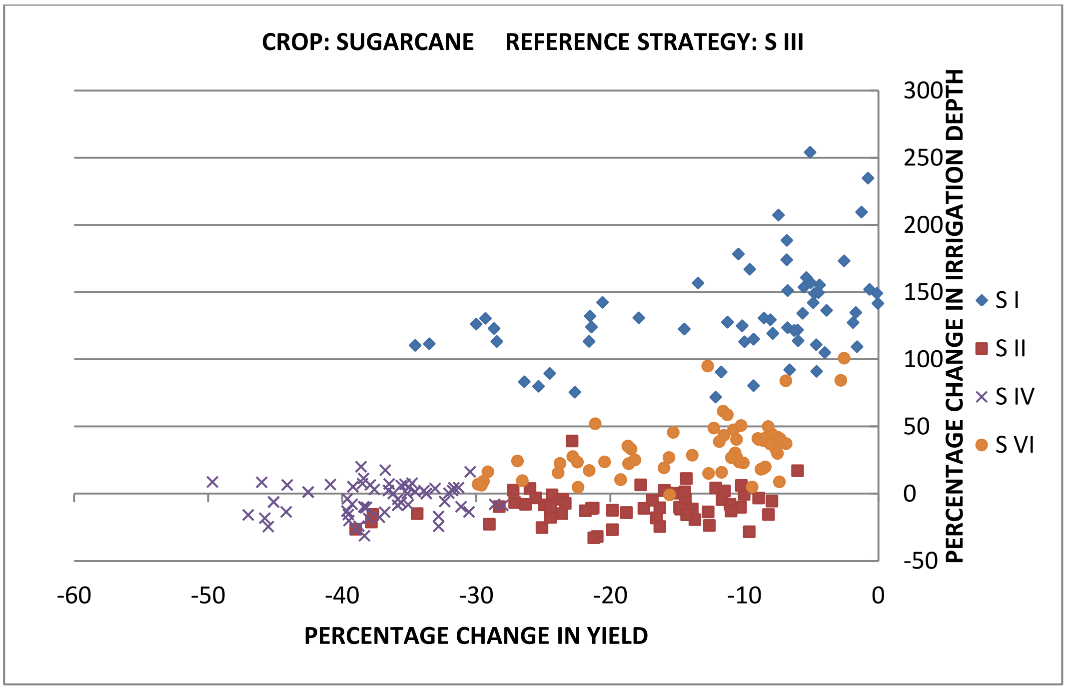


Fig 5.32: Percentage change in yield versus percentage change in irrigation depth for sugarcane under irrigation strategies S I, S II, S IV and VI with respect to strategy S III (no moisture stress conditions)

5.11.5 Evaluating Irrigation Strategies for Sugarcane

The influence of various strategies on yield and irrigation depth was derived by examining the relationship of percentage change in yield versus percentage change in irrigation depth, with respect to reference strategy S III, which is considered to be ideal in terms of yield and optimum irrigation depth. Fig 5.32 demonstrates that in strategy S I, S VI, and S II the variability in average percentage change in yield is not so significant, and the reduction in yield is 11 percent, 14 percent, and 19 percent respectively. Nevertheless, average percentage change in irrigation depth is 133 percent, 32 percent, and −9 percent respectively, indicating the increase in irrigation depth for S I and S VI, while decrease in irrigation depth for S II strategy is seen clearly. If savings in water is given prime importance with substantial yield strategy S II could be considered appropriate, for preferential adoption in comparison to others. Strategy S IV although has an average decrease in irrigation depth by 4 percent in comparison to strategy S III, but the average reduction in yield is as high as 37 percent, indicating its use would not be so beneficial. Irrigation strategy S IV show comparatively more reduction in yield due to its sensitivity to moisture deficit. This strategy could only be recommended with caution. Strategies S II, S VI, and S I can be recommended in order of merit for sugarcane, to attain higher yields with significant water savings.

5.12 Irrigation Scheduling Strategies for Cabbage

Cabbage falls under the category of vegetables. The cabbage is a two seasonal; herein it is sown in 17th September and harvested after 165days of crop seasonal length. The various irrigation treatments/ strategies utilized for cabbage are illustrated in Table 5.25, and are as follows: (i) Strategy S I: Irrigation is decided to be given in two set types. In first set, fixed irrigation is applied immediately after sowing, and the next irrigation of fixed depth is given at 7days interval. In second set, the irrigation is given after 20 days of sowing, and then followed by irrigations of fixed depth at 12 days interval. (ii) Strategy S II: First irrigation is given immediately after sowing, and afterwards irrigation of fixed depth is applied at that point of time, when soil moisture reaches at 100 per cent of readily available water. (iii) Strategy S III: Irrigation is triggered at 100 per cent of readily available water, and amount equivalent to soil moisture depletion is applied. (iv.) Strategy S IV: Protective irrigation of reduced fixed depth is applied, when soil moisture depletion equals 80 percent of total available water. (v) Strategy S V: Two irrigations of reduced fixed depth are applied at seven days gap after sowing in first phase. In second phase irrigation of reduced fixed depth is applied at gap of 20days, and irrigation is triggered post 20 days of sowing, and (vi) Strategy S VI: First phase irrigation of reduced irrigation depth is applied up to 36 days of sowing at an interval of seven days. Second phase irrigation is given at an interval of 10 days from 50days of post sowing upto five days of pre harvesting. For each strategy (number of blocks × number of years) 120 simulations are carried out for cabbage crop.

5.12.1 Water Balance, Yield and Efficiencies for Cabbage

In order to do accounting of water; yield, water productivity, and irrigation water productivity attained for study period of cabbage is carried out by computing daily water balance for all blocks. For illustrative purpose results of block 1 are summarized in Table 5.26. In cabbage furrow irrigation method is applied, thus the irrigation values in column 3 and 4 of Table 5.26 are required to be divided by fraction wetted 0.6 to obtain total irrigation depth. The results obtained show that strategy S III gives highest values of yield, WUE, and IWUE with least values of surface run off and flow to groundwater confirming to be the best option. It is observed that if fixed depth (F.D.) is much greater than RAW depth, as in case of strategy S II when irrigation is triggered at 100 percent RAW, than it results in greater runoff leading to lower irrigation water use efficiency IWUE. Further, in case of blocks having sandy clay soil the value of RAW is low, than the amount of irrigation depth is to be carefully decided in

Table 5.25: Irrigation scheduling strategies for cabbage crop

Case	Irrigation Strategy for cabbage		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1, 8	80 mm	Irrigation of 80 mm fixed depth is applied at a fixed interval of 7days subsequently.
	20, 32, 44, 56, 68, 80, 92, 104, 116, 128, 140 & 152	80 mm	Irrigation of 80 mm fixed depth is applied at a fixed interval of 12days fixed interval post 20 days of sowing.
S II	1- 160	80 mm	Irrigation of 80 mm depth is applied, as moisture level reaches at 100 percent of readily available water from date of sowing.
S III	1-165	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions.
S IV	1- 160	40 mm,	Irrigation of fixed depth of 40 mm is applied as protective irrigation, when moisture depletion reaches 80 percent of total available water.
S V	1, 8	60 mm	Irrigation of 60 mm fixed depth is applied at a fixed interval of 7days subsequently.
	20, 40, 60, 80, 100, 120, 140 & 160	60 mm	Irrigation of 60 mm fixed depth is applied at a fixed interval of 20 days fixed interval post 20 days of sowing.
S VI	1, 8, 15, 22, 29 & 36	40 mm	Irrigation of 40 mm fixed depth is applied at a fixed interval of 7 days subsequently.
	50, 60, 70, 80, 90, 100, 110,120, 130, 140, 150 & 160	60 mm	Irrigation of 60 mm fixed depth is applied at a fixed interval of 10 days from 50 days post date of sowing subsequently.

***** From date of sowing. Date of sowing 17th September and Harvesting on 28th February.

strategy S II. In case of cabbage strategy S II gives approximately similar yield to strategy S III however; the IWUE is the least, while the flow to surface runoff and groundwater is highest amongst all strategies, suggesting adjustment required in the irrigation depth,

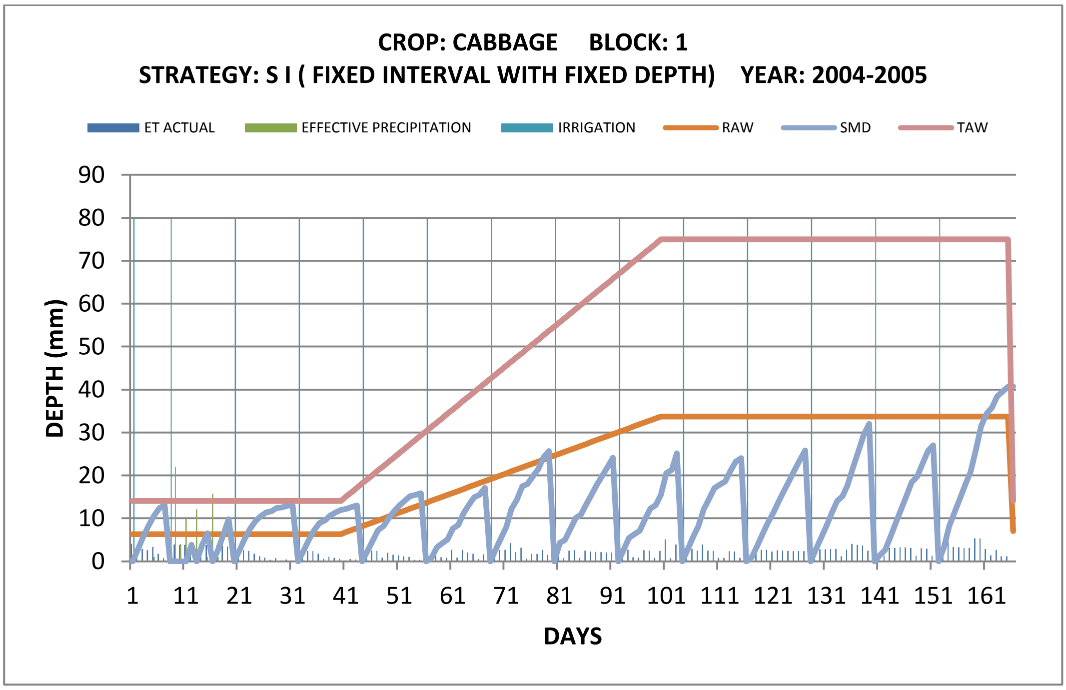
Table 5.26: Water balance, yield and efficiencies of cabbage crop in sandy clay (HSG – C) soil in Block 1 (grown in 4.48% of CCA 9868 ha)

Irrigation Strategies for Cabbage	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha/ mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	361	92	240	432	149	-208	-344	64982	180.10	96.70	1.91
	2005-2006	390	146	240	432	156	-207	-376	62165	159.22	92.51	1.91
	2006-2007	468	85	240	432	176	-188	-278	60318	128.99	89.76	1.91
	2007-2008	436	122	240	432	167	-216	-309	62522	143.53	93.04	1.91
	2008-2009	503	63	240	432	226	-192	-265	54690	108.82	81.38	1.91
	2009-2010	506	0	240	432	222	-157	-231	49269	97.38	73.32	1.91
	Average	444	85	240	432	183	-195	-301	58991	136.34	87.78	1.91
Strategy S II 100% RAW with F.D.	2004-2005	399	92	576	480	149	-241	-656	70000	175.44	66.29	2.12
	2005-2006	459	146	624	528	187	-254	-773	69015	150.30	59.91	2.33
	2006-2007	557	85	768	672	216	-311	-874	70000	125.78	48.61	2.97
	2007-2008	498	122	576	576	179	-290	-665	70000	140.64	60.76	2.55
	2008-2009	652	63	768	816	281	-360	-915	68071	104.35	42.97	3.61
	2009-2010	718	0	1056	912	296	-397	-1148	69962	97.44	35.55	4.03
	Average	547	85	728	664	218	-309	-839	69508	132.33	52.35	2.94
Strategy S III No Stress	2004-2005	442	92	60	195	157	-22	-40	70000	158.36	274.82	0.86
	2005-2006	424	146	29	193	174	-34	-84	70000	165.16	315.37	0.85
	2006-2007	473	85	57	202	184	-21	-34	70000	147.90	270.14	0.89
	2007-2008	418	122	59	182	143	-37	-51	70000	167.38	289.82	0.81
	2008-2009	463	63	43	215	192	-26	-24	70000	151.14	271.48	0.95
	2009-2010	484	0	61	223	200	0	0	70000	144.50	246.32	0.99
	Average	451	85	52	202	175	-23	-39	70000	155.74	277.99	0.89
Strategy S IV Protective Irrigation	2004-2005	327	92	168	96	132	-47	-114	44267	135.24	167.68	0.42
	2005-2006	304	146	120	96	145	-55	-149	44455	146.16	205.81	0.42
	2006-2007	354	85	168	120	146	-49	-116	46398	131.11	161.10	0.53
	2007-2008	311	122	168	96	119	-65	-129	45465	146.19	172.21	0.42
	2008-2009	346	63	168	120	163	-54	-114	45192	130.79	156.92	0.53
	2009-2010	366	0	240	120	172	-40	-126	42972	117.34	119.37	0.53
	Average	335	85	172	108	146	-52	-125	44791	134.47	163.85	0.48
Strategy S V Deficit Irrigation	2004-2005	363	92	144	216	134	-84	-139	51546	142.02	143.18	0.95
	2005-2006	344	146	144	216	133	-85	-209	51132	148.53	142.03	0.95
	2006-2007	381	85	144	216	132	-65	-131	49081	128.77	136.34	0.95
	2007-2008	344	122	144	216	120	-108	-151	51404	149.44	142.79	0.95
	2008-2009	358	63	144	216	154	-80	-139	45696	127.59	126.93	0.95
	2009-2010	360	0	144	216	150	-46	-104	42031	116.74	116.75	0.95
	Average	358	85	144	216	137	-78	-145	48482	135.51	134.67	0.95
Strategy S VI Combination	2004-2005	435	92	144	432	166	-241	-158	66170	152.06	114.88	1.91
	2005-2006	426	146	144	432	165	-236	-226	67846	159.32	117.79	1.91
	2006-2007	461	85	144	432	164	-211	-153	66004	143.28	114.59	1.91
	2007-2008	417	122	144	432	150	-259	-172	66223	158.76	114.97	1.91
	2008-2009	456	63	144	432	192	-226	-149	65285	143.11	113.34	1.91
	2009-2010	472	0	144	432	193	-184	-113	63461	134.39	110.18	1.91
	Average	445	85	144	432	172	-226	-162	65832	148.48	114.29	1.91

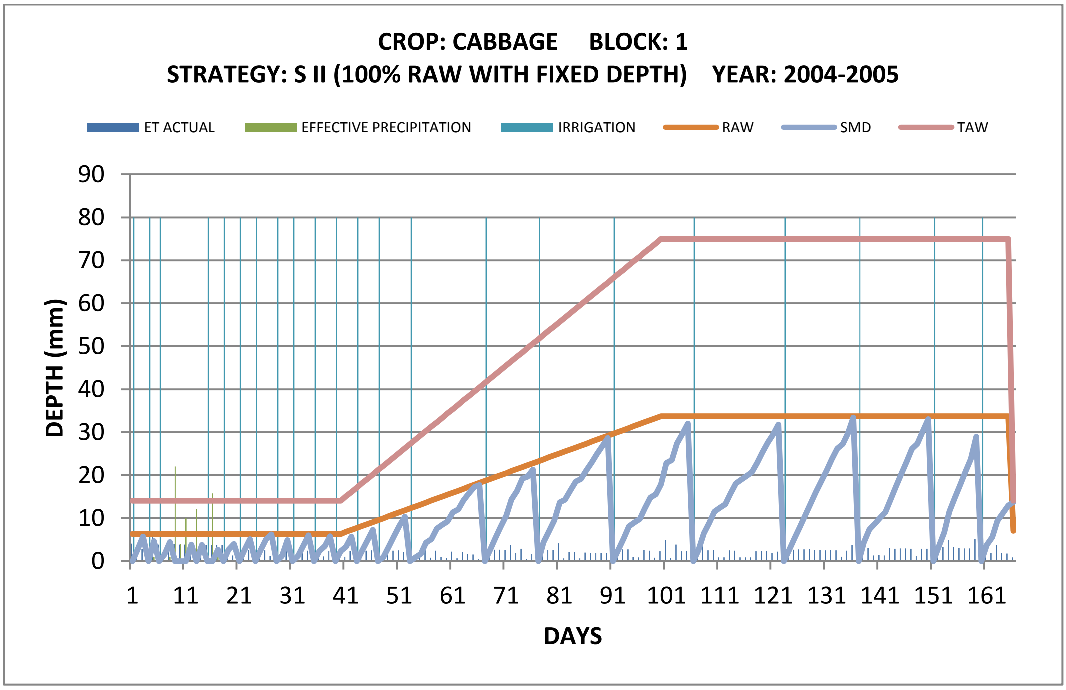
Note: No. of rainy days for cabbage crop period in years 2004, 2005, 2006,2007,2008 and 2009 are 9, 9, 8, 8, 5 and 0 days respectively.

especially in initial vegetative stages. With strategy S VI, significant high yield is attained with significant water saving, thus if priority to water saving is given without much reduction in yield strategy S VI be recommended. Amongst strategies S I, S V, and S IV we can say that WUE is similar, but amount of irrigation applied has great impact on the yield. Larger the amount of water application, greater is the yield. However higher rationing of water does not affect the yield to great extent, which is evident from observing strategies S IV (yield=44791 kg/ha; irrigation=280 mm) and S V (yield=48482 kg/ha; irrigation=360 mm).

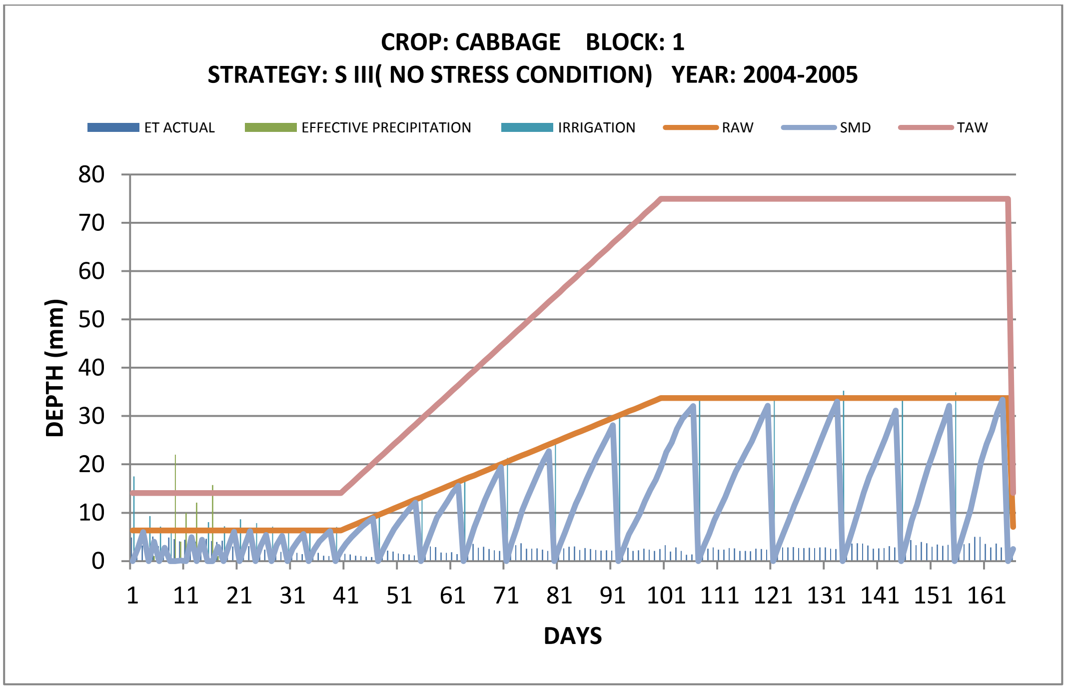
The relationship between soil moisture pattern and yield for different treatments is revealed by Fig 5.33 (a-f) and Table 5.26. Figure clearly shows that no moisture stress is visible in strategies S II and S III, thus both would give maximum potential yield. It also shows that in vegetative stage the amount of water lost due to run off and flow to groundwater is large, which is ratified by Table 5.26. Moisture stress during initial stage and development stage does not have any serious impact on yield which was established, while examining strategies SI and S VI. The reduction in yield could be substantial, if moisture stress is felt in all the crop growth stages that were confirmed by strategies S IV and S V.



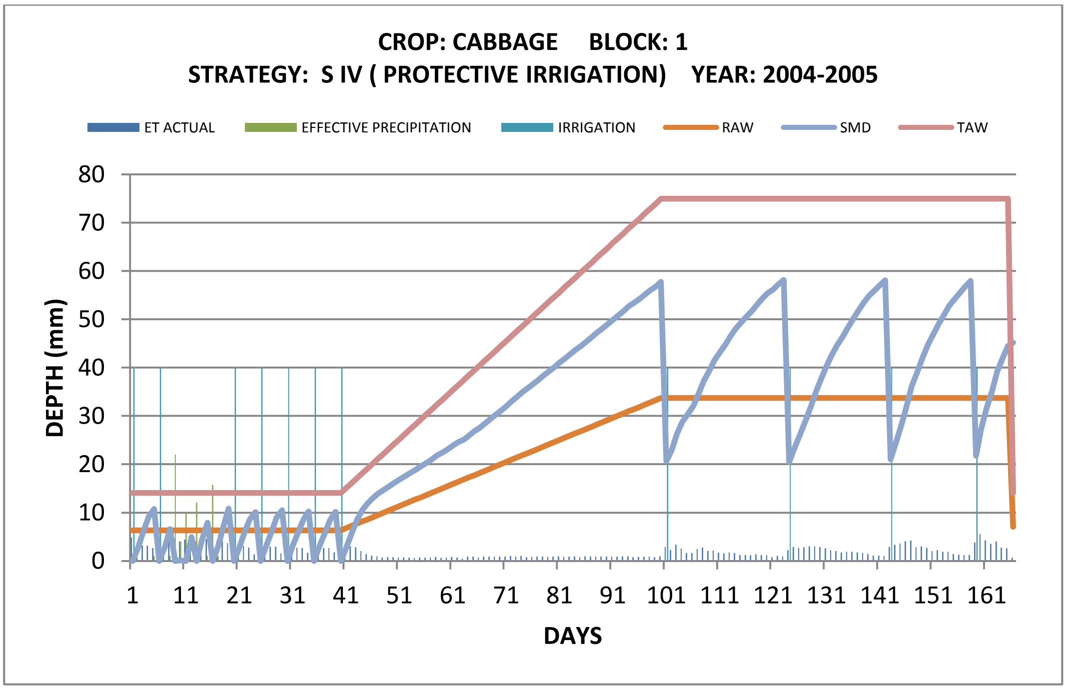
5.33 (a)


CROP: CABBAGE BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
90
80
70
60
50
40
30
20
10
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

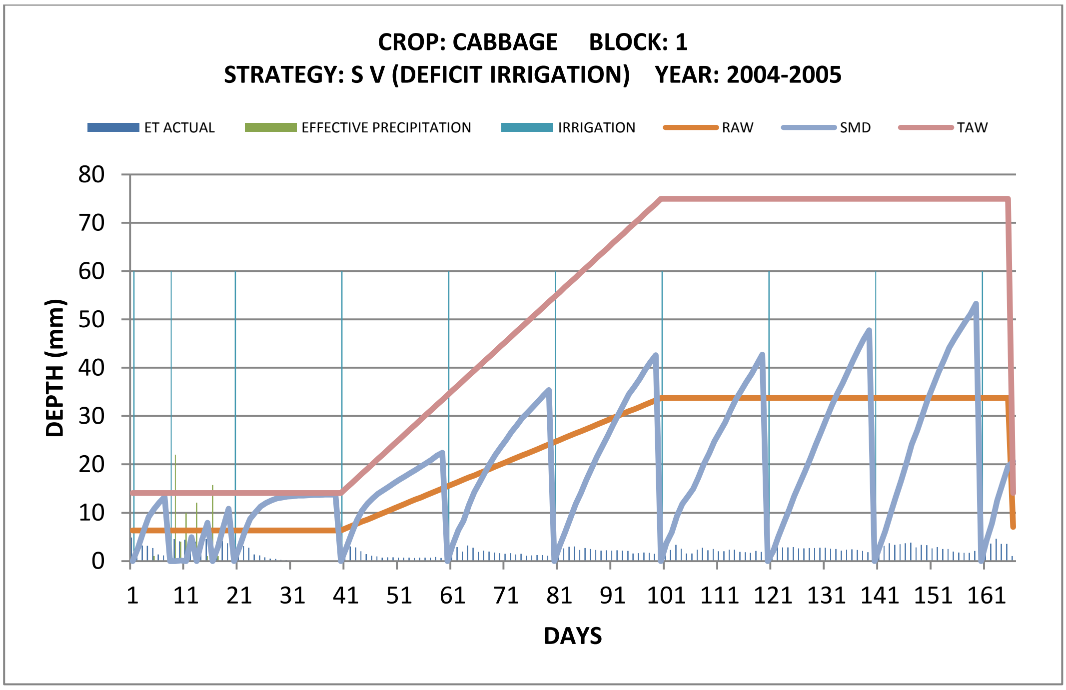
5.33 (b)


CROP: CABBAGE BLOCK: 1
STRATEGY: S III(NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
80
70
60
50
40
30
20
10
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

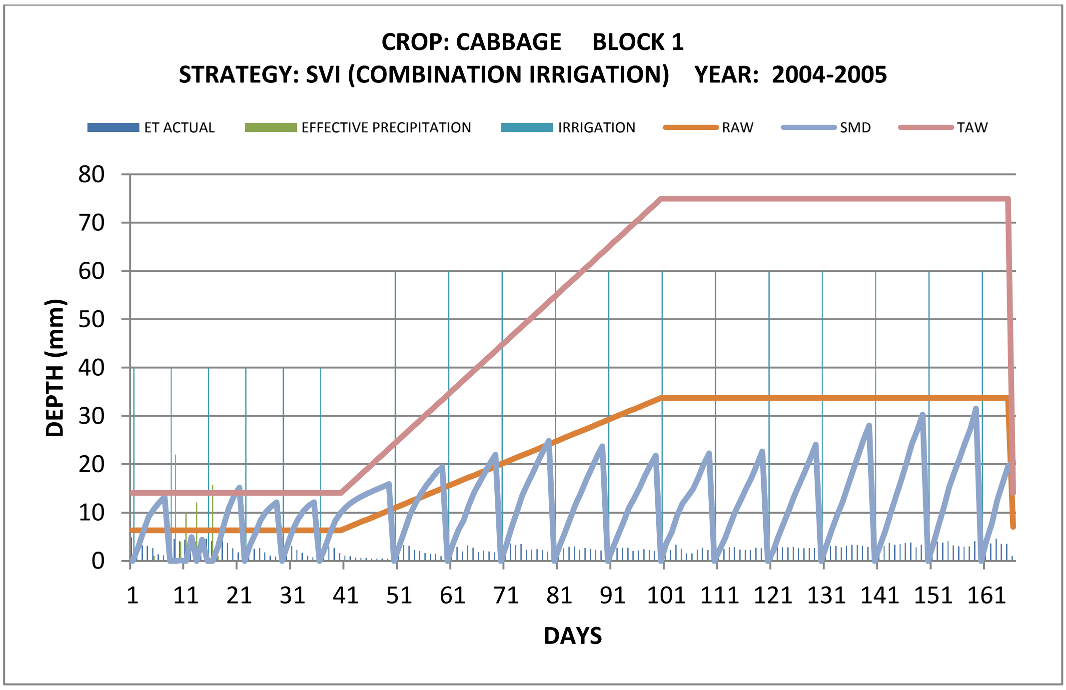
5.33 (c)


CROP: CABBAGE BLOCK: 1
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
80
70
60
50
40
30
20
10
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

5.33 (d)


CROP: CABBAGE BLOCK: 1
STRATEGY: S V (DEFICIT IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
80
70
60
50
40
30
20
10
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161
DAYS

5.33 (e)



5.33 (f)

Fig 5.33(a-f): Soil moisture balance for irrigation strategies S I to S VI for cabbage crop year 2004-2005

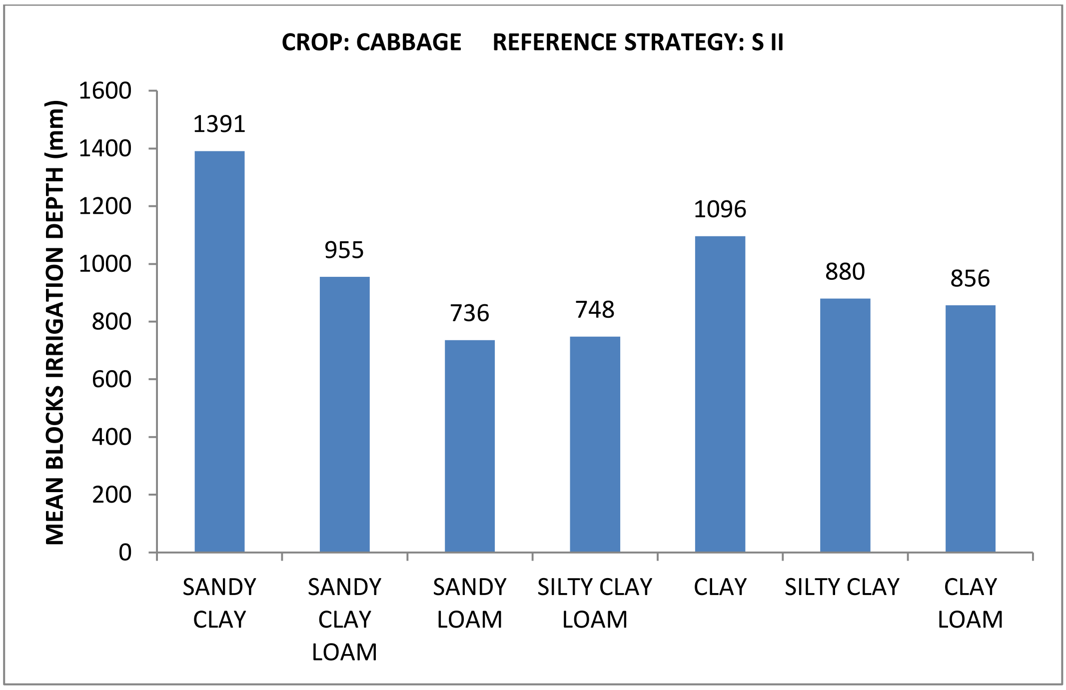


Fig 5.34: Effect of soil type on cabbage irrigation depth under strategy S II

5.12.2 Effect of Soil Type on Cabbage Irrigation Depth

The influence of type of soil on irrigation depth was examined for reference strategy S II. The averages irrigation depth of all blocks having same soil type was carried out refer Fig 5.34. Wherein, the 10 blocks of sandy clay showed the maximum depth of 1391 mm amongst all soil types. The averages of 3 blocks of sandy clay loam had irrigation depth of around 1000 mm, while one block of clay showed slight increase in depth (1096 mm). Similar irrigation depth were observed for each block of silty clay and clay loam (880 mm and 856 mm) respectively. Least irrigation depths with minor difference was seen in sandy loam and silty clay loam (736 mm and 748 mm) respectively.

