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Research Article

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Development of Decision Support System for On-Farm Irrigation Water Management

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ABSTRACT

In this study a Decision Support System (DSS) was developed for on-farm irrigation water management to determine when to irrigate and how much to irrigate for border, sprinkler and drip irrigation systems for wheat, maize, potato and chilli crops. It is based on five datasets viz. weather, crop, soil, water quality and irrigation system. The DSS was developed under PHP server side scripting language at frontend and MySQL datasets at backend. The DSS can be accessed by user in two ways; first if user having weather data, Second, if user not having weather data. The irrigation scheduling for border irrigation system was based on total ETc during irrigation interval and previous applied depth of irrigation but for sprinkler and drip irrigation were based on total ETc during irrigation interval and pre decided irrigation frequency. Overall, this research will be very helpful to the farmer to take the decision on when to irrigate and how much to irrigate for sustainable on-farm irrigation water management.

Key words: *Reference evapotranspiration, crop water requirement, irrigation scheduling, Decision support system, on-farm water management.*

INTRODUCTION

Water is the most critical input for enhancing agricultural productivity and therefore expansion of irrigation has been a key strategy in the development of agriculture in India. As per record of Ministry of Agriculture, Govt. of India, the net and gross irrigated area during 2010 were 63.256 and 86.423 million ha[2] respectively, percentage of net irrigated area to net cultivated area was 45.17 % and among the states, Punjab has highest percentage of 97.95 % of gross irrigated area to the total cropped area[4]. The improper irrigation causes declining ground water table and high costs of pumping which necessitate that water be applied only when it is needed to prevent appreciable yield reductions. Frequent irrigation, when soil profile is moderately wet, can result in excessive and inefficient use of water, where excessive drying of the soil profile before irrigation can result in significant yield reductions.

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Therefore, irrigation water management is needed at farm level. Therefore, precise irrigation water management is need of the hour. The precision technologies will help to obtain a better knowledge of the crop agronomy and irrigation, detecting water stress, determining crop water requirements and obtaining accurate irrigation schedules. The determination of these effective irrigation schedules requires the accurate determination of water requirement of the crops. It will help the farmers in deciding when and how much to irrigate. This can be done easily by decision support system for on-farm irrigation water management because it relates to weather, soil, crop and water quality and conditions that can be used to calculate how much water is required and when an irrigator should give next irrigation. It is hypothesized that when DSS derived irrigation schedules will be followed, precision in water saving could be achieved by the use of scientific principles rather than using thumb rules.

MATERIAL AND METHODS

Development of datasets

A study was conducted for Ludhiana district of Punjab (India). To develop DSS, firstly develop the weather, crop, soil, irrigation water quality and irrigation system datasets in MySQL database. These datasets stores parameters which are used in make irrigation schedules for different irrigation system for given crops. Firstly weather dataset developed by using daily basis agro-meteorological data is generated for future years by using simple mean method for all weather parameters that are required in FAO Penman-Monteith method. The daily data is generated on the basis of fourty-two years (1970- 2012) daily climatic data which was collected from School of Climate Change and Agro-meteorology, PAU, Ludhiana. Second, soil dataset developed using parameters soil type, soil pH and electrical conductivity (EC) of all blocks of Ludhiana district was taken from the geospatial fertility status of Punjab soils published by Department of Soil Science, PAU, Ludhiana. Third, crop datasets developed using parameters such as crop variety, family, crop sowing/planting date and indusial and total growing duration of crop stages were taken from package of practices for crops and vegetables of Punjab Agricultural University, Ludhiana[3]. The growing period of four stages and their corresponding K_c values for the selected crops were obtained from School of Climate Change and Agro-meteorology, PAU, Ludhiana as given in Table 1. Fourth, irrigation water quality dataset developed using water qualities parameters such as pH and electrical conductivity of irrigation water (EC_w) were taken for all blocks of Ludhiana from the manual of ground water quality for irrigation in Punjab, Punjab Remote Sensing Centre Ludhiana. Electrical conductivity of soil saturation extract (EC_e) for a given crop appropriate to the tolerable degree of yield reduction estimated as $1.5*EC_w$[5]. Fifth dataset is irrigation system to store to irrigation systems efficiencies.

Table 1: Crop coefficient (K_c) values of different crops at different stages

Crop	Kc Initial	KcDevelopment	Kc Mid	KcLate
Wheat	0.5	1.36	1.42	0.42
Maize	0.7	0.85	1.15	1.05
Potato	0.95	1.05	1.15	0.9
Chilli	0.15	0.75	1.15	0.7

Irrigation water requirement

In this study ET_o was computed by FAO Penman-Monteith[1], Blaney and Criddle[6] and Pan Evaporation[1] methods.

$IR = ET_c - P_e$	$ET_c = K_c * ET_o$

Where, ET_c is total crop evapotranspiration (mm), IR is irrigation requirement (mm), P_e is effective rainfall (mm) taken to be 65% of the rainfall[7], K_c is crop coefficient and ET_o is reference crop evapotranspiration (mm day^{-1})

Irrigation Scheduling:

Objective of irrigation scheduling is to apply right amount of water at right time and determines the process to decide when and how much to irrigate[8].

How much to irrigate: The gross irrigation requirement accounts for losses of water included during conveyance and application of irrigation water to the field. The field irrigation efficiency was taken 40, 65 and 90 % for border, sprinkler and drip irrigation systems respectively[9].

$$IR_g = \frac{IR_n}{E_f} * 100 \qquad IR_{gv} = \frac{IR_{nv}}{E_f} * 100$$

Where, IR_g and IR_{gv} are gross irrigation requirements in mm and litres, IR_n and IR_{nv} are net irrigation requirements in mm and litres and E_f is field irrigation efficiency (%). In case of sprinkler and drip irrigation systems, leaching requirement are not considered, so that net irrigation water requirement is same as IR. But for border irrigation system, leaching requirement is considered,

$$IR_n = IR + LR \qquad IR_{nv} = IR_n * A_a * 10^4$$

Where, IR_{nv} is net irrigation requirement (litres), A_a is net given cropped area (ha), IR_n and LR are net irrigation and leaching requirement (mm) respectively. The following equation was used as a guideline for calculating LR based on irrigation water salinity and crop salt tolerance[10].

$$LF = \frac{E_{cw}}{5E_{ce} - E_{cw}} \qquad LR = \frac{ET_c}{1 - LF} - ET_c$$

Where, LF and LR are leaching fraction in decimal and leaching requirement (mm), E_{cw} is electrical conductivity of irrigation water (ds/m) and Ece is electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (ds/m).

