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Effect of different sensor-based irrigation levels on growth, yield and economic viability of spinach (*Spinacia oleracea* L.) under reduced runoff farming

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Abstract
Sensor based irrigation scheduling plays a vital role to rationalize irrigation water. A field experiment was conducted at AICRP on Dryland Agriculture, UAS, GKVK, Bengaluru during 2021-22 and 2022-23 to study the effect of irrigation scheduling in spinach Irrigation was assessed at 75, 50 and 25% ASM along with surface irrigation as a control. Scheduling irrigation at 75% ASM resulted in significantly higher growth attributes *viz.,* plant height (36.18 and 37.83 cm, respectively), number of leaves (22.61 and 22.19, respectively), leaf length (34.17, 35.23 cm, respectively) leaf width (11.10 and 10.29 cm, respectively), fresh weight (55.95 and 63.38 g plant^{-1}) and dry weight (6.20 and 5.06 g plant^{-1}) at 30 and 60 DAS, respectively. Furthermore, scheduling irrigation at 75% ASM resulted in the higher mean leaf yield (3.85 t ha^{-1}) compared to surface irrigation (2.89 t ha^{-1}). Water use compared to surface irrigation decreased by 60.00 and 57.18 per cent at 75% ASM, 51.90 and 50.92 per cent at 50% ASM and 46.00 and 48.00 per cent at 25% ASM during 2021 and 2022, respectively. WUE followed a descending order: 75% ASM (3.15 kg m^{-3}) > 50% ASM (2.28 kg m^{-3}) > 25% ASM (1.06 kg m^{-3}) > surface irrigation (0.96 kg m^{-3}). The gross return (Rs. 456966 ha^{-1}), net return (Rs. 223736 ha^{-1}) and B: C ratio (1.96) recorded substantially higher at 75% ASM over surface irrigation.

Keywords: Available Soil Moisture (ASM), reduced runoff farming, spinach, surface irrigation and Water Use Efficiency (WUE)

Introduction
Water is the driving force of agriculture, playing a critical role at all the stages of plant growth. Rainfall and irrigation remain the primary means of delivering water to crops, ensuring proper functioning of numerous biochemical processes. However, climate change poses a significant threat to water management in crops (Fazilah *et al.,* 2019) [1], characterized by rising temperature and altered rainfall pattern.

Rainwater harvesting (RWH) has long been seen as a sustainable method of enhancing the water productivity of dryland agriculture. When there is a significant amount of rainfall during a short period of time and the rest of the year is dry, the extra water can be stored in RWH structures and used for farming during the rain free period. RWH bridges the gap, ensuring efficient water use and boosting agricultural productivity in drylands (Gaddikeri *et al*.) [2]. Further, optimization of irrigation levels is a key factor in maximizing crop yield and water use efficiency. Wabela *et al.* (2022) [3] found that optimizing irrigation based on moisture-stress-sensitivity levels can save irrigation water and maximize crop yield.

The integration of IoT and automation in irrigation systems has the potential to transform farming practices, promoting sustainable agriculture and increasing efficiency (Archana *et al.*, 2023; Kantilal *et al.,* 2023 and Kaushik, 2023) [4-6]. These systems monitor soil moisture content in the rhizospehere, maintain optimal water levels for maximum yield. Leveraging Internet of Things (IoT) provide farmers with real-time data, allowing them to regulate water flow precisely, preventing both under and over-watering. This level of control translates to significant water savings while ensuring higher crop quality.

