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RESEARCH ARTICLE

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Analysing Root Architecture and Nutrients Uptake in Zero-till *Rabi* Maize with *Kharif* Legumes and Nitrogen Gradient Levels

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ABSTRACT

Background: Root morphology acts as a dynamic pull-push mechanism for nutrient uptake, supporting growth above and below ground. Root architecture evolves in tandem with plant development, facilitating efficient nutrient absorption throughout each growth stage. From sowing to harvest, roots adapt to the soil substrate, optimizing nutrient availability. This synergy between root growth and nutrient dynamics is crucial for overall plant health and productivity.

Methods: The research trail was planned focusing on root development and nutrient uptake at MRC-ARI, Rajendrangar, Hyderabad during two seasons of 2021-22 and 2022-23. The trail was designed with split-plot comprising of 6 main treatments C_1N_1: groundnut$_{100\%\ RDN}$-maize, C_1N_2: groundnut$_{75\%\ RDN}$-maize, C_2N_1: soybean$_{100\%\ RDN}$-maize, C_2N_2: soybean$_{75\%\ RDN}$-maize, C_3N_1: greengram$_{100\%\ RDN}$-maize, C_3N_2: greengram$_{75\%\ RDN}$-maize and 3 sub-plots *viz.*100% RDN, 125% RDN, 150% RDN during 2021-22 and 2022-23.

Result: In legume-based maize cropping systems, greengram with 100% RDN demonstrated higher root length, root volume, root density and higher N, P and K uptakes over soybean and groundnut from 30 DAS to harvest in both years. Besides to nitrogen levels, *rabi* maize treated with 150% RDN had noticeably better root morphology and plant nutrient uptake than 125% and 100% RDN across all crop growth stages. Conversely, the interactive effect (biomass residues × nitrogen gradient levels) in zero-till *rabi* maize was found to be non-significant in both 2021-22 and 2022-23.

Key words: Legume residues, Plant nutrient uptake, Root length, Volume and nitrogen levels.

INTRODUCTION

In contemporary agriculture, the primary objective is to enhance food production sustainably, while minimizing environmental impact. The global practice of intensive mono-cropping, particularly in cereals, has indeed increased staple crop production but has also disrupted ecological balance, leading to issues like pollution and resource overexploitation (Srivastav *et al.,* 2021; Shah *et al.,* 2003).

Maize, the "Queen of Cereals", plays an important role in the worldwide agricultural economy, ranking third among cereals behind rice and wheat. Its agility, heavy feeder, cost-effectiveness and nutritional importance for both humans and animals make it a key crop (Tiwari *et al.,* 2022). Legumes in cropping systems appear to be a promising answer from both an environmental and economic standpoint. This integration not only improves soil nitrogen levels but also decreases reliance on inorganic fertilizers (Rahman *et al.,* 2014). Growers may make a major contribution to indigenous nitrogen generation by growing legumes, which are natural nitrogen factories in the field. Furthermore, root architecture is very important to above-ground development and yield production, specifically nutrient absorption and use efficiency and tolerance to adversity (Postma *et al.,* 2014). While the root system and canopy compete for energy and nutrient resources (York *et al.,* 2013), they also maintain the dynamic balance and development of plant growth (York *et al.,* 2015 and Chimungu *et al.,* 2014). Thus, it is essential to study root morphological characteristics and mechanisms of how N application rates regulate the root morphology in maize. Root characteristics are essential to root growth and their distribution significantly influences the uptake of nutrients and soil moisture (Liu *et al.,* 2019), which directly affects crop growth and development (Li *et al.,* 2019).

Root morphological characteristics are closely related to root absorption, assimilation and transport to above-ground plant parts. The root system includes root length, lateral root branching, root occurrence, three-dimensional distribution in space, root growth angle, root growth and available soil water (Wang *et al.,* 2020; Mu *et al.,* 2015). Nitrogen (N), aside from roots, is the most crucial nutrient for crop growth and increasing grain output and over use of artificial fertilizers has contributed significantly to agricultural yield increases (Lynch *et al.,* 2013; Zhao *et al.,* 2018). N-efficient maize varieties have much more underground nodes, longer length and developed cortical ventilation tissue, which are beneficial to absorb more nitrogen from the soil. (Peng *et al.,* 2010; Kishore *et al.,* 2025; Sinha *et al.,* 2018; Makwana *et al.,* 2016).

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Therefore, understanding the relationship between root architecture and above-ground growth, productivity and N absorption may improve N use efficiency that might increase grain yield (Jia *et al.,* 2018; Lodha *et al.,* 2021). The purpose of the study is to determine how *kharif* legumes affect the morphology of the roots and the uptake of nutrients by the plants in *rabi* maize.

MATERIALS AND METHODS

In the years 2021-2022 and 2022-2023, the experimental research location is situated at MRC-ARI, Rajendrangar, Hyderabad. The trail farm is located at 542.3 meters above sea level, with latitude 17°19°N and longitude 78°23°E. It lies in the Southern Telangana Agro-Climatic Zone and is categorized by Troll as Semi-Arid Tropics.

