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RESEARCH PAPER

Influence of drip irrigation and fertigation levels on soil biological properties in pre-seasonal plant and ratoon sugarcane

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Abstract: A field experiment was conducted during the pre-season (2023-2025) at the Agricultural Research Station, Sankeshwar, Karnataka, India, to evaluate the effect of drip fertigation at different irrigation and nutrient levels on growth parameters of sugarcane. The experiment was laid out in a strip block design comprising three drip irrigation schedules based on reference evapotranspiration (ET_o) applied at critical growth stages *viz.,* germination, tillering, canopy establishment, grand growth and maturity and three fertigation levels of 75, 100 and 125 per cent of the recommended dose of fertilizers (RDF), along with surface irrigation and drip fertigation controls. Fertigation was applied at 15-day intervals up to 240 days after planting (DAP), while irrigation was scheduled at three-day intervals until harvest. Results revealed that drip irrigation levels exerted a pronounced influence on soil biological properties in both plant cane and ratoon cane. Higher irrigation level (I_3) consistently recorded greater dehydrogenase activity, with values reaching 38.28 and 37.31 µg TPF formed g^{-1} soil day^{-1} at harvest in plant cane and ratoon cane, respectively. A similar trend was observed for urease activity, which ranged up to 22.24 µg NH4 –N g^{-1} soil day^{-1} at 180 days after planting (DAP), and phosphatase activity, which peaked at 485.22 µg PNP released g^{-1} soil h^{-1} under I_3 in plant cane. Soil biomass carbon also showed higher values under I_3, particularly at early growth stages, indicating improved microbial proliferation under optimal soil moisture regimes. Although fertigation levels did not significantly influence most soil biological parameters, lower to moderate fertigation (75 per cent RDF) generally resulted in numerically higher enzyme activities and microbial biomass carbon compared to higher fertigation levels which affected the soil biological properties. The interaction of higher irrigation with moderate fertigation (I_3 F_1) consistently recorded superior values of soil enzyme activities and microbial biomass in both crop cycles.Surface irrigation under recommended package of practices recorded comparatively lower soil biological activity due to non-uniform moisture and nutrient distribution. Overall, the study demonstrated that optimized drip irrigation combined with moderate fertigation enhances soil microbial activity and enzymatic functions, thereby improving soil biological health and sustainability of sugarcane production in both plant and ratoon cane systems.

Key words: Drip irrigation, Fertigation, Pre-seasonal sugarcane, Soil microbial biomass

Introduction

Sugarcane (*Saccharum* spp.) is one of the world's most important perennial cash crops, providing raw material for sugar, ethanol, molasses and several co-products that support rural economies and agro-industries. It plays a vital role in food, fuel and industrial sectors due to its high biomass yield and versatility. Globally, sugarcane was cultivated on 26.08 million hectares (m ha), producing 19.22 million tonnes (m t) of cane with an average productivity of 65.5 t ha^{-1} (FAO, 2022). In India, sugarcane was cultivated over 5.83 m ha, yielding 494.22 m t of cane with an average productivity of 84.01 t ha^{-1} (Anon., 2023). In in India Uttar Pradesh, Maharashtra and Karnataka contributes a major share of national sugarcane output. In Karnataka, sugarcane cultivation covers significant acreage with notable production levels, making it a key component of the state's agricultural portfolio.

Soil health and fertility are critical determinants of sustained sugarcane productivity. Soil biological properties, including microbial biomass carbon, dehydrogenase, urease and phosphatase activities are sensitive indicators of soil biological functioning, nutrient cycling and organic matter turnover. Microbial biomass carbon reflects the living component of soil organic matter, which drives nutrient transformation and availability, while soil enzymes catalyze key biogeochemical processes, such as organic matter decomposition (Jenkinson and Ladd, 1981). These properties respond to soil moisture and nutrient management and thus serve as integrative measures of soil quality under different agronomic practices. In this context, understanding the effects of varying drip irrigation levels and fertigation rates on soil biological attributes in sugarcane is essential for developing sustainable and productive cropping systems. The present study was conducted to evaluate how different irrigation and nutrient management strategies influence soil dehydrogenase, urease and phosphatase activities, as well as microbial biomass carbon, during plant cane and ratoon cane cycles.

Material and methods

The field experiment was carried out during 2023-25 at the Agricultural Research Station (ARS), Sankeshwar, Karnataka, India. The research site is geographically situated at 16°242 N latitude and 74°502 E longitude, at an elevation of 638 m above mean sea level and falls under the Northern Transition Zone of Karnataka (Zone-8). The soil of the experimental field was a medium black clay loam, classified as Vertisol according to the USDA soil taxonomy.