5.12.3 Effect of Irrigation on Groundwater for Cabbage

The contribution of various irrigation treatments/strategies towards rise or fall in groundwater table was summarized in Table 5.27 for few blocks, which have been selected by irrigation authorities for monitoring purpose. The decrease in fall of groundwater table for all selected blocks according to type of strategies are shown in descending order S II, S IV, S V, and S III respectively. The maximum rise in groundwater table is in strategy S VI. Strategy S I shows rise of groundwater in blocks 10, 6BR2, 9A2R2 and 9B1R2, while remaining blocks show fall in groundwater.

5.12.4 Irrigation Depth for Cabbage under Strategies S I to S VI

The impact of various irrigation strategies on irrigation depth range for cabbage is demonstrated in Figure 5.35. For cabbage furrow irrigation method is selected, thus to obtain applied irrigation depth it needs to be divided by fraction wetted of 0.6. Minimum variability in irrigation depth range was in strategies S III and S IV, with average irrigation depth of 251 mm and 232 mm respectively. Strategy S II has large variability in range of irrigation depth, indicating the sensitiveness of strategy towards rainfall, soil moisture, and climatic conditions. Strategy S II is found to be unsuitable as over irrigation is observed in initial stages, and the irrigation depth in various soils needs to be selected cautiously. The other strategies belong to fixed depth category.

Table 5.27: Average net groundwater withdrawals (years 2004-2009) for cabbage under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for cabbage crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	43	372	25	117	64	-83
6A1	Sc	1 to 15	42	506	39	142	66	-73
8	Scl	0.5to 6.5	47	495	38	143	71	-69
10	Scl	1.5 to 18	-41	318	27	39	49	-129
11A2	Sc	3 to >30	44	500	38	140	68	-72
6A3R2	C	>30	39	404	35	104	75	-83
6BR2	Sic	1.2to>30	-3	325	35	71	67	-105
9A2R2	Sicl	1 to >30	-47	284	31	40	52	-134
9B1R2	Cl	0.5 to 23	-61	287	27	43	42	-147

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . Cabbage crop is sown in all blocks. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

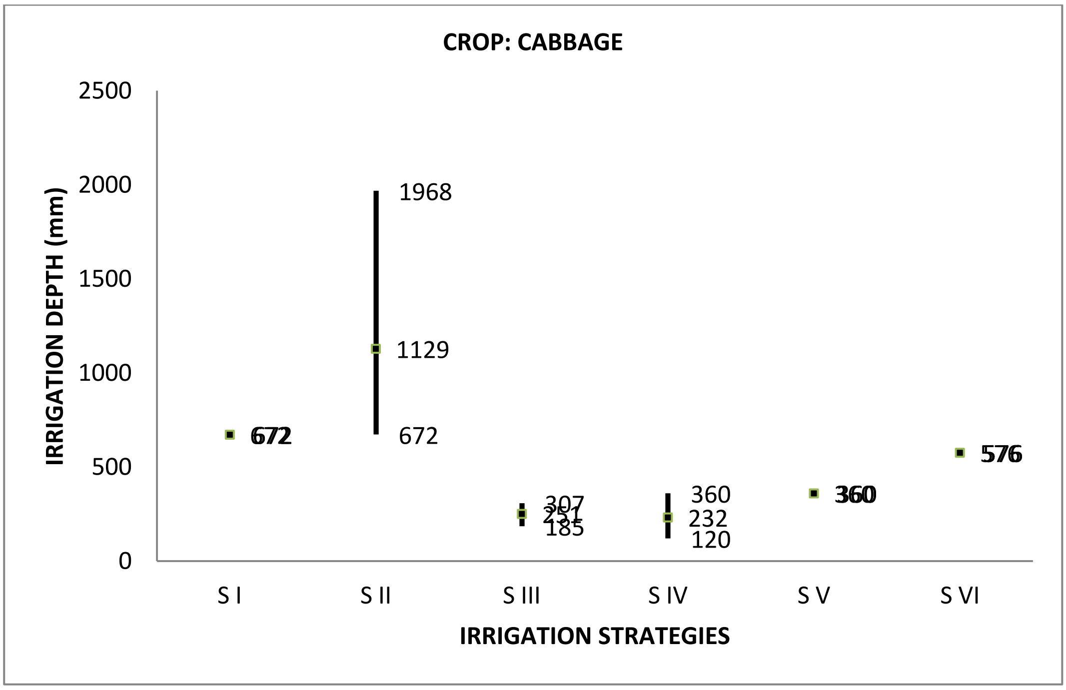


Fig 5.35: Irrigation depth range for cabbage crop for strategies S I to S VI

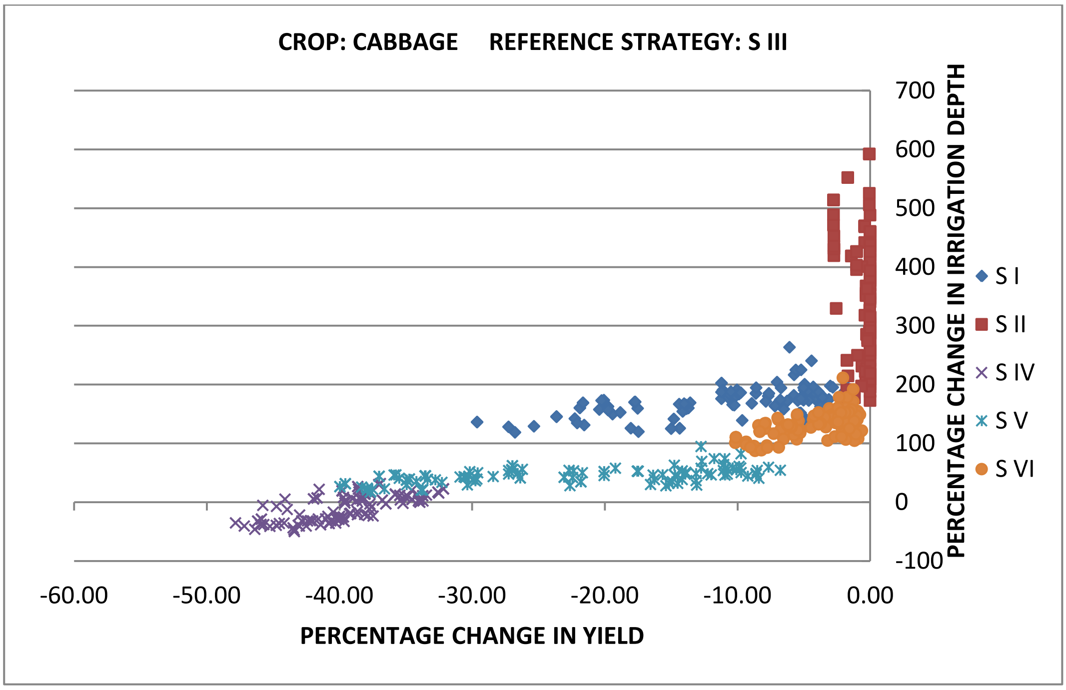


Fig 5.36: Percentage change in yield versus percentage change in irrigation depth for cabbage under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.12.5 Evaluating Irrigation Strategies for Cabbage

The relationship between yield and irrigation depth help in deciding the robustness of the strategy. Strategy S III was taken as reference strategy for comparing the other strategies this was done because maximum potential yield with optimum water is attained by it. It is clearly evident from the Figure 5.36 that maximum yield after strategy S III is achieved by strategy S II however; variability in irrigation depth is very high with range of 160 percent to 593 percent, and with average increase of 346 percent, *which makes it unsuitable for usage*. Variability in irrigation depth for strategy S II is significant, indicating its sensitiveness towards climatic and soil moisture conditions. To opt for a strategy where reduction in average yield is minimal with reasonable rise in average irrigation depth is S VI (yield reduction of 4 percent with increase in irrigation depth of 131 percent). Strategy S I have range of yield reduction from 2 percent to 30 percent with average reduction of 11 percent, for cabbage crop in selected blocks of region I and II. The increase in irrigation depth for S I varied from 119 percent to 264 percent with average increase in irrigation depth of 170 percent with respect to strategy S III. Strategy SIV had very high average yield reduction of 39 percent with range of 32 percent to 48 percent in reduction of yield however; S IV had average decrease in irrigation depth of 8 percent. The range of irrigation depth for S IV was between −50 percent to +32 percent. However, substantial water saving could be achieved with strategy S IV though the yield reduction was very high. Thus this strategy should be used with caution during very dry years. Irrigation strategy S IV show comparatively more reduction in yield due to its sensitivity to moisture deficit. This strategy could only be recommended with caution. With strategy S V the average yield reduction obtained is 24 percent (range −7 percent to −40 percent) with average increase in irrigation depth of 45 percent (range 17 percent to 95 percent) with reference strategy S III. The strategies may be recommended in order of S III, S II, S VI, SI, S V, and SIV considering the yield attained. If water savings was only criteria, than recommendations would be in order of S III, S IV, S V, SVI, S I, and S II. Strategies best suited and recommended in order of merit for attaining significant yield and water savings simultaneously for cabbage are S III, followed by S VI, S II and SI.

5.13 Irrigation Scheduling Strategies for Cotton

Cotton is a two seasonal fibre crop. It is grown with the onset of monsoon and is usually rainfed during monsoon. It is not irrigated during that period until unless rainfall is erratic or delayed. Three or four irrigations are required and applied, post one month monsoon depending upon the crop variety. The crop is sown on 27th July and harvested on 6th February for the base year 2003. The six irrigation strategies worked out for Cotton crop has been shown in the Table 5.28, which is as follows: (i) Strategy S I is the conventional one followed by the growers, wherein irrigation of fixed depth and at fixed interval is applied post month monsoon from subsequent days of sowing as mentioned in table. In case of delay, or erratic monsoon just to save the crop irrigation is applied from day one of sowing to 90 days of sowing, when soil moisture depletion reaches upto 100 percent total available water (TAW). (ii) Strategy S II is designed to give irrigation of fixed depth from post one month of sowing up to last irrigation cut off i.e. 15 days pre harvesting. The irrigation is triggered when soil moisture depletion reaches 100 percent of readily available water. (iii) Strategy S III is model derived no stress condition strategy. Irrigation is triggered when soil moisture depletion reaches 100 percent of readily available water, and amount of water applied is equivalent to 100 percent soil moisture depletion. (iv.) Strategy S IV being protective irrigation strategy where irrigation is triggered, when soil moisture depletion (SMD) reaches 80 percent of TAW, and the irrigation applied is half the irrigation depth to the normal irrigation depth. (v) Strategy S V is a 10 day deficit irrigation strategy during flowering is implemented to check the yield reduction then the conventional strategies, and (vi) In Strategy S VI irrigation of fixed depth is applied at fixed 20 day interval post one month monsoon. While, during monsoon period half the irrigation depth than the normal is applied, when SMD reaches 80 percent TAW. This is done to save ground water and to prevent crop from any severe moisture stress.

Table 5.28: Irrigation scheduling strategies for cotton crop

Case	Irrigation Strategy for Cotton		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
I	1-90 100,120,140 ,160 and180	80mm 80mm	Irrigation of 80 mm fixed depth is applied, when moisture depletion reaches 100 percent of total available water TAW subsequently from post date of sowing 27th July upto 90 days of sowing. Then, from 100 days upto 180 days of sowing, irrigation of 80 mm fixed depth is applied at a fixed interval of 20 days.
II	30-180 Varying	80 mm	After 30 days post sowing, irrigation of 80 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water.
III	1-195 Varying	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions
IV	30-180 Varying	40 mm,	After 30 days post of sowing, irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water.
V	1-109, 110, 140,160 & 180 days	80 mm 80mm	Irrigation of 80 mm fixed depth is applied subsequently upto 109 days of sowing, when moisture depletion reaches 100 percent of total available water. Then irrigation of 80mm fixed depth is applied on 110 days of sowing, followed by irrigation after 30 days. Then, upto 180 from days of sowing, irrigation of 80 mm fixed depth is applied at a fixed interval of 20 days
VI	1-109, 110-170 days	40 mm 80mm	Irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water subsequently from post date of sowing upto 109 days of sowing. Then, from 110 days upto 170 days of sowing, irrigation of 80 mm fixed depth is applied at a fixed interval of 20 days

* From date of sowing. Date of sowing 27th July and Harvesting on 6th February.

Table 5.29: Water balance, yield and efficiencies of cotton crop in sandy clay (HSG – C) soil in block 1 (grown in 66.75% of CCA 9868 ha)

Irrigation Strategies for Cotton	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	562	924	96	240	155	-203	-650	2214	3.94	6.59	15.809
	2005-2006	636	430	192	240	179	-125	-280	2465	3.88	5.71	15.809
	2006-2007	758	1284	144	240	192	-116	-986	2412	3.18	6.28	15.809
	2007-2008	644	466	144	240	195	-105	-295	2331	3.62	6.07	15.809
	2008-2009	713	720	144	240	222	-126	-486	2198	3.08	5.73	15.809
	2009-2010	656	211	288	240	262	-58	-287	1888	2.88	3.58	15.809
	Average	662	672	168	240	201	-122	-498	2251	3.43	5.66	15.809
Strategy S II 100% RAW with F.D.	2004-2005	576	924	192	96	173	-143	-666	2487	4.32	8.63	6.323
	2005-2006	623	430	96	144	189	-78	-157	2376	3.81	9.90	9.485
	2006-2007	800	1284	144	192	176	-73	-923	2460	3.07	7.32	12.647
	2007-2008	651	466	144	144	212	-78	-237	2460	3.78	8.54	9.485
	2008-2009	795	720	144	192	234	-76	-419	2338	2.94	6.96	12.647
	2009-2010	796	211	192	240	320	-73	-94	1865	2.34	4.32	15.809
	Average	707	672	152	168	217	-87	-416	2331	3.38	7.61	11.066
Strategy S III No Stress	2004-2005	563	924	85	151	177	-143	-630	2500	4.44	10.63	9.924
	2005-2006	551	430	96	150	159	-133	-151	2500	4.54	10.16	9.865
	2006-2007	655	1284	90	150	194	-145	-916	2500	3.82	10.45	9.852
	2007-2008	573	466	77	151	179	-112	-188	2500	4.36	11.00	9.927
	2008-2009	618	720	87	199	179	-151	-416	2500	4.04	8.72	13.119
	2009-2010	654	211	169	152	273	-55	-95	2500	3.82	7.80	9.989
	Average	602	672	101	159	193	-123	-399	2500	4.17	9.79	10.446
Strategy S IV Protective Irrigation	2004-2005	524	924	48	120	208	-143	-632	2185	4.17	13.01	7.904
	2005-2006	493	430	24	120	183	-126	-138	2057	4.17	14.29	7.904
	2006-2007	615	1284	48	120	124	-80	-881	2183	3.55	12.99	7.904
	2007-2008	551	466	48	120	205	-92	-195	2225	4.03	13.24	7.904
	2008-2009	559	720	72	120	141	-100	-393	2048	3.66	10.67	7.904
	2009-2010	550	211	96	144	263	-63	-101	1730	3.15	7.21	9.485
	Average	549	672	56	124	187	-101	-390	2071	3.79	11.90	8.168
Strategy S V Deficit Irrigation	2004-2005	474	924	0	192	143	-160	-625	1918	4.05	9.99	12.647
	2005-2006	513	430	144	192	148	-148	-253	2224	4.33	6.62	12.647
	2006-2007	606	1284	48	192	153	-129	-942	2127	3.51	8.86	12.647
	2007-2008	523	466	48	192	150	-112	-222	2080	3.98	8.67	12.647
	2008-2009	523	720	96	192	144	-165	-464	1873	3.58	6.50	12.647
	2009-2010	545	211	240	192	218	-80	-235	1944	3.56	4.50	12.647
	Average	531	672	96	192	159	-132	-457	2028	3.84	7.52	12.647
Strategy S VI Combination	2004-2005	552	924	72	216	187	-198	-650	2431	4.41	8.44	14.228
	2005-2006	546	430	96	216	171	-170	-197	2457	4.50	7.87	14.228
	2006-2007	644	1284	96	216	180	-186	-946	2445	3.80	7.84	14.228
	2007-2008	573	466	72	216	184	-152	-213	2446	4.27	8.49	14.228
	2008-2009	610	720	144	216	194	-213	-451	2427	3.98	6.74	14.228
	2009-2010	638	211	216	216	268	-102	-171	2408	3.77	5.57	14.228
	Average	594	672	116	216	197	-170	-438	2436	4.12	7.49	14.228

Note: No. of rainy days for Cotton crop period in year 2004, 2005, 2006, 2007, 2008 and 2009 are 37, 37, 41, 39, 38 and 17 days respectively.

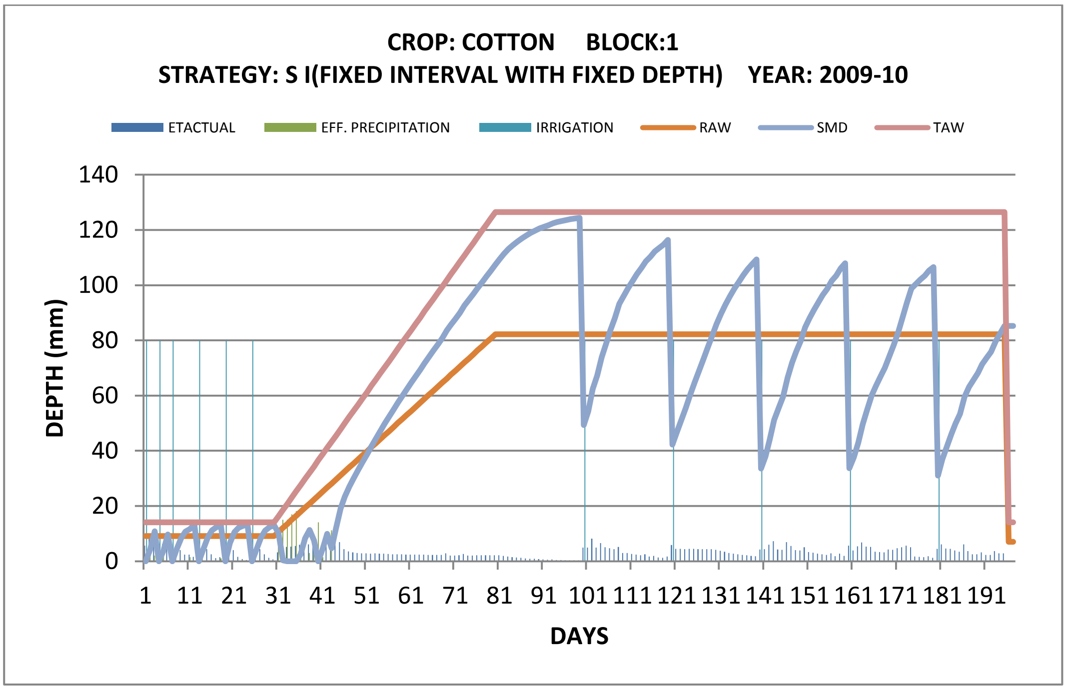
5.13.1 Water Balance, Yield and Efficiencies for Cotton

WEAP MABIA Model was run for 2004 to 2010 to compute yield, components of soil moisture balance, WUE, and IWUE, for all the 20 blocks and all the aforesaid strategies. To avoid replication results of block 1 only is shown in tabular form in Table 5.29. In cotton furrow irrigation method is applied thus column 3 and 4 of Table 5.29 needs to be divided by fraction wetted 0.6 value to obtain total irrigation depth. On analysing the results it was ample clear that strategy S III was best suit suited, where irrigation strategies could be automated. With automated system the farmers can save time and labour by allowing the automated system to monitor crop water status, and help determine when to apply irrigations (O'Shaughnessy et al., 2012).

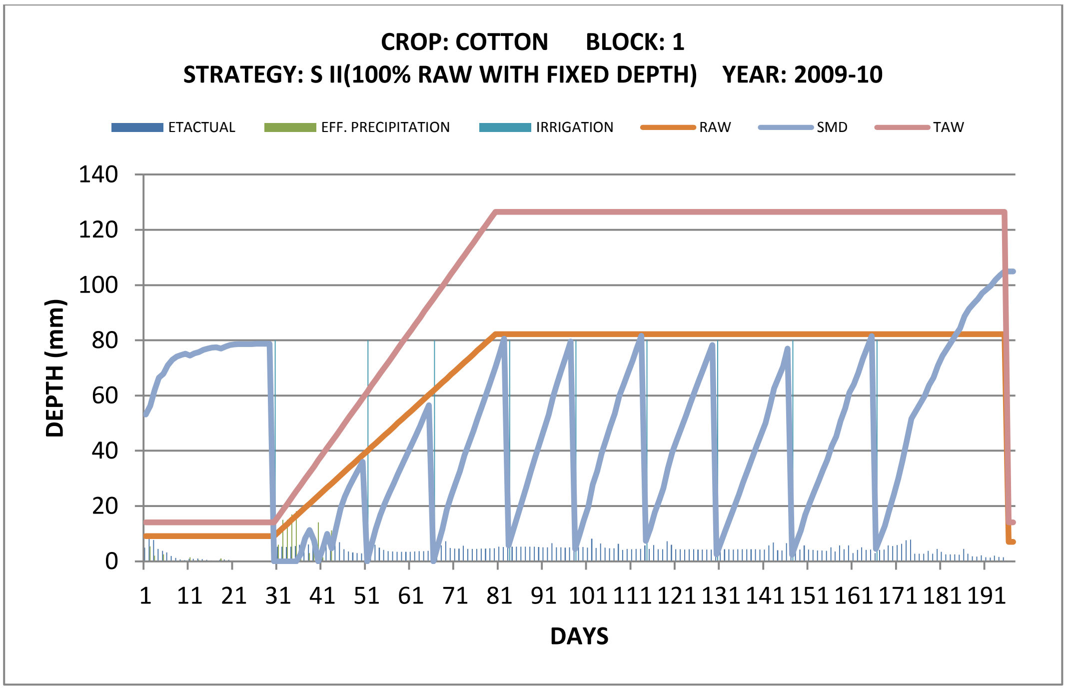
Daily soil moisture balance, averages of ET actual, precipitation, groundwater irrigation, surface runoff, and flow to groundwater, yield, WUE, and IWUE were simulated, for year 2004-2009, for all six strategies, and all 20 blocks, for cotton crop. It was observed that components of water balance and WUE were also strongly influenced by seasonal conditions. Yield variation with seasonal variation was noticed spatially. Simulated results of various parameters found for block 1 has been shown in the Table 5.29. In block 1 strategy S III and S VI had nearly identical averaged (2004-2010) values of yield and WUE amongst all. Remaining strategies had near identical WUE, but with minor variation in averaged yield, however, IWUE variation was large. As a policy irrigation is cut off 15 days ahead of harvesting for cotton in all the strategies, except strategy S III, thus depending upon strategy the last irrigation could be even earlier, than the cut off fixed, in that case the water stress after last cut off would vary, depending upon the soil moisture retention and influence the evapotranspiration rate. Accumulated crop evapotranspiration estimates for crop growing season ranged from 531 mm to 707 mm for cotton with strategy S II having the upper limit and strategy S V having the lower limit.

The sowing is started with the onset of monsoon for cotton crop, thus date 27th July is selected for 2003 base year as sufficient moisture prevailed during the period. During the simulations carried out for the study period the model takes the same date throughout, and it does not allow changing the sowing period date in between. Due to this limitation of the model the crop could be under soil moisture conditions, if the rains would be delayed or erratic. The results could be encouraging if this limitation could have been overcome. The effect of irrigation, effective precipitation on $ET_{actual,}$ and SMD throughout the growing season of cotton has been shown in Fig 5.37(a-f). The strategy S I (conventional) and strategy S

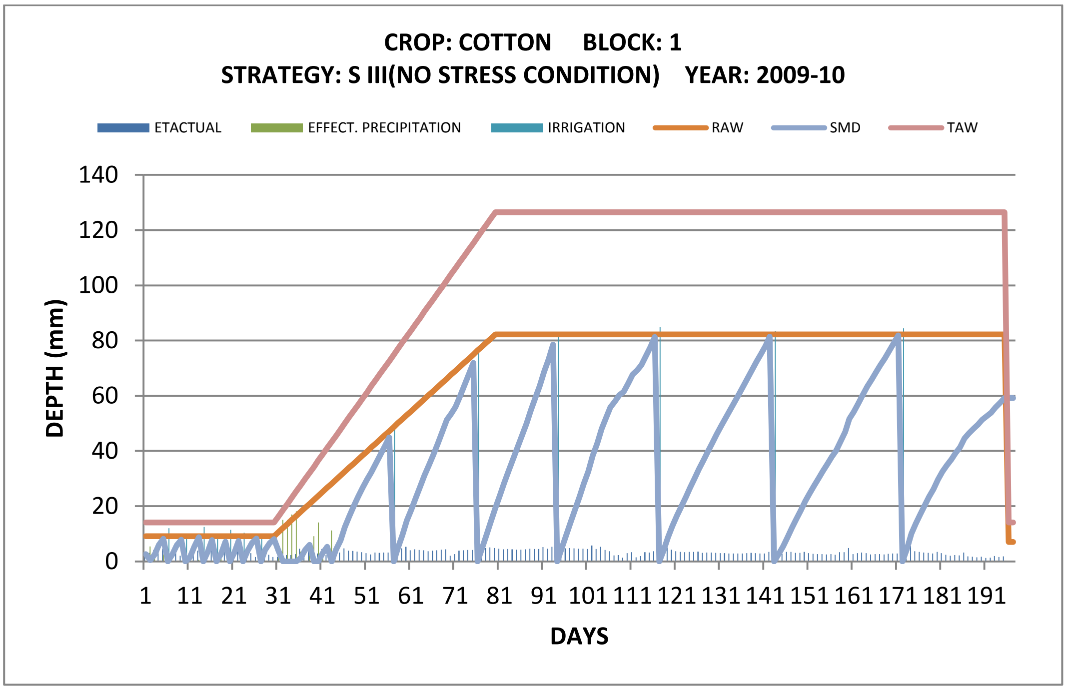
IV(protective) shows effect of water stress during the all the stages, specifically development, and mid stage. In strategy S II as the irrigation is given post one month sowing; severe and mild water stress is visible in initial vegetative and late stage respectively. As no water stress was developed during the initial flowering stage in strategy S VI this could result in enhancement of yield.



