

Enhancing Mulberry Growth and Leaf Yield through Sensor-Based Drip Irrigation and Nitrogen Management

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ABSTRACT

Global water use is rising, especially in developing countries like India where irrigation is the largest consumers of fresh water. Although drip irrigation is well known for its application efficiency, reduced soil erosion, weed growth and labour requirements, it lacks decision-making based on soil moisture content to determine when and how much to irrigate, often leading to over- or under-irrigation by farmers. A field experiment was conducted to study the effect of soil moisture sensor-based drip irrigation and nitrogen management on growth and yield in mulberry at GKVK, Bengaluru during 2022-23. There were nine treatment combinations of Horizontal factor (irrigation management) included conventional drip irrigation (I_1), yellow soil moisture indicator (YSMI) (I_2)-based irrigation and sensor-based drip irrigation (I_3), whereas vertical factor (nitrogen management) included no nitrogen (N_1) (control), 100 per cent recommended dose of nitrogen (N_2) and NDVI based nano urea application (N_3) laid out in strip plot design. Among different treatment combination, sensor-based drip irrigation with NDVI based nano urea application recorded significantly higher shoot length (54.61, 105.37 and 119.06 cm at 30, 45 and 60 DAP, respectively), number of shoots plant⁻¹ (18.47, 25.27 and 25.73 at 30, 45 and 60 DAP, respectively), number of leaves plant⁻¹ (144.92, 305.93 and 334.76 at 30, 45 and 60 DAP, respectively), leaf area (74.18, 131.72 and 166.07 cm² at 30, 45 and 60 DAP, respectively), leaf dry matter accumulation (54.39, 211.03 and 335.15 g plant⁻¹ at 30, 45 and 60 DAP, respectively) and highest leaf yield (718.20 g plant⁻¹) at 60 DAP compared to other treatment combinations, whereas the lowest growth and yield parameters were observed under YSMI (I_2N_1). These results showed that sensor-based drip irrigation with NDVI based nano urea application is appropriate to enhance leaf yield and water productivity in mulberry.

Keywords : Mulberry, Soilmoisture sensor, Drip irrigation, IoT, Sericulture

THE 2023 edition of the United Nations (UN) World Water Development Report (WWDR) has provided an update on the present trends of clean water availability and future expectations. Water use has been increasing globally by roughly 1 per cent per year over the last 40 years and is expected to grow at a similar rate through to 2050, driven by a combination of population growth, socio-economic development and changing consumption patterns.

The bulk of this increase is concentrated in middle and lower-income countries, particularly in emerging economies like India (Koncagul and Connor, 2023). India had abundant supply of water resources. However, from being a water abundant country, gradually progressing towards water scarcity due to increasing population pressure and urbanization. At present, it is sustaining 18 per cent of world population with only 4 per cent of global

water resources (Kapahi *et al.*, 2022, Rajaram & Qadri, 2014 and Chakraborti, *et al.*, 2019).

Due to the increasing population in the country, the national per capita annual availability of water has reduced from 1,816 cubic metre in 2001 to 1,544 cubic metre in 2011. This is a reduction of 15 per cent (Baggio *et al.*, 2021, Kummur *et al.*, 2016 and Gulati *et al.*, 2018). The first consequence of scarcity is increasing use and depletion of groundwater. The rate of global groundwater storage depletion is estimated to be between 100 and 200 km³/year, accounting for 15 to 25 per cent of all groundwater withdrawals. India, the world's largest user of groundwater, extracts an estimated 251 km³ annually, with 89 per cent of this water being used for irrigation (Pointet, 2022, Pramanik *et al.*, 2022, Anonymous, 2023b and Joshi, *et al.*, 2021) 9 per cent for domestic use and 2 per cent for industrial use of total extraction (Suhag, 2016).

Irrigation is a technical measure used to replenish water necessary for crop growth and adequate water supply is critical for normal crop growth and high and stable yields. As a result, irrigation is a critical consideration. However, conventional irrigation methods not only result in overwatering but also raise the risk of ground water pollution due to the leaching of chemicals and nutrients from the crop's root zone, contributing to the depletion of freshwater resources (Yang *et al.*, 2023). The advent of drip-irrigation is a significant technological improvement in irrigation system which helps in combating water scarcity in agriculture and its allied sectors. Mulberry silkworm is a monophagous insect which reared only on the leaves of mulberry (*Morus* spp.) (Mahimasanthi *et al.*, 2019). About 80 per cent of mulberry garden in the country is under irrigated condition which shows the importance of irrigation for the mulberry crop (Rajaram and Qadri, 2014).

