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Estimation of Irrigation Water Requirement and Irrigation Scheduling of Carrots under Drip Irrigation system in Rwanda

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Abstract

The study aimed to estimate the Irrigation Water Requirement and Irrigation scheduling of Carrot plant under Drip irrigation system at IPRC Gishari Farm located in Rwamagana District, Rwanda. Experimentally, the study covered the total area of 120 m x 64 m= 7680 m2 or 0.768ha of cropped land. The area of sub plots was 30 m x 16 m= 480 m2 or 0.048 ha of land. The Cropwat 8 computer packages was used to compute Reference evapotranspiration, Irrigation Water Requirement (IWR) and irrigation scheduling in drip irrigation installed for carrot production at the experimental site. The study findings showed that the monthly average mean of solar radiation was 34.9 MJ/m^2/day while its range varies from 32.2 MJ/m^2/day to 37.5 MJ/m^2/day. It was found that also that the mean ETo from the experimental site is 5.94 mm/day. Its range varies from 5.43 mm/day to 6.47 mm/day. The total of rain fall and effective rain fall was found to be 1148.6mm and 962.6mm for the period of twelve months. It was found that the total irrigation water requirement for carrot production under drip irrigation for the season starting from 16 May to 19 August was found to be 273.2 mm while the Net Irrigation Water Requirement (NIWR) was found to be 3,557.3m3/ha which is very low compared to Gross Irrigation Water Requirement (GIWR). The GIWR from the experimental site was found to be 6,532.6m3/ha. The water deficit accrued in drip irrigation system was found to be 2,975.3 m3/ha. It was found that also the planting date of carrot started on 16 May of the year and the harvesting date was scheduled on 19 August and the total duration of the crop was 100 days. The moisture depletion pattern during the irrigation schedule varies from 32% to 66% with an average depletion of 54.5% for the whole cropping period. It is concluded that the total amount of water stored in carrot root zone is less than the total needed water and the crop cannot suffer from water deficit. For crop water requirement, it was also found that the total of rain fall was higher than effective rain fall stored in root zone for the period of twelve months and these implies higher Crop water need and as results Maximum potential yield for most irrigated carrot under drip trickle irrigation system in the study area has increased substantially during the irrigated plot.

Keywords: *crop water requirement, drip irrigation, Irrigation Scheduling, Rwanda*

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1. Introduction

Rwanda has abundant water resources, they are not evenly distributed. Rainfall is high in the western part of the country and low in the east. The issue of variability is critical for lands on hillsides where water cannot be retained. Farms in the eastern part of the country, where rainfall is lowest, are therefore the most vulnerable. With reference to surface water bodies, the eastern part of Rwanda has abundant rivers and lakes that could be harnessed for irrigation purposes. For ground water resources, central and eastern parts of the country indicate good potential especially for springs and borehole development [6]. Currently, the most commonly used method is flood irrigation in the marshlands. Plans are afoot to set up demonstration farms in drought-prone eastern Rwanda to educate farmers about the advantages of irrigation. The importance of the role of irrigated agriculture in achieving food security and offering a way out of poverty is not in question. Where irrigation has been introduced, doubling of yields is commonly achieved [6].

Drip irrigation figures prominently in proposed solutions to the water crisis. In national and international policy documents, it is seen and promoted as a device to use water more efficiently [7, 4]. The belief in the water saving potential of drip irrigation is often substantiated with impressive statistics and measurements. The study conducted by Rao [4] and Postel et al. [3], for instance, claims that drip irrigation has the potential to at least double crop yield per unit water in many applications, including irrigation of most vegetables, cotton, sugarcane, and orchard and vineyard crops. A collection of research results from various Indian research institutes indicates typical water use reductions with drip irrigation of 30–60% and typical yield increases of 20–50% for a variety of crops, including cotton, sugarcane, grapes, tomatoes, and bananas [3]. Together, the greater water application efficiency and higher yields produce a doubling or tripling of water productivity [3]. Likewise, in an article in Nature, Van der Kooij et al. [7] asserts that

"Shifting from conventional surface irrigation to drip irrigation in India has increased overall water productivity by 42–255% for crops as diverse as banana, cotton, sugar cane and sweet potato". Numbers like those mentioned by Klaver [1] circulate widely in irrigation and water policy reports, underscoring that drip irrigation is a promising technology to help solve the water crisis. Reports also often contrast drip irrigation with surface irrigation methods, which are presented as inefficient and using excessive amounts of water. A World Bank report for instance states: "Drip irrigation uses 30–50% less water than surface irrigation, reduces salinization and waterlogging, and achieves up to 95% irrigation efficiency" [7].

