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Research Paper

Sub-surface drip fertigation of nitrogen coupled with crop residue incorporation enhanced the growth and yield of maize in an alluvial soils

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ABSTRACT

A two-year field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi, to standardize the N-fertigation schedule and crop residue management in sub-surface drip fertigated (SSDF) maize [Pusa HQPM 1' improved: double bio-fortified]. The experiment was laid-out in a split-plot design with 3 replications. There were 8 main-plot treatments comprising different N sub-surface drip fertigation levels (0, 50, 75, 100% RDN) with one conventional cultivation of maize, where RDN (150 kg/ha) was applied as per recommendation. Under sub-surface fertigation of N, each dose of N was divided into 3-and 4-splits, for fertigation. Sub-plot treatments included greengram residue (3 t/ha) and no greengram residue incorporation. P and K (60 kg P_2O_5/ha and 40 kg K_2O/ha respectively) fertilizers were supplied equally in all the plots by SSDF. Results revealed that plant height at various stages statistically varied with levels and splits of SSDF-N and crop residue incorporation. The highest plant height and leaf area were recorded with 100% RDN-4S which remained at par with 100% RDN-3S and 75% RDN-4S. Conventional maize cultivation was inferior to 'RDN100' and 75%, however on par with 50% RDN. The nitrogen uptake was found significantly superior in 100 and 75%RDN over conventional and control treatments. Similarly, the grain yield of maize was highest under 100% 'RDN-4' &3 S, and 75% RDN-4S, which were at par with one another. Overall, it could be concluded that sub-surface fertigation of N not only improved the growth and yield of maize but also helped in 25–50% saving of valuable fertilizer.

Key words: Absolute growth rate, CROPWAT, ETc., Leaf-area, Plant height, Nitrogen uptake

India's Indo-Gangetic Plains (IGP), long synonymous with the rice-wheat cropping system, faces a myriad of challenges including diminishing factor productivity, soil health degradation, residue burning, greenhouse gas emissions, and a deepening of groundwater level (Dass *et al*., 2015; Dass *et al*., 2016; Dhayal *et al*., 2023). Amid these challenges, the diversification of rice with maize is advocated by researchers and policymakers, a strategy hailed for its higher water productivity compared to rice–maize and requires 80–85% less water to produce one kilogram of grain (Bouman, 2009; Gathala *et al*., 2013). However, recognizing that diversification alone cannot fully address water shortages and declining productivity, a comprehensive approach is imperative.

Maize (*Zea mays* L.), the third most vital cereal crop in India after rice and wheat, holds global significance due to its versatile applications in food, feed, fodder, and various industrial products (Sharma and Dass, 2012). It has a wider adaptability, thriving at altitudes up to 3000 m amsl.; cultivated across 188 million ha in more than 170 countries, maize production globally reaches a staggering 1,423 mt. In India, maize spans approximately oves 10.04 m ha, yielding an annual production of 33.62 mt (Pocket Book of Agricultural Statistics, 2022). Despite its prominence, India's maize productivity lags, standing at 3.3 t/ha half of the world average (5.7 t/ha). Enhancing varietal and agronomic methods becomes imperative to bridge this gap and achieve higher yield.

The nutrient-intensive nature of maize, requiring substantial nitrogen fertilization (150–200 kg/ha), exacerbates soil and water pollution concerns. Addressing this dual challenge necessitates innovative solutions, with drip irrigation emerging as a viable option (Kaur *et al.,* 2024). However, the conventional surface drip fertigation (SDF)

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system poses operational inconveniences during the growing season. In contrast, sub-surface drip fertigation (SSDF) eliminates the need for laterals anchoring, extends their economic life, curtails evaporation, ensures targeted delivery of water and nutrients to the root zone, discourages weed growth, reduces labor costs, and facilitates streamlined cultural farming practices (Ayars *et al*., 1999; Kaur *et al*., 2024). Despite the advantages, scant research exists on standardizing nitrogen fertigation using SSDF in maize within the IGP region, making it imperative to explore and develop SSDF as a promising technology for nutrient and water-use efficiency enhancement and for conserving resources.