Climate conditions were suitable for crop growth throughout the course of the two years, with mean minimum temperatures ranging from 12.6°C to 21.2°C and mean maximum temperatures ranging from 26.3° to 33.2°C. During the crop-growing season in both years, the optimal rainfall (878.54 mm) and sunlight hours (0.9 to 10 hours day^{-1}) were noted.

The research was organized in a split-plot design with 6 main-plots which includes C_1N_1: groundnut$_{100\%\ RDN}$-maize, C_1N_2: groundnut$_{75\%\ RDN}$-maize, C_2N_1: soybean$_{100\%\ RDN}$-maize, C_2N_2: soybean$_{75\%\ RDN}$-maize, C_3N_1: greengram$_{100\%\ RDN}$-maize, C_3N_2: greengram$_{75\%\ RDN}$-maize cropping systems and 3 sub-plots: F_1: 100% RDN, F_2:125% RDN, F_3:150% RDN in *rabi* respectively during two years. Legume crops (groundnut, soybean and greengram) were planted on June 25th of the *kharif* season with a 30 cm × 10 cm spacing in both years.

In 2021-2022 and 2022-2023 respectively, zero-till conditions were used to plant *rabi* maize on September 25th and soybean and groundnut on October 23rd, after the greengram harvest. The maize crop was planted with a 60 cm × 20 cm spacing and fertilized with 80 kg ha^{-1} of phosphate and potash as a base dose.

The prescribed nitrogen was applied in various levels based on the treatments. For groundnut, soybean and greengram, the required nitrogen dosages during *kharif* are 20, 60, 20 and 240 kg ha^{-1} for *rabi* maize, respectively.

Weedicides and pesticides were used based on necessity, assessing crop damage and field circumstances. A statistical study of the legume-maize system data with nitrogen levels in split-plot design was carried out using SPSS software to compare the data and examine it for treatment interactions.

Root length and root volume

Root length and root volume of respective crops *viz.,* greengram, soybean, groundnut during *kharif* and maize during *rabi* were recorded at 30, 60, 90 DAS from the five plants pulled out of the gross plot with residual soil moisture. Root volume was assessed using water displacement method and results were expressed in cm^3. Root length was measured using meter scale and expressed in cm.

Root dry weight

Root dry weights were determined at 30, 60 and 90 DAS, when the representative plant samples are harvested at the soil surface level with a core sampler of 7.0 cm in diameter by 80 cm deep which was designed for two-person operation. The roots were separated from the soil and washed. The roots were dried at 75°C to obtain constant weight and weighed in grams.

Plant samples

The crop samples collected at different intervals were sundried for 2 days and then dried in hot air oven at 60ÚC to a constant weight were used for analysis after grinding by using the Willey mill and this powder was used for estimation of N, P and K content.

Nitrogen uptake (kg ha^{-1})

Firstly, the nitrogen content (%) in the plant was estimated by micro Kjeldhal method using Kelplus N analyser after digesting the samples with H_2SO_4 and H_2O_2 (Piper,1966). The uptake was calculated by the formula:

$$\text{N uptake (kg ha}^{-1}\text{)} = \frac{\text{N content (\%)} \times \text{Dry matter production (kg ha}^{-1}\text{)}}{100}$$

Phosphorus uptake (kg ha^{-1})

The tri-acid (HNO_3, $HClO_4$ and H_2SO_4) in the ratio of (9:3:1) respectively digested plant were analyzed for phosphorus content by Vanado-molybdo phosphoric acid. The intensity of yellow colour developed was measured by using spectrophotometer at 420 nm (Piper, 1966). Finally, the uptake was calculated by the formula:

$$\text{P uptake (kg ha}^{-1}\text{)} = \frac{\text{P content (\%)} \times \text{Dry matter production (kg ha}^{-1}\text{)}}{100}$$

Potassium uptake (kg ha^{-1})

Potassium content in the tri-acid was determined with flame photometer (Piper, 1966). The uptake was calculated by formula:

$$\text{K uptake (kg ha}^{-1}\text{)} = \frac{\text{K content (\%)} \times \text{Dry matter production (kg ha}^{-1}\text{)}}{100}$$

RESULTS AND DISCUSSION

Root parameters

The root metrics (root length, root dry weight and root volume) during crop phenophases of the zero-till *rabi* maize sequence were influenced by nitrogen doses and prior legume residues in both years of study (Table 1, 2, 3 and Fig 1).

According to data obtained from 30, 60 and 90 DAS and at harvest, greengram 100% RDN as *kharif,* followed