Irrigation pumping time

The pumping time of border irrigation system per application was calculated on the basis of volumetric method and the discharge rate was calculated,

$$IP_t = \frac{IR_{gv}}{Q} \qquad Q = \frac{V}{T} * 60$$

Where, IP_t and IR_{gv} are irrigation period (h) and gross irrigation required in term of volume (l), Q and V are discharge rate of pump (lph) and volume of container or bucket (l) and T is time required to fill-up container or bucket (min). The pumping time of sprinkler per application was calculated on the basis of discharge rate of one sprinkler, spacing of sprinkler along the lateral and spacing of laterals along the sub-main line, length of lateral and sub-main line.

$N_s = \frac{L_l}{S_s}$	$A_c = S_l * S_m * N_s * N_l$
$N_l = \frac{L_{sm}}{S_l}$	$N_{sm} = \frac{A_a * 10^4}{A_c}$
$Q = q_s * N_s * N_l$	$T = \frac{IR_{gv}}{Q}$
$IP_t = T * N_{sm}$	

The pumping time of drip irrigation system per application is calculated on the basis of discharge rate of one emitter, spacing of emitters along the lateral and spacing of latters along the sub-main line, length of lateral and sub-main line.

$N_{em} = \frac{L_l}{S_{em}}$	$N_{sm} = \frac{A_a * 10^4}{A_c}$
$N_l = \frac{L_{sm}}{S_l}$	$Q = q_s * N_l$
$A_c = \frac{S_{em} * S_l * N_l * p}{100}$	$T = \frac{IR_{gv}}{Q}$
	$IP_t = T * N_{sm}$

Where, L_l and L_{sm} are total length of lateral and sub main line (m), A_a and A_c are net cropped (ha) and area covered by system in one sub-main line (m^2), S_s and S_l are spacing of sprinkler along lateral and sub-main line (m), N_l and N_{sm} are number of lateral along sub-main and main line, the notations Nem is number of emitters and Sem is spacing between emitters along the lateral N_s is number of sprinkler, T and IP_t are time taken to irrigate one shift (h) and irrigation period (h) q_s and Q are discharge rate (lph) and discharge rate of pump (lph).

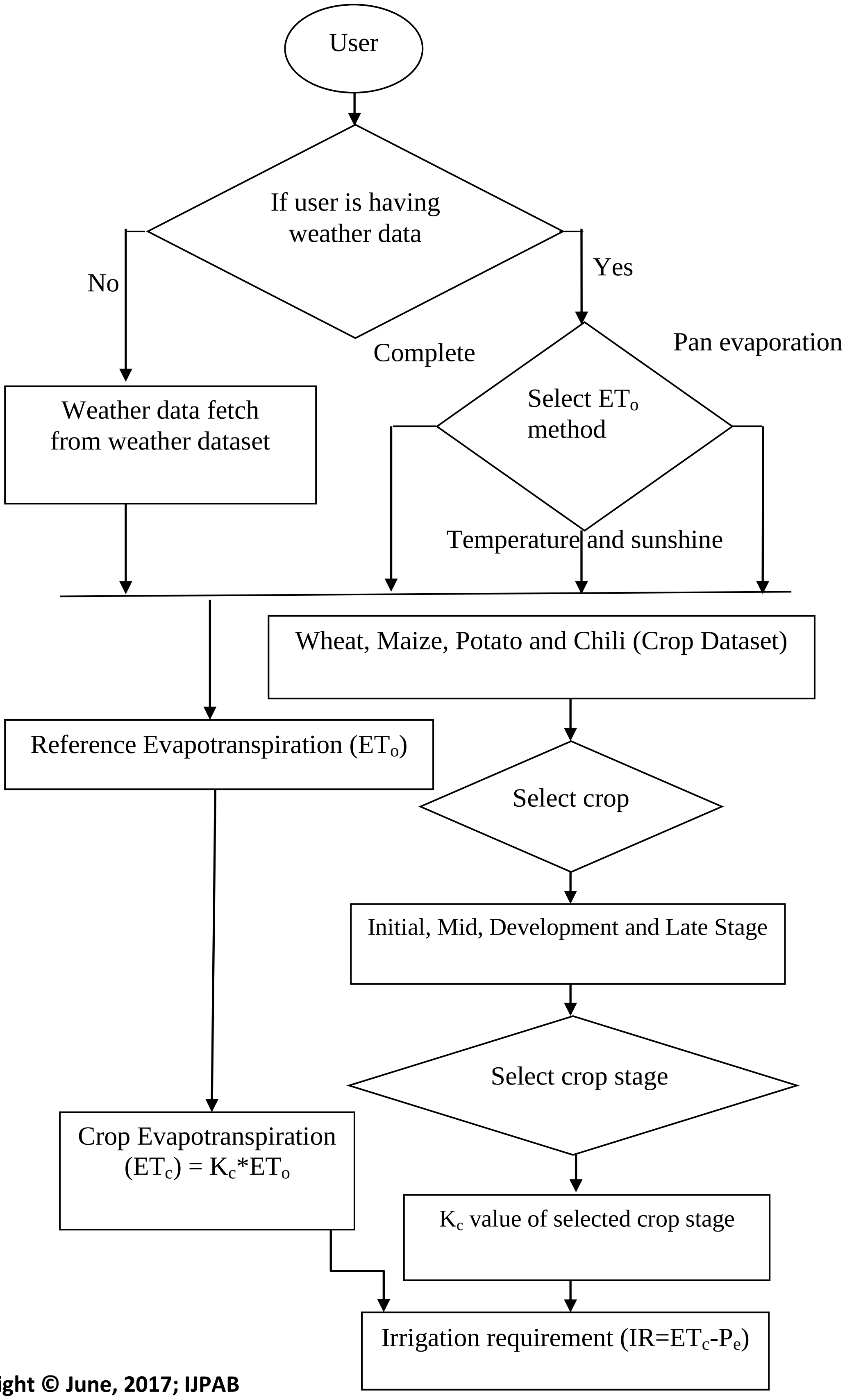
When to irrigate

In case of border irrigation system, it was calculated as when gross irrigation depth is less than or equal to previous applied depth of irrigation in other terms it is ratio of net irrigation water requirement (IR_n in mm) and crop evapotranspiration (ET_c in mm/day). But for sprinkler and drip irrigation system irrigation frequency were taken 7 and 2 days respectively.

