Irrigation Scheduling under High Efficiency (Pressurized) Irrigation Systems

Mumtaz Awan¹, Shehzad Ahmad², Ali Ajaz³

- 1- Project Agronomist, National Engineering Services Pakistan (NESPAK)
- 2- Design Engineer, National Engineering Services Pakistan (NESPAK)
- 3- Assistant Design Engineer, National Engineering Services Pakistan (NESPAK)

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Project Agronomist

Shehzad Ahmad
Design Engineer (HEIS)

Ali Ajaz
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PREFACE

This is, indeed, highly gratifying to observe that high efficiency irrigation systems have established their worth with the farming community in Punjab and their acceptance is accelerating on day to day basis. The benefits of these HEISs have been experienced pragmatically by the beneficiaries and their interviews reveal that substantial savings in water, fertilizers, pesticides specially the weedicides, energy and labor have been realized on most of the same. As a result extensive installation of drip and sprinkler irrigation systems under [REDACTED] is in progress which, indeed, is helping in combating with shortage of irrigation water in the country on one hand and is proving effective in bringing the yield levels of crops of the country at par with the world standards on the other. Their affectivity, however, largely depends upon accurate scheduling of irrigation through the same and a definite rise in their efficiency may be accrued through proper monitoring of the schedules both with respect to their preparation as well as their implementation.

Since HEISs are relatively a new intervention in Pakistan, there exists a dearth of relevant printed material regarding various operational aspects of the systems especially in relation to preparation of fertigation, irrigation and chemigation schedules. Perhaps, the most critical and the most wanted facet of these newly introduced systems is the preparation of proper irrigation schedules for various crops being grown in their command. In addition, the training of project staff and the users of the systems regarding these schedules covering their understanding and implementation in the field appears to be a missing link. A fair analysis of the factors leading to such gaps reflects that lack of technical material on the subject is the primary reason

The effort made by PSC in the form of this manual is expected to serve the purpose in question. Solved examples of preparation of schedules for a number of crops have been added to give an in depth orientation to the reader. Through requisite review of this manual, it will not only be possible to check and monitor the irrigation schedules supplied on some of the sites by the SSCs for their authenticity and accuracy but it will also enable the project staff especially the HEIS teams to prepare and provide the same at the farms/sites without these schedules on instant basis.

1 INTRODUCTION

Improvement in crop production cannot be ascertained without adoption of advanced management practices. If all the inputs required for improved yields are managed on the basis of latest economic principles and focus is made on taking up the entire agricultural enterprise on commercial footings, it may be firmly envisaged that a production level at par with the international standards may be achieved without any qualm and apprehension. Handsome research has been carried out regarding each input and clues have been determined which have brought significant developments in the area of desired objectives. Irrigation is one of the major inputs which like other ones, has attracted considerable attention of the researchers. Resultantly, highly effective and comprehensive aspects of this input have been unveiled especially with reference to soil-plant-water-atmosphere relationships.

An advanced method of irrigation must ensure that there is neither over irrigation which brings the soil often to saturation point completely eliminating the oxygen from the root zone nor under irrigation which often renders the soil moisture down to a level where ionic absorption of nutrients is impeded. Both of these physiological stresses adversely affect the plant growth and drag it to a position where in the reduction in yield below its potential becomes a natural end result. High Efficiency Irrigation Systems, especially the drip irrigation, have made this breakthrough and have proven to be the ideal methods. In addition to protecting the plants from any physiological stress, these help in ample saving of energy, economize labor, facilitate optimum application of nutrients and significantly reduce the incidence of weeds infestation. These have, virtually, made it possible to apply correct amount of water to the plants at exact time. Accordingly, the crop does not face any shortage of water or air or nutrients throughout its period of growth and this helps in hitting the potential both in yield as well as quality of production. This is, however, to be kept in view that the efficiency of HEISs depends primarily upon appropriate irrigation scheduling. If the time of application of water does not synchronize with the crop water requirement in exact accordance, certainly the efficiency of the system will go to adverse. In case the application time is higher than the requirement, both irrigation water and the energy will be wasted and in case the irrigation has been scheduled for a time span lesser than the requirement, it will result in reduction of the yield and wastage of resources. It is, therefore, highly important that after installation of the HEISs, not only their apposite irrigation schedules are prepared but the same are implemented with extreme care also so that the desired and expected benefits of these systems may be accrued in letter and spirit.

Irrigation Scheduling deals with application of irrigation water to a crop at the right time in the right amount. In other words, it focuses upon when to irrigate a crop and how much water to apply during each irrigation. The significance of this parameter of crop production is revealed from the fact that full potential of any crop cannot be hit unless scheduling of irrigation water is made in such a way that the crop never faces its shortage throughout its period of growth. Under conditions of low water availability, not only the absorption or ionic uptake of nutrients is held back but many other physiological processes in the plant cells get impeded also which ultimately lead to low yields. Contrarily, over irrigation proves detrimental in a number of ways

as it blocks the availability of oxygen to the roots, it leads to leaching of valuable nutrients down to the zone below root level and results in wastage of water as well energy.

It, therefore, becomes vital that irrigation of a crop is managed in such a way that an optimum moisture level is maintained in the root zone to effectively fulfill the needs of the plants throughout the period of their demand and this is possible only through proper irrigation scheduling.

2 METHODS OF IRRIGATION SCHEDULING

Several methods have been devised by the irrigation experts to determine proper time of applying irrigation to a crop and estimating the volume of water to be applied at each irrigation. All of these can be categorized in three broad groups.