Table 1: Root length (cm) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**												
C_1N_1: Groundnut$_{100\% RDN}$	17.49	17.14	17.32	37.33	34.49	35.91	68.42	66.30	67.36	84.17	86.72	85.45
C_1N_2: Groundnut$_{75\% RDN}$	14.46	14.37	14.42	32.59	30.52	31.56	63.83	62.76	63.30	80.17	82.46	81.32
C_2N_1: Soybean$_{100\% RDN}$	20.07	19.84	19.96	42.56	39.24	40.90	76.07	73.05	74.56	93.39	92.71	93.05
C_2N_2: Soybean$_{75\% RDN}$	19.45	19.08	19.27	41.28	38.00	39.64	72.13	70.01	71.07	89.50	89.65	89.58
C_3N_1: Greengram$_{100\% RDN}$	21.68	21.38	21.53	45.45	44.87	45.16	80.92	79.46	80.19	101.70	99.25	100.48
C_3N_2: Greengram$_{75\% RDN}$	20.76	20.53	20.65	43.53	41.18	42.36	76.63	75.63	76.13	97.64	95.47	96.56
SEm±	0.18	0.16	-	0.28	0.59	-	0.98	0.87	-	1.21	0.86	-
C.D. (P=0.05)	0.57	0.51	-	0.88	1.85	-	2.85	2.55	-	3.81	2.70	-
***Rabi* maize with varied nitrogen fertility levels (F)**												
F_1: 100% RDN	17.35	17.09	17.22	37.62	34.73	36.18	69.70	68.57	69.14	90.81	87.52	89.17
F_2: 125% RDN	18.97	18.74	18.86	40.47	38.68	39.58	73.43	72.50	72.97	94.63	91.42	93.03
F_3: 150% RDN	20.69	20.34	20.52	43.28	41.45	42.37	76.88	75.50	76.19	98.87	96.69	97.78
SEm±	0.17	0.13	-	0.27	0.63	-	0.54	0.32	-	0.48	0.58	-
C.D. (P=0.05)	0.50	0.37	-	0.79	1.85	-	1.56	0.92	-	1.39	1.70	-
Interaction												
Sub treatments at same level of main treatments F × (C × N)												
SEm±	0.37	0.28	-	0.51	1.46	-	1.23	0.65	-	1.03	1.36	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F												
SEm±	0.42	0.31	-	0.66	1.55	-	1.31	0.77	-	1.17	1.42	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

Table 2: Root dry weight (g) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**												
C_1N_1: Groundnut$_{100\% RDN}$	17.54	16.48	17.01	42.22	44.00	43.11	57.89	55.98	56.94	68.63	62.30	65.47
C_1N_2: Groundnut$_{75\% RDN}$	16.36	15.82	16.09	37.83	35.84	36.84	52.63	50.83	51.73	65.40	58.07	61.74
C_2N_1: Soybean$_{100\% RDN}$	18.84	18.32	18.58	48.82	49.56	49.19	63.43	61.50	62.47	74.55	72.18	73.37
C_2N_2: Soybean$_{75\% RDN}$	18.13	17.43	17.78	45.52	46.99	46.26	60.84	59.02	59.93	71.87	67.95	69.91
C3N1: Greengram$_{100\% RDN}$	21.46	20.45	20.96	53.52	52.88	53.20	68.81	66.71	67.76	80.99	80.15	80.57
C_3N2: Greengram$_{75\% RDN}$	19.52	19.08	19.30	51.89	50.47	51.18	64.94	63.94	64.44	77.58	76.28	76.93
SEm ±	0.20	0.20	-	0.65	0.22	-	0.36	0.64	-	0.93	1.26	-
C.D. (P=0.05)	0.62	0.62	-	2.05	0.70	-	1.14	2.02	-	2.93	3.97	-
***Rabi* maize with varied nitrogen fertility levels (F)**												
F_1: 100% RDN	16.48	15.83	16.16	43.26	41.90	42.58	56.91	55.38	56.15	68.12	66.08	67.10
F_2: 125% RDN	18.75	17.95	18.35	47.78	46.56	47.17	61.76	60.23	61.00	75.15	73.02	74.09
F_3: 150% RDN	20.70	20.01	20.36	51.36	49.92	50.64	65.60	63.53	64.57	78.74	76.62	77.68
SEm ±	0.13	0.11	-	0.45	0.37	-	0.31	0.28	-	0.64	0.80	-
C.D. (P=0.05)	0.37	0.33	-	1.30	1.08	-	0.92	0.81	-	1.87	2.34	-
Interaction												
Sub treatments at same level of Main treatments F × (C × N)												
SEm ±	0.26	0.21	-	0.94	0.86	-	0.89	0.58	-	1.43	1.70	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F												
SEm ±	0.30	0.28	-	1.09	0.91	-	0.96	0.68	-	1.57	1.96	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