Development of Decision Support System

The Decision Support System was developed under PHP server side scripting language at frontend and MySQL datasets at backend. The developed DSS user can be accessed by two ways to calculate ET_o, first if user is having weather data and second, if user is not having weather data. In first case, users have option to choose FAO Penman-monteith or FAO Blaney-Criddle or Pan-evaporation method as availability of weather data and then users have option to choose border or sprinkler or drip irrigation system. The results for border irrigation system, the net and gross irrigation requirement, pumping time and irrigation frequency were calculated based on one day ET_c and previous applied depth of irrigation. But for sprinkler and drip irrigation systems the net and gross irrigation requirement and pumping time were calculated based on one day ET_c and pre decided irrigation frequency. In second case, if a user is not having weather data, all useful data is retrieved from backend developed MySQL weather dataset and then users have option to choose border or sprinkler or drip irrigation system. The results for border irrigation system, the net and gross irrigation requirement, pumping time and irrigation frequency were calculated on the basis of total

ET_c and leaching requirement during irrigation interval and previous applied depth of irrigation. But for sprinkler and drip irrigation, the net and gross irrigation requirement and pumping time was calculated based on total ET_c during irrigation interval and pre decided irrigation frequency. The flowchart of decision support system for on-farm irrigation water management is given in Fig.1.



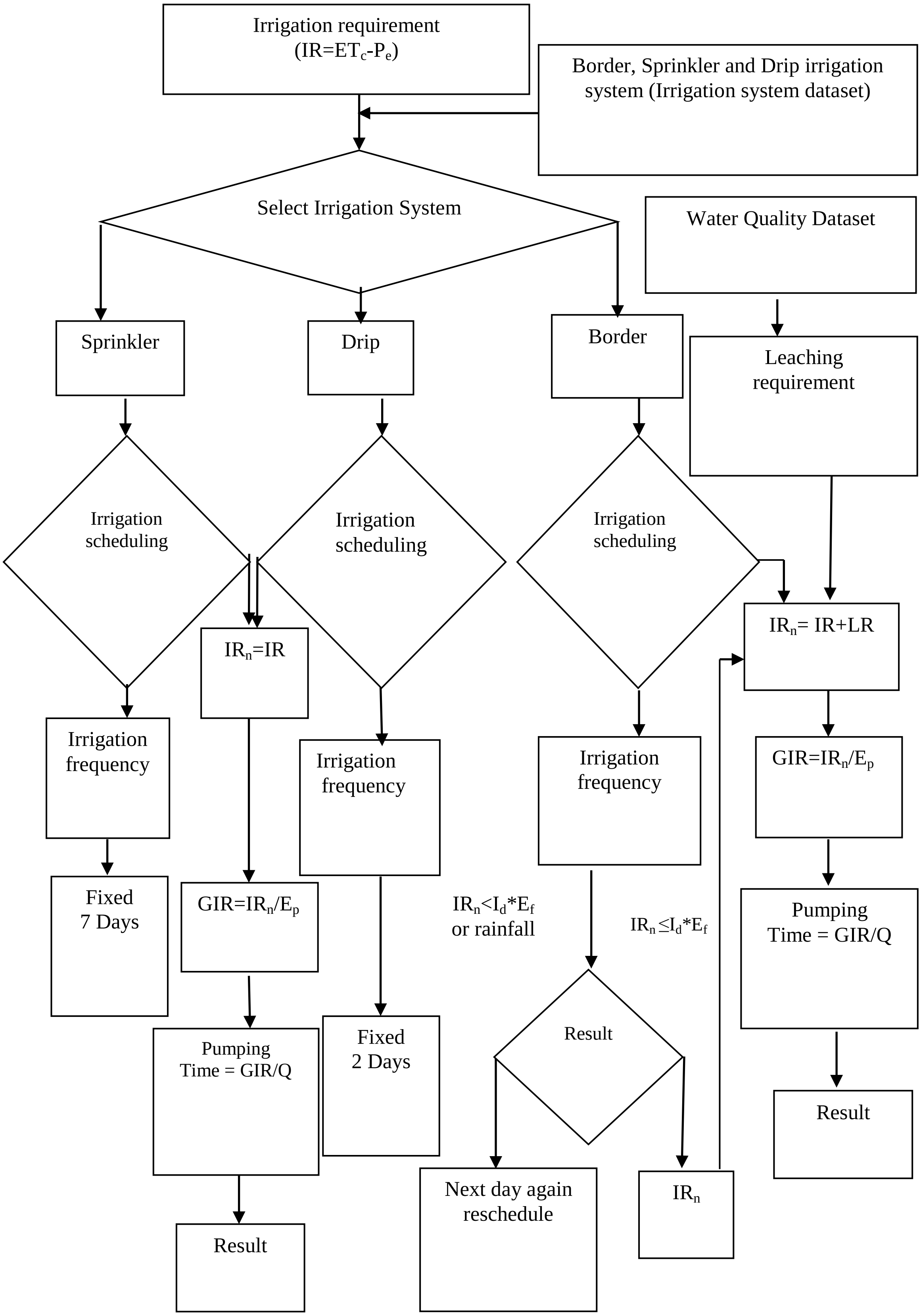


Fig. 1: Flowchart of decision support system for on farm irrigation water management

RESULTS AND DISCUSSION

Decision Support System for user having weather data

There is user can select any one of FAO Penman-Monteith, FAO Blaney-Criddle and Pan-Evaporation methods to calculate ET_o on the basis of availability of weather data as shown in Fig 2. The webpage shown in Fig.3 give details of inputs required in FAO Penman-Monteith method. The required weather data inputs are maximum and minimum air temperature, maximum and minimum relative humidity, sunshine hours, wind speed, rainfall, crop data inputs including crop name, variety, sowing or planting date and the block name. The webpage shown in Fig.4 gives the details of inputs required in FAO Blaney-Criddle. The required weather data inputs are maximum and minimum air temperature sunshine hours and rainfall. Other weather and crop parameters are same as used in FAO Penman-Monteith input. The webpage shown in Fig.5 give details of inputs required in Pan Evaporation method. The required weather data input is only pan evaporation, rainfall and crop parameters are same as used in FAO Penman-Monteith input form Enter all useful parameters and click on 'Submit' button as shown in Fig. 3, or 4 or 5 corresponding to select reference evapotranspiration method. The estimated ET_o and ET_c are retrieved on this webpage and here user has option to select any one of given irrigation systems, viz. border, sprinkler and drip system as shown in Fig. 6.

