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Optimizing Irrigation for Vegetable Crops through Automation under Protected Cultivation

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Abstract

Water scarcity is a major threat to vegetable production, reducing yield up to 50 per cent. To investigate the effect of different irrigation levels on vegetable growth and yield, a two-years field experiment (2021-2022 & 2022-2023) was conducted at AICRP for Dryland Agriculture, UAS, GKVK, Bengaluru. The experiment compared sensor-based irrigation at 75, 50 and 25 per cent ASM levels (available soil moisture) to traditional surface irrigation for four vegetable crops: broccoli, capsicum, pole bean and cherry tomato. Sensor-based irrigation at 75 per cent ASM emerged as the optimum level. Plants grown under 75 per cent ASM exhibited significantly higher plant height (54.20, 87.38, 124.88 and 151.18 cm, respectively), number of leaves (26.43, 50.98, 69.59 and 77.04, respectively), leaf area (465, 1204, 2806 and 3540 cm^2, respectively) and SPAD values (52.01, 54.40, 58.88 and 54.26, respectively) at 30, 60, 90 and 120 DAT/P. Furthermore, scheduling irrigation at 75 per cent ASM resulted in the higher mean yield in all the four vegetables: broccoli (26.05 t ha^{-1}), capsicum (48.59 t ha^{-1}), pole bean (37.08 t ha^{-1}) and cherry tomato (42.02 t ha^{-1}). This study demonstrates that, sensor-based irrigation at 75 per cent ASM is a better promising approach for vegetable production. This approach not only conserves water, but also enhances productivity of vegetables.

Keywords : Dryland agriculture, Broccoli, Capsicum, Cherry tomato, Pole beans, Irrigation

Water, once seemingly plentiful, is swiftly becoming biggest constraint in crop production. Climate change, urbanization and population growth exacerbate this challenge by intensifying competition for this vital resource, placing agricultural demand in direct conflict with domestic and industrial needs. This precarious balance necessitates a fundamental transformation in irrigation practices, prioritizing efficiency, reliability and economic viability (Aris and Agung, 2023).

Traditionally, irrigation practices have often been haphazard, marked by waste and inefficiency. This is not only squandering a precious resource but also negatively impacts on crop yield. Therefore, it is essential to formulate an efficient, reliable and economically viable irrigation management strategy in order to irrigate more land area with the existing water resources. Sensor-based irrigation systems offer a promising solution. These systems collect real-time data on soil moisture, temperature and other factors, enabling informed decisions regarding irrigation scheduling and water application delivering precise water quantum based on the specific needs of crop at different growth stages (Mirza, 2023).

Water scarcity affects the productivity of all types of crops *i.e.,* field crops, fruit crops, spices and especially vegetable crops. Vegetables, being succulent by definition, for the most part, comprised of mostly more than 90 per cent water (Anonymous, 2010). Therefore, water limitation enormously impacts the growth and yield of vegetables; dry season conditions diminish vegetable profitability and productivity.

Vegetables are essential part of a healthy diet, with over 40 per cent of the population in India depends on them for their daily meals. Popular exotic vegetables like broccoli, capsicum, pole beans and cherry tomato are cultivated worldwide and offer valuable health benefits. They showcase diverse culinary uses, from raw consumption to incorporation in various dishes. Each has unique characteristics: broccoli for its health, capsicum for its spice, cherry tomatoes for their sweetness and pole beans for their climbing habit which maximise the garden space. Yield of these vegetables suffers due to excess/ inadequate irrigation management, Therefore, the effect of different irrigation levels on vegetable production needs serious attention (Singh *et al*., 2013). This article focus mainly on the effect of sensor based different irrigation levels on the growth, physiological process and yield of vegetables.