Spinach is a favourite leafy vegetable throughout the world, because of its richness in important minerals and vitamins (Ekinci *et al.* 2015) [7]. Furthermore, it has less calories but high quantities of bioactive molecules such as glucuronic acid derivatives of flavonoids and p-coumaric acid derivatives which exhibit strong antioxidant activity (Lamhamdi *et al.* 2013; Xu and Leskovar 2015) [8, 9]. Its higher water content necessitates a greater water requirement throughout its life cycle compared to other vegetables. Study by Imtiyaz *et al.* (2000) [10] demonstrated positive correlation between irrigation water and spinach yield. However, water scarcity demands a shift towards water productivity. The use of sensor technology in horticulture has shown potential for increasing water use efficiency (WUE) and minimizing environmental impacts (Nasarullah *et al.*, 2022) [11]. Yetik and Candogan, (2022) [12] conducted experiments on sugar beet and recommended different irrigation levels based on soil water depletion to achieve the higher root and sugar yield. Overall, sensor-based irrigation systems have the potential to enhance irrigation water use efficiency and maintain productivity (Maitethia, 2022) [13]. Thus, this research was conducted to evaluate the growth, yield and economic viability of spinach under varying irrigation levels.

Materials and Methods

A field experiment on sensor-based irrigation in spinach was carried out during *kharif* 2021-22 and 2022-23 at AICRP on Dryland Agriculture, University of Agricultural Sciences (UAS), Gandhi Krishi Vignana Kendra (GKVK), Bengaluru. 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 dominated with coarse sand (53.4%) followed by silt (16.6%). clay (15.2%) and fine sand (14.8%). The soil reaction was acidic (5.26) with an 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 four treatments arranged in a RCBD with 6 replications. The four treatments include: 75% ASM, 50% ASM, 25% ASM, surface irrigation. The land was thoroughly ploughed using a small tiller inside the poly house and brought to a fine tilth. The bed size of 1 m wide, 0.15 m height and 17.1 m long was prepared manually using a spade. A walking space of 45 cm was maintained between the beds. Spinach seeds were directly sown in the hole made at a depth of 2-6 cm. Variety used in this experiment was Arka Anupam with the spacing 30*30 cm.

Growth parameters like plant height, number of leaves, leaf length, leaf width, fresh and dry weight, root length and root width readings of five randomly selected plants was recorded at 30 and 60 DAS. The leaf yield (kg/ plot) obtained from each net plot area was converted to kg ha^{-1}.

The experimental data collected on various growth components of plant were subjected to student's 't' test. Whenever table 't' test value is more than calculated 't' value of two means, inferred as significant different exist between the treatments means and indicated with '*'. Otherwise, abbreviation "NS" (Non-Significant) was indicated.

Results and Discussions

Plant height and number of leaves

As shown in Table 1, sensor-based irrigation schedule at 75% ASM recorded significantly higher plant height (36.18 and 37.83 cm, respectively) and number of leaves (22.61 and 22.19, respectively) at 30 and 60 DAS. This was followed by scheduling of irrigation at 50% ASM (32.20, 34.73 cm and 19.97, 19.97, respectively) as compared surface irrigation. Conversely, scheduling irrigation at 25% ASM recorded significantly lower plant height (28.68, 27.94 cm, respectively) and number of leaves (9.76 and 9.77, respectively) at 30 and 60 DAS. The decrease in height and number of leaves might be either due to reduction in cell elongation or inhibition of cell division, which is one of the most water stress sensitive physiological processes because of a drop in turgor pressure. Similar results are also reported by Hanson *et al.* (2006) [14] and Nasarullah *et al.* (2022) [15]. Further, Reyes *et al.* (2018) [16] observed the reduced cellular turgor leads to reduced CO_2 assimilation under water shortage leading to a slower plant growth and lower photosynthetic rate.

Leaf length and leaf width

The results revealed that scheduling irrigation at 75% ASM recorded significantly higher spinach leaf length (34.17, 35.23 cm, respectively) and leaf width (11.10 and 10.29 cm, respectively). Furthermore, the scheduling of irrigation at 50% ASM also noted significantly higher leaf length (31.96 and 32.83 cm, respectively) and width (9.93 and 9.52, cm) compared to surface irrigation (30.35, 31.79 and 8.87, 8.49 cm, respectively) at 30 and 60 DAS. However, the scheduling of irrigation at 25% ASM resulted in significantly lower leaf length (27.20 and 27.26 cm, respectively) and leaf width (6.97 and 7.13 cm, respectively) at 30 and 60 DAS. To adapt to water shortage, plants reduce their number of leaves and total leaf surface area. Water stress initially affect plants by reducing leaf number and area, followed by a decrease in yield and dry matter production (Nagaz *et al.*, 2009) [17, 18].

