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Impact of Legume Residues and Nitrogen Levels on Soil Nutrient Dynamics in Zero-Till Maize Cropping System

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ABSTRACT: An experiment was conducted to study the influence of residual effect of preceding legumes and nitrogen levels on zero-till *rabi* maize on soil nutrient dynamics at Maize Research Centre, Agricultural Research Institute, Rajendranagar, Hyderabad during *kharif* and *rabi* seasons of 2021-22 and 2022-23. The experiment was laid out in split-plot design with 18 treatments consisted of three cropping sequences with 100% RDN and 75% RDN *viz.*, 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 as main plots and 3 sub-plots *viz.* F_1: 100%RDN, F_2: 125%RDN, F_3:150% RDN, during *rabi* respectively. Among the different cropping systems, significantly higher soil aggregates and available soil N was noted in preceding *kharif* greengram with 100% RDN on *rabi* zero-till maize cropping sequence over soybean and groundnut-maize cropping sequences. Subsequently, higher penetration resistance and bulk density was seen in groundnut with 100% RDN- *rabi* maize followed by soybean and greengram- maize sequence in two years of study. On the other hand, with the application of 150% RDN for *rabi* maize reported higher soil penetration resistance, aggregates, bulk density and available soil N than 125% RDN and lowest soil penetration resistance, aggregates, bulk density and available soil N was observed in 100% RDN in *rabi* respectively. Conversely, the post-harvest soil pH, EC, OC, available soil P and K were not influenced by the effect of preceding legume residues on succeeding *rabi* maize with varied levels of nitrogen. Further the interaction effect in post-harvest soil physical and chemical properties was found to be non-significant during both the years of the study.

Keywords: Cropping sequence, Nitrogen levels. Soil penetration resistance, Bulk density, Soil aggregates.

INTRODUCTION

Cereal-based cropping systems, like rice-wheat and maize-wheat, prevail in India's Indo-Gangetic Plains (IGP) (Balaji *et al.*, 2018). However, the continuous cultivation of cereals in this region results in soil degradation, nutrient depletion, environmental issues, and reduced crop yields (Davari *et al.*, 2012). Additionally, IGP fields remain fallow for approximately 70-80 days during the summer following the winter crop harvest (Meena *et al.*, 2015).

Employing crop rotations with cereals and legumes offers a cost-effective strategy for bolstering soil fertility and overall system productivity. Legumes, renowned for adding substantial organic carbon and fixing atmospheric nitrogen into the soil, should be evaluated as an alternative nitrogen source in crop sequences. Rising N fertilizer costs and environmental concerns are driving the shift towards organic nutrient sources. Exploring cost-effective, abundant organic sources like leguminous crop residues could address this challenge. These residues provide essential nutrients and enhance soil quality, benefiting crop yield and soil fertility (Zoumane *et al.*, 2000; Mandal *et al.*, 2004).

Introducing alternative cropping systems that incorporate legumes like soybean, groundnut and greengram during the *kharif* season, supported by reliable irrigation, offers opportunities to boost crop yields and enhance soil health while providing additional income to farmers in the Indo-Gangetic Plains (IGP) region (Meena *et al.*, 2015; Balaji *et al.*, 2018). Traditional tillage practices, characterized by intensive soil preparation, can delay the planting of greengram by 7-10 days (Chouhan *et al*., 2003) thus enhanced conservational tillage practices like zero-tillage in the cereal system.

Studying the beneficial legume residue retention to improve soil productivity. Thus enhances plant growth, soil physico-chemical nutrient status and the decomposition of residual matter across various legume systems. Our aim is to identify the most suitable system for optimal soil nutrient status in the legume-maize sequence. To achieve this, we conducted a study to assess the impact of legume residues and nitrogen levels on soil nutrient dynamics in zero-till maize cropping system during 2021-22 and 2022-23.