Table 3: Root volume (cm^3) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Harvest		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**												
C_1N_1: Groundnut$_{100\% RDN}$	13.63	10.58	12.11	31.50	27.02	29.26	48.96	44.87	46.92	62.59	62.36	62.48
C_1N_2: Groundnut$_{75\% RDN}$	13.31	9.67	11.49	27.72	24.70	26.21	43.08	41.25	42.17	59.12	59.63	59.38
C_2N_1: Soybean$_{100\% RDN}$	14.56	13.64	14.10	33.32	31.66	32.49	54.13	51.44	52.79	68.00	67.26	67.63
C_2N_2: Soybean$_{75\% RDN}$	13.96	12.82	13.39	32.19	29.25	30.72	51.68	47.46	49.57	64.96	64.97	64.97
C_3N_1: Greengram$_{100\% RDN}$	15.58	15.39	15.49	36.76	36.06	36.41	59.16	57.88	58.52	75.62	74.71	75.17
C_3N_2: Greengram$_{75\% RDN}$	14.98	14.50	14.74	34.64	33.91	34.28	57.04	54.44	55.74	73.16	72.10	72.63
SEm ±	0.08	0.27	-	0.30	0.65	-	0.33	0.78	-	0.71	0.62	-
C.D. (P=0.05)	0.25	0.84	-	0.94	2.05	-	1.03	2.46	-	2.24	1.96	-
***Rabi* maize with varied nitrogen fertility levels (F)**												
F_1: 100% RDN	13.36	11.09	12.23	29.79	28.59	29.19	47.89	46.30	47.10	63.48	61.56	62.52
F_2: 125% RDN	14.41	13.95	14.18	33.16	32.04	32.60	52.03	50.15	51.09	68.40	66.43	67.42
F_3: 150% RDN	15.60	15.14	15.37	35.72	34.48	35.10	55.10	52.98	54.04	71.80	70.03	70.92
SEm ±	0.08	0.26	-	0.23	0.75	-	0.34	0.63	-	0.73	0.52	-
C.D. (P=0.05)	0.23	0.75	-	0.68	2.18	-	0.99	1.84	-	2.14	1.52	-
Interaction												
Sub treatments at same level of Main treatments F × (C × N)												
SEm ±	0.14	0.52	-	0.46	1.75	-	0.72	1.43	-	1.65	1.05	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F												
SEm ±	0.20	0.63	-	0.57	1.83	-	0.83	1.55	-	1.79	1.28	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

Table 4: Nitrogen uptake (kg ha^{-1}) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Grain			Straw		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**															
C_1N_1: Groundnut$_{100\% RDN}$	1.43	1.51	1.47	9.24	7.82	8.53	19.15	19.10	19.13	13.04	16.23	14.64	7.84	9.41	8.63
C_1N_2: Groundnut$_{75\% RDN}$	0.71	0.69	0.70	8.76	5.38	7.07	17.03	17.21	17.12	11.45	12.29	11.87	8.42	8.71	8.57
C_2N_1: Soybean$_{100\% RDN}$	2.98	3.29	3.14	12.11	12.61	12.36	23.27	23.12	23.20	16.59	19.38	17.99	9.71	10.87	10.29
C_2N_2: Soybean$_{75\% RDN}$	2.16	2.32	2.24	10.59	10.23	10.41	21.39	21.17	21.28	15.29	18.05	16.67	9.01	10.12	9.57
C_3N_1: Greengram$_{100\% RDN}$	4.26	4.95	4.61	15.77	17.86	16.82	26.01	27.33	26.67	19.94	21.78	20.86	10.98	12.66	11.82
C_3N_2: Greengram$_{75\% RDN}$	3.74	4.10	3.92	14.70	15.07	14.89	24.01	25.05	24.53	18.20	20.52	19.36	10.30	11.81	11.06
SEm±	0.22	0.25	-	0.23	0.75	-	0.71	0.62	-	0.36	0.39	-	0.21	0.23	-
C.D. (P=0.05)	0.69	0.80	-	0.73	2.35	-	1.87	1.78	-	1.22	1.11	-	0.56	0.67	-
***Rabi* maize with varied nitrogen fertility levels (F)**															
F_1: 100% RDN	3.31	3.57	3.44	10.15	11.16	10.66	19.95	21.08	20.52	15.94	17.20	16.57	9.22	9.94	9.58
F_2: 125% RDN	3.75	3.92	3.84	11.58	12.27	11.93	21.97	23.21	22.59	18.34	19.50	18.92	10.31	10.92	10.62
F3: 150% RDN	3.95	4.16	4.06	12.56	13.91	13.24	23.61	25.11	24.36	19.92	21.62	20.77	11.20	12.02	11.61
SEm±	0.06	0.13	-	0.13	0.65	-	0.43	0.41	-	0.43	0.49	-	0.30	0.28	-
C.D. (P=0.05)	0.18	0.38	-	0.37	1.91	-	1.23	1.19	-	1.24	1.42	-	0.75	0.73	-
Interaction															
Sub treatments at same level of main treatments F × (C × N)															
SEm±	0.12	0.28	-	0.26	1.34	-	1.47	1.73	-	0.54	0.80	-	0.69	0.58	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F															
SEm±	0.15	0.32	-	0.31	1.60	-	1.64	1.84	-	0.78	0.92	-	0.85	0.79	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

