



Effect of Establishment Methods and Residual Nitrogen on Moongbean in Wheat based Cropping Systems

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ABSTRACT

Background: Agricultural production faces challenges, such as soil depletion, declining yields and climate variability, necessitating sustainable practices. Conservation agriculture (CA) improves soil health, ecosystem conservation and resource efficiency but is underutilized in cereal-based systems in South Asia. Incorporating legumes, such as green gram into cropping systems enhances nitrogen turnover and soil health. This study examines the effects of CA practices and residual nitrogen on green gram performance and soil health in a wheat-green gram-maize cropping system.

Methods: A two-year field study (*Rabi* 2021-*Kharif* 2023) was conducted at Indian Agricultural Research Institute, New Delhi, on sandy loam soil. The experiment was conducted using a split plot design and replicated thrice. Main plot treatments comprised of three crop establishment methods: conventional tillage (CT), zero tillage with residue retention (ZT+R) and permanent raised beds with residue retention (PB+R), whereas subplot treatments consist seven nitrogen management (NM) strategies for wheat and maize (varying RDN levels with prilled urea or nano-urea). No nitrogen was applied to the green gram, relying on the residual nitrogen from the wheat, as phosphorus and potassium were applied as per recommendation.

Result: Permanent raised beds with residue retention (PB+R) significantly improved plant height, biomass, LAI, yield and nitrogen uptake compared with conventional tillage (CT) and zero tillage with residue retention (ZT+R). Nitrogen management with 100% RDN enhanced the nitrogen uptake, chlorophyll content and protein content. PB+R with 100% RDN recorded significantly highest green gram yield (0.85 t ha⁻¹) and nitrogen uptake, attributed to improved root proliferation, water conservation and nutrient acquisition. permanent raised beds with residue retention along with 100% RDN also recorded the highest net returns and B:C ratio.

Key words: Conservation agriculture, Green gram, Nitrogen management, Residual nitrogen, Soil health.

INTRODUCTION

Sustainable Development Goals (SDGs) aim to eradicate poverty and hunger while preserving resources, but unsustainable farming practices, soil degradation and climate change threaten food security, with major crop yields in India expected to decline by 2050 and 2080 (Ministry of Agriculture and Farmers Welfare, 2023).

Conservation agriculture (CA) offers a sustainable alternative by emphasizing minimal soil disturbance, permanent soil cover and crop rotation. This approach enhances soil structure, water retention and agroecosystem resilience (Food and Agriculture Organization of the United Nations, 2020). Practices like no-till farming and residue retention improve crop performance (Babu *et al.*, 2018), while raised beds optimize moisture and aeration (Yadav *et al.*, 2019). Maize-wheat cropping system covers an area of about 1.86 million hectares in the Indo-Gangetic Plains, is a viable alternative to the rice-wheat system but remains resource-intensive, depleting soil organic carbon and nutrients (Hazra *et al.*, 2019). Integrating short-duration greengram into this system enhances soil nitrogen fertility, improves yields and maintains food security (Kumar *et al.*, 2023) and (Neha *et al.*, 2016). Greengram, as a summer

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cover crop, fixes atmospheric nitrogen, reduces fertilizer dependency, enhanced soil health and productivity (Ru *et al.*, 2023).

Nitrogen use efficiency in maize-wheat systems is below 40%, necessitating innovative solutions. Nanofertilizers, with higher efficiency and environmental safety, present a promising alternative. Their nanoscale properties improve nutrient absorption and cost-effectiveness as compared to conventional fertilizers. At the same time, quantification and effective utilization of the residual nitrogen applied during the preceding crop is required. Keeping the above facts in view, the study evaluates the residual effects of nitrogen applied to wheat and maize on green gram under different establishment methods.

MATERIALS AND METHODS

A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi, India (28°38'8"N, 77°9'4"E, 228 m AMSL) from 2021 winter season, to 2023 rainy season, in the Trans-Gangetic Plains agro-climatic zone. During the green gram growing periods, average maximum temperatures were 39.7°C (Spring, 2022) and 36.7°C (Spring, 2023), with relative humidity ranging from 8-97.5%. Total rainfall of about 178.2 mm and 388.2 mm was received during the crop growing season. While evaporation was 538.2 mm and 449 mm, respectively. The Experimental soil was sandy loam in texture with medium soil fertility.

