Irrigation Scheduling through CROPWAT & WEAP software

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ABSTRACT

Adequate as well as well-timed water supplies corresponding to crop water requirement of a crop during its life span is central to the normal growth of a crop. This also means no reduction in crop produce ignoring other factors that influence crop yield. Correct assessment of crop water requirement under a prevailing climatic condition is an essential element in order to determine the amount of water required and timing of irrigation. The effect and the timing of water deficit on crop growth and yield are ordinarily governed by distribution/scheduling of available but limited water supply over growing periods of the crops, and prioritization of water supply amongst crops during the growing season. Crops undergoing stress at some interval tend to produce harvest that will fetch a lower price at the market. While water stress may negatively affect the crop, there are also negative effects of over-watering. Over-watered root crops tend to be tasteless or bland in flavour. In order to avert water stress setting in in a crop or a group of crops under command, and to realize rich produce at the end of crop season, a discreet irrigation scheduling aims at providing right amount of water to crops when it need the water the most. This paper seeks to elaborate and establish the strength of CROPWAT 8.0 and MABIA method on Water Evaluation And Planning (WEAP) software in preparation of irrigation scheduling for crops, and rapid evaluation of its impact on crop yield. In summary, both software are excellent soft tool, and aid irrigation engineers in their decision making process about when and how much to irrigate in order to achieve maximum benefit.

1. IRRIGATION SCHEDULING

Irrigation scheduling has been in practice primarily for regulating an optimum water supply for productivity, with soil water content always being maintained within the confines of readily available water (RAW) capacity. With availability of a few software such as CROPWAT and WEAP software, estimation of irrigation scheduling for an individual crop is no longer a weary and time intensive exercise for irrigation engineers. In this way, irrigation scheduling can be brought into the realms of use, or at most the refinement of existing practical applications can be thought of.

Of the two software reported above, CROPWAT 8.0 handles irrigation scheduling for each crop individually. Several factors govern varying schedule of irrigation for diverse crops, even if they are planted together. If a command is growing more than one crop with having a single source of irrigation, and also because of a few local factors, it may not be practical to adhere to irrigation schedule for every crop, as output by software. This calls for reaching a trade-off in defining a common schedule in a manner that no substantial loss of harvest arises. Evaluation of this altered schedule can be easily gauged in CROPWAT 8.0.

In contrast with CROPWAT, MABIA method in WEAP help user develop irrigation schedule for all crops together, and also permits the user to construct one or more scenarios away from initial condition. Aside from this, software outputs a number of tables and charts assisting the user to retain or modify input data.

This paper seeks to bundle the salient features of both tools in order to establish their merits over weary and time-intensive approach of computing crop water requirement, and determination of irrigation scheduling manually. To demonstrate rapid assessment of irrigation scheduling of wheat crop in this article, a set of data has been picked up from a study given to WALMI, Patna by CWC in order to estimate water use efficiency of Kamla Irrigation Project in Bihar. The altitude of command area is 70m, while its Latitude and Longitude are $26^{0}35'$ & $86^{0}10'$ respectively.

2. IRRIGATION SCHEDULING USING SOFT TOOLS

2.1. Application of CROPWAT 8.0

Computerized program can easily access databases for climate and crop characteristics to allow for speedy determination of irrigation water requirements. Computerized irrigation scheduling has enabled the use of real-time weather data from on-site weather stations to improve efficiency. In the event real data is unavailable, an indicative schedule can be worked out based on averaged climatic conditions experienced in the study area for a significant length of time. Despite this, it is equally important to appreciate that irrigation scheduling program are no better than the data used or the ability of the user to interpret the output.

The Food & Agricultural Organization (FAO) CROPWAT model for irrigation scheduling offers the possibility to:

- Design an indicative irrigation schedules, and its impact over yield;
- Evaluate field irrigation program in terms of efficiency of water use and yield reduction
- Simulate field irrigation program under water deficiency conditions, rain-fed conditions, supplementary irrigation, etc.

2.1.1 Data required

To work out irrigation scheduling, the CROPWAT 8.0 demands data on reference crop evapo-transpiration, rainfall, crop data and soil data to be input in the program. This is facilitated by a number of windows that pop up one after another to let user feed a particular set of data.

Reference Crop evapo-transpiration, ET_0: This is defined as the daily water needs of a reference crop adequately watered and pest-free. CROPWAT computes ET_0 by applying Penman Monteith method- a method recommended by FAO, and is claimed to offer consistent result as compared to other methods used for identical purpose. As is referred to in para 1, Figure 1 holds climatic data related to project site under Kamla Irrigation Project.

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\jayanagr....