MATERIALS AND METHODS

The experimental research took place at the Maize Research Centre, Agricultural Research Institute, Rajendranagar, Hyderabad during 2021-22 and 2022-23 of *kharif* and *rabi* respectively. The research area is located at an altitude of 542.3 meters above sea level, situated at 17°19′N latitude and 78°23′E longitude. It falls within the Southern Telangana Agro-Climatic Zone of Telangana and is categorized as Semi-Arid Tropics based on Troll's classification. The weather conditions during the crop season was highly favorable for the legume-maize sequence, with mean minimal (12.6° to 21.2°C) and maximum temperature (26.3° to 33.2°C) in the location's usual climate norms. Throughout the crop growth period, there was optimum rainfall 878.54mmand sunshine hours (0.9 to 10 hours day^{-1}) during the entire cropping system in both years. The experiment was organized in split-plot design consisted of 3 main plots and 6 sub-plots, representing Groundnut-zero-till maize, Soybean-zero-till maize, and Greengram-zero-till maize cropping sequences in main-plots and varied levels of recommended nitrogen *viz*., 100% RDN - 100% RDN, 100% RDN - 125% RDN, 100% RDN - 150% RDN, 75% RDN - 100% RDN, 75% RDN - 125% RDN, and 75% RDN - 150% RDN in sub-plots in both the years.

During *kharif* season, legumes crops (groundnut, soybean, and greengram), were planted on June 25th, in both the years with a spacing of 30 cm x10 cm. Subsequently, *rabi* maize was sown on 25th September after the harvest of greengram and 23rd October in case of soybean and groundnut, under zero-till conditions during 2021-22 and 2022-23 respectively. The maize crop was planted with a spacing of 60 cm × 20 cm and fertilized with phosphorus and potash @ 80 kg ha^{-1} each as basal dose. Varied levels of recommended nitrogen was applied as per the treatments. Need based recommended plant protection and weed control measures were followed for both legumes and maize during the study period. The recommended dose of nitrogen applied for groundnut, soybean and greengram during *kharif* are 20, 60, 20 and 240 kg ha^{-1} for *rabi* maize respectively.

Soil Physical Analysis

Soil penetration resistance (Milli Pascals). Soil penetration resistance measured with cone penetrometer after two days of irrigation in each experimental plot at different depths 0-15, 15-30 cm and readings were recorded.

Soil aggregates (>0.25 mm %). Soil aggregates were determined by wet sieving method for this collected dry soil clod from the field. Weighed 50 grams of aggregates, added 10 ml of water to saturate the soil sample. Transferred the nest of sieve to the wet sieving drum adjusted the level of water in drum in such away that aggregates just dipped in to water. Sieve shaker was switched on and oscillated it for 30 minutes, after that remove the nest of sieves and transferred the materials on each sieve separately in aluminum boxes and kept the aluminum boxes in hot air oven. Amount of aggregate from > 0.25 mm sieve determined by subtracting the weight of coarse fraction from the oven dry aggregated material on the sieve (Black, 1965).

Bulk density (g cm^{-3}). The bulk density of soil at different soil depths at the end of the experimentation was measured using core sampler method. After harvest, soil samples were collected from different depths from three places in each plot. The triplicate soil samples for respective depths were dried in the hot air oven at 105ºC for 48 hours for estimation of dry weight. The bulk density was calculated as follows:

$$\text{Bulk density (g cm}^{-3}) = \frac{\text{Mass of soil oven dry weight basis (g)}}{\text{Core volume (cm}^{-3})}$$

Collection and Preparation of Soil Samples. After the harvest of legume crops, the soil samples were collected from all the treatments (0-30 cm) with core sampler and brought to the laboratory in polythene bags. The soil samples were dried under shade and ground with pestle and mortar and sieved through 2 mm sieve. The processed soil samples were analysed for pH, EC, OC and available soil N, P and K. The powdered soil samples were again powdered in pestle and mortar and passed through 0.2mm sieve for organic carbon analysis. The procedures adopted for analysis of various characteristics in initial and post-harvest soil samples are explained under different sub–heads.

Soil reaction (pH). The pH of soil was determined in 1: 2.5 soil to water suspension after stirring the samples intermittently for half an hour using a pH meter.

Electrical conductivity (EC). The electrical conductivity of the soil was determined in the supernatant of 1:2.5 soil water suspension that was used for the pH determined by using Systronics direct digital conductivity meter-304 (Jackson, 1973).

Organic carbon (OC). The organic carbon content was estimated by Walkley and Black's wet oxidation method (Walkley and Black 1934).

Available nitrogen (kg ha^{-1}). Determination of available nitrogen was done by alkaline potassium permanganate method suggested by Subbiah and Asija (1956). The soil was tested with alkaline $KMnO_4$ in the presence of NAOH and thus, the ammonia released was distilled and absorbed in a known volume of boric acid and stannous mixed indicator and titrated with a standard sulphuric acid.