Table 5: Phosphorus uptake (kg ha^{-1}) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Grain			Straw		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**															
C_1N_1: Groundnut$_{100\% RDN}$	1.43	1.51	1.47	9.24	7.82	8.53	19.15	19.10	19.13	13.04	16.23	14.64	7.84	9.41	8.63
C_1N_2: Groundnut$_{75\% RDN}$	0.71	0.69	0.70	8.76	5.38	7.07	17.03	17.21	17.12	11.45	12.29	11.87	8.42	8.71	8.57
C_2N_1: Soybean$_{100\% RDN}$	2.98	3.29	3.14	12.11	12.61	12.36	23.27	23.12	23.20	16.59	19.38	17.99	9.71	10.87	10.29
C_2N_2: Soybean$_{75\% RDN}$	2.16	2.32	2.24	10.59	10.23	10.41	21.39	21.17	21.28	15.29	18.05	16.67	9.01	10.12	9.57
C3N_1: Greengram$_{100\% RDN}$	4.26	4.95	4.61	15.77	17.86	16.82	26.01	27.33	26.67	19.94	21.78	20.86	10.98	12.66	11.82
C_3N_2: Greengram$_{75\% RDN}$	3.74	4.10	3.92	14.70	15.07	14.89	24.01	25.05	24.53	18.20	20.52	19.36	10.30	11.81	11.06
SEm±	0.22	0.25	-	0.23	0.75	-	0.71	0.62	-	0.36	0.39	-	0.21	0.23	-
C.D. (P=0.05)	0.69	0.80	-	0.73	2.35	-	1.87	1.78	-	1.22	1.11	-	0.56	0.67	-
***Rabi* maize with varied nitrogen fertility levels (F)**															
F_1: 100% RDN	3.31	3.57	3.44	10.15	11.16	10.66	19.95	21.08	20.52	15.94	17.20	16.57	9.22	9.94	9.58
F_2: 125% RDN	3.75	3.92	3.84	11.58	12.27	11.93	21.97	23.21	22.59	18.34	19.50	18.92	10.31	10.92	10.62
F_3: 150% RDN	3.95	4.16	4.06	12.56	13.91	13.24	23.61	25.11	24.36	19.92	21.62	20.77	11.20	12.02	11.61
SEm±	0.06	0.13	-	0.13	0.65	-	0.43	0.41	-	0.43	0.49	-	0.30	0.28	-
C.D. (P=0.05)	0.18	0.38	-	0.37	1.91	-	1.23	1.19	-	1.24	1.42	-	0.75	0.73	-
Interaction															
Sub treatments at same level of main treatments F × (C × N)															
SEm±	0.12	0.28	-	0.26	1.34	-	1.47	1.73	-	0.54	0.80	-	0.69	0.58	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F															
SEm±	0.15	0.32	-	0.31	1.60	-	1.64	1.84	-	0.78	0.92	-	0.85	0.79	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

Table 6: Potassium uptake (kg ha^{-1}) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	30 DAS			60 DAS			90 DAS			Grain			Straw		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**															
C_1N_1: Groundnut$_{100\% RDN}$	12.50	11.78	12.14	65.29	64.33	64.81	84.37	83.49	83.93	43.55	42.62	43.09	97.86	96.82	97.34
C_1N_2: Groundnut$_{75\% RDN}$	11.44	11.31	11.38	61.41	60.05	60.73	80.71	79.89	80.30	41.59	40.83	41.21	93.08	92.05	92.57
C_2N_1: Soybean$_{100\% RDN}$	13.96	13.69	13.83	74.99	73.69	74.34	103.25	102.62	102.94	47.51	46.57	47.04	110.08	108.97	109.53
C_2N_2: Soybean$_{75\% RDN}$	13.43	13.08	13.26	69.45	68.44	68.95	99.00	97.80	98.40	43.57	42.73	43.15	107.11	106.24	106.68
C_3N_1: Greengram$_{100\% RDN}$	14.55	14.38	14.47	84.94	84.19	84.57	119.02	118.12	118.57	53.01	52.19	52.60	120.66	119.48	120.07
C_3N_2: Greengram$_{75\% RDN}$	14.28	13.63	13.96	81.19	80.14	80.67	114.97	114.28	114.63	50.11	49.07	49.59	118.43	117.42	117.93
SEm ±	0.08	0.01	-	0.52	0.65	-	0.67	0.98	-	0.06	0.03	-	0.73	0.55	-
C.D. (P=0.05)	0.24	0.02	-	1.65	2.06	-	2.11	3.08	-	0.19	0.09	-	2.19	1.72	-
***Rabi* maize with varied nitrogen fertility levels (F)**															
F_1: 100% RDN	12.61	12.24	12.43	68.02	67.04	67.53	94.83	94.06	94.45	43.00	42.03	42.52	103.85	102.92	103.39
F_2: 125% RDN	13.30	12.88	13.09	73.44	72.44	72.94	99.89	98.95	99.42	46.51	45.45	45.98	108.10	107.00	107.55
F_3: 150% RDN	14.17	13.82	14.00	77.17	75.93	76.55	105.95	105.10	105.53	50.16	49.53	49.85	111.66	110.57	111.12
SEm ±	0.10	0.09	-	0.39	0.44	-	0.74	0.72	-	0.34	0.34	-	0.74	0.80	-
C.D. (P=0.05)	0.30	0.27	-	1.15	1.29	-	2.15	2.09	-	0.99	0.99	-	2.17	2.34	-
Interaction															
Sub treatments at same level of Main treatments F × (C × N)															
SEm ±	0.71	0.87	-	3.21	2.57	-	1.73	1.88	-	0.37	0.39	-	3.77	1.59	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
Main treatments at same/different level of sub treatments (C × N) × F															
SEm ±	0.83	1.06	-	3.71	2.76	-	1.83	1.98	-	0.4	0.41	-	3.82	1.64	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-

by rabi maize, demonstrated significantly longer root length, dry weight and volume than greengram 75% RDN, soybean and groundnut (75 and 100% RDN). In terms of nitrogen levels, 150% RDN also showed noticeably higher root length, dry weight and volume than 125% and 100% RDN. Furthermore, the interaction between legume residues (*kharif*) and nitrogen gradient levels (*rabi*) was found non-significant.