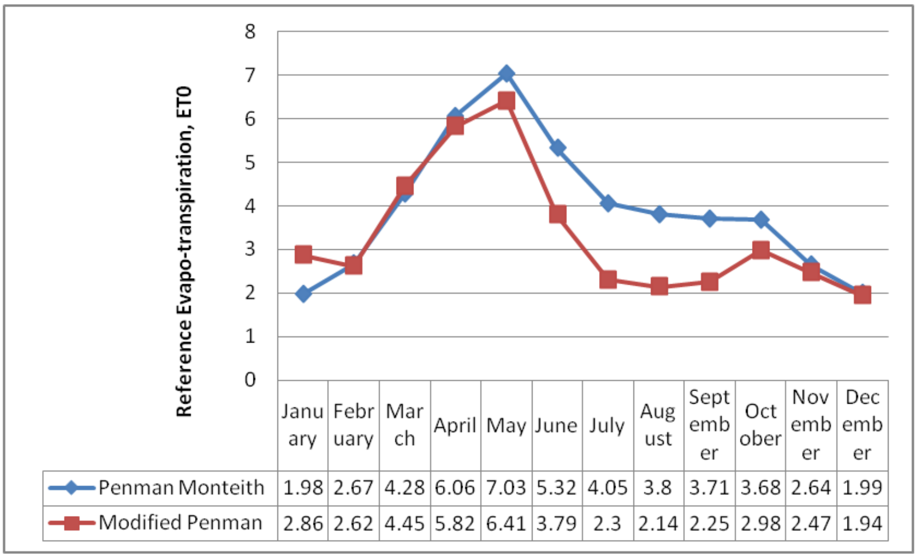
Country India Station Jayanagar, Bihar

Altitude 70 m. Latitude 26.58 °N Longitude 86.17 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	fraction	MJ/m?/day	mm/day
January	10.0	23.6	72	0.5	0.77	14.8	1.98
February	11.6	25.9	62	0.6	0.80	17.9	2.67
March	16.3	31.7	46	1.0	0.85	22.1	4.28
April	21.3	35.9	44	1.6	0.80	24.2	6.06
May	24.7	36.4	55	2.3	0.81	26.1	7.03
June	24.7	34.5	71	2.1	0.50	20.3	5.32
July	26.0	32.4	80	1.9	0.30	16.1	4.05
August	26.2	32.1	81	1.7	0.32	15.5	3.80
September	25.8	32.2	78	1.3	0.40	15.4	3.71
October	22.3	31.4	72	0.7	0.75	18.0	3.68
November	15.2	28.7	70	0.3	0.85	16.3	2.64
December	10.8	25.2	75	0.3	0.85	14.8	1.99
Average	19.6	30.8	67	1.2	0.67	18.5	3.93

Figure 1 Computation of ETo by Penman Monteith method

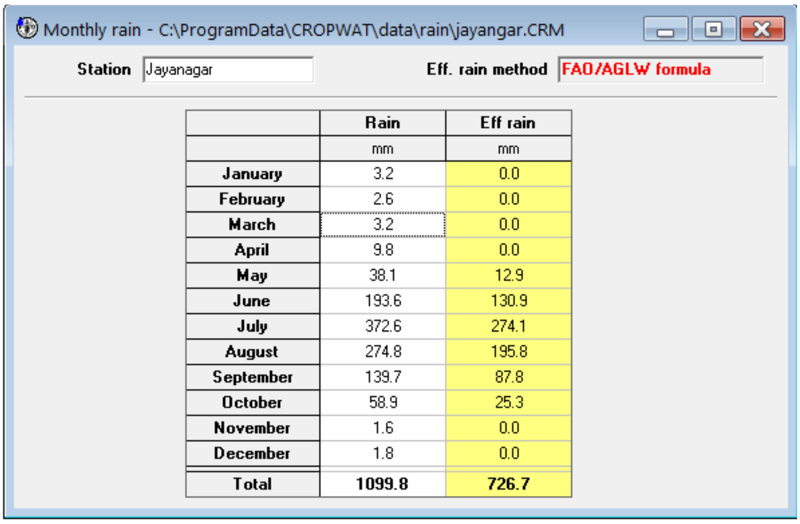
Figure 2 depicts a chart showing the variation in reference evaporation across the year computed by application of both Penman Monteith and Modified Penman methods. As is observed from the chart, values obtained by both methods don't agree with each other particularly during monsoon period where spread between two curves is quite distinct, while both are more or less identical particularly during rainless period. This kind of study can be extended to other part of the country before one can arrive at a definite conclusion.



	January	February	March	April	May	June	July	August	September	October	November	December
Penman Monteith	1.98	2.67	4.28	6.06	7.03	5.32	4.05	3.8	3.71	3.68	2.64	1.99
Modified Penman	2.86	2.62	4.45	5.82	6.41	3.79	2.3	2.14	2.25	2.98	2.47	1.94

Figure 2 Comparison between Penman Monteith & Modified Penman Methods

Rainfall: Depending on the objective of the irrigation scheduling, monthly rainfall averages, rainfall at different levels of probability, historical data or actual data are used in the analysis. A complex issue involved in the process is to determine the fraction of rainfall that contributes toward building of soil moisture content. CROPWAT lets the user to choose among a couple of options to model their study. Availability of rainfall data as well as data for climatic parameters considered in Figure 1 for sufficient length is scarcely observed in majority of cases. CLIMWAT 2.0, developed by FAO holds climatic data across India for determination of ET0 by Penman Monteith method. A facility is available for export of data from this software to CROPWAT 8.0. To download this software, reader may wish to visit http://www.fao.org/nr/water/infores_databases_climwat.html/ . In the current study, FAO recommended formula has been chosen to determine effective rainfall.


Monthly rain - C:\ProgramData\CROPWAT\data\rain\jayangar.CRM

Station: Jayanagar   Eff. rain method: FAO/AGLW formula

	Rain	Eff rain
	mm	mm
January	3.2	0.0
February	2.6	0.0
March	3.2	0.0
April	9.8	0.0
May	38.1	12.9
June	193.6	130.9
July	372.6	274.1
August	274.8	195.8
September	139.7	87.8
October	58.9	25.3
November	1.6	0.0
December	1.8	0.0
Total	**1099.8**	**726.7**

Figure 3 Estimation of Effective Rainfall

Crop data: A range of data such as crop coefficient, K_c; rooting depth; length of plant growth stages; planting date; and allowable depletion are required to be keyed for each crop in the software. Furthermore, in order to assess the effect of water stress on yield, the yield response factor valid for each growth stage is also required. This factor is also not alike for crops. FAO manual 56, which may be downloaded from http://www.kimberly.uidaho.edu/ref-et/fao56.pdf , contains K_c for a variety of crops for their various stages of growth. A different K_c value for a crop is possible for consideration, if it is supported by local research.

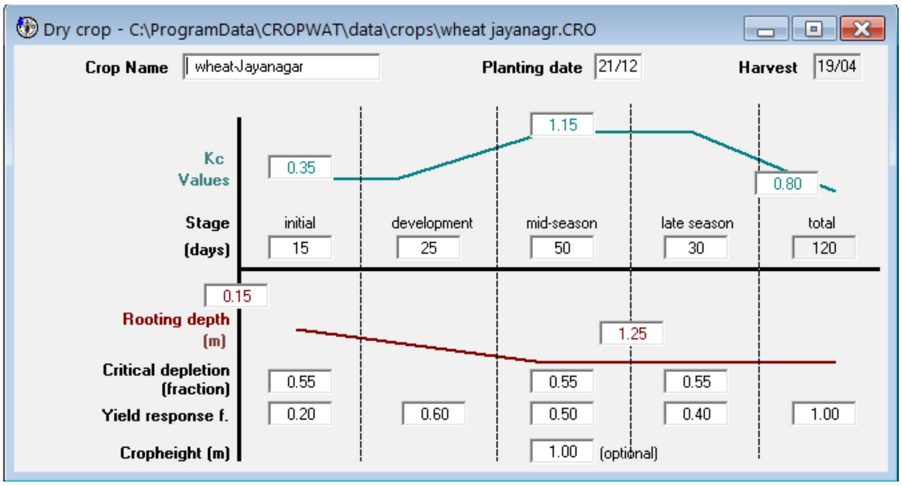


Figure 4 Defining Crop Characteristics

Soil data: The soil parameters important for irrigation scheduling and required for irrigation scheduling using the FAO CROPWAT programme are elaborated below:

- Total available soil moisture content (SMta), defined as the difference in soil moisture content between field capacity (FC) and wilting point (PWP). This is the total amount of water available to the crop and depends on texture, structure and organic matter content;
- Initial soil moisture depletion indicates the dryness of the soil at the beginning of irrigation. This is expressed as a depletion percentage from FC;
- Maximum rooting depth will in most cases be determined by the genetic characteristics of the plant. In some cases the root depth can be restricted by limiting layers of soil;
- Maximum rain infiltration rate allows for an estimate of the surface runoff for the effective rain calculation. This is a function of rain intensity, soil type and slope class

Presence of sand, silt, and clay in various proportions determines the type of soil, and its moisture holding capacity. In absence of local data, soil moisture capacity from Figure 5 may be used for analysis while entering it into CROPWAT using window at Figure 6.

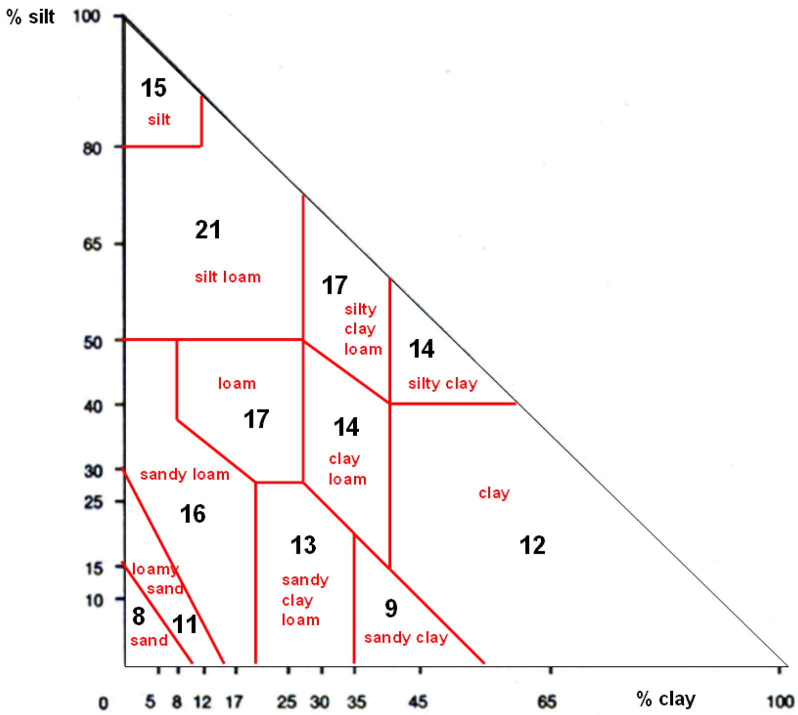


Figure 5 Available Water Capacity as per FAO soil texture class

Predominant soil in the command area is of Silty Clay Loam, and accordingly its soil moisture holding capacity is fed in the software. Additionally, it is assumed that soil moisture at the beginning of crop grow is zero in order to account for initial irrigation required to prepare the soil before seeds are dispersed in the field.

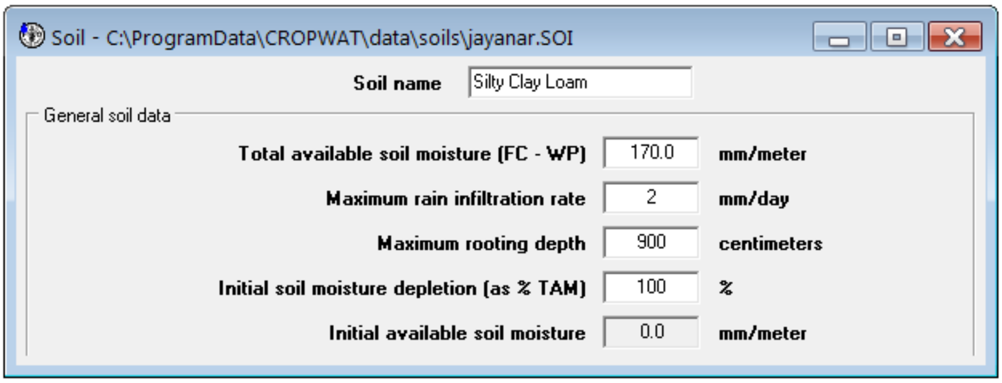


Figure 6 To Define Soil Moisture Retention Capacity

2.1.2 Irrigation scheduling options

CROPWAT allows a range of options, depending on the objective of the user and the design restrictions that the irrigation system imposes. The scheduling options refer to two different categories:

• Timing options – related to WHEN irrigation is to be applied- A screenshot of CROPWAT software depicts the irrigation timing option available therein. User basing on constraints imposed by water availability at the source can elect most appropriate choice among them and evaluate its impact on the yield and other losses.

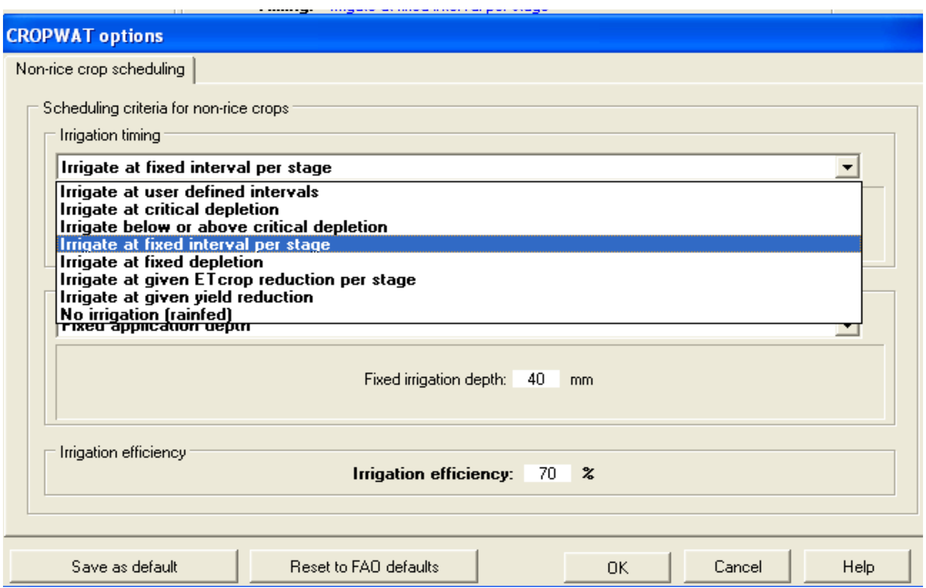


Figure 7 Irrigation Scheduling Option

• Application options – HOW MUCH water is to be given per irrigation turn- Here too software offers multiple options to choose for yield analysis. Additionally, user can also modify irrigation efficiency according to the method of irrigation practiced in the region.