MATERIALS AND METHODS

The field experiment was conducted during the *kharif* seasons of 2022 and 2023 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°63'N; 77°15'E), which falls under the Indian Trans-Gangetic Plains Zone (Agro-climatic Zone-VI), characterized by a sub-tropical and semi-arid climate. During 2-years of experimentation, various meteorological data recorded at the meteorological observatory, Division of Agricultural Physics are presented in Fig. 1 and 2. Soil of the experimental field was sandy loam in texture with pH 8.15,

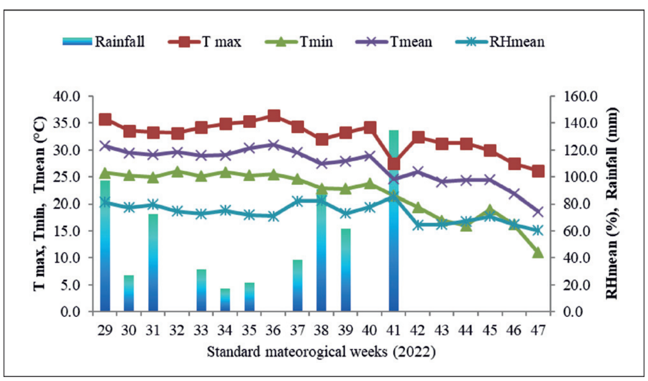


Fig. 1. Weekly meteorological parameters in 2022

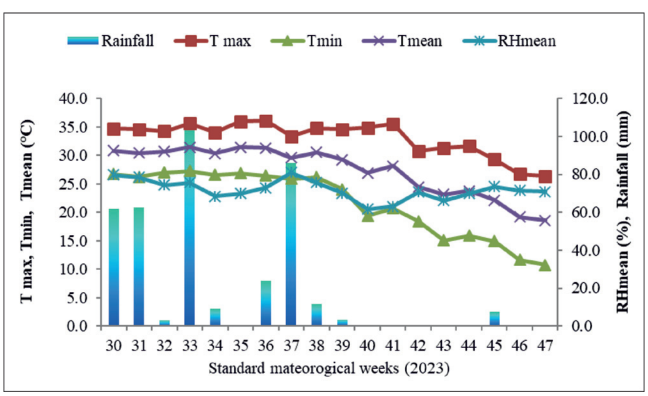


Fig. 2. Weekly meteorological parameters in 2023

Walkley and Black C (oxidizable SOC) 0.49 %, EC 0.43 dS/m, $KMnO_4$ oxidizable N 198.2 kg/ha, 0.5 M $NaHCO_3$ extractable-P 15.7 kg/ha and 1 N NH_4OAc extractable-K 286 kg/ha, in 0–15cm soil depth. The experiment was laid-out in a split-plot design with three replications of 8 main-plot and 2 sub-plot treatments. Main-plot treatments consisted of different N sub-surface drip fertigation levels (0, 50, 75, and 100% RDN) with one conventional cultivation of maize, where RDN (150 kg/ha) was applied as per recommendation. Under subsurface fertigation of N, each dose of N was divided into 3-splits and 4-splits, for fertigation (Table 2). Sub-plot treatments included greengram residue (3 t/ha) and no greengram residue incorporation. The P and K (60 P_2O_5 and 40 kg K_2O/ha) were supplied equally in all the plots.

Daily weather data (i.e., maximum and minimum temperature, mean relative humidity, wind speed, sunshine hours) obtained from ICAR-IARI Agromet Observatory were used to estimate the reference evapo-transpiration (ET_o) by CROPWAT developed by Land and Water Division of FAO. The crop was irrigated twice a week at an interval of 2–3 days till physiological maturity based upon 80% cumulative ETc of the previous days and subtracting effective rainfall during the corresponding period.

Plant growth, *viz.* height, dry matter accumulation (DMA), leaf area, and absolute growth rate (AGR) were recorded periodically at 20- day interval to assess the effect of different treatments on maize. AGR stands for the overall height increase in a plant during a given period of time. AGR was determined at 20-day intervals using the following formula from Dube (2011):

$$AGR = \left(\frac{H_2 - H_1}{T_2 - T_1}\right)$$

Where, H_1 is height of plant at sampling time (T_1); H_2, height of plant at sampling time (T_2).

Nitrogen (N) content in maize samples was determined by the modified Kjeldahl digestion method (Nelson and Somers, 1973), and total nitrogen uptake was calculated by multiplying the respective N content by the total biomass produced. Maize grain yield was recorded from the net-plot area of each treatment and replication. After separating the cobs from the stover, the husk, and silk were removed. For each plot, the resulting cobs were threshed after sun-drying. The grain yield of maize was calculated at a moisture content of 14% and expressed as t/ha. The experimental data collected were analyzed using analysis of variance (ANOVA) technique and the critical difference (P=0.05) value was calculated to identify significant differences among treatments as described by Rana *et al*. (2014).