Additionally, the covering of legume wastes on the ensuing maize fields improved the availability of soil moisture and even decreased the volatility of phosphate and nitrogen, which allowed the root to develop morphologically till harvest (anchorage, elongation and breadth dimensions). Similar results from Choudhary and Behera (2014); Kumar *et al.* (2015); Singh *et al.* (2022) and Karunakaran *et al.* (2014).

Table 7: Grain and straw yield (kg ha^{-1}) of zero-till *rabi* maize as influenced by *kharif* legumes and nitrogen fertility levels during 2021-22 and 2022-23.

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean
***Kharif* legumes × nitrogen levels (C×N)**						
C_1N_1: Groundnut$_{100\% RDN}$	7957	7755	7856	9851	9661	9756
C_1N_2: Groundnut$_{75\% RDN}$	6963	6804	6884	8707	8486	8596
C_2N_1: Soybean$_{100\% RDN}$	8073	8192	8299	10337	10196	10267
C_2N_2: Soybean$_{75\% RDN}$	7798	7622	7710	9630	9451	9541
C_3N_1: Greengram$_{100\% RDN}$	9193	9089	9141	11250	11073	11173
C_3N_2: Greengram$_{75\% RDN}$	8480	8302	8391	10383	10305	10377
SEm ±	61	35	-	59	57	-
C.D. (P=0.05)	191	102	-	192	180	-
***Rabi* maize with varied nitrogen fertility levels (F)**						
F_1: 100% RDN	7407	7229	7318	9207	9012	9110
F_2: 125% RDN	8059	8054	8140	10116	9974	10067
F_3: 150% RDN	8766	8599	8682	10756	10599	10678
SEm ±	39	35	-	32	43	-
C.D. (P=0.05)	112	101	-	94	124	-
Interaction						
Sub treatments at same level of Main treatments F × (C × N)						
SEm ±	168	156	-	159	172	-
C.D. (P=0.05)	486	451	-	462	498	-
Main treatments at same/different level of sub treatments (C × N) × F						
SEm ±	153	143	-	142	160	-
C.D. (P=0.05)	475	430	-	430	480	-

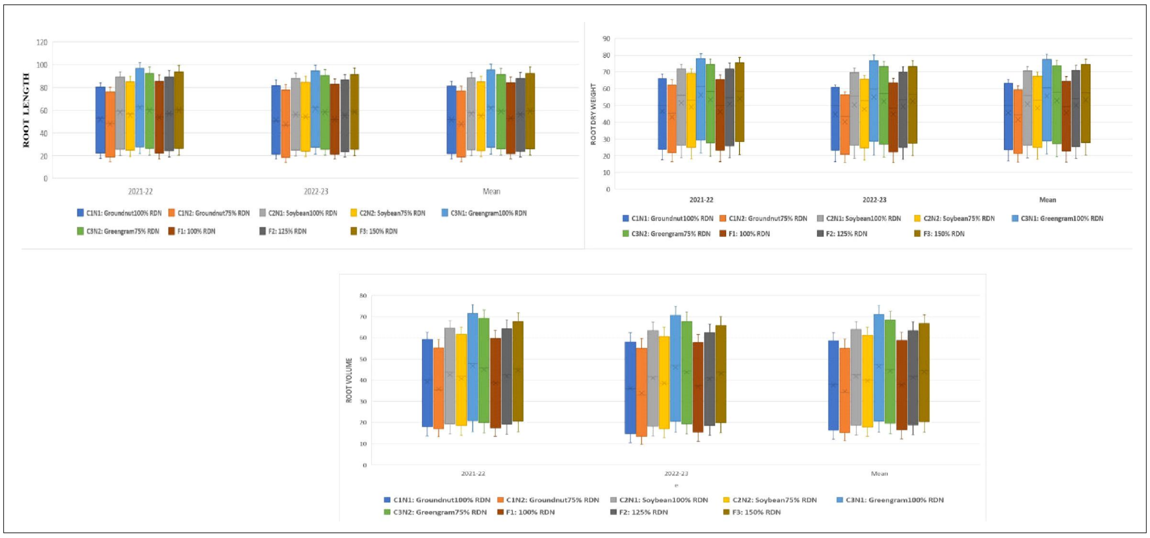

Fig 1: Influence of *kharif* legumes with varied nitrogen on the root morphology of zero-till *rabi* maize in 2021-22 and 2022-23.

Fig 2: Zero-till maize at tasseling stage grown after greengram at 100%-125% RDN in *kharif* and *rabi* seasons.

Fig 3: Zero-till maize at tasseling stage grown after greengram at 100%-150% RDN in *kharif* and *rabi* seasons.

Fig 4: Maize cobs at 100-125% RDN in *kharif* and *rabi* seasons.

Fig 5: Maize cobs at 100-150% RDN in *kharif* and *rabi* seasons.

Nutrient studies

The nitrogen gradient levels at 30, 60, 90 DAS and at harvest on zero-till rabi maize during the two years of the study, as well as the preceding kharif legume, affected the nutrient studies, specifically the N, P and K uptake (Table 4,5 and 6).