Fig. 2: DSS screen for user having weather data

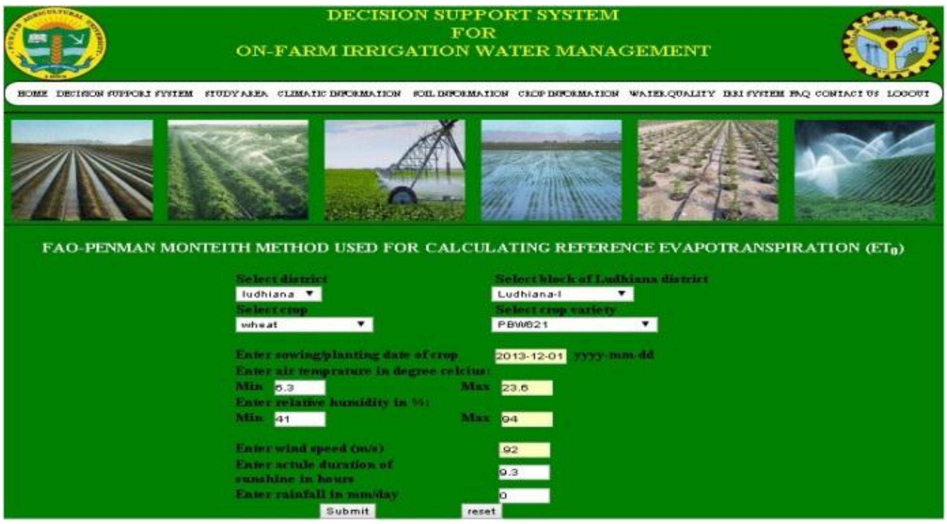


Fig. 3: FAO-Penman Montieth inputs form

Border irrigation system input form

The webpage shown in Fig. 7 gives the details of inputs required in border irrigation system which include soil type, net cropped area, previous irrigation depth, volume of bucket or container and time taken to fill-up it. The output results given on the basis of previous depth of irrigation applied and total ET_c during irrigation interval is shown in Fig. 8.

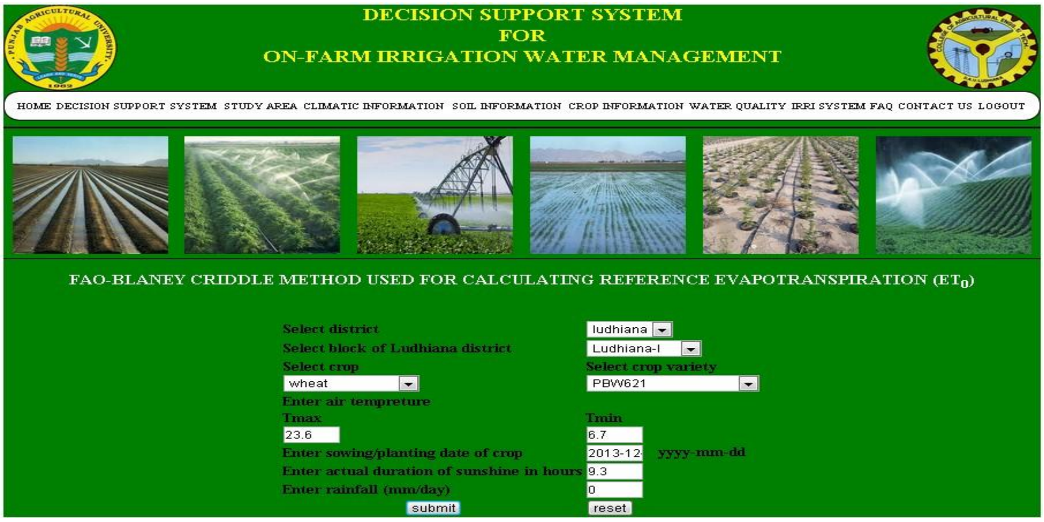


Fig. 4: FAO-Blaney-Criddle inputs form

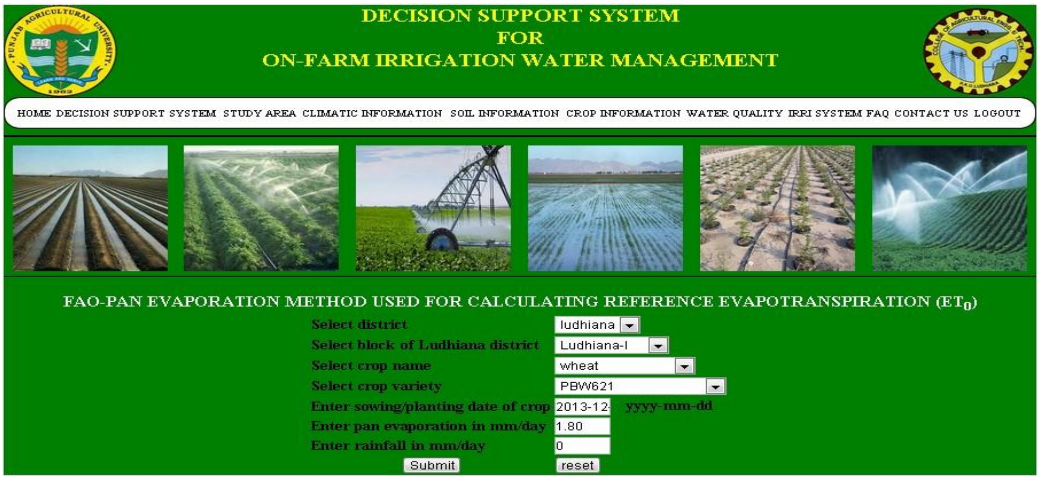
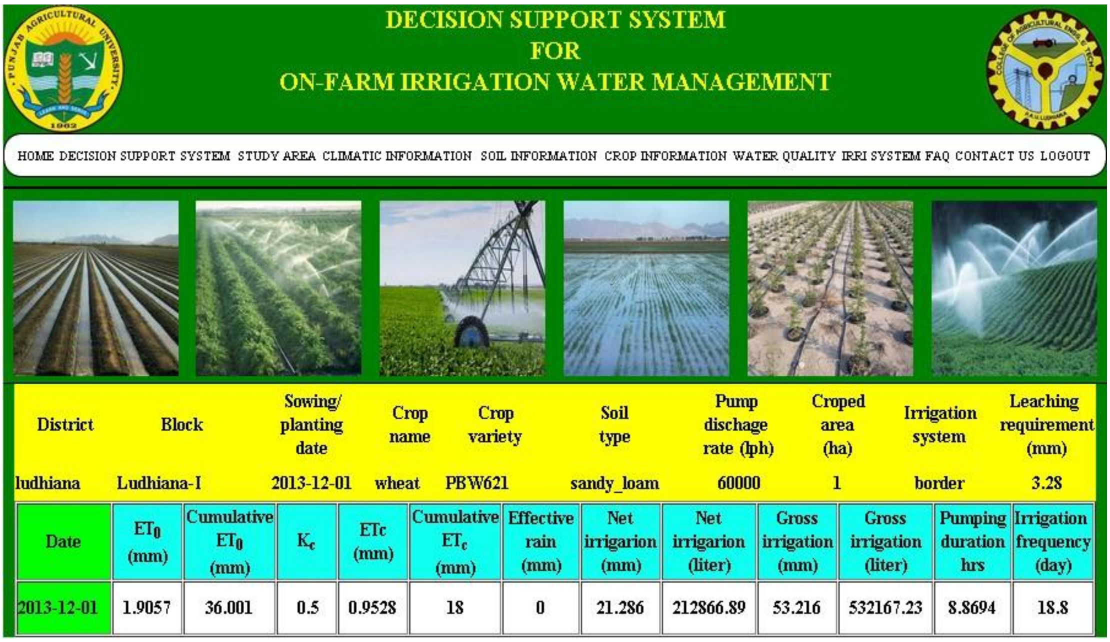