The experiment was structured in a strip block design comprising three drip irrigation regimes as vertical strips and three fertigation levels as horizontal strips. The drip irrigation treatments consisted of irrigation scheduled at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o during germination, tillering, canopy establishment, grand growth and maturity stages, respectively (I), 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at the corresponding growth stages (I,) and 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at the respective stages (I_3). Fertigation treatments included application of 75 per cent of the recommended dose of fertilizers (188:56:143 kg N:P:K ha^{-1}) through fertigation (F_1), 100 per cent RDF (250:75:190 kg N:P:K ha^{-1} through fertigation (F_2) and 125 per cent RDF (313:94:238 kg N:P:K ha^{-1}) through fertigation (F_3). In addition, two control treatments were included, namely drip fertigation and surface irrigation with fertilizer application as per the recommended package of practices of UAS, Dharwad (2021).

Farmyard manure at 25 t ha^{-1}, micronutrients such as $FeSO_4$ and $ZnSO_4$ at 25 kg ha^{-1} each, and biofertilizers including *Azospirillum* and phosphate solubilizing bacteria (PSB) at 10 kg ha^{-1} each were uniformly applied across all treatments. Fertigation was administered at 15-day intervals up to 240 days after planting (DAP), while irrigation was continued up to harvest at three-day intervals. For drip-fertigated treatments, the entire phosphorus requirement and 10 per cent each of nitrogen and potassium were applied as basal dose through mono-ammonium phosphate, urea and muriate of potash, respectively and the remaining 90 per cent of nitrogen and potassium was supplied in eight equal splits through fertigation. In surface-irrigated plots (C_2), 10 per cent nitrogen and the full dose of phosphorus and potassium were applied as basal dose, while the remaining 90 per cent nitrogen was applied at the tillering stage. Observations on growth and related parameters were recorded using standard procedures and the collected data were subjected to statistical analysis following the method outlined by Gomez and Gomez (1984).

Results and discussion

Dehydrogenase activity of soil

Dehydrogenase activity of soil, expressed as µg TPF formed g^{-1} soil day^{-1} (Casida *et al*., 1964), was influenced by drip irrigation levels, fertigation levels and their interaction during plant cane and ratoon cane at 240 days after planting (DAP) and at harvest (Table 1 & 2).

In the plant cane crop, drip irrigation levels showed non-significant differences at 240 DAP, with dehydrogenase activity ranging from 41.50 to 43.86 µg TPF g^{-1} soil day^{-1} (Table 1), whereas at harvest, significant differences were observed. The highest dehydrogenase activity was recorded under I_3 (38.28 µg TPF g^{-1} soil day^{-1}), followed by I_2 (36.67 µg TPF g^{-1} soil day^{-1}), while I_1 recorded the lowest value (35.32 µg TPF g^{-1} soil day^{-1}) (Table 1). In the ratoon cane crop, although the differences among irrigation levels were statistically non-significant at both stages, a similar increasing trend was observed with higher irrigation regimes. The consistently higher enzyme activity

Table 1. Dehydrogenase activity in plant cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Dehydrogenase activity (µg TPF formed g^{-1} soil day^{-1})	
		240 DAP	At harvest
Drip irrigation levels (I)			
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	41.50^{a}	35.32^{b}
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG& M stages, respectively	43.07^{a}	36.67^{ab}
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG& M stages, respectively	43.86^{a}	38.28^{a}
	S.Em±	0.53	0.46
Fertigation levels (F)			
F_1	75% RDF (through fertigation)	41.88^{a}	35.90^{a}
F_2	100 % RDF (through fertigation)	42.87^{a}	36.70^{a}
F_3	125 % RDF (through fertigation)	43.68^{a}	37.67^{a}
	S.Em±	0.92	0.77
Interaction (I×F)			
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	40.80^{b}	34.58^{ab}
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	41.74^{ab}	35.12^{ab}
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	41.95^{ab}	36.25^{ab}
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	42.81^{ab}	35.24^{ab}
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	43.32^{ab}	36.85^{ab}
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	43.08^{ab}	37.92^{a}
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	42.02^{ab}	37.88^{a}
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	43.55^{ab}	38.12^{a}
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	45.88^{a}	38.83^{a}
C_1	Recommended package of practice - DI	41.41^{ab}	34.29^{ab}
C_2	Recommended package of practice - SI	39.55^{b}	32.08^{b}
	S.Em±	1.21	1.09

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (250:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