Experiment was laid out in split plot design and replicated thrice. The treatment comprised of three crop establishment methods (CEMs): Conventional tillage (CT), zero tillage with residue retention (ZT+R) and permanent raised bed with residue retention (PB+R) as a main plots and seven nitrogen management (NM) as sub plot treatment viz, 100% Recommended Dose of Nitrogen (RDN) (150kg and 180 Kg per ha in wheat and maize respectively), 75% RDN, 75% RDN with 2% prilled urea foliar spray at 35 days after sowing (DAS), 75% RDN with nano urea (4.0% total nitrogen (w/v)) foliar spray at 35 DAS, 50% RDN with two foliar sprays of 2% prilled urea at 35 and 55 DAS, 50% RDN with two foliar sprays of nano urea [4.0% total nitrogen (w/v)] at 35 and 55 DAS and absolute control (No nitrogen application). Where the subplot treatments were imposed only in wheat and maize, whereas greengram was grown on the residual nitrogen availability from the preceding crops. Phosphorus and potassium applied to all the crops in the system as per recommended dose. Green gram (PUSA-1431) was sown at spacing of 30 cm × 10 cm using a seed rate of 20 kg/ha on residual nitrogen from wheat and maize, with retention of residues (3 t/ha) of wheat and maize in zero tillage and permanent raised bed residue retention treatments. Data collection included growth and physiological parameters at 30 and 60 days after sowing (DAS). Plant height, dry matter production, leaf area index (LAI), chlorophyll content (DMSO method), leaf nitrogen (Kjeldahl method), NDVI and SPAD values were measured. Yield attributes such as seed yield, stover yield, pods per plant and seeds per pod were

recorded at maturity. Economic efficiency was evaluated by calculating cost of cultivation, gross returns, net returns and benefit-cost ratio. Data were analyzed using ANOVA at 5% significance level ($P \leq 0.05$) and Pearson's correlation coefficients computed in R Studio.

RESULTS AND DISCUSSION

Experimental results revealed that significant effect of crop establishment methods and residual nitrogen on green gram.

Effect on growth parameters

Data presented in Table 1 revealed that permanent raised bed with residue retention (PB+R) recorded significantly higher plant height, dry matter accumulation which was at par with zero tillage with residue retention (ZT+R). However in case of residual nitrogen, 100 per cent N applied to wheat and maize registered significantly higher growth parameters. Almost similar trend was followed at 60 DAS with respect to plant height and dry matter accumulation of greengram crop. This might be attributed to improved soil health and optimal nitrogen availability (Das *et al.*, 2021). Enhanced growth under PB + R is linked to moisture retention, residue decomposition and improved root aeration (Ghosh *et al.*, 2020). Residue preservation improves nutrient turnover and microbiological processes, as noted by Jat *et al.* (2019). Zhang *et al.* (2021) and Sharma *et al.* (2020). These results emphasize the synergistic benefits which lead to enhanced canopy development, nutrient cycling and crop productivity. These findings align with Wen *et al.* (2023), emphasizing the role of residual nitrogen in sustaining legume growth.

Effect on nitrogen metabolism

Crop establishing methods and nitrogen management strategies significantly influenced nitrogen metabolism and photosynthetic indicators, including leaf nitrogen content, chlorophyll content, SPAD and NDVI at 25 and 50 DAS. (Table 2). Permanent raised bed with residue retention (PB+R) recorded the highest leaf nitrogen (2.66% at 25 DAS, 2.65% at 50 DAS) and chlorophyll content (2.36 mg/g at 25 DAS, 2.35 mg/g at 50 DAS), which was at par with zero tillage with residue retention (ZT+R) due to improved soil conditions and nitrogen release from residue decomposition (Jat *et al.*, 2019). Conventional tillage (CT) exhibited the lowest values due to greater soil disturbance.

Residual nitrogen also significantly affected nitrogen metabolism, with 100% recommended nitrogen (N100%) recorded significantly highest leaf nitrogen (2.83% at 25 DAS, 2.81% at 50 DAS) and chlorophyll content (2.44 mg/g), attributed to enhanced nitrogen assimilation (Zhang *et al.*, 2021) and (Bochalya *et al.*, 2022). 75% recommended nitrogen supplemented foliar spray either with 2% prilled urea or nano urea (N75% + One 2% NUFS/PUFS) resulted in enhanced nitrogen uptake, whereas 50% recommended nitrogen supplemented with two foliar sprays either with 2% prilled urea or nano urea recorded lower performances.

Table 1: Effect of crop establishment methods and nitrogen management practices on growth parameters yield and yield attributes of greengram (Pooled data).