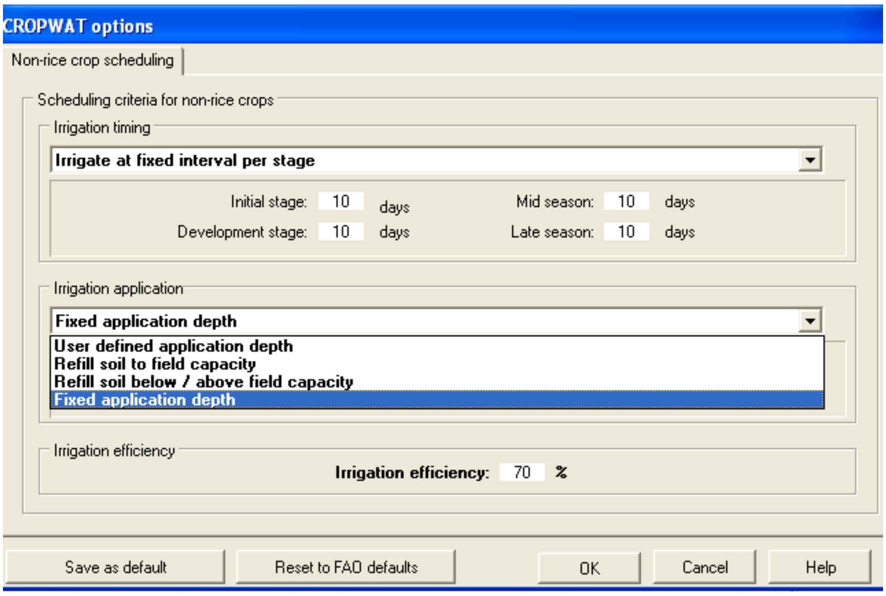


Figure 8 Irrigation Scheduling Option

2.1.3 Example - Irrigation Scheduling for Wheat crop

With that all relevant data, as listed in the preceding paragraph, keyed in the CROPWAT 8.0, and electing most favoured option, i.e. irrigation at critical depletion stage in a manner that soil regains its moisture upto 'Field Capacity', irrigation schedule for wheat crop is shown in Figure 9 with yield reduction as 0.2%. Other losses associated with current choice of irrigation schedule are displayed in the lower half of this figure.

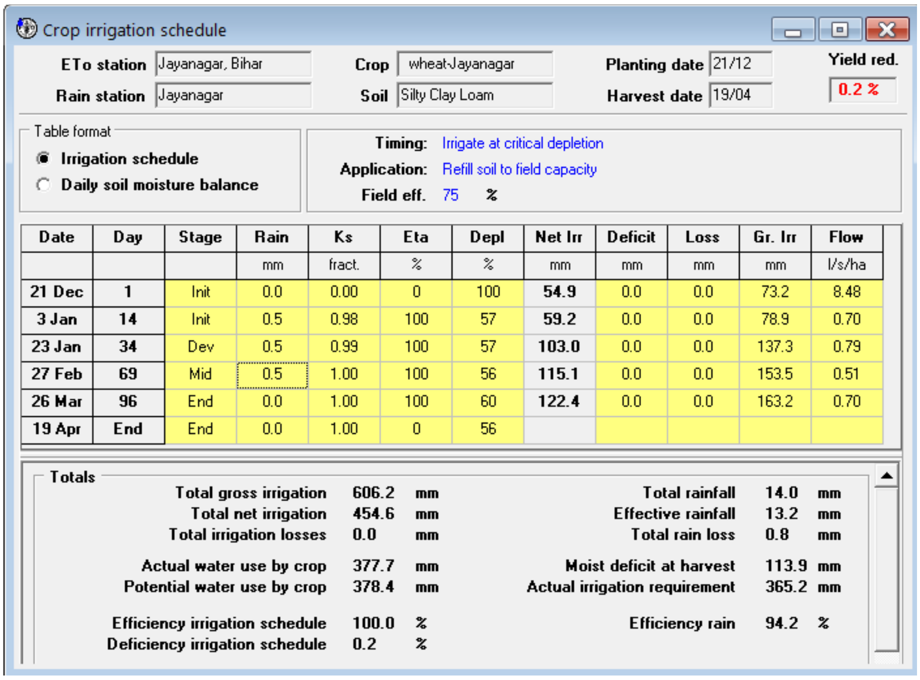


Figure 9 Schedule with no stress in the crop.
This implies that moisture level has never dipped below the zone of RAW.

CROPWAT also generates a visual aid, as reflected in Figure 10, depicting the variation in soil moisture depletion over the life span of the crop, and how software triggers the irrigation upto field capacity when moisture level reaches the RAW every time.

