__Original Research Article__

Studies on Nutrient uptake, Nutrient use efficiencyand water productivity of Drip irrigated Ratoon Sugarcane as influenced by water soluble fertilizers

Abstract:

A field experiment was conducted at Zonal Agricultural Research Station, V.C. Farm, Mandya during 2020-21 to study the Nutrient content and Uptake of Drip irrigated Ratoon Sugarcane as influenced by water soluble fertilizers. The experimental site was red sandy loam soil with neutral pH, normal electrical conductivity, medium organic carbon, low available nitrogen, medium phosphorus and potassium content. The experiment was laid out in Randomized Complete Block Design with three replications comprising seven treatments with VCF-0517 sugarcane variety. The results revealed that application of 150 per cent RDF through WSF (325.9 kg ha^{-1} N, 46.5 kg ha^{-1} P_2O_5, 338.4 K_2O kg ha^{-1}) recorded significantly higher nitrogen, phosphorus and potassium uptake compared to 100 per cent RDF through WSF (287.3 kg ha^{-1} N, 37.5 kg ha^{-1} P_2O_5, 282.6 kg ha^{-1} K_2O) and 75 per cent RDF through WSF (269.9 kg ha^{-1} N, 33.4 kg ha^{-1} P_2O_5, 253.6 kg ha^{-1} K_2O). Application of WSF at 75 per cent RDF resulted in greater NUE in case of nitrogen, phosphorus and potassium (348.3 kg kg^{-1}, 870.7 kg kg^{-1} and 696.5 kg kg^{-1} respectively) when compared with other fertigation levels and conventional fertilizer application.

Keywords: Fertigation, WSF (water soluble fertilizers), NUE (nutrient use efficiency)**,**fertigation levels,manure production

Introduction:

Sugarcane (Saccharum officinarum L.) stands as a pivotal economic crop globally, coveted for its myriad applications, including sugar, fiber, biofuel, and manure production. Its cultivation is deeply intertwined with the manufacturing processes of sugar, gur, and khandasari, catering to the escalating demand for sweeteners, driven by the burgeoning population. Yet, the expansive growth of sugarcane cultivation faces formidable challenges, constrained by competition from food, fiber, and oilseed crops, compounded by the encroachment of urbanization and industrialization amidst burgeoning populations. A critical challenge looming over sugarcane cultivation worldwide stems from constraints in water, land, and labour, alongside the relentless ascent of input costs. Water scarcity emerges as a particularly acute bottleneck, exacerbated by the imperatives of irrigation. The crux of effective water management pivots on minimizing wasteful consumption, curtailing production costs, and sustaining productivity (Qureshi & Afghan, 2005). To surmount these challenges and amplify sugarcane production and productivity, the adoption of cutting-edge technologies like drip fertigation with water-soluble fertilizers assumes paramount significance.

In tandem with enhancing production, optimizing irrigation water management with nutrient delivery assumes pivotal importance in mitigating the cultivation costs of sugarcane. Fertigation emerges as a transformative approach, synchronizing nutrient supply with crop demand and curbing fertilizer usage by a notable 25–30% (Bhoi et al., 1999). This multifaceted technique not only bolsters sugarcane yields but also mitigates groundwater contamination by curtailing water and nutrient leaching from the rhizosphere. Through the judicious delivery of soluble fertilizers directly to the root zone via irrigation systems, fertigation facilitates frequent applications in smaller quantities, presenting a viable avenue for cultivating crops in environments akin to fertilizer solutions. Despite the manifold benefits, the widespread adoption of drip irrigation is impeded by its elevated installation costs. Nonetheless, strategic interventions such as altering lateral spacing and transitioning to paired row planting configurations hold promise in ameliorating these cost barriers. While a wealth of research underscores the efficacy of fertigation in sugarcane cultivation, the imperative lies in delineating location-specific optimal fertilizer levels under drip fertigation to maximize fertilizer utilization efficiency. Furthermore, the investigation into the effects of applying Mono Ammonium Phosphate (MAP), an acidic fertilizer, assumes precedence. Yet, such granular data remain sparse, particularly in the context of the arid soils characterizing Karnataka's southern dry zone, underscoring the exigency of ongoing research endeavors in this domain.

In elucidating the intricate nexus between water, nutrients, and sugarcane cultivation, it becomes evident that technological innovations like drip fertigation harbor immense potential in circumventing the prevailing constraints and ushering in a paradigm shift in sugarcane cultivation practices. By synergizing the efficacies of water and nutrient management, farmers can navigate the challenges posed by resource scarcity and escalating input costs, fostering sustainable agricultural practices that are imperative for the vitality of the sugarcane industry in an increasingly resource-constrained world. Thus, the journey towards maximizing sugarcane productivity while minimizing environmental footprints unfolds against the backdrop of relentless innovation and unwavering commitment to sustainable agricultural practices.