Table 1. Details of the experimental treatments

Main-plot (Sub-surface drip fertigation of N ($SSDF_N$)
M_1, 0% RDN (control)
M_2, 50% RDN with 3 splits (1/3 each at 20, 45, 65 DAS)
M_3, 50% RDN with 4 splits (1/4 each at 20, 35, 50, 65 DAS)
M_4, 75% RDN with 3 splits (1/3 each at 20, 45, 65 DAS)
M_5, 75% RDN with 4 splits (1/4 each at 20, 35, 50, 65 DAS)
M_6, 100% RDN with 3 splits (1/3 each at 20, 45, 65 DAS)
M_7, 100% RDN with 4 splits (1/4 each at 20, 35, 50, 65 DAS)
M_8, Surface irrigation with RDN (150 kg/ha)
Sub-plot (Crop residue incorporation @ 3 t/ha)
S_1, Residue
S_2, No-residue

RESULTS AND DISCUSSION

Plant height and leaf area

Plant height was recorded highest in conventional cultivation of maize at 20 DAS both in 2022 and 2023 seasons; however, there was no significant difference in height among all the treatments at this stage (Table 3). At 40 DAS, there was surge in plant height in all the treatments where highest plant height was recorded in 100% RDN-4S (128 cm) and the lowest in control (86 cm); plant height in 75% RDN-4S and 100% RDN-3S was at par with 100% RDN-4S in both study years. Using 50% RDN-4S and conventional maize cultivation stood alike.

In 2022, plant height at 60 DAS was 33.6% more compared to 40 DAS under 100% RDN-4S. Plants in 100% RDN-4S were 47 cm taller than control (No N). In the second year (2023), plants at 60 DAS were 31, 30, 27 and 36% taller in 100% RDN-4S, 100% RDN-3S, 75% RDN-4S and in 75% RDN-3S, respectively, compared to 40 DAS; the rate of increase was more or less the same in all of these four treatments. There was no significant difference in plant height among 50%RDN-4S, 50%RDN-3S and conventional N management. As expected control plot recorded the lowest plant height. At 80 DAS, the plant height increased in the order: 100%RDN-4S> 100%RDN-3S>75%RDN-4S. However, there was no significant difference between them. The remaining treatments were in the order: conventional >75%RDN-3S>50%RDN-4S>50%RDN-3S, however, they were at par. Regarding residue management, plot with residue had 4.3, 9, 14 and 17 cm greater plant height than no residue plot in 2023 at 20, 40, 60, 80 DAS, respectively.

Leaf area was influenced significantly by different N management options across all growth stages (20, 40, 60 and 80 DAS). At 20 DAS, the leaf area ranged between (1405–1571cm^2/plant) with the maximum leaf area (1,571 cm^2/plant) being under conventional; however, there was no significant difference between all treatments during both study years (Fig. 3a & b). At 40 and 60 DAS, the leaf area ranged between 5,442–4,007 cm^2/plant and 7,688–5,574 cm^2/plant in 2022 and 5,224–3806 cm^2/plant and 7,458–5,407 cm^2/plant in 2023. The highest leaf area was recorded under 100% RDN-4S which was significantly higher than 75% RDN-3S, 50% RDN-4S, 50% RDN-3S and 0% RDN and statistically at par with 100% RDN-3S, 75% RDN-4S and conventional. At 80 DAS, lowest leaf area was observed in control with value of 4,459 and 4,281 cm^2/plant in both year. Conventional N management (150 kg N/ha) and 50% RDN-4S through SSDF were at par with each other. The leaf area was statistically identical in 100% RDN-4S 100% RDN-3S and 75% RDN-4S.

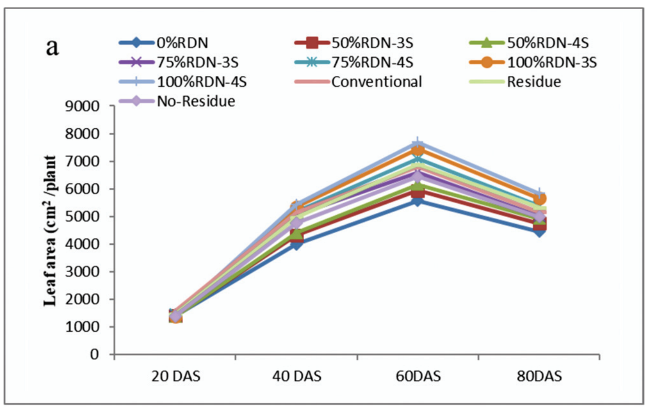
Plants utilized a diverse range of chemical nitrogen (N)