2.1 Soil - related Methods

This group includes approaches through which the soil contents are estimated in terms of percentage of water or in terms of tension for moisture that is existing in the soil compared to the level of moisture at its field capacity and the irrigations are scheduled on the bases of this percentage or tension. Methods such as Feel and Appearance, Gravimetric measurement, Use of Gypsum Blocks, Use of Tensiometers, Gamma Rays attenuation and Use of Neutron Probe have been referred very often. All of these methods need establishment of a correlation with respect to plant water use for scheduling irrigations and all have certain merits and demerits concerning particularly the accuracy of results, difficulty in use and cost effectiveness.

A general assumption or principle is kept in view while scheduling irrigations through soil related methods. It has been realized on the basis of research observations that plants can easily absorb water from soil so far it is above 50% of its field capacity. In clayey soils, this limit is considered better if fixed as 60% as these soils hold the moisture more tightly compared to other soils, for loamy soils, this should be 50% and in case of sands, one go even up to 40% although the water holding capacity of sandy soils is the least i.e. almost 1/3 of the capacity of clays. The frequency of irrigations, however, will be higher in case of sandy soils. The units often used for expressing the level of tension are bars or atmospheres.

2.2 Plants - Related Methods

The criterion used in this category of methods is the same as above i.e. moisture contents of the plant parts or in case of deficiency the moisture stress in the plant parts. The symptoms reflected by the plants or direct measurements of the moisture contents are made as base for deciding the time to irrigate. As per opinion of the most of the professionals, plants related methods may be considered as most dependable as the same reflect an integration of all the factors contributing/leading towards making an appropriate decision for scheduling of irrigations. Irrigation scheduling through Plant Appearance, Measurement of transpiration through Stem Flow, Measurement of water tension through Pressure Chamber, Measurement of Trunk Diameter Fluctuations, and Measurement of Leaf Transpiration through Porometer and Measurement of Canopy Temperature through Infrared Thermometry are the methods falling under this category.

2.3 Weather - Related Methods

The amount of water used by the plant for its growth and development normally referred as consumptive use or evapotranspiration has been observed to be a function of weather parameters including radiation, temperature, humidity and wind velocity. The value of crop evapotranspiration is denoted by ET_c and is determined with the help of reference evapotranspiration (ET_o) and the ratio of evapotranspiration of any crop at a particular stage of growth to that of reference crop referred as crop coefficient (K_c). This approach has become highly popular because of its accuracy and practicability. The values of ET_o for various locations have been determined by the experts through direct, indirect and empirical methods. Recently, a panel of experts of FAO has recommended Penman Monteith equation as a method to determine ET_o values which is now being used world over. Similarly, the values of K_c have also been determined by the respective experts for wide spread locations. The use of evaporation pans has been considered an easy way of determining consumptive use of crops by many researchers but the approach of determining ET_c through multiplication of ET_o with K_c has proven its worth being the most accurate and has, therefore, achieved a universal acceptance.

The method/approach mentioned the last has been adopted for preparation of irrigation schedules for crops being grown under HEISs and is discussed hereunder with respect to its application in the field.

To prepare an irrigation schedule of a crop, the information is collected and processed with the help of four documents: one Basic Data Sheet to record all particulars pertaining to the Farm, Crop and the system, two – the Table reflecting values of reference evapotranspiration ET_o for all the districts of Punjab, three - the figures of crop growth coefficient curves regarding main crops to ascertain the weekly, decadal or monthly change in the values of K_c factor and four - the Irrigation Schedule Calculation Sheet along with the formulae to process and develop required information necessary to reach the objective.

Basic Data Sheet is given as Table 1, the values of ET_o for all districts of Punjab as Table 2, the values of Crop Growth Stage Coefficient for different agronomic crops as Table 3, of vegetable crops as Table 4 and of orchards as Table 5. In addition, a sample blank excel sheet to prepare an Irrigation Schedule has been given as Table 6. Moreover, worked examples for prepared irrigation schedules for Cotton, Sugarcane, Maize, Wheat, Citrus and Peas have also been added as Tables 7, 8, 9, 10, 11 and 12 respectively. The soft copy of Tables 6-12 is attached in the form of compact disc.

3 STEPS FOR PREPARATION OF IRRIGATION SCHEDULE

The preparation of an Irrigation schedule is completed through following three steps:

1. Calculation of Daily Crop Water Requirement (CWR)
2. Calculation of Application Rate and
3. Calculation of Application Time.

The same are discussed as in details below:

3.1 Calculation of Daily Crop Water Requirements (CWR)

- i. Refer to Basic Data Sheet (Table 1) and fill the basic data regarding all the required particulars.
- ii. Refer to Irrigation Schedule Preparation Sheet (Table 6) and enter the months in column (a), decade number of the month in column (b) & decade number of the crop in column (c) with effect from the date of sowing of crop indicating the number of crop days for the months, decades or weeks of crop duration in column (d).

It should be kept in mind that we are calculating Daily CWR (crop water requirement) for a particular week or decade because of progressive change in K_c value during every following week or decade. Some professionals take the K_c values on monthly basis and prepare the irrigation schedules. It is correct but comparatively less accurate than the schedules prepared on the basis of weekly or ten days values of K_c . These are, however, workable for orchards but not desirable for agronomic and vegetable crops. On the other hand, irrigation schedule may be prepared on daily basis also, if desired. This schedule will incorporate the changes in K_c values on day to day basis and will rank as the most accurate schedule.

- iii. Refer to Table-2 indicating ET_o values for all the months for various districts of Punjab, record corresponding ET_o value for each month, decade or week in column (e).
- iv. Refer to Tables 3, 4 and 5 reflecting K_c values of growth stages during a crop season. Ascertain the K_c value for each week, decade or month and record it on the IS Preparation sheet against the corresponding week, decade or month in column (f). The weekly or decadal values can best be picked through crop growth coefficient curves. The same are given as Figures 1-5 for crops mentioned above.