Fig. 5: Pan Evaporation inputs form

Fig. 6: Irrigation systems form

Fig. 7: Border irrigation systems inputs form



District	Block	Sowing/ planting date	Crop name	Crop variety	Soil type	Pump dischage rate (lph)	Croped area (ha)	Irrigation system	Leaching requirement (mm)
ludhiana	Ludhiana-I	2013-12-01	wheat	PBW621	sandy_loam	60000	1	border	3.28

Date	ET_0 (mm)	Cumulative ET_0 (mm)	K_c	ETc (mm)	Cumulative ET_c (mm)	Effective rain (mm)	Net irrigarion (mm)	Net irrigarion (liter)	Gross irrigation (mm)	Gross irrigation (liter)	Pumping duration hrs	Irrigation frequency (day)
2013-12-01	1.9057	36.001	0.5	0.9528	18	0	21.286	212866.89	53.216	532167.23	8.8694	18.8

Fig. 8: Output screen of border irrigation system

Sprinkler irrigation system input form

The webpage shown in Fig.9 gives details of inputs required in sprinkler irrigation system which are soil type, net cropped area, discharge rate of an sprinkler, spacing between sprinkler along the lateral, spacing between laterals along the sub-main lines, length of lateral and length of sub-main line. Output is shown in Fig. 10.

Drip irrigation system input form

The webpage shown in Fig.11 gives the details of inputs required in drip irrigation system, which are soil type, net cropped area, first irrigation depth, discharge rate of an drip emitter, wetting percentage, spacing between emitters along the lateral, spacing between laterals along the sub-main lines, length of lateral and length of sub-main line and output results shown in Fig. 12.