Material and Methods

A field experiment on sensor-based irrigation in broccoli, capsicum, pole bean and cherry tomato under protected condition was carried out during *kharif* 2022 and 2023 at AICRP on Dryland Agriculture, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore. The site of experimentation was in Agro Climatic Zone V (Eastern Dry Zone) of Karnataka, located in 12º 51' N Latitude and 77º 35' E Longitude at an altitude of 930 m above mean sea level (MSL). The soil of the experimental site is red sandy loam with 53.4 per cent coarse sand, 14.8 per cent fine sand, 16.6 per cent silt and 15.2 per cent clay as soil components. The soil reaction was acidic (5.26) with EC of 0.14 dS m^{-1}, low in available nitrogen (252.86 kg ha^{-1}), available phosphorus (49.31 kg ha^{-1}) and available potassium (166.04 kg ha^{-1}). The study was conducted with 16 treatments arranged in FRCBD with three replications. The sixteen treatments include: 75 per cent ASM + broccoli, 50 per cent ASM + broccoli, 25 per cent ASM + broccoli, surface irrigation + broccoli, 75 per cent ASM + capsicum, 50 per cent ASM + capsicum, 25 per cent ASM + capsicum, surface irrigation + capsicum, 75 per cent ASM + pole bean, 50 per cent ASM + pole bean, 25 per cent ASM + pole bean, surface irrigation + pole bean, 75 per cent ASM + cherry tomato, 50 per cent ASM + cherry tomato, 25 per cent ASM + cherry tomato, surface irrigation + cherry tomato. The land was thoroughly ploughed using a small tiller inside the poly house and brought to a fine tilth. The bed size of 100 cm wide, 15 cm height and 17.1 meter long was prepared manually using a spade. A walking space of 45 cm was maintained between the beds. Seedlings were raised in sterilized cocopeat trays @ one seed per cell. Seedlings of 21-25 days age old were used for broccoli and cherry tomato and 30-35 days old in capsicum. While, pole bean seeds were directly sown in a hole to a depth of 5-6 cm.

Table 1

Crop and variety details

Crop	Variety	Spacing	Sowing dates	
			2021-22	2022-23
Broccoli	Saaki	30 cm x 30 cm	13-8-2021	8-8-2022
Capsicum	Indira	45 cm x 45 cm	13-8-2021	8-8-2022
Pole beans	Selection - 9	30 cm x 30 cm	13-8-2021	8-8-2022
Cherry tomato	Zyrconita	45 cm x 45 cm	4-8-2021	8-8-2022

Irrigation was provided daily for 30 minutes for the first 15 days. Later, 20 days after transplanting, irrigation water discharge per square meter was based on treatment with an automated sensor irrigation system (Smart Flow) developed by Cultivate, which irrigates based on soil moisture percentages. As for surface irrigation, water was applied through pipe directly to the plots and a water meter was used to measure the amount of water applied for each irrigation.

TABLE 2

Irrigation regimes for different irrigation levels

Irrigation regimes	Vegetative stage	
	FC (Vol %)	ASM (Vol %)
I_1 : 75 % ASM	27.5 %	24.5 %
I_2 : 50 % ASM	27.5 %	21.5 %
I_3 : 25 % ASM	27.5 %	18.5 %
I_4 : Surface irrigation	-	-

Growth parameters like plant height, number of leaves per plant, leaf area and SPAD meter readings of five randomly selected plants were recorded at 30, 60, 90 DAS and at harvest. During each picking, curd/fruits/pods were harvested from the plots as per the treatments, weighed and expressed as t ha^{-1}. Later the respective curd/fruits/pod yield of different crops was converted into capsicum equivalent yield (CEY) using the formula given below.

$$\text{Capsicum equivalent yield (t ha}^{-1}\text{)} = \frac{\text{Yield of crop (kg ha}^{-1}\text{)} \times \text{Price of crop (Rs.kg}^{-1}\text{)}}{\text{Price of capscicum (Rs.kg}^{-1}\text{)}}$$

The differences between 16 treatments in respect of biometric observations and curd/fruit/pod yield was tested for Analysis of Variance (ANOVA) in each year and also pooled over years. Whenever F-test was significant for comparison among the treatment means, an appropriate value of Critical Differences (CD) was worked out. Otherwise against CD values abbreviation 'NS' (Non-Significant) was indicated. All the data was analyzed and the results are presented and discussed at a probability level of 5 per cent (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Plant Height (cm)