Mulberry requires about 1.5-2.0" acre water per irrigation at an interval of 6 - 12 days depending upon the type of soil and seasons. About eight number of irrigations is required per crop of 65-70 days duration to achieve the maximum leaf yield. Thus, the annual

requirement of irrigation water for 5 crops is about 75" acre equal to 1875 mm rainfall distributed equally at 36 mm per week or 5-6 mm per day (Dandin *et al.*, 2003 and Rajaram, *et al.*, 2016). But about 80 per cent of average annual rainfall of 1,160 mm (Lal, 2000, Gupta & Deshpande, 2004) is received in 4-5 months in our country, hence the irrigation demand for mulberry crop is not possible to meet by rainfall alone.

India is second largest silk producing country in the world with a share of 41.40 per cent of raw silk production in the world (Anonymous, 2023a) and is unique in producing of all known four varieties of natural silk namely Mulberry, Tasar, Eri and Muga. Among the four varieties of silk, Mulberry silk is the most popular one contributing around 75.59 per cent of total raw silk production of the country from 2.53 lakh ha of mulberry cultivation (CSB 2022-23). Of the total mulberry silk of 27,654 MT produced in the country about 92.70 per cent is produced from the traditional sericulture states namely Karnataka, Andhra Pradesh, Tamil Nadu and West Bengal. During 2020-21, India produced around a total of 38913 MT raw silk, which created an employment opportunity to 9.76 million persons (Kumar and Kumar, 2024).

In recent years, the adoption of drip irrigation gains momentum owing to its positive impact on productivity and quality of produces. In present days, automation of irrigation system has been proposed as a water saving technique in crop production (Panigrahi, *et al.*, 2019). For the crop water relationship, an automated irrigation system may irrigate fields based on the available soil moisture, soil type and climatic parameters. These technologies are ideal for precisely irrigating fields using drip irrigation systems in the existing water and manpower constraints. Integration of automation with drip irrigation may further increase the water saving and yield under drip irrigation (Krishna desai & Mudalagiriappa, 2022 and Kumar, *et al.*, 2023).

The mulberry silkworm (*Bombyx mori*), a monophagous insect, derives nearly 70 per cent of its silk protein from the proteins in mulberry leaves for

its growth and development. Nitrogen is the major constituent for protein (Umesha & Sannappa, 2014). Urea is the most widely used N-fertilizer due to its high nitrogen content 46 per cent and cost efficiency. However, its low use efficiency leads to significant losses, causing environmental issues like nitrate leaching and N-oxide emissions (Lawrencia, *et al.*, 2021). Now a days, nano fertilizers are aimed to make nutrients more available to leaves, consequently increasing nutrient use efficiency (Goutam, *et al.*, 2023).

Therefore, by keeping above aspects and their importance, the present study was carried out to study the performance of automated drip irrigation and nitrogen management through nano urea in mulberry.

MATERIAL AND METHODS

Experimental Site

Field experiment was carried out during 2022-2023 at the Department of Sericulture, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru. The experimental site is located in the Eastern Dry Zone (zone-5) of Karnataka at 12°58'2" N latitude and 77°35'2" E longitude and at an altitude of 930 m above mean sea level. The soil of the experimental plot is clay loam in texture. Furthermore, the experimental site exhibited the annual precipitation of 941.5 mm, mean maximum temperature of 29.2°C, mean minimum temperature of 17.9°C, average relative humidity of 66.5 per cent, average wind speed of 7.7 Kmph, mean potential evapotranspiration of 4.8 mm and average sunshine hours of 7.1 as the average climate values for the past 50 years (1972 to 2022). The variety selected for the study was Victory-1 (V1), which is the ruling mulberry variety of south Indian states. During field experiment, the precipitation varied at 17.35 per cent higher in 2023 compared to average climatic value of last 50 years. The average humidity value is 0.5 per cent higher in 2023. Similarly, the average high temperature showed a gradually increasing trend, that is 0.1 °C higher than corresponding average climatic value. Conversely the average wind

speed was 3 Kmph lesser when compared to average climatic value of last 50 years. The PET value showed a value of 4.8 which is 0.7 mm higher than average PET value of last 50 years. The meteorological data pertaining to monthly total rainfall, mean maximum and minimum temperature, relative humidity, bright sunshine hours and evaporation of experimental site were recorded and furnished in Table 1.

Treatments and Layout

Automatic irrigation was scheduled using soil moisture sensor in mulberry. There were nine treatment combinations comprising of three different drip irrigation and nitrogen management methods, replicated three times and laid out in strip plot design. In the experimental design, Horizontal factor included irrigation management methods such as conventional drip irrigation (I_1), yellow soil moisture (SMI) indicator-based irrigation (I_2) and sensor-based drip irrigation (I_3), whereas vertical factor includes nitrogen management methods *viz.*, included no nitrogen (N_1) (control), 100 per cent recommended dose of nitrogen (N_2) and Normalized Difference Vegetation Index (NDVI) based nano urea application (N_3). Soil water sensor-based irrigation was performed at 50 per cent depletion of available soil moisture in the top 0.3m soil layer. The performance of automated drip irrigation was compared with manually operated drip Irrigation in the mulberry crop. A plot (47.88m²) with 24 plants in 4 adjacent rows was taken, leaving the border effect there were eight centrally located plants of each plot, which were considered as experimental plants for recording growth and developmental parameters.