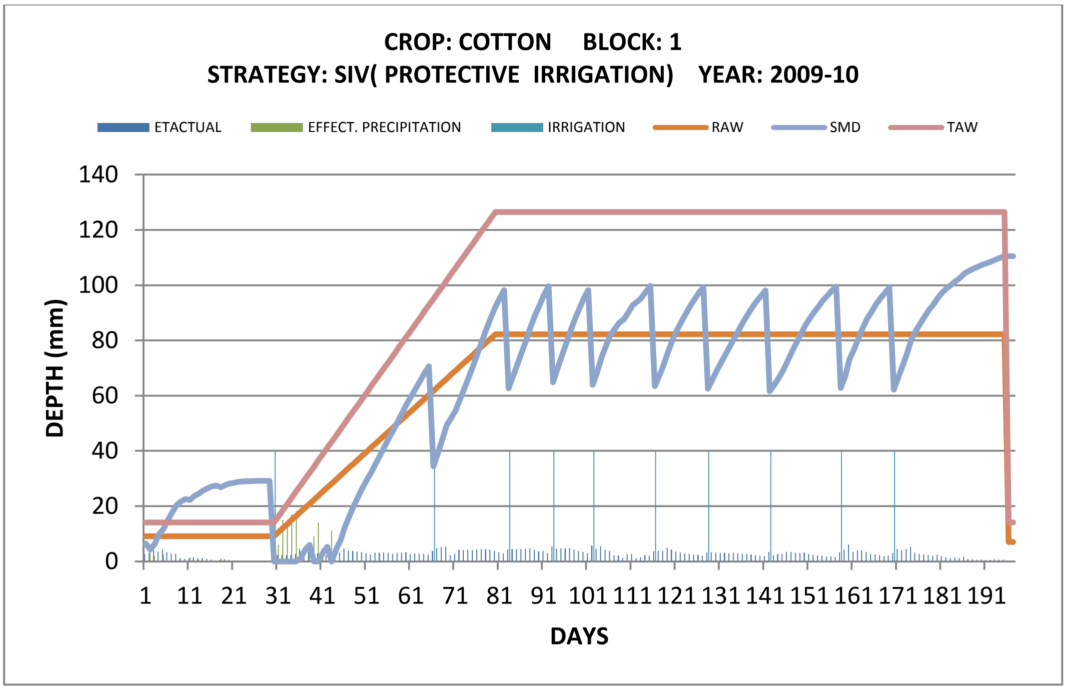
5.37 (a)



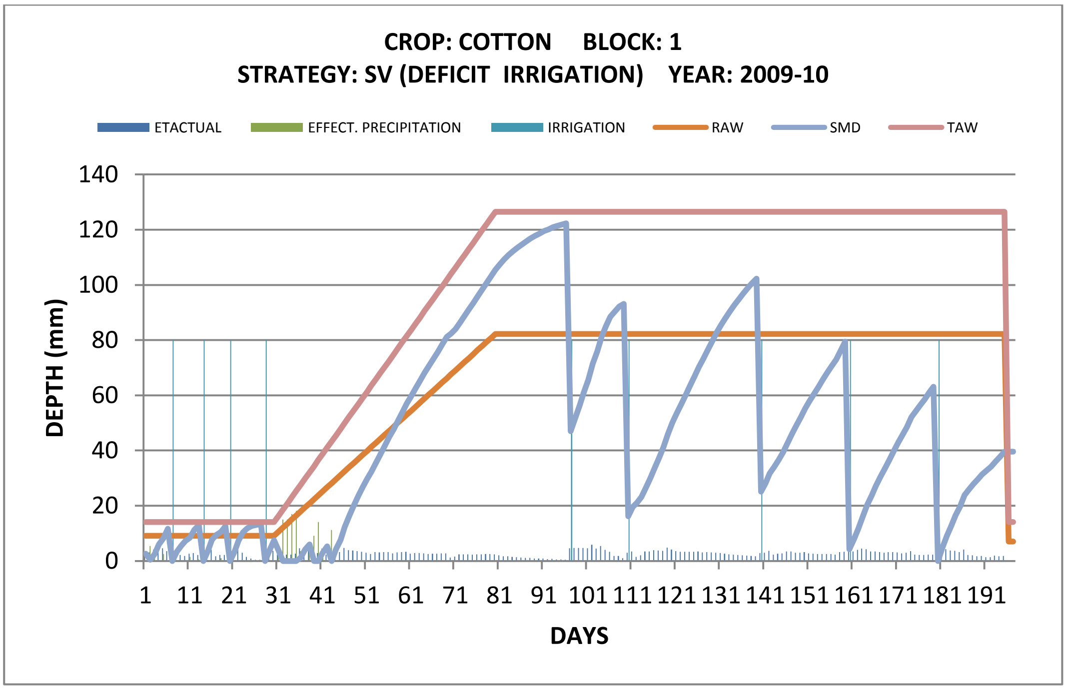
5.37 (b)


CROP: COTTON BLOCK: 1
STRATEGY: S III(NO STRESS CONDITION) YEAR: 2009-10
ETACTUAL
EFFECT. PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191
DAYS

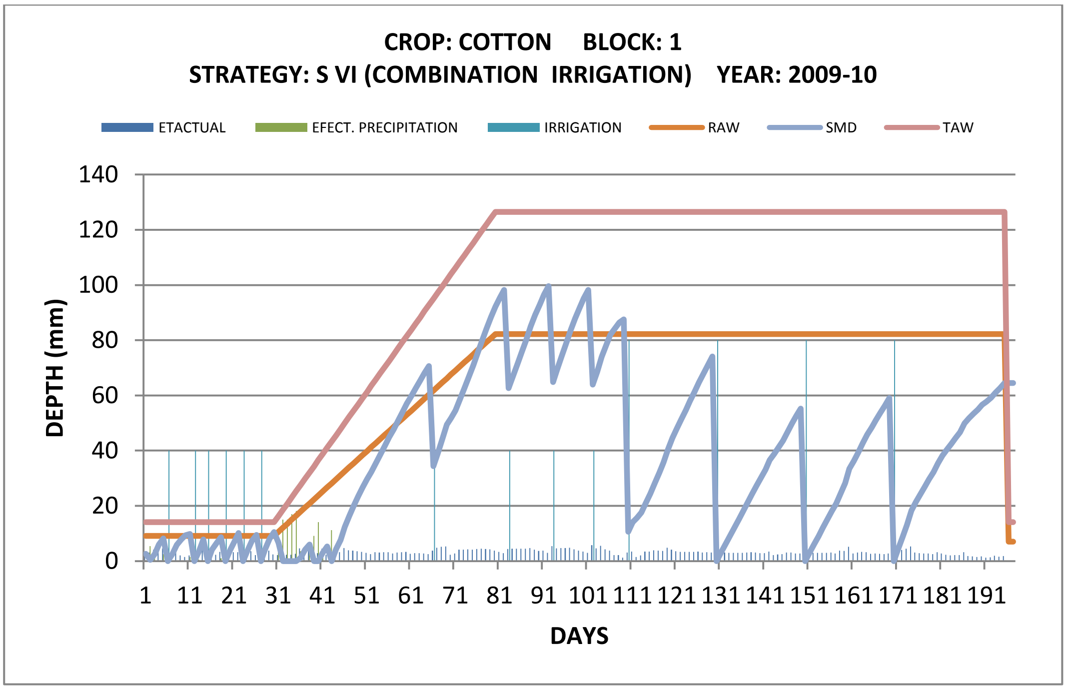
5.37 (c)


CROP: COTTON BLOCK: 1
STRATEGY: SIV(PROTECTIVE IRRIGATION) YEAR: 2009-10
ETACTUAL
EFFECT. PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191
DAYS

5.37 (d)



5.37 (e)



5.37 (f)

Fig 5.37(a-f): Soil moisture balance for irrigation strategies S I to S VI for cotton crop year 2009-2010

5.13.2 Effect of Soil Type on Cotton Irrigation Depth

To evaluate the effect of soil on irrigation depth for cotton crop the strategy S II was considered as reference strategy for sake of comparison, as irrigation water of fixed depth was applied to achieve no stress condition after vegetative stage, resulting in near to potential yield. Cotton crop grown in sandy clay soil required maximum mean irrigation depth of 303 mm refer Fig. 5.38. Average irrigation depth for cotton crop varied between 200 mm to 250 mm in sandy clay loam, clay, and silty clay soils. Average irrigation depth range for cotton crop in sandy loam, silty clay loam, and clay loam was between 188 mm to 208 mm.

5.13.3 Effect of Irrigation on Groundwater for Cotton

Average ground water withdrawals for cotton crop were evaluated for the six strategies in selected region I and II areas having high ground water table to study any adverse effects, and there results are shown in Table 5.30. Strategies having very high negative values are not suitable to be recommended as it led to groundwater table rise. Minor rise in ground water is observed in all strategies. Strategies S II and S III are the appropriate amongst all. Strategies S IV or S V can also be used depending upon the block having lesser rise of groundwater table which could be noted down from table.

5.13.4 Irrigation Depth for Cotton under Strategies S I to S VI

Irrigation depth range of water required for cotton against various irrigation strategies has been shown in Fig 5.39. The results are encouraging and states that in case of automated irrigation strategies the water requirement would be optimum with large savings of water. Strategies S II, S VI and S V have an equal upper limit of 432mm, while lower limit is 144 mm, 192 mm, and 192 mm respectively, though yield reduction is large in strategy S V due to 10 day deficit irrigation during flowering. Strategy S I (conventional), uses maximum depth of irrigation amongst all strategies, with lower limit and upper limit being both high then the rest.

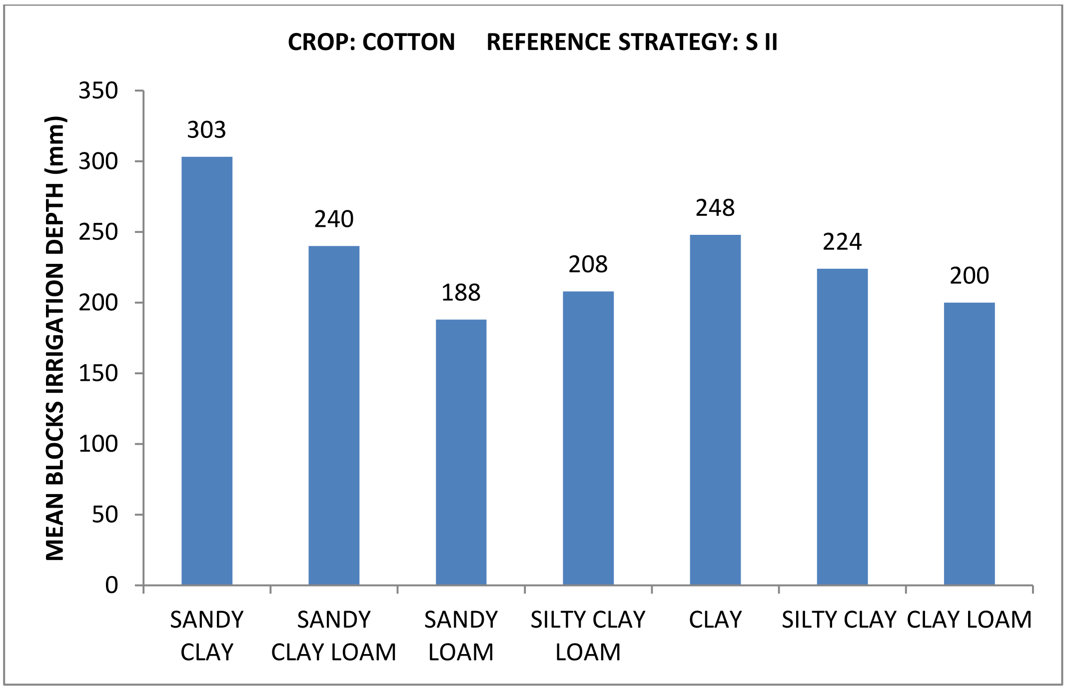


Fig 5.38: Effect of soil type on cotton irrigation depth under strategy S II

Table 5.30: Average net groundwater withdrawals (years 2004-2009) for cotton crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for cotton crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-3	14	-46	-80	-72	-93
6A1	Sc	1 to 15	-52	12	-15	-42	-31	-53
8	Scl	0.5to 6.5	-18	53	16	-10	-3	-19
10	Scl	1.5 to 18	-93	-36	-44	-66	-69	-103
11A2	Sc	3 to >30	-46	19	-10	-35	-25	-41
6A3R2	C	>30	-42	28	8	-11	-20	-41
6BR2	Sic	1.2to>30	-71	-14	-24	-47	-57	-77
9A2R2	Sicl	1 to >30	-95	-52	-49	-56	-72	-98
9B1R2	Cl	0.5 to 23	-103	-37	-31	-68	-81	-109

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

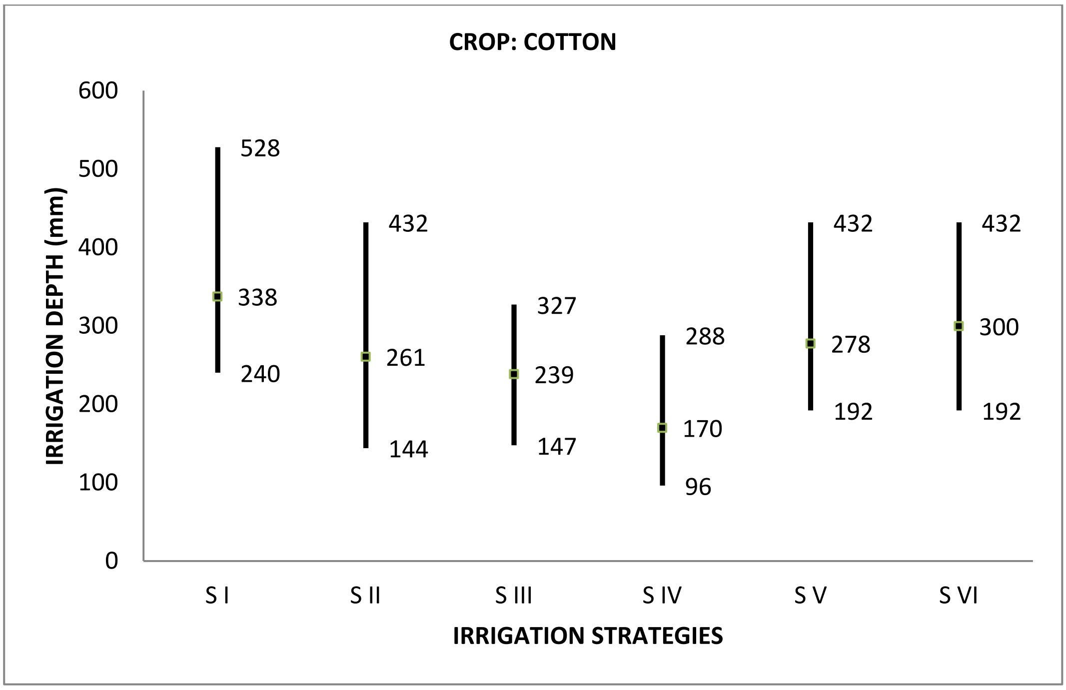


Fig 5.39: Irrigation depth range for cotton crop for strategies S I to S VI

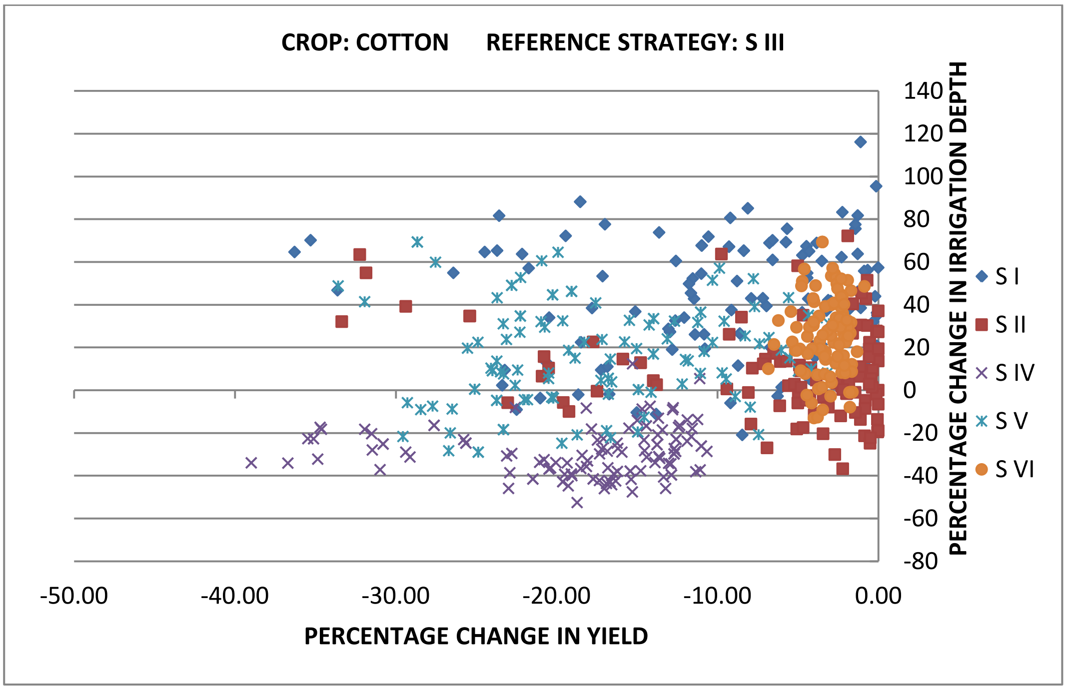


Fig 5.40: Percentage change in yield versus percentage change in irrigation depth for cotton crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.13.5 Evaluating Irrigation Strategies for Cotton

The relation of percentage change in yield to percentage change in irrigation depth with respect to model determined no stress condition strategy (which would ideally give the maximum yield with optimum irrigation) was derived for all strategies. On comparing the various strategies the best strategy obtained was strategy S III, followed by S VI. In S VI there was mild average reduction in yield of 3 percent, where the range varied (1 to 7 percent) however, with an average increase in irrigation depth of 26 percent with varied range (-13 percent to 69 percent). From yield point of view, difference in yield between S VI and S II is negligible, with an exception of dry year 2009, across the region I and II, where averaged yield reduction for S II, was in range of 14 percent to 33 percent. Strategy S II water usage range was −37 to 72 percent than the ideal no moisture stress condition with average increase in irrigation depth of 9 percent. Strategy S I showed averaged 42 percent more usage of water with average yield reduction of 10 percent. Strategy S IV had average yield reduction of 18 percent (range of 11 percent to 39 percent) with averaged decrease in irrigation depth of 29 percent (range −53 percent to 12 percent). Strategy S V had decrease in average yield 17 percent (yield reduction range of 3 percent to 34 percent) respectively with average increase in water usage 16 percent and with range −29 to 69 percent respectively. This indicates that average yield reduction for strategy S IV and SV is similar nevertheless; average increase in irrigation depth is more for S V. The order of usage of strategy to be recommended in terms of yield could be S III, SVI, S II, S I, S V, and S IV. Keeping water savings in mind the order of usage of irrigation strategy recommendations could be S IV, S III, S II, S V, S VI, and S I respectively. Strategies best suited and recommended in order of merit for attaining significant yield and water savings simultaneously for cotton are S III, followed by S VI, S II, and SI.

5.14 Irrigation Scheduling Strategies for Groundnut

Kharif groundnut crop is sown at the onset of monsoon. The crop has 120 days of crop seasonal length. The assessment of irrigation strategies, which could be beneficial from stake holders' point of view, is very much necessary. The different irrigation strategies employed for Kharif groundnut are summarized in Table 5.31. (i) Strategy S I: Post eight days of sowing fixed irrigation depth is applied at fixed gap of 10 days. (ii) Strategy S II: Irrigation of fixed depth is applied post 20 days of sowing and the irrigation is triggered, when moisture depletion reaches 100 per cent of readily available water. (iii) Strategy S III: Irrigation equivalent to soil moisture depletion is applied, when soil moisture depletion equals 100 percent of RAW. (iv.) Strategy S IV: Irrigation of reduced fixed depth is given when soil moisture depletion is equivalent to 80 per cent of total available water. (v) Strategy S V: Deficit irrigation of fixed depth is applied in first phase at interval of 30 days from sowing. In second phase, irrigation of fixed depth is applied at gap of fortnight from 40 days of sowing, and (vi) Strategy S VI: In first phase, irrigation of reduced depth is applied from day of sowing upto 21 days, when SMD equals 80 per cent of TAW. In second phase, irrigation is given from 22 days of sowing onwards and reduced fixed depth is applied, when SMD reaches 100 per cent of RAW. Total 114 simulations for daily soil water balance for groundnut crop was carried out. The initial depletion at the starting of the 2003 base period was taken as zero. The maximum potential yield for groundnut crop selected was 2500 Kg per hectare.

Table 5.31: Irrigation scheduling strategies for groundnut crop

Case	Irrigation Strategy for groundnut		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	8,18,28,38,48,58,68,78,88,98, 108 & 118	50mm	Irrigation of 50 mm fixed depth is applied at a fixed interval of 10 days from post 8 days of sowing.
S II	20-118	50 mm	After 20 days post sowing, irrigation of 50 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water (RAW).
S III	1-120	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water (RAW), to attain no moisture stress conditions
S IV	20-118	25 mm,	After 20 days post of sowing, irrigation of 25 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW).
S V	1, 31 40, 55 & 70	25 mm 35 mm	Irrigation of 25 mm fixed depth is applied at fixed interval of 30 days. Then irrigation of 35mm fixed depth is applied at a fixed interval of 15 days from post 40 days of sowing.
S VI	1-21 , 22-118	20 mm 50mm	Irrigation of 20 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW). Then, from 22 days upto 118 days of sowing, irrigation of 50 mm fixed depth is applied, when moisture depletion reaches at 100% RAW.

* From date of sowing. Date of sowing 1st July and Harvesting on 28th October.

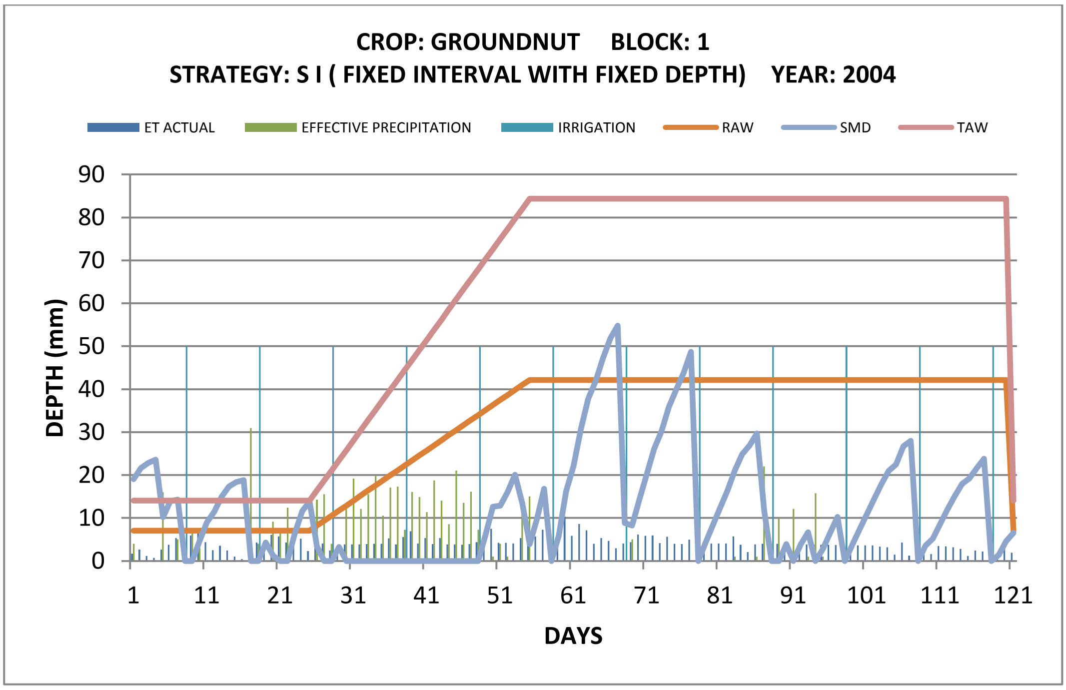
Table 5.32: Water balance, yield and efficiencies of groundnut crop in sandy clay (HSG – C) soil in block 1 (grown in 2.59% of CCA 9868 ha)

Irrigation Strategies for Groundnut	Year	ETc act	Eff. Preci	GW Irrign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE
		mm	Mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm
		1	2	3	4	5	6	7	8	9
Strategy S I F.I with F.D.	2004-2005	489	1068	360	65	-362	-642	2328	4.76	6.47
	2005-2006	465	655	360	92	-273	-368	2325	5.00	6.46
	2006-2007	648	1660	360	62	-271	-1162	2376	3.66	6.60
	2007-2008	503	1050	360	73	-296	-684	2470	4.91	6.86
	2008-2009	519	966	360	68	-290	-586	2302	4.43	6.40
	2009-2010	610	508	360	152	-150	-260	2254	3.69	6.26
	Average	539	984	360	85	-274	-617	2343	4.41	6.51
Strategy S II 100% RAW with F.D.	2004-2005	488	1068	180	85	-258	-587	2343	4.80	13.02
	2005-2006	473	655	240	104	-160	-365	2361	4.99	9.84
	2006-2007	646	1660	210	74	-178	-1119	2362	3.66	11.25
	2007-2008	497	1050	150	57	-130	-632	2463	4.96	16.42
	2008-2009	532	966	240	72	-172	-574	2366	4.45	9.86
	2009-2010	634	508	330	160	-120	-243	2375	3.74	7.20
	Average	545	984	225	92	-170	-587	2378	4.43	11.26
Strategy S III No Stress	2004-2005	423	1068	118	94	-281	-576	2500	5.91	21.18
	2005-2006	373	655	81	89	-151	-299	2500	6.70	31.04
	2006-2007	507	1660	123	72	-243	-1105	2500	4.93	20.29
	2007-2008	419	1050	106	75	-183	-630	2500	5.97	23.53
	2008-2009	457	966	112	80	-185	-516	2500	5.48	22.39
	2009-2010	466	508	190	119	-118	-234	2500	5.36	13.13
	Average	441	984	122	88	-194	-560	2500	5.72	21.93
Strategy S IV Protective Irrigation	2004-2005	370	1068	60	67	-265	-560	1885	5.10	31.42
	2005-2006	334	655	30	73	-126	-298	2006	6.00	66.85
	2006-2007	471	1660	45	11	-171	-1074	2123	4.51	47.18
	2007-2008	393	1050	30	42	-132	-598	2231	5.68	74.35
	2008-2009	428	966	75	30	-143	-500	2080	4.86	27.74
	2009-2010	373	508	75	53	-54	-210	1684	4.52	22.46
	Average	395	984	53	46	-148	-540	2002	5.11	45.00
Strategy V Deficit Irrigation	2004-2005	360	1068	93	59	-276	-584	1787	4.96	19.21
	2005-2006	335	655	93	88	-199	-302	2024	6.04	21.76
	2006-2007	469	1660	93	3	-202	-1084	2173	4.63	23.36
	2007-2008	376	1050	93	51	-188	-630	2099	5.59	22.57
	2008-2009	374	966	93	22	-204	-503	1702	4.56	18.30
	2009-2010	324	508	93	42	-107	-212	1174	3.62	12.62
	Average	373	984	93	44	-196	-553	1826	4.90	19.64
Strategy S VI Combination	2004-2005	422	1068	156	91	-299	-594	2493	5.91	15.98
	2005-2006	371	655	144	86	-175	-339	2480	6.69	17.22
	2006-2007	504	1660	162	68	-266	-1119	2487	4.93	15.35
	2007-2008	416	1050	144	73	-209	-642	2495	5.99	17.32
	2008-2009	461	966	198	80	-205	-578	2478	5.37	12.52
	2009-2010	465	508	246	116	-161	-243	2482	5.34	10.09
	Average	440	984	175	86	-219	-586	2486	5.70	14.75

Note: No. of rainy days for groundnut crop period in year 2004, 2005, 2006, 2007, 2008 and 2009 are 48, 46, 55, 55, 57 and 39 days respectively.

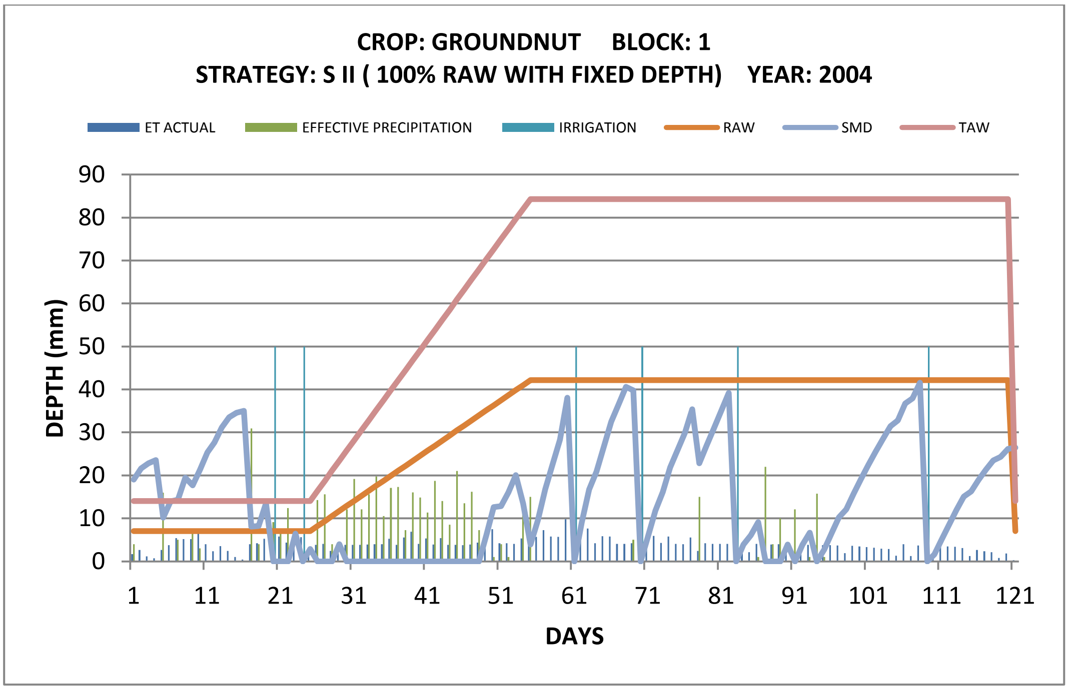
5.14.1 Water Balance, Yield and Efficiencies for Groundnut

The computation of daily water balance, yield and efficiencies for all 19 blocks for the study period was carried out. Results of block 1 only have been summarized in Table 5.32. Furrow irrigation method is adopted for groundnut crop here, thus values in column 3 of Table 5.32 are required to be divided by 0.6 fraction wetted value. The results establish that strategy S III was the best option amongst the all, as it gave the maximum yield with optimum utilization of irrigation water, followed by strategy S VI with high yield and WUE however, with moderate losses due to surface runoff and flow to groundwater, thus having relatively low IWUE. Slight reduction in yield was observed in strategy S II, as it was decided to irrigate only at late vegetative stage to reduce the number of irrigations, presuming the soil would hold sufficient moisture after the onset of monsoon. WUE and IWUE were relatively lower, than aforesaid strategies with reasonably low flow to groundwater. Strategy S I had nearly similar yield, WUE although, with comparatively low IWUE indicating larger losses than discussed above strategies. Strategy S IV yield was comparatively less than the other strategies, but had significant high WUE and highest IWUE, indicating the best usage of irrigation water with minimum losses amongst all strategies. Strategy S V did not perform upto the satisfactory level giving least yield although IWUE was significantly high in comparison to other strategies. Influence of soil moisture depletion on yield was carried out which are demonstrated through Figure 5.41 (a-f) and the results are summarized in Table 5.32. It is clearly evident from looking at Figure 5.41 c, 5.41 f, and Table 5.32 that maximum yield would be attained in S III and S VI, as no moisture stress is visible throughout in former strategy, while in later strategy insignificant moisture stress is seen in initial vegetative stage only. Further, in strategy SVI mild moisture stress is seen in initial stage, but it should not affect the yield, which results in table confirmed. Strategy S II showed significant moisture stress in initial stage only, which could affect the reduction in yield slightly. In strategy S I mild stress during initial stage and mid season stage will cause reduction in yield further, the surface run off and flow to groundwater will be significant due to more number of irrigations in Kharif. The stress on account of soil moisture is found for large duration initial and mid season stage, which should have a tremendous impact on yield however, the yield reduction is not as large as one would expect. This shows that groundnut is not so sensitive to moisture stress during this period. In case of strategy S V (deficit irrigation) more reduction in yield is reported, because moisture stress is slightly low during initial, mid season stage, but it is more prominent during late mid season stage, indicating the sensitiveness towards moisture stress during this period.