Scheduling of irrigation at 75 per cent ASM registered significantly higher plant height at 120 DAT/S (151.18 cm) followed by 50 per cent ASM (147.63 cm) and significantly lower plant height was recorded in scheduling of irrigation at 25 per cent ASM (128.55 cm) compared to surface irrigation (142.81 cm). Irrigating at 75 and 50 per cent ASM has resulted in 5.86 and 3.37 per cent higher plant height over surface irrigation, respectively. Similarly, per cent increase in plant height was observed during 30 DAT/S (6.67%), 60 DAT/S (4.52%) and 90 DAT/S (7.56%) in 75 per cent ASM over surface irrigation (Table 3).

Among the interactions, 75 per cent ASM irrigation led to significantly taller plants in broccoli, capsicum, pole bean and cherry tomato at 120 DAT/S (70.27, 130.46, 192.26 and 211.73 cm, respectively) compared to surface irrigation. However, the 25 per cent ASM irrigation resulted in significantly lower plant height (57.66, 97.74, 174.56 and 184.23 cm, respectively) for all the tested vegetable crops. Similar trend was observed at 30, 60 and 90 DAT/S (Table 3). This decrease in plant height at 25 per cent ASM may be associated to two key factors. Firstly, restricted water availability disrupts photosynthesis process, leading to a shortage of the building blocks needed for growth. Secondly, water stress triggers a cascade of defence mechanisms within the plant. These stress response pathways divert resources towards survival, often at the expense of growth. Plants under water stress may break down existing sugars to fuel these stress-response processes, further reducing the available resources for cell division and elongation, leading to stunted growth and lower plant height. Similar results were reported by Thentu *et al.* (2016) in broccoli; Kumar & Kumar (2017) in bell pepper; Raju *et al.* (2020) and Raddy *et al.* (2022).

Number of Leaves Per Plant

Substantial difference was observed among the irrigation treatments with respect to number of leaves, irrigation at 75 per cent ASM produced significantly

TABLE 3

Influence of irrigation regimes on periodical plant height (cm) of broccoli, capsicum, pole bean and cherry tomato at 30, 60, 90 and 120 DAT/S (2 years pooled data)

Treatments	At 30 DAT/S	At 60 DAT/S	At 90 DAT/S	At 120 DAT/S
I : *Irrigation regimes*				
I_1 : 75 % ASM	54.20	87.38	124.88	151.18
I_2 : 50 % ASM	50.33	81.49	118.03	147.63
I_3 : 25 % ASM	43.63	75.77	106.11	128.55
I_4 : Surface irrigation	50.81	83.60	116.10	142.81
S. Em. ±	0.63	0.52	0.77	1.42
C.D. (p=0.05)	1.83	1.51	2.23	4.10
C : *Different vegetable crops*				
C_1 = Broccoli	36.03	44.36	67.20	66.10
C_2 = Capsicum	32.93	53.10	79.73	119.88
C_3 = Pole bean	96.45	156.30	166.77	181.90
C_4 = Cherry tomato	33.55	74.49	151.40	202.28
Interaction (I×C)				
C_1I_1	40.69	50.41	72.37	70.27
C_1I_2	34.77	40.98	66.81	66.53
C_1I_3	29.50	38.03	58.59	57.66
C_1I_4	39.17	48.00	72.37	69.94
C_2I_1	36.08	57.19	84.99	130.46
C_2I_2	33.60	53.49	82.90	126.28
C_2I_3	28.65	49.20	73.97	97.74
C_2I_4	33.39	52.53	77.07	125.05
C_3I_1	104.32	164.57	175.91	194.26
C_3I_2	97.76	157.16	168.32	192.62
C_3I_3	86.83	147.06	158.80	174.56
C_3I_4	96.90	156.40	164.04	168.17
C_4I_1	37.24	79.77	167.57	211.73
C_4I_2	35.18	74.33	154.07	205.08
C_4I_3	29.54	68.78	133.07	184.23
C_4I_4	32.24	75.07	150.90	208.07
S. Em. ±	1.27	1.05	1.54	2.84
C.D. (p=0.05)	3.66	3.03	4.46	8.20

higher number of leaves (26.43) trailed by 50 per cent ASM (25.00) compared to surface irrigation (23.06 cm). This magnitude of increase was 14.61 and 8.41 per cent, respectively. In contrast, irrigation schedule at 25 per cent ASM recorded significantly lower number of leaves (18.73), which is 18.77 per cent lower than surface irrigation at 30 DAT/between interactions, significantly higher number of leaves at