- v. Record the values of Canopy Factor for each week, decade or month similar to above in column (g) through fair assessment of ground coverage by the crop as per its corresponding stage.
- vi. Multiply ET_0 value of each week, decade or month with the related K_c value and canopy factor to get the value of Daily Basic CWR for that week, decade or month and enter it in column (h).
- vii. Divide the basic CWR with efficiency factor to determine Daily Gross CWR for that week, decade or month and enter in column (i).
- viii. Subtract the amount of moisture contributed by soil, rainfall or ground water table reflecting in column (j) from the daily gross CWR and this will give us the daily net CWR of that crop. Enter this value in column (k).

3.2 Calculation of Daily Application Rate

- a) The time in which a specific crop water requirement can be fulfilled depends on two factors: the amount of water being diverted or applied to a field per unit time also termed as "Flow Rate". Higher is the amount of flow, lesser will be the time required to fill the root zone.
- b) the size of the field or zone being irrigated i.e. bigger is the field, longer will be the time required to complete the irrigation. Both of these factors have been put together in the term "Application Rate" which may be defined as the amount of water being applied to a unit piece of land in a unit time. The units for flow rate used commonly are "Liters per second (lps), Liters per hour (lpH), Cubic meters per hour (m^3/h) and the units for area used commonly are "Square meters (m^2) and Hectares (Ha)". If the flow rate is in liters per hour (usual discharge/flow rate of emitters) and the area is in m^2 , the unit for Application Rate is "mm/hour". Its simple mathematical relationship is given as under:

$$\text{Application Rate (mm/hr)} = \text{Flow Rate in Liters per Hour} / \text{Area in } m^2$$

If the system flow rate is taken in cubic meters (m^3) per hour and the area is taken in hectares, then:

$$\text{Application Rate (mm/hr)} = \text{SFR (} m^3 \text{)*0.1/Area (Ha)}$$

Calculate application rate separately and enter it in column (l) of the Irrigation Scheme (IS) Preparation Sheet.

3.3 Calculation of Application Time

It is the time required to complete the CWR of a field or zone. The application rate has already been calculated. Application Time can be calculated by dividing the CWR of a day by the application rate. The formula is:

$$\text{Application Time (hours)} = \text{CWR (mm/day)} / \text{Application Rate (mm/hr)}$$

In this way, one can calculate the time of application for all the weeks or decades or even months as per assessment period of daily CWR.

With the help of formula given above, determine the values of application time in hours entering it in column (m). Multiply these values with the number of minutes in an hour to get the values of application time in minutes and enter the same in column (n).

To calculate the time required to irrigate all the zones, multiply the time value for one zone with the number of zones highlighting the figure in column (o).

4 Daily and Seasonal Volume of Water

For additional facilitation of the professionals, a column titled "Volume of Water Required" has been added. Though it does not have direct relationship with irrigation scheduling, an estimate of the amount of water required for a particular day may help the farmer in timely planning and ensuring the availability of requisite amount of water in the storage tank in case it is short. The amount of water required may be calculated as under:

$$\text{Volume of Water/Day (m}^3\text{)} = \text{System Flow Rate (m}^3\text{)} * \text{Irrigation Time/Day (hr)}$$

For seasonal estimate of the volume of water required by the crop, the daily values of volume will be multiplied with the requisite number of crop days to obtain the volume required in a week or decade and this value should be entered in column (p). A total of these decadal values will give us the seasonal water requirement/volume for that crop.

In addition, this value helps in comparing the volume of water applied under drip irrigation with the volume of water needed under surface irrigation. Certainly, a considerable volume of water applied under surface irrigation goes waste because of its absorption in areas out of the root zone and its evaporation up in the atmosphere without any use to the crop. The devastation of energy is another overwhelming loss. These losses contribute in lowering the efficiency of the surface irrigation system sometimes down to 50%. This comparison may help the farmers in extra planning in relation to their irrigation system and thus saving not only the precious water resource but also the valuable energy from wastage.

The volume water consumed in surface irrigation of a crop can be calculated as under:-

The example is taken of the citrus orchard with its irrigation schedule given in table 10. The area of the orchard is 15 acres, discharge at the farm is 1.5 cusecs, time required for irrigation of one acre is 2 hours and the number of irrigations in one year is 20.

$$\text{Discharge in surface irrigation} = 1.5 \text{ cusecs} = 42 \text{ lps} = 151.2 \text{ m}^3/\text{hr}$$

$$\text{Time for one irrigation} = 2 \text{ hr}$$

$$\text{Volume for one irrigation} = 151.2 * 2 \text{ (hours)} = 302.4 \text{ m}^3 \text{ per acre}$$

$$\text{Volume for 15 acres irrigation} = 302.4 * 15 = 4536 \text{ m}^3$$

$$\text{Volume for 20 irrigations} = 4536 * 20 = 90720 \text{ m}^3$$

This volume can now be compared with that required under drip system which is only 10524 m³ i.e. about 12%.