Irrigation Scheduling and Crop Management Practices

Irrigation was scheduled through drip system with 2L per hour emitter discharge per plant fixed on high density polyethylene lateral pipe and PVC sub-main and main pipe. Water was supplied to mains using an immersible pump from the aborewell. The water from the borewell flows through macro sand filter, which filters the sand particles, with the help of backflush the sediment is flushed out,

TABLE 1
Meteorological data of the experimental site during 2022-23 at GKVK, UAS, Bangalore

Month	Rainfall (mm)		Mean Relative Humidity- RH (%)			Mean Daily Air Temperature (°C)						Mean Daily Sunshine Hours (SSH) (hr day ⁻¹)			Mean PET (mm)			
	N	A	D	N	A	D	Minimum (T-min)			Maximum (T-max)			N	A	D	N	A	D
							N	A	D	N	A	D						
November-2022	60.6	30	-30.6	87	87	0	26.8	25.2	-1.6	16.7	16.6	-0.1	6.3	5.3	-1	3.2	2.7	-0.5
December- 2022	14.3	94.6	80.3	87	89	2	26.3	25.8	-0.5	14.8	16.4	1.6	7.2	6	-1.2	3.1	3.2	0.1
January- 2023	1.5	0	-1.5	86	83	-3	27.4	26.6	-0.8	14.1	13.5	-0.6	8.8	8.2	-0.6	3.4	4.0	0.6
February- 2023	9.1	0	-9.1	81	76	-5	29.8	29.8	0	15.5	15.6	0.1	9.6	9.1	-0.5	4.1	4.8	0.7
March- 2023	16.6	24.8	8.2	77	75	-2	32.6	31.1	-1.5	18	18.3	0.3	9.3	8.4	-0.9	4.8	5.2	0.4
April- 2023	49.2	24.8	-24.4	80	82	2	33.6	33.3	-0.3	20.5	20.5	0	8.2	8.2	0	5.1	3.9	-1.2
May- 2023	109.3	154.8	45.5	83	86	3	32.9	31.4	-1.5	20.5	21.1	0.6	8.2	7.1	-1.1	5.1	5.1	0
June- 2023	82.2	67	-15.2	87	82	-5	29.5	31.2	1.7	19.5	20.5	1	5.9	7.3	1.4	4.5	4.5	0
July- 2023	106.8	115.2	8.4	88	81	-7	28.2	28.3	0.1	19.1	19.6	0.5	4.5	3.1	-1.4	4.1	4.4	0.3
August- 2023	130	25.8	-104.2	89	84	-5	27.7	30.5	2.8	18.9	20.2	1.3	4.7	7.2	2.5	4	4.9	0.9
September- 2023	194	194	0	89	86	-3	28.1	29.3	1.2	18.9	19.8	0.9	5.7	5.7	0	3.8	3.3	-0.5
October- 2023	167.8	67.6	-100.2	88	87	-1	27.9	30.1	2.2	18.3	19.5	1.2	6.1	7.3	1.2	3.6	4.3	0.7
Total	941.4	798.6	-142.8	85.17	83.17	-2	29.23	29.38	0.15	17.9	18.47	0.57	7.04	6.90	-0.14	4.07	4.19	0.12

Note : Monthly rainfall was the sum of daily rainfall of all the days in that month except that all other parameters were averages of all the days. Tmax = Maximum temperature, Tmin = Minimum temperature, RH = Relative humidity, SSH = Bright sunshine hours, N - Normal, mean of past 49 years (1972-2022), PET = Potential evapo transpiration, A - Actual meteorological data during crop period, D - Deviation from the normal (A-D)

then to microfilter, which removes dirt, debris and microscopic particles and then water flows through digital water meter, which records the quantity flown. The drip emitters were placed at 0.5 m away from plant stem.