Material and Methods

The field experiment was conducted in D block of Zonal Agricultural Research Station, V.C. Farm, Mandya. The station is situated between 12°18' and 13°04' North latitude and 76°19' and 77°20' East longitude and at an altitude of 697 meters above mean sea level in southern dry zone (Zone–VI of NARP) of Karnataka which falls in southern dry zone (Region III) of India. Ratoon sugarcane was grown with seven treatments replicated thrice by adopting randomized complete block design. Treatment details follows like this

T_1: Control

T_2: RDF through CF + No FYM

T_3: RDF through CF + FYM

T_4: 150% RDF through WSF + FYM

T_5: 125% RDF through WSF + FYM

T_6: 100% RDF through WSF + FYM

T_7: 75% RDF through WSF + FYM

NOTE: RDF: Recommended dose of fertilizer- 250:100:125 kg NPK ha^{-1}, CF-Conventional fertilizers (Urea, SSP and MOP); FYM - Farm yard manure (15 t ha^{-1}); WSF-Water soluble fertilizers (Urea, MAP, MOP).

Main crop was sowed during December 2018 and it was harvested during January 2020 from onwards crop kept for ratooning and harvested January 2021. The soil belongs *Alfisols* as per USDA classification. Composite soil samples were drawn from the experimental site during the growth stages and samples were air dried, powdered, sieved and analyzed for various physical and chemical properties.

Plant samples collected from each treatment separately, dried and powdered by using mixer grinder with stainless steel blade. The powdered samples were stored in airtight containers for further chemical analysis. These samples were used for N, P, and K estimation. Nitrogen was estimated with wet digestion and distillation adopting the procedure given by Jackson (1973). Phosphorus in plant samples was estimated upon digestion followed by colorimetric estimation using spectrophotometer adopting the procedure given by Jackson (1973). Total potassium of plant samples was estimated by flame photometry following the procedure given by Jackson (1973). Uptake of nitrogen, phosphorus and potassium were calculated using the following formula and expressed in kg ha^{-1}.

Nutrient uptake (kg ha^{-1}) = Nutrient content of cane (%) X Cane dry weight (t ha^{-1}) X 10

The total amount of a specific nutrient (such as nitrogen, phosphorus, or potassium) taken up by the crop per hectare. It considers the nutrient content of the cane, the dry weight of the cane per hectare, and a conversion factor (10) to ensure the result is in kilograms per hectare.

Nutrient use efficiency (NUE):Nutrient use efficiency was calculated by using the formula and expressed in kg kg^{-1}.NUE is a measure of how effectively plants utilize applied nutrients, specifically fertilizers, to produce yield. It can be expressed as the ratio of the increase in yield (or nutrient uptake) to the amount of fertilizer applied.

$$\text{AE}(\text{kg kg}^{-1}) = \frac{[\text{Grain yield in treated plot}\ (\text{kg ha}^{-1}) - \text{Grain yield in control plot}\ (\text{kg ha}^{-1})]}{\text{Fertilizer nutrient applied}\ (\text{kg ha}^{-1})}$$

$$\text{RE}(\text{kg kg}^{-1}) = \frac{[\text{Nutrient uptake in treated plot}\ (\text{kg ha}^{-1}) - \text{Nutrient uptake in control plot}\ (\text{kg ha}^{-1})]}{\text{Fertilizer nutrient applied}\ (\text{kg ha}^{-1})}$$

Results and Discussion

Table 1: Influence of levels of water-soluble fertilizers through fertigation on nutrient uptake ratoon sugarcane at harvest

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1: Control	75.6	11.4	108.5
T_2: RDF through conventional fertilizer +No FYM	206.2	24.7	205.5
T_3: RDF through conventional fertilizers + FYM	221.7	27.8	218.1
T_4: 150% RDF through water soluble fertilizers+ FYM	325.9	46.5	338.4
T_5: 125% RDF through water soluble fertilizers +FYM	322.1	44.8	300.2
T_6: 100% RDF through water soluble fertilizers +FYM	287.3	37.5	282.6
T_7: 75% RDF through water soluble fertilizers + FYM	269.9	33.4	253.6

S.Em ±	8.73	2.72	5.17
CD (p≤0.05)	26.91	8.39	15.93

Note: RDF: Recommended Dosage of Fertilizer- 250:100:125 kg NPK ha^{-1}, **FYM:** Farm Yard Manure; Urea, SSP and MOP applied to soil in T_2 and T_3; Urea, MAP and MOP applied through drip in T_4 to T_7.