TABLE 4

Periodical number of leaves plant^{-1} as influenced by irrigation regimes (2 years pooled data)

Treatments	At 30 DAT/S	At 60 DAT/S	At 90 DAT/S	At 120 DAT/S
I: *Irrigation regimes*				
I_1 : 75 % ASM	26.43	50.98	69.59	77.04
I_2 : 50 % ASM	25.00	44.00	62.94	69.38
I_3 : 25% ASM	18.73	38.48	56.30	55.57
I_4 : Surface irrigation	23.06	41.89	63.53	67.88
S. Em. ±	0.33	0.46	0.61	2.05
C.D. (p=0.05)	0.95	1.33	1.78	5.91
C : *Different vegetable crops*				
C_1 = Broccoli	9.86	16.23	20.07	15.07
C_2 = Capsicum	22.71	57.10	95.90	106.50
C_3 = Pole bean	44.04	75.90	82.19	79.88
C_4 = Cherry tomato	16.60	26.11	54.20	68.42
Interaction (I×C)				
$C_1 I_1$	10.23	18.90	21.73	16.23
$C_1 I_2$	9.57	15.23	19.57	14.73
$C_1 I_3$	8.90	13.23	16.90	12.23
$C_1 I_4$	10.73	17.57	22.07	17.07
$C_2 I_1$	27.57	65.08	103.73	120.51
$C_2 I_2$	24.87	58.74	96.07	116.15
$C_2 I_3$	16.47	51.57	92.9	81.16
$C_2 I_4$	21.95	53.00	90.91	108.19
$C_3 I_1$	48.89	90.21	94.17	89.34
$C_3 I_2$	47.66	76.44	82.23	80.07
$C_3 I_3$	36.46	66.52	69.45	70.65
$C_3 I_4$	43.16	70.43	82.91	79.47
$C_4 I_1$	19.02	29.74	58.73	82.07
$C_4 I_2$	17.90	25.57	53.9	66.58
$C_4 I_3$	13.08	22.57	45.93	58.24
$C_4 I_4$	16.41	26.56	57.25	66.78
S. Em. ±	0.66	0.92	1.23	4.10
C.D. (p=0.05)	1.91	2.66	3.55	11.83

30 DAT/S was observed in broccoli, capsicum, pole bean and cherry tomato under the 75 per cent ASM (10.23, 27.57, 48.89 and 19.02 leaves per plant, respectively). The significantly lower number of leaves was under 25 per cent ASM treatment (8.90, 16.47, 36.46 and 13.08 leaves per plant, respectively). Similar trends were observed at 60, 90 and 120 DAT/S (Table 4). The plausible explanations for these results are plants grown under optimal irrigation conditions will have more energy, resources and will

TABLE 5

Influence of irrigation regimes and vegetable crops on leaf area (cm²) at 30, 60, 90 and 120 DAT/S (2 years pooled data)

Treatments	At 30 DAT/S	At 60 DAT/S	At 90 DAT/S	At 120 DAT/S
I: *Irrigation regimes*				
I_1: 75 % ASM	465	1204	2806	3540
I_2: 50 % ASM	424	1053	2338	3208
I_3: 25 % ASM	357	910	1712	2293
I_4: Surface irrigation	418	1016	2272	3143
S. Em. ±	7.56	21.45	66.72	59.53
C.D. (p=0.05)	21.82	61.96	192.70	171.94
C: *Different vegetable crops*				
C_1 = Broccoli	596	841	2386	3761
C_2 = Capsicum	655	1617	3185	4822
C_3 = Pole bean	63	84	144	188
C_4 = Cherry tomato	351	1641	3413	3422
Interaction (I×C)				
C_1I_1	669	1060	3332	4778
C_1I_2	598	849	2626	4359
C_1I_3	287	357	1033	1760
C_1I_4	617	808	2521	4117
C_2I_1	717	1806	3646	5091
C_2I_2	664	1629	3188	4889
C_2I_3	591	1468	2774	4329
C_2I_4	647	1563	3132	4978
C_3I_1	67	89	150	197
C_3I_2	64	86	146	191
C_3I_3	59	78	135	176
C_3I_4	61	84	146	189
C_4I_1	409	1860	4095	4095
C_4I_2	371	1649	3393	3393
C_4I_3	279	1446	2875	2875
C_4I_4	344	1608	3288	3288
S. Em. ±	15.11	42.90	93.79	119.07
C.D. (p=0.05)	43.65	123.91	270.89	343.89