In soil moisture sensor-based drip Irrigation (I_3), the soil multipoint moisture sensor was installed at 30 cm soil depth and irrigation was scheduled using soil moisture depletion approach, *i.e.*, The moisture content between field capacity (FC) and permanent wilting point (PWP) is considered as available water.

$$\text{Available water (AW)} = FC - PWP \dots\dots\dots(1)$$

AW is the maximum available moisture content (% v/v), FC is the moisture content at field capacity (% v/v) and PWP is the moisture content at permanent wilting point (% v/v) (Rai *et al.*, 2017). when the soil moisture in the root zone of mulberry plants depleted to 50 per cent of the available soil moisture (DASM), the multipoint sensor recorded the values and sent a signal to a solenoid valve powered by a solar panel. This action opened the valve for irrigation and simultaneously sent a signal to the IoT gateway, which was installed at the

highest point of the Department of Sericulture building. The IoT controller then notified the user to activate the immersible motor pump. Irrigation continued until the soil moisture level reached field capacity, as recorded by the soil sensor. All data and system activities were accessed through the web or mobile application developed by Cultivate. The schematic layout of sensor-based drip irrigation is given in Fig. 1.

In conventional drip irrigation (I_1), the irrigation was scheduled based on irrigation water/cumulative pan evaporation (IW/CPE) approach. The first drip irrigation was given immediately after pruning of crop. Then drip irrigation was executed as per IW/CPE ratio 0.8, the cumulative pan evaporation (CPE) values were calculated from daily pan evaporation observed with the help of Class A open pan evaporimeter installed at the UAS, GKVK, Bengaluru. The amount of irrigation required to be given is estimated using the formula, (Seenappa and Devakumar, 2015),

$$IW/ CPE = 0.8 \dots\dots\dots(2)$$

The amount of evaporation per time unit (day) was calculated considering the rainfall. This is the pan

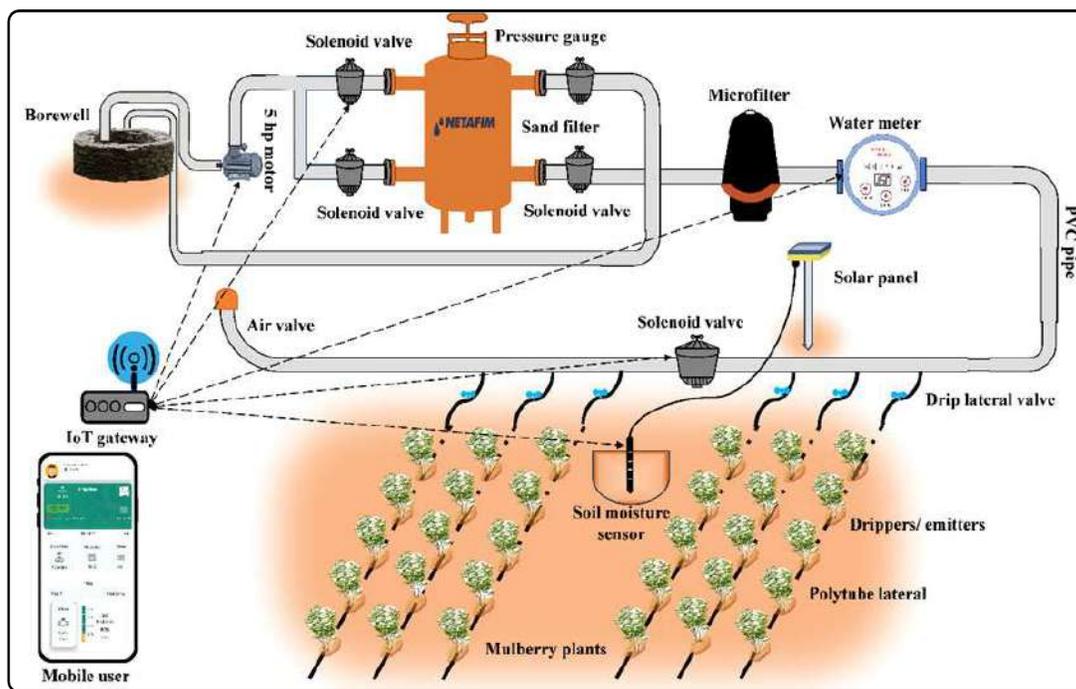


Fig. 1 : Schematic layout of the sensor - based drip irrigation

evaporation: Epan (mm day⁻¹). The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

$$ET_o = K_p * E_{pan} \dots\dots\dots(3)$$

Whereas,

ET_o is reference evapotranspiration (mm day⁻¹),

K_p is pan coefficient,

Epan is pan evaporation (mm day⁻¹) (Allen *et al.*, 1998)

The water in the pan and the standard grass field do not react in exactly the same way to the climate. Therefore, a special coefficient is used (K_p) to relate one to the other. For the Class A evaporation pan, the K pan varies between 0.35 and 0.85 (Avg. = 0.70). The pan evapotranspiration (ET_o) value for 3 days was recorded to get cumulative pan evaporation. Based on the formula (2), the amount of irrigation required is calculated and applied.