The data pertaining to total nutrient uptake as influenced by different levels of WSF of ratoon sugarcane are furnished in Table 1. Application of 150 per cent RDF through WSF (325.9 kg ha^{-1}) recorded significantly higher nitrogen uptake compared to 100 per cent RDF through WSF (287.3 kg ha^{-1}) and 75 per cent RDF through WSF (269.9 kg ha^{-1}), which is on par with 125 per cent RDF (322.1 kg ha^{-1}). Soil application of 100 per cent RDF through conventional fertilizers with FYM (221.7 kg ha^{-1}) and without FYM (206.2 kg ha^{-1}) exhibit significantly lower uptake of nitrogen compared WSF applied treatments. Soil application of 100 per cent RDF through conventional fertilizer with FYM (27.8 kg ha^{-1}) and without FYM (24.7 kg ha^{-1}) exhibit significantly lower uptake of phosphorus compared to WSF applied treatments except 75 per cent RDF through WSF (33.4 kg ha^{-1}). Application of 150 per cent RDF through WSF (46.5 kg ha^{-1}) recorded significantly higher phosphorus uptake compared to 100 per cent RDF through WSF (37.5 kg ha^{-1}) and 75 per cent RDF through WSF (33.4 kg ha^{-1}), which is on par with 125 per cent RDF (44.8 kg ha^{-1}). Higher potassium uptake was noticed with the application of 150 per cent RDF through WSF (338.4 kg ha^{-1}) compared to 125 per cent RDF (300.2 kg ha^{-1}), 100 per cent RDF through WSF (282.6 kg ha^{-1}) and 75 per cent RDF through WSF (253.6 kg ha^{-1}). Soil application of 100 per cent RDF through conventional fertilizers with FYM (218.1 kg ha^{-1}) and without FYM (205.5 kg ha^{-1}) exhibited significantly lower uptake of potassium compared to WSF applied treatments.

The implementation of drip fertigation has consistently demonstrated superior nutrient availability compared to conventional methods of fertilizer application in sugarcane cultivation. This enhanced availability of nutrients can be attributed to several factors inherent to the drip fertigation system. Firstly, the practice of split application of fertilizers over an extended period, often spanning up to nine months, allows for a more gradual and regulated release of nutrients into the soil. This prolonged and staggered application mitigates the risk of nutrient loss through leaching, volatilization, and surface runoff, which are common phenomena associated with conventional surface irrigation and fertilizer application methods. By delivering nutrients directly to the root zone, drip fertigation optimizes nutrient solubilization and uptake by the crop, fostering efficient nutrient absorption and utilization (Annappa et al., 2023).

Moreover, the precise delivery of nutrients near the root zone via drip irrigation facilitates their rapid assimilation by the crop. This proximity to the roots ensures that the nutrients remain readily available for uptake, minimizing their loss to the surrounding environment. Consequently, the crop can access a continuous and consistent supply of essential nutrients, promoting robust growth and development throughout the growing season. The efficacy of drip fertigation in enhancing nutrient availability has been corroborated by previous studies. Shukla et al. (2007) and Selvakumar (2006) reported similar findings, documenting higher levels of available nitrogen, phosphorus, and potassium with drip fertigation compared to conventional methods. These studies underscore the pivotal role of drip fertigation in optimizing nutrient management practices and maximizing nutrient utilization efficiency in sugarcane cultivation.

In contrast, conventional fertilizer application methods, such as the application of 100% recommended dose of fertilizer (RDF) with surface irrigation, often result in suboptimal nutrient availability. The inherent limitations of surface irrigation, coupled with the higher risk of nutrient loss, contribute to reduced nutrient availability in the soil. Nutrients applied to the soil surface are susceptible to leaching, especially in regions with high rainfall or excessive irrigation, leading to their downward movement beyond the root zone. Additionally, volatilization and surface runoff further exacerbate nutrient losses, diminishing their effectiveness in supporting crop growth and productivity. The findings of Shobana (2002) and Aneg Singh et al. (2007) echo these observations, highlighting the inferior nutrient availability associated with conventional fertilizer application methods in sugarcane cultivation. These studies underscore the imperative of adopting alternative nutrient management strategies, such as drip fertigation, to enhance nutrient availability, optimize resource utilization, and improve overall crop performance.

The adoption of drip fertigation represents a paradigm shift in nutrient management practices, offering a sustainable solution to the challenges posed by nutrient loss and inefficient resource utilization in sugarcane cultivation. By promoting precise nutrient delivery, minimizing wastage, and maximizing nutrient uptake by the crop, drip fertigation emerges as a cornerstone of modern agricultural practices aimed at enhancing productivity, profitability, and environmental sustainability in sugarcane cultivation (Annappa et al., 2023).