Table 2. Dehydrogenase activity in ratoon cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Dehydrogenase activity (µg TPF formed g^{-1} soil day^{-1})	
		240 DAP	At harvest
Drip irrigation levels (I)			
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	40.96[a]	34.66[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG& M stages, respectively.	42.24[a]	36.47[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG& M stages, respectively.	43.04[a]	37.31[a]
	S.Em.±	0.85	0.59
Fertigation levels (F)			
F_1	75% RDF (through fertigation)	41.18[a]	35.48[a]
F_2	100% RDF (through fertigation)	42.18[a]	36.59[a]
F_3	125% RDF (through fertigation)	42.88[a]	36.86[a]
	S.Em.±	0.66	0.65
Interaction (I×F)			
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	39.90[a]	33.90[a]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	41.01[a]	34.98[a]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	41.96[a]	35.11[a]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	41.62[a]	34.98[a]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	42.55[a]	36.98[a]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	42.56[a]	37.45[a]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	42.02[a]	36.11[a]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	42.98[a]	37.80[a]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	44.11[a]	38.01[a]
C_1	Recommended package of practice - DI	41.77[a]	34.98[a]
C_2	Recommended package of practice - SI	40.20[a]	34.02[a]
	S.Em±	0.97	0.90

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (313:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

under higher irrigation levels in both crop cycles may be attributed to improved soil moisture availability, which favours microbial growth and enzymatic activity. Zhang *et al.*(2020) reported that soil moisture is a key regulator of dehydrogenase activity as it directly influences microbial respiration and oxidative enzyme systems. Similar findings under drip-irrigated sugarcane were reported by Balasubramanian *et al.* (2012).

Fertigation levels did not exert a significant influence on dehydrogenase activity in either plant cane or ratoon cane at both stages of observation (Table 1& 2). However, numerical increases were evident with higher fertigation levels. In plant cane, dehydrogenase activity at 240 DAP increased from 41.88 µg TPF g^{-1} soil day^{-1} under 75 per cent RDF (F_1) to 43.68 µg TPF g^{-1} soil day^{-1} under 125 per cent RDF (F_3), while at harvest, the values ranged from 35.90 to 37.67 µg TPF g^{-1} soil day^{-1} (Table 1). Similarly, in ratoon cane, at 240 DAP, dehydrogenase activity increased from 41.18 µg TPF g^{-1} soil day^{-1} under F_1 to 42.88 µg TPF g^{-1} soil day^{-1} under F_3, while at harvest, the corresponding values ranged from 35.48 to 36.86 µg TPF g^{-1} soil day^{-1} (Table 2). Continuous nutrient supply through fertigation enhances microbial proliferation and metabolic activity, leading to higher dehydrogenase activity (Ghosh *et al*. 2023).

The interaction effect of drip irrigation and fertigation levels was significant in plant cane and non-significant in ratoon cane. In plant cane, the treatment combination I_3F_3 recorded the highest dehydrogenase activity of 45.88 µg TPF g^{-1} soil day^{-1} at 240 DAP and 38.83 µg TPF g^{-1} soil day^{-1} at harvest (Table 1). In ratoon cane also, I_3F_3 recorded the maximum dehydrogenase activity, with values of 44.11 µg TPF g^{-1} soil day^{-1} at 240 DAP and 38.01 µg TPF g^{-1} soil day^{-1} at harvest (Table 2). The lowest values were generally recorded under lower irrigation and fertigation combinations, such as I_1F_1, which recorded 40.80 and 34.58 µg TPF g^{-1} soil day^{-1} in plant cane and 39.90 and 33.90 µg TPF g^{-1} soil day^{-1} in ratoon cane at 240 DAP and harvest, respectively.The recommended package of practice under surface irrigation (C_2) resulted in lower dehydrogenase activity compared to other treatments in both plant and ratoon cane. In plant cane, C_2 recorded 39.55 µg TPF g^{-1} soil day^{-1} at 240 DAP and 32.08 µg TPF g^{-1} soil day^{-1} at harvest, while in ratoon cane the corresponding values were 40.20 and 34.02 µg TPF g^{-1} soil day^{-1} (Table 2). This was mainly because of ununiformed distribution of moisture and nutrient throughout the crop growth period.

Urease activity of soil

Urease activity of soil, expressed as µg NH_4 –N g^{-1} soil day^{-1} (Tabatabai and Bremner, 1972), was studied under different drip irrigation levels, fertigation levels and their interaction during plant cane and ratoon cane at 120, 180 and 240 days after planting (DAP) (Table 3 & 4).