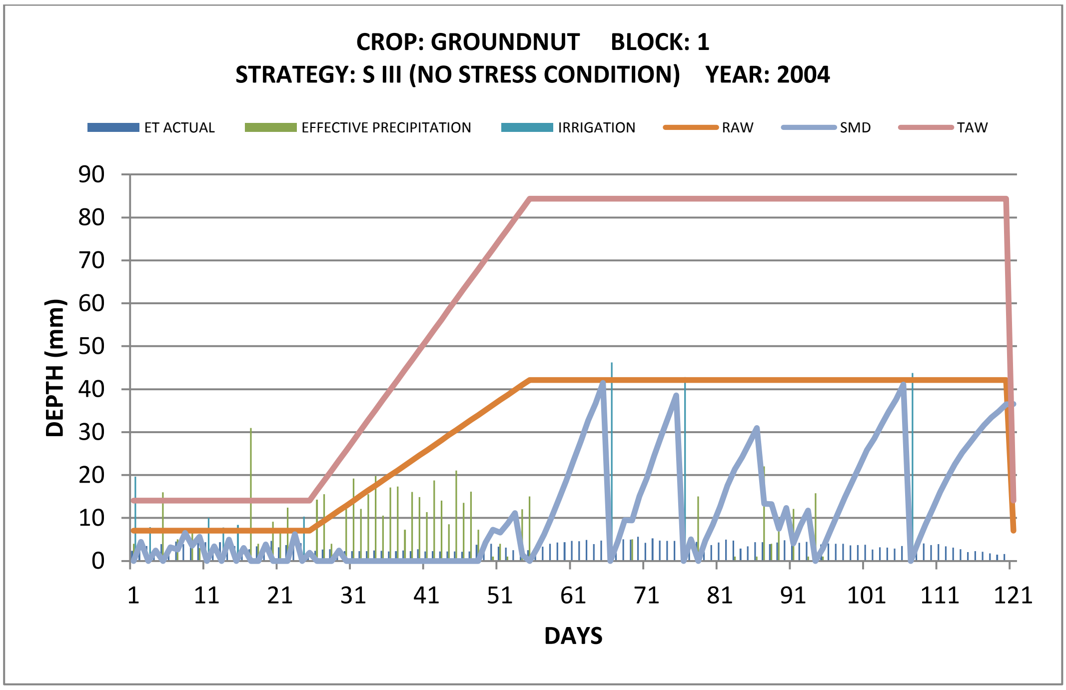
CROP: GROUNDNUT BLOCK: 1
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
0
10
20
30
40
50
60
70
80
90
1
11
21
31
41
51
61
71
81
91
101
111
121
DAYS

5.41 (a)



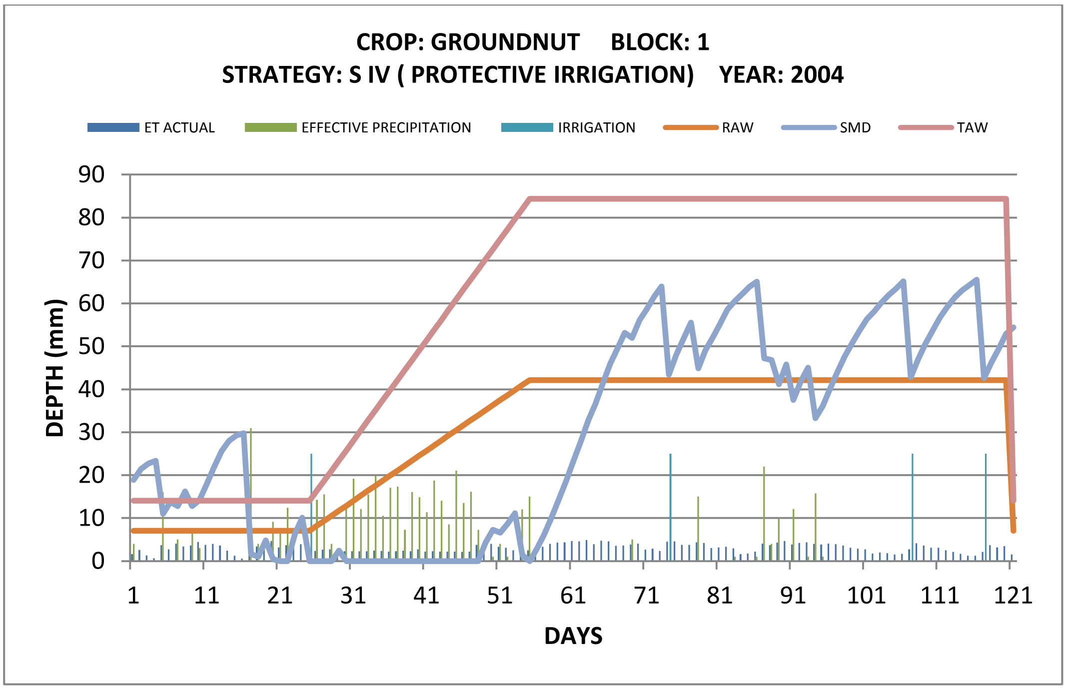
CROP: GROUNDNUT BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
0
10
20
30
40
50
60
70
80
90
1
11
21
31
41
51
61
71
81
91
101
111
121
DAYS

5.41 (b)



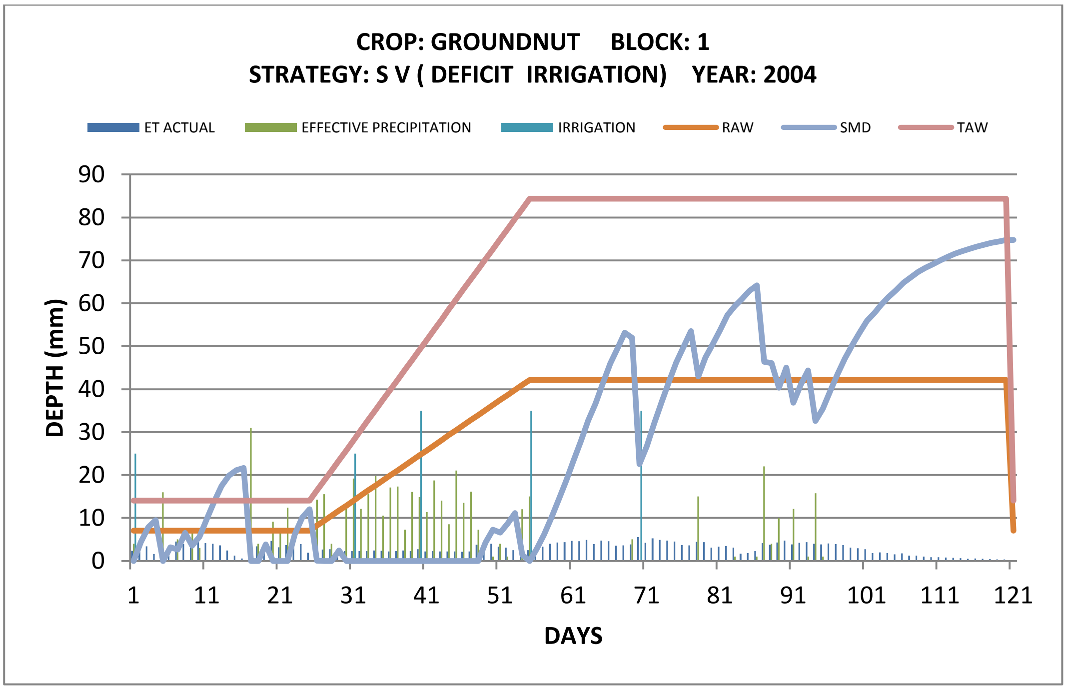
CROP: GROUNDNUT BLOCK: 1
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
111
121
DAYS

5.41 (c)

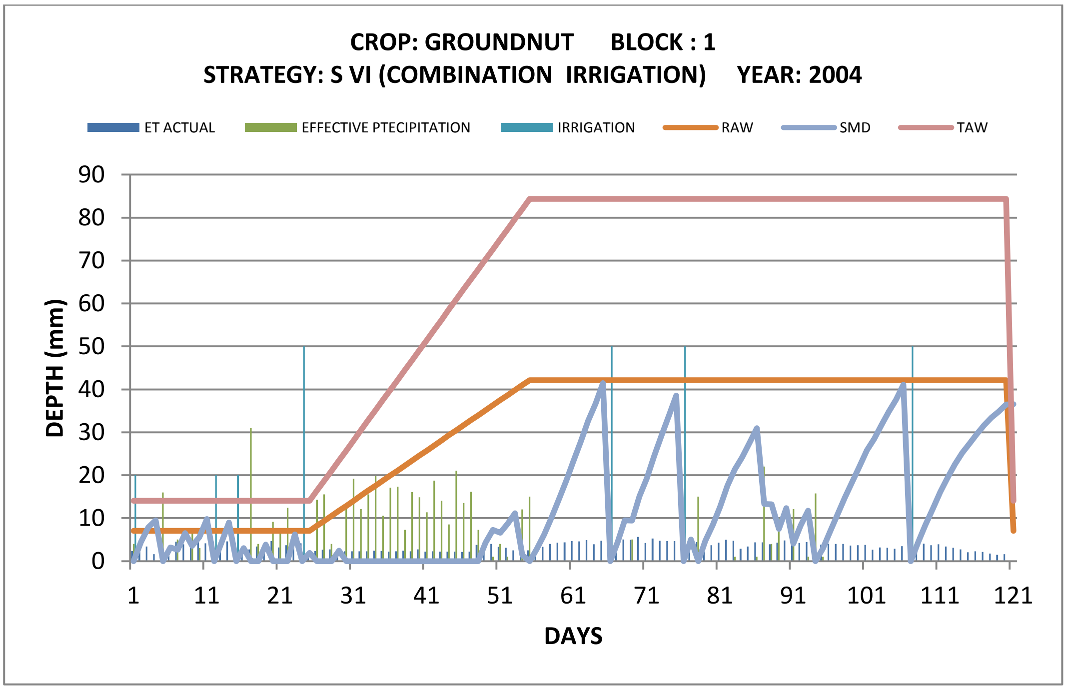


CROP: GROUNDNUT BLOCK: 1
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
90
80
70
60
50
40
30
20
10
0
1
11
21
31
41
51
61
71
81
91
101
111
121
DAYS

5.41 (d)



5.41 (e)



5.41 (f)

Fig 5.41(a-f): Soil moisture balance for irrigation strategies S I to S VI for groundnut crop year 2004

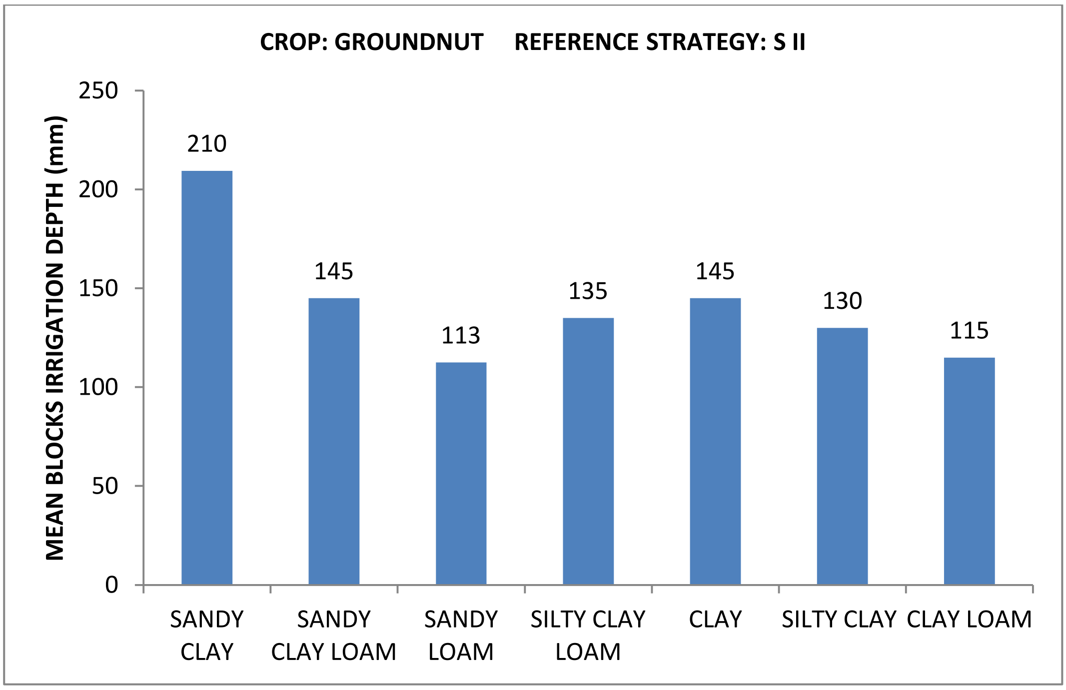


Fig 5.42: Effect of soil type on groundnut irrigation depth under strategy S II

5.14.2 Effect of Soil Type on Groundnut Irrigation Depth

Depth of irrigation requirement according to soil type for groundnut was undertaken with reference strategy S II. Figure 5.42 clearly shows the irrigation depth of various soil types. Averages of 10 blocks for sandy clay were 210 mm which was highest amongst all soils. Averages of three blocks of sandy clay loam and one block of clay was 145mm. Irrigation depth averages of two blocks for sandy loam and one block of clay loam was nearly similar (~115mm) which was least requirement irrigation depth. Silty clay loam and silty clay had similar irrigation depth (~135mm).

5.14.3 Effect of Irrigation on Groundwater for Groundnut

Average net groundwater withdrawals for study period under groundnut crop are summarized for all irrigation strategies in Table 5.33. The results show that rise in groundwater is seen for all blocks under strategies S II, S III, SIV, S V, and SVI with exception, of block 8 under strategy SII and SVI. The rise in groundwater is significant for blocks 4B, 10, and 9B1R2. Moderate rise in water table is in 6A1, 11A2, and 6BR2. In case of strategy S I except, block 10 and 9B1R2 there is fall in the water table with maximum fall in block 6A3R2, where already the static water level is below 30 m.

Table 5.33: Average net groundwater withdrawals (years 2004-2009) for groundnut crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for groundnut crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	22	-22	-144	-173	-174	-107
6A1	Sc	1 to 15	50	-18	-50	-79	-92	-17
8	Scl	0.5to 6.5	63	13	-21	-48	-69	12
10	Scl	1.5 to 18	-14	-59	-74	-104	-103	-59
11A2	Sc	3 to >30	36	-21	-51	-82	-99	-18
6A3R2	C	>30	84	-3	-16	-44	-44	-3
6BR2	Sic	1.2to>30	34	-38	-62	-81	-82	-31
9B1R2	Cl	0.5 to 23	-5	-58	-80	-101	-95	-64

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The groundnut crop is not sown in block 9A2R2. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

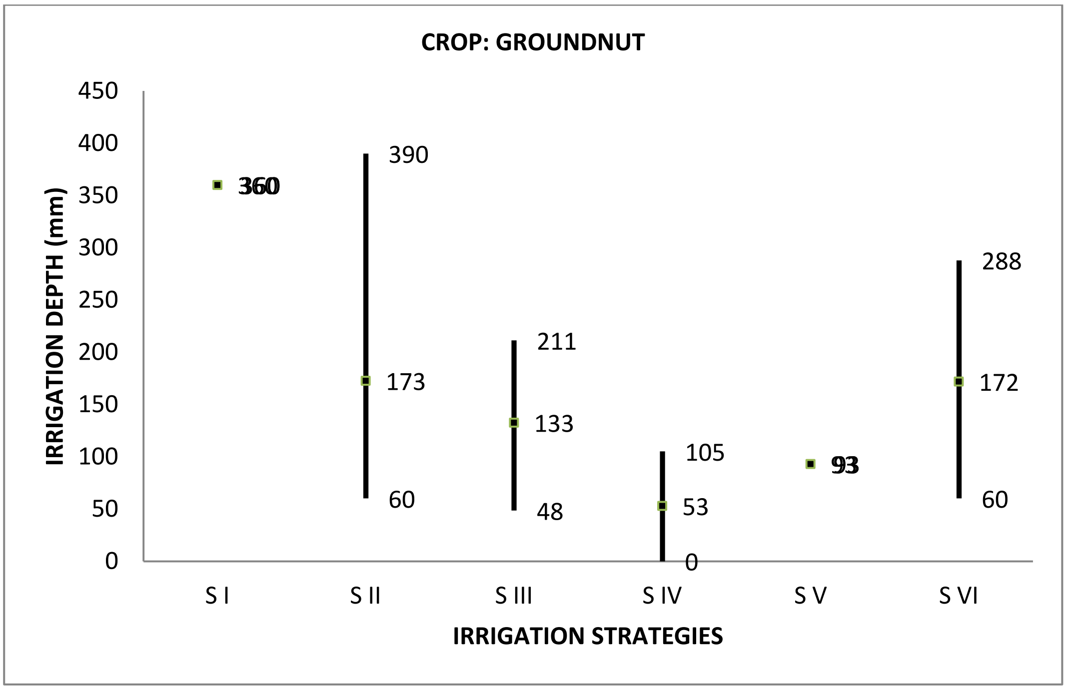


Fig 5.43: Irrigation depth range for groundnut crop for strategies S I to S VI

5.14.4 Irrigation Depth for Groundnut under Strategies S I to S VI

Irrigation depth range under groundnut crop for various irrigation strategies is demonstrated in Figure 5.43. The variability in irrigation depth is prominent in strategies S II and SVI, but the average irrigation depth (~172mm) is similar. Amongst the two strategies the maximum value is more in case of strategy SII, this shows the sensitiveness of the strategy to rainfall, soil moisture, and climatic conditions. Strategies S III and S IV have low variability in irrigation depth, although the maximum value of SIV is well below average value of S III, indicating large amount of water saving in this strategy. Irrigation method for groundnut adopted here is furrow, thus irrigation depth values in Figure 5.43 require to be divided by fraction wetted (0.6) to obtain total irrigation depth.

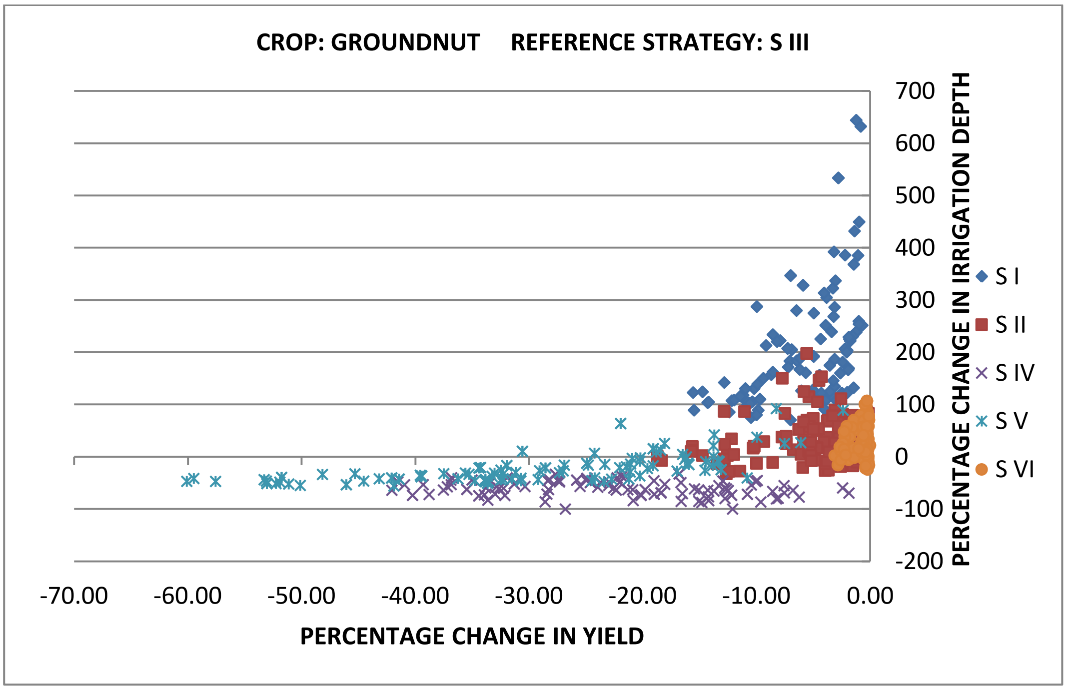


Fig 5.44: Percentage change in yield versus percentage change in irrigation depth for groundnut crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.14.5 Evaluating Irrigation Strategies for Groundnut

The relationship between percentage change in yield and percentage change in irrigation depth of various irrigation strategies, with respect to reference strategy S III are demonstrated in Figure 5.44. It is clearly evident that after strategy S III, the best suited strategy is S VI with range in reduction of 0 percent to 3 percent, and average reduction of 1 percent. The percentage change in irrigation depth is in range of -24 percent to 107 percent with average increase in irrigation depth of 33 percent. Strategy S II can be rated next to it with average reduction of 6 percent, and range of 0 percent to 19 percent. Percentage change in irrigation depth for strategy S II is in range of -32 percent to 198 percent with average irrigation depth increase of 36 percent. Strategy SI has average reduction in yield of 6 percent with range of −1 percent to −16 percent, but the percentage change in irrigation depth varies to great extent with range of 70 percent to 644 percent, and average of 202 percent, indicating the excess usage of water than the requirement. Average reduction in yield is 23 percent with range of −2 percent to −42 percent for strategy SIV nevertheless, with average reduction of 61 percent in irrigation depth and applied irrigation water was in range of no irrigation to 33 percent less irrigation depth, in comparison to strategy S III. Strategy S V performed well below the expectations with average reduction in yield of 29 percent and with yield range of −2 percent to −60 percent however, the irrigation depth varied from −56 percent to 92 percent, and with average decrease in irrigation depth of 22 percent. The strategies to be opted from yield point of view only could be in order of S III, S V I, S II, SI, SIV, and S V. The strategies to be opted from water savings point of view only could be SIV, S V, S III, SVI, S II, and S I. On considering the yield and water saving factor together the strategies which could be opted in order of merit are S III, S VI, S II, and S I.

5.15 Irrigation Scheduling Strategies for Castor

Castor is a two seasonal cash crop grown on 27th July having 180 days of crop seasonal length. The irrigation scheduling strategies selected (refer Table 5.34) are as follows: (i) Strategy S I: Irrigation of fixed depth is applied after initial stage on fixed growth stage days. (ii) Strategy S II: Fixed irrigation depth is applied post initial stage in the crop growth stage, whenever SMD is equivalent to 100 per cent RAW. (iii) Strategy S III: Irrigation equivalent to SMD is applied, whenever soil moisture depletion reaches 100 per cent of RAW. (iv.) Post initial stage reduced fixed depth irrigation is applied, when the SMD equals 80 percent of TAW. (v) Strategy S V: Irrigation is given in two phases. In first phase, post initial stage upto 119 days of crop growth stage irrigation of fixed depth is applied and irrigation is triggered, when soil moisture depletion reaches 80 percent of TAW. In second phase, two irrigations of fixed depth is applied at gap of 30 days on and after 120 days of crop growth stage, and (vi) Strategy S VI: In this strategy the irrigation is applied in two phases. First phase, comprise of reduced fixed irrigation depth from day of sowing to 60 days of crop growth stage, and the irrigation is triggered at 80 percent of TAW. In second phase, irrigation of reduced fixed depth is applied from 61 days to 150 days of crop growth stage, and irrigation is induced at 100 percent of RAW. At starting of computation of soil water balance the soil is assumed to be at field capacity. The maximum potential yield stated for the castor crop here is 2500 Kg per hectare. Total 120 simulations were done for each irrigation strategy of castor crop.

Table 5.34: Irrigation scheduling strategies for castor crop

Case	Irrigation Strategy for castor		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	25, 45, 65, 85, 105, 125 & 145	80mm	Irrigation of 80 mm fixed depth is applied at a fixed interval of 20 days from post 25 days of sowing.
S II	25-150	80 mm	After 25 days post sowing, irrigation of 80 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water (RAW).
S III	1-180	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water (RAW), to attain no moisture stress conditions.
S IV	25-150	40 mm,	After 25 days post of sowing, irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW).
S V	25- 119 120 & 150	60 mm 80 mm	After 25 days post of sowing, irrigation of 60 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW). Then irrigation of 80 mm fixed depth is applied at a fixed interval of 30 days from post 120 days of sowing.
S VI	1-60, 61-150	40 mm 60mm	Irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW). Then, from 61 days upto 150 days of sowing, irrigation of 60 mm fixed depth is applied, when moisture depletion reaches at 100% RAW.

***** From date of sowing. Date of sowing 27th July and Harvesting on 22nd January.

5.15.1 Water Balance, Yield and Efficiencies for Castor

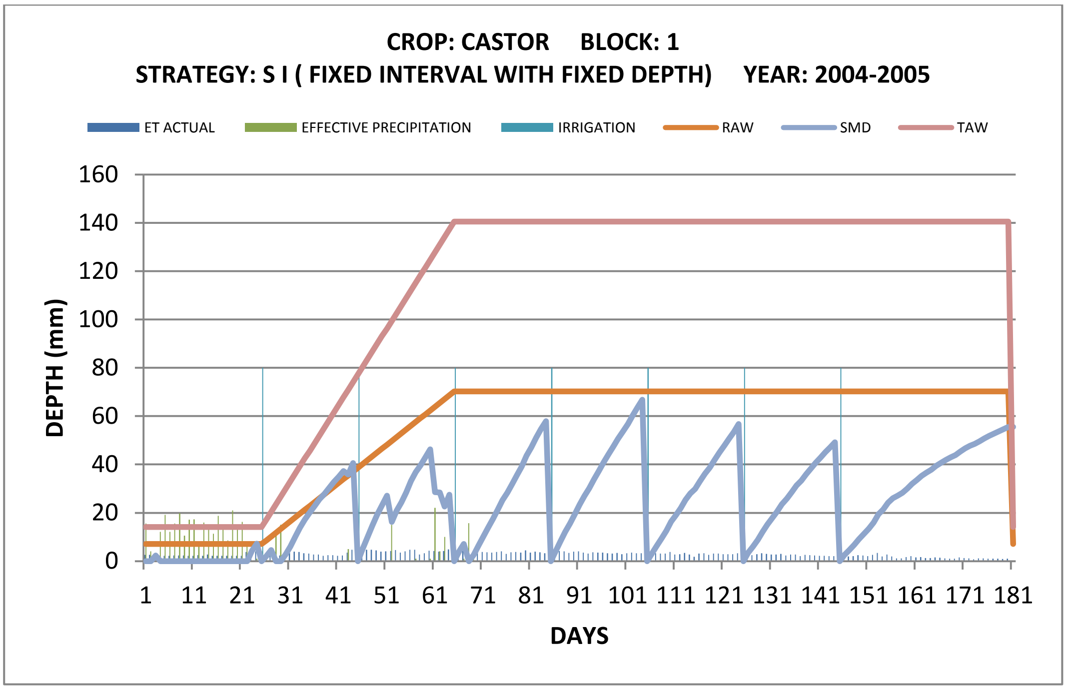
Daily soil moisture balance was calculated for all the treatments for study period in 20 blocks where castor is grown. As it would be cumbersome to discuss the results for all the blocks only results of block1 has been summarized in Table 5.35. Furrow method is applied to irrigate castor crop over here, thus the values in column 3 and 4 are to be divided by fraction wetted 0.6. The data of table demonstrates that strategy S III had maximum potential yield. It is also observed that yield increases, when amount of irrigation was more at any particular instance of crop growth stage for e.g. strategies S I, S II and S VI, except strategy S III, where irrigation is given equivalent to soil moisture stress conditions only at that point of time. Amongst strategies S I and S VI the crop evapotranspiration, yield, and WUE attained were alike, but IWUE of S VI was significantly large, indicating that with optimum irrigation depth the utilization of stored water in root zone is best. The value of IWUE is highest amongst the all strategies in S VI. The decrease in yield in strategy S II could be due to the policy to irrigate post initial stage only. The delay in monsoon or dry year could have significant impact on yield due to moisture stress this is apparent, when 2009 dry year data is examined. On studying the strategies S IV and S V we find that the yield for S IV is least, although the IWUE is the highest amongst all strategies, implying that better water usage is accomplished with this strategy. In strategy S V no significant difference is noted in WUE and IWUE however, the mild yield reduction is observed.

The soil moisture pattern influence on yield could be examined with help of Figure 5.45(a-f) and Table 5.35. In case of strategy S I, S II and S III no noticeable moisture stress is visible, throughout the crop growth stage, implying that near potential yield could be attained, which is also ratified while examining the results in the table. In case of strategy S IV except initial stage, soil moisture stress is substantially visible in all stages; implying that severe reduction of yield was possible. Since the crop is drought resistant the reduction in yield is not as prominent as it would be in case of other crops. For strategy S V the moisture stress pattern is visible during development stage and during the period of starting mid season stage, indicating the reduction in yield would be not so significant. Mild yield reduction in strategy S VI is due to moisture stress during development and late mid season stage, implying that these stages are not so critical from yield reduction point of view. In strategy S II the large quantity of irrigation during development has significantly affected in the lower values of IWUE. Implying that proper utilization of irrigation water would have been possible, if irrigation depths were reduced during that period.