Table 1: Influence of irrigation regimes on plant height and number of leaves of spinach at 30 and 60 DAS

Treatment	Plant height (cm)			Plant height (cm)			Number of leaves			Number of leaves		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
I_1: 75% ASM	35.98*	36.38*	36.18*	35.69*	39.97*	37.83*	23.00*	22.22*	22.61*	21.99*	22.39*	22.19*
I_2: 50% ASM	32.65*	31.74*	32.20*	33.33*	36.13*	34.73*	19.00*	19.85*	19.43*	19.97*	19.38*	19.67*
I_3: 25% ASM	27.65*	29.71*	28.68*	28.27*	27.61*	27.94*	10.00*	9.52*	9.76*	9.92*	9.63*	9.77*
I_4: Surface irrigation	30.58	30.50	30.54	31.27	34.90	33.09	17.00	16.89	16.94	17.29	18.09	17.69

*Significant at 5% over control (I_4: Surface irrigation) with paired t test

Table 2: Influence of irrigation regimes on fresh weight and dry weight of spinach at 30 and 60 DAS

Treatment	Fresh weight (g)			Fresh weight (g)			Dry weight (g)			Dry weight (g)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
I_1: 75% ASM	54.40*	57.50*	55.95*	57.50*	55.95*	63.38*	5.82*	6.58*	6.20*	4.83*	5.29*	5.06*
I_2: 50% ASM	46.90*	49.20*	48.05*	49.20*	48.05*	57.41*	4.03*	4.69*	4.36*	4.08*	4.67*	4.37*
I_3: 25% ASM	27.00*	25.80*	26.40*	25.80*	26.40*	34.19*	2.67*	3.26*	2.96*	2.89*	3.34*	3.11*
I_4: Surface irrigation	45.10	42.12	43.61	42.12	43.61	46.50	3.41	4.15	3.78	3.13	3.59	3.36

*Significant at 5% over control (I_4: Surface irrigation) with paired t test

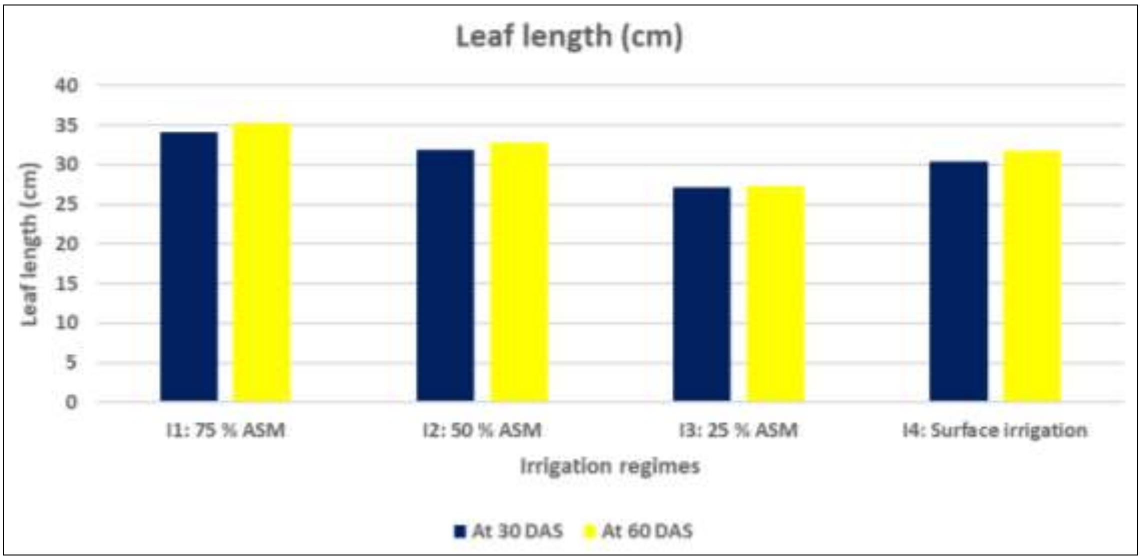

Fig 1: Influence of irrigation regimes on leaf length (cm)