Available phosphorus (kgha^{-1}). The estimation of available P was done by using Olsen's extract (0.5 N sodium bicarbonate solution of pH 8.5) as referenced by Olsen *et al.* (1954) and determined calorimetrically. The intensity of blue color complex was measured at 660 nm wavelength with a calorimeter.

Available potassium (kgha^{-1}). Available potassium was determined by extracting the soil with neutral normal ammonium acetate solution and estimated using flame photometer method as outlined by Jackson (1973).

RESULTS AND DISCUSSION

The soil physical properties of zero-till maize was significantly impacted by the residual retention of *kharif* legumes on *rabi* maize, with varied nitrogen levels, as mentioned in Table 1.

Soil penetration resistance (Milli pascals). Among the different crop sequences studied, preceding groundnut residues with 100% RDN retained in zero-till *rabi* maize showed significantly higher soil penetration resistance (1.91, 1.89 M pa), followed by groundnut with 75% RDN (1.88, 1.85 M pa), soybean with 75% RDN (1.75, 1.77 M pa) and 100%RDN (1.82, 1.82 M pa), however lowest was seen with greengram residues with 75% RDN (1.67, 1.64 M pa) respectively. The addition of greengram residues had a positive impact on the soil compaction in zero-till maize crop's root development due to higher biomass production in *kharif* and retention in *rabi* maize field enhanced the soil moisture and loosen the soil in both years. (Table 1).

Among different nitrogen levels applied, the F_3 treatment where application of 150% RDN to *rabi* maize registered significantly higher soil penetration resistance (1.85, 1.83 M pa) compared to F_2 treatment with 125% nitrogen (1.80, 1.78 M pa). Further lower resistance was recorded with F_1 treatment with 100% RDN (1.73, 1.72 M pa) respectively. This might be due to higher doses favored for the better root development that reduced the compaction at the surface and sub-surface layers in the soil.

Soil aggregates (>0.25 mm %). Greengram with 100% RDN followed by succeeding maize sequence recorded significantly higher soil aggregates (47.01, 46.21 %) over the greengram with 75% RDN (44.09, 43.18 %), soybean with 100% RDN (41.03, 40.26 %) and 75% RDN (38.22, 37.29 %) and lowest was registered with groundnut at 75% RDN on *rabi* maize sequences (32.41, 31.23 %) respectively during *kharif* and *rabi* of 2021-22 and 2022-23 (Table 1).

However, with addition of 150% RDN in *rabi* resulted in higher soil aggregates (41.93, 40.86 %) in comparison with the 125% RDN (39.86, 39.09 %) and 100% RDN (37.17, 36.24 %) in two consecutive years of study. This suggests that the higher doses favored for the binding of the micro and macro aggregates together for the better crop establishment and even encouraged the soil under zero-till conditions. The research revealed that there was no substantial interaction observed between the prior legume-maize system and varied nitrogen levels in both years. These findings were in line of Hazra *et al.*, 2019.

Bulk density (g cm^{-3}). As in similar trend of soil penetration resistance, *kharif* groundnut with 100% RDN on *rabi* maize sequence reported higher bulk density (1.47, 1.49 g cm^{-3}) when compared with groundnut with 75% RDN (1.44, 1.44 g cm^{-3}), soybean with 75% RDN (1.38, 1.36 g cm^{-3}) and 100% RDN (1.41, 1.40 g cm^{-3}) and lowest was seen in greengram with 75% RDN (1.32, 1.28 g cm^{-3}) on *rabi* maize cropping sequence respectively in both years of study (Table 1).

Fertilizer application with 150% RDN in *rabi* led to higher bulk density (1.46, 1.44 g cm^{-3}) compared to 100% RDN (1.40, 1.39 g cm^{-3}) and 125% RDN (1.41, 1.43 g cm^{-3}). Further, the interaction effect was not statistically significant between the legume residues and nitrogen levels in 2021-22 and 2022-23. This might be due to added residues reduced the compactness in soils and subsequent showed lesser bulk density. Similar finding were in Meena *et al.,* 2015.

Post-harvest soil physio-chemical properties (pH, EC& OC). From the study it was evidenced that, the soil physio-chemical properties were not significantly influenced by residues of preceding legumes and nitrogen levels on *rabi* maize after two years of experimentation. Among the different legume based cropping systems the range of pH& EC were not varied much during 2021-22 and 2022-23. However, among varied nitrogen levels100%, 125%, 150% RDN applied in *rabi* maize along with 100% RDN in *kharif*, the pH & EC were increased at higher doses during 2021-22. However, slight decrease was noticed in pH on subsequent year 2022-23 (Table 2).