In the plant cane, drip irrigation levels did not differ significantly with respect to urease activity at any stage of observation. However, a consistent numerical increase in urease activity was observed with increasing irrigation levels. At 120 DAP, urease activity ranged from 17.09 µg NH_4 –N g^{-1} soil day^{-1} under I1 to 17.66 µg NH_4 –N g^{-1} soil day^{-1} under I_3. At 180 DAP,

Table 3. Urease activity in plant cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Urease activity ($\mu g\ NH_4$-N g^{-1} of soil day^{-1})		
		120 DAP	180 DAP	240 DAP
Drip irrigation levels (I)				
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	17.09[a]	20.19[a]	8.48[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG& M stages, respectively	17.27[a]	21.44[a]	19.52[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG& M stages, respectively	17.66[a]	22.24[a]	20.43[a]
	S.Em±	0.61	0.32	0.28
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	17.44[a]	21.92[a]	19.73[a]
F_2	100% RDF (through fertigation)	17.40[a]	21.72[a]	19.53[a]
F_3	125% RDF (through fertigation)	17.19[a]	20.63[a]	19.09[a]
	S.Em±	0.37	0.45	0.42
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	17.14[a]	20.20[a]	18.68[ab]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	17.11[a]	20.11[a]	18.51[ab]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	17.05[a]	20.05[a]	18.25[ab]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	17.39[a]	21.79[a]	20.02[ab]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	17.32[a]	21.52[a]	19.54[ab]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	17.21[a]	20.90[a]	19.11[ab]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	17.80[a]	22.75[a]	20.68[ab]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	17.77[a]	22.02[a]	20.44[ab]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	17.42[a]	21.85[a]	19.88[a]
C_1	Recommended package of practice - DI	17.30[a]	20.02[a]	18.60[ab]
C_2	Recommended package of practice - SI	17.10[a]	19.99[a]	7.88[b]
	S.Em±	0.38	0.59	0.58

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (250:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

the corresponding values increased from 20.19 to 22.24 µg NH_4 –N g^{-1} soil day^{-1}, while at 240 DAP, urease activity ranged from 18.48 to 20.43 µg NH_4 –N g^{-1} soil day^{-1} under I_1 and I_3, respectively (Table 3). A similar trend was observed in the ratoon cane crop, wherein differences among drip irrigation levels were statistically non-significant, but higher irrigation regimes recorded greater urease activity. At 120 DAP, urease activity ranged from 17.19 µg NH_4 –N g^{-1} soil day^{-1} under I_1 to 17.55 µg NH_4 –N g^{-1} soil day^{-1} under I_3. At 180 DAP, values varied from 20.29 to 22.18 µg NH_4 –N g^{-1} soil day^{-1}, while at 240 DAP, urease activity ranged from 18.96 to 20.02 µg NH_4 –N g^{-1} soil day^{-1} (Table 4). The numerically higher urease activity under increased irrigation levels in both crop cycles may be attributed to favourable soil moisture conditions that enhance microbial activity and enzyme synthesis. Similar enhancement of urease activity under drip irrigation systems has been reported by Singh *et al.* (2015).

Fertigation levels did not significantly influence urease activity in either plant cane or ratoon cane at any stage. Both in plant and ratooncane, urease activity were reduced numerically as the fertigation levels increased at all the growth stages. In plant cane at 120 DAP it was reduced from 17.44 to 17.19 µg NH_4–N g^{-1} soil day^{-1}, at 180 DAP from 21.92 to 20.63 µg NH_4 –N g^{-1} soil $day^{-1}$and at 240 DAP from 19.73 to 19.09 µg NH_4–N g^{-1} soil day^{-1} under F_1 and F_3, respectively (Table 3). Similarly, in ratoon cane, urease activity varied from 17.49 to 17.14 µg NH_4 – N g^{-1} soil day^{-1} at 120 DAP, 21.54 to 20.85 µg NH_4 –N g^{-1} soil day^{-1} at 180 DAP, and 19.42 to 18.62 µg NH_4 –N g^{-1} soil day^{-1} at 240 DAP under different fertigation levels (Table 4). The slightly higher urease activity at lower fertigation levels might be due to more efficient microbial utilization of applied nitrogen under moderate nutrient supply (Barush and Mishra, 1984).

The interaction effect of drip irrigation and fertigation levels was non-significant at all stages in both plant cane and ratoon cane. However, numerically higher urease activity was consistently observed under higher irrigation levels combined with lower fertigation levels. In plant cane, the highest urease activity was recorded under I_3F_1, with values of 17.80, 22.75 and 20.68 µg NH_4 –N g^{-1} soil day^{-1} at 120, 180 and 240 DAP, respectively (Table 3). In ratoon cane, I_3F_1 also recorded higher urease activity, with corresponding values of 17.82, 22.59 and 20.25 µg NH_4 – N g^{-1} soil day^{-1} (Table 4). The recommended package of practice under surface irrigation (C_2) consistently recorded lower urease activity compared to drip-irrigated treatments. In plant cane, C_2 recorded 17.10, 19.99 and 17.88 µg NH_4 –N g^{-1} soil day^{-1} at 120, 180 and 240 DAP, respectively (Table 3), while in ratoon cane the corresponding values were 16.90, 19.98 and 17.90 µg NH_4 –Ng^{-1} soil day^{-1} (Table 4) mainly because of lower availability of moisture and nutrient at required growth stage.