Treatments	Plant height (cm)		Dry matter accumulation (g m ⁻²)		LAI		Pods per plant	Seeds per pods	Test weight (g)	Grain yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS						
Crop establishment methods (CEM)												
CT	7.32b	31.51b	37.37b	207.7	1.321	2.34	24.40b	8.64	39.98	0.74c	2.76c	26.4c
ZT+R	7.35a	31.55b	37.54a	209.11	1.326	2.355	25.60a	9.24	39.98	0.79b	2.88b	27.46b
PB+R	7.38a	31.99a	37.62a	209.64	1.329	2.361	25.83a	9.26	39.98	0.81a	2.93a	27.63a
SEM±	0.01	0.02	0.05	0.14	0.001	0.001	0.11	0.08	0.01	0.012	0.01	0.05
LSD (P=0.05)	0.04	0.07	0.15	0.47	0.002	0.003	0.36	0.26	0.02	0.030	0.02	0.17
Nitrogen management (NM)												
N Zero	5.36e	25.06e	32.65d	155.72g	1.261	1.715	17.00e	7.83	39.95	0.54c	2.42c	23.52d
N 100%	7.93a	35.51a	40.90a	234.78a	1.364	2.529	30.94a	9.67	40.02	0.850a	3.00a	28.51a
N 75%	7.75c	34.51c	39.26b	226.81d	1.344	2.481	27.06c	9.28	39.98	0.80a	2.92a	27.82a
N 75% + one 2% PUFS	7.79c	34.67b	39.30b	227.36c	1.349	2.49	27.17c	9.28	39.98	0.82a	2.97a	27.92a
N 75% + one NUFS	7.86b	34.74b	39.38b	228.97b	1.362	2.511	27.50b	9.28	39.99	0.83a	2.98a	28.18a
N 50% + Two 2% PUFS	7.34d	28.56d	35.43c	193.62f	1.294	2.368	23.35d	8.83	39.97	0.70b	2.74b	25.73b
N 50% + Two 2% NUFS	7.35d	28.64d	35.45c	194.47e	1.301	2.371	23.37d	9.17	39.97	0.74b	2.78b	25.78c
SEM±	0.01	0.03	0.04	0.12	0.001	0.001	0.11	0.09	0.01	0.020	0.068	0.063
LSD (P=0.05)	0.04	0.09	0.12	0.33	0.003	0.003	0.31	0.24	0.02	0.054	0.190	1.764
C × N	0.07	0.19	0.24	0.67	0.006	0.006	0.62	0.48	0.05	0.006	0.038	0.354

NDVI and SPAD readings mirrored these trends, with N100% achieving the highest values. Permanent raised bed along with residue retention and 100% recommended nitrogen maximized nitrogen metabolism and canopy health, synergistic benefits of conservation agriculture and optimal nitrogen management.

Effect on yield and yield attributes

Crop establishment methods significantly influenced yield attributes and gram yield (Table 1). Permanent raised bed with residue retention (PB+R) recorded significantly highest pods per plant (25.83), seeds per pod (9.26), grain yield (0.81 t ha^{-1}), biological yield (2.93 t ha^{-1}) and harvest index (27.63%). This might be attributed to improved soil conditions, better moisture retention and enhanced root-zone nutrient availability. Conventional tillage recorded significantly (CT) showed the lowest values due to higher soil compaction and reduced water-holding capacity (Singh *et al.*, 2020; Kumar *et al.*, 2024 and Ghosh *et al.*, 2019).

Residual nitrogen from nitrogen management treatments also significantly affects yield attributes and yield. 100% recommended nitrogen (N100%) recorded significantly highest pods per plant (30.94), Seeds per pod (9.67), 1000-grain weight (40.02 g) and grain yield (0.85 t ha^{-1}) due to sufficient residual nitrogen boosting vegetative growth and reproductive development (Subramanian *et al.*, 2020). 75% recommended nitrogen along with foliar spray of nano urea (N75% + NUFS) applied to the preceding crop enhanced nitrogen uptake efficiency. Interaction effect

between crop establishment methods and nitrogen management was found to be nonsignificant except at physiological maturity. (Singh *et al.*, 2019).