exhibit enhanced nutrient uptake to produce new leaves. Ravish & Singh (2015); Farrag *et al.* (2016) in potato; Hossain & Mohona (2018) in broccoli and Ramya *et al.* (2023), reported similar results.

Leaf Area Per Plant (cm²)

Significantly higher leaf area per plant was observed in 75 per cent ASM at 30, 60, 90 and 120

DAT/S (465, 1204, 2806 and 3540 cm^2, respectively) lags behind 50 per cent ASM (424, 1053, 2338 and 3208 cm^2, respectively). While 25 per cent ASM, recorded lower leaf area per plant (357, 910, 1712 and 2293 cm^2, respectively) compared to surface irrigation (418, 1016, 2272 and 3143 cm^2 respectively). When irrigated with 75 per cent ASM, all four crops *viz.,* broccoli, capsicum, pole beans and cherry tomato exhibited significantly higher leaf area per plant (4778, 5091, 197 and 4095 cm^2 per plant, respectively) at 120 DAT/S. These values were 16.05, 2.26, 3.91 and 24.54 per cent higher than surface irrigation, similar trends were observed at 30, 60 and 90 DAT/S (Table 5). Higher irrigation regime helps plant to maintain a turgid condition leading to wider opening of stomata for longer period, which might remain turgid and increased the leaf area in plants. These findings are consistent with previous studies reported by Ezekiel *et al.* (2013) in tomato and Roti *et al.* (2016) in cabbage; Abdelbaset *et al.* (2023) in lettuce crop and Ramya *et al.* (2023).

SPAD Value

SPAD values were significantly higher in 75 per cent ASM at 30, 60, 90 and 120 DAT/S (52.01, 54.40, 58.88 and 54.26, respectively) followed by 50 per cent ASM (48.62, 52.06, 52.07 and 52.20, respectively). While, 25 per cent ASM recorded significantly lower SPAD value (44.44, 45.10, 46.44 and 47.72, respectively) compared to surface irrigation (48.02, 50.24, 55.44 and 51.10, respectively).

When irrigated with 75 per cent ASM, all four crops *viz.,* broccoli, capsicum, pole bean and cherry tomato exhibited significantly higher SPAD value (68.86, 55.84, 48.80 and 43.55, respectively) followed by 50 per cent ASM (67.81, 54.54, 45.27 and 41.19, respectively). Conversely, significantly lower leaf area was observed with 25 per cent ASM (55.92, 42.37, 43.26 and 39.35, respectively) at 120 DAT/S compared to surface irrigation (Fig. 1). Similar trend was observed at 30, 60 and 90 DAT/S. Elevated nutrient uptake particularly nitrogen was observed under 75 per cent ASM conditions translated to significantly higher SPAD values, since nitrogen is a crucial component of chloroplast porphyrins, plays a direct role in regulating chlorophyll content and leaf greenness. Consequently, both 25 per cent ASM and surface irrigation treatments observed lesser SPAD value. Sezen *et al*. (2008) reported similar findings, which indicatedlarge irrigation intervals reduces colour brightness in green bean.