Phosphatase activity of soil

Phosphatase activity of soil, expressed as µg PNP released g^{-1} soil h^{-1} (Evazi and Tabatabai, 1977), was studied under different drip irrigation levels, fertigation levels and their

Table 4. Urease activity in ratoon cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Urease activity (µg NH_4-N g^{-1} of soil day^{-1})		
		120 DAP	180 DAP	240DAP
Drip irrigation levels (I)				
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	17.19[a]	20.29[a]	18.96[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	17.27[a]	21.57[a]	19.87[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M stages, respectively	17.55[a]	22.18[a]	20.02[a]
	S.Em.±	0.27	0.32	0.29
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	17.49[a]	21.54[a]	19.42[a]
F_2	100% RDF (through fertigation)	17.37[a]	21.25[a]	19.21[a]
F_3	125% RDF (through fertigation)	17.14[a]	20.85[a]	18.62[a]
	S.Em.±	0.37	0.45	0.41
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	17.14[a]	20.21[a]	18.42[a]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	17.09[a]	20.12[a]	18.23[a]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	17.04[a]	20.04[a]	18.04[a]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	17.42[a]	21.82[a]	19.68[a]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	17.33[a]	21.56[a]	19.34[a]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	17.27[a]	20.92[a]	18.89[a]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	17.82[a]	22.59[a]	20.25[a]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	17.70[a]	22.08[a]	20.07[a]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	17.52[a]	21.88[a]	19.44[a]
C_1	Recommended package of practice - DI	17.10[a]	20.09[a]	18.10[a]
C_2	Recommended package of practice - SI	16.90[a]	19.98[a]	17.90[a]
	S.Em±	0.46	0.59	0.51

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (313:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

interactions during plant cane and ratoon cane at 120, 180 and 240 days after planting (DAP) (Table 5 & 6).

In the plant cane, drip irrigation levels did not differ significantly at any stage of observation; however, a consistent numerical increase in phosphatase activity was observed with higher irrigation levels. At 120 DAP, phosphatase activity was higher under I_3(372.96 µg PNP released g^{-1} soil h^{-1}) and lowest under I_1 (350.52 µg PNP released g^{-1} soil h^{-1}). At 180 DAP, the I_3 was highest (485.22 µg PNP released g^{-1} soil h^{-1}) and I_1 was lowest (468.77 µg PNP released g^{-1} soil h^{-1}), at 240 DAP also the same trend was followed, I_3 (444.31 µg PNP released g^{-1} soil h^{-1}) was highest and I_1 (426.22 µg PNP released g^{-1} soil h^{-1}) was lowest (Table 5). The higher phosphatase activity under increased drip irrigation levels may be attributed to improved soil moisture conditions favouring microbial activity and enzymatic release.In the ratoon cane crop, a similar trend was observed, wherein phosphatase activity increased numerically with higher irrigation levels. At 120, 180 and 240 DAP, phosphatase activity was numerically higher under I_3(364.49, 484.41 and 444.16 µg PNP released g^{-1} soil h^{-1}, respectively) (Table 6). The similarity in response between plant and ratoon cane indicates the sustained influence of drip irrigation on soil enzymatic activity.

Fertigation levels did not exert a significant effect on phosphatase activity in both plant and ratoon cane but here also the phosphatase activity was decreased as the fertigation levels increased. In plant cane, phosphatase activity at 120 DAP was numerically higher under F_1 (361.62 µg PNP released g^{-1} soil h^{-1}) and lowest under F_3(353.93 µg PNP released g^{-1} soil h^{-1}). Even at 180 and 240 DAP also, the numerically higher values were recorded in F_1 (478.22 and 436.53 µg PNP released g^{-1} soil h^{-1} respectively) and lowest in F_3 (469.73 and 428.97 µg PNP released g^{-1} soil h^{-1}, respectively) (Table 5).The same trend was noticed in ratoon cane also. The slightly higher enzyme activity under lower fertigation levels may be due to greater microbial demand for phosphorus under moderate nutrient availability.