Effect on nitrogen uptake and protein content

Crop establishment methods significantly influenced nitrogen uptake, nitrogen harvest index (NHI), protein concentration and protein yield in greengram (Table 3). Permanent raised bed with residue retention recorded the highest nitrogen uptake, with an NHI of 0.49, grain protein concentration of 21.07% and protein yield of 0.17 t ha^{-1} . This was attributed to improved nitrogen mineralization and availability through residue retention, which enhanced soil properties and microbial activity (Lu *et al.*, 2021). Zero tillage with residue retention exhibited a comparable performance, highlighting the critical role of minimal soil disturbances and residue retention in enhancing nitrogen cycling and improving soil organic matter dynamics. Conventional tillage recorded lower nitrogen uptake (54.50 kg ha^{-1}) and protein yield (0.16 t ha^{-1}) due to nitrogen losses from leaching and volatilization.

Residual nitrogen from nitrogen management strategies also significantly impacted residual effects on greengram. 100% recommended nitrogen applied to wheat resulted significantly highest nitrogen uptake (60.45 kg ha^{-1}), seed nitrogen uptake (28.82 kg ha^{-1}) and protein yield (0.18 t ha^{-1}), which resulted optimal nitrogen utilization. 75% recommended nitrogen with one nano-urea foliar spray (NUFS) recorded similar results,

Table 2: Effect of crop establishment methods and residual nitrogen on nitrogen content in leaf, chlorophyll content, SPAD and NDVI values in green gram.

Treatments	At 25 DAS				At 50 DAS			
	Nitrogen content in leaf (%)	Chlorophyll content in leaves (mg g^{-1})	SPAD value	NDVI values	Nitrogen content in leaf (%)	Chlorophyll content in leaves (mg g^{-1})	SPAD value	NDVI values
Crop establishment methods (CEM)								
CT	2.63	2.33	41.53	0.37	2.63	2.33	41.29	0.36
ZT+R	2.65	2.35	41.85	0.37	2.64	2.35	41.77	0.37
PB+R	2.66	2.36	41.95	0.38	2.65	2.35	41.95	0.38
SEM $\pm$	0.009	0.006	0.148	0.001	0.004	0.002	0.078	0.004
LSD (P=0.05)	0.02	0.013	0.266	0.003	0.012	0.006	0.256	0.007
Nitrogen management (N)								
N Zero	2.21	1.88	33.69	0.33	2.19	1.86	32.00	0.31
N 100%	2.83	2.46	43.30	0.41	2.80	2.44	42.00	0.39
N 75%	2.78	2.43	40.00	0.38	2.76	2.41	38.68	0.36
N 75% + one 2% PUFS	2.79	2.44	40.68	0.39	2.77	2.42	39.61	0.37
N 75% + one NUFS	2.81	2.45	41.72	0.40	2.79	2.43	40.86	0.38
N 50% + Two 2% PUFS	2.54	2.39	34.97	0.35	2.50	2.33	33.88	0.33
N 50% + Two 2% NUFS	2.55	2.40	35.34	0.36	2.52	2.34	34.65	0.34
SEM $\pm$	0.007	0.004	0.090	0.001	0.006	0.003	0.082	0.001
LSD (P=0.05)	0.020	0.011	0.254	0.002	0.018	0.008	0.231	0.003
C $\times$ N	0.04	0.02	0.51	0.05	0.04	0.02	0.46	0.01

Table 3: Effect of crop establishment methods and nitrogen management practices on nitrogen content, uptake, nitrogen harvest index, Protein content, protein yield and economics of greengram (Pooled data).