Table.1. Basic Data Sheet for Preparation of Irrigation Schedule

Sr. No.	Particulars	Detail
A	Farm Specifics	
1	Name of Farmer	
2	Educational Level	
3	Village	
4	Tehsil	
5	District	
B	Crop Data	
1	Name of Crop	
2	Crop Growth Duration	
3	Total Area of The Crop	
4	Date of Sowing	
5	Expected Date of Harvesting	
6	R-R Distance	
7	P-P Distance	
8	ET _o Values for the Period of Crop Duration	
9	Crop Growth Coefficient Curve	
10	Tentative Values of Canopy Factor	
C	System Particulars	
1	Type of System (Drip or Sprinkler)	
2	System Flow Rate/Discharge	
3	System Efficiency	
4	Moisture Status of the Root Zone Before Sowing	
5	Depth of Ground Water Table	
6	Value of Effective Rainfall on its Occurrence	
7	Number of Zones	
8	Area of Each Zone	
9	L-L Distance	
10	E-E Distance	
11	Discharge/Flow Rate of Each Emitter	
12	Number of Emitters in one Zone	
13	Value of Daily CWR	
14	Irrigation Cycle	
15	Storage Tank Capacity	

Table. 2. Reference Evapotranspiration of All Districts of Punjab

Sr. No.	Districts	ET _o (mm)/Day											
		Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Attock	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
2	Bahawalnaga	1.9	2.9	4.3	6.0	7.6	8.3	6.4	6.1	5.5	4.2	2.6	1.8
3	Bahawalpur	1.8	2.8	4.1	5.5	6.8	7.7	6.2	6.0	5.3	3.9	2.5	1.7
4	Bhakkar	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
5	Chakwal	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
6	Chiniot	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
7	Dera Ghazi	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
8	Faisalabad	1.4	2.2	3.6	4.9	6.2	6.5	5.3	4.8	4.6	3.3	1.9	1.3
9	Gujranwala	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
10	Gujrat	1.5	2.3	3.7	5.2	6.6	6.9	5.4	4.6	4.8	3.9	2.6	1.7
11	Hafizabad	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
12	Jhang	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
13	Jhelum	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
14	Kasur	1.3	2.1	3.5	4.8	6.0	6.3	4.9	4.6	4.3	3.1	1.8	1.2
15	Khanewal	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
16	Khushab	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
17	Lahore	1.3	2.3	3.6	5.3	6.2	6.2	5.4	4.8	4.4	3.2	2.1	1.4
18	Layyah	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
19	Lodhran	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
20	Mandi	1.5	2.3	3.7	5.2	6.6	6.9	5.4	4.6	4.8	3.9	2.6	1.7
21	Mianwali	1.4	1.9	2.9	4.3	5.7	6.2	5.8	5.1	4.7	3.4	2.1	1.4
22	Multan	1.4	2.1	3.2	4.8	6.1	7.0	6.1	5.9	5.1	3.4	2.1	1.4
23	Muzaffargarh	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
24	Norowal	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
25	Nankana	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
26	Okara	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
27	Pakpattan	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
28	R. Y. Khan	1.9	2.9	4.3	5.7	7.0	7.8	6.4	6.1	5.3	4.0	2.5	1.8
29	Rajanpur	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
30	Rawalpindi	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
31	Sahiwal	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
32	Sargodha	1.5	2.4	3.8	5.3	6.8	7.2	5.8	5.0	4.9	3.8	2.5	1.6
33	Sheikhupura	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
34	Sialkot	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
35	T T Singh	1.4	2.2	3.6	4.9	6.2	6.5	5.3	4.8	4.6	3.3	1.9	1.3
36	Vehari	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5

Table 3. Duration of Growth Stages of Agronomic Crops & Corresponding Kc Values

Sr. No	Crop	Date of Sowing	Duration of Initial stage (Days)	Kc initial	Duration of Development Stage (Days)	Kc Development	Duration of Middle Stage (Days)	Kc Mid stage (Peak Value)	Duration of Late Stage (Days)	Kc Late stage	Total days	Date of Harvesting
1	Barley	Nov	15	0.3	25	0.9	50	1.15	30	1.0	120	April
2	Beans	Jun	15	0.4	25	0.7	35	1.05	20	0.95	95	Sep & Oct
3	Canola	Oct	25	0.35	45	0.7	70	1.15	40	1.0	180	Mar & April
4	Castor Beans	March	25	0.35	40	0.8	65	1.15	50	1.1	180	Sep & Oct
5	Cotton	April	30	0.5	50	0.8	60	1.25	55	0.9	195	Nov & Dec
6	Grams	Oct	20	0.4	30	0.9	45	1.05	20	1	115	Feb & Mar
7	Groundnut	March	25	0.5	35	0.8	45	1.15	25	0.85	130	July & Aug
8	Maize	Feb/Jul	20	0.5	30	0.85	40	1.2	20/25	0.9	115	May & Nov
9	Millets	Jun/Jul	15	0.4	25	0.7	40	1.0	25	0.9	105	October
10	Rapeseed	Oct	25	0.35	45	0.7	70	1.15	40	1.0	180	Mar & Apr
11	Rice	Jun/Jul	30	1.15	30	1.15	60	1.2	30	1.05	150	Nov & Dec
12	Safflower	Nov	25	0.5	40	0.8	65	1.0	30	0.8	160	April
13	Sesame	Jun/Jul	15	0.35	25	1	50	1.1	20	1.0	110	Oct & Nov
14	Sorghum	July	20	0.4	35	0.7	40	1.1	30	0.8	125	Nov & Dec
15	Soybeans	Feb July	20/20	0.4	25/35	0.8	50/60	1.15	15/20	0.8	110/130	June & Nov
16	Sugarcane	Feb Sep	30/35	0.5	60/65	0.9	180/200	1.3	60/90	0.8	330/390	Dec & Jan
17	Sugar Beets	Oct	30	0.5	45	0.6	90	1.2	15	0.9	180	April
18	Sunflower	Jan Feb	25	0.4	35	0.7	45	1.2	25	0.8	130	June
19	Sweet Corn	Feb July	20	0.3	30	0.7	40	1.15	20	1.1	110	June & Nov
20	Mustard	Oct	25	0.3	45	0.7	70	1.0	40	1.1	180	April
21	Tobacco	Oct	30	0.4	40	0.8	50	1.2	30	0.9	150	Mar & April
22	Wheat	Nov	15	0.4	25	0.8	50	1.2	30	0.7	120	April