In Yellow SMI based drip irrigation (I₂), the soil moisture sensor was installed in plot, whenever the indicator shows yellow LED, it indicates that Low moisture is available, irrigation is necessary, the irrigation is started manually through drip, till it shows blue LED, which is ample moisture available, no need of further irrigation.

Further, under vertical factor, zero nitrogen application (N₁), 100 per cent Recommended dose of nitrogen application (N₂) is given along with other standard packages of practices for mulberry and NDVI based Nano urea application is carried out with help of Green seeker instrument which works on optical sensor technology by emitting and measuring the reflection of light at two specific wave lengths one in the visible spectrum (660 nm) and other in the near-infrared spectrum (770 nm). Measured spectral reflectance is expressed as spectral vegetation indices such as Normalized Difference Vegetation Index (NDVI). NDVI values typically range from 0 to 1, higher value indicating healthier and nitrogen rich vegetation.

Measurements and Analysis

The quantities of water applied under different treatments were recorded using water meters and manually calculated using formula,

$$\text{Irrigation duration} = \frac{\text{Volume of water needed}}{\text{Emitter discharge} \times \text{No of emitters}}$$

The plant vegetative growth parameters such as shoot length (cm), No. of shoots plant⁻¹, No. of leaves plant⁻¹, Single leaf area (cm²), Internodal distance (cm) and Leaf dry matter accumulation (g plant⁻¹) were recorder at different intervals, 30, 45 and 60 Days after pruning (DAP) and leaf yield (g plant⁻¹) were recorded at the end of each season. The total yield ha⁻¹ (MT) under different treatments were calculated by multiplying the number of plants per ha (13887 no.) with average weight of leaf per plant.

Statistical Analysis

The data generated were subjected to analysis of variance (ANOVA) and seperation of means was obtained using Duncan multiple range test (DMRT), using O.P. Stat software (Strip plot design). The treatment means and interaction effects were compared using critical difference values at 5 per cent.

RESULTS AND DISCUSSION

Mulberry Vegetative Growth Parameters

The plant vegetative growth under different methods of irrigation and nitrogen management treatments is presented in Table 2 & 3. The growth parameters *viz.* shoot length and no. of shoots plant⁻¹ of mulberry were significantly influenced by different methods of irrigation and nitrogen management at 45 and 60 DAP. However, the highest shoot length and no. of shoots plant⁻¹ did not differ significantly with respect to interaction effect at 30 DAP. The maximum growth and no. of shoots per plant were observed in sensor-based drip irrigated plot (I₃), whereas the minimum values were recorded in Yellow SMI based drip irrigation (I₂). Among the interaction effect, the treatment (T₆) sensor-based drip irrigation with NDVI based nano urea application showed maximum growth and least was observed in treatment (T₄) yellow SMI based drip irrigation with zero nitrogen

TABLE 2
Highest shoot length (cm) of mulberry at various growth stages influenced by different methods of irrigation and nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	49.97	91.98	104.81
I ₂	44.13	82.74	93.79
I ₃	50.38	95.53	112.81
F-test	*	*	*
S.Em. ±	0.463	0.81	3.523
CD @ 5 %	1.39	2.261	9.83
Nitrogen management (N)			
N ₁	44.77	81.92	94.32
N ₂	48.09	89.85	104.61
N ₃	51.61	98.48	112.48
F-test	*	*	*
S.Em. ±	0.769	0.49	2.296
CD @ 5 %	2.147	1.371	6.408
Interaction (I×N)			
T ₁ - I ₁ N ₁	45.67	80.08	89.63
T ₂ - I ₁ N ₂	50.65	92.56	109.81
T ₃ - I ₁ N ₃	53.60	103.30	114.99
T ₄ - I ₂ N ₁	41.77	78.20	85.41
T ₅ - I ₂ N ₂	43.98	83.24	92.56
T ₆ - I ₂ N ₃	46.63	86.78	103.39
T ₇ - I ₃ N ₁	46.89	87.47	107.92
T ₈ - I ₃ N ₂	49.63	93.75	111.45
T ₉ - I ₃ N ₃	54.61	105.37	119.06
F-test	NS	*	*
S.Em. ±	1.097	1.764	1.464
CD @ 5 %	-	4.924	4.085

*Significant at 5%, NS- Non significant,
 DAP - Days after pruning,

DASM = Depletion of available soil moisture and
 SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