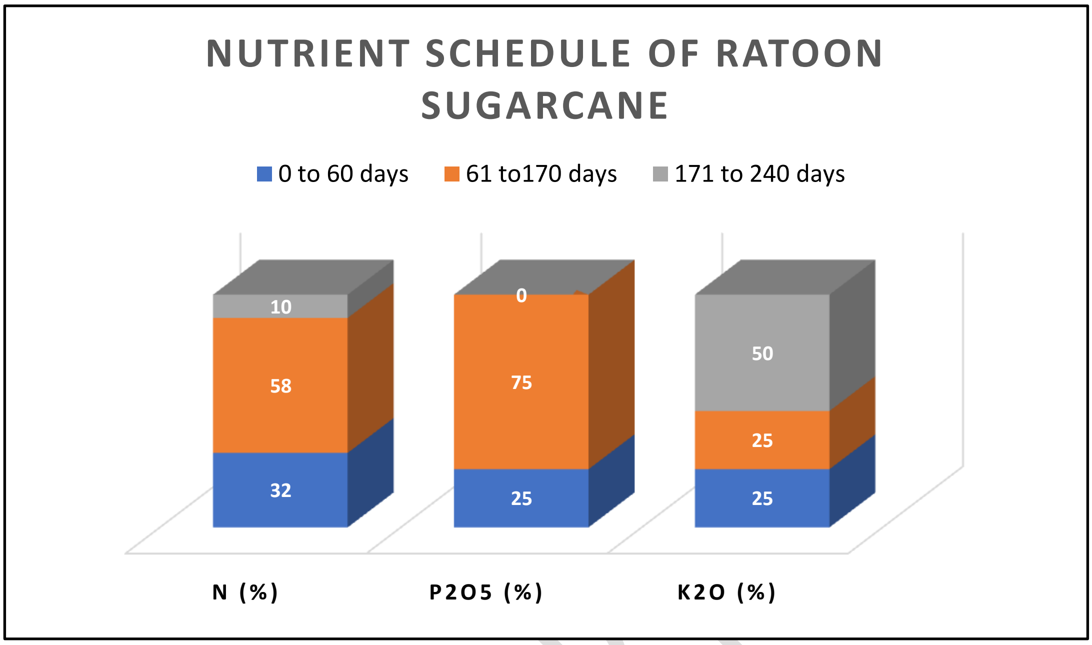
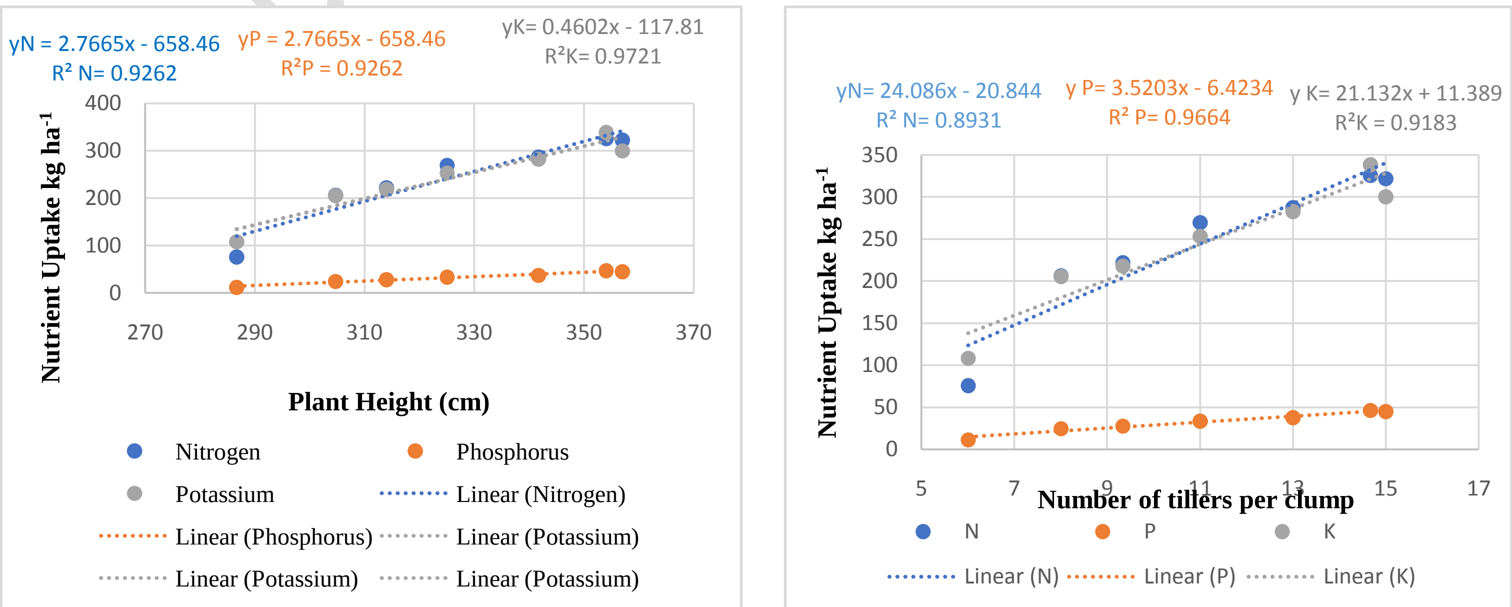