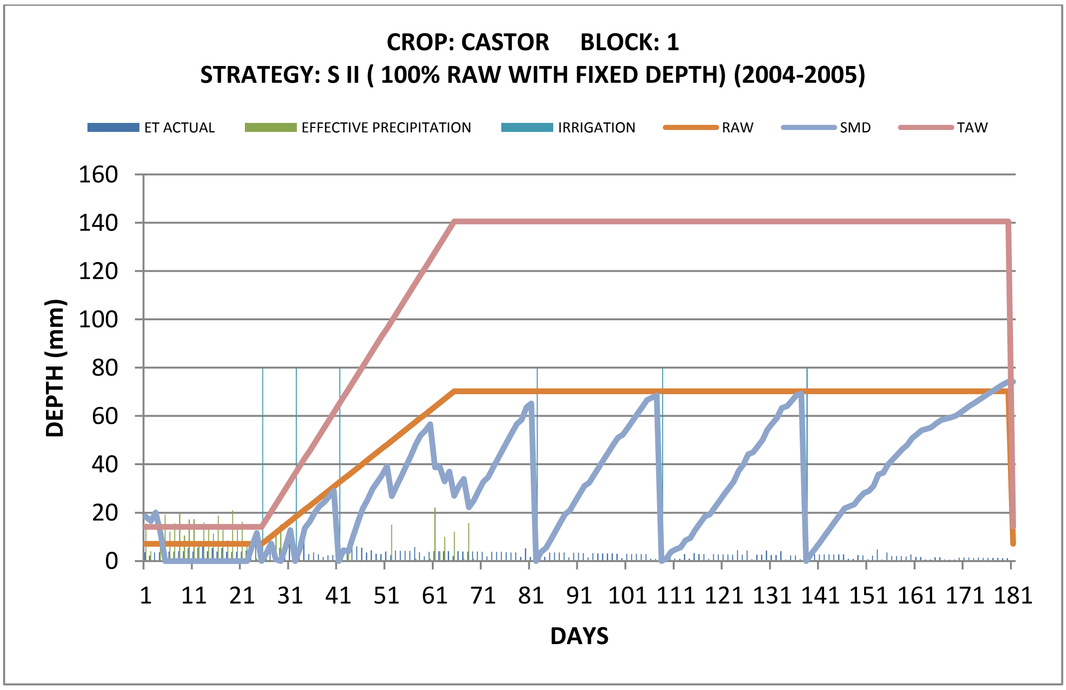
Table 5.35: Water balance, yield and efficiencies of castor crop in sandy clay (HSG – C) soil in block 1 (grown in 2.74% of CCA 9868 ha)

Irrigation Strategies for Castor	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	Mm	mm	mm	mm	Kg/ha	Kg/ha/mm	Kg/ha/mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	518	924	192	144	172	-259	-655	2487	4.80	7.40	0.39
	2005-2006	494	430	192	144	162	-267	-168	2458	4.98	7.32	0.39
	2006-2007	587	1284	192	144	148	-236	-946	2465	4.20	7.34	0.39
	2007-2008	524	466	192	144	172	-202	-249	2492	4.75	7.42	0.39
	2008-2009	549	720	192	144	144	-186	-464	2453	4.47	7.30	0.39
	2009-2010	553	211	192	144	244	-103	-134	2272	4.11	6.76	0.39
	Average	538	672	192	144	174	-209	-436	2438	4.55	7.26	0.39
Strategy S II 100% RAW with F.D.	2004-2005	552	924	192	96	153	-164	-650	2489	4.51	8.64	0.26
	2005-2006	612	430	144	144	181	-97	-190	2457	4.01	8.53	0.39
	2006-2007	746	1284	240	96	188	-128	-935	2407	3.23	7.16	0.26
	2007-2008	594	466	192	96	194	-78	-276	2437	4.11	8.46	0.26
	2008-2009	715	720	192	144	183	-84	-440	2308	3.23	6.87	0.39
	2009-2010	740	211	336	144	289	-96	-144	2142	2.89	4.46	0.39
	Average	660	672	216	120	198	-108	-439	2373	3.66	7.35	0.32
Strategy S III No Stress	2004-2005	532	924	85	129	155	-146	-615	2500	4.70	11.65	0.35
	2005-2006	509	430	87	128	147	-125	-159	2500	4.92	11.65	0.35
	2006-2007	600	1284	70	129	159	-121	-920	2500	4.16	12.59	0.35
	2007-2008	531	466	62	129	157	-88	-196	2500	4.71	13.05	0.35
	2008-2009	564	720	119	129	153	-147	-409	2500	4.43	10.08	0.35
	2009-2010	601	211	162	127	249	-64	-85	2500	4.16	8.63	0.34
	Average	556	672	98	129	170	-115	-397	2500	4.51	11.27	0.35
Strategy S IV Protective Irrigation	2004-2005	404	924	24	48	162	-139	-615	1662	4.12	23.09	0.13
	2005-2006	403	430	24	48	150	-108	-141	1841	4.57	25.57	0.13
	2006-2007	502	1284	24	72	69	-67	-879	1909	3.81	19.89	0.19
	2007-2008	445	466	24	72	167	-83	-202	1900	4.27	19.79	0.19
	2008-2009	450	720	48	72	84	-84	-390	1821	4.05	15.17	0.19
	2009-2010	416	211	72	72	209	-63	-85	1529	3.67	10.62	0.19
	Average	436	672	36	64	140	-91	-385	1777	4.08	19.02	0.17
Strategy S V Deficit Irrigation	2004-2005	465	924	36	132	142	-153	-615	1992	4.28	11.86	0.36
	2005-2006	470	430	36	132	133	-108	-153	2234	4.75	13.30	0.36
	2006-2007	555	1284	36	132	132	-106	-922	2233	4.02	13.29	0.36
	2007-2008	491	466	36	132	154	-83	-214	2200	4.48	13.10	0.36
	2008-2009	507	720	72	132	122	-114	-424	2122	4.18	10.40	0.36
	2009-2010	503	211	108	132	219	-66	-101	1870	3.72	7.79	0.36
	Average	499	672	54	132	150	-105	-405	2108	4.24	11.62	0.36
Strategy S VI Combination	2004-2005	494	924	72	72	180	-139	-615	2293	4.64	15.93	0.19
	2005-2006	483	430	108	72	175	-116	-185	2394	4.95	13.30	0.19
	2006-2007	585	1284	108	108	127	-116	-925	2466	4.21	11.42	0.29
	2007-2008	524	466	60	108	175	-84	-201	2492	4.75	14.83	0.29
	2008-2009	561	720	168	108	167	-158	-444	2485	4.43	9.00	0.29
	2009-2010	586	211	228	108	266	-79	-148	2427	4.14	7.22	0.29
	Average	539	672	124	96	181	-115	-420	2426	4.52	11.95	0.26

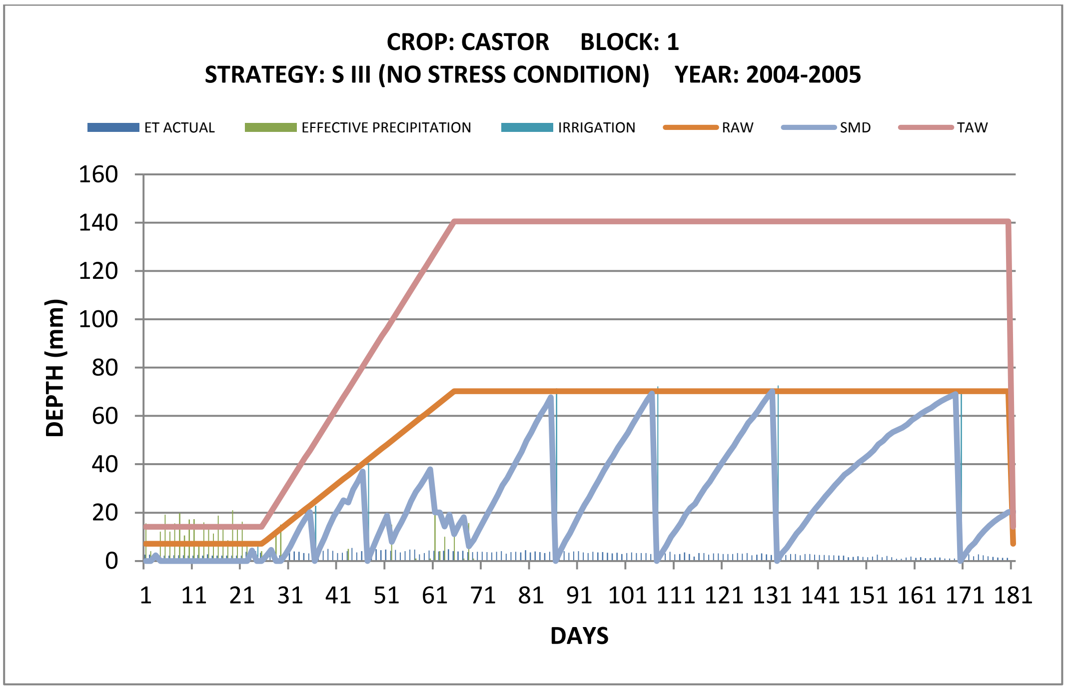
No. of Rainy days for Castor crop period in years 2004, 2005, 2006, 2007, 2008 and 2009 are 37, 37, 41, 39, 38 and 17 respectively.


CROP: CASTOR BLOCK: 1
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

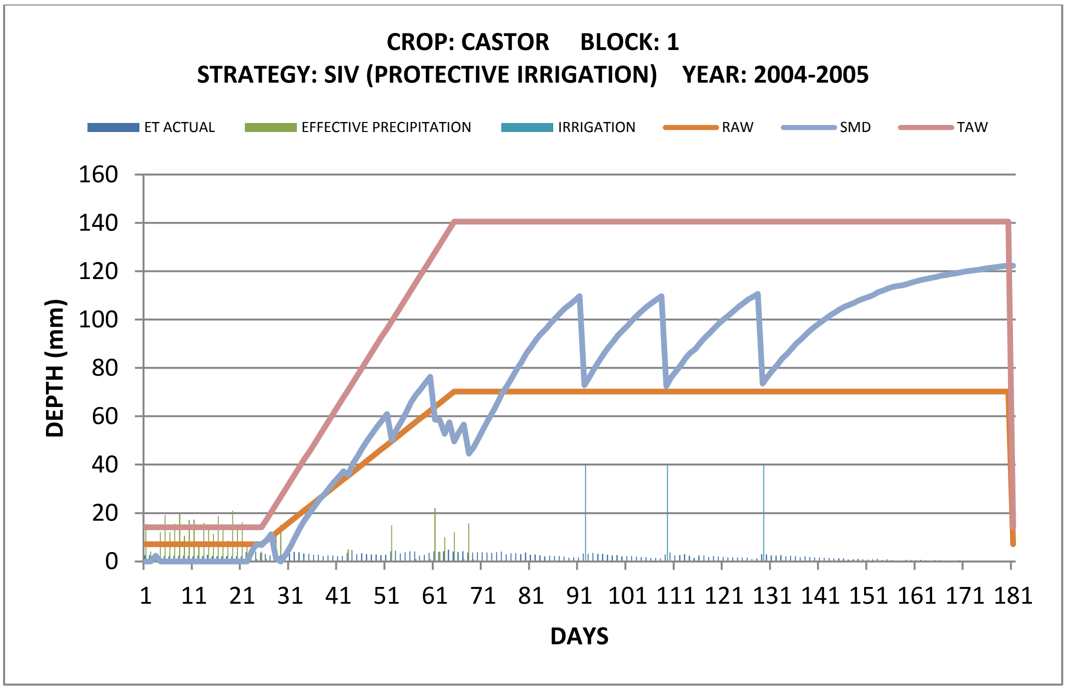
5.45 (a)


CROP: CASTOR BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) (2004-2005)
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

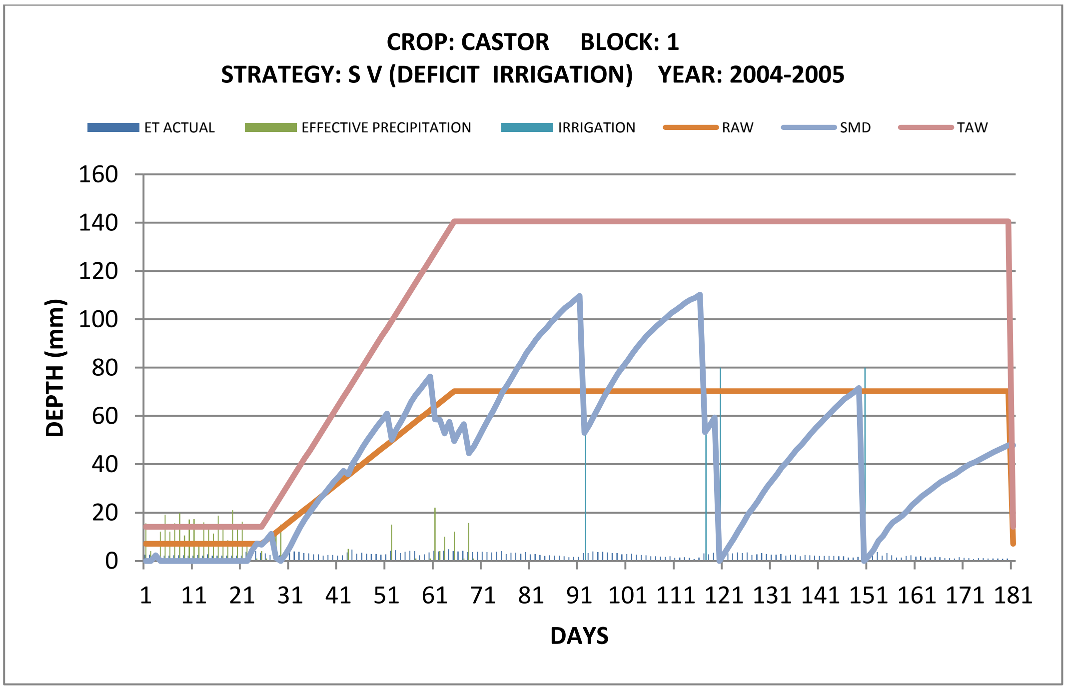
5.45 (b)


CROP: CASTOR BLOCK: 1
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

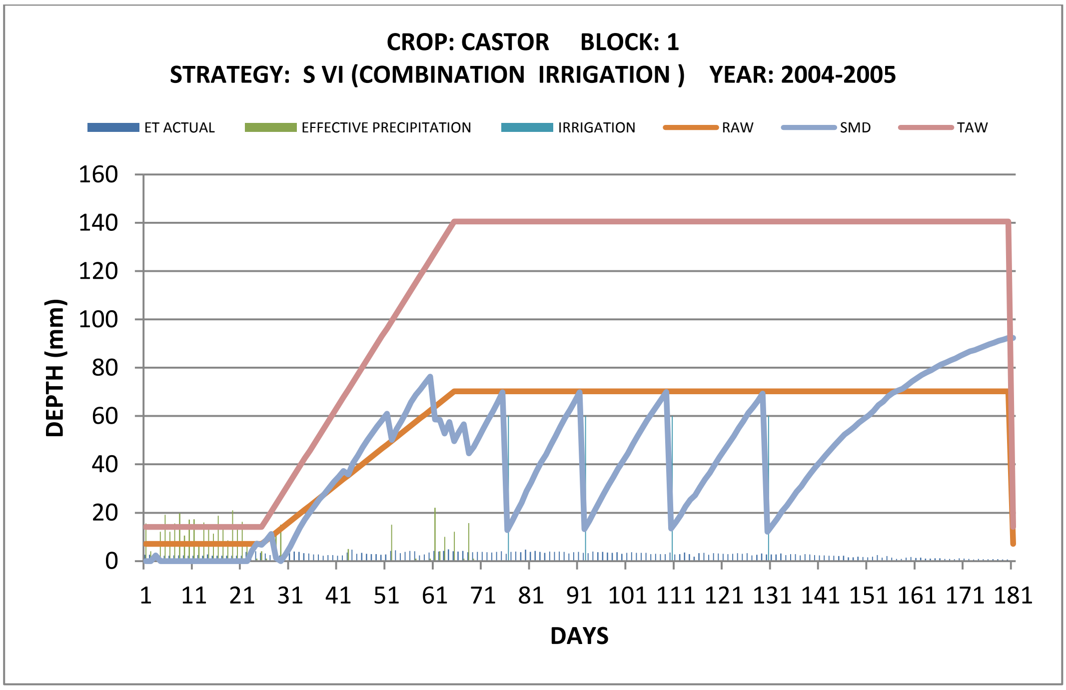
5.45 (c)


CROP: CASTOR BLOCK: 1
STRATEGY: SIV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

5.45 (d)



5.45 (e)



5.45 (f)

Fig 5.45(a-f): Soil moisture balance for irrigation strategies S I to S VI for castor crop year 2004-2005

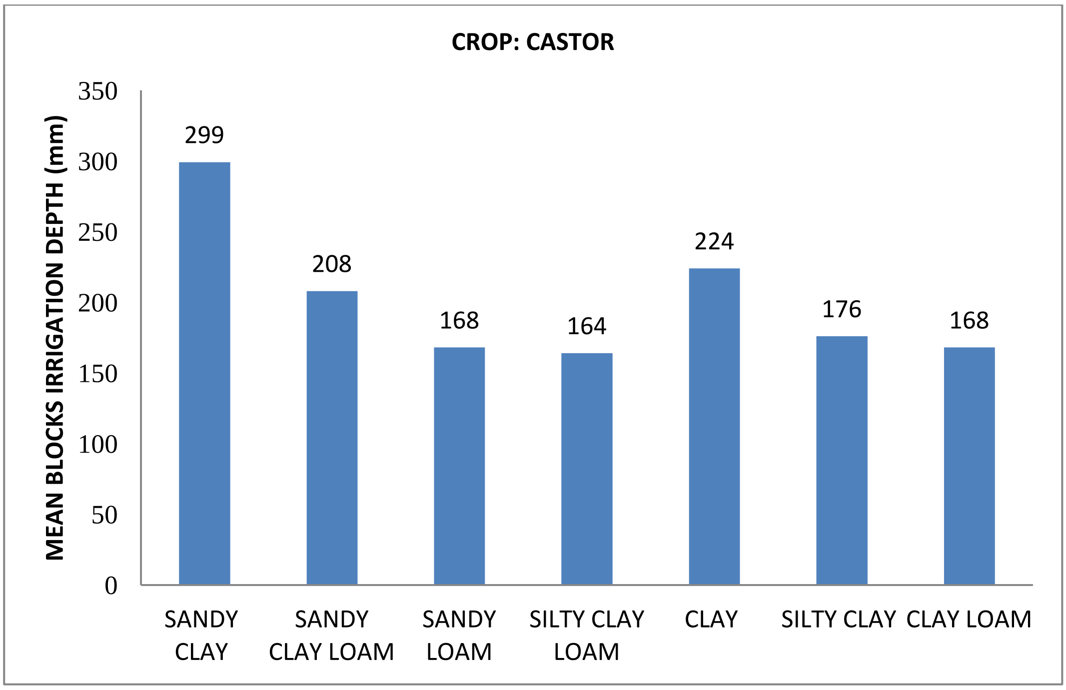


Fig 5.46: Effect of soil type on castor irrigation depth under strategy S II

5.15.2 Effect of Soil Type on Castor Irrigation Depth

On examining the impact of soil on castor irrigation depth via Figure 5.46 it was seen that no significant difference is observed in average irrigation depth, except for 10 blocks of sandy clay (299 mm) , 3 blocks of sandy clay loam (208 mm), and 1 block of clay (224 mm). Other type of soils had nearly similar irrigation depth (~168mm), establishing that soil type did not have any severe impact on irrigation depth.

5.15.3 Effect of Irrigation on Groundwater for Castor

Average net groundwater withdrawals for study period under castor crop are summarized for all irrigation strategies in Table 5.36. The results show that rise in groundwater is seen for all the blocks for strategies S IV and S V. For strategy S II, except block 10, 9A2R2, and 9B1R2 there is fall in the water table. Further, to note that for blocks 10, 9A2R2, and 9B1R2 there is increase in water table irrespective of any of the strategy is used, thus need is to be cautious in selecting the irrigation strategy.

Table 5.36: Average net groundwater withdrawals (years 2004-2009) for castor crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for castor crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
4B	Sc	7 to 22	-48	54	-56	-92	-89	-32
6A1	Sc	1 to 15	-6	17	-9	-54	-50	15
8	Scl	0.5to 6.5	16	70	28	-18	-24	61
10	Scl	1.5 to 18	-35	-11	-25	-62	-82	-29
11A2	Sc	3 to >30	1	44	10	-44	-43	38
6A3R2	C	>30	21	41	16	-9	-24	46
6BR2	Sic	1.2to>30	-1	10	-13	-32	-53	2
9A2R2	Sicl	1 to >30	-35	-1	-17	-40	-69	-29
9B1R2	Cl	0.5 to 23	-47	-22	-42	-56	-80	-34

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The castor crop is sown in all blocks. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

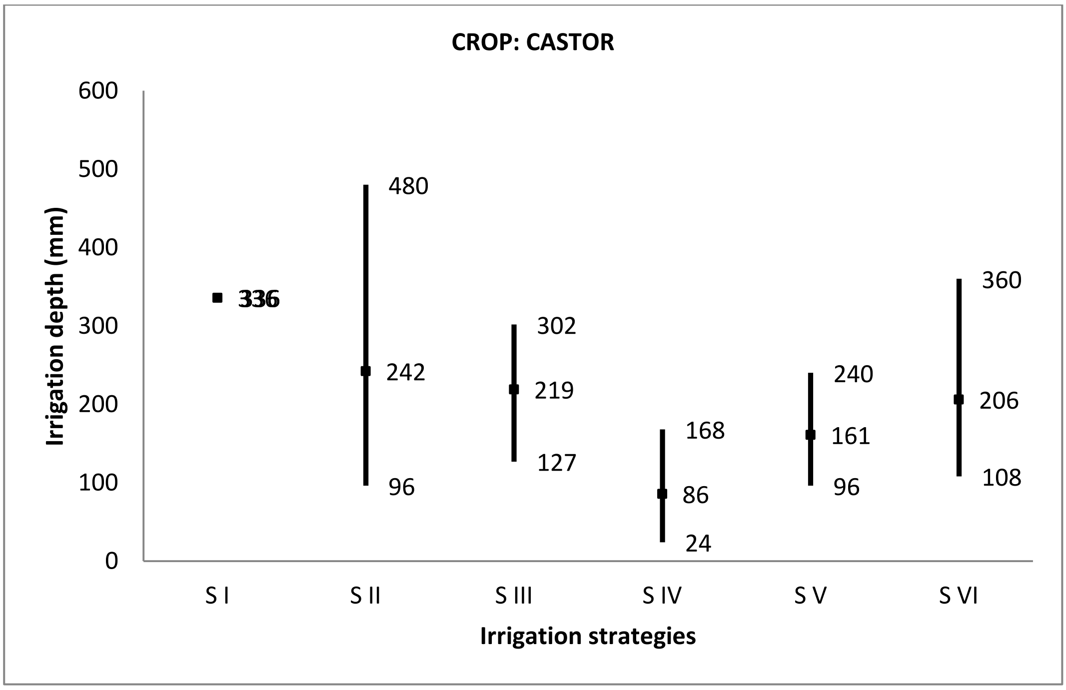


Fig 5.47: Irrigation depth range for castor crop for strategies S I to S VI

5.15.4 Irrigation Depth for Castor under Strategies S I to S VI

The influence of irrigation strategies on the range of irrigation depth was summarized in the Fig: 5.47. The difference in variability for strategies S II and S VI is relatively large than the other three strategies except S I. This shows that S II and S VI are sensitive to precipitation, soil wetness and climatic conditions. Though variability is low for strategies S III, S IV, and S VI their minimum and maximum limits are significantly different with strategy S IV having both limits very low, indicating low water usage than optimum requirement by the strategy.

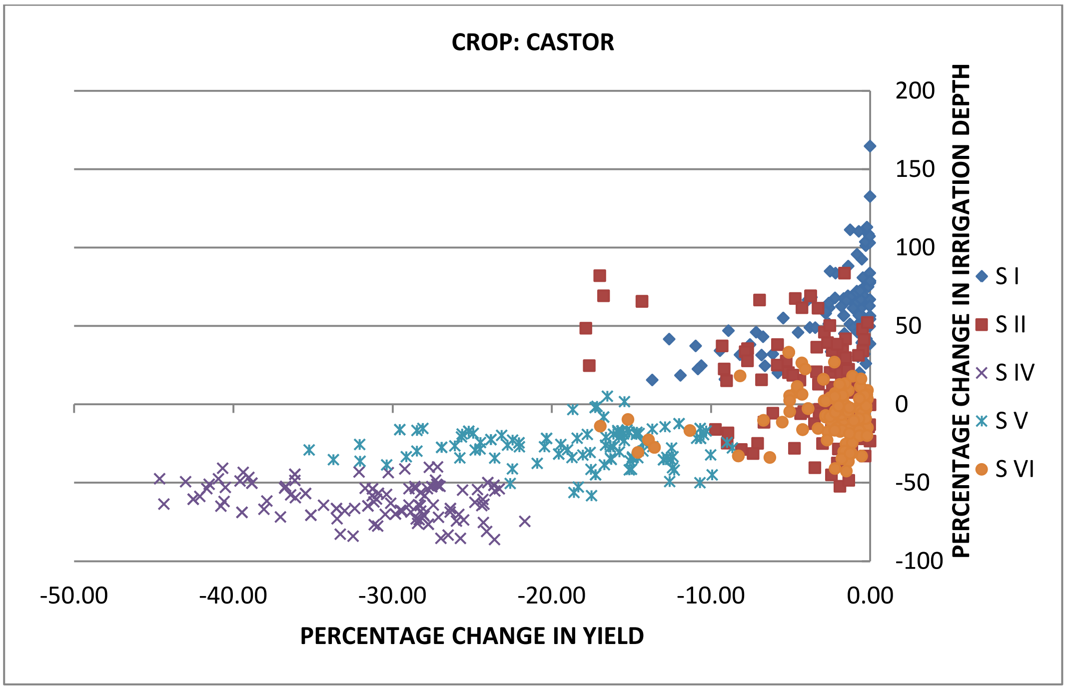


Fig 5.48: Percentage change in yield versus percentage change in irrigation depth for castor crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.15.5 Evaluating Irrigation Strategies for Castor

To test the appropriate strategy in terms of yield and irrigation water applied for castor, the relationship for the percentage change in yield versus percentage change in irrigation depth with reference to no moisture stress condition strategy S III was established with Figure 5.48. On observing it was found that strategies S I (yield reduction=2 percent), S II (yield reduction=4 percent), and S VI (yield reduction=3 percent) had nearly similar average yields. Although, their average percentages change in irrigation depths were prominently different. Irrigation depth for strategies S I (57 percent high), S II (11 percent high), and S VI (6 percent low), indicated that strategy S VI, S II, and S I in order of merit would be more appropriate, when proper yield and water savings both were to be considered together. Further, it could be observed that rate of decrease in average irrigation depth for deficit irrigation strategy SV (−26 percent) and protective irrigation strategy S IV (−61 percent) does not have similar impact in rate of decrease of the average yield for strategies S V (−18 percent) and S IV (−31 percent). This shows that the castor crop is relatively drought resistant, and thus it can be of great help while deciding irrigation during dry years.

5.16 Irrigation Scheduling Strategies for Tobacco

Tobacco is two seasonal and a cash crop, grown at the onset of monsoon. The crop is transplanted in the month of September having 180 days of crop seasonal length. The irrigation strategies adopted for tobacco are presented in Table 5.37, as follows: (i) Strategy S I: Fixed irrigation depth applied at fixed irrigation interval from date of sowing onwards. (ii) Strategy S II: Fixed irrigation depth applied, when SMD equals 100 per cent of readily available water. (iii) Strategy S III: Irrigation equivalent to SMD is applied, when SMD reaches 100 per cent of RAW. (iv.) Strategy S IV: Irrigation depth reduced to half applied, when SMD reaches 80 percent of TAW. (v) Strategy S V: In first two months, irrigation of fixed depth is applied, when SMD reaches 80 percent of TAW. Afterwards the irrigation of fixed depth is applied at fixed irrigation interval, and (vi) Strategy S VI: In first 50 days of crop growth stage, reduced to half irrigation depth is applied, when SMD reaches 100 per cent of RAW. Afterwards irrigation of fixed depth is applied at reduced interval. The initial soil moisture depletion at the starting of the computation is at field capacity. The maximum potential yield is taken as 3000 Kg per hectare.

5.16.1 Water Balance, Yield and Efficiencies for Tobacco

Daily soil moisture balance was computed for 10 blocks where tobacco is grown; the total simulations were 60 for each strategy. The results of block 9A1 are summarized in Table 5.38. Furrow irrigation method is applied for tobacco crop, thus the values in column 3 and 4 in Table 5.38 are required to be divided by fraction wetted 0.6 value. On examining the results it was found that strategy S III had highest values of yield, WUE, IWUE with minimum flow of surface run off, and flow to groundwater. After strategy S III, strategy S VI had highest crop evapotranspiration, yield, and WUE, but with second lowest IWUE amongst all strategies, thus indicating sufficient water savings could not be achieved with this strategy. Strategy S II stood next to strategy S VI with mild reduction in yield and WUE, but with slight increase in IWUE. Strategies S I and SV have nearly similar yields and WUE however; strategy S I is slightly better than S V in terms of yield, but IWUE is substantially high in S V, indicating more water savings is possible with S V.

Table 5.37: Irrigation scheduling strategies for tobacco crop

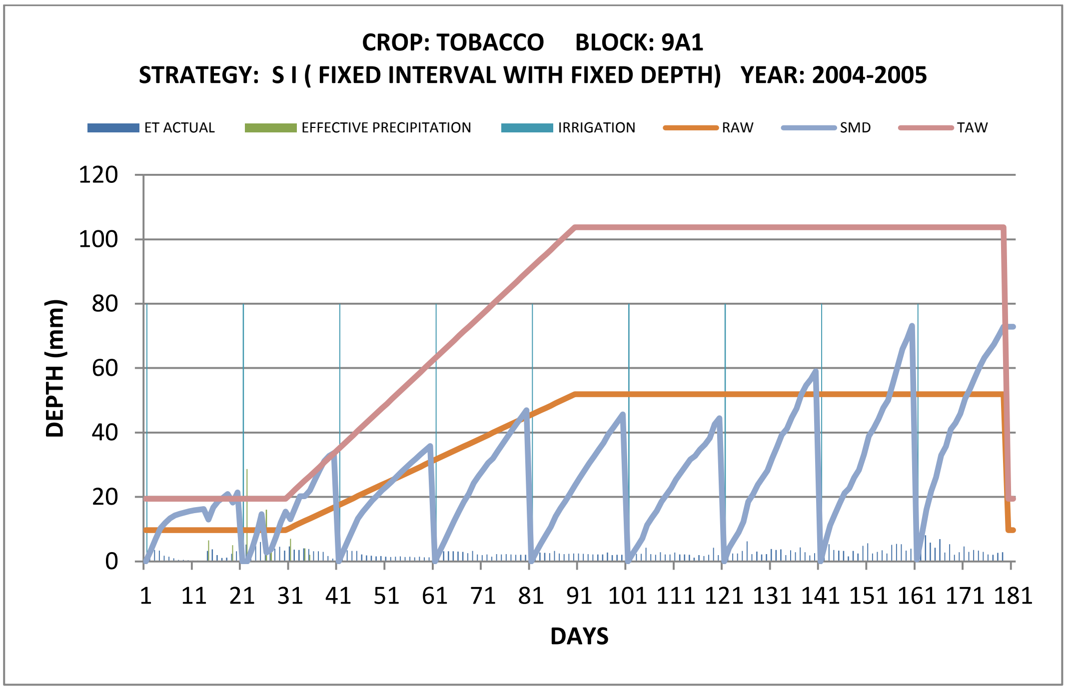
Case	Irrigation Strategy for tobacco		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
S I	1, 21, 41, 61, 81, 101, 121, 141 & 161	80mm	Irrigation of 80 mm fixed depth is applied at a fixed interval of 20 days from days of sowing.
S II	1-165	80 mm	Irrigation of 80 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water.
S III	1-180	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water (RAW), to attain no moisture stress conditions
S IV	1-165	40 mm,	Irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW).
S V	1- 60 61, 86, 111, 136 & 161	40 mm 80 mm	Irrigation of 40 mm fixed depth is applied, when moisture depletion reaches 80 percent of total available water (TAW). Then irrigation of 80 mm fixed depth is applied at a fixed interval of 25 days from post 61 days of sowing.
VI	1-50, 60, 75, 90, 105, 120, 135, 150 & 165	40 mm 60mm	Irrigation of 80 mm fixed depth is applied, when moisture depletion reaches 100 percent of readily available water (RAW). Then, from 60 days upto 165 days of sowing, irrigation of 80 mm fixed depth is applied at 15 days fixed interval.