According to Sentelhas et al. [5], irrigation water requirement is a function of multiple factors including weather data of the area. Net irrigation water requirement (NIWR) of the crop is the quantity of water necessary for crop growth since the initial stage to harvesting, and the quality of water utilized by the crops is optimum during the development stage. Information on irrigation efficiency is necessary to be able to transform NIWR into gross irrigation water requirement (GIWR), which is the quantity of water to be applied in reality, taking into account water losses. To cope with the aforementioned climatic conditions and the future projection, accurate estimation of crop water use may be a priority for water management and planning under conservative agriculture [2]. Thus this study was carried out at IPRC Gishari Farm located in Rwamagana District with the aim of estimating Irrigation Water Requirement as well as Irrigation Scheduling of Carrot under drip irrigation system and proposing feasible ways to reduce water losses in the irrigated areas.

2. Materials and Methods

2.1. Site Description

Geographically, Rwamagana District is one of the seven Districts of the Eastern Province. It is bordered by Gicumbi and Gatsibo Districts in the North, Kayonza District in the East, Bugesera and Ngoma Districts in the South, Kicukiro and Gasabo Districts in the West. It is composed of 14 Sectors with a total surface area of 691.9 km^2. The topography of the District of Rwamagana is characterized, in general, by lowly undulating hills separated by valleys, some of which are swampy and boggy. It is located in what is called "eastern plateau" and is between 1400–1700 m a.s.l. The District is classified as a medium altitude District which lies at about 1°57′9" South, 30°26′16" East. The climate is a moderate tropical climate with four seasons (two dry and two wet seasons), with a tendency to aridity. The rainfall increases during the months of April–May and October–December of every year. Average annual precipitation is 1000 mm while the average temperature ranges between 19°C and 30°C with the minimum of 13°C and maximum of 30°C sometimes exceeding, and less variability throughout the year and the District has very fertile soils (Rwamagana DDP document, 2013).

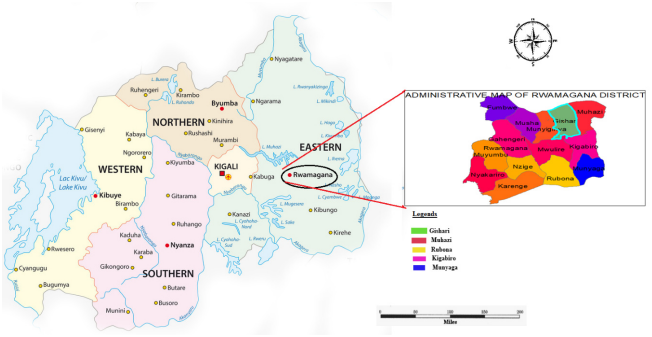


Figure 1. Administrative map of Rwamagana District indicating the study area

2.2. Methods

The irrigation scheme covers an area of 120 m × 64 m = 7680 m^2 (0.768 ha) of cropped land. The area of sub plots was 30 m × 16 m = 480 m^2 (0.048 ha) of land. Figure 2 shows the experimental layout indicating needful details.