TABLE 3
Number of shoots plant⁻¹ of mulberry at various growth stages influenced by different methods of irrigation and nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	17.44	22.33	22.96
I ₂	15.73	20.87	21.51
I ₃	17.67	23.76	24.51
F-test	NS	*	*
S.Em. ±	0.734	0.256	0.33
CD @ 5 %	-	0.716	0.921
Nitrogen management (N)			
N ₁	15.96	20.36	20.93
N ₂	16.96	22.62	23.33
N ₃	17.93	23.98	24.71
F-test	NS	*	*
S.Em. ±	1.017	0.48	0.504
CD @ 5 %	-	1.341	1.408
Interaction (I×N)			
T ₁ - I ₁ N ₁	15.87	19.87	20.27
T ₂ - I ₁ N ₂	17.20	22.67	23.13
T ₃ - I ₁ N ₃	19.27	24.47	25.47
T ₄ - I ₂ N ₁	15.27	18.93	19.47
T ₅ - I ₂ N ₂	15.87	21.47	22.13
T ₆ - I ₂ N ₃	16.07	22.20	22.93
T ₇ - I ₃ N ₁	16.75	22.27	23.07
T ₈ - I ₃ N ₂	17.80	23.73	24.73
T ₉ - I ₃ N ₃	18.47	25.27	25.73
F-test	NS	NS	NS
S.Em. ±	0.706	0.518	0.674
CD @ 5 %	-	-	-

*Significant at 5%, NS- Non significant,
 DAP - Days after pruning,

DASM = Depletion of available soil moisture and
 SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

application. This may be due to the maximum availability of water in sensor-based irrigation and miniature dimension of nano urea, that helped to absorb and assimilate at faster rate (Sharma *et al.*, 2022) and also when nano urea given in split dose using NDVI, nitrogen losses will be at lower rate. Whereas the interaction effect among different treatment combination for no. of shoots per plant found non-significant.

Mulberry Leaf Growth Parameters

The parameters *viz.* number of leaves plant⁻¹ and single leaf area were significantly influenced by different methods of irrigation and nitrogen management at 30, 45 and 60 DAP. The maximum number of leaves and single leaf area were observed in sensor-based drip irrigated plot (I₃) and NDVI based nano urea applied treatment (N₃), whereas the minimum values were recorded in Yellow SMI based drip irrigation (I₂). Among the interaction effect, the treatment (T₉) sensor-based drip irrigation with NDVI based nano urea application showed higher leaf area and number of leaves and least was observed in treatment (T₄) yellow SMI based drip irrigation with zero nitrogen application (Table 4 and 5). The findings are in line with Barkunan *et al.* (2019) recorded higher leaf area in paddy with sensor based automated drip irrigation was mainly due to uniform availability of water at required time and quantity which helped in consistent cell division and cell expansion. Whereas the interaction effect among different treatment combination for number of leaves plant⁻¹ and single leaf area found non-significant at 30 DAP.

Though the internodal distance was decreased by methods of irrigation, but it didn't differ significantly, however the leaf dry matter accumulation in mulberry differed significantly due to methods of irrigation. Among the interaction effect, the treatment (T₉) sensor-based drip irrigation with NDVI based nano urea application showed higher accumulation as the leaf area is increased which in turn increases the dry matter accumulation (Table 6 and 7). The findings are in line with Suma *et al.* (2022) who reported that adequate irrigation with stipulated depletion along

TABLE 4
Number of leaves plant⁻¹ of mulberry at various growth stages influenced by different methods of irrigation and nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	124.54	280.80	308.27
I ₂	110.80	267.60	294.58
I ₃	135.13	289.96	318.15
F-test	*	*	*
S.Em. ±	2.471	0.887	0.611
CD @ 5 %	6.895	2.191	1.705
Nitrogen management (N)			
N ₁	110.85	262.16	289.06
N ₂	125.14	282.07	309.34
N ₃	134.48	294.13	322.59
F-test	*	*	*
S.Em. ±	1.874	1.83	0.88
CD @ 5 %	5.23	5.111	2.472
Interaction (I×N)			
T ₁ - I ₁ N ₁	105.10	258.87	285.86
T ₂ - I ₁ N ₂	131.38	287.20	313.44
T ₃ - I ₁ N ₃	137.13	296.33	325.51
T ₄ - I ₂ N ₁	99.32	255.07	280.63
T ₅ - I ₂ N ₂	111.70	267.60	295.59
T ₆ - I ₂ N ₃	121.38	280.13	307.50
T ₇ - I ₃ N ₁	128.12	272.53	300.70
T ₈ - I ₃ N ₂	132.34	291.40	318.99
T ₉ - I ₃ N ₃	144.92	305.93	334.76
F-test	NS	*	*
S.Em. ±	3.569	1.764	1.324
CD @ 5 %	-	4.923	3.694

*Significant at 5%, NS- Non significant,
DAP - Days after pruning,

DASM = Depletion of available soil moisture and
SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