Table 2. Effect of SSDF of N and crop residue incorporation on plant height at 20 days interval

Treatment	Plant height (cm)							
	20 DAS		40 DAS		60 DAS		80 DAS	
	2022	2023	2022	2023	2022	2023	2022	2023
Nitrogen fertigation levels								
0%RDN	39.0	36.7	86	83	146	143	177	174
50%RDN-3S	40.1	37.3	90	90	161	158	196	193
50%RDN-4S	41.4	38.3	100	101	165	162	202	197
75%RDN-3S	40.4	39.4	108	111	170	166	207	203
75%RDN-4S	40.6	41.9	126	130	182	179	222	219
100%RDN-3S	39.5	41.7	124	128	188	184	229	224
100%RDN-4S	39.1	41.0	128	130	193	189	235	231
Conventional	44.0	44.2	98	100	177	173	215	211
SEm±	1.66	1.657	2.73	2.781	5.13	5.03	6.24	6.12
CD (P=0.05)	NS	NS	8.06	8.20	15.13	14.85	18.40	18.06
Residue management								
Residue	41.2	42.2	111	114	178	176	217	215
No-Residue	39.8	37.9	104	105	167	162	204	198
SEm±	0.59	0.56	1.13	1.16	1.48	1.46	1.80	1.77
CD (P=0.05)	NS	1.64	3.31	3.39	4.35	4.27	5.28	5.18

Table 3. Effect of SSDF of N and crop residue incorporation on absolute growth rate of maize at 20 days interval

Treatment	Absolute growth rate (g/day)							
	0–20 DAS		20–40 DAS		40–60 DAS		60–80 DAS	
	2022	2023	2022	2023	2022	2023	2022	2023
Nitrogen fertigation levels								
0% RDN	1.980	1.834	2.303	2.301	2.852	2.789	1.564	1.533
50% RDN-3S	2.006	1.866	2.536	2.630	3.158	3.089	1.773	1.737
50% RDN-4S	2.042	1.913	2.967	3.149	3.183	3.113	1.817	1.780
75% RDN-3S	2.027	1.971	3.357	3.671	3.183	3.113	1.885	1.847
75% RDN-4S	2.029	2.097	4.263	4.387	3.208	3.138	2.092	2.050
100% RDN-3S	1.999	2.084	4.168	4.296	3.217	3.146	2.066	2.025
100% RDN-4S	1.987	2.051	4.413	4.446	3.242	3.170	2.123	2.081
Conventional	2.199	2.211	2.976	2.858	2.942	2.877	1.784	1.748
SEm±	0.086	0.083	0.180	0.185	0.069	0.068	0.052	0.051
CD (P=0.05)	NS	NS	0.530	0.545	0.204	0.199	0.153	0.150
Residue management								
Residue	2.062	2.110	3.500	3.597	3.203	3.132	1.944	1.905
No-Residue	2.005	1.897	3.245	3.338	3.044	2.977	1.832	1.795
SEm±	0.031	0.028	0.068	0.062	0.045	0.044	0.026	0.026
CD (P=0.05)	NS	0.082	0.199	0.181	0.131	0.129	0.077	0.075



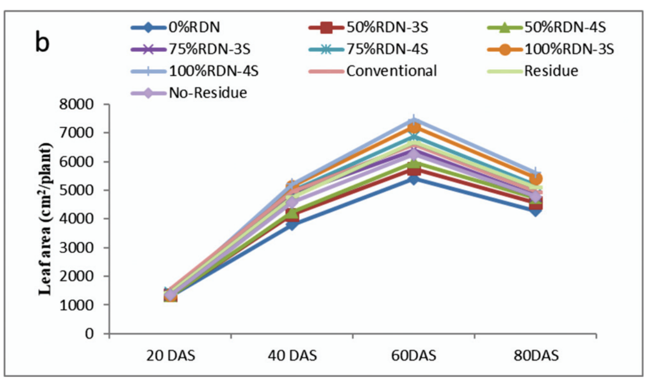


Fig. 3. Effect of SSDF-N and residue on leaf area of maize in 2022 (a) 2023 (b)