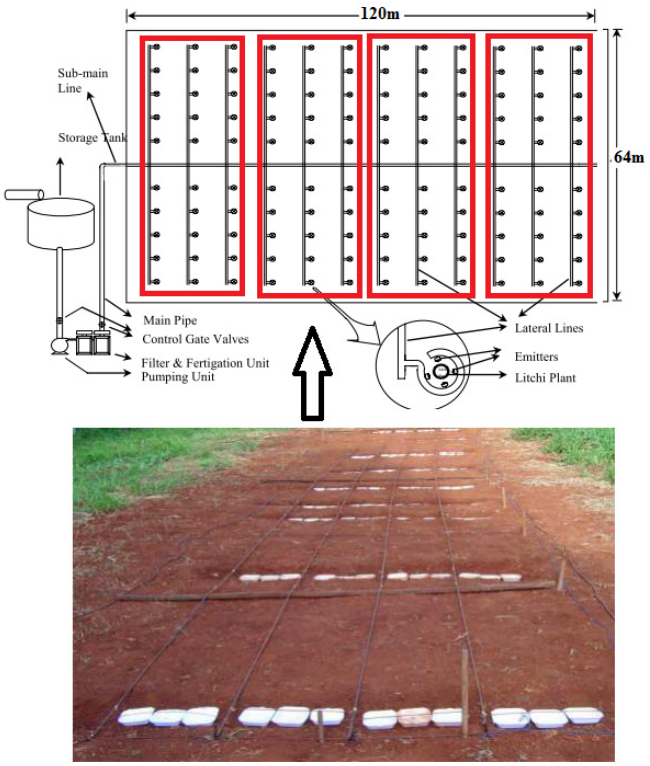


Figure 2. Field experimental layout

The drip irrigation system comprised the water pumping unit, main pipes, and control gate valve, filters and fertigation unit, emitters (drippers) and drip lines. The system also covered the storage tank and sub-main lines that act in water delivering. The experiment was conducted on 4 plots having the same size.

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2.3. Data Analysis

The climatic data collected from Rwanda Metrological Agency (RMA) for the period of 30 years from 1989 to 2019 were analyzed. The Cropwat 8.0 computer package was used to compute Reference evapotranspiration, Crop water Requirement and irrigation scheduling in drip irrigation installed for carrot production.

3. Results and Discussion

The computer software CROPWAT 8.0 was developed by FAO to estimate the crop water requirements, irrigation requirements of carrots and irrigation schedule at the experimental site (IPRC Gishari farm) using the input data like climate data, rainfall, crop data and soil data. The crop water requirement was worked out and expressed in millimetre per day.

3.1. Determination of Reference Evapotranspiration (ETo) under Carrot Crop

Reference evapotranspiration is the evapotranspiration from a reference surface and not a water surface. It closely represents the evapotranspiration of alfalfa grass based on physical, physiological and aerodynamic parameters. The summary of findings of reference evapotranspiration (ETo) for different months is shown in below:

Table 1. Reference Evapotranspiration (ETo) under carrot crop

Months	Min Temp	Max Temp	Humidity	Wind Speed	Sunshine duration	Rad	ETo
	T°C	T°C	RH (%)	km/day	Hours	MJ/m^2/day	mm/day
January	15.0	26.4	70	91	17.7	35.2	5.94
February	15.3	27.2	67	93	18.3	37.5	6.47
March	15.3	26.4	73	91	17.7	37.3	6.43
April	15.1	25.4	80	95	17.1	35.5	6.00
May	14.8	25.0	79	103	16.8	33.4	5.53
June	13.8	25.6	69	109	17.0	32.6	5.42
July	13.2	26.0	61	122	19.0	35.8	5.94
August	14.2	26.8	61	128	18.2	36.3	6.25
September	14.9	26.9	65	125	17.5	36.4	6.39
October	15.1	26.3	70	111	16.4	34.5	6.01
November	15.0	25.4	76	95	15.6	32.2	5.46
December	14.9	25.7	74	90	16.1	32.3	5.43
Average	**14.7**	**26.1**	**70**	**104**	**17.3**	**34.9**	**5.94**

The weather data like minimum and maximum temperature in °C, relative humidity (%), wind speed (km/h), sunshine duration in hours/day were fed into CROPWAT 8.0 computer package. The solar radiation (MJ/m^2/day) and Reference evapotranspiration (ETo) were generated automatically. The results presented in Table 1 revealed that monthly average mean of solar radiation was 34.9 MJ/m^2/day while its range varies from 32.2 MJ/m^2/day to 37.5 MJ/m^2/day. The difference between maximum and minimum solar radiation was found to be 5.3 MJ/m^2/day which is very high. This will require the farmer to supply sufficient water to compensate for water deficit. The lowest solar radiation was recorded in November while the highest solar radiation was recorded in February. In addition, Table 1 shows that the mean ETo for the IPRC Gishari farm experimental site was found to be 5.94 mm/day. Its range varies from 5.43 mm/day to 6.47 mm/day. The maximum ETo was found in the month of February while the minimum was found in the month of December. The difference between maximum and minimum of ETo was found to be 1.04 mm/day.

3.2. Determination of Crop Water Requirement (CWR) of Carrot

In irrigation practice, Crop water requirement is mainly a function of crop evapotranspiration which should be monitored in the mid-stages attributed to more crop water demand owing to full canopy development in addition to evaporative demand. However, in the late stage, though there is not much variation in the atmospheric demand, the transpiration rate decreases due to decrease in physiological activity of plants. The determination of crop water requirement relies effectively on the total precipitation and effective rainfall. The results related to Crop Water Requirement are shown in the subheadings below.