Figure 1: Nutrient scheduling for sugarcane for fertigation

In contrast to the soil application of urea, SSP and MOP, the application of water-soluble fertilisers (Urea, MAP, and MOP) delivered the nutrients during the crucial crop growth phases (Nutrients supplied according to fertilizer schedule as given in Figure 1) while synchronising with the demand and reaching nutrient absorption sites. In contrast to soil application of fertilizers where there is a broad range in nutrient availability, early strong growth of cane with the availability of the needed quantity of water and nutrients with WSF. According to Chaudhary (2019), favourable moisture availability under drip fertigation boosted nutrient uptake and supported good tiller formation.

(A) (B)



(C)

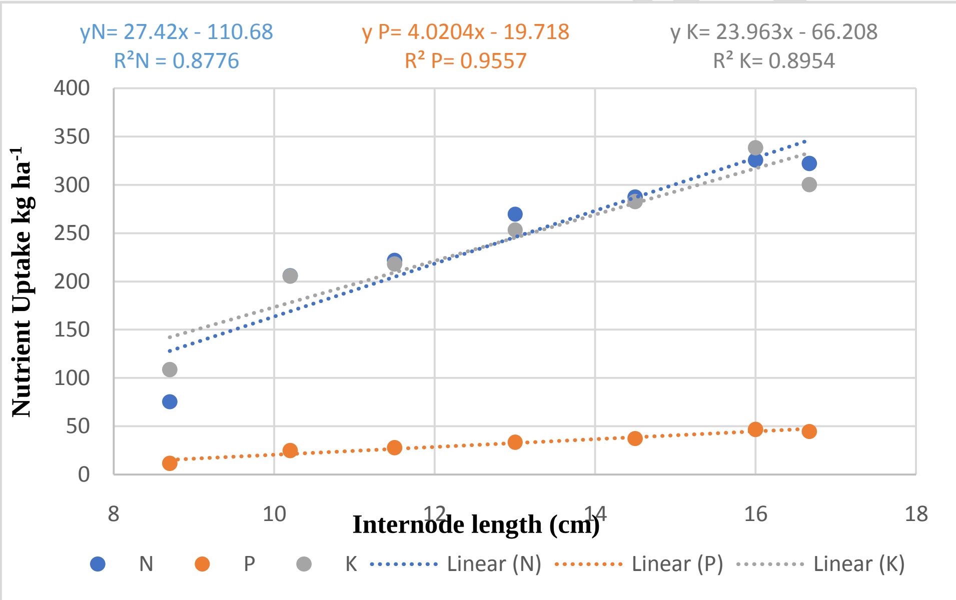


Figure 2: Study of correlation between Nutrient Uptake and Plant height (A), number of tillers per clump (B) and internodal length (C).

The data on plant height (A), number of tillers per clump (B) and internodal length (C) recorded at harvest as influenced by conventional and water-soluble fertilizers were analyzed statistically and presented in Figure 2.A strong correlation was noticed with the uptake of N, P and K with Plant height, number of tillers and internode length. The plant heightat harvest with the application of 125 per cent RDF through WSF was significantly higher (357 cm) compared to 100 per cent RDF through WSF (341.7 cm) and 75 per cent RDF through WSF (325 cm), which is on par with 150 per cent RDF through WSF (354 cm). Soil application of

100 per cent RDF through conventional fertilizer with FYM (314 cm at harvest) and without FYM (304.7 cm at harvest), were significantly lower than WSF applied treatments.

Cane yield mainly depends on the number of millable canes and hence tillering is the principal component attributed towards achieving higher cane yield. Number of tillers clump^{-1} at harvest with the application of 125 per cent RDF through WSF was significantly higher (15.0 clump^{-1}) compared 100 per cent RDF through WSF (13.0 clump^{-1}) and 75 per cent RDF through WSF (11.0 clump^{-1}), which is on par with 150 per cent RDF through WSF (14.67 clump^{-1}).Soil application of 100 per cent RDF through conventional fertilizer with FYM (9.33 clump^{-1} at harvest, respectively) and without FYM (8.0clump^{-1} at harvest) were significantly lower than WSF applied treatments.

Drip fertigation with different levels of WSF at harvest recorded significantly higher internodal length in T_5 treatment (16.67cm) compared to T_6 (14.50 cm) and T_7 treatment (13.0 cm), which is on par with T_4 treatment (16.0 cm). Whereas significantly lower internodal length was recorded in conventional fertilizer soil-based application with FYM (11.50 cm) and without FYM (10.20 cm) compared to WSF applied treatments.