TABLE 5
Leaf area (cm²) of mulberry at various growth stages influenced by different methods of irrigation and nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	68.27	117.54	137.07
I ₂	64.70	104.86	120.98
I ₃	72.04	123.53	149.44
F-test	*	*	*
S.Em. ±	0.336	1.392	1.44
CD @ 5 %	0.938	3.885	4.029
Nitrogen management (N)			
N ₁	64.60	103.94	119.61
N ₂	69.34	117.08	137.19
N ₃	71.08	124.91	150.70
F-test	*	*	*
S.Em. ±	0.698	1.612	1.06
CD @ 5 %	1.95	4.5	2.958
Interaction (I×N)			
T ₁ - I ₁ N ₁	62.37	101.40	114.51
T ₂ - I ₁ N ₂	70.93	121.82	142.27
T ₃ - I ₁ N ₃	71.52	129.42	154.44
T ₄ - I ₂ N ₁	61.65	93.37	105.46
T ₅ - I ₂ N ₂	64.92	107.60	125.91
T ₆ - I ₂ N ₃	67.54	113.60	131.59
T ₇ - I ₃ N ₁	69.76	117.05	138.87
T ₈ - I ₃ N ₂	72.18	121.83	143.40
T ₉ - I ₃ N ₃	74.18	131.72	166.07
F-test	NS	*	*
S.Em. ±	1.447	1.907	2.832
CD @ 5 %	-	5.323	7.904

*Significant at 5%, NS- Non significant,
DAP - Days after pruning,

DASM = Depletion of available soil moisture and
SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

TABLE 6
Internodal distance (cm) of mulberry at various growth stages as influenced by different methods of irrigation and nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	5.55	5.67	5.74
I ₂	5.67	5.78	5.87
I ₃	5.49	5.61	5.68
F-test	*	*	*
S.Em. ±	0.015	0.029	0.027
CD @ 5 %	0.044	0.081	0.078
Nitrogen management (N)			
N ₁	5.68	5.79	5.88
N ₂	5.56	5.68	5.74
N ₃	5.47	5.59	5.66
F-test	*	*	*
S.Em. ±	0.031	0.008	0.012
CD @ 5 %	0.089	0.024	0.036
Interaction (I×N)			
T ₁ - I ₁ N ₁	5.70	5.81	5.90
T ₂ - I ₁ N ₂	5.54	5.67	5.72
T ₃ - I ₁ N ₃	5.41	5.53	5.59
T ₄ - I ₂ N ₁	5.76	5.87	5.94
T ₅ - I ₂ N ₂	5.65	5.76	5.85
T ₆ - I ₂ N ₃	5.60	5.72	5.81
T ₇ - I ₃ N ₁	5.59	5.70	5.81
T ₈ - I ₃ N ₂	5.48	5.61	5.66
T ₉ - I ₃ N ₃	5.40	5.52	5.56
F-test	NS	NS	NS
S.Em. ±	0.027	0.035	0.021
CD @ 5 %	-	-	-

*Significant at 5%, NS- Non significant,
DAP - Days after pruning,

DASM = Depletion of available soil moisture and
SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

TABLE 7
Leaf dry matter accumulation (g plant⁻¹)
in mulberry at various growth stages influenced
by different methods of irrigation and
nitrogen management

Treatments	30 DAP	45 DAP	60 DAP
Irrigation management (I)			
I ₁	48.18	185.88	312.55
I ₂	43.22	170.18	288.69
I ₃	50.41	192.58	321.53
F-test	*	*	*
S.Em. ±	0.406	1.492	0.915
CD @ 5 %	1.133	4.164	2.554
Nitrogen management (N)			
N ₁	41.74	166.67	284.09
N ₂	48.28	183.27	312.91
N ₃	51.81	198.70	325.78
F-test	*	*	*
S.Em. ±	0.389	0.712	1.902
CD @ 5 %	1.088	1.988	5.307
Interaction (I×N)			
T ₁ - I ₁ N ₁	40.63	166.86	286.92
T ₂ - I ₁ N ₂	49.75	187.24	320.93
T ₃ - I ₁ N ₃	54.17	203.54	329.81
T ₄ - I ₂ N ₁	39.84	157.29	260.15
T ₅ - I ₂ N ₂	42.97	171.73	293.54
T ₆ - I ₂ N ₃	46.86	181.52	312.37
T ₇ - I ₃ N ₁	44.74	175.86	305.19
T ₈ - I ₃ N ₂	52.12	190.84	324.26
T ₉ - I ₃ N ₃	54.39	211.03	335.15
F-test	NS	*	*
S.Em. ±	1.227	2.105	1.437
CD @ 5 %	-	5.875	4.012

*Significant at 5%, NS- Non significant,
DAP - Days after pruning,

DASM = Depletion of available soil moisture and
SMI = Soil moisture indicator

Irrigation management - (I)

- I₁ - Drip irrigation as per POP
- I₂ - Yellow SMI based drip irrigation
- I₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

- N₁ - Control (No nitrogen)
- N₂ - 100% RDN as per POP
- N₃ - NDVI based nitrogen management with nano-N

with nano nitrogen spray at regular intervals enhanced dry matter accumulation in aerobic rice because of improved rate of absorption, translocation of nano nitrogen and finally leads to higher assimilation.