***** From date of sowing. Date of sowing 7th September and Harvesting on 4th March.

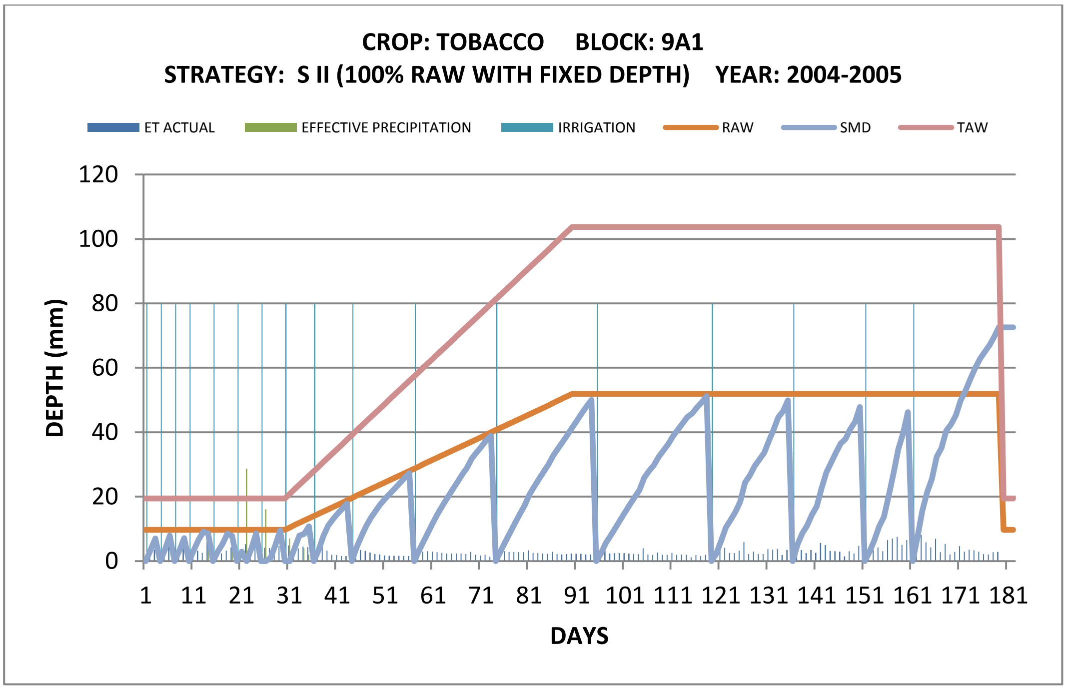
Table 5.38: Water balance, yield and efficiencies of tobacco crop in sandy clay loam (HSG – C) soil in Block 9A1 (grown in 0.34% of CCA 8546 ha)

Irrigation Strategies for Tobacco	Year	ETc act	Eff. preci	GW Irrign.	Canal Irign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE	Canal Water Demand
		mm	mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm	M. cum
		1	2	3	4	5	6	7	8	9	10	11
Strategy S I F.I with F.D.	2004-2005	505	108	144	288	215	-130	-119	2615	5.18	6.05	0.08
	2005-2006	478	384	144	288	200	-237	-300	2618	5.47	6.06	0.08
	2006-2007	427	26	144	288	196	-139	-88	2474	5.79	5.73	0.08
	2007-2008	485	234	144	288	192	-172	-201	2453	5.06	5.68	0.08
	2008-2009	454	99	144	288	195	-163	-109	2683	5.91	6.21	0.08
	2009-2010	454	47	144	288	209	-141	-93	2542	5.60	5.88	0.08
	Average	467	150	144	288	201	-164	-152	2564	5.50	5.94	0.08
Strategy S II 100% RAW with F.D.	2004-2005	567	108	480	336	244	-231	-369	2918	5.14	3.58	0.10
	2005-2006	532	384	384	288	218	-295	-446	2950	5.54	4.39	0.08
	2006-2007	506	26	576	288	235	-225	-394	2825	5.58	3.27	0.08
	2007-2008	539	234	432	288	227	-265	-377	2928	5.43	4.07	0.08
	2008-2009	491	99	384	288	219	-214	-285	2809	5.73	4.18	0.08
	2009-2010	528	47	528	288	243	-215	-363	2820	5.34	3.46	0.08
	Average	527	150	464	296	231	-241	-373	2875	5.46	3.82	0.09
Strategy S III No Stress	2004-2005	578	108	82	234	227	-26	-47	3000	5.19	9.49	0.07
	2005-2006	527	384	53	235	183	-110	-217	3000	5.69	10.43	0.07
	2006-2007	489	26	77	208	199	-12	-10	3000	6.14	10.51	0.06
	2007-2008	542	234	64	206	215	-72	-105	3000	5.54	11.13	0.06
	2008-2009	487	99	50	202	201	-37	-28	3000	6.16	11.88	0.06
	2009-2010	517	47	75	212	218	-19	-16	3000	5.80	10.44	0.06
	Average	523	150	67	216	207	-46	-71	3000	5.75	10.65	0.06
Strategy S IV Protective Irrigation	2004-2005	427	108	120	120	190	-49	-62	1620	3.79	6.75	0.03
	2005-2006	377	384	72	120	168	-132	-235	1528	4.05	7.96	0.03
	2006-2007	308	26	96	96	166	-40	-36	1235	4.01	6.43	0.03
	2007-2008	380	234	48	120	167	-82	-107	1426	3.75	8.49	0.03
	2008-2009	354	99	72	120	167	-58	-46	1567	4.43	8.16	0.03
	2009-2010	356	47	96	120	184	-47	-44	1374	3.86	6.36	0.03
	Average	367	150	84	116	174	-68	-88	1458	3.98	7.36	0.03
Strategy S V Deficit Irrigation	2004-2005	515	108	120	240	216	-106	-63	2616	5.08	7.27	0.07
	2005-2006	465	384	72	240	195	-190	-235	2512	5.40	8.05	0.07
	2006-2007	423	26	96	240	195	-98	-36	2385	5.64	7.10	0.07
	2007-2008	471	234	48	240	190	-134	-107	2446	5.19	8.49	0.07
	2008-2009	435	99	72	240	188	-117	-46	2485	5.71	7.97	0.07
	2009-2010	440	47	96	240	208	-107	-44	2252	5.11	6.70	0.07
	Average	458	150	84	240	199	-125	-89	2449	5.36	7.60	0.07
Strategy S VI Combination	2004-2005	569	108	240	288	242	-189	-121	2900	5.10	5.49	0.08
	2005-2006	535	384	168	288	217	-255	-267	2947	5.51	6.46	0.08
	2006-2007	528	26	288	288	232	-200	-105	2995	5.67	5.20	0.08
	2007-2008	547	234	192	288	220	-216	-171	2972	5.43	6.19	0.08
	2008-2009	515	99	192	288	214	-191	-87	2999	5.83	6.25	0.08
	2009-2010	545	47	264	288	243	-199	-99	2927	5.37	5.30	0.08
	Average	540	150	224	288	228	-208	-142	2957	5.49	5.82	0.08

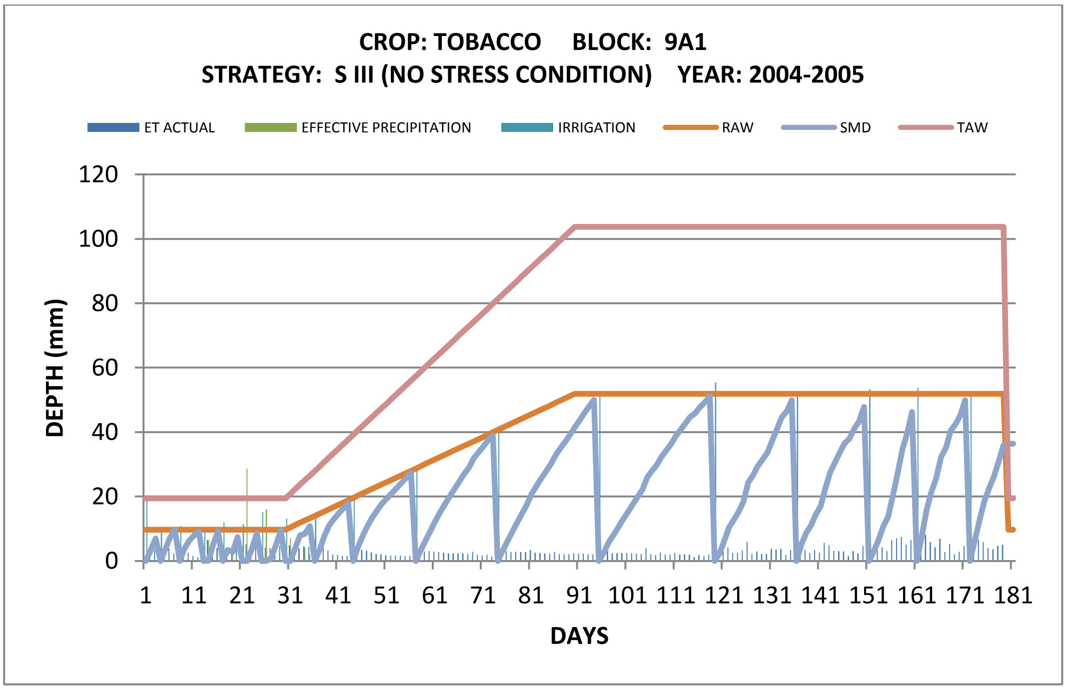
No. of rainy days for tobacco crop period in years 2004, 2005, 2006, 2007, 2008 and 2009 are 8, 13, 1, 14, 9 and 2 days respectively.


CROP: TOBACCO BLOCK: 9A1
STRATEGY: S I (FIXED INTERVAL WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

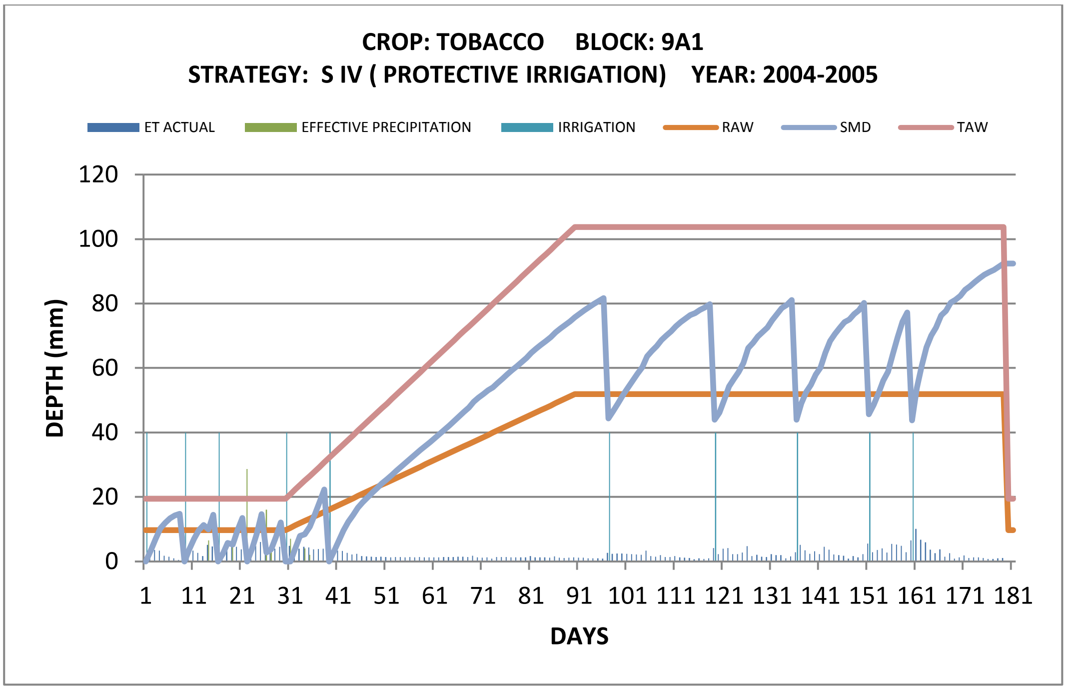
5.49 (a)


CROP: TOBACCO BLOCK: 9A1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
120
100
80
60
40
20
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181
DAYS

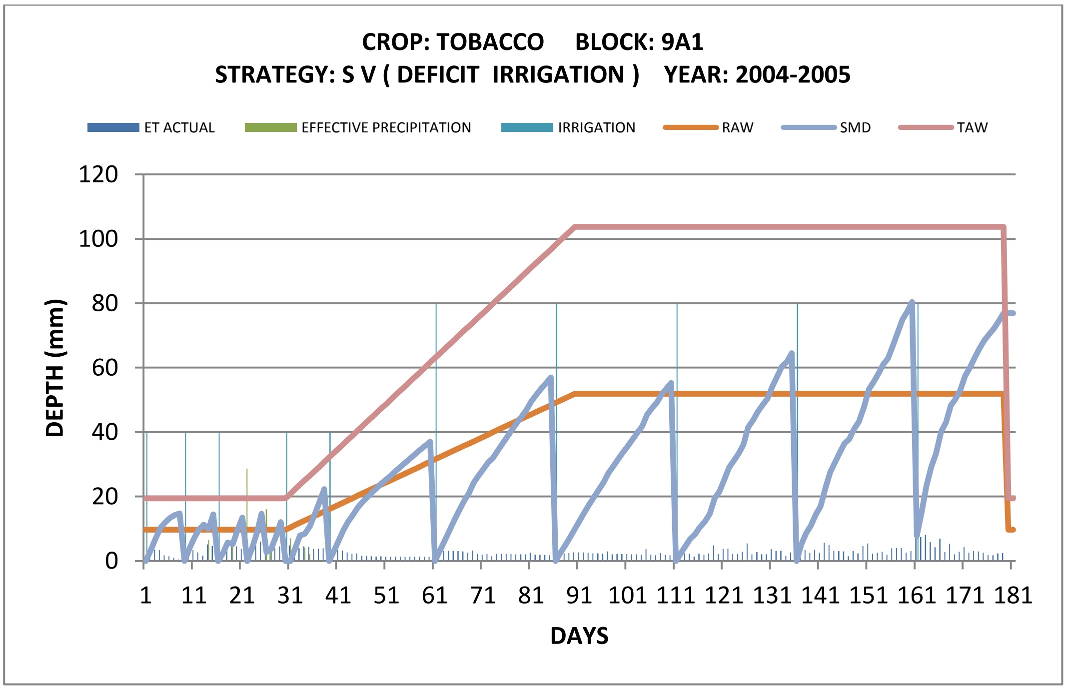
5.49 (b)


CROP: TOBACCO BLOCK: 9A1
STRATEGY: S III (NO STRESS CONDITION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS
0
20
40
60
80
100
120
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181

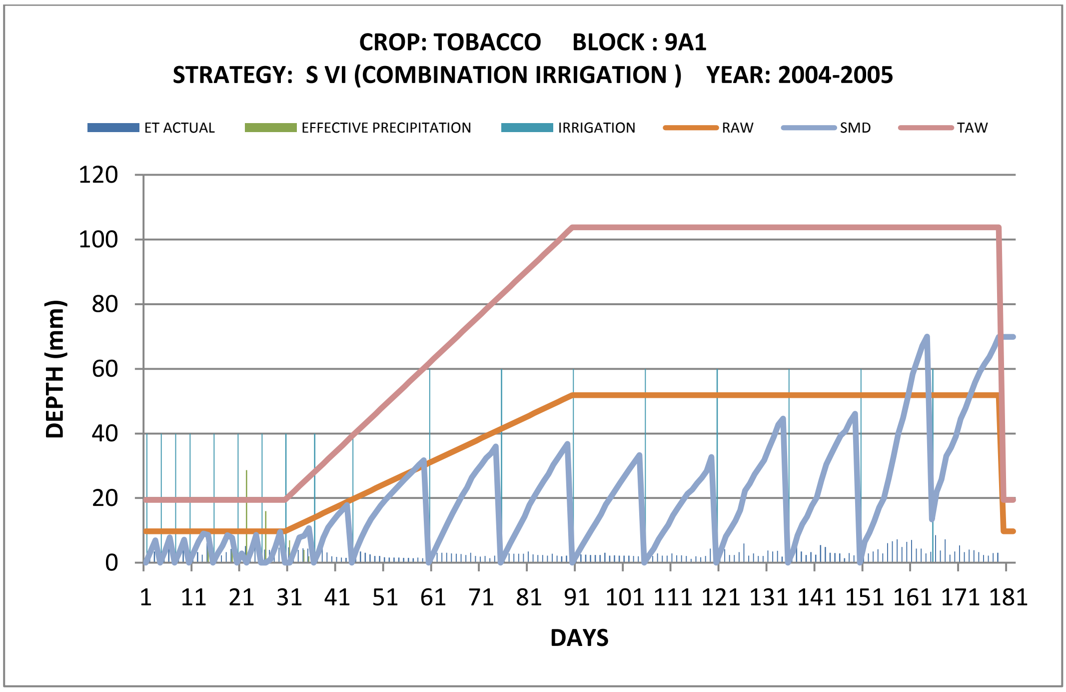
5.49 (c)


CROP: TOBACCO BLOCK: 9A1
STRATEGY: S IV (PROTECTIVE IRRIGATION) YEAR: 2004-2005
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
DAYS
0
20
40
60
80
100
120
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181

5.49 (d)



5.49 (e)



5.49 (f)

Fig 5.49(a-f): Soil moisture balance for irrigation strategies S I to S VI for tobacco crop year 2004

In case of S IV (protective irrigation) strategy, the yield reduction is large in comparison to the water savings, while IWUE values are, nearly similar to S V. Data in Table 5.38 and Figure 5.49 (a-f) is demonstrated to understand the soil moisture stress impact on tobacco yield. As, slight moisture deficit is visible only during late mid season stage; yield in strategy S II and S VI results into nearly maximum potential. In strategy S II reduction in irrigation depth in initial stages could have resulted in higher irrigation water use efficiency. In S I and S V similar yield is attained with variable moisture stress in initial stage, while mild moisture deficit scenario in development and late mid season stage show that tobacco is critically sensitive to moisture stress, during development and mid season stage. In strategy S IV moisture deficit is visible in all crop growth stages, although severe moisture stress during mid season stage lead to higher reduction in yield.

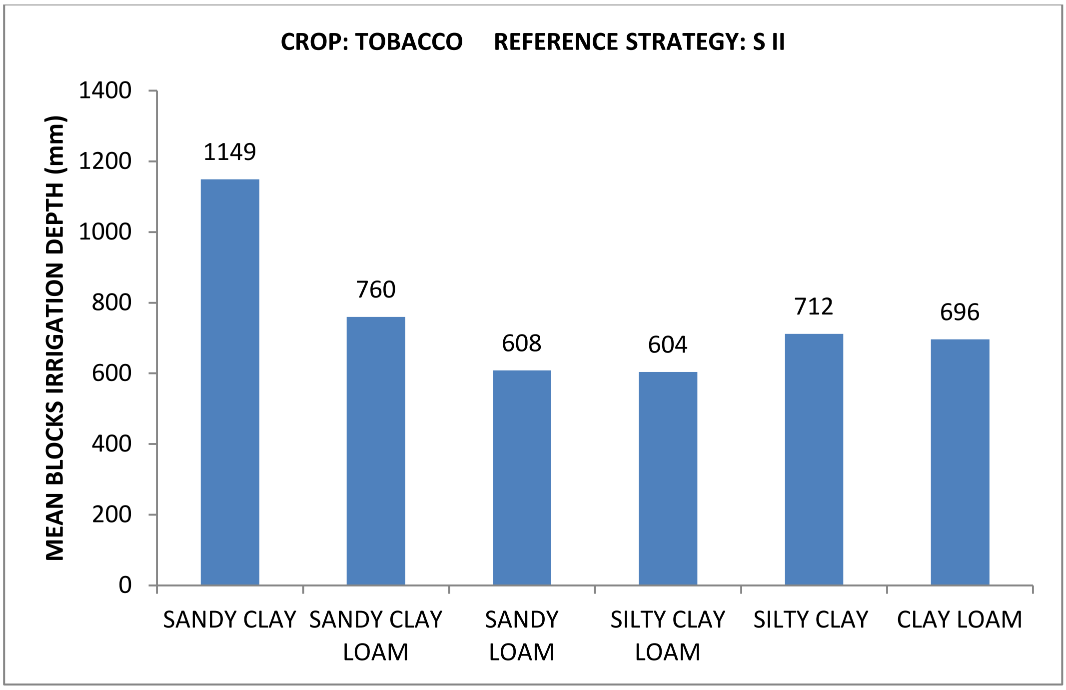


Fig 5.50: Effect of soil type on tobacco irrigation depth under strategy S II

5.16.2 Effect of Soil Type on Tobacco Irrigation Depth

On examining the impact of soil on tobacco irrigation depth via Figure 5.50, it is seen that 3 blocks of sandy clay demonstrate large average irrigation depth of 1149 mm, indicating that the soil drained faster, and moisture holding capacity was for shorter duration. Two blocks of sandy clay loam had average irrigation depth of 760 mm. No significant difference was observed in irrigation depths of sandy loam and silty clay loam (~600 mm). Mild difference in irrigation depths in silty clay (712 mm) and clay loam (696 mm) was seen.

Table 5.39: Average net groundwater withdrawals (years 2004-2009) for tobacco crop period under irrigation strategies S I to S VI.

Block	Soil	SWL Range in m	Average net groundwater withdrawals in mm (2004-2009) for tobacco crop period					
			Strategy S I	Strategy S II	Strategy S III	Strategy S IV	Strategy S V	Strategy S VI
10	Scl	1.5 to 18	-20	223	21	16	-41	16
11A2	Sc	3 to >30	6	432	46	95	32	151
6BR2	Sic	1.2to>30	7	273	37	37	-12	40
9A2R2	Sicl	1 to >30	-10	230	33	18	-36	-2
9B1R2	Cl	0.5 to 23	-20	229	27	15	-44	1

Note: Sandy clay (Sc), sandy clay loam (Scl), clay (C), silty clay(Sic),silty clay loam(Sicl), clay loam(Cl) . The tobacco crop is not sown in 4B, 6A1, 8, 6A3R2 blocks. The negative sign indicates that groundwater recharge (due to rain and irrigation) is more than groundwater pumping for irrigation

5.16.3 Effect of Irrigation on Groundwater for Tobacco

Average net groundwater withdrawals for study period under tobacco crop are summarized for all irrigation strategies in Table 5.39. The results show that fall in groundwater is seen for all the blocks for strategies S II, S III, S IV, and S VI taken up for monitoring purpose, where tobacco is grown except for strategy S I and SV for certain blocks. In strategy S I and S V very mild rising of water table is seen, except block 11A2.

5.16.4 Irrigation Depth for Tobacco under Strategies S I to S VI

The variability in irrigation depth range is profoundly noticeable in strategies S II (Figure 5.51) this is due to selection of strategy to irrigate the crop, which is deeply influenced by the rainfall, prevailing soil moisture, and climatic conditions. Variability in irrigation depth range is meagre in strategies S III, SIV, S V, and S VI although, difference in minimum, maximum, and averages amongst the four strategies is distinctly noticeable. Further strategy S IV values are on slightly lower side than optimum value.

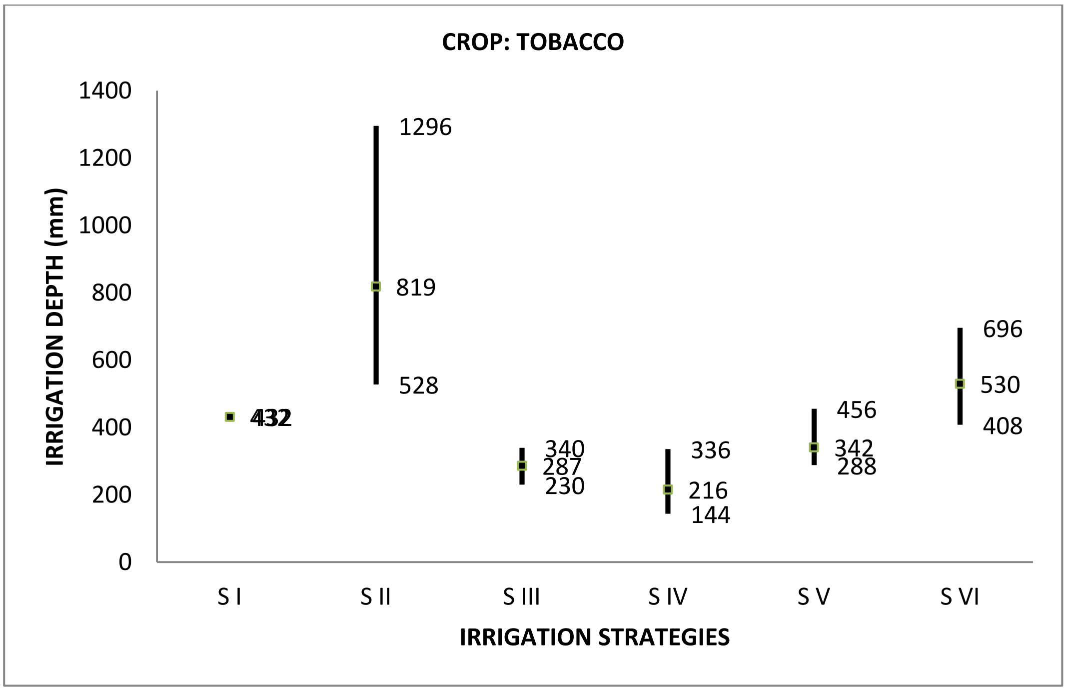


Fig 5.51: Irrigation depth range for tobacco crop for strategies S I to S VI

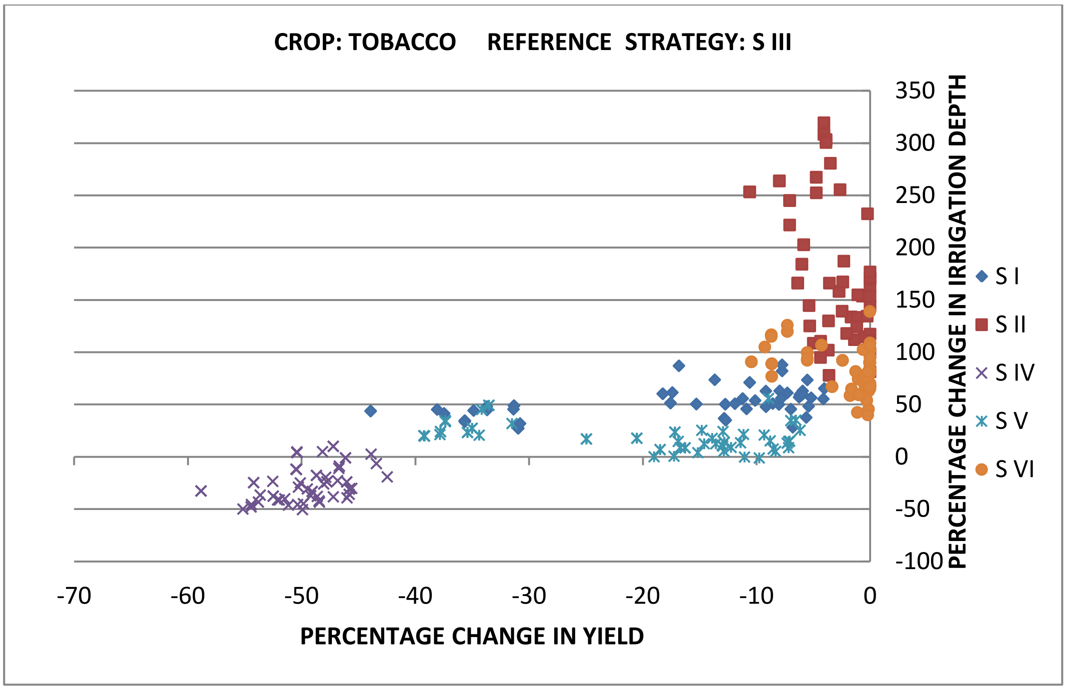


Fig 5.52: Percentage change in yield versus percentage change in irrigation depth for tobacco crop under irrigation strategies S I, S II, S IV, S V and S VI with respect to strategy S III (no moisture stress conditions)

5.16.5 Evaluating Irrigation Strategies for Tobacco

The relationship between percentage change in yield and percentage change in irrigation depth of various irrigation strategies with respect to reference strategy S III for tobacco are demonstrated in Figure 5.52. It is clearly evident that after strategy S III the best suited strategy is S VI with range yield in reduction of 0 percent to 10 percent and average reduction of 3 percent. The percentage in irrigation depth is in range of 40 percent to 139 percent with average increase in irrigation depth of 85 percent. Strategy S II can be rated next to it with average reduction of 3 percent and range of 0 percent to 11 percent. Percentage change in irrigation depth, for strategy S II is in range of 78 percent to 319 percent with average irrigation depth increase of 183 percent. Strategy SI has average reduction in yield of 18 percent, with wide range of yield reduction of 4 percent to 44 percent this is due to 3 blocks of sandy clay soil, where the moisture stress is severe in initial stage as we are irrigating post initial stage only. The percentage change in irrigation depth variation, for strategy S I is not to that extent with range of irrigation depth increase of 27 percent to 88 percent, and average increase in irrigation depth of 52 percent. Average reduction in yield is 20 percent with range of −6 percent to −39 percent for strategy SV nevertheless, with average increase of 19 percent in irrigation depth, and applied irrigation water was in range of −1 percent to 56 percent irrigation depth in comparison to strategy S III. Strategy S IV performed well below the expectations with average reduction in yield of 49 percent, and with yield range of −42 percent to −59 percent however, the irrigation depth varied from -51 percent to 10 percent, and with average decrease in irrigation depth of 25 percent. The strategies to be opted from yield point of view only could be in order of S III, S V I, S II, SI, and SV. The strategy S IV shows very low yield, thus it would be advisable to recommend only after increasing the irrigation depth (in range of 50mm to 60 mm), for increasing the yield. Irrigation strategy S IV show comparatively more reduction in yield due to its sensitivity to moisture deficit. This strategy could only be recommended with caution. The strategies to be opted from water savings point of view only could be S III, SV, S I, S VI, and S II. On considering the yield and water saving factor together the strategies, which could be opted in order of merit are S III, S VI, S II, and S I.

5.17 Irrigation Scheduling Strategies for Alfalfa

Alfalfa is a fodder crop grown with the onset of monsoon. The adopted irrigation strategies (refer Table 5.40) are as follows: (i) Strategy S I: Fixed irrigation interval with fixed depth.

(ii) Strategy S II: Fixed depth of irrigation and irrigation is applied at 100 percent of RAW. (iii) Strategy S III: Irrigation equivalent to SMD is applied, when SMD reaches 100 percent of RAW. (iv.) Strategy S IV: Fixed irrigation depth applied, when SMD reaches 100 percent of TAW. (v) Strategy S V: Reduced to half fixed irrigation depth applied, when SMD reaches 100 percent of RAW. The maximum potential yield taken is 3000 kg. The soil is at field capacity at the beginning of the soil moisture balance computation.

Table 5.40: Irrigation scheduling strategies for alfalfa crop

Case	Irrigation Strategy for alfalfa		
	Irrigation Scheduling*	Irrigation Amount mm	Remarks
II	1-45	50 mm	Irrigation of 50 mm fixed depth is applied, as moisture level reaches at 100 percent of readily available water.
III	1-45	Varying	Irrigation equivalent to moisture depletion is applied, as moisture depletion reaches 100 per cent of readily available water, to attain no moisture stress conditions
IV	1-45	100 mm,	Irrigation of 100 mm fixed depth is applied when moisture depletion reaches 100 percent of total available water (TAW).

