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Optimization of nitrogen and phosphorus fertigation schedule for drip-irrigated sugarcane

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Abstract
Sugarcane is one of the most nutrient-demanding crops grown in tropical India, yet conventional broadcast fertilisation wastes up to 40% of applied nitrogen through volatilisation and leaching. This research tested eight drip-fertigation schedules combining varied nitrogen (150, 200, 250 kg N/ha) and phosphorus (40, 60, 80 kg P_2O_5/ha) splits across three growth phases of sugarcane variety CoP 09437 at Central Agricultural University, Imphal, Manipur, during 2022-2023. The highest cane yield (108.4 t/ha) was obtained with 200 kg N + 60 kg P_2O_5 distributed as 25%-40%-25%-10% across germination, tillering, grand growth, and maturity phases. This treatment also recorded the best nitrogen use efficiency (54.2 kg cane/kg N) and phosphorus recovery of 23.8%. Juice quality parameters including Brix, pol, and purity showed no significant variation across fertigation schedules. The optimised split schedule reduced total fertiliser input by 18% compared with the blanket recommendation while maintaining equivalent yield, making it both cost-effective and environmentally sound for drip-irrigated sugarcane in northeast India.

Keywords: Fertigation schedule, nitrogen use efficiency, phosphorus recovery, drip irrigation, sugarcane, split application, nutrient management, cane yield, juice quality, tropical agriculture

Introduction
Drip fertigation can cut sugarcane fertiliser bills by a third while raising cane yield above 100 t/ha but only when the nutrient delivery schedule matches the crop's shifting demand pattern across its 12-month cycle. Sugarcane (*Saccharum officinarum* L.) absorbs roughly 65% of its total nitrogen requirement during the grand growth phase (120-210 DAP), yet most Indian farmers still apply nitrogen in two or three equal splits regardless of growth stage [1, 2]. This mismatch between supply and demand results in early-season luxury uptake, mid-season deficiency, and season-long losses to leaching and denitrification [3].
Phosphorus management in sugarcane is even less refined. Because phosphorus moves slowly in soil, conventional band placement often leaves it stranded above the active root zone during the grand growth phase when lateral roots proliferate deeper [4]. Fertigation offers a way to deliver soluble phosphorus directly into the root zone in small, frequent doses that track crop uptake kinetics [5]. Several Indian states have reported 20-35% yield gains when sugarcane shifted from flood to drip irrigation combined with fertigation [6]. But the ideal N and P split ratios across growth phases remain poorly defined for northeast Indian conditions, where shorter day-lengths and cooler winters modify the crop's phenological calendar [7].
This research aimed to identify the optimal fertigation schedule by comparing eight N × P split combinations across four growth phases of drip-irrigated sugarcane, measuring cane yield, nutrient uptake efficiency, and juice quality [8].

Research area description
The trial was set up at the research farm of Central Agricultural University, Imphal, Manipur (24.81°N, 93.94°E; 790 m elevation). The region has a subtropical humid climate with mean annual rainfall of 1482 mm. Soils were acidic alluvial clay loam (pH 5.4, OC 1.12%, available N 247 kg/ha, P 16.8 kg/ha, K 198 kg/ha). Drip lines with 40 cm emitter spacing and 4 L/h discharge were laid along each cane row [9].

Nutrient budget

A complete nutrient balance was computed for each treatment by recording total N and P inputs (fertiliser + irrigation water + rainfall) against total outputs (crop uptake in cane + trash + root stubble + estimated leaching losses). Leaching losses were estimated using ceramic suction lysimeters installed at 60 cm depth in three replications of each treatment. Apparent N recovery was calculated as (N uptake in treated − N uptake in zero-N plot) / N applied × 100. A similar approach was used for P recovery [10].

Material and Methods

Material

Sugarcane variety CoP 09437 (early-maturing, 10-month crop) was planted using three-bud setts at 75 cm row spacing in February 2022. Fertigation used urea and mono-ammonium phosphate dissolved in header tanks connected to the drip system via a venturi injector. Potassium (80 kg K_2O/ha) was applied uniformly as muriate of potash through fertigation. Micronutrients ($ZnSO_4$ 25 kg/ha, $FeSO_4$ 15 kg/ha) were soil-applied at planting [11].