With regard to percent Organic Carbon content, a slight improvement was observed in greengram-maize cropping sequence compared to other two cropping sequences during both years. However, the nitrogen levels did not showed much impact on organic carbon content during both the years.

The interaction effect on pH, EC and OC values were found not significant with legume residues and nitrogen does in zero-till *rabi* maize in both the years.

Soil available nutrient status

Available Nitrogen (kg ha^{-1}). The post-harvest observations revealed that available nitrogen was influenced by the *kharif* legume residues and nitrogen doses in *rabi* maize in both years.

From the data, it was clearly evidenced that greengram residues with 100% RDN had significantly higher soil available nitrogen (267.56, 264.67 kg ha^{-1}) than greengram with 75% RDN (260.47, 258.33 kg ha^{-1}), soybean with 75% RDN (24.03, 245.00 kg ha^{-1}) and 100% RDN (253.38, 251.00 kg ha^{-1}), however lowest was registered with groundnut residues with 75% RDN (234.89, 232.33 kg ha^{-1}) on *rabi* maize in 2021-22 and 2022-23 research study.

Among the nitrogen does *viz.* higher soil available nitrogen was evidenced with 150% RDN (257.52, 255.00 kg ha^{-1}) over 125% RDN (251.19, 248.00 kg ha^{-1}) and further lower was seen in 100% RDN (245.32, 245.50 kg ha^{-1}) in both years of study (Table 3). These finding were similar to Bama *et al.* (2017), Srinivasalu *et al.*, 2020 and Gantayat *et al.* (2021).

The interaction effect of combined legume residues and recommended nitrogen levels was found to be non-significant. The application of varied levels of nitrogen witnessed significant trend in availability and uptake and even supplemented by the residual activity until harvest. Similar findings were seen with the studies conducted by Chary *et al.* (2019).

Available Potassium (kg ha^{-1}). The higher available soil potassium levels were recorded in greengram-maize sequence compared to soybean and groundnut sequence. However, the results were found to be non-significant. In comparison to first year (2021-22), there was marginal decrease in soil available potassium values over 2nd year (2022-23). Furthermore, there was no significant interaction was observed with soil potassium levels in both the years. Research finding were inline with Deshmukh *et al.* (2019) (Table 3).

Table 1: Resistance, Aggregates and Bulk density of zero-till *rabi* maize as influenced by preceding *kharif* legumes and nitrogen levels during 2021-22 and 2022-23.

Treatments	Penetration resistance			Aggregates			Bulk density		
Cropping systems	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
C_1N_1: Groundnut$_{100\%RDN}$ - maize	1.91	1.89	1.90	35.16	34.19	34.68	1.47	1.49	1.48
C_1N_2: Groundnut$_{75\%RDN}$ - maize	1.88	1.85	1.87	32.41	31.23	31.82	1.44	1.44	1.44
C_2N_1: Soybean$_{100\%RDN}$ - maize	1.82	1.82	1.82	41.03	40.26	40.65	1.41	1.40	1.41
C_2N_2: Soybean$_{75\%RDN}$ - maize	1.75	1.77	1.76	38.22	37.29	37.76	1.38	1.36	1.37
C_3N_1: Greengram$_{100\%RDN}$ - maize	1.71	1.69	1.70	47.01	46.21	46.61	1.35	1.32	1.34
C_3N_2: Greengram$_{75\%RDN}$ - maize	1.67	1.64	1.66	44.09	43.18	43.64	1.32	1.28	1.30
SEm±	0.02	0.01	-	0.32	0.40	-	0.01	0.01	-
C.D. (P=0.05)	0.06	0.04	-	1.00	1.27	-	0.02	0.03	-
Nitrogen levels									
F_1: 100% RDN	1.73	1.72	1.73	37.17	36.24	36.71	1.40	1.39	1.40
F_2: 125% RDN	1.80	1.78	1.79	39.86	39.09	39.48	1.43	1.41	1.42
F_3: 150% RDN	1.85	1.83	1.84	41.93	40.86	41.40	1.46	1.44	1.45
SEm±	0.01	0.01	-	0.22	0.20	-	0.01	0.01	-
C.D. (P=0.05)	0.03	0.03	-	0.65	0.60	-	0.02	0.02	-
Interaction effect									
SEm±	0.02	0.03	-	0.55	0.50	-	0.02	0.02	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-

Table 2: Post-harvest soil pH, EC, OC (%) of zero-till *rabi* maize as influenced by preceding *kharif* legumes and nitrogen levels during 2021-22 and 2022-23.