***** From date of sowing. Date of sowing 1st July and Cutting on 14th August.

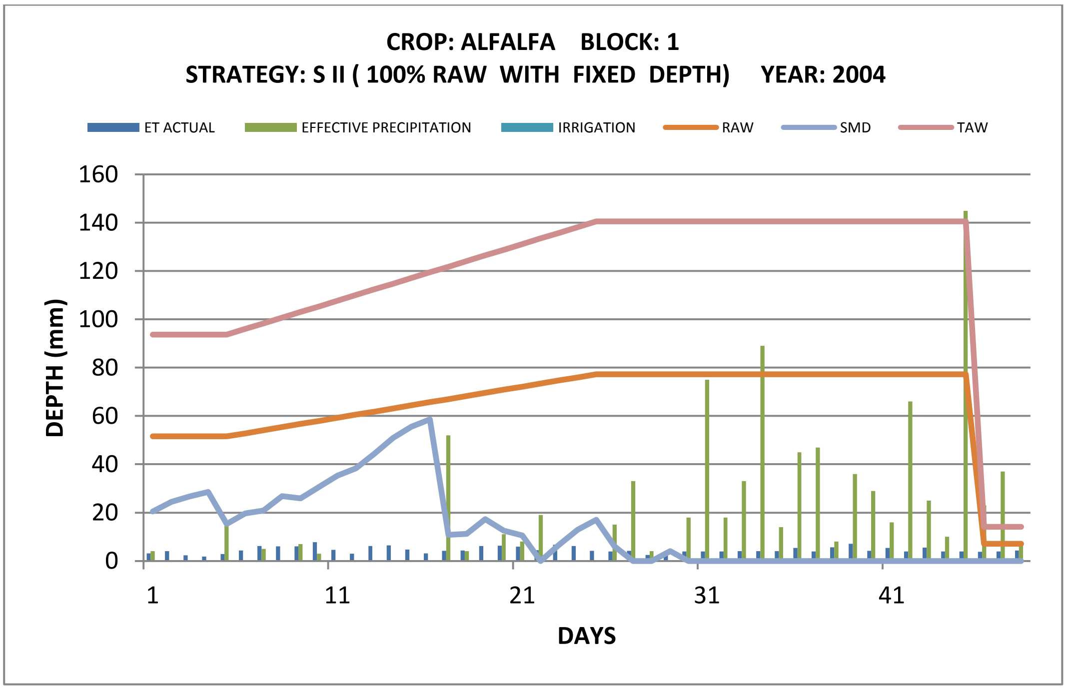
5.17.1 Water Balance, Yield and Efficiencies for Alfalfa

For Alfalfa soil water balance, yield and efficiencies for all 20 blocks were computed for five irrigation strategies for study period. The results of block 1 are summarized in Table 5.41. It is clearly evident from table that alfalfa up to first cutting the crop would flourish under rain fed condition, and it would not require irrigation under normal monsoon. The yield obtained is of maximum potential with all strategies. To understand the effect of irrigation strategy on soil moisture pattern Figure 5.53 (a-c) is illustrated, which shows that no soil moisture stress is visible in any of the strategies, thus resulting into maximum yield.

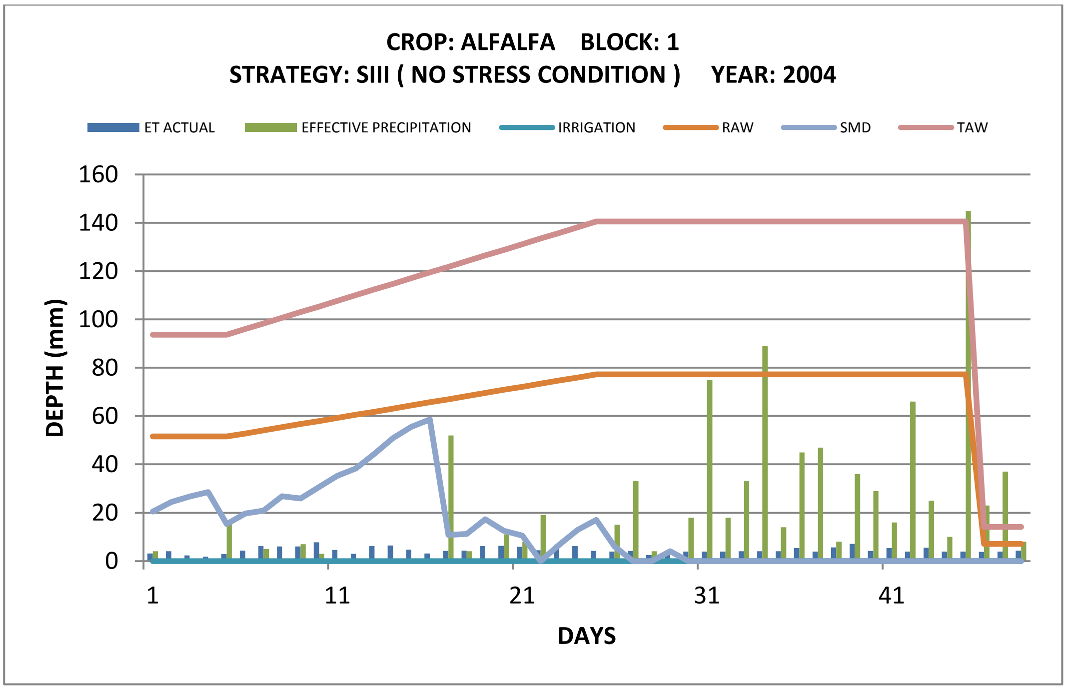
Table 5.41: Water balance, yield and efficiencies of alfalfa crop in sandy clay loam (HSG – C) soil in block 1 (grown in 9.06% of CCA 9868 ha)

Irrigation Strategies for Alfalfa	Year	ETc act	Eff. preci	GW Irrign.	Net Decrease in Soil moisture	Flow to GW	Run off	Yield	WUE	IWUE
		mm	mm	mm	mm	mm	mm	Kg/ha	Kg/ha /mm	Kg/ha/ mm
		1	2	3	4	5	6	7	8	9
Strategy S II 100% RAW with F.D.	2004-2005	208	855	0	-21	-529	-96	3000	14.42	NA
	2005-2006	214	399	0	16	-116	-84	3000	13.99	NA
	2006-2007	310	1431	0	9	-683	-446	3000	9.67	NA
	2007-2008	223	789	0	-2	-353	-211	3000	13.42	NA
	2008-2009	238	588	0	-23	-230	-96	3000	12.59	NA
	2009-2010	273	310	50	34	-121	0	3000	10.98	60.00
	Average	245	729	8	2	-339	-156	3000	12.51	
Strategy S III No Stress	2004-2005	208	855	0	-21	-529	-96	3000	14.42	NA
	2005-2006	214	399	0	16	-116	-84	3000	13.99	NA
	2006-2007	310	1431	0	9	-683	-446	3000	9.67	NA
	2007-2008	223	789	0	-2	-353	-211	3000	13.42	NA
	2008-2009	238	588	0	-23	-230	-96	3000	12.59	NA
	2009-2010	273	310	83	1	-121	0	3000	10.98	36.17
	Average	245	729	14	-3	-339	-156	3000	12.51	
Strategy S IV Protective Irrigation	2004-2005	208	855	0	-21	-529	-96	3000	14.42	NA
	2005-2006	214	399	0	16	-116	-84	3000	13.99	NA
	2006-2007	310	1431	0	9	-683	-446	3000	9.67	NA
	2007-2008	223	789	0	-2	-353	-211	3000	13.42	NA
	2008-2009	238	588	0	-23	-230	-96	3000	12.59	NA
	2009-2010	266	310	0	77	-121	0	3000	11.29	NA
	Average	243	729	0	9	-339	-156	3000	12.56	

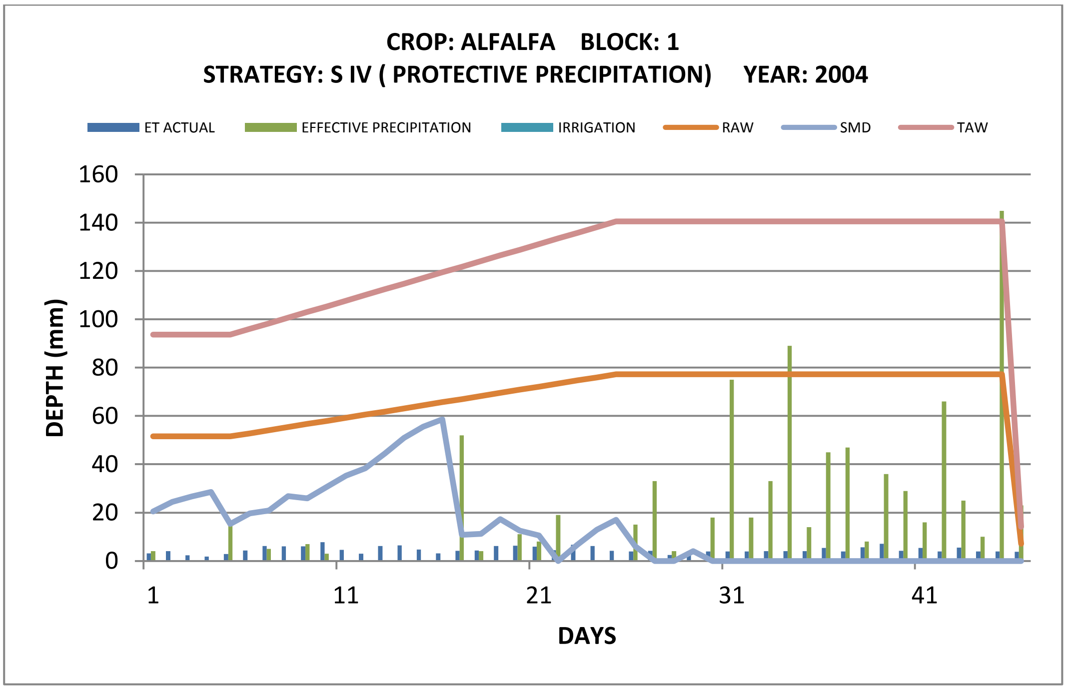
No. of rainy days for alfalfa crop period in years 2004, 2005, 2006, 2007, 2008 and 2009 are 29 23, 33, 31, 37 and 28 days respectively


CROP: ALFALFA BLOCK: 1
STRATEGY: S II (100% RAW WITH FIXED DEPTH) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1
11
21
31
41
DAYS

5.53 (a)


CROP: ALFALFA BLOCK: 1
STRATEGY: SIII (NO STRESS CONDITION) YEAR: 2004
ET ACTUAL
EFFECTIVE PRECIPITATION
IRRIGATION
RAW
SMD
TAW
DEPTH (mm)
160
140
120
100
80
60
40
20
0
1
11
21
31
41
DAYS

5.53 (b)



5.53 (c)

Fig 5.53 (a-c): Soil moisture balance for irrigation strategies S II to S IV for Alfalfa crop year 2004

Further Figure 5.54 reveal that range of irrigation depth for strategies S II, S III, and S V is same, thus no variability in irrigation depth is noticeable, for any afore mentioned strategies.

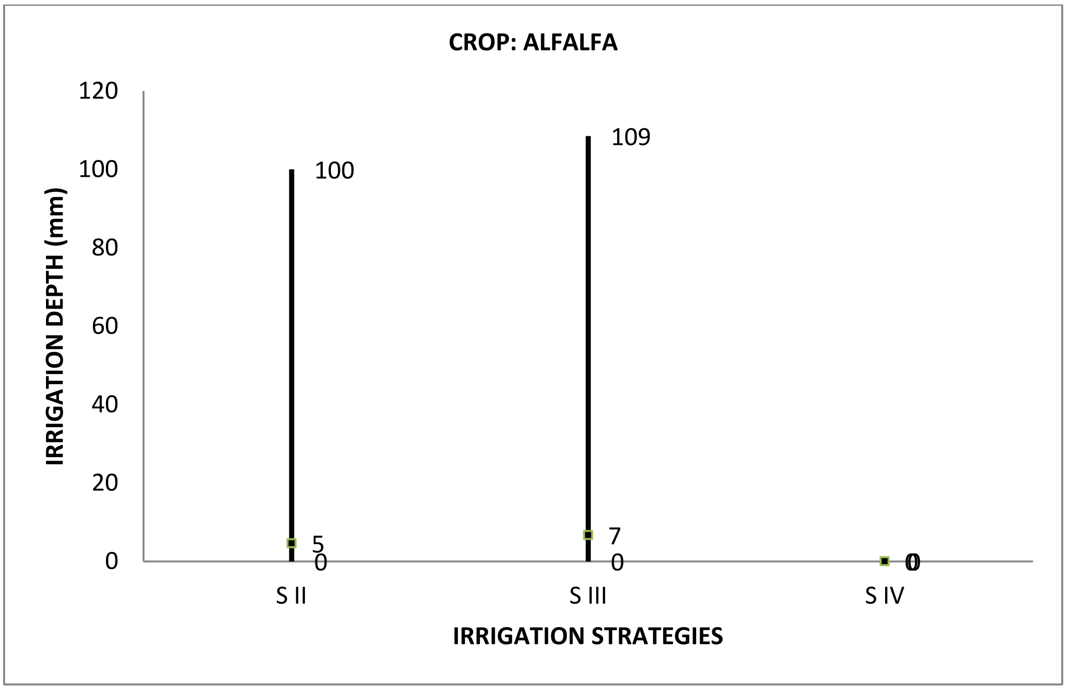


Fig 5.54: Irrigation depth range for alfalfa crop for strategies S II to S IV

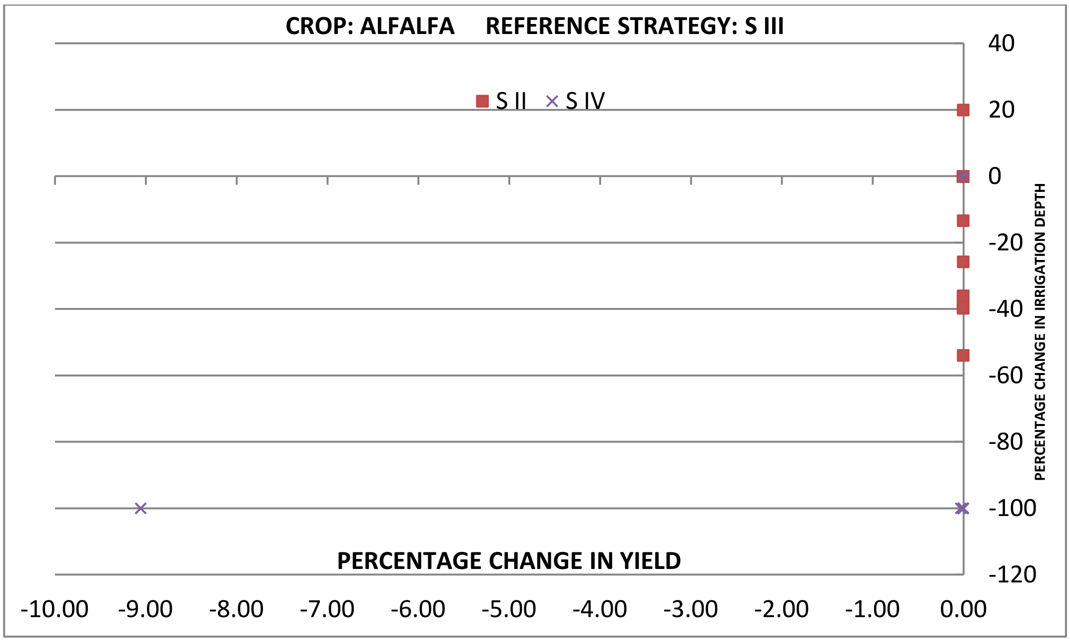


Fig 5.55: Percentage change in yield versus percentage change in irrigation depth for alfalfa crop under irrigation strategies S II and S IV with respect to strategy S III (no moisture stress conditions)

On examining the relationship between percentage change in yield versus percentage change in irrigation depth with respect to strategy S III, it was noted that all strategies performed equally well, as the duration for crop season was 45 days only before first cutting, which would be the beginning of monsoon, thus crop would be mostly rain fed, except during delay in monsoon or dry period.

5.18 Statistical Analysis

Objective of the study was to identify the best irrigation strategy for each crop in study area of agro-climatic regions I and II. In agro-climatic region I sixteen number of blocks while, for region II four blocks of varying areas have been selected for study purpose. Due to vastness of the study area it was difficult to conduct real life experiment and to obtain the data in a short span of time. In present environment simulated experimental WEAP- MABIA tool is used to generate the data of yield, for different irrigation strategies, over different types of blocks. The controllable parameters are date of sowing, type of crop, type of soil, crop parameters, and irrigation, which are maintained and controlled using WEAP-MABIA model. In these blocks various irrigation strategies are employed taking into account the availability of ground water/ canal water, climatic conditions, crop yield, and water savings. Water balance and yield per hectare simulations, for study period 2003 to 2010 were carried out for crops grown in blocks in the base period 2003, under appropriate irrigation strategies S I, S II, S III, S IV, S V, and S

VI. Data was analyzed as Randomized Block Design (RBD) without replication, using Microsoft Excel in Windows 7. Statistical of RBD of statistical design of experiments was used to find appropriate irrigation strategies for each crop. RBD ANOVA for each crop was obtained for testing the following null hypothesis:

$H_{0\ 1n}$: For each crop, irrigation strategies have similar effect.

$H_{0\ 2n}$: For each crop, block effects are similar.

Against $H_{0,}$ following alternatives were examined

$H_{0\ 1a}$: Effects of irrigation strategies differ significantly (i.e. strategies are not equally effective).

$H_{0\ 2a}$: Blocks are not homogeneous, and there is significant difference between their effects.

As ANOVA uses F test, F value was calculated and F *critical* was obtained for 5 percent and 1 percent level of significance by Excel. If F value is less then F *critical* for 5 percent level of significance, then the test is insignificant denoting that there is no significant difference in the effect of irrigation strategies in the study under taken. In that case null hypothesis may be accepted. If F > F *critical* for 5 percent level of significance, then test is significant (denoted by *). If F > F *critical* for 1 percent level of significance, then test is highly significant (denoted by **). In this case null hypothesis would be rejected and alternative hypothesis would be accepted.

Statistical analysis was carried out as explained in methodology chapter 3, and RBD ANOVA table was prepared and shown in Table 5.42. Now to decide which strategy would be the best amongst them, they are placed in descending order of the mean yields of crops, and multiple comparisons are carried out by computing Standard Error (SE) & Critical Difference (CD) (Table 5.43).

For illustration purpose: Take MSE and d.f for strategies, from RBD ANOVA Table 5.42, for rice crop and find CD value.

$SE = \sqrt{(2MSE/r)} = \sqrt{(2 \times 324673.2/ (113+1))} = 75.47$,

$CD = SE \times t_{\alpha} = 75.47 \times 1.645 = 124.15$

Note: t-value ($t_{5\%,\ error\ d.f.}$) = 1.645 for error d.f. > 120.

If difference in their average effect between consecutive pair of irrigation strategies is greater than CD, it indicates that there is a significant difference in the effect of two irrigation strategies under consideration. Significant difference in two irrigation strategies is denoted by upper bar (¯) over that pair.

Table 5.42: Randomised Block Design ANOVA Table for all fourteen crops

Crop	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*5% F crit*	*1% F crit*
Rice	Blocks	1.01E+08	113	892459.1	2.748792**	6.01E-15	1.257824	1.381359
	Strategies	6.56E+08	5	1.31E+08	403.8786**	7.2E-184	2.229971	3.049719
	Error	1.83E+08	565	324673.2				
	Total	9.4E+08	683					
Wheat	Blocks	11362256	119	95481.14	2.899349**	2.84E-17	1.250777	1.370506
	Strategies	47785981	5	9557196	290.2107**	6.1E-157	2.229168	3.048073
	Error	19594496	595	32931.93				
	Total	78742733	719					
Jowar	Blocks	1828317	119	15364.01	2.238236**	5.37E-09	1.268949	1.399214
	Strategies	5629905	3	1876635	273.389**	4.05E-92	2.629917	3.836912
	Error	2450569	357	6864.339				
	Total	9908791	479					
Bajri	Blocks	6761903	95	71177.92	5.66976**	1.54E-34	1.291053	1.43317
	Strategies	3375729	4	843932.3	67.22441**	5.59E-43	2.39543	3.368858
	Error	4770503	380	12553.96				
	Total	14908135	479					
Maize	Blocks	6300553	107	58883.67	3.762563**	3.05E-24	1.265484	1.393182
	Strategies	1.92E+08	5	38353150	2450.699**	0	2.230864	3.051551
	Error	8372688	535	15649.88				
	Total	2.06E+08	647					
Tuver	Blocks	1829579	83	22043.13	2.070258**	1.65E-06	1.304474	1.453789
	Strategies	25205436	5	5041087	473.4514**	6.1E-169	2.235736	3.061549
	Error	4418724	415	10647.53				
	Total	31453739	503					
Chana	Blocks	510879.5	113	4521.058	1.998766**	1.37E-07	1.257824	1.381359
	Strategies	6408669	5	1281734	566.6564**	2E-217	2.229971	3.049719
	Error	1277987	565	2261.924				
	Total	8197535	683					
Sugarcane	Blocks	3.34E+09	65	51363779	3.21596**	1.96E-11	1.358318	1.539152
	Strategies	2.77E+10	4	6.93E+09	433.8732**	9.9E-114	2.406362	3.392083
	Error	4.15E+09	260	15971521				
	Total	3.52E+10	329					
Cabbage	Blocks	3.11E+09	119	26124378	2.149383**	2.26E-09	1.250777	1.370506
	Strategies	7.13E+10	5	1.43E+10	1173.623**	2.2E-305	2.229168	3.048073
	Error	7.23E+09	595	12154363				
	Total	8.17E+10	719					
Cotton	Blocks	7504707	119	63064.77	4.119809**	1.28E-30	1.250777	1.370506
	Strategies	21162280	5	4232456	276.4921**	1.5E-152	2.229168	3.048073
	Error	9108077	595	15307.69				
	Total	37775065	719					
Groundnut	Blocks	8855383	113	78366.22	3.550416**	2.8E-23	1.257824	1.381359
	Strategies	53529318	5	10705864	485.0338**	9.8E-202	2.229971	3.049719
	Error	12470910	565	22072.41				
	Total	74855611	683					
Castor	Blocks	3941488	119	33121.75	5.305717**	4.02E-43	1.250777	1.370506
	Strategies	57748285	5	11549657	1850.12**	0	2.229168	3.048073
	Error	3714378	595	6242.652				
	Total	65404151	719					
Tobacco	Blocks	6857221	59	116224.1	3.593995**	2.55E-13	1.366817	1.552161
	Strategies	93245653	5	18649131	576.6867**	6.2E-150	2.244599	3.079774
	Error	9539831	295	32338.41				
	Total	1.1E+08	359					
Alfalfa	Blocks	24377.39	119	204.852	1	0.492956	1.29097	1.434289
	Strategies	412.3146	2	206.1573	1.006372	0.367093	3.033758	4.695438
	Error	48754.78	238	204.852				
	Total	73544.49	359					

Table 5.43: Mean Yields of crops under Irrigation Strategies in descending order in Kg/hectare for the study period year 2004-2010

Crop	Mean Yields of crops under Irrigation Strategies in descending order in Kg/hectare for study period year 2004-2010						Critical Difference (C.D.)
Rice	S III	S VI	S II	S I	S V	S IV	
	4351.098	4348.689	4282.902	2799.68	2320.933	2116.337	124.15
Wheat	S II	S III	S VI	S I	S IV	S V	
	3980.445	3978.845	3836.215	3711.061	3425.453	3315.124	38.54
Jowar	S III	S I	S II	S IV			
	3000	2930.285	2813.171	2717.546			17.60
Bajri	S III	S I	S II	S V	S IV		
	2000	1933.198	1825.907	1793.427	1789.534		26.60
Maize	S III	S II	S VI	S I	S V	S IV	
	3000	2940.808	2815.753	2656.539	2384.017	1404.369	28.00
Tuver	S III	S VI	S II	S I	S V	S IV	
	1500	1433.693	1424.941	1249.976	1097.891	861.6022	26.19
Chana	S III	S II	S VI	S I	S V	S IV	
	1600	1599.039	1535.586	1447.85	1440.747	1328.846	10.36
Sugarcane	S III	S I	S VI	S II	S IV		
	75000	66714.02	64258.95	60905.4	46985.36		1144.41
Cabbage	S III	S II	S VI	S I	S V	S IV	
	70000	69671.97	66917.99	62071.7	53534.31	42383.19	740.38
Cotton	S III	S VI	S II	S I	S V	S IV	
	2500	2421.519	2350.25	2253.009	2068.232	2039.605	26.28
Groundnut	S III	S VI	S I	S II	S IV	S V	
	2500	2478.02	2352.499	2349.356	1933.694	1762.994	32.37
Castor	S III	S I	S VI	S II	S V	S IV	
	2500	2439.181	2428.462	2408.324	2043.287	1717.528	16.78
Tobacco	S III	S VI	S II	S I	S V	S IV	
	3000	2918.321	2897.786	2471.753	2393.885	1517.441	54.01

In case of rice as there is no bar between S III and S VI, we can recommend either of the strategy, as there is no significant difference between the two strategies. Similarly, while comparing S VI and S II, either of the two strategies may be chosen as no bar is there between them. Whereas, while comparing S II and S I; S I and S V; SV and S IV, as they have bar, the strategies resulting in higher yield shall be opted amongst them.

The results of the Table 5.43 are self explanatory showing that strategy S III is best suited, for all crops including wheat (negligible difference in S II and S III, because of post moisture stress in strategy S III due to early irrigation cut off). Irrigation with strategy S III is feasible, if irrigation requirement is triggered, according to soil moisture deficit with help of automated sensor installed to assess the soil moisture status. The second best strategy is S VI, S II, or S I, depending upon crop however; if water savings is also considered together, then S VI is better placed than other strategies. Table 5.43 provides good insight into the selection of the strategy however; the reasonable water saving criteria requires to be taken into consideration, before recommending a particular strategy.

5.19 Water Demand

The water demand simulations are carried out to for appropriate irrigation strategies S I to S VI, for all fourteen crops during the study period, in 16 blocks of region I, and four blocks of region II, of Sardar Sarovar Project. Percentage cropped area in hectares of various crops in the region I and II during the year 2003 were obtained from agriculture department and taken as base for simulation purpose, for the study period. The month of July is selected as starting of water year as mostly sowing period of the major crops is initiated by the farmers then. The policy of the SSNL authorities is to provide canal water during November to April, to promote conjunctive use of ground water and canal water. In view of the above policy, ground water demand was calculated from 1st of July upto end of October for the crops. Also, canal water demand was calculated from 1st November upto end of April. As, no summer crops are selected the water demand during month of May and June is nil. Month wise water demand, for all crops during the study period in the respective 20 blocks were estimated strategy wise. Due to vastness of results water demand of all blocks are not produced here. But for illustration purpose, results of block 9A1 are shown specifically below as all selected crops are represented in this block.

Table 5.44: Monthly Canal Water Demand (Cubic Meter) crop wise for block 9 A1 under irrigation strategy S VI

Year	⇩Crops	Area in hectares	November	December	January	February	March	April
2004-2005	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	122139	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	2258195	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	3077	3077
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	5409703	4661877	3765436	1998055	3077	3077
2005-2006	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	244279	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	1505463	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	3077	3077
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	4779111	4661877	3765436	1998055	3077	3077
2006-2007	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	122139	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	2258195	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	3077	3077
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	5409703	4661877	3765436	1998055	3077	3077
2007-2008	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	244279	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	2258195	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	4615	4615
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	5531843	4661877	3765436	1998055	4615	4615
2008-2009	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	244279	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	1505463	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	3077	3077
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	4779111	4661877	3765436	1998055	3077	3077
2009-2010	Cabbage	238.43	257508	257508	257508	257508	0	0
	Castor	339.28	122139	122139	0	0	0	0
	Chana	69.22	33227	49840	33227	0	0	0
	Cotton	3136.38	2258195	3010927	1505463	0	0	0
	Maize	470.03	451229	338422	225614	0	0	0
	Sugarcane	2.56	3077	3077	4615	1538	3077	3077
	Tobacco	29.06	20921	20921	20921	20921	0	0
	Tuver	605.91	545320	0	0	0	0	0
	Wheat	1227.21	1718088	859044	1718088	1718088	0	0
	Sum	6118.08	5409703	4661877	3765436	1998055	3077	3077

Table 5.45: Crop wise monthly ground water demand (Cubic Meter) for years 2004 to 2006 for block 9A1 (Area 8546 ha.) under irrigation strategy S VI

Year	⇩Crops	Area in ha.	Ground water demand (Cubic Meter)			
			July	Aug	Sept	Oct
2004	Bajri	181.18	0	0	0	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	81426	0	122139	122139
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	0	0	0	752732
	Gnut	57.26	34355	0	34355	17177
	Jowar	928.10	0	0	417643	0
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	2307	0	0	1538
	Tobacco	29.06	0	0	41841	27894
	Tuver	605.91	0	0	545320	545320
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	3030087	2401255	3616018	4249242
2005	Bajri	181.18	135881	0	0	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	81426	162853	0	122139
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	752732	1505463	0	752732
	Gnut	57.26	48097	17177	0	34355
	Jowar	928.10	0	0	0	0
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	1154	0	0	1538
	Tobacco	29.06	0	0	20921	27894
	Tuver	605.91	0	817980	0	817980
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	3931288	4904729	2475639	4539080
2006	Bajri	181.18	0	0	0	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	162853	0	0	366418
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	752732	0	0	1505463
	Gnut	57.26	37790	0	17177	34355
	Jowar	928.10	0	0	0	417643
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	2307	0	0	1538
	Tobacco	29.06	0	0	48815	34868
	Tuver	605.91	0	0	272660	817980
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	3867680	2401255	2793371	5960707

Table 5.46: Crop wise monthly ground water demand (Cubic Meter) for years 2007 to 2009 for block 9A1 (Area 8546 ha.) under irrigation strategy S VI

Year	⇩Crops	Area in ha.	Ground water demand (Cubic Meter)			
			July	Aug	Sept	Oct
2007	Bajri	181.18	0	0	0	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	81426	0	0	122139
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	752732	752732	0	0
	Gnut	57.26	48097	0	0	17177
	Jowar	928.10	0	0	0	0
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	1154	0	0	1538
	Tobacco	29.06	0	0	27894	27894
	Tuver	605.91	0	272660	0	545320
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	3795407	3426647	2482613	3496510
2008	Bajri	181.18	0	0	0	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	162853	81426	0	122139
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	752732	752732	0	752732
	Gnut	57.26	61839	0	17177	34355
	Jowar	928.10	0	0	0	0
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	1154	0	0	1538
	Tobacco	29.06	0	0	27894	27894
	Tuver	605.91	0	272660	0	817980
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	3890575	3508073	2499790	4539080
2009	Bajri	181.18	0	0	135881	0
	Cabbage	238.43	0	0	114448	228896
	Castor	339.28	0	325705	122139	122139
	Chana	69.22	0	0	0	16613
	Cotton	3136.38	0	3763658	0	752732
	Gnut	57.26	20613	34355	34355	17177
	Jowar	928.10	0	0	417643	417643
	Maize	470.03	0	0	0	112807
	Rice	762.30	2911998	2401255	2340271	2424124
	Sugarcane	2.56	1154	0	0	1538
	Tobacco	29.06	0	0	48815	27894
	Tuver	605.91	0	817980	545320	545320
	Alfalfa	459.77	0	0	0	0
	Sum	7279.48	2933765	7342954	3758873	4666885

Table 5.47: Monthly Canal Water Demand in (Cubic Meter) for irrigation strategies S I to S VI for block 9A1 (Area in 8546 ha.) during study period 2004-2010

Year	Strategies	Nov	Dec	Jan	Feb	March	April
2004-2005	S I	5185226	4237021	5445904	1964777	3846	1923
	S II	5347523	1395032	2867961	1976801	3846	3846
	S III	1228536	2780158	1687179	3566244	1101531	2664
	S IV	4080390	1471348	2624630	989746	2307	3461
	S V	3367936	2992467	4043087	923865	3846	3846
	S VI	5409703	4661877	3765436	1998055	3077	3077
2005-2006	S I	5185226	4237021	5445904	1964777	3846	1923
	S II	5639463	2916365	2854014	1976801	1923	3846
	S III	3402774	629723	3678876	1336173	11845	2662
	S IV	3090088	1472501	1011701	1848790	2307	3461
	S V	3367936	2994390	4043087	923865	1923	3846
	S VI	4779111	4661877	3765436	1998055	3077	3077
2006-2007	S I	5185226	4237021	5445904	1964777	3846	1923
	S II	4618771	3873987	1362497	1962854	3846	1923
	S III	3064956	2999632	1677536	1293138	2623	5268
	S IV	3235507	1455888	1781046	1784593	2307	2307
	S V	3367936	2992467	4043087	923865	3846	1923
	S VI	5409703	4661877	3765436	1998055	3077	3077
2007-2008	S I	5185226	4237021	5445904	1964777	862890	1923
	S II	5538962	3016866	2867961	1962854	1923	3846
	S III	3419769	711634	3825038	1274057	2663	2686
	S IV	3235507	2232207	2729310	932522	2307	2307
	S V	3367936	2994390	4043087	923865	1923	3846
	S VI	5531843	4661877	3765436	1998055	4615	4615
2008-2009	S I	5185226	4237021	5445904	1964777	3846	1923
	S II	4972652	3761462	2867961	1962854	1923	3846
	S III	3277213	847092	3554380	1356562	2648	2699
	S IV	2337357	2225233	1870745	989746	2307	2307
	S V	3367936	2994390	4043087	923865	1923	3846
	S VI	4779111	4661877	3765436	1998055	3077	3077
2009-2010	S I	5185226	4237021	5445904	1964777	3846	1923
	S II	4646691	3596687	2867961	2077302	3846	3846
	S III	3071587	3033050	1498153	1274075	1111699	2708
	S IV	3852392	1701329	2640090	989746	2307	3461
	S V	3245796	2992467	4043087	923865	3846	3846
	S VI	5409703	4661877	3765436	1998055	3077	3077

The water demand for all irrigation strategies varied significantly, but amongst them strategy S VI is selected, because of its minimal yield reduction, water savings, and easy in implantation by all stakeholders. Crop wise monthly canal water demand in block 9A1, during the study period, under strategy S VI has been tabulated in Table 5.44. The wet, normal, and dry years (according to type of monsoon), early withdrawal of monsoon, and soil moisture condition post monsoon, has influenced water demand in month of November, for crops castor and cotton, resulting into fluctuations in demand. For sugarcane in year 2008, the water demand has increased in month of March and April. Monthly canal water demand is nearly same for other months, during the study period (Table 5.44). Similarly crop wise ground water monthly demand, for study period under irrigation strategy S V I are demonstrated in Table 5.45 (2004-2006) and Table 5.46 (2007-2009). Ground water monthly demand was same for the crops cabbage, chana, maize, and rice during the study period. The demand did not vary as fixed depth of irrigation was provided in this strategy, but with the change in depth and interval of irrigation, then the conventional (Strategy S I of fixed depth irrigation with fixed interval) practices. Ground water demand for bajra was nil with exception of year 2005, due to delay of monsoon, and year 2009 being a dry year. In case of jowar no demand was there in month of July and August, but variability was ranging from nil to 417643 cubic meters in September and October month. Significant variability in ground water demand was observed for crops castor, cotton, groundnut, sugarcane, tobacco, and tuver. However, no groundwater demand was required for cotton (September), sugarcane (August, September), and tuver (July). The initial soil moisture conditions due to rainfall in post monsoon significantly influence the fluctuations of water demand in month of November, for crops castor and cotton in other blocks of region I and II, of Sardar Sarovar Project. Tobacco is sown in month of September, thus demand is nil in July and August. Alfalfa does not require any ground water irrigation thus demand is nil. The variability in ground water demand for afore said crops, indicates the sensitiveness of the irrigation strategy towards rainfall, soil moisture, and climatic conditions.