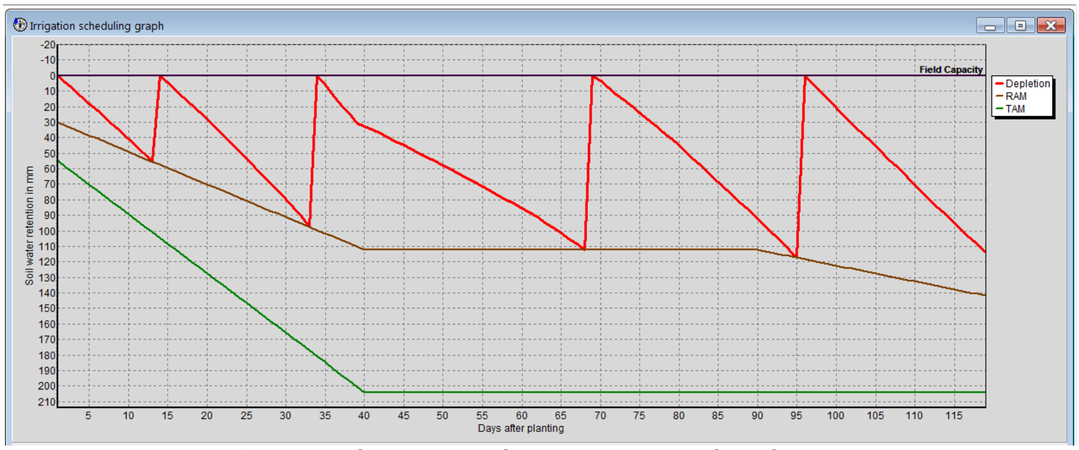


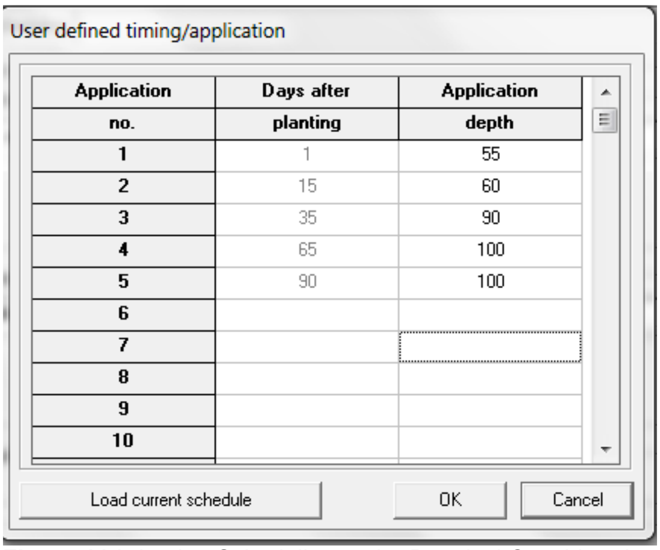
Figure 10 Soil Moisture Swing over various Crop Stages

Where a combination of crops is grown simultaneously in a farm, Irrigation schedules for individual crops can be determined by similar steps illustrated above. However, in order to accommodate timely water application for one crop, a compromise needs to be made by departing from irrigation schedule by a day or more in case of others crops. Consequently, the departure from ideal condition brings down produce differently for different crops. In such a scenario, common and monthly schedule is best option amalgamating the water need of various crops and optimizing the yield from the farm. In doing so, the crop that fetches more money in the market should be given priority. This exercise has to be finished separately and manually.

Simplifications thus introduced make the schedule practical and 'user-friendly' for the farmers. A pre-defined irrigation schedules for the rest of the month immensely help farmers organize their work, household activities accordingly.

The rainfall can be considered at the time the irrigation schedule is applied. By using a rain gauge and by recording the amount of rainfall on a daily basis, a number of days are skipped, depending on the amount of rainfall, the daily water requirements and the moisture to be replenished in the root zone depth of the soil.

In the backdrop of this discussion, if the farm schedule indicates irrigation frequency and a fixed application depth as shown in Figure 11, its impact on the yield can easily be evaluated by CROPWAT 8.0 as above; which is around 1.1%. Additionally, the former schedule arrangement demonstrates efficiency irrigation schedule as 100%, the latter also indicating the same as in either case, water has never been delivered over and above field capacity level.


User defined timing/application

Application no.	Days after planting	Application depth
1	1	55
2	15	60
3	35	90
4	65	100
5	90	100
6		
7		
8		
9		
10		

Load current schedule OK Cancel

Figure 11 Irrigation Scheduling under Practical Consideration

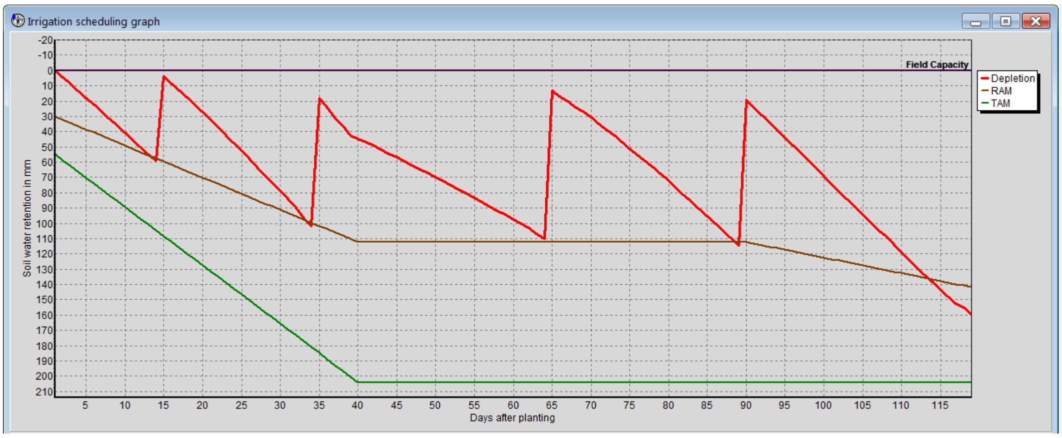
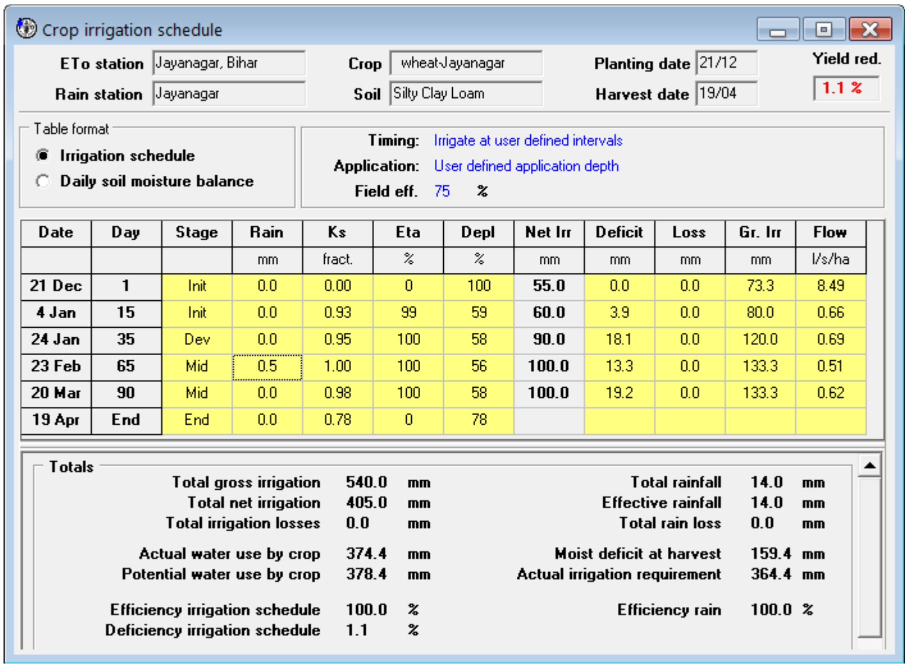