Treatments	Nitrogen content (%)		Nitrogen uptake (kg/ha)		Nutrient harvest index (NHI)	Protein content in grain (%)	Protein yield (t/ha)	Cost of cultivation ('000 Rs./ha)	Gross returns ('000 Rs./ha)	Net returns ('000 Rs./ha)	Net B:C	Economic efficiency (Rs./ha/day)
	Seed	Stover	Seed	Total								
Crop establishment methods (CEM)												
CT	3.36	1.35	26.32c	54.50b	0.48	21.03	0.16	34.71b	66.86c	32.15b	1.41b	459
ZT+ R	3.36	1.36	26.70b	55.40a	0.48	21.07	0.17	33.25a	67.710b	34.47a	1.61b	492
PB+R	3.37	1.36	26.89a	55.63a	0.48	21.07	0.17	33.25a	68.16a	34.91a	1.64a	499
SEM±	0.00	0.00	0.04	0.09	0.00	0.01	0.00		0.08	0.26	0.00	1.56
LSD (P=0.05)	0.01	0.01	0.11	0.30	0.00	0.02	0.00		0.27	0.86	0.01	12.32
Nitrogen management (NM)												
N Zero	3.33	1.32	21.72f	45.62e	0.46	20.89	0.14	33.73	55.70f	21.96f	0.97f	314
N 100%	3.38	1.39	28.82a	60.45a	0.48	21.18	0.18	33.73	72.75a	39.02a	1.82a	557
N 75%	3.37	1.37	28.27d	57.55c	0.49	21.14	0.18	33.73	71.33d	37.59d	1.70d	537
N 75% + one 2% PUFs	3.37	1.37	28.39c	57.83bc	0.49	21.14	0.18	33.73	71.65c	37.92c	1.72c	542
N 75% + one NUFS	3.37	1.38	28.66b	58.07b	0.49	21.15	0.18	33.73	72.28b	38.55b	1.76b	551
N 50% + Two 2% PUFs	3.34	1.35	25.26e	53.27d	0.47	20.95	0.16	33.73	64.62e	30.89e	1.47e	441
N 50% + Two 2% NUFS	3.35	1.35	25.33e	53.32d	0.47	20.95	0.16	33.73	64.71e	30.98e	1.47e	443
SEM±	0.00	0.00	0.04	0.10	0.00	0.01	0.00		0.08	0.08	0.00	1.21
LSD (P=0.05)	0.02	0.02	0.10	0.29	0.00	0.02	0.00		0.24	0.24	0.01	3.39
C × N	0.01	0.01	0.20	0.59	0.00	0.04	0.00		0.47	0.47	0.02	6.78

enhanced uptake and reducing waste by increasing uptake efficiency (Prasad *et al.*, 2021). Reduced nitrogen application (N50% + NUFS) led to a decline in performance, highlighting the critical role of adequate basal nitrogen application in sustaining optimal crop growth and productivity. Permanent raised bed with residue retention (PB+R), combined with precise nitrogen management, enhanced residual nitrogen availability, improved crop productivity and maintained grain quality. This highlights the synergistic benefits of conservation agriculture practices in optimizing nitrogen use efficiency.

Impact on profitability of greengram production

Crop establishment methods and nitrogen management strategies significantly affect greengram profitability as shown in Table 3. Permanent raised bed with residue retention recorded the lowest cost of cultivation (₹ 33,250/ha) and the highest gross returns (₹ 68,160/ha), net returns (₹ 34,910/ha), Net B: C ratio (1.64) and economic efficiency (₹ 499/ha/day) which was closely followed by zero tillage

with residue retention with net returns of ₹ 34,470/ha and economic efficiency of ₹ 492/ha/day. Conservation tillage recorded the lowest profitability.

Nitrogen management also influenced profitability. 100% recommended nitrogen achieved the highest gross returns (₹ 72,750/ha), net returns (₹ 39,020/ha) and net B:C ratio (1.82). 75% recommended nitrogen + one foliar spray either with nano-urea or 2% prilled urea recorded net returns (₹ 38,550/ha and ₹ 37,920/ha). Control treatment had the lowest gross returns (₹ 55,700/ha) and net B: C ratio (0.97). Permanent raised bed and zero tillage with residue retention combined with N100% or N75% + nano-urea recorded highest returns. Economic efficiency improved (₹ 539/ha/day) due to higher productivity.

Correlation analysis of growth, nitrogen uptake and yield parameters in greengram

This study highlights strongly correlated between growth, nitrogen uptake and yield parameters in greengram under different crop establishment methods and nitrogen management strategies. Pearson correlation coefficients