forms, encompassing simple inorganic N compounds like NH_4^+ and NO_3^-, as well as more complex polymeric N forms, such as proteins (Paungfoo *et al*., 2008; Choudhary *et al.,* 2008; Bamboriya *et al.,* 2023). Maximum plant height can be achieved by applying N in splits as plant height increased proportionally with N splits up to a certain level (Anjum *et al.,* 2018; Pandagale *et al*., 2018; Scharf *et al*., 2002). Due to N fertigation at the rate of 100% RDN, maize exhibited a significant increase of 11% in plant height compared to non-fertigated maize (Dhayal *et al*., 2023; Kumar and Choudhary, 2023). Time of application of N along with right dose is considered as the most prominent and pivotal factor for a higher productivity of maize as it helps in absorption of N at the period of substantial N requirement (Gharge *et al*., 2020). The application of N during later stages of the vegetative phase in maize extended the growth phase. The prolonged growth period led to increased nutrient assimilation by the crops (Rajpoot *et al*., 2021). Consequently, there was a noticeable rise in plant height, mean single leaf area, and overall leaf area per plant.

Absolute growth rate (AGR)

*Absolute growth rate (*AGR) of maize in the first year (2022) at 0–20 DAS showed non-significant relationship among treatments. The highest AGR (2.2 g/day) was recorded in conventional system and lowest in control (No-N). The AGR (g/day) was statistically alike in residue applied and no-residue plots in the first year. But in the second year (2023), AGR at 0–20 DAS significantly differed among the N-fertigation levels and residue management treatments. In second year, the highest AGR was recorded in conventional system and lowest in control. In 2022, AGR at 20–40, 40–60 and 0–80 DAS revealed statistically significant relationships across various treatments. Use of 100%RDN-4S system exhibited the highest AGR. Conversely, 0% RDN (control) treatment recorded the lowest

AGR. AGR (g/day) was found to be statistically different between residue and no-residue treatments. Applying 100% RDN-4S system exhibited enhanced AGR of 32.6, 9.3 and 16% over conventional system at 20–40, 40–60 and 60–80 DAS, respectively in the first year (2022). In second year (2023) 100% RDN-4S system exhibited AGR enhancement of 35.7, 9.2 and 16% over conventional system at 20–40, 40–60 and 60–80 DAS, respectively. The periodic optimum supply of N directly into the root zone might have influenced the growth of maize, which led to the better AGR (cm/plant), in 100%RDN-4S and 75%RDN-4S as compared to conventional where N was given by broadcasting/top-dressing. Though the rate of fertilization is same under 100% RDN SSDF and conventional system, the splitting and method of delivery played an important role in synchronized and periodic availability of N in maize. Results are in corroboration with those of Hokmalipour and Darbandi (2011).

Total nitrogen uptake

Total N uptake varied from 51 to 185 kg/ha in various subsurface drip fertigation treatments. Nitrogen uptake in 100%RDN-SSDF was 24–34% higher over conventional (Fig. 4). Direct application of N in the root zone help in better availability and uptake of nutrients under SSDF treatments Conventional surface application of fertilizer led to lesser availability to plants, and increased losses, such as runoff, leaching, and volatilization, which cause environmental pollution (Dhayal *et al.,* 2023; Rana *et al.,* 2023). Residue incorporation improved the total N uptake by 9–13% over no-residue. Legume residue incorporation supplies nitrogen to succeeding crops in addition to enriching soil with organic matter (Sharma and Behera, 2009).