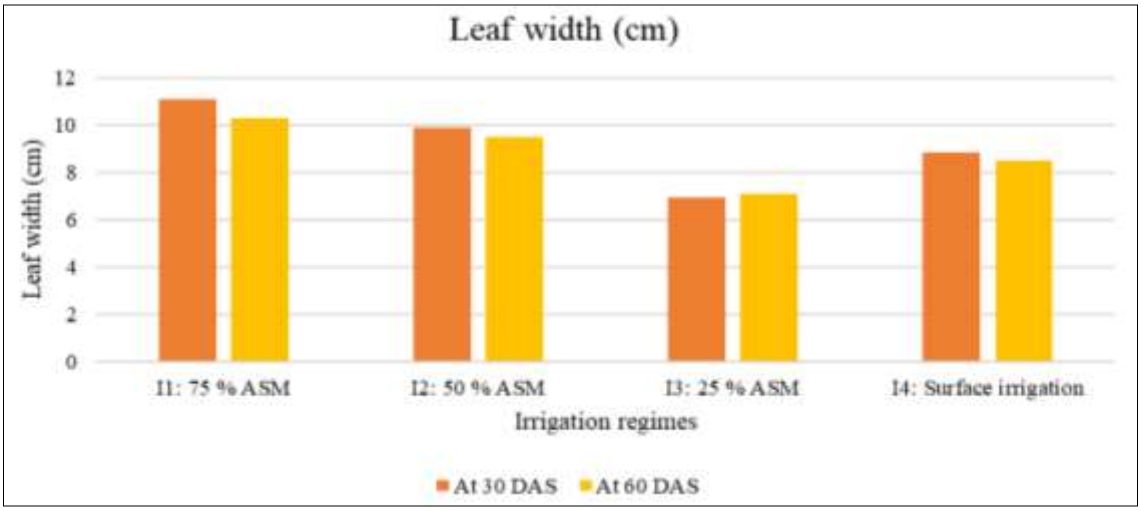

Fig 2: Influence of irrigation regimes on leaf width (cm)

Fig. 1 shows that frequent and adequate irrigation (75% ASM) results in a higher number of leaves compared to treatments with 50%, 25% ASM and surface irrigation. Similar findings were reported by Atikullah *et al.* (2014) [19] in wheat.

Fresh weight and dry weight

Data displayed in Table (2) revealed that scheduling irrigation at 75% ASM significantly increased the fresh and dry weight compared to surface irrigation. At 30 DAS, the fresh weight was 55.95 g plant^{-1} and dry weight was 6.20 g plant^{-1}, whereas it was only 43.61 and 3.78 g plant^{-1}, respectively for surface irrigation. This trend was consistent at 60 DAS (63.38 vs. 46.50 and 5.06 vs. 3.36 g plant^{-1}, respectively). However, the scheduling of irrigation at 25% ASM resulted in significantly lower fresh weight (26.40 and 34.19 g plant^{-1} at 30 and 60 DAS, respectively) and dry weight (2.96 and 3.11 g plant^{-1} at 30 and 60 DAS, respectively). The higher fresh and dry weight values at 75% ASM obtained herein may be due to the abundance irrigation water levels encourage the absorption of water and nutrients in the cells which might enhanced the volume and photosynthetic efficiency. In this concern, many investigators reported that providing the spinach plants with adequate moisture by shortening irrigation intervals leads to an increase in fresh and dry weight as reported by Gheysari *et al.* (2015) [20] and Zhao *et al.* (2022) [21]