3.2.1. Determination of Effective Rainfall (Eff. Rain) of the Experimental Site

When rain falls, part of the rainwater goes as runoff and another part of the water percolates downward. The remaining part of water stored in the root zone is called effective rainfall. Based on the values of ETo calculated above, the total rain and effective rainfall for different months are shown in Table 2.

Table 2. Determination of Effective Rainfall (Eff. Rain) of the experimental site

Months	ETo (mm/day)	Rain (mm)	Eff. Rain (mm)
January	5.94	109.4	90.3
February	6.47	83.7	72.5
March	6.43	123.1	98.9
April	6.00	122.6	98.6
May	5.53	114.9	93.8
June	5.42	63.1	56.7
July	5.94	53.0	48.5
August	6.25	81.1	70.6
September	6.39	77.0	67.5
October	6.01	102.1	85.4
November	5.46	121.5	97.9
December	5.43	97.1	82.0
Total	**5.94**	**1148.6**	**962.6**

Reference evapotranspiration was computed to be 5.94 mm/day. Its range varies from 5.43 mm/day to 6.47 mm/day. The maximum ETo was found in the month of February while the minimum was found in the month of December. The difference between maximum and minimum of ETo was found to be 1.04 mm/day. The total rainfall (Total Water requirement) and effective rainfall (Crop Water Requirement) was found to be 1148.6 mm and 962.6 mm for the period of twelve months. It was also found that the maximum effective rainfall of 98.9 mm was observed at the end of the month of March and the minimum effective rainfall was found to be 48.5 mm during July. It shows that July is the driest month, which needs more irrigation, and the highest rainfall was found in the end of March with 123.1 mm.

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3.2.2. Determination of Gross Irrigation, Net Irrigation and Water Deficit of the Experimental Site

Net irrigation water requirement (NIWR) is the quantity of water necessary for crop growth. It is expressed in millimeters per year or in m^3/ha per year (1 mm = 10 m^3/ha). It depends on the cropping pattern and the climate. Information on irrigation efficiency is necessary to be able to transform NIWR into gross irrigation water requirement (GIWR), which is the quantity of water to be applied in reality, taking into account water losses. Multiplying GIWR by the area that is suitable for irrigation gives the total water requirement for that area. In this study water requirements are expressed in km^3/year. Based on results concerning the total rainfall, the crop water requirement per decade was given as 207.1 mm/dec and results are summarized in Table 3.

Table 3. Gross Irrigation (GI) and Net Irrigation of the experimental site

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
Period and development stages			coeff	(mm/day)	(mm/dec)	(mm/dec)	(mm/dec)
May	2	Init	0.45	2.49	22.4	29.5	0.00
May	3	Init	0.45	2.47	27.2	28.1	0.00
Jun	1	Deve	0.56	3.04	30.4	22.1	8.30
Jun	2	Deve	0.75	4.07	40.7	17.6	23.10
Jun	3	Deve	0.95	5.29	52.9	17.1	35.80
Jul	1	Mid	1.03	5.95	59.5	16.1	43.40
Jul	2	Mid	1.03	6.13	61.3	14.8	46.50
Jul	3	Late	1.03	6.23	68.6	17.7	50.90
Aug	1	Late	0.98	6.05	60.5	21.8	38.60
Aug	2	Late	0.91	5.70	51.3	22.2	26.60
Total / Average					**474.7**	**207.1**	**273.2**
NIWR =	$\frac{\sum_1^n \text{CWR}\times S_i}{S} = \frac{\sum_1^n \text{Irr Req}\times S_i}{S}$, S is the cultivated area, ha				273.2/0.768 = 355.73 × 10 = 3,557.3 m^3/ha		
GIWR =	NIWR + Water Losses				501.7/0.768 = 653.26 × 10 = 6,532.6 m^3/ha		
Losses	GIWR − NIWR				(6,532.6 − 3,557.3) m^3/ha = 2,975.3 m^3/ha		

Due to high wind speed observed at the experimental site, water losses called water deficit in drip irrigation system was also taken into consideration. Table 3 shows that the total irrigation water requirement for carrot production under drip irrigation for the season starting from 16 May to 19 August was found to be 273.2 mm. This low water requirement for carrot farming is mainly due to higher effective rainfall in the experimental site from 16 May to 19 August found to be 273.2 mm. It was also found out that the Net Irrigation Water Requirement (NIWR) was found to be 3,557.3 m^3/ha which is very low compared to Gross Irrigation Water Requirement (GIWR). As prescribed earlier, Gross Irrigation Water Requirement (GIWR) is the amount of water to be extracted (by diversion, pumping) and applied to the irrigation scheme. It includes NIWR plus water losses. The GIWR from the experimental site was found to be 6,532.6 m^3/ha respectively. The water deficit (water losses) accrued in drip irrigation system was found to be 2,975.3 m^3/ha.