Table. 4 Duration of Growth Stages and Kc Values of Vegetables Crops

Sr. No	Crop	Date of Sowing	Initial Stage		Development Stage		Mid Stage (Peak Value)		Late Stage		Total Days	Date of Harvesting
			Duration	Kc	Duration	Kc	Duration	Kc	Duration	Kc		
1	Ash gourd	Oct & Feb	15	0.6	25	0.9	50	1	30	1	120	March
2	Bitter gourd	Mar Jun	30	0.6	40	0.9	50	1	30	1	150	Sep & Oct
3	Beans (green)	Oct	15	0.4	25	0.7	25	0.95	10	0.95	75	Jan
4	Beans dry	Mar	15	0.4	25	0.8	35	1.15	20	0.7	95	July
5	Bringle	Apr	30	0.6	50	0.9	60	1.05	40	0.9	180	Nov & Dec
6	Cabbage	Oct	30	0.4	40	0.9	65	1.05	30	1	165	Feb & Mar
7	Capsicum	Mar	25	0.5	35	0.8	45	1.05	25	0.9	130	July & Aug
8	Carrot	Oct	15	0.7	25	0.9	40	1.05	20	0.95	100	January
9	Cauliflower	Aug	15	0.7	25	0.9	40	1.05	20	0.95	100	December
10	Chilies	Feb	30	0.3	40	0.5	70	0.75	30	1	170	August
11	Cucumber	Feb / Mar	15	0.6	20	0.9	30	1	15	0.9	80	May/ Jun
12	Egg Plant	Nov	20	0.6	30	0.8	55	1.05	25	0.9	130	April
13	Garlic	Sep/ Oct	30	0.7	40	0.9	70	1	30	0.7	170	March/April
14	Ladyfinger	Feb / Mar	15	0.7	20	0.8	40	1	15	0.9	90	May/June
		Jun	15	0.7	20	0.8	40	1	15	0.9	90	September
15	Lettuce	Feb/Sep	25	0.7	35	0.8	30	1	10	0.95	100	Dec & Jan
16	Muskmelon	Mar	20	0.5	25	0.75	40	1.05	15	0.75	100	July/August
17	Onion dry	Oct	15	0.5	25	0.75	70	1.05	30	0.75	140	April
18	Onion (Gr)	Oct	15	0.5	25	0.75	60	1	—	—	100	February
19	Peas (Gr)	Sep/ Oct	20	0.5	25	0.85	35	1.15	—	—	80	Dec/Jan
20	Peas seed	Sep/ Oct	20	0.5	25	0.85	35	1.15	20	0.3	100	Jan/Feb
21	Potato	Sep/ Oct	25	0.5	30	0.85	35	1.15	30	0.75	1.20	Dec/Jan
22	Pumpkin	Feb	20	0.6	30	0.9	30	1	20	0.8	100	June/July
23	Radish	July Nov	10	0.7	15	0.8	20	0.9	5	0.85	50	Sep to Jan
24	Spinach	Mar June	20	0.7	30	0.85	40	1	10	0.95	100	July to Oct
25	Squash	Feb June	25	0.5	35	0.75	25	0.95	15	0.75	100	June & Oct
26	Tomato	Sep/ Oct	30	0.6	40	0.9	40	1.15	25	0.8	135	Feb/March
27	Turnip	Sep Nov	10	0.5	20	0.85	25	1.1	5	0.95	60	Nov to Jan
28	Watermelon	Feb/ Mar	15	0.4	30	0.7	30	1	25	0.75	100	June/July

Table. 5. Duration of Growth Stages and Kc Values of Fruit Crops

Sr. No.	Fruit Name	Initial Stage	Kc Initial	Dev. Stage	Kc Dev.	Mid Stage	Kc Mid	Late Stage	Kc Late
1	Almond		0.4				0.9		0.65
2	Apple		0.45				0.95		0.7
3	Apricot		0.45				0.9		0.65
4	Banana		0.5				1.1		1
5	Ber						1.1		
6	Berries		0.3				1.05		0.5
7	Chiku						1.1		
8	Citrus		0.5				0.65-0.8		0.6-0.85
9	Cherries		0.45				0.95		0.7
10	Date Palm		0.9				0.95		0.95
11	Fig						1		
12	Grapes		0.3				0.95		0.45
13	Guava						1		
14	Lychee						1.05		
15	Mango						0.65		
16	Mulberry		0.4		0.7		1		1
17	Olives		0.6		0.65		0.7		0.7
18	Peaches		0.45				0.9		0.65
19	Pears		0.45				0.95		0.7
20	Plum		0.45				1.15		0.65
21	Pomegranate		0.5		0.7		0.75		0.75
22	Strawberry						0.85

Figure – 1 Crop Growth Stage Coefficient (K_c) Curve for Cotton

Figure – 3 Crop Growth Stage Coefficient (K_c) Curve for Sugarcane

Figure – 2 Crop Growth Stage Coefficient (K_c) Curve for Maize

Figure – 4 Crop Growth Stage Coefficient (K_c) Curve for Wheat

Figure – 5 Crop Growth Stage Coefficient (K_c) Curve for Citrus

Figure – 6 Crop Growth Stage Coefficient (K_c) Curve for Peas

Table. 6. Sample Sheet for Preparation of Irrigation Schedule

[illegible]