Treatments	pH			EC			OC		
Cropping systems	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
C_1N_1: Groundnut$_{100\%RDN}$ - maize	7.49	7.43	7.46	0.44	0.43	0.44	0.43	0.44	0.44
C_1N_2: Groundnut$_{75\%RDN}$ - maize	7.59	7.55	7.57	0.45	0.44	0.45	0.45	0.47	0.46
C_2N_1: Soybean$_{100\%RDN}$ - maize	7.64	7.50	7.57	0.46	0.45	0.46	0.45	0.47	0.46
C_2N_2: Soybean$_{75\%RDN}$ - maize	7.59	7.53	7.56	0.49	0.48	0.49	0.47	0.48	0.48
C_3N_1: Greengram$_{100\%RDN}$ - maize	7.61	7.60	7.61	0.50	0.49	0.50	0.48	0.47	0.48
C_3N_2: Greengram$_{75\%RDN}$ - maize	7.73	7.78	7.76	0.51	0.51	0.51	0.50	0.51	0.51
SEm±	0.07	0.08	-	0.01	0.02	-	0.03	0.04	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-
Nitrogen levels									
F_1: 100% RDN	7.57	7.55	7.56	0.46	0.45	0.46	0.45	0.46	0.46
F_2: 125% RDN	7.62	7.56	7.59	0.47	0.47	0.47	0.47	0.47	0.47
F_3: 150% RDN	7.63	7.58	7.61	0.49	0.49	0.49	0.48	0.49	0.49
SEm±	0.06	0.06	-	0.03	0.04	-	0.04	0.03	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-
Interaction effect									
SEm±	0.15	0.14	-	0.03	0.04	-	0.06	0.07	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-

Table 3: Available soil N, P and K (kg ha^{-1}) of zero-till *rabi* maize as influenced by preceding *kharif* legumes and nitrogen levels during 2021-22 and 2022-23.

Treatments	Available N			Available P			Available K		
Cropping systems	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
C_1N_1: Groundnut$_{100\%RDN}$ - maize	241.02	238.67	239.85	72.57	72.78	72.68	361.85	354.69	358.27
C_1N_2: Groundnut$_{75\%RDN}$ - maize	234.89	232.33	233.61	67.63	66.67	67.15	355.59	349.13	352.36
C_2N_1: Soybean$_{100\%RDN}$ - maize	253.38	251.00	252.19	79.76	78.33	79.05	374.37	363.87	369.12
C_2N_2: Soybean$_{75\%RDN}$ - maize	247.03	245.00	246.02	74.68	73.67	74.18	368.27	359.15	363.71
C_3N_1: Greengram$_{100\%RDN}$ - maize	267.56	264.67	266.12	84.18	85.23	84.71	384.24	370.95	377.60
C_3N_2: Greengram$_{75\%RDN}$ - maize	260.47	258.33	259.40	80.25	79.33	79.79	381.07	367.20	374.14
SEm±	1.94	1.82	-	5.22	4.98	-	38.65	20.88	-
C.D. (P=0.05)	6.10	5.72	-	NS	NS	-	NS	NS	-
Nitrogen levels									
F_1: 100% RDN	245.32	242.50	243.91	72.81	72.56	72.69	366.69	357.38	362.04
F_2: 125% RDN	251.19	248.00	249.60	76.53	76.45	76.49	370.89	360.69	365.79
F_3: 150% RDN	257.52	255.00	256.26	80.21	79.00	79.61	375.12	364.43	369.78
SEm±	1.46	1.30	-	3.71	2.95	-	21.74	26.32	-
C.D. (P=0.05)	4.25	3.79	-	NS	NS	-	NS	NS	-
Interaction effect									
SEm±	3.57	3.18	-	9.10	7.22	-	53.25	64.48	-
C.D. (P=0.05)	NS	NS	-	NS	NS	-	NS	NS	-

CONCLUSIONS

The study highlights the significance of residue retention of *kharif* legumes in *rabi* zero-till maize on soil physico-chemical properties and available nutrient status for enhanced crop growth and development which led to sustainable soil fertility.

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