Mulberry Leaf Yield Parameters

The data presented in Table 8 shows that leaf yield of mulberry has been significantly influenced due to methods of irrigation in mulberry at 60 DAP. The average water required under sensor-based drip irrigation treatments was 16.22 ha cm compared with 18.50 ha cm in manually operated drip system. However, the sensor-based irrigation produced 3 per cent higher yield (53.57 t ha⁻¹). Among the interaction effect, the treatment (T₉) sensor-based drip irrigation with NDVI based nano urea application showed higher leaf yield and least was observed in treatment (T₄) yellow SMI based drip irrigation with NO nitrogen application.

Similar finding was reported by Suvitha *et al.* (2021) who recorded higher crop yield and WUE of okra under soil moisture sensor-based drip irrigation with 100 per cent RDF which might be due to watering the crop based on their requirement at the required time. Whereas, a conventional method of irrigation registered a lower fruit yield, which might be attributed to larger intervals between the irrigation as well as water loss through evaporation, percolation and conveyance losses will reduce the water uptake resulted in lower yield.

Comparable results were reported by Kumar *et al.* (2023), who found that the grain yield of sweet corn under sensor-based irrigation at 43.5 per cent of field capacity (FC) was significantly higher (14.12 t ha⁻¹) compared to 100 per cent ETc - based drip irrigation (12.22 t ha⁻¹) and sensor - based irrigation at 34.8 per cent FC (10.58 t ha⁻¹).

Among different treatment combinations, sensor-based drip irrigation @ 50 DASM with NDVI based nano urea application showed the better results when compared to other treatment combinations. The higher yield of 57.96 MT/ year (3.1% increase over conventional drip irrigation) with less water

TABLE 8
Leaf yield of mulberry as influenced by different methods of irrigation and nitrogen management at 60 DAP

Treatments	Per plant (g plant ⁻¹)	Per crop (kg ha ⁻¹ crop ⁻¹)	Per year (kg ha ⁻¹ year ⁻¹)	Per year (MT)
Irrigation management (I)				
I ₁	643.17	8650.61	51903.63	51.90
I ₂	580.85	7812.45	46874.70	46.87
I ₃	663.80	8928.05	53568.31	53.57
F-test	*	-	-	-
S.Em. ±	6.699	-	-	-
CD @ 5 %	18.691	-	-	-
Nitrogen management (N)				
N ₁	562.49	7565.45	45392.73	45.39
N ₂	647.28	8705.92	52235.52	52.24
N ₃	678.05	9119.73	54718.39	54.72
F-test	*	-	-	-
S.Em. ±	10.30	-	-	-
CD @ 5 %	28.762	-	-	-
Interaction (I×N)				
T ₁ - I ₁ N ₁	558.21	7507.96	45047.79	45.05
T ₂ - I ₁ N ₂	676.81	9103.05	54618.32	54.62
T ₃ - I ₁ N ₃	694.48	9340.80	56044.78	56.04
T ₄ - I ₂ N ₁	540.10	7264.28	43585.67	43.59
T ₅ - I ₂ N ₂	581.00	7814.41	46886.46	46.89
T ₆ - I ₂ N ₃	621.46	8358.66	50151.98	50.15
T ₇ - I ₃ N ₁	589.15	7924.11	47544.65	47.54
T ₈ - I ₃ N ₂	684.04	9200.30	55201.79	55.20
T ₉ - I ₃ N ₃	718.20	9659.75	57958.50	57.96
F-test	*	-	-	-
S.Em. ±	11.894	-	-	-
CD @ 5 %	33.186	-	-	-

*Significant at 5%, NS- Non significant, DAP - Days after pruning,
DASM = Depletion of available soil moisture and SMI = Soil moisture indicator

Irrigation management - (I)

I₁ - Drip irrigation as per POPI₂ - Yellow SMI based drip irrigationI₃ - Sensor based automated drip irrigation at 50% DASM

Nitrogen management - (N)

N₁ - Control (No nitrogen)N₂ - 100% RDN as per POPN₃ - NDVI based nitrogen management with nano-N

enhanced water productivity under sensor-based irrigation. This proposed system involves the eradication of the difficulties faced by the farmers due to delay in onset of monsoon and improves quality leaf production by optimizing and bringing more area under the irrigation. Based on these results, it can be inferred that soil moisture sensor-based irrigation could be a better option for mulberry cultivation in water scarce regions.

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