Table 7. Irrigation Schedule for Cotton Crop

Farmer's Name - Rao Atif Ali				District - Muzaffar Garh				Crop - Cotton		Area under Crop - 14 Acres			Date of Sowing - 26.4.12		
Date of Harvest - 22.10.12				System Flow Rate(m ³ /hr) - 49				Application Rate(mm/hr) - 5.33				No. of Zones - 7		Size of one Zone - 2 acres	
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily ETo (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil/Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate(mm/hr)	Irrigation Time per zone/Day (hours)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones(Hrs)	Volume of Water Required(m ³)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Apr	3	1	5	5.2	0.34	0.4	0.71	0.79	0.00	0.79	5.33	0.15	9	1.0	253
May	1	2	10	6.4	0.4	0.7	1.79	1.99	0.00	1.99	5.33	0.37	22	2.6	1281
	2	3	10	6.4	0.5	0.8	2.56	2.84	0.00	2.84	5.33	0.53	32	3.7	1830
	3	4	11	6.4	0.62	0.9	3.57	3.97	0.00	3.97	5.33	0.74	45	5.2	2809
Jun	1	5	10	7.6	0.74	1	5.62	6.25	0.00	6.25	5.33	1.17	70	8.2	4021
	2	6	10	7.6	0.82	1	6.23	6.92	0.00	6.92	5.33	1.30	78	9.1	4456
	3	7	10	7.6	0.92	1	6.99	7.77	0.00	7.77	5.33	1.46	87	10.2	4999
Jul	1	8	10	6.2	0.98	1	6.08	6.75	0.00	6.75	5.33	1.27	76	8.9	4345
	2	9	10	6.2	1	1	6.20	6.89	0.00	6.89	5.33	1.29	78	9.0	4433
	3	10	11	6.2	0.98	1	6.08	6.75	0.00	6.75	5.33	1.27	76	8.9	4779
Aug	1	11	10	5.9	0.95	1.1	6.17	6.85	0.00	6.85	5.33	1.29	77	9.0	4409
	2	12	10	5.9	0.9	1.1	5.84	6.49	0.00	6.49	5.33	1.22	73	8.5	4176
	3	13	11	5.9	0.8	1.1	5.19	5.77	0.00	5.77	5.33	1.08	65	7.6	4084
Sep	1	14	10	5.2	0.72	1	3.74	4.16	0.00	4.16	5.33	0.78	47	5.5	2677
	2	15	10	5.2	0.65	1	3.38	3.76	0.00	3.76	5.33	0.70	42	4.9	2417
	3	16	10	5.2	0.56	1	2.91	3.24	0.00	3.24	5.33	0.61	36	4.2	2082
Oct	1	17	10	3.5	0.48	1	1.88	1.87	0.00	1.87	5.33	0.35	21	2.5	1201
	2	18	10	3.5	0.44	1	1.54	1.71	0.00	1.71	5.33	0.32	19	2.2	1101
	3	19	2	4.5	0.42	1	1.89	2.10	0.00	2.10	5.33	0.39	24	2.8	270
Total															55625

Table. 8. Irrigation Schedule for Sugarcane Crop

Farmer Name: Muhammad Azam				District: MB Din		Crop: Sugarcane			Area under Crop: 9 Acre			Date of Sowing: 13.9.12			
Date of Harvest: 1.11.13			Q:	8.99 lps	32.4 m3/h	Application Rate(mm/hr):			5.33	No. of Zones: 6		Size of one Zone= 1.50 acre or 0.6 Ha			
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil / Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate (mm/hr)	Irrigation Time per zone/Day (hr)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones (hr)	Volume of Water (m3)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Sep	2	1	7	4.8	0.45	0.3	0.65	0.7	0	0.7	5.33	0.14	8	0.81	184
	3	2	10	4.8	0.54	0.4	1.04	1.2	0	1.2	5.33	0.22	13	1.30	420
Oct	1	3	10	3.9	0.6	0.4	0.94	1.0	0	1.0	5.33	0.20	12	1.17	379
	2	4	10	3.9	0.64	0.4	1.00	1.1	0	1.1	5.33	0.21	12	1.25	405
	3	5	11	3.9	0.7	0.5	1.37	1.5	0	1.5	5.33	0.28	17	1.71	608
Nov	1	6	10	2.6	0.78	0.5	1.01	1.1	0	1.1	5.33	0.21	13	1.27	411
	2	7	10	2.6	0.82	0.5	1.07	1.2	0	1.2	5.33	0.22	13	1.33	432
	3	8	10	2.6	0.88	0.6	1.37	1.5	0	1.5	5.33	0.29	17	1.72	556
Dec	1	9	10	1.7	0.94	0.7	1.12	1.2	0	1.2	5.33	0.23	14	1.40	453
	2	10	10	1.7	1	0.7	1.19	1.3	0	1.3	5.33	0.25	15	1.49	482
	3	11	11	1.7	1.04	0.7	1.24	1.4	0	1.4	5.33	0.26	15	1.55	552
Jan	1	12	10	1.5	1.08	0.7	1.13	1.3	0	1.3	5.33	0.24	14	1.42	460
	2	13	10	1.5	1.1	0.7	1.16	1.3	0	1.3	5.33	0.24	14	1.44	468
	3	14	11	1.5	1.14	0.75	1.28	1.4	0	1.4	5.33	0.27	16	1.60	572
Feb	1	15	10	2.3	1.18	0.75	2.04	2.3	0	2.3	5.33	0.42	25	2.55	825
	2	16	10	2.3	1.22	0.8	2.24	2.5	0	2.5	5.33	0.47	28	2.81	910
	3	17	8	2.3	1.26	0.85	2.46	2.7	0	2.7	5.33	0.51	31	3.08	799
Mar	1	18	10	3.7	1.28	0.9	4.26	4.7	0	4.7	5.33	0.89	53	5.33	1727
	2	19	10	3.7	1.3	0.95	4.57	5.1	0	5.1	5.33	0.95	57	5.72	1852
	3	20	11	3.7	1.3	1	4.81	5.3	0	5.3	5.33	1.00	60	6.02	2144
Apr	1	21	10	5.2	1.3	1	6.76	7.5	0	7.5	5.33	1.41	85	8.46	2740
	2	22	10	5.2	1.28	1	6.66	7.4	0	7.4	5.33	1.39	83	8.33	2697
	3	23	10	5.2	1.24	1	6.45	7.2	0	7.2	5.33	1.34	81	8.07	2613

Continued.....