Figure 12 Altered Irrigation Schedule more practical than previous one


Crop irrigation schedule

ETo station: Jayanagar, Bihar | Crop: wheat-Jayanagar | Planting date: 21/12 | Yield red.: 1.1 %
Rain station: Jayanagar | Soil: Silty Clay Loam | Harvest date: 19/04

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at user defined intervals
Application: User defined application depth
Field eff. 75 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
21 Dec	1	Init	0.0	0.00	0	100	55.0	0.0	0.0	73.3	8.49
4 Jan	15	Init	0.0	0.93	99	59	60.0	3.9	0.0	80.0	0.66
24 Jan	35	Dev	0.0	0.95	100	58	90.0	18.1	0.0	120.0	0.69
23 Feb	65	Mid	0.5	1.00	100	56	100.0	13.3	0.0	133.3	0.51
20 Mar	90	Mid	0.0	0.98	100	58	100.0	19.2	0.0	133.3	0.62
19 Apr	End	End	0.0	0.78	0	78					

Totals

Total gross irrigation	540.0	mm	Total rainfall	14.0	mm
Total net irrigation	405.0	mm	Effective rainfall	14.0	mm
Total irrigation losses	0.0	mm	Total rain loss	0.0	mm
Actual water use by crop	374.4	mm	Moist deficit at harvest	159.4	mm
Potential water use by crop	378.4	mm	Actual irrigation requirement	364.4	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	100.0	%
Deficiency irrigation schedule	1.1	%			

Figure 13 Impact on Yield

A slight fall in yield in latter case is can be attributed to soil moisture diving below RAW in the late season stage of the crop. A prudent Irrigation scheduling so determined demonstrate the application of this software in arriving at most practical scheduling within bounds of practical constraints with negligible impact on overall harvest.

2.2 Irrigation Scheduling through MABIA on WEAP software

Water Evaluation & Planning (WEAP) Software is an excellent tool available to engineers to optimize the distribution of available water, and to assess the impact of fluctuation in water availability scenario under climate change, or for that matter any other overriding reasons that may bring about alteration in catchment characteristics. For more details, and to download this software, please visit http://www.weap21.org/

MABIA method on WEAP software is a dual crop coefficient approach to work out crop water requirement. This approach, unlike a single Kc value as used in CROPWAT 8.0, defines two components, Ke, to account for evaporation losses, and Kcb, basal coefficient to count transpiration losses from crop (Figure 14). This method is considered more advanced one in that even if transpiration from crop is at its peak, evaporation losses from exposed soil around the crop may swing between zero to a maximum value according to the degree of wetness of soil.

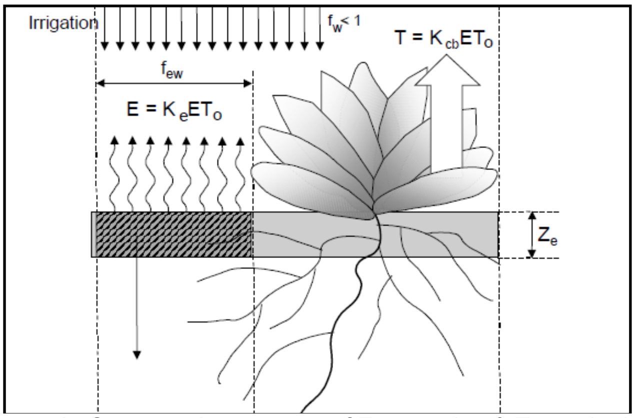


Figure 14 Separate Assessment of Evaporation & Transpiration

The benefit of using this software over CROPWAT 8.0 is enumerated next:

- It considers more advance approach of estimating crop water requirement on daily basis for a study area. This apart, software keeps a track on daily variation of humidity and wind velocity and readjusts K_{cb} of a crop if humidity and wind speed differs from 45% and 2m/sec respectively. Equation used in computation of K_{cb} appears below:

$$K_{cb} = K_{cb\,(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}$$

- This software allows for developing and comparing a series of scenario that deviates from ideal field condition, and thus enable its users to select that works the best for them;
- In addition to analyzing reduction or gain in produce because of alteration in irrigation scheduling, user can also watch fluctuation in market value of the harvest;
- Data requirement to define variety of crops and soil as per FAO guidelines is readily available on this medium, and user can use the same or modify it, if credible evidence, based on local research, suggests otherwise;
- In the event of non-availability of soil properties such as FC, and WP, a number of pedo-transfer functions developed on the basis of observed data are available to generate these values;
- WEAP offers excellent flexibility in analysis and presentation of data for better comprehension and its appreciation by decision makers.

2.2.1 Data required

Table 1 summarizes the data required preferably on daily basis to compute daily crop water requirement and also to schedule irrigation. In majority of cases, availability of daily data is a major concern. To overcome this constraint, WEAP offers a couple of options to choose for disaggregation of monthly climatic parameters into daily basis. Nevertheless, user should be able to distinguish the pattern of this new set of disaggregated values which may vary from actual pattern. Upon noticing any abnormal pattern, the same needs to be attended beforehand.