3.2.3. Determination of Irrigation Scheduling of the Experimental Site

Irrigation scheduling is essential for good water management and it deals with two classical questions related to irrigation. These are (1) how much to irrigate and (2) how often to irrigate (irrigation intervals). How often and how to irrigate is a function of irrigation water needs of the crop. However, longer gap between irrigations is maintained in other irrigation systems. In any case, irrigation interval is chosen such that crop does not suffer from water stress. The CROPWAT 8.0 computer package was built to work out the irrigation scheduling by keeping the irrigation efficiency of 70%. The effect of irrigation schedule is shown in Table 4 below.

Based on the results generated from CROPWAT 8.0 computer package, Table 4 brings out the irrigation schedule by indicating the dates and corresponding gross and net irrigation. The planting of carrot started on 16 May of the year and the harvesting date was scheduled on 19 August and the total duration of the crop was 100 days. There were three stages of the crop namely initial stage, development stage, mid stage and harvesting end stage. The water stress coefficient (K_s) was assumed to be 1 and the actual evapotranspiration (ET_a) was assumed as 100% during the entire cropping season.

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Table 4. Irrigation scheduling (Irrigation intervals) of the experimental site

Date	Day	Stage	Rain	Irrigation Scheduling and Rainfall							
Irrigation scheduling			Mm	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
				fract.	%	%	Mm	mm	mm	Mm	L/s/ha
16-May	5	Init	0.00	1.00	100.00	50.00	10.00	0.00	0.00	14.20	0.33
21-May	10	Init	0.00	1.00	100.00	57.00	12.40	0.00	0.00	17.80	0.41
1-Jun	21	Dev	0.00	1.00	100.00	60.00	15.40	0.00	0.00	22.00	0.23
11-Jun	31	Dev	0.00	1.00	100.00	55.00	16.20	0.00	0.00	23.20	0.27
16-Jun	36	Dev	0.00	1.00	100.00	52.00	16.30	0.00	0.00	23.30	0.54
21-Jun	41	Dev	0.00	1.00	100.00	65.00	21.60	0.00	0.00	30.80	0.71
26-Jun	46	Dev	0.00	1.00	100.00	61.00	21.10	0.00	0.00	30.20	0.70
30-Jun	50	Dev	0.00	1.00	100.00	58.00	21.10	0.00	0.00	30.20	0.87
5-Jul	55	Mid	0.00	1.00	100.00	58.00	21.00	0.00	0.00	30.00	0.69
10-Jul	60	Mid	0.00	1.00	100.00	66.00	23.80	0.00	0.00	34.00	0.79
15-Jul	65	Mid	0.00	1.00	100.00	63.00	22.70	0.00	0.00	32.50	0.75
19-Jul	69	Mid	0.00	1.00	100.00	51.00	18.40	0.00	0.00	26.30	0.76
22-Jul	72	Mid	0.00	1.00	100.00	51.00	18.60	0.00	0.00	26.60	1.03
25-Jul	75	Mid	0.00	1.00	100.00	52.00	18.70	0.00	0.00	26.70	1.03
29-Jul	79	Mid	0.00	1.00	100.00	52.00	18.70	0.00	0.00	26.70	0.77
1-Aug	82	End	0.00	1.00	100.00	51.00	18.50	0.00	0.00	26.40	1.02
5-Aug	86	End	0.00	1.00	100.00	50.00	18.10	0.00	0.00	25.90	0.75
9-Aug	90	End	0.00	1.00	100.00	50.00	18.10	0.00	0.00	25.90	0.75
15-Aug	96	End	0.00	1.00	100.00	56.00	20.30	0.00	0.00	29.00	0.56
19-Aug	End	End	0.00	1.00	0.00	32.00					
Total Irrigation requirement (16 May to 19 August)							**351**	**0.00**	**0.00**	**501.7**	**12.96**

Irrigation Scheduling	**Quantity**	**Rainfall parameters**	**Quantity**
Total Irrigation	501.60 mm	Total rainfall	243.9 mm
Total Net Irrigation	351.10 mm	Effective rainfall	107.9 mm
Total Irrigation Losses	0.00 mm	Total rain loss	136 mm
Actual water use by crop	469 mm	Moist deficit at harvest	11.4 mm
Potential water by crop	469 mm	Actual Irrigation requirement	361 mm
Efficiency Irrigation schedule	100%	Efficiency Rain	44.3%
Deficiency Irrigation schedule	0.00%	–	–