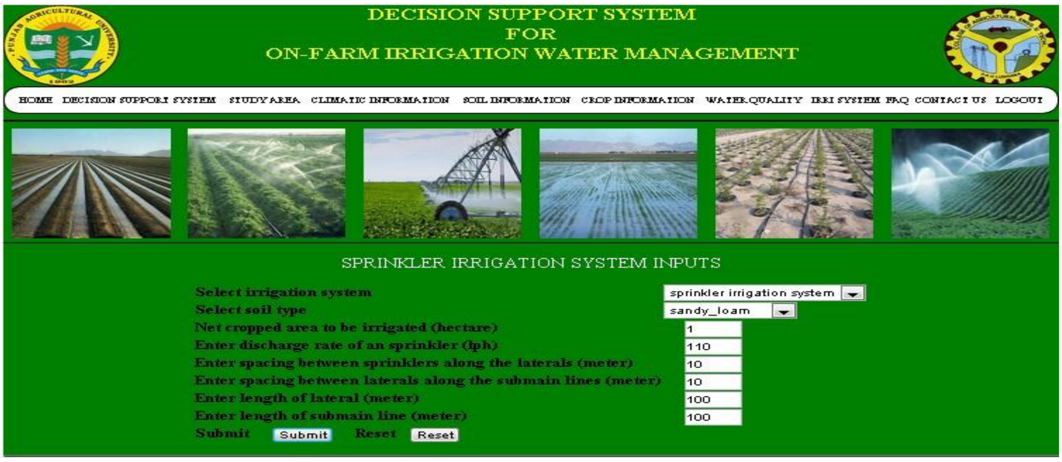


Fig. 9: Sprinkler irrigation systems inputs form

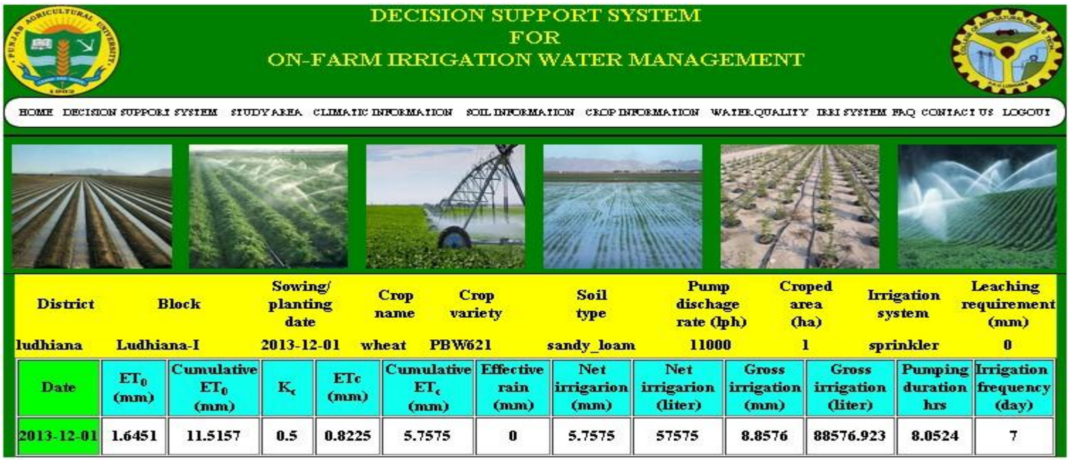


Fig. 10: Output screen of sprinkler irrigation system

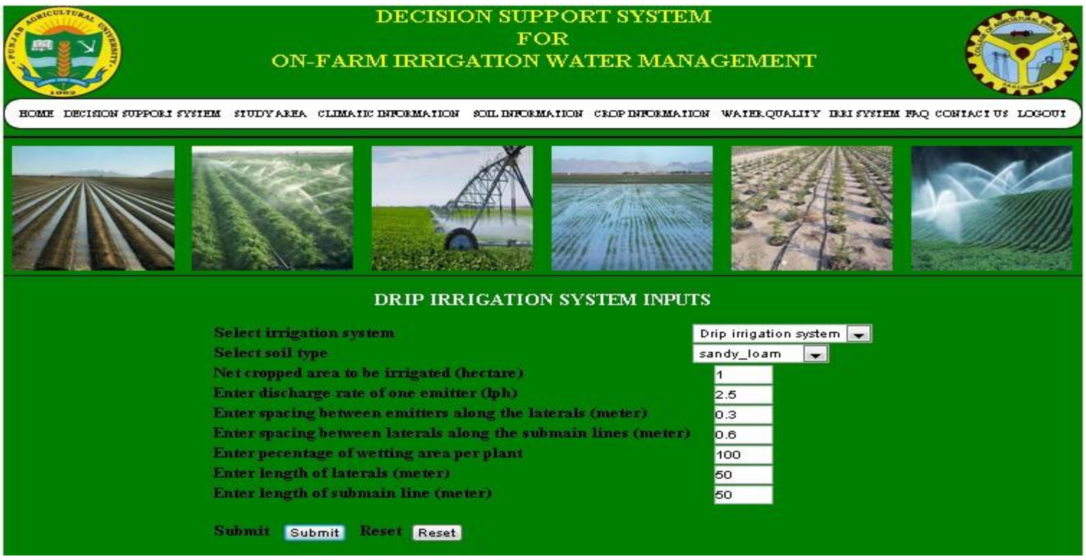


Fig. 11: Design of drip irrigation systems form

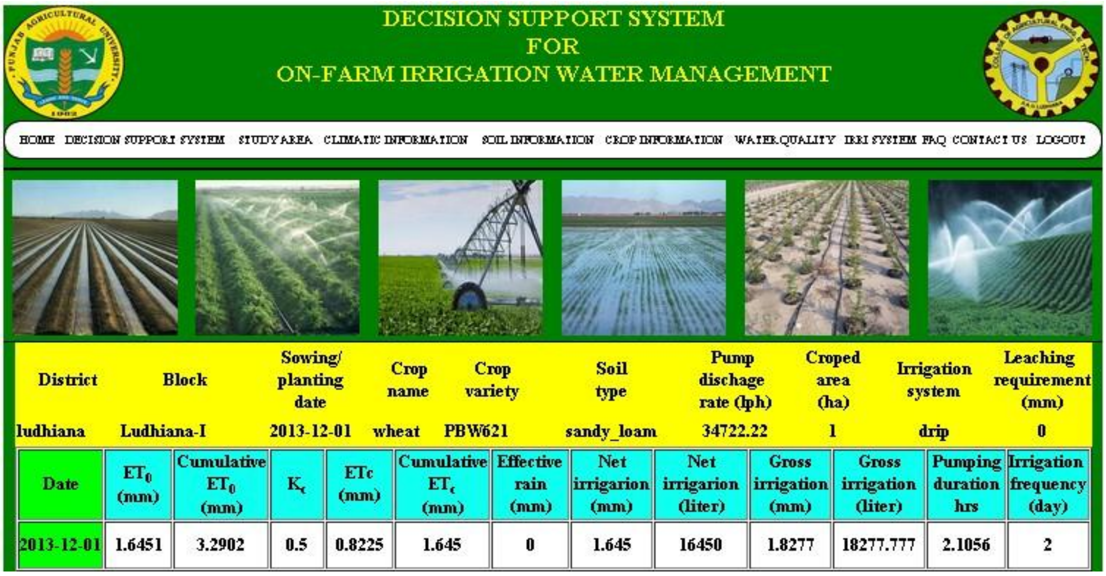


Fig. 12: Design of output screen of drip irrigation system

Decision Support System screen for user not having weather data

If user clicks on the 'user is not having weather data' on previous webpage then the new webpage opens called FAO Penman-Monteith input form as shown in Fig.13. This screen gives the details of inputs crop name, variety, sowing or planting date, block name and rainfall. The developed module estimate ET_o and ET_c as hidden output on the next form of irrigation systems.

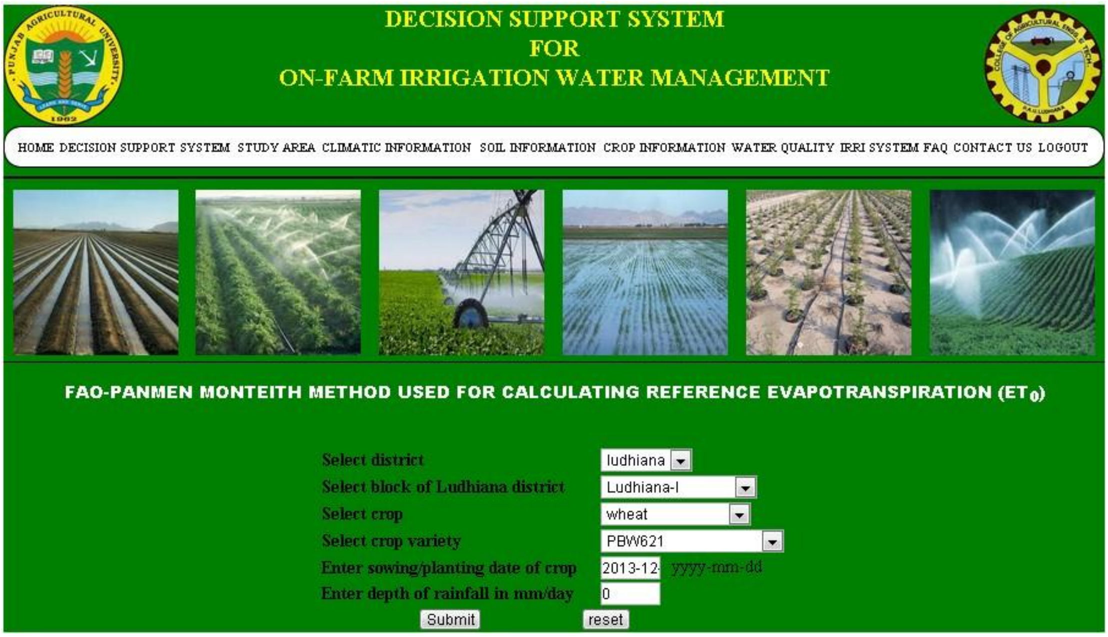
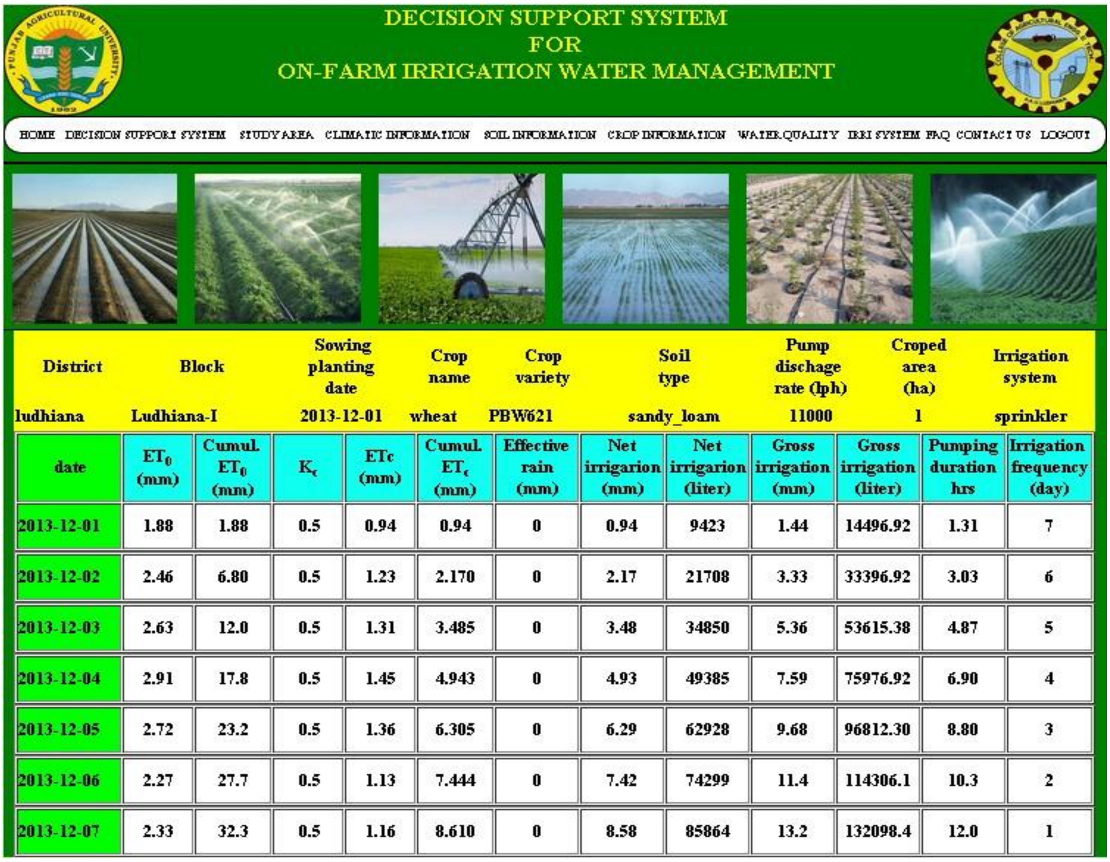