Monthly canal water demand for block 9A1, for the study period under irrigation strategies S I to S VI is estimated and demonstrated in Table 5.47. In strategy S I the canal water demand is same for all years, except in year 2008; wherein an extra irrigation was applied for wheat crop, resulting into change in demand in month of March. Both the strategies S II and S III are highly influenced by changes in climatic and post monsoon soil moisture conditions, thus significant variability was noticed in their monthly canal water demand, during the study period. In strategies S IV significant variability was observed, except month of March.

Strategy S V showed mild variability, except month of January and February. Due to cotton and castor crop in month of November, significant variability in canal water demand was observed, as discussed previously in strategy S VI. During the study period in other months the canal water demand remained constant, except for year 2008 in month of March and April, due to slight increase in sugarcane water demand.

Monthly water demand for groundwater and canal water for 16 blocks of region I, and four blocks of region II, under irrigation strategies S III (refer figure 5.56 and figure 5.57) and S VI (refer figure 5.58 and figure 5.59), for the study period were computed. As the canal is operated in study area from November to April only, the groundwater demand is computed from July to October. Irrespective of dry or wet scenarios, peak water demand in study area under strategy S III is month of October, while for strategy S VI it is December. Fluctuations of canal water demand under strategy S VI is noticed during month of November, afterwards the demand is same, except year 2008. Wide fluctuations in groundwater demand in month of August is seen in years 2005 and 2009; this is due to less rain, during that month in both the regions.

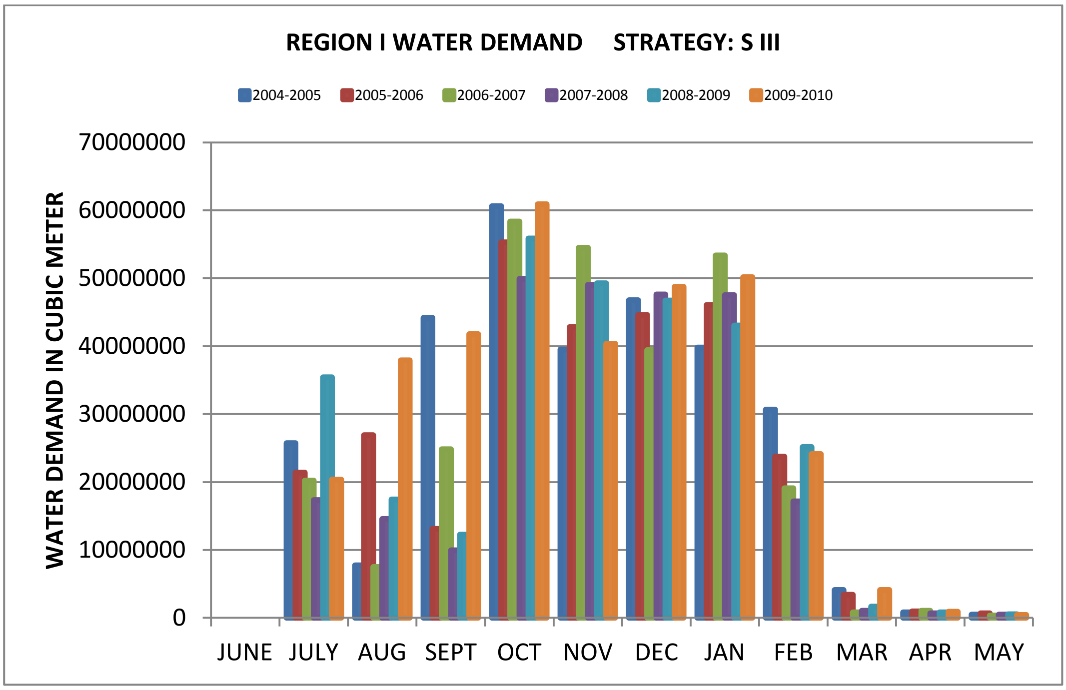


Fig 5.56: Water demand under irrigation strategy S III for region I

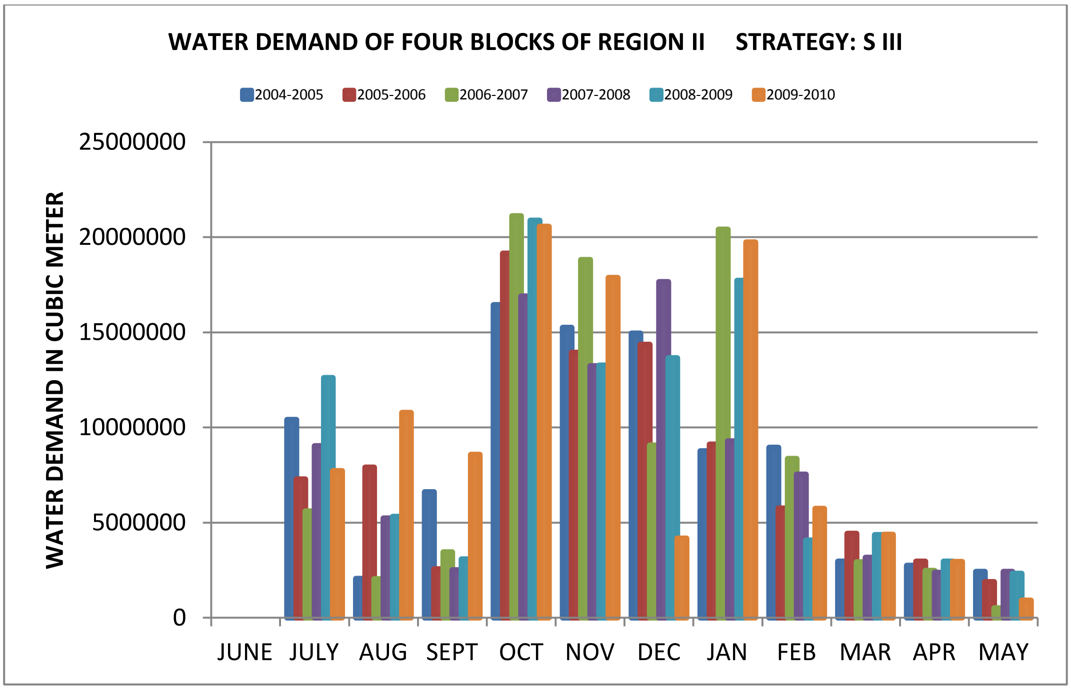


Fig 5.57: Water demand under irrigation strategy S III for four blocks of region II

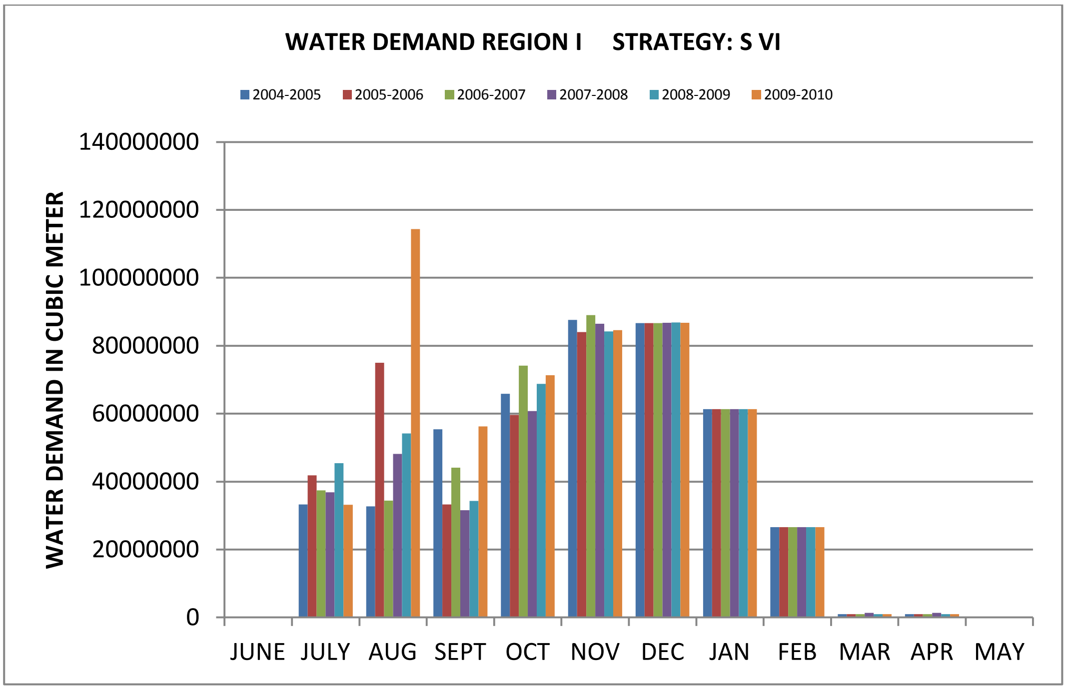


Fig 5.58: Water demand under irrigation strategy S VI for region I

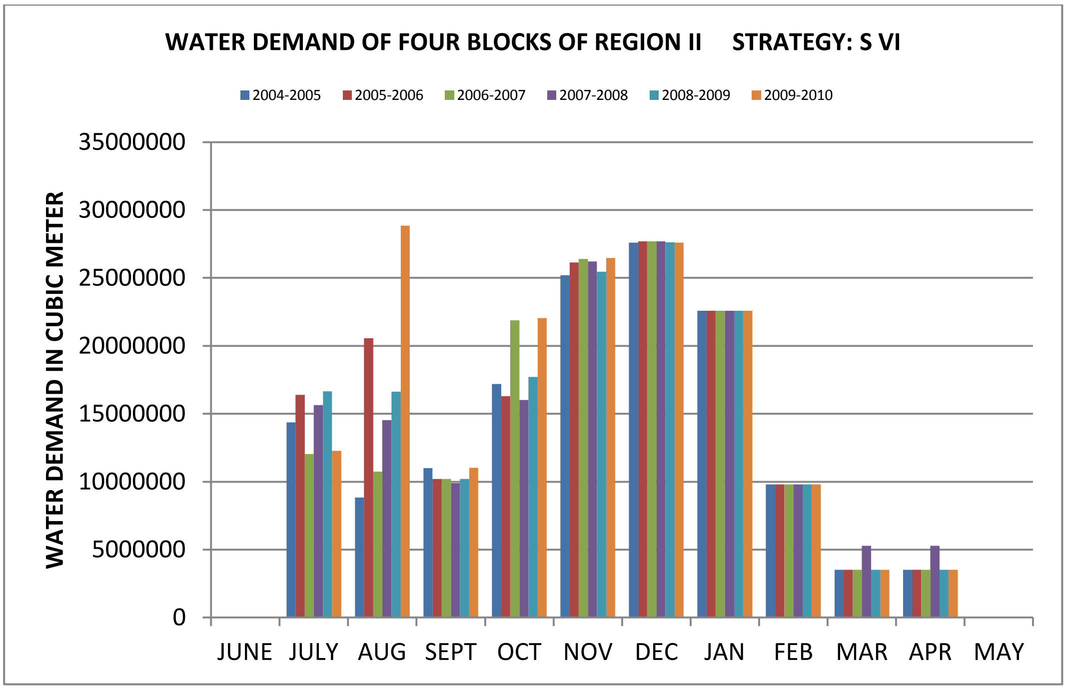


Fig 5.59: Water demand under irrigation strategy S VI for four blocks of region II

5.20 Computing ET_a and ET_c using P-M Model Coupled with K_{cb}

Crop evapotranspiration (ET_c) measurement is not easy and requires sophisticated, expensive equipment and trained research personnel. Complexities involved in estimation of crop water requirements with different parameters to be considered have made it a challenging task. Advent of automatic weather stations (AWS) has enabled the availability of meteorological data on daily/ hourly basis, which can be used to precisely estimate reference evapotranspiration using FAO-56 P-M model. FAO-56 P-M model is considered, as sole standard method, provided all climatic data are available. Reference evapotranspiration is computed using Penman-Monteith model using daily climatic data. Potential and actual evapotranspiration can be computed multiplying reference evapotranspiration obtained through Penman-Monteith to crop coefficient value under pristine and water stress conditions, as shown in Figure 5.60, for the cotton crop in block 9B1R2 for year 2004. Crop is under water stress during 123 day of sowing to 132 day of sowing, thus actual evapotranspiration is less than the potential evapotranspiration, during this period. FAO-56 Penman Monteith model is found very useful, to precisely estimate daily potential evapotranspiration using daily climatological data. Further, the dual crop coefficient approach helps in computing, separately soil evaporation and transpiration, under normal and water stress condition. Figure 5.61 shows soil evaporation from the surface layer from 41 day of sowing to 55 days of sowing, for cotton crop in block 9B1R2, for year 2009 post wetting of soil. During this period it is seen that immediately after precipitation the evaporation rate is higher than transpiration, and subsequently it equalize, and then it reduces. Figure 5.61 demonstrate, that the daily variation in soil surface wetness, soil moisture profile, due to frequent or light wetting, because of rainfall, and irrigation has a significant impact on crop evapotranspiration.

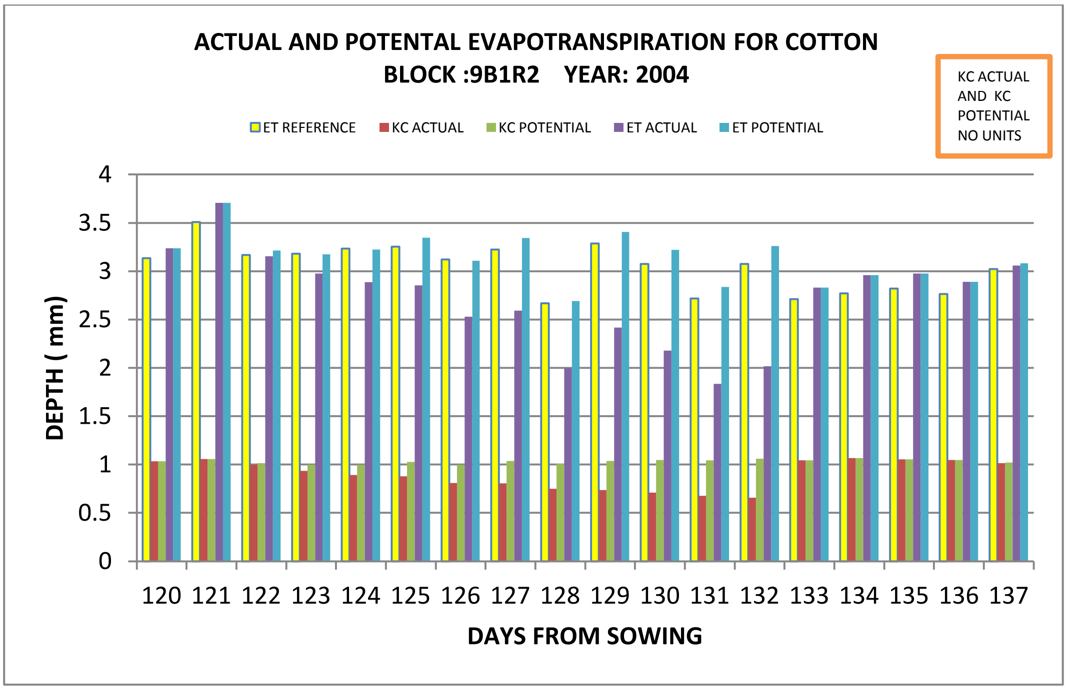


Figure 5.60: Actual and potential evapotranspiration for cotton in block 9B1R2 for year 2004

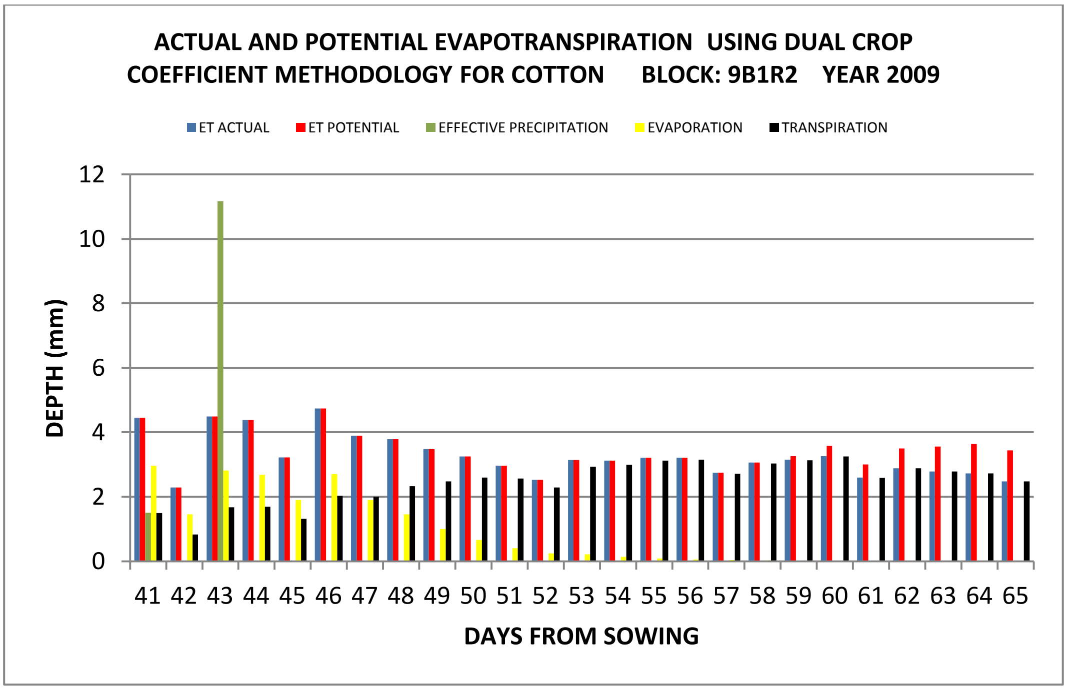


Figure 5.61: Actual and potential evapotranspiration while using dual crop coefficient methodology for cotton crop in block 9B1R2 for year 2009

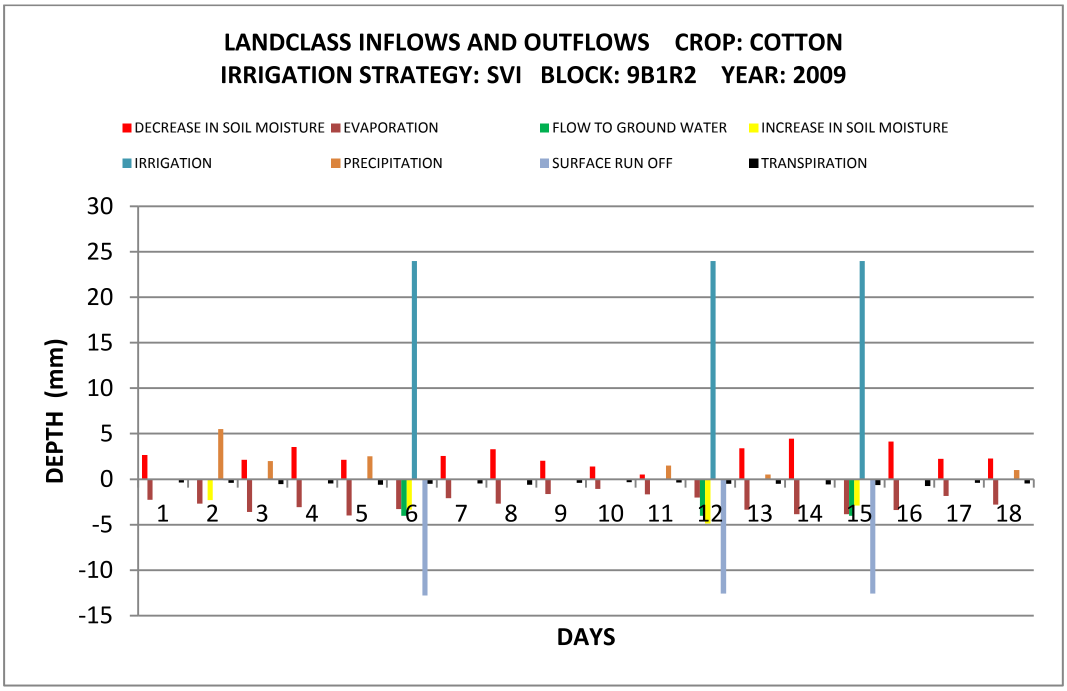


Figure 5.62: Land class inflows and outflows under irrigation strategy S VI for cotton crop in block 9B1R2 for year 2009

5.21 Computing Soil Moisture Balance on Daily Basis

Soil moisture content is a critical state variable that determines the response of a soil- crop system to any water input. Continuing monitoring of soil moisture content is of great significance in irrigation management (Rao, 1987). Crop water requirements can be estimated by calculating the soil water balance of the root zone on daily basis. This will help in planning the timing and depth of irrigation. Soil moisture balance on daily basis helps in understanding response to change in soil moisture, flow to groundwater, surface run off, evaporation, and transpiration due to any input, or no input of water in form of irrigation, and/or precipitation. Figure 5.62 shows the land class inflows and outflows, while monitoring soil moisture balance on daily basis, for cotton crop in block 9B1R2 for year 2009, under irrigation strategy S VI, from the sowing period to the 18th day of sowing. Soil moisture balance computation on daily basis plays an important role, for evaluation of irrigation scheduling, crop yield, and recharge to groundwater. The daily variation in soil surface wetness, soil moisture profile due to frequent or light wetting, because of rainfall and irrigation has a significant impact on crop evapotranspiration. Thus, it can be concluded that WEAP-MABIA model used in this study to find actual evapotranspiration using Penman Monteith Method and dual crop coefficient approach is found to be of great use. Comprehensive FAO-56 P-M model coupled with, dual crop coefficient (Kcb) approach, and soil moisture balance (SMB) model is an excellent decision support tool, for evolving irrigation strategies under varied situations.

5.22 Discussion

To cater to the conventional practices followed among cultivators, irrigation of fixed depth at fixed intervals, according to type of crop, soil, and climatic conditions is proposed in form of strategy S I. In this strategy S I the crops grown in Kharif season would be normally over irrigated, as the irrigation interval can't be adjusted according to the prevailing soil moisture conditions, due to the limitations of the irrigation strategy. However, adjustment of irrigation depth during the initial vegetative stage can reduce the amount of over irrigation. In areas, where ground water is shallow and showing rising trend the strategy S I is recommended during Kharif season. Strategy S II is proposed to overcome the above limitations, by triggering irrigation of a fixed depth whenever, soil moisture depletion reaches 100 percent of readily available water (RAW). Strategy S II has large variability in range of irrigation depth, indicating the sensitiveness of strategy towards rainfall, soil moisture, and climatic conditions. It is observed in strategy S II, that if fixed depth irrigation is much greater than RAW depth, it results in greater runoff, leading to lower irrigation water use efficiency IWUE. Further in case of blocks, having sandy clay soil where the value of RAW is low, than the amount of irrigation depth is to be carefully decided in strategy S II. Strategy S III is best suited and performs well as moisture stress conditions are prevented in this strategy. Irrigation equivalent to soil moisture depletion (SMD) is applied in strategy S III, resulting into ideal condition i.e. no water loss in form of surface flow and flow to ground water. Highest yield of crop with maximum water saving is achieved for all the crops, and is the best strategy amongst the recommended six strategies However, in initial vegetative growth stage frequent irrigation is required. As the timing of irrigation is highly dependent on climatic variation and rainfall, its implementation is challenging. Irrigation with this strategy is feasible, if irrigation is triggered by monitoring the soil moisture deficit with help of automated sensors installed to assess the soil moisture status No moisture stress is observed in strategy S III, provided irrigation is not cut off early as for crops like sugarcane, wheat etc, to obtain good yield as per prevailing practices. Sometimes strategy S II would give more yields then strategy S III, as fixed depth of irrigation post cut off would prevent water stress conditions this was observed, while irrigating wheat and sugarcane crop. Strategy S IV ensures minimal yield with protective irrigation for crops, where the farmers are dependant mostly on rainfall and would resort to irrigation only just to save the crop. In case of strategy S IV irrigation of fixed depth is applied at 80 percent of TAW, this is done in view of a famine like situation, or due to reluctance of farmer to irrigate, through ground water because of not owning a well/tube well. In strategy S IV the crops having critical permissible soil moisture depletion factor ‘p’ less than 80 percent would have significant yield reduction. However; the crops which are drought resistant like bajra, castor etc could give reasonable yield, if irrigated with this strategy. To obtain better yields with less water; regulated deficit irrigation (Strategy S V) be applied during a specific growth stage/s, depending upon crop. Mild water stress during different growth stage/ s reduces the yield marginally for some crops, with significant increase in irrigation water use efficiency in comparison to traditional practices. In strategy S V, regulated deficit irrigation is proposed with an intention of water savings in case of shortage of irrigation water, or to increase the yield by withholding the water, during specific growth stage of crop. Results can be relatively good in some type of crops. In strategy S VI combination of two or more strategies has been tried to overcome some of the difficulties faced above, to obtain reasonable good yield and water savings. The outcome of results for strategy S VI is encouraging. In initial vegetative stage the irrigation depth in various soils needs to be selected cautiously for strategy S VI. The Kharif crops if not irrigated under less or delayed rainfall, then their yield is affected. Various irrigation strategies suggested for irrigating Kharif crops utilize only groundwater, whereas canal water is used post Kharif season. Conjunctive use of surface and ground water in the area can withheld the rising trend of water table in certain pockets of the region. Irrigation scheduling if applied based on the soil water status would give high yields. However; the irrigation depth range varies significantly during wet and dry years, for all such strategies which use irrigation trigger method for soil moisture depletion levels to reach certain percent of readily available water, or total available water. In case of rice due to software limitations, the simulation for the standing water over the ground is not considered, and hence the excess irrigation or rainfall after saturation of soil generates surface run off. In actual practise such surface run off is prevented by constructing the bunds, and this reduces the requirement of daily irrigation.

5.23 Closure

Penman- Monteith model coupled with dual crop coefficient approach and soil moisture balance model to estimate crop water requirements on daily basis proved to be a good tool. Water use efficiency and irrigation water use efficiency, water demand estimated for major fourteen crops in 16 blocks of region I, and four blocks of region II, and evaluating six alternative strategies for crops will be of great help to irrigation managers in decision making for matching the irrigation supply, and demand in various scenarios. In next chapter we discuss the specific conclusions and recommendations arrived at by undertaking this study, limitations of the study, major contributions that can be attributed to this research work and future scope of work.