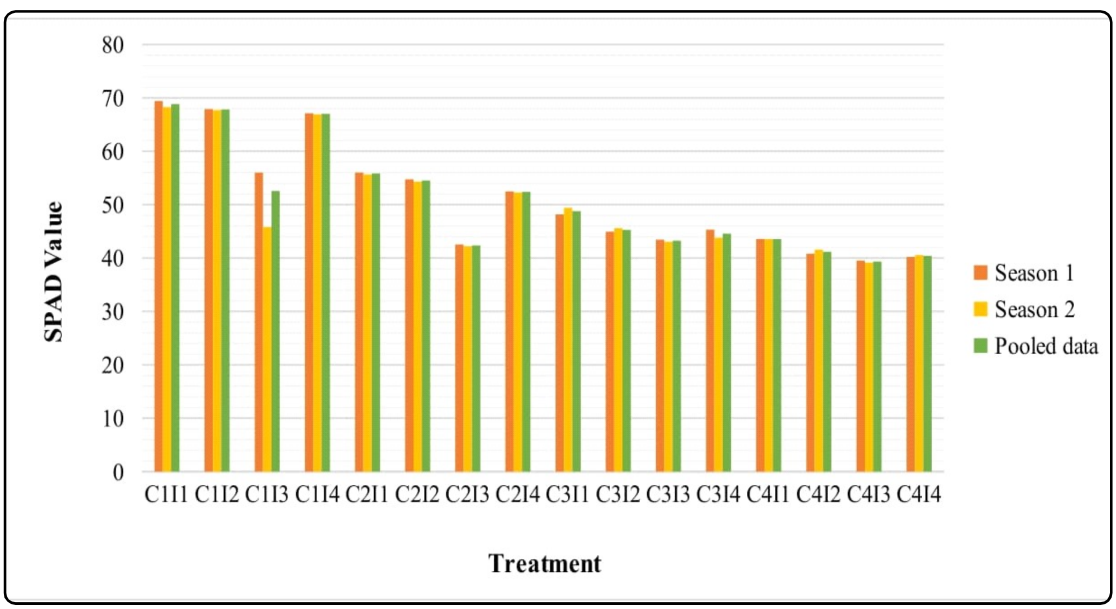

Fig. 1 : Influence of irrigation regimes on SPAD values

Leaf Area Duration (days)

The yield of any crop is directly proportional to its duration. As the duration increases, there will be more availability of opportunity time for light interception, carbon dioxide capture and photosynthesis. This in turn can lead to higher biomass production and crop yield. significantly higher leaf area duration (LAD) was under 75 per cent ASM (16.73, 40.42 and 66.58 days, respectively), trailed by 50 per cent ASM (14.64, 33.71 and 58.03 days, respectively). However, 25 per cent ASM recorded significantly lower LAD (12.35, 23.88 and 37.00 days, respectively) compared to surface irrigation (14.25, 32.59 and 56.25 days, respectively) at 30-60, 60-90 and 90-120 DAT/S.

The combination of broccoli, capsicum, pole bean and cherry tomato with 75 per cent ASM exhibited significantly higher LAD values at 30-60 DAT/S (28.81, 18.80, 2.55 and 16.85 days, respectively), 60-90 DAT/S (73.20, 40.39 3.99 and 44.11 days, respectively) and 90-120 DAT/S (135.17, 64.71, 5.79 and 60.67 days, respectively) and significantly lower LAD was recorded with 25 per cent ASM treatment at 30-60 DAT/S (19.36, 15.25, 2.28 and 16.80 days, respectively), 60 -90 DAT/S (45.31, 31.42, 3.55 and 44.11 days, respectively) and 90-120 DAT/S (68.70, 52.62, 5.18 and 42.59 days, respectively) for broccoli, capsicum, pole bean and cherry tomato (Table 6). Similar findings were also reported by Ningoji *et al.* (2021).

Capsicum Equivalent Yield in Different Crops

The curd/fruit/pod yield of different vegetable crops in different irrigation levels were converted into capsicum equivalent yield to analyse and compare the water productivity. Automated sensor-based scheduling of irrigation at 75 per cent ASM resulted in significantly higher capsicum equivalent yield (38.81 t ha^{-1}) as compared to surface irrigation (33.37 t ha^{-1}) followed by scheduling of irrigation at 50 per cent ASM (34.42 t ha^{-1}) and significantly lower yield was at 25 per cent ASM (30.36 t ha^{-1}). Scheduling irrigation at 75 and 50 per cent ASM registered 16.30 and 3.14 per cent higher fruit yield over surface irrigation (Table 7).