Fig. 13: FAO Penman-Monteith inputs forms

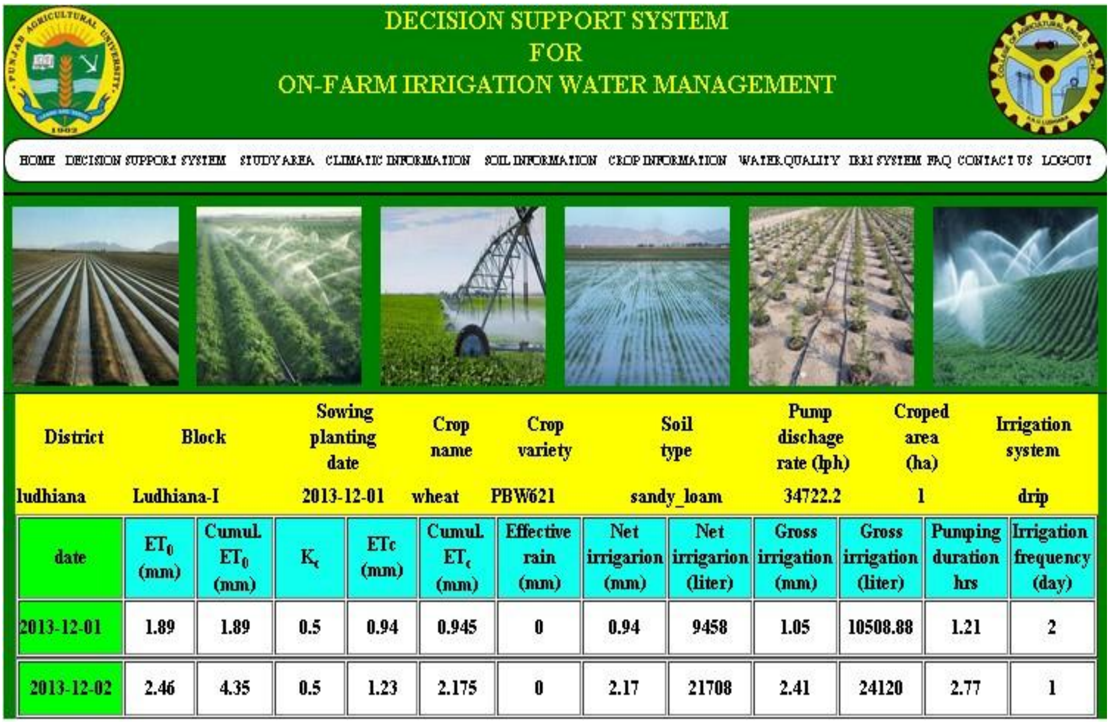
The estimated ETo and ETc are retrieved on this form from FAO Penman-Monteith. This webpage asks user to select any one of given irrigation systems, viz. border, sprinkler and drip system as shown above in Fig. 6. In border, sprinkler and drip irrigation system inputs required same as webpage shown above in Fig. 7, 8 and 9 respectively. The output results for sprinkler and drip are given on the basis of irrigation frequency and total ET_c during irrigation interval is shown in Fig. 14 and 15 respectively.



District	Block	Sowing planting date	Crop name	Crop variety	Soil type	Pump dischage rate (lph)	Croped area (ha)	Irrigation system
ludhiana	Ludhiana-I	2013-12-01	wheat	PBW621	sandy_loam	11000	1	sprinkler

date	ET_0 (mm)	Cumul. ET_0 (mm)	K_c	ETc (mm)	Cumul. ET_c (mm)	Effective rain (mm)	Net irrigarion (mm)	Net irrigarion (liter)	Gross irrigation (mm)	Gross irrigation (liter)	Pumping duration hrs	Irrigation frequency (day)
2013-12-01	1.88	1.88	0.5	0.94	0.94	0	0.94	9423	1.44	14496.92	1.31	7
2013-12-02	2.46	6.80	0.5	1.23	2.170	0	2.17	21708	3.33	33396.92	3.03	6
2013-12-03	2.63	12.0	0.5	1.31	3.485	0	3.48	34850	5.36	53615.38	4.87	5
2013-12-04	2.91	17.8	0.5	1.45	4.943	0	4.93	49385	7.59	75976.92	6.90	4
2013-12-05	2.72	23.2	0.5	1.36	6.305	0	6.29	62928	9.68	96812.30	8.80	3
2013-12-06	2.27	27.7	0.5	1.13	7.444	0	7.42	74299	11.4	114306.1	10.3	2
2013-12-07	2.33	32.3	0.5	1.16	8.610	0	8.58	85864	13.2	132098.4	12.0	1