Root length and root width

The study clearly demonstrated the substantial impact of varying irrigation levels on root length and width of spinach. Scheduling of irrigation at 75% ASM resulted in significantly higher root length (14.90 and 15.20 cm, respectively) width (7.45 and 8.40 cm, respectively) of spinach at 30 and 60 DAS compared to surface irrigation (12.92, 14.35 and 6.21, 7.62 cm, respectively). In contrast, irrigation scheduling at 25% ASM recorded significantly lower root length (9.80 and 11.28 cm, respectively) width (5.25 and 5.87 cm, respectively) at 30 and 60 DAS. However, no significant differences in root length or width was observed between 50% ASM and surface irrigation (Table 3). The first organ to be impacted by water stress will be the plant's root system. In numerous vegetable crops, water stress is seen first by the root framework, the development of horizontal lateral roots might stop, mostly by suppression of the sidelong root meristems that require both water and oxygen (Deak *et al.*, 2005) [22]. In this study, the water regime at 25% ASM resulted in shortened root length and width of spinach plant, suggesting it might be stressful for spinach under these conditions. Plant roots will not grow quicker if they are overwatered at a time (surface irrigation) but on the other hand, under watering will suppress their development (Jabeen *et al.*, 2019) [23]. Hence, it can be concluded that 25% ASM likely represent water stress for spinach in this experiment.

Table 3: Influence of irrigation regimes on root length and root width (cm) of spinach

Treatments	Root length at 30 DAS			Root length at 60 DAS			Root width at 30 DAS			Root width at 60 DAS		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
I_1: 75% ASM	14.50*	15.30*	14.90*	21.16*	16.16*	15.20*	7.00*	7.90*	7.45*	8.00*	8.80*	8.40*
I_2: 50% ASM	14.35 NS	14.20NS	14.27 NS	16.16 NS	13.98 NS	15.07 NS	6.24NS	6.62 NS	6.43 NS	7.46 NS	8.36 NS	7.92 NS
I_3: 25% ASM	10.00*	9.80*	9.80*	10.75*	11.80*	11.28*	4.90*	5.60*	5.25*	5.47*	6.28*	5.87*
I_4: Surface irrigation	13.24	12.60	12.92	15.20	13.50	14.35	6.01	6.40	6.21	7.11	8.13	7.62

*Significant at 5% over control (I_4: Surface irrigation) with paired t test; NS- non significant

Table 4: Yield and irrigation production efficiency of spinach as influenced by irrigation levels

Treatment	Mean water applied (mm)		Mean yield per plant (g/plant)			Mean yield (t ha^{-1})			WUE (kg m^{-3})		
	2021-22	2022-23	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
I_1: 75% ASM	116.96	128.91	53.04*	54.27*	53.66*	3.94*	3.77*	3.85*	3.37*	2.93*	3.15*
I_2: 50% ASM	140.64	147.74	44.75*	47.63*	46.19*	3.30*	3.27*	3.28*	2.35*	2.21*	2.28*
I_3: 25% ASM	155.85	156.51	30.18*	28.96*	29.57*	1.73*	1.58*	1.65*	1.11*	1.01*	1.06*
I_4: Surface irrigation	292.40	301.02	38.92	43.16	41.04	2.85	2.92	2.89	0.96	0.97	0.96

*Significant at 5% over control (I_4: Surface irrigation) with paired t test

Yield and irrigation production efficiency of spinach

In both the 2021-22 and 2022-23 seasons, irrigation levels significantly influenced the marketable yield of spinach. Automated sensor-based irrigation scheduling at 75% ASM resulted in significantly higher leaf yield of spinach (3.85 t ha^{-1}) as compared to surface irrigation (2.89 t ha^{-1}) trailed by irrigation scheduling at 50% ASM (3.28 t ha^{-1}) and significantly lower yield was at 25% ASM (1.58 t ha^{-1}) (Table 4). Notably, scheduling irrigation at 75 and 50% ASM registered 33.22 and 13.49 per cent higher leaf yield over surface irrigation. A similar trend was observed in mean yield per plant.