TABLE 6

Leaf area duration (LAD) in days as influenced by irrigation levels in different vegetable crops (2 years pooled data)

Treatments	LAD at 30-60 DAT/S	LAD at 60-90 DAT/S	LAD at 90-120 DAT/S
I: *Irrigation regimes*			
I_1: 75 % ASM	16.73	40.42	66.58
I_2: 50 % ASM	14.64	33.71	58.03
I_3: 25 % ASM	12.35	23.88	37.00
I_4: Surface irrigation	14.25	32.59	56.25
S. Em. ±	0.25	0.65	1.12
C.D. (p=0.05)	0.72	1.89	3.24
C: *Different vegetable crops*			
C_1 = Broccoli	23.95	53.78	102.46
C_2 = Capsicum	16.82	35.57	59.31
C_3 = Pole bean	2.45	3.81	5.54
C_4 = Cherry tomato	14.75	37.43	50.56
Interaction (I×C)			
C_1I_1	28.81	73.20	135.17
C_1I_2	24.12	57.92	116.41
C_1I_3	19.36	45.31	68.70
C_1I_4	23.75	55.49	110.64
C_2I_1	18.69	40.39	64.71
C_2I_2	16.98	35.68	59.83
C_2I_3	15.25	31.42	52.62
C_2I_4	16.37	34.78	60.07
C_3I_1	2.59	3.99	5.79
C_3I_2	2.50	3.87	5.62
C_3I_3	2.28	3.55	5.18
C_3I_4	2.43	3.83	5.58
C_4I_1	16.80	44.11	60.67
C_4I_2	14.96	37.35	50.26
C_4I_3	12.78	32.01	42.59
C_4I_4	14.46	36.27	48.71
S. Em. ±	0.50	1.31	2.24
C.D. (p=0.05)	1.45	3.77	6.48

TABLE 7

Fruit yield of four vegetable crops under four irrigation regimes (2 years pooled data)

Treatments	Capsicum fruit equivalent yield (t ha^{-1})		
	Season-1	Season-2	Pooled
I: *Irrigation regimes*			
I_1: 75 % ASM	38.70	38.92	38.81
I_2: 50 % ASM	35.17	33.67	34.42
I_3: 25 % ASM	30.96	29.73	30.36
I_4: Surface irrigation	33.68	33.05	33.37
S. Em. ±	0.66	0.62	0.49
C.D. (p=0.05)	1.90	1.79	1.41
C: *Different vegetable crops*			
C_1 = Broccoli	22.80	23.30	23.05
C_2 = Capsicum	44.95	44.29	44.62
C_3 = Pole bean	30.98	31.38	31.18
C_4 = Cherry tomato	39.79	36.42	38.11
Interaction (I×C)			
C_1I_1	25.80	26.30	26.05
C_1I_2	23.41	24.52	23.96
C_1I_3	18.45	18.96	18.71
C_1I_4	23.52	23.43	23.47
C_2I_1	49.06	48.11	48.59
C_2I_2	45.60	44.98	45.29
C_2I_3	41.70	39.92	40.81
C_2I_4	43.43	44.16	43.80
C_3I_1	37.41	36.76	37.08
C_3I_2	31.21	32.35	31.78
C_3I_3	25.89	27.07	26.48
C_3I_4	29.40	29.34	29.37
C_4I_1	42.53	41.50	42.02
C_4I_2	40.33	36.92	38.63
C_4I_3	37.81	33.08	35.44
C_4I_4	38.50	34.17	36.33
S. Em. ±	1.31	1.24	0.97
C.D. (p=0.05)	3.79	3.59	2.81

Among the crops, capsicum showed higher capsicum equivalent yield (44.62 t ha^{-1}) followed by cherry tomato (38.11 t ha^{-1}) and pole bean (31.18 t ha^{-1}), while broccoli (23.05 t ha^{-1}) recorded lower equivalent yield. The observed yield differences among tested crops under the same irrigation level stem from a combination of physiological traits, nutrient dynamics, pest susceptibility. Capsicum and cherry tomato exhibited higher yield potential might be due to their drought tolerance, higher NUE and continued harvesting for longer duration.