The interaction effect between drip irrigation and fertigation levels was non-significant in both plant cane and ratoon cane. However, higher phosphatase activity was consistently observed under higher irrigation levels combined with lower fertigation levels. In plant cane, the treatment I_3F_1 recorded phosphatase activity of 373.32, 487.32 and 449.98 µg PNP released g^{-1} soil h^{-1} at 120, 180 and 240 DAP(Table 5), respectively. In ratoon cane, the same treatment recorded 370.14, 486.55 and 445.25 µg PNP released g^{-1} soil h^{-1} at the corresponding stages (Table 6). The superior performance of I_3 and I_3F_1 treatments indicates that optimum irrigation combined with moderate nutrient supply enhances phosphorus cycling. Comparable trends under drip-irrigated sugarcane have been documented by Ramesh *et al.* (2018).The recommended package of practice under surface irrigation (C_2) consistently recorded lower phosphatase activity compared to drip irrigation treatments. In plant cane, C_2 recorded 330.55, 451.55 and 422.33 µg PNP released g^{-1} soil h^{-1} at 120, 180 and 240 DAP, respectively (Table 5), while in ratoon cane, the corresponding values were 338.11, 459.87 and 421.68 µg PNP released g^{-1} soil h^{-1}(Table 6).

Table 5. Phosphatase activity in plant cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Phosphatase activity (µg PNP released g^{-1} of soil h^{-1})		
		120 DAP	180 DAP	240 DAP
	Drip irrigation levels (I)			
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	350.52[a]	468.77[a]	426.22[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	359.85[a]	475.52[a]	434.06[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M stages, respectively	372.96[a]	485.22[a]	444.31[a]
	S.Em±	5.02	6.77	6.14
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	361.62[a]	478.22[a]	436.53[a]
F_2	100% RDF (through fertigation)	357.79[a]	472.56[a]	431.09[a]
F_3	125% RDF (through fertigation)	353.93[a]	469.73[a]4	28.97[a]
	S.Em±	8.16	10.2	9.87
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	354.22[a]	468.12[a]	437.22[a]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	351.12[a]	465.33[a]	433.33[a]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	350.22[a]	462.85[a]	430.12[a]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	364.32[a]	479.22[a]	445.40[a]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	362.12[a]	477.12[a]	442.65[a]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	360.12[a]	473.21[a]	439.12[a]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	373.32[a]	487.32[a]	449.98[a]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	371.12[a]	485.22[a]	444.28[a]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	370.45[a]	480.12[a]	441.66[a]
C_1	Recommended package of practice - DI	352.23[a]	480.32[a]	430.12[a]
C_2	Recommended package of practice - SI	330.55[a]	451.55[a]	422.33[a]
	S.Em±	10.61	14.02	12.79

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (250:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

Table 6. Phosphatase activity in ratoon cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Phosphatase activity (µg PNP released g^{-1} of soil h^{-1})		
		120 DAP	180 DAP	240 DAP
Drip irrigation levels (I)				
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages,respectively	349.60[a]	466.86[a]	427.13[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	358.71[a]	475.20[a]	434.72[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M stages, respectively	364.49[a]	484.41[a]	444.16[a]
	S.Em±	5.20	6.99	6.37
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	359.34[a]	475.67[a]	436.08[a]
F_2	100% RDF (through fertigation)	355.16[a]	470.61[a]	431.18[a]
F_3	125% RDF (through fertigation)	349.30[a]	467.20[a]	427.75[a]
	S.Em±	7.67	10.18	9.34
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	349.45[a]	467.33[a]	440.87[a]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	341.22[a]	464.36[a]	437.63[a]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	338.12[a]	460.90[a]	432.90[a]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	367.44[a]	477.13[a]	444.12[a]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	364.14[a]	473.11[a]	440.80[a]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	360.55[a]	479.36[a]	437.25[a]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	370.14[a]	486.55[a]	445.25[a]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	367.11[a]	484.36[a]	443.12[a]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	365.23[a]	480.33[a]	440.10[a]
C_1	Recommended package of practice - DI	344.21[a]	468.22[a]	439.77[a]
C_2	Recommended package of practice - SI	338.11[a]	459.87[a]	421.68[a]
	S.Em±	9.81	13.04	11.94

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (313:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