The results suggested that, among the different kharif legume crops, *rabi* maize absorbed more nitrogen, phosphorus and potassium from greengram residues at 100% RDN than from greengram residues at 75% RDN, soybean and groundnut. Furthermore, compared to lesser dosages (125 and 100% RDN), the application of 150% RDN in no-till rabi maize resulted in increased plant uptakes (N, P and K), whereas the association between the nitrogen gradient levels and kharif legumes was not significant in 2021-22 or 2022-23 at any of the crop stages.

The synergistic effect of green gram residues combined with nitrogen application enhanced nutrient assimilation, mobilization and translocation from source to sink, promoting efficient biomass accumulation and dry matter production in *rabi* maize. These results agreed with those of Wortmann *et al.* (2011); Gantayat *et al.* (2021); Roshan *et al.* (2013); Mauriya *et al.* (2024); Meena *et al.* (2011) and Usman *et al.* (2013).

Yields study

Studies on nitrogen, phosphorus and potassium uptake in zero-till rabi maize show that root morphology synergistically enhances crop growth during the critical tasseling and silking stages. This enhancement led to yields beyond the potential and resulted in higher residual biomass, as observed with kharif greengram. These were in-line with Sairam *et al.,* 2024 (Table 7, Fig 2, 3, 4 and 5).

CONCLUSION

The research trial demonstrated that applying 100% RDN to greengram followed by 150% RDN to maize in the rabi season significantly enhanced residue decomposition and stimulated robust root proliferation. This nutrient management approach improved nutrient mobility and accumulation in above ground plant tissues across key phenological stages (30 DAS to harvest) over two consecutive years, highlighting its potential to optimize crop nutrient dynamics and productivity.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

REFERENCES

Chimungu, J.G., Brown, K.M., Lynch, J.P. (2014). Reduced root cortical cell file number improves drought tolerance in maize. Plant Physiol. 166: 1943-1955.

Choudhary, R.L. and Behera, U.K. (2014). Effect of sequential tillage practices and N levels on soil health and root parameters in maize (*Zea mays*)-wheat (*Tritium aestivum*) cropping system. Journal of Soil and Water Conservation. 13(1): pp.73-82.

Gantayat, B.P., Mohapatra, A.K., Jena, S., Rout, K.K and Patra, B. (2021). Effect of *kharif* legumes on nutrient uptake by *rabi* maize. International Journal of Chemical Studies. 9(1): 3493-3497.

Jia, Q.M., Xu, Y.Y., Ali, S., Sun, L.F., Ding, R.X., Ren, X.L., Zhang, P., Jia, Z.K. (2018).Strategies of supplemental irrigation and modified planting densities to improve the root growth and lodging resistance of maize (*Zea mays L.*) under the ridge-furrow rainfall harvesting system. Field Crops Res. 224: 48-49.

Karunakaran, V. and Behera, U.K. (2014). Influence of sequential tillage and residue management practices on soil and root parameters in soybean (*Glycine max*)- wheat (*Triticum aestivum*) cropping system. Indian Journal of Agricultural Sciences. 85(2): 182-188.

Kishore, A.S., Sreelatha, D., Reddy, M.M., Kumar, M.V.N. and Kumar, T.S. (2025). Nitrogen gradient optimization with *kharif* legumes on agronomic parameters in zero-till *rabi* maize. Legume Research. 48(2): 260-275. doi: 10.18805/LR-5307.

Kumar, S., Dhar, S., Om, H. and Meena, R.L. (2015). Enhanced root traits and productivity of maize (*Zea mays*) and wheat (*Triticum aestivum*) in maize-wheat cropping system through integrated potassium management. Indian Journal of Agricultural Sciences. 85(2): 251-255.

Li, J., Li, C.Y. (2019). Seventy-year major research progress in plant hormones by Chinese scholars. Signa Vitaesigna Vinae. 49: 1227-1281.

Liu, Z.G., Zhao, Y., Guo, S., Cheng, S., Guan, Y.J., Cai, H.G., Mi, G.H., Yuan, L.X., Chen, F.J. (2019). Enhanced crown root number and length confers potential for yield improvement and fertilizer reduction in N-efficiency maize cultivars. Field Crops Res. 241: 107562.

Lodha, B., Jena, S.N., Paikaray, R.K. and Nayak, J.K. (2021). Dry matter accumulation, yield and nutrient uptake by *rabi* maize (*Zea mays* L.) under different weed management practices and soil residual nutrient. The Pharma Innovation Journal. 10(5): 229-232.

Lynch, J.P. (2013). Steep, cheap and deep: An ideotype to optimize water and N acquisition by maize root systems. Ann. Bot. 112: 347-357.

Makwana, N.D., Thanki, J.D., Der, P.B. and Nandaniya, J.K. (2016). Grain yield, nutrient uptake and economics of *rabi* maize under different fertilizer levels and organic sources in south Gujarat condition. Advances in Life Sciences. 5(5): 1661-1664.

Mauriya, A.K., Hashim, M., Verma, R.B., Kumar, P., Kumari, M.,Sahu, R., Verma, R.K. and Maurya, V.K. (2024). Evaluation of *rabi* maize-based intercropping system for augmenting the productivity and profitability of *rabi* maize under irrigated conditions of Bihar. Indian Journal of Agricultural Research. doi: 10.18805/IJARe.A-6213.