Table 1 Data Required for MABIA Method

CLIMATE	CROP	SOIL	IRRIGATION
Rainfall	K_{cb}	Soil Type	Types
Humidity	Planting Date	Saturation capacity	Efficiency
Wind speed	Length of Each Stages	Field Capacity	
Minimum Temperature	Critical Depletion Factor	Wilting coefficient	

Maximum Temperature	Rooting depth	Coarse Fragments	
Sunshine hours	Crop Height		
	Yield Stress Factor		
	Infiltration Rate		

2.1.3 Example - Irrigation Scheduling for Wheat crop using WEAP

An illustration of irrigation scheduling with the help of data available for Kamla Irrigation Project showcases the strength of WEAP software. To construct Kamla Irrigation Project model, Kamal river network shape file was first develop using ASTER DEM, and the same was imported in the WEAP (Figure 15). Software has capacity to export this model along with outputs as per choice of user to Google Earth platform for its better appreciation and visualization.

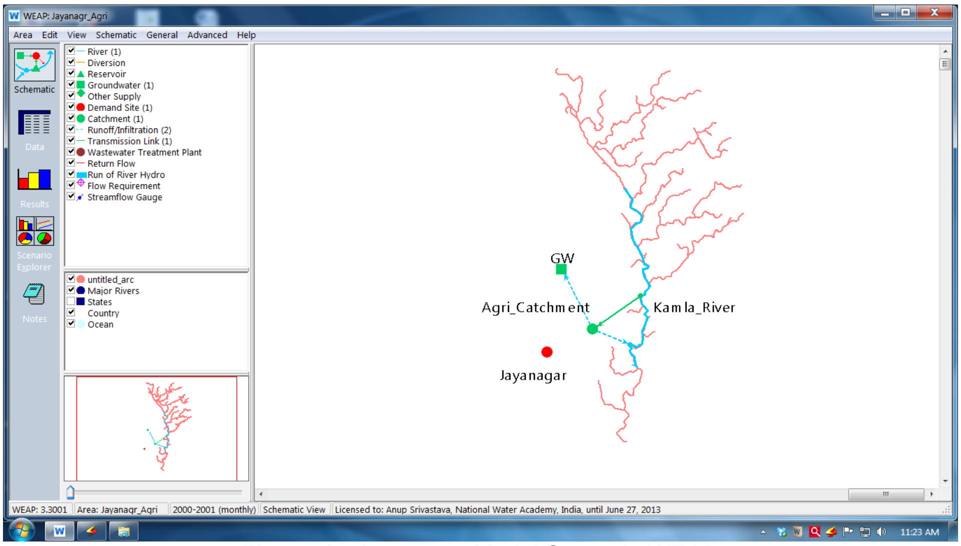


Figure 15 Jayanagar Model Set-up in WEAP

Like CROPWAT 8.0, this software, as shown in Figure 16, permits user to set timing and amount of irrigation crop-wise.

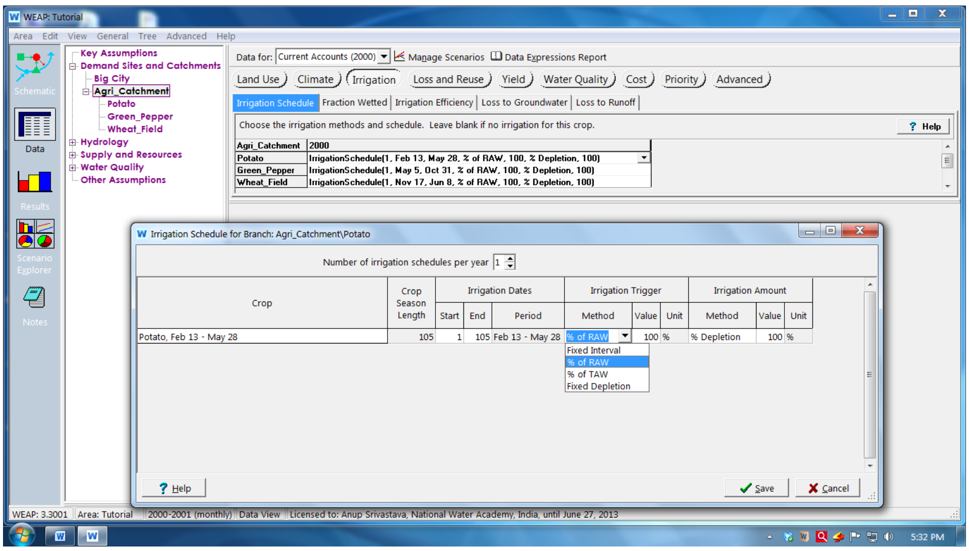


Figure 16 When & How Much to Irrigate

Two screenshots that follow this paragraph in Figure 17 & 18 underline the impact of alteration in irrigation scheduling. In the preceding one, reader may notice that moisture depletion has never dipped below RAW (Readily Available Water) as user has opted for irrigation when moisture level reaches the RAW, and during the process of watering, the amount of irrigation added is upto FC level. With Dual Crop coefficient approach, number of irrigation reduces to four with large interval between second and third irrigation. Additionally, volume of water required to meet crop water requirement is now assessed at around 380mm as against 454mm obtained with application of single crop coefficient method.

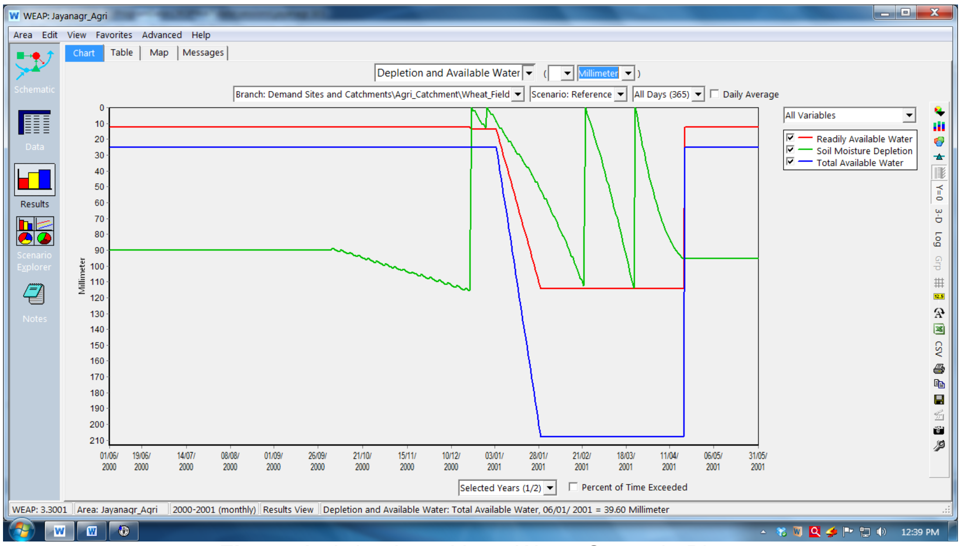


Figure 17 Irrigation with no Water Stress in Plant

WEAP allows the user to generate a variety of scenarios each representing different set up of model parameters which are likely to change over the years because of several reasons. The reason could be from change in cropping pattern to variation in the climatic condition. Under each scenario, modeller can evaluate the combined impact of all such reasons on total production or indicative irrigation scheduling devised earlier. Figure 18 highlights movement of moisture level below the RAW – a stage where crop grows in stressed condition leading to decline in produce.