Table 7. Soil biomass carbon in plant cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Soil biomass carbon (µg g^{-1} soil)		
		120 DAP	180 DAP	240 DAP
Drip irrigation levels (I)				
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	184.31^{b}	277.06^{a}	318.52^{a}
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_oat G, T, CE, GG & M stages, respectively.	189.92^{ab}	285.97^{a}	328.59^{a}
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_oat G, T, CE, GG & M stages, respectively.	201.85^{a}	301.59^{a}	336.31^{a}
	S.Em±	1.80	4.10	4.64
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	194.87^{a}	291.82^{a}	331.90^{a}
F_2	100% RDF (through fertigation)	192.14^{a}	288.56^{a}	328.21^{a}
F_3	125% RDF (through fertigation)	189.07^{a}	284.25^{a}	323.31^{a}
	S.Em±	4.05	6.06	6.92
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	187.06^{a-c}	279.21^{a}	322.44^{a}
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	184.65^{a-c}	277.21^{a}	318.25^{a}
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	181.22^{bc}	274.77^{a}	314.88^{a}
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	192.44^{ab}	289.12^{a}	333.14^{a}
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	190.21^{a-c}	286.25^{a}	329.18^{a}
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	187.11^{a-c}	282.55^{a}	323.45^{a}
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	205.12^{a}	307.12^{a}	340.12^{a}
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	201.55^{ab}	302.21^{a}	337.21^{a}
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	198.88^{ab}	295.44^{a}	331.59^{a}
C_1	Recommended package of practice - DI	180.11^{bc}	278.99^{a}	320.89^{a}
C_2	Recommended package of practice - SI	169.32^{c}	275.90^{a}	312.52^{a}
	S.Em±	4.26	7.40	8.38

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (250:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

Soil biomass carbon

Soil biomass carbon, expressed as µg g^{-1} soil (Carter, 1991), was studied under different drip irrigation levels, fertigation levels and their interactions during plant cane and ratoon cane at 120, 180 and 240 days after planting (DAP) (Table 7 & 8).

In the plant cane crop, drip irrigation levels significantly influenced soil biomass carbon at 120 DAP, while differences were non-significant at 180 and 240 DAP. At 120 DAP, I_3 was recorded significantly higher soil biomass carbon (201.85 µg g^{-1} soil) and it was on-par with I_2 (189.92 µg g^{-1} soil) and lowest was observed in I_1 (184.31 µg g^{-1} soil). At both 180 and 240 DAP, soil biomass carbon was numerically higher under I_3(301.59 and 336.31 µg g^{-1} soil, respectively) and lowest in I_1 (277.06 and 318.52 µg g^{-1} soil) (Table 7). The higher soil biomass carbon under increased drip irrigation levels may be attributed to improved soil moisture availability, which supports microbial growth and organic carbon turnover. In the ratoon cane crop, drip irrigation levels showed non-significant differences at all stages, but a consistent numerical increase was observed with higher irrigation levels. The similar trend in ratoon cane indicates the sustained influence of drip irrigation on soil microbial biomass across crop cycles. Enhanced enzyme activity under drip irrigation has been reported due to favourable soil moisture and aeration conditions (Bandick and Dick, 1999; Li *et al*., 2007).

Fertigation levels did not exert a significant effect on soil biomass carbon in either plant cane or ratoon cane but the soil biomass carbon content was reduced as the fertigation level increased. In plant cane, soil biomass carbon under F_1, F_2 and F_3 at 120 DAP was 194.87, 192.14 and 189.07 µg g^{-1} soil, respectively. At 180 DAP, corresponding values were 291.82, 288.56 and 284.25 µg g^{-1} soil, while at 240 DAP, values of 331.90, 328.21 and 323.31 µg g^{-1} soil were recorded (Table 7). Similarly, in ratoon cane, soil biomass carbon at 120 DAP under F_1, F_2 and F_3 was 203.82, 198.50 and 195.35 µg g^{-1} soil, respectively. At 180 DAP, values of 305.28, 301.17 and 297.22 µg g^{-1} soil were recorded, while at 240 DAP, soil biomass carbon under F_1, F_2 and F_3 was 292.59, 287.07 and 282.36 µg g^{-1} soil, respectively (Table 8). Slightly higher biomass carbon under lower fertigation levels may be due to favourable environment for the microbial assimilation of carbon. Balanced nutrient availability supports microbial metabolism and biomass build-up (Marschner *et al.*, 2003).

The interaction effect between drip irrigation and fertigation levels showed significant variation at 120 DAP in plant cane, while differences were non-significant at later stages and in ratoon cane. In plant cane, the treatment I_3F_1 recorded the highest soil biomass carbon of 205.12 µg g^{-1} soil at 120 DAP, 307.12 µg g^{-1} soil at 180 DAP and 340.12 µg g^{-1} soil at 240 DAP (Table 7). In ratoon cane also, I_3F_1 recorded higher soil biomass carbon, with values of 211.07, 322.48 and 305.35 µg g^{-1} soil at 120, 180 and 240 DAP, respectively (Table 8). The higher values under this treatment combination indicate the synergistic effect of higher irrigation levels and moderate fertigation on microbial biomass build-up. Similar improvements in soil biological properties under drip fertigation in sugarcane have been reported earlier (Balasubramanian *et al.*, 2012).The recommended package of practice under surface irrigation (C_2)