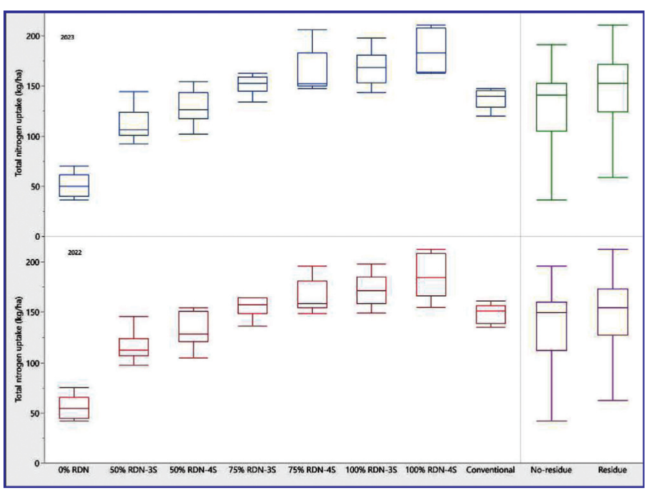


Fig. 4. Effect of SSDF-N and residue on total plant N uptake

Grain, stover yield and harvest index

In the two years of research, 100%RDN-4S resulted in the highest grain yield (6.73 t/ha, 6.53 t/ha) which, however, stood statistically at par with 100%RDN-3S (6.49 t/ha, 6.20 t/ha) and 75%RDN-4S (6.65 t/ha 1, 6.36 t/ha). Sub-surface fertigation of varying N levels increased maize kernel yield by 68-123 % in 2022, and 58-116 % in 2023, over control (Fig. 5). In comparison to conventional maize cultivation, 75%RDN-4S and 100%RDN-4S produced 19–23, and 20–25.3% higher yield across the years, while 75%RDN-3S and 100%RDN-3S could improve the yield by 14–17% and 16–19%, respectively. With 50% less N than conventional cultivation, 50%RDN-4S and 50%RDN-3S, resulted in yield alike conventional cultivation. Residue incorporation increased yield by 5 and 8.3% in 2022 and 2023, respectively, over no-residue. The higher grain yield under higher doses and splitting might be due to the continuous availability of soil mineral N, would have supported the better growth, development of the maize, nutrient uptake, which is evident from the better plant height, leaf area, and nitrogen uptake in the present study (Pratap *et al.,* 2022; Sachin *et al.,* 2023). Similar results were found by Dhayal *et al.* (2023) and Patra *et al.* (2021).

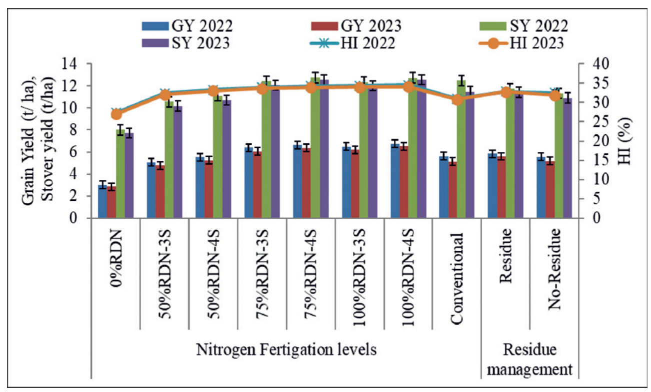


Fig. 5. Effect of SSDF-N and residue on grain, straw yield, and harvest index of maize

Notes: (GY is grain yield; SY is stover yield, HI is harvest index)

Similarly, 100% RDN-4S resulted in an increment of straw yield which, was however, statistically at par with 100% RDN-3S. Splitting the N dose into 4 splits with 25% less N than RDN, the stover yield of 75%RDN-4S was at par with the former treatments (100%RDN). Using 50% RDN in 3 or 4 splits produced similar stover yield as in conventional treatment. Stover yield was 11.76 and 11.42 t/ha in mungbean residue incorporated plot and 11.34, 10.91 t/ha in no residue plot in 2022 and 2023, respectively. Treatment fertilized with 100% RDN into 4 splits showed the harvest index comparable with 100%RDN-3S, 75% RDN-4S, 75% RDN-3S and 50% RDN-4S. All these treatments were significantly superior to control and conventional maize cultivation. Greater harvest index was recorded in residue applied plots than no-residue plots.

Higher grain, stover yield under sub-surface drip fertigation at 100% RDN and 75% RDN over conventional N management (100%RDN and surface irrigation) might be due to more synchronized, close proximity of delivery of N under SSDF over conventional cultivation.

The study revealed significant improvement in maize growth, productivity, and nutrient utilization under subsurface drip fertigation (SSDF) compared to conventional methods. Using 100% RDN-4S resulted in the highest grain yield (6.73 t/ha, 6.53 t/ha) which was, however, at par with 100% RDN-3S (6.49, 6.20 t/ha) and 75%RDN-4S (5.51, 5.24 t/ha). The application of 100% RDN-4S, 100% RDN-3S, and 75% RDN-4S doubled the yield over control, whereas 19–25% increment over conventional. Additionally, the incorporation of greengram residue positively influenced plant height and leaf area, contributing to an overall improvement in yield and harvest index. The findings of this two-year study underscore the efficacy of subsurface fertigation of N, particularly 75% RDN-4S, in optimizing maize growth, yield, and nutrient utilization. Moreover, subsurface drip fertigation of 50% RDN resulted in similar growth and productivity as in 100%RDN applied in a conventional way; both offering a promising approach for sustainable agricultural practices, by saving ~25–50% valuable N fertilizer.

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