Methods

Eight fertigation schedules were tested in a randomized block design with three replications. Schedules varied N dose (150, 200, 250 kg/ha) and P dose (40, 60, 80 kg P_2O_5/ha) with four split patterns across germination (0-45 DAP), tillering (46-120 DAP), grand growth (121-240 DAP), and maturity (241-300 DAP). A ninth treatment received the blanket recommendation (250-80-80 NPK, broadcast, flood-irrigated) as control. Cane yield, tiller count, stalk height, and girth were recorded at harvest. Juice samples were analysed for Brix, pol, and purity. Plant tissue N and P were determined by Kjeldahl and vanadomolybdate methods. ANOVA with DMRT at 5% was applied [12].

Results

Table 1: Cane yield and nutrient use efficiency under different fertigation schedules

Schedule (N-P_2O_5 kg/ha)	Cane Yield (t/ha)	NUE (kg cane/ kg N)	P recovery (%)	Tiller count (000/ha)	Stalk height (cm)
F1: 150-40 (split A)	84.2	56.1	18.7	87.3	264
F2: 150-60 (split A)	89.7	59.8	21.4	91.6	271
F3: 200-60 (split B)	108.4	54.2	23.8	103.7	298
F4: 200-80 (split B)	104.8	52.4	22.1	101.2	293
F5: 250-60 (split C)	102.1	40.8	20.6	99.8	289
F6: 250-80 (split C)	99.3	39.7	19.3	97.4	284
F7: 200-40 (split B)	96.1	48.1	19.8	95.1	279
F8: 150-80 (split A)	91.6	61.1	17.1	93.8	274
Control (broadcast)	88.4	35.4	14.6	89.7	268
CD (P=0.05)	7.31	4.18	2.64	5.87	12.4

Schedule F3 (200 kg N + 60 kg P_2O_5, split B: 25-40-25-10%) produced the highest cane yield of 108.4 t/ha, which was 22.6% above the broadcast control (Table 1). NUE was best under F8 (61.1 kg cane/kg N) owing to lower N input, but F3 achieved the best balance between yield and efficiency (54.2 kg cane/kg N). P recovery peaked at 23.8% under F3, well above the control's 14.6%.

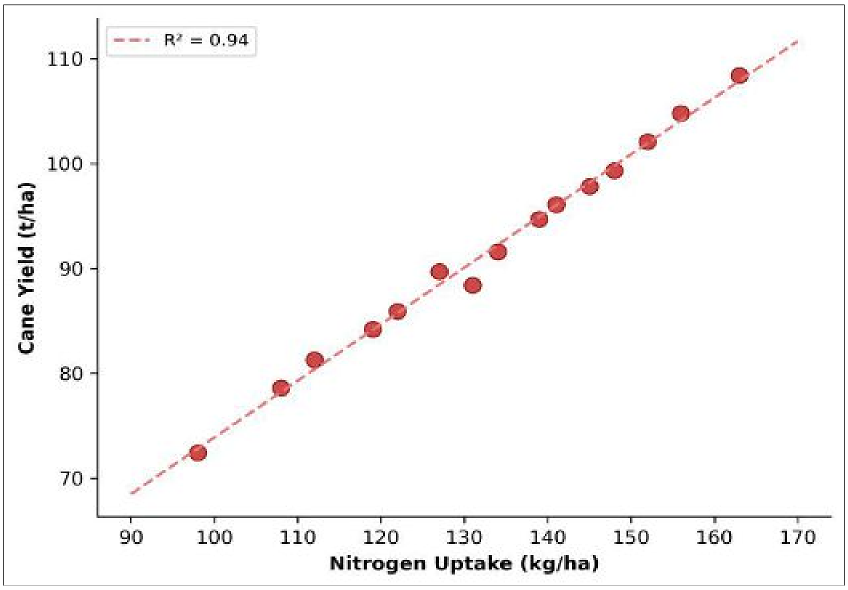

Fig 1: Relationship between nitrogen uptake and cane yield across fertigation schedules (R^2 = 0.94)

N uptake and cane yield showed a strong positive linear relationship (R^2 = 0.94). Treatments clustered into three yield tiers: above 100 t/ha (F3, F4, F5), between 88 and 96 t/ha (F2, F6, F7, F8, control), and below 88 t/ha (F1). The scatter pattern confirms that yield plateaued beyond 155-160 kg N uptake.