Fig. 14: Output screen of sprinkler irrigation system



District	Block	Sowing planting date	Crop name	Crop variety	Soil type	Pump dischage rate (lph)	Croped area (ha)	Irrigation system
ludhiana	Ludhiana-I	2013-12-01	wheat	PBW621	sandy_loam	34722.2	1	drip

date	ET_0 (mm)	Cumul. ET_0 (mm)	K_c	ETc (mm)	Cumul. ET_c (mm)	Effective rain (mm)	Net irrigarion (mm)	Net irrigarion (liter)	Gross irrigation (mm)	Gross irrigation (liter)	Pumping duration hrs	Irrigation frequency (day)
2013-12-01	1.89	1.89	0.5	0.94	0.945	0	0.94	9458	1.05	10508.88	1.21	2
2013-12-02	2.46	4.35	0.5	1.23	2.175	0	2.17	21708	2.41	24120	2.77	1

Fig. 15: Output screen of drip irrigation system

The output results for border given on the basis of previous depth of irrigation applied and total ET_c during irrigation interval is shown in Fig. 16

District	Block	Sowing planting date	Crop name	Crop variety	Soil type	Pump dischage rate (lph)	Croped area (ha)	Irrigation system
ludhiana	Ludhiana-I	2013-12-01	wheat	PBW621	sandy_loam	60000	1	border

date	ET_0 (mm)	Cumul. ET_0 (mm)	K_c	ETc (mm)	Cumul. ET_c (mm)	Effective rain (mm)	Leaching (mm)	Net irrigarion (mm)	Net irrigarion (liter)	Gross irrigation (mm)	Gross irrigation (liter)	Pumping duration hrs	Irrigation frequency (day)
2013-12-01	1.88	1.88	0.5	0.94	0.94	0	0	0.94	9422	2.35	23555	0.39	18.0
2013-12-02	2.46	4.34	0.5	1.23	2.17	0	0	2.17	21707	5.42	54267.5	0.90	10.5
2013-12-03	2.62	6.96	0.5	1.31	3.48	0	0	3.48	34849	8.71	87122.5	1.45	7.50
2013-12-04	2.91	9.87	0.5	1.45	4.93	0	0	4.93	49384	12.3	123460	2.05	5.62
2013-12-05	2.72	12.5	0.5	1.36	6.29	0	0	6.29	62927	15.7	157317.5	2.62	4.70
2013-12-06	2.27	14.7	0.5	1.13	7.42	0	0	7.42	74298	18.5	185745	3.09	4.20
2013-12-07	2.33	17.0	0.5	1.16	8.58	0	0	8.58	85863	21.4	214657.5	3.57	3.69
2013-12-08	2.27	19.2	0.5	1.13	9.71	0	0	9.71	97159	24.2	242897.5	4.04	3.31
2013-12-09	1.43	20.6	0.5	0.71	10.4	0	0	10.4	104250	26.0	260625	4.34	3.23
2013-12-10	2.05	22.6	0.5	1.02	11.4	0	0	11.4	114270	28.5	285675	4.76	2.89
2013-12-11	2.38	24.9	0.5	1.19	12.5	0	0	12.5	125940	31.4	314850	5.24	2.61
2013-12-12	1.81	26.7	0.5	0.90	13.4	0	0	13.4	134070	33.5	335175	5.58	2.51
2013-12-13	2.42	29.1	0.5	1.21	14.6	0	0	14.6	146120	36.5	365300	6.08	2.27
2013-12-14	2.26	31.3	0.5	1.13	15.7	0	0	15.7	157300	39.3	393250	6.55	2.13
2013-12-15	1.93	33.2	0.5	0.96	16.6	0	0	16.6	166680	41.6	416700	6.94	2.04
2013-12-16	2.05	35.2	0.5	1.02	17.6	0	3.21	20.8	176290	44.0	440725	7.34	1.08

Fig. 16: Output screen of border irrigation system

Testing of Decision Support System

The DSS developed has backup link with PHP programming having updated weather data and hence the DSS can also be run without providing specific weather data inputs. The testing of DSS in absence of weather data was done by using the backup weather data for making the irrigation scheduling of wheat crop season for border, sprinkler and drip irrigation systems. The inputs given for running the DSS are shown in Table 2

Table 2: Common parameters used in irrigation scheduling

Parameters	**Inputs**	**Parameters**	**Inputs**
District	Ludhiana	Block	Ludhiana-I
Crop	Wheat	Variety	PBW 621
Soil type	Sandy loam	Sowing date	2011-12-12
Net cropped area	1 hectare	Irrigation systems	Border, Sprinkler, Drip
Border irrigation system inputs		**Sprinkler irrigation system inputs**	
Previous depth of irrigation (I_d)	75 mm	Discharge rate of an sprinkler	110 lph
Volume of bucket/ container	1000 liters	Spacing of sprinklers along the lateral and sub-main line	10 meters
Pumping time taken to fill up the tank	1 minute	Length of lateral and sub-main line	100 meters
Drip irrigation system inputs			
Discharge rate of an emitter	2.50 lph	Spacing of lateral along the sub-main line	0.6 meter
Spacing of emitters along the lateral	0.3 meter	Length of lateral and sub-main line	50 meter

Irrigation scheduling of irrigation systems

- For the border irrigation system results were computed using pump discharge rate of 60,000 lph, total no of predicted irrigation were 5, average volume of water and pumping time required per irrigation 7,31,901 liters and 12.20 hours respectively. It was resulted that in border irrigation system the DSS predicted irrigation on 13th Jan, 01st Feb, 05th, 15th and 31st March.
- For the sprinkler irrigation system results were computed using pump discharge rate of 11,000 lph, total no of irrigation predicted were 15, average volume of water and pumping time required per irrigation 1,42,265.61 liters and 13.83 hours respectively. It was resulted that in sprinkler irrigation system 37.58 % of water saving with respect to border irrigation system.
- For the drip irrigation system results were computed using pump discharge rate of 34,722.22 lph, total no of predicted irrigation were 54, average volume of water and pumping time required per irrigation 33,313.52 liters and 3.80 hours respectively. It was resulted that in drip irrigation system 50.84 % and 21.24 % of water saving in comparison to border and sprinkler irrigation system respectively.

CONCLUSION

The DSS was developed for on-farm irrigation water management to make the irrigation scheduling for border, sprinkler and drip irrigation systems for wheat, maize, potato and chilli crops. Overall, this research will be very helpful to the farmer to take the decision on when to irrigate and how much to irrigate for sustainable on-farm irrigation water management. Moreover, there is need to adopt the management strategies to minimize losses of irrigation water and crop yield at farm level.

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