Farmer Name: Muhammad Azam			District: MB Din			Crop: Sugarcane			Area under Crop: 9 Acre			Date of Sowing: 13.9.12			
Date of Harvest: 1.11.13			Q:	8.99 ips	32.4 m3/h		Application Rate(mm/hr):		5.33	No. of Zones: 6		Size of one Zone= 1.50 acre or 0.6 Ha			
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Correspondi ng Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil / Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate (mm/hr)	Irrigation Time per zone/Day (hr)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones (hr)	Volume of Water (m3)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
May	1	24	10	6.6	1.2	1	7.92	8.8	0	8.8	5.33	1.65	99	9.91	3210
	2	25	10	6.6	1.18	1	7.79	8.7	0	8.7	5.33	1.62	97	9.74	3156
	3	26	11	6.6	1.16	1	7.66	8.5	0	8.5	5.33	1.60	96	9.58	3413
Jun	1	27	10	6.9	1.12	1	7.73	8.6	0	8.6	5.33	1.61	97	9.67	3132
	2	28	10	6.9	1.1	1	7.59	8.4	0	8.4	5.33	1.58	95	9.49	3076
	3	29	10	6.9	1.06	1	7.31	8.1	0	8.1	5.33	1.52	91	9.15	2964
Jul	1	30	10	5.4	1.04	1	5.62	6.2	0	6.2	5.33	1.17	70	7.02	2276
	2	31	10	5.4	1.02	1	5.51	6.1	0	6.1	5.33	1.15	69	6.89	2232
	3	32	11	5.4	0.96	1	5.18	5.8	0	5.8	5.33	1.08	65	6.48	2311
Aug	1	33	10	4.8	0.92	1	4.42	4.9	0	4.9	5.33	0.92	55	5.52	1790
	2	34	10	4.8	0.9	1	4.32	4.8	0	4.8	5.33	0.90	54	5.40	1751
	3	35	11	4.8	0.88	1	4.22	4.7	0	4.7	5.33	0.88	53	5.28	1883
Sep	1	36	10	4.6	0.85	1	3.91	4.3	0	4.3	5.33	0.82	49	4.89	1585
	2	37	10	4.6	0.82	1	3.77	4.2	0	4.2	5.33	0.79	47	4.72	1529
	3	38	10	4.6	0.8	1	3.68	4.1	0	4.1	5.33	0.77	46	4.60	1491
Oct	1	39	10	3.9	0.78	1	3.04	3.4	0	3.4	5.33	0.63	38	3.80	1233
	2	40	10	3.9	0.76	1	2.96	3.3	0	3.3	5.33	0.62	37	3.71	1201
	3	41	11	3.9	0.75	1	2.93	3.3	0	3.3	5.33	0.61	37	3.66	1304
Total															62224

Note: - Irrigation of Sugarcane Crop should be stopped about one month before harvest

Table. 9. Irrigation Schedule for Maize Crop

Farmer Name: Farman Ali Basra			District: Layyah		Crop: Maize			Area under Crop: 13.4 Acre			Date of Sowing: 16.7.12				
Date of Harvest: 24.10.12			Q:	24 lps	86 m ³ /h	Application Rate(mm/hr):			5.25	No. of Zones: 7		Size of one Zone= 1.91 acre			
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil / Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate (mm/hr)	Irrigation Time per zone/Day (hr)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones (hr)	Volume of Water (m ³)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Jul	2	1	5	6.1	0.45	0.3	0.82	0.9	0	0.9	11.25	0.08	5	0.57	245
	3	2	11	6.1	0.64	0.4	1.56	1.7	0	1.7	11.25	0.15	9	1.08	1021
Aug	1	3	10	5.6	0.86	0.4	1.93	2.1	0	2.1	11.25	0.19	11	1.52	1309
	2	4	10	5.6	1.05	0.4	2.35	2.6	0	2.6	11.25	0.23	14	1.86	1598
	3	5	11	5.6	1.2	0.5	3.36	3.7	0	3.7	11.25	0.33	20	2.65	2511
Sep	1	6	10	5	1.2	0.5	3.00	3.3	0	3.3	11.25	0.30	18	2.37	2039
	2	7	10	5	1.2	0.5	3.00	3.3	0	3.3	11.25	0.30	18	2.37	2039
	3	8	10	5	1.1	0.6	3.30	3.7	0	3.7	11.25	0.33	20	2.61	2242
Oct	1	9	10	3.5	1.05	0.7	2.57	2.9	0	2.9	11.25	0.25	15	2.03	1748
	2	10	10	3.5	1	0.7	2.45	2.7	0	2.7	11.25	0.24	15	1.94	1665
	3	11	4	3.5	0.9	0.7	2.21	2.5	0	2.5	11.25	0.22	13	1.74	599
Total														17016	