The results indicated that different vegetable crops responded differently to varying irrigation levels. Capsicum showed a 4.79 t ha^{-1} (10.93%) increase in fruit yield at 75 per cent ASM compared to surface irrigation (43.80 t ha^{-1}), while pole bean and cherry tomato showed an increase of 7.71 t ha^{-1} (26.25%) and 5.69 t ha^{-1} (15.66%), respectively. Broccoli, on the other hand, showed a lower increase in fruit yield from 23.47 to 26.05 t ha^{-1} (10.99%) under the same conditions. Significantly higher curd/fruit/pod was due to improved growth and yield attributes *viz.,* higher plant height, number of leaves per plant, leaf area compared to surface irrigation (Table 3 to 5). Higher productive leaves contributed for higher number of curd/fruits/pods which ultimately contributed for higher yield.

Simple Linear Regression Analysis

Although correlation gives information about the nature of relationship that exists between different variables, the significance of the relation and extent is not well defined (Sanam *et al.,* 2021). In this study, the linear relationships between fruit yield and two crucial growth parameters - plant height and number of leaves - were analyzed under varying irrigation levels (Fig. 2). The results indicate that, the number of leaves has a significantly stronger influence on fruit yield compared to plant height. This is evident from the R-squared values, where the number of leaves account for 77.92 per cent against plant height only accounts for 19.48 percentage.

This study demonstrated that sensor-based irrigation at 75 per cent ASM is a superior approach for

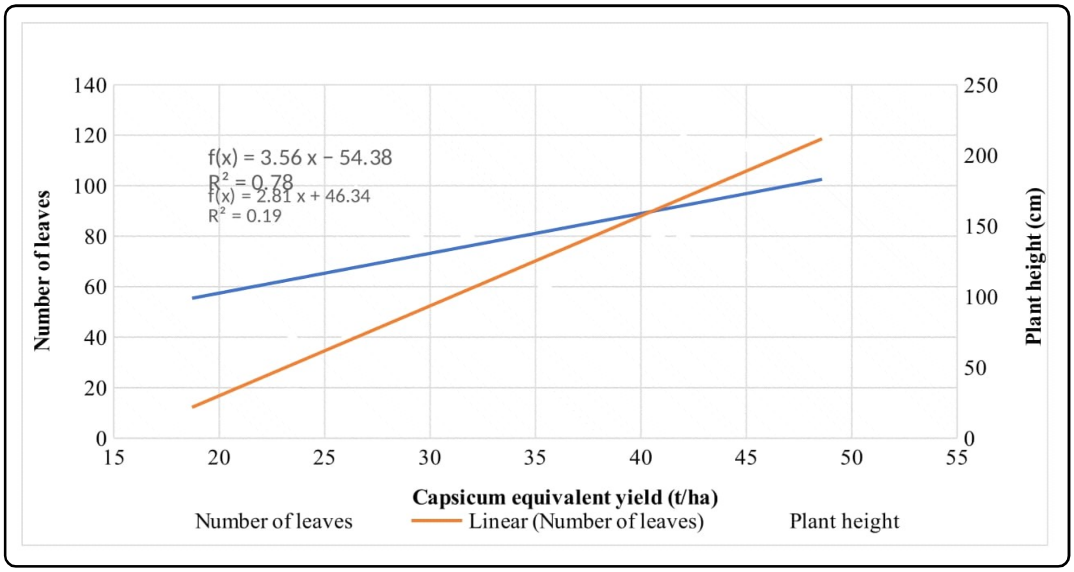

Fig. 2 : Simple linear regression relationship between yield Vs plant height (cm) and number of leaves per plant

sustainable vegetable production, offering significant water conservation and yield enhancement. Widespread adoption of this method has the potential to improve agricultural water management and ensure food security in the face of water scarcity.

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