Meena, K.N., Kumar, A., Rana, D.S and Meena, M.C. (2011). Productivity and nutrient uptake of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system under different bio-sources and nitrogen levels. Indian Journal of Agronomy. 56(3): 182-188.

Mu, X., Chen, F., Wu, Q., Chen, Q., Wang, J., Yuan, L., Mi, G. (2015). Genetic improvement of root growth increases maize yield *via* enhanced post-silking nitrogen uptake. Eur. J. Agron. 63: 55-61.

Peng, Y.F., Niu, J.F., Peng, Z.P., Zhang, F.S., Li, C.J. (2010). Shoot growth potential drives N uptake in maize plants and correlates with root growth in the soil. Field Crops Res. 115: 85-93.

Postma, J.A., Dathe, A., Lynch, J.P. (2014). The optimal lateral root branching density for maize depends on nitrogen and phosphorus availability. Plant Physiol. 166: 590-602.

Rahman, M.M., Islam, A.M., Azirun, S.M. and Boyce, A.N. (2014). Tropical legume crop rotation and nitrogen fertilizer effects on agronomic and nitrogen efficiency of rice. The Scientific World Journal. doi: 10.1155/2014/490841.

Revathi, K., Rekha, M.S., Lakshmi, N.V. and Rani, P.P. (2019). Effect of planting densities and nitrogen levels on nutrient uptake of *rabi* maize (*Zea mays* L.). Green Farming. 10(1): 1-6.

Roshan, C., Singh, N. and Nepalia, V. (2013). Productivity and economics of quality protein maize (*Zea mays*) as influenced by nitrogen levels, its scheduling and sulphur application. Indian Journal of Agronomy. 58(3): 340-343.

Sairam, M., Maitra, S., Sain, S., Gaikwad, D.J. and Sagar, L. (2024). Dry matter accumulation and physiological growth parameters of maize as influenced by different nutrient management practices. Agricultural Science Digest. 44(2): 219-225. doi: 10.18805/ag.D-5835.

Shah, Z., Shah, H., Peoples, M.B., Schwenke, G. and Herridge, D.F. (2003). Crop residue and fertiliser N effects on nitrogen fixation and yields of legume-cereal rotations and soil organic fertility. Field Crops Research. 83(1): 1-11.

Singh, Pratap, K., Meena, V., Somasundaram, J., Singh, S., Dotaniya, M.L., Das, H., Singh, O. and Srivastava, A. (2022). Interactive effect of tillage and crop residue management on weed dynamics, root characteristics, crop productivity, profitability and nutrient uptake in chickpea (*Cicer arietinum* L.) under vertisol of central India. Plos One. 17(12): e0279831.

Sinha, A.K., Deep, K.P., Minz, A., Kumar, B., Barla, S. and Alam, M.P. (2018). Effect of crop residue incorporation in maize on nutrient status their uptake and yield in acid soil of Ranchi. Journal of Pharmacognosy and Phytochemistry. 7(1S): 3246-3251.

Srivastav, A.L., Dhyani, R., Ranjan, M., Madhav, S. and Sillanpaa, M. (2021). Climate-resilient strategies for sustainable management of water resources and agriculture. Environmental Science and Pollution Research. 28(31): 41576-41595.

Tiwari, D.K., Chaturvedi, D.P., Singh, T., Yadav, T.K and Awadhiya, P. (2022). Effect of nitrogen and sulphur levels on growth, yield and quality of maize (*Zea mays* L.). The Pharma Innovation Journal. 11(1): 418-422.

Usman, A., Osunde, A.O. and Bala, A. (2013). Nitrogen contribution of some selected legumes to a sorghum-based cropping system in the southern Guinea savanna of Nigeria. African Journal of Agricultural Research. 8(49): 6446-6456.

Wang, J., Han, J.L., Yang, M., Yao, D.D., Zhou, Y.F., Wang, W.P., Wu, Z.X., Yang, Q. (2020). Study on the nitrogen uptake and metabolism in varying nitrogen efficient maize varieties. J. Nucl. Agric. Sci. 34: 2800-2812.

Wortmann, C.S., Tarkalson, D.D., Shapiro, C.A., Dobermann, A.R., Ferguson, R.B., Hergert, G.W and Walters, D. (2011). Nitrogen use efficiency of irrigated corn for three cropping systems in Nebraska. Agronomy Journal. 103(1): 76-84.

York, L.M., Lynch, J.P. (2015). Intensive field phenotyping of maize (*Zea mays* L.) root crowns identifies phenes and phene integration associated with plant growth and nitrogen acquisition. J. Exp. Bot. 66: 5493-5505.

York, L.M., Nord, E.A., Lynch, J.P. (2013). Integration of rootphenes for soil resource acquisition. Front. Plant Sci. 4: 355.

Zhao, J., Xue, Q.W., Kirk, E.J., Hou, X.B., Hao, B.Z., Thomas, H.M., Xu, W.W., Steven, R.E., Susan, A.O.S., David, K.B. (2018). Shoot and root traits in drought tolerant maize (*Zea mays* L.) hybrids. J. Integr. Agric. 17: 1093-1105.