Application of WSF at 150, 125, 100 and 75 per cent of RDF through drip recorded significantly higher growth parameters viz., plant height, number of tillers and internodal length compared to soil application of conventional fertilizers at 100 per cent RDF with or without FYM. The results also indicated that application of WSF at 75 per cent RDF through drip affects the growth parameters significantly higher compared to the soil application of conventional fertilizers at 100 per cent RDF with or without FYM, thus application of WSF at 75 per cent of RDF through drip resulted in not only saving 25 per cent RDF which aims at better water and nutrient supply to the root zone and their by achieving higher growth attributes reported by Mahendran and Dhanalakshmi (2003) in sugarcane.

Higher plant height, number of tillers and internodal length were observed in 125 per cent RDF through drip, but beyond 125 per cent RDF through drip there was slight reduction in the growth parameters indicating law of diminishing marginal returns as indicated by Alfred Marshal. The results also agreed with the findings of Nadagouda (2011) in sugarcane. The increase in plant height, number of tillers and internodal length can be attributed to incremental supply of (WSF - Urea, MAP and MOP for a period of 6 months & Urea and MOP up to 9 months) nutrients throughout the crop growth compared to soil application indicating timely and continuous supply of nutrients to the root zone for better growth and development.

The observed increase in plant height with higher levels of drip fertigation in sugarcane cultivation can be attributed to several interrelated factors that collectively contribute to enhanced plant growth and development. Firstly, the continuous availability of nutrients and moisture in close proximity to the rhizosphere facilitates optimal nutrient uptake by the roots, thereby supporting vigorous vegetative growth. This sustained access to essential resources stimulates root proliferation, leading to a denser and more extensive root system. As a result, the plant is better equipped to extract nutrients and water from the soil, promoting overall growth and vitality (Annappa et al., 2023).

Furthermore, the improved availability of nutrients at critical stages of crop growth is instrumental in promoting cell differentiation and metabolism, facilitating robust growth and development throughout successive growth phases. The heightening of plant stature is indicative of the plant's ability to allocate resources efficiently, channeling nutrients and energy towards structural growth and biomass accumulation. This phenomenon is further supported by the findings of Aujla et al. (2005), who reported similar observations in sugarcane cultivation, underscoring the positive correlation between drip fertigation and plant height enhancement.

In addition to stimulating vertical growth, drip fertigation also exerts a pronounced influence on tillering dynamics in sugarcane. Compared to conventional soil application of fertilizers, drip fertigation treatments consistently exhibit higher levels of tillering, indicative of enhanced vegetative proliferation and canopy development. The application of water-soluble fertilizers, such as urea, Mono Ammonium Phosphate (MAP), and Muriate of Potash (MOP), via drip fertigation ensures the synchronized supply of nutrients during critical growth stages, optimizing nutrient availability and uptake. This early and sustained nutrient provisioning fosters vigorous early growth, bolstering tiller production and canopy expansion. The findings of Gouthaman (2010) further corroborate these observations, highlighting the role of favorable moisture availability under drip fertigation in augmenting nutrient uptake and promoting tiller proliferation.

Moreover, the supply of 125% recommended dose of fertilizer (RDF) through water-soluble fertilizers via drip fertigation induces distinct morphological changes in sugarcane, characterized by thicker and longer internodes. This phenomenon can be attributed to the timely and adequate supply of nutrients and moisture, which facilitate greater photosynthetic activity and assimilate transport. The enhanced photosynthetic mobility and transportation of photosynthates fuel rapid cell division and elongation, culminating in the elongation of internodes and overall plant stature (Annappa et al., 2023). The observations of Veeraputhiran et al. (2002) underscore the pivotal role of nutrient and moisture supply in shaping sugarcane morphology and growth dynamics under drip fertigation regimes.

In essence, the multifaceted benefits of drip fertigation in sugarcane cultivation extend beyond mere nutrient delivery, encompassing enhanced moisture management, optimized resource utilization, and augmented growth dynamics. By providing a conducive environment for robust root development, efficient nutrient uptake, and vigorous vegetative growth, drip fertigation emerges as a cornerstone of modern agricultural practices aimed at maximizing productivity, sustainability, and profitability in sugarcane cultivation.

Table 2: Influence of levels of water-soluble fertilizers through fertigation on agronomic efficiency and water productivity (t ha-cm^{-1}) of ratoon sugarcane

Treatments	**N**	**P**	**K**	**Water productivity (t ha-cm^{-1})**
	kg kg^{-1}			
T_1: Control	-	-	-	0.54
T_2:RDF through conventional fertilizer +No FYM	187.8	469.6	375.7	0.73
T_3:RDF through conventional fertilizers + FYM	217.5	543.8	435.0	0.86
T_4: 150% RDF through water soluble fertilizers+ FYM	233.5	583.7	466.9	1.06
T_5: 125% RDF through water soluble fertilizers +FYM	289.0	722.4	577.9	1.08
T_6: 100% RDF through water soluble fertilizers +FYM	303.5	758.8	607.0	0.99
T_7: 75% RDF through water soluble	348.3	870.7	696.5	0.93

fertilizers + FYM				
S.Em ±	NA	NA	NA	0.04
CD ($p \leq 0.05$)				0.12

Note: RDF: Recommended Dosage of Fertilizer- 250:100:125 kg NPK ha^{-1}, **FYM:** Farm Yard Manure, NA: Not Analyzed Urea, SSP and MOP applied to soil in T_2 and T_3; Urea, MAP and MOP applied through drip in T_4 to T_7.