Table 10. Irrigation Schedule for Wheat

Farmer Name- M. Riaz			District- Gujrat		Crop- Wheat		Area under Crop- 4 Acre				Date of Sowing- 25.11.13				
Date of Harvest- 10.4.14			System Flow Rate(m ³ /hr)=12.6			Application Rate(mm/hr)=6.29			No. of Zones= 8		Size of one Zone= 0.5 acre				
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil / Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate (mm/hr)	Irrigation Time per zone/Day (hr)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones (hr)	Volume of Water (m ³)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Nov	3	1	6	2.6	0.4	1	1.04	1.5	0	1.5	6.29	0.24	14.2	1.9	142.9
Dec	1	2	10	1.7	0.4	1	0.68	1.0	0	1.0	6.29	0.15	9.3	1.2	155.7
	2	3	10	1.7	0.8	1	1.36	1.9	0	1.9	6.29	0.31	18.5	2.5	311.4
	3	4	11	1.7	0.8	1	1.36	1.9	0	1.9	6.29	0.31	18.5	2.5	342.5
Jan	1	5	10	1.5	0.9	1	1.35	1.9	0	1.9	6.29	0.31	18.4	2.5	309.1
	2	6	10	1.5	1.2	1	1.8	2.6	0	2.6	6.29	0.41	24.5	3.3	412.1
	3	7	11	1.5	1.2	1	1.8	2.6	0	2.6	6.29	0.41	24.5	3.3	453.3
Feb	1	8	10	2.3	1.2	1	2.76	3.9	0	3.9	6.29	0.63	37.6	5.0	631.9
	2	9	10	2.3	1.2	1	2.76	3.9	0	3.9	6.29	0.63	37.6	5.0	631.9
	3	10	8	2.3	1.2	1	2.76	3.9	0	3.9	6.29	0.63	37.6	5.0	505.5
Mar	1	11	10	3.7	0.9	1	3.33	4.8	0	4.8	6.29	0.76	45.4	6.1	762.4
	2	12	10	3.7	0.7	1	2.59	3.7	0	3.7	6.29	0.59	35.3	4.7	592.9
	3	13	10	*											
Apr	1	14	10	*											
Total			136												5251.3

* Avoid sprinkler irrigation during fluorescence

Table 11. Irrigation Schedule for Citrus

Farmer- Ch. Nisar Ahmad, M. Garh			Crop- Citrus			Sowing Date- 8.3.12			Harvesting Date-			Area under crop-15 Acres			
System Flow Rate-17.21 m ³ /H			No. of Zones- 5			App. Rate- 1.43 mm/H									
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil/Rainfall Contribution (mm)	Daily Net CWR	Application Rate (mm/H)	Irrigation Time/ zone/ Day (hours)	Irrigation Time/zone/Day (minutes)	Irrigation Time for all zones(Hrs)	Volume of water Required (m ³)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Mar			31	4.1	0.65	0.1	0.27	0.30	0.0	0.30	1.43	0.21	12	1.04	552
Apr			30	5.2	0.65	0.12	0.41	0.45	0.0	0.45	1.43	0.32	19	1.58	814
May			31	6.4	0.65	0.13	0.54	0.60	0.0	0.60	1.43	0.42	25	2.10	1121
Jun			30	7.6	0.65	0.14	0.69	0.77	0.0	0.77	1.43	0.54	32	2.69	1387
Jul			31	6.2	0.65	0.15	0.60	0.67	0.0	0.67	1.43	0.47	28	2.35	1253
Aug			31	5.9	0.65	0.16	0.61	0.68	0.0	0.68	1.43	0.48	29	2.38	1272
Sep			30	5.2	0.65	0.16	0.54	0.60	0.0	0.60	1.43	0.42	25	2.10	1085
Oct			31	3.5	0.65	0.18	0.41	0.46	0.0	0.46	1.43	0.32	19	1.59	849
Nov			30	2	0.65	0.2	0.26	0.29	0.0	0.29	1.43	0.20	12	1.01	522
Dec			31	1.5	0.65	0.22	0.21	0.24	0.0	0.24	1.43	0.17	10	0.83	445
Jan			31	1.5	0.65	0.23	0.22	0.25	0.0	0.25	1.43	0.17	10	0.87	465
Feb			28	2.5	0.65	0.25	0.41	0.45	0.0	0.45	1.43	0.32	19	1.58	761
Total															10524

Table 12. Irrigation Schedule for Peas

Farmer Name: Salah ud Din				District: Pakpattan		Crop: Peas (Green)			Area under Crop: 5.76 Acres			Date of Sowing: 1.10.13			
Date of Harvest: 30.12.13			Q:	6.8 lps	24.4 m3/h		Application Rate(mm/hr):		7.35	No. of Zones: 7		Size of one Zone = 0.82 acre or 0.332 Ha			
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil / Rainfall Contribution (mm)	Daily Final CWR (mm)	Application Rate (mm/hr)	Irrigation Time per zone/Day (hr)	Irrigation Time per zone/Day (minutes)	Irrigation Time for all zones (hr)	Volume of Water (m3)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
Oct	1	1	10	3.5	0.5	0.3	0.53	0.6	0	0.6	7.35	0.08	5	0.56	478
	2	2	10	3.5	0.58	0.4	0.81	0.9	0	0.9	7.35	0.12	7	0.86	739
	3	3	11	3.5	0.72	0.45	1.13	1.3	0	1.3	7.35	0.17	10	1.20	1135
Nov	1	4	10	2	0.85	0.5	0.85	0.9	0	0.9	7.35	0.13	8	0.90	774
	2	5	10	2	1.04	0.6	1.25	1.4	0	1.4	7.35	0.19	11	1.32	1136
	3	6	10	2	1.12	0.7	1.57	1.7	0	1.7	7.35	0.24	14	1.66	1427
Dec	1	7	10	1.5	1.15	0.8	1.38	1.5	0	1.5	7.35	0.21	13	1.46	1256
	2	8	10	1.5	1.15	0.9	1.55	1.7	0	1.7	7.35	0.23	14	1.64	1413
	3	9	10	1.5	1.15	1	1.73	1.9	0	1.9	7.35	0.26	16	1.83	1570
Total															9927

References:

WILL BE FURNISHED ON REQUEST.