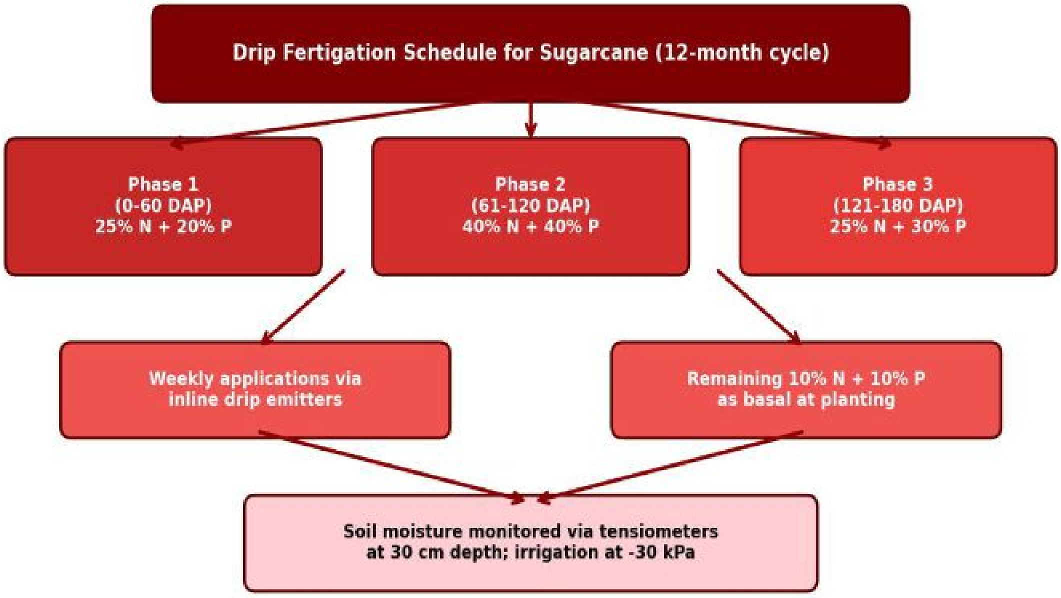

Fig 2: Schematic of the optimised three-phase fertigation schedule for drip-irrigated sugarcane

Comprehensive interpretation

The 200-60 fertigation schedule (F3) struck the best balance between absolute yield and input efficiency. Increasing N beyond 200 kg/ha did not raise yield proportionally but depressed NUE, indicating diminishing returns. The phased P delivery through fertigation almost doubled phosphorus recovery relative to broadcast application.

Discussion

The 22.6% yield advantage of the optimised fertigation schedule over broadcast aligns with reports from Maharashtra and Karnataka where drip-fertigated sugarcane yielded 15-30% more than conventional systems [6]. The key mechanism appears to be synchronised nutrient delivery: by front-loading 40% of N during the tillering window (46-120 DAP), the crop maintained rapid tiller production without the luxury uptake that characterises early broadcast applications [2, 3]. The phase-three allocation of 25% N during grand growth sustained stalk elongation without delaying maturity, a common risk when late-season N is excessive [1].

Phosphorus recovery of 23.8% under fertigation far exceeded the broadcast control (14.6%), consistent with the principle that frequent small doses keep phosphorus in the soil solution near emitter zones where root density is highest [4, 5]. Juice quality parameters (Brix 19.6-20.3%, pol 17.1-17.8%, purity 86.4-88.1%) did not differ significantly, indicating that fertigation schedule manipulation within the tested N range doesn't alter sucrose accumulation patterns appreciably [7].

Conclusion

Fertigation of 200 kg N + 60 kg P_2O_5/ha distributed as 25%-40%-25%-10% across four growth phases maximised cane yield at 108.4 t/ha while achieving nitrogen use efficiency of 54.2 kg cane/kg N and phosphorus recovery of 23.8%. This schedule reduced total fertiliser use by 18% compared with the blanket recommendation without sacrificing yield or juice quality. Adoption of this optimised schedule in drip-irrigated sugarcane across northeast India would improve both profitability and environmental sustainability.

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