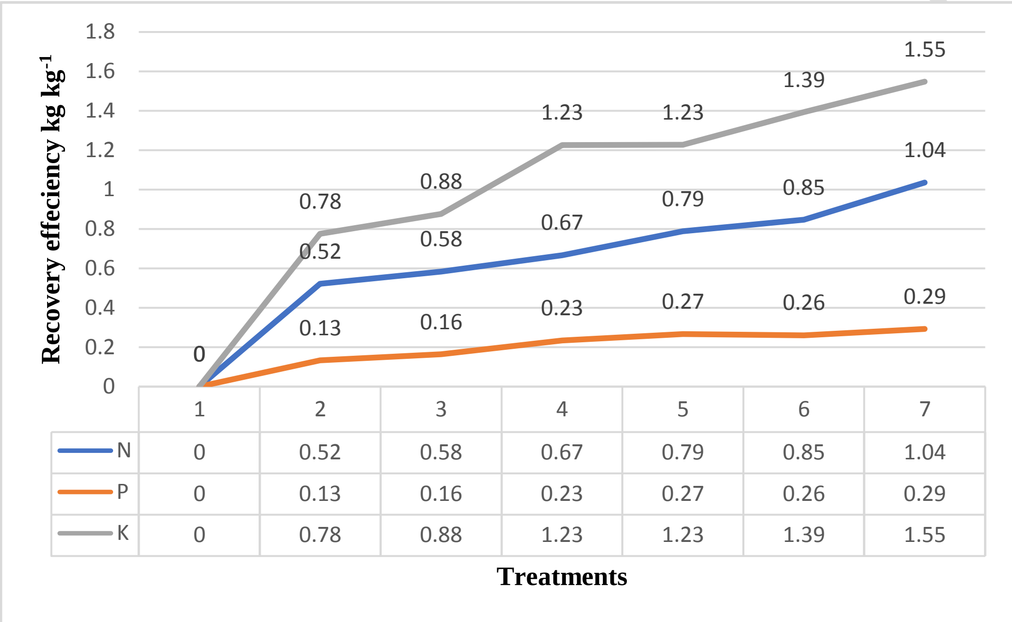


Figure 3: Influence of levels of water-soluble fertilizers through fertigation on Recovery efficiency of N, P and K.

Based on the amount of nutrients applied and its corresponding yield, Agronomic use efficiency is worked out for N, P and K and observed variation due to different levels of WSF are furnished in Table 2. Application of WSF at 75 per cent RDF resulted in greater NUE in case of nitrogen (348.3 kg kg^{-1}) when compared with other fertigation levels (T4-233.5, T5-289.0, T6- 303.5 kg kg^{-1}, respectively) and conventional fertilizer application (T2-187.8 kg kg^{-1}, T3-217.5 kg kg^{-1}). Nutrient use efficiency was higher in case of phosphorus with application of WSF at 75 per cent RDF (870.7 kg kg^{-1}) when compared with other fertigation levels (T4-583.7, T5-720.7, T6-758.8 kg kg^{-1}, respectively) and soil application (T2-469.6 kg kg^{-1}, T3-543.8 kg kg^{-1}). Nutrient use efficiency was greater in case of potassium with application of WSF at 75 per cent RDF (696.5 kg kg^{-1}) when compared with other fertigation levels (T4-466.9, T5-577.9, T6-607.0 kg kg^{-1}, respectively) and soil application (T2-375.7 kg kg^{-1}, T3-435.0 kg kg^{-1}).

Recovery efficiency is worked out for N, P and K (Figure 3) and observed variation due to different levels of WSF. Application of WSF at 75 per cent RDF resulted in greater RE in case of nitrogen (1.04 kg kg^{-1}) when compared with other fertigation levels (T4-0.67, T5-0.79, T6- 0.85 kg kg^{-1}, respectively) and conventional fertilizer application (T2-0.52 kg kg^{-1}, T3-0.58 kg kg^{-1}). Recovery efficiency of phosphorus with application of WSF at 75 per cent RDF (0.29 kg kg^{-1}) when compared with other fertigation levels (T4-0.23, T5-0.27, T6-0.26 kg kg^{-1}, respectively) and soil application (T2-0.13 kg kg^{-1}, T3-0.16 kg kg^{-1}).REK (Recovery efficiency of potassium) was greater with application of WSF at 75 per cent RDF (1.55 kg kg^{-1}) when compared with other fertigation levels (T4-1.23, T5-1.23, T6-1.39 kg kg^{-1}, respectively) and soil application (T2-0.78 kg kg^{-1}, T3-0.88 kg kg^{-1}).