Table 8. Soil biomass carbon in ratoon cane under pre-seasonal sugarcane as influenced by drip irrigation and fertigation

Treatment		Soil biomass carbon (µg g^{-1} soil)		
		120 DAP	180 DAP	240DAP
Drip irrigation levels (I)				
I_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M stages, respectively	192.92[a]	288.88[a]	278.30[a]
I_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_oat G, T, CE, GG & M stages, respectively	196.91[a]	299.32[a]	284.36[a]
I_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M stages, respectively	207.84[a]	315.47[a]	299.37[a]
S.Em.±		2.85	4.29	4.13
Fertigation levels (F)				
F_1	75% RDF (through fertigation)	203.82[a]	305.28[a]	292.59[a]
F_2	100% RDF (through fertigation)	198.50[a]	301.17[a]	287.07[a]
F_3	125% RDF (through fertigation)	195.35[a]	297.22[a]	282.36[a]
	S.Em.±	4.21	6.34	6.03
Interaction (I×F)				
I_1F_1	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	196.41[ab]	290.38[a]	284.57[a]
I_1F_2	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	193.88[ab]	288.30[a]	276.77[a]
I_1F_3	DI at 0.6, 0.8, 1.0, 1.2 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	188.47[ab]	287.96[a]	273.56[a]
I_2F_1	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 75% RDF	203.99[ab]	303.00[a]	287.85[a]
I_2F_2	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 100% RDF	194.01[ab]	299.70[a]	284.72[a]
I_2F_3	DI at 0.8, 1.0, 1.2, 1.4 and 0.8 ET_o at G, T, CE, GG & M with 125% RDF	192.72[ab]	295.26[a]	280.50[a]
I_3F_1	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 75% RDF	211.07[a]	322.48[a]	305.35[a]
I_3F_2	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 100% RDF	207.60[a]	315.51[a]	299.73[a]
I_3F_3	DI at 1.0, 1.2, 1.4, 1.6 and 1.0 ET_o at G, T, CE, GG & M with 125% RDF	204.85[ab]	308.44[a]	293.02[a]
C_1	Recommended package of practice - DI	189.12[ab]	287.36[a]	272.42[a]
C_2	Recommended package of practice - SI	179.48[b]	284.45[a]	268.39[a]
	S.Em.±	5.14	7.74	7.38

C- Control, DI-Drip irrigation, ETo-Actual evapotranspiration (mm), G-Germination, T-Tillering, CE-Canopy establishment, GG-Grand growth, M-Maturity, RDF-Recommended dose of fertilizer (313:75:190 kg N, P_2O_5 and K_2O per ha) and SI-Surface irrigation.
Means followed by the same letter (s) within a column do not differ significantly by DMRT (P=0.05)

consistently recorded lower soil biomass carbon compared to drip irrigation treatments. In plant cane, C_2 recorded 169.32, 275.90 and 312.52 µg g^{-1} soil at 120, 180 and 240 DAP, respectively, (Table 7) while in ratoon cane, the corresponding values were 179.48, 284.45 and 268.39 µg g^{-1} soil (Table 8). Reduced soil moisture uniformity under surface irrigation might have limited microbial activity and biomass accumulation.Similarly, Li (2020) and Zhou (2022) highlighted that the synergistic effect of adequate moisture and nutrient availability under drip fertigation significantly enhances soil microbial and enzymatic activity.

Conclusion

The study clearly demonstrated that drip irrigation and fertigation practices influenced soil biological properties in sugarcane during both plant cane and ratoon cane cycles. Higher drip irrigation levels (I_3) consistently enhanced dehydrogenase, urease and phosphatase activities, as well as soil biomass carbon, indicating improved soil microbial activity and biological health under optimum soil moisture conditions. Although fertigation levels did not show significant effects, lower to moderate fertigation (75 per cent RDF) generally supported higher enzyme activities and microbial biomass, suggesting efficient microbial utilization of nutrients under balanced nutrient supply and the higher level of fertigation affected the soil microbial population. Interaction effects further revealed that the combination of higher irrigation with moderate fertigation (I_3F_1) was most effective in sustaining soil enzymatic activity and microbial biomass across growth stages. In contrast, the recommended surface irrigation practice resulted in lower soil biological activity due to non-uniform moisture and nutrient distribution. Overall, optimized drip irrigation coupled with appropriate fertigation emerged as a viable strategy for sustaining soil biological health and productivity of per-seasonal sugarcane in both plant and ratoon cane.

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