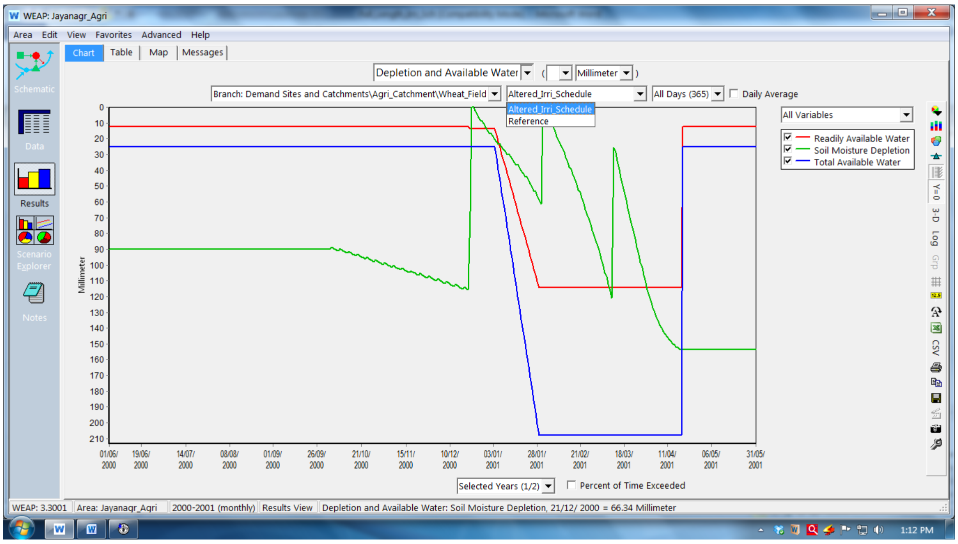


Figure 18 Induced Stress in Plant because of poor Irrigation Scheduling

A departure from standard irrigation schedule where moisture stress is permitted to set in is bound to impede normal growth of the plant, and hence fall in harvest. WEAP allows the user to create these two scenario side by side, and offers user a visual as well as tabular aid to assess the impact of his/her selection of irrigation scheduling. Next two screenshots at Figure 19 & 20 compare the drop in produce as well as its impact over market value the crop will earn. First bar on the left indicates produce and market value under stressed condition while the higher one when there is no stress in the crop.

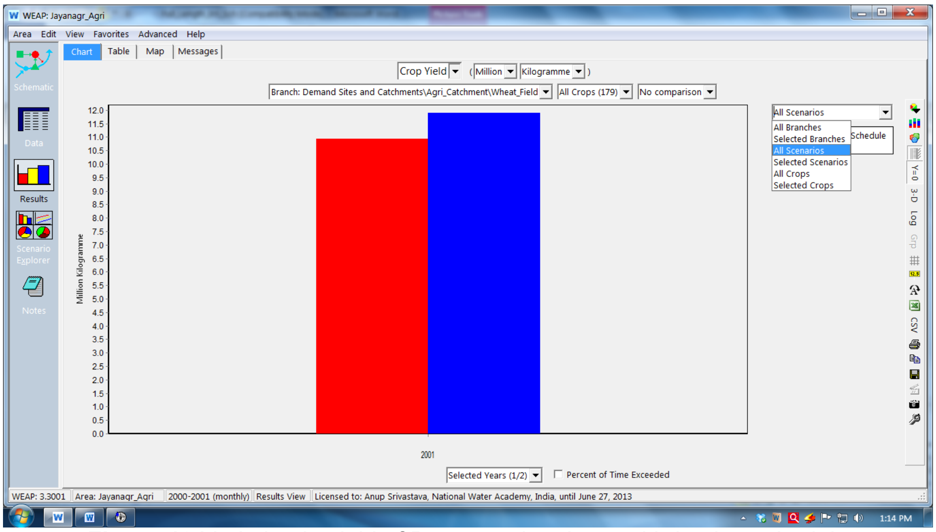


Figure 19 Variation in yield of Potato under changed irrigation schedule

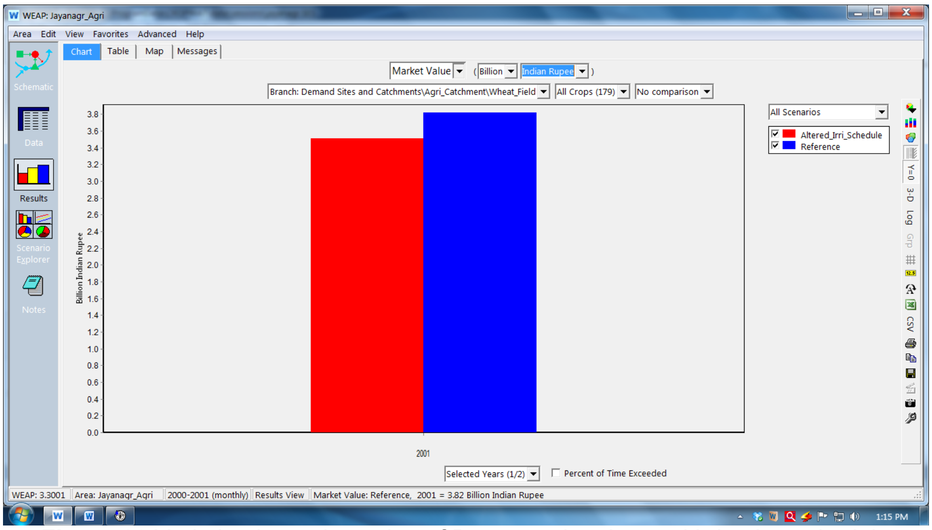


Figure 20 Variation in market value of Potato under changed irrigation schedule

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