Irrigation scheduling also significantly impacted spinach's water productivity. Scheduling at 75% ASM resulted in significantly lower water usage compared to surface irrigation method during both the years **(**116.96 and 128.91 mm, accounting to 60.00 and 57.18 per cent lower compared to surface irrigation (292.40 mm and 301.02 mm in 2021 and 2022, respectively). 50% ASM utilized 140.64 mm (51.90% less) and 147.74 mm (50.92% less) during 2021-22 and 2022-23, respectively. Similarly, 25% ASM utilized 155.85 mm (46.00% less) and 156.51 mm (48.00% less) during 2021-22 and 2022-23, respectively. The WUE followed the order of 75% ASM (3.15 kg m^{-3}) > 50% ASM (2.28 kg m^{-3}) > 25% ASM (1.06 kg m^{-3}) > Surface Irrigation (0.96 kg m^{-3}). Bozkurt *et al.* (2009) [24] and Basma *et al.* (2022) [25] also reported similar results.

Scheduling irrigation at 75% ASM in spinach resulted in higher gross return (Rs. 456966 ha^{-1}), net return (Rs. 223736 ha^{-1}) and B: C ratio (1.96) as compared to surface irrigation followed by 50% ASM (Rs. 387872 ha^{-1},154842 ha^{-1} and 1.96, respectively) and scheduling of irrigation at 25% ASM observed lower gross return (Rs. 272612 ha^{-1}), net return (Rs. 40182 ha^{-1}) and B: C ratio (1.17) (Table 5).

The higher net return and B: C ratio was mainly attributed to higher leaf yield at 75% ASM (3.85 t ha^{-1}). The poor economic performance with 25% ASM was mainly attributed to lower leaf yield (1.65 t ha^{-1}). The results were in line with Patil *et al.* (2013) [26] in lettuce.

This study was done in order to define the optimum irrigation scheduling by using a simple soil moisture sensor under protected cultivation. Under study circumstances, we can conclude that, applying 75% ASM will help to achieve the maximum growth, yield and profitability compared to traditional surface irrigation.

Table 5: Economic evaluation of irrigation regimes on lettuce and spinach under sensor-based irrigation

Treatment	Cost of cultivation (Rs. ha^{-1})			Gross return (Rs. ha^{-1})			Net return (Rs. ha^{-1})			B: C ratio		
	Season-1	Season-2	Pooled	Season-1	Season-2	Pooled	Season-1	Season-2	Pooled	Season-1	Season-2	Pooled
I_1	232720	233741	233230	436966	476966	456966	204246	243225	223736	1.88	2.04	1.96
I_2	232520	233541	233030	386872	388872	387872	154352	155331	154842	1.66	1.67	1.66
I_3	231920	232941	232430	257612	287612	272612	25692	54671	40182	1.11	1.23	1.17
I_4	194680	195700	195190	302163	312163	307163	107483	116463	111973	1.55	1.60	1.57

Note: I_1 = 75% ASM + spinach, I_2 = 50% ASM + spinach,
I_3 = 25% ASM + spinach, I_4= Surface irrigation + spinach

Conclusion

Study highlights the pivotal role of irrigation management in influencing the growth, yield, and economic outcomes of spinach cultivation under protected conditions. Through meticulous analysis, it was evident that scheduling irrigation at 75% ASM consistently yielded superior results across various growth parameters and economic indicators compared to other irrigation levels, notably outperforming traditional surface irrigation methods. These findings underscore the importance of adopting automated sensor-based irrigation scheduling to optimize water usage and maximize spinach productivity. By embracing such innovative irrigation strategies, growers can enhance both the quality and profitability of spinach cultivation while ensuring sustainable water management practices. Thus, this study contributes valuable insights toward the advancement of efficient irrigation techniques for protected cultivation systems.

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