Efficient fertilizer management is paramount for optimizing the growth and yield of ratoon sugarcane. The utilization of water-soluble fertilizers (WSF) through drip irrigation, precisely targeted to the active root zone, represents a strategic approach to minimize nutrient losses and enhance nutrient use efficiency. This practice facilitates the direct delivery of nutrients to the root system, mitigating potential losses through leaching, volatilization, and soil fixation (Annappa et al., 2023). The consequential enhancement in nutrient use efficiency is instrumental in augmenting crop productivity while optimizing fertilizer inputs. The findings align closely with previous research conducted by Veeraputhiran (2000), Aujla et al. (2005), and Subramani (2008), who similarly reported higher nutrient use efficiency under drip fertigation compared to conventional soil application of fertilizers. By delivering nutrients directly to the root zone, drip fertigation ensures a more targeted and efficient utilization of fertilizers, minimizing wastage and maximizing nutrient uptake by the crop.

The availability of plant nutrients in the soil is a critical determinant of cane production potential. Factors such as leaching of nutrients, volatilization of fertilizers, and soil nutrient fixation can significantly impact nutrient availability and, consequently, crop performance. The targeted application of water-soluble fertilizers through drip irrigation circumvents these challenges by delivering nutrients precisely to the root zone, minimizing nutrient losses and optimizing their availability for plant uptake. The study conducted by Debashis Chakraborty et al. (1999) corroborates these observations, highlighting the efficacy of drip fertigation in mitigating nutrient losses and enhancing nutrient availability in the soil. By minimizing nutrient wastage and maximizing nutrient uptake by the crop, drip fertigation emerges as a sustainable and efficient approach to fertilizer management in ratoon sugarcane cultivation.

The adoption of drip fertigation with water-soluble fertilizers represents a strategic approach to optimize fertilizer use efficiency and enhance nutrient availability in ratoon sugarcane cultivation. By minimizing nutrient losses and maximizing nutrient uptake by the crop, drip fertigation holds immense potential to improve productivity, sustainability, and profitability in sugarcane farming systems. Further research and extension efforts are warranted to promote the widespread adoption of drip fertigation as a best practice in fertilizer management for ratoon sugarcane production.

Water productivity (t ha-cm^{-1}) represented in the Table 2 shows that Application of 125 % RDF through WSF (1.08 t ha-cm^{-1}) found statistically on par with 150 % RDF (1.06 t ha- cm^{-1}) and 100 % RDF (0.99 t ha-cm^{-1}). However, due to lower cane yield, the least WUE was noticed with control (0.54 t ha-cm^{-1}). In addition, application of WSF at 75 % RDF registered significantly greater water productivity (0.93 t ha-cm^{-1}) when compared with soil application of conventional fertilizer without FYM (0.73 t ha-cm^{-1}), which is on par with soil application of conventional fertilizer with FYM (0.86 t ha-cm^{-1}). Water use efficiency of cane increased by 26 per cent in drip fertigation system, when same quantity of water was applied as compared to surface irrigation (Aujla *et al*., 2005). The minimum loss of water resulted in the lower water requirement in drip fertigation system compared to surface irrigation (Sankar *et al*., 2008). Effective utilization of available water supplied at regular intervals throughout the crop period to meet out the crop demand increases the water productivity under drip fertigation system (Annappa et al., 2023).

Conclusion:

Application of 150 per cent RDF through WSF recorded significantly higher nitrogen (325.9 kg ha^{-1}), phosphorus (46.5 kg ha^{-1}) and potassium (338.4 kg ha^{-1}) uptake compared to conventional fertilizer soil-based application and NUE found to be higher withapplication of 75 per cent of RDF through WSF,noticed greater nutrient use efficiency of nitrogen (348.3kg kg^{-1}), phosphorus (870.7kg kg^{-1}) and potassium (696.5 kg kg^{-1}) when compared with other fertigation levels and soil application of conventional fertilizers. Application of WSF at 125 per cent RDF noticed significantly greater WUE (1.08 t ha-cm^{-1}) compared to conventional fertilizer soil-based application with FYM (0.86 t ha-cm^{-1}) and without FYM (0.73 t ha-cm^{-1}), which is on par with 150 per cent RDF (1.06 t ha-cm^{-1}) and 100 per cent RDF (0.99 t ha-cm^{-1}) through WSF.

Competing interests: Authors have declared that no competinginterests exist.

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