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The moisture depletion pattern during the irrigation schedule varies from 32% to 66% with an average depletion of 54.5% for the whole cropping period. The net irrigation supplied to the field varies from 10 mm to 23.8 mm with an average net irrigation requirement 18.47 mm. The total net irrigation supplied to the field was 351 mm. It was found that there was no deficit of irrigation to the crop and hence it was marked as 0 mm during the entire cropping schedule of May to August. The gross irrigation water requirement was varying from 14.2 mm to 34 mm with an average gross irrigation requirement of 26.4 mm. The Gross Irrigation requirement was found to be 501.7 mm. During the irrigation scheduling, the average flow rate of water to the field was computed and was found to be 0.68 L/s/ha and its range varies from 0.33 to 0.79 L/s/ha respectively. Similarly, total rainfall during the season was 243.9 mm and the effective rainfall during the season of Sep to March was 107.9 mm. The total rain loss accrued in the field was found to be 136 mm. The computed moisture deficit at the harvesting stage was 11.4 mm. The study findings also showed that the actual irrigation requirement was found to be 361 mm while the irrigation efficiency of the modeling was 100% and the efficiency of rain was 28.7% respectively.

4. Conclusion and Recommendations

It was found that monthly average mean of solar radiation was 34.9 MJ/m^2/day while its range varies from 32.2 MJ/m^2/day to 37.5 MJ/m^2/day. The difference between maximum and minimum solar radiation was found to be 5.3 MJ/m^2/day which is very high.

It was also found that the mean ETo from the experimental site was found to be 5.94 mm/day. Its range varies from 5.43 mm/day to 6.47 mm/day. The maximum ETo was found in the month of February while the minimum was found in the month of December. The difference between maximum and minimum of ETo was found to be 1.04 mm/day.

The total of rainfall (Total Water requirement) and effective rainfall (Crop Water Requirement) was found to be 1148.6 mm and 962.6 mm for the period of twelve months. It was also found that the maximum effective rainfall of 98.9 mm was found at the end of the month of March and the minimum effective rainfall was found to be 48.5 mm during July.

It was found that the total irrigation water requirement for carrot production under drip irrigation for the season starting from 16 May to 19 August was found to be 273.2 mm. It was also found that the Net Irrigation Water Requirement (NIWR) was found to be 3,557.3 m^3/ha which is very low compared to Gross Irrigation Water Requirement (GIWR). The GIWR from the experimental site was found to be 6,532.6 m^3/ha. The water deficit (water losses) accrued in drip irrigation system was found to be 2,975.3 m^3/ha.

There is a need to address the global irrigation efficiency to reduce the water deficit for the installed drip irrigation system to perform perfectly.

Based on the results generated from CROPWAT 8.0 computer package, the planting date of carrot started on 16 May of the year and the harvesting date was scheduled on 19 August and the total duration of the crop was 100 days. The water stress coefficient (K_s) was assumed to be 1 and the actual evapotranspiration (ET_a) was assumed as 100% during the entire cropping season. The moisture depletion pattern during the irrigation schedule varies from 32% to 66% with an average depletion of 54.5% for the whole cropping period. The net irrigation supplied to the field varies from 10 mm to 23.8 mm with an average net irrigation requirement 18.47 mm. The total net irrigation supplied to the field was 351 mm. The gross irrigation water requirement was varying from 14.2 mm to 34 mm with an average gross irrigation requirement of 26.4 mm.

Referring to irrigation scheduling, it was found that the Gross Irrigation requirement was 501.7 mm. The average flow rate of water to the field was computed and worked out to be 0.68 L/s/ha and its range varies from 0.33 to 0.79 L/s/ha. It was also found that total rainfall during the season was 243.9 mm and the effective rainfall during the season of Sep to March was 107.9 mm. The total rain loss accrued in the field was found to be 136 mm. The computed moisture deficit at the harvesting stage was 11.4 mm. The study findings also showed that the actual irrigation requirement was found to be 361 mm while the irrigation efficiency of the modeling was 100% and the efficiency of rain was 28.7%. Hence, based on the above conclusion, a similar study could be undertaken to assess the root cause of improper water delivery into the field at 100% as was pumped by the pumping unit.

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