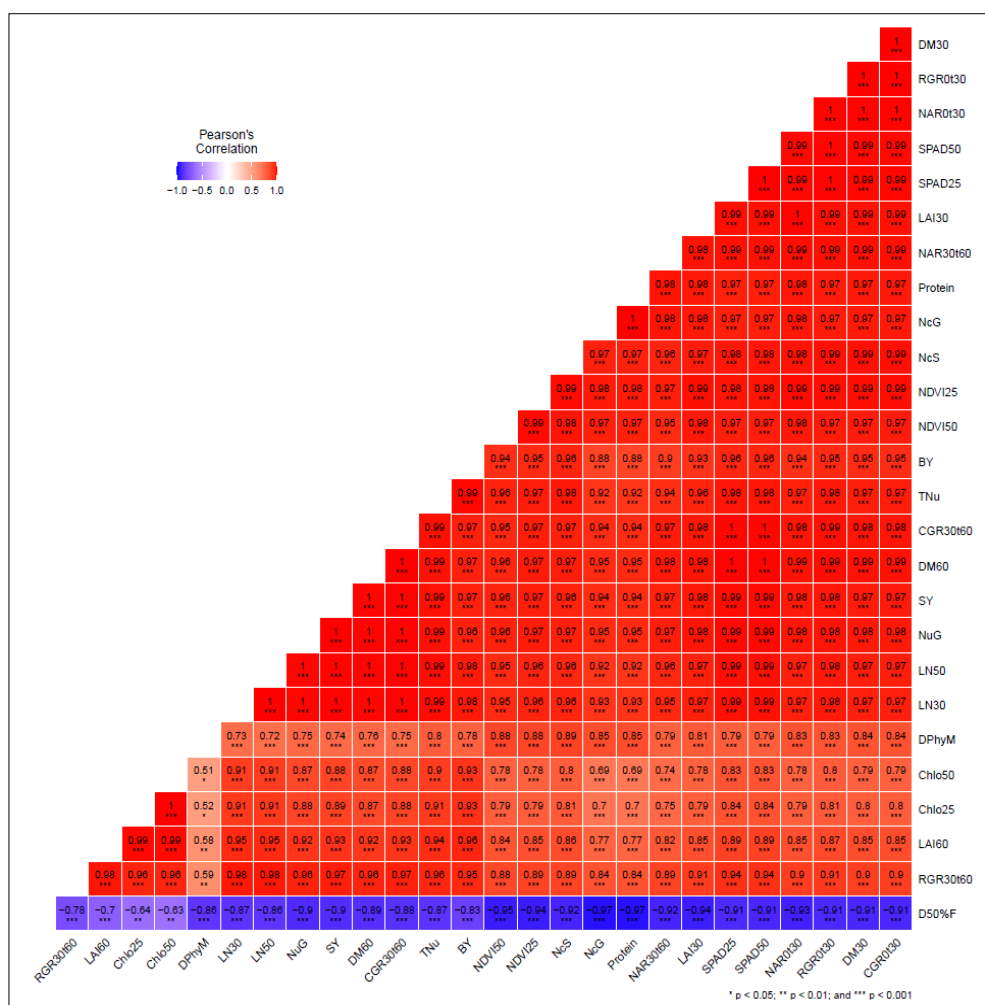


Fig 1: Heat map on a person's correlation coefficient between the growth and yield parameters of the greengram as influenced by the crop establishment methods and residual nitrogen.

revealed agronomic, physiological and yield attributes, aiding optimal management practices. Heat map (Fig 1) shows a strong relationship between growth and yield attributes. Seed yield correlated highly with biological yield ($r = 0.99$, $p < 0.001$), indicating that higher biomass enhanced seed yield. Seed yield significantly correlated with number of pods per plant, pod length and 1000-grain weight ($r = 0.96-0.97$, $p < 0.001$), emphasizing the importance of pod and seed quality.

Growth parameters such as plant height and dry matter at 30 and 60 DAS were positively linked with the leaf area index (LAI), showing early vegetative vigor as a yield determinant. Phenological traits, like days to 50% flowering, negatively correlated with vegetative growth ($r = -0.71$ to -0.86), suggesting balance between early growth and delayed flowering. Longer maturity duration positively correlated with seed yield ($r = 0.89$) and BY ($r = 0.85$).

Nitrogen content in leaves improved LAI, boosting photosynthesis and biomass. Nitrogen uptake strongly influenced seed yield ($r = 0.92$) and BY ($r = 0.91$). Grain and stover nitrogen concentrations correlated with protein content ($r = 0.84$).

CONCLUSION

Application of 100 per cent recommended dose of nitrogen (N100%) during preceding crop increased the residual nitrogen availability under permanent raised bed with crop residue retention (PB+R) which further enhanced greengram yield, biomass production and profitability. PB+R achieved the highest grain yield (0.85 t ha^{-1}), biological yield (2.93 t ha^{-1}) and harvest index (27.63%) by improving soil health and nutrient cycling. N100% excelled, while N75% with nano-urea spray delivered comparable results, with 21.18% grain protein and ₹ 38,550/ha net returns. Residual nitrogen from prior crops boosted soil fertility. Strong correlations emerged between seed yield and biological yield ($r = 0.99$), pod number ($r = 0.97$) and pod length ($r = 0.96$). These findings highlight the synergy of conservation agriculture and nitrogen management in enhancing productivity, profitability and soil sustainability. However, further studies are required to quantify residual nitrogen and legume effect.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

In this experiment, there is no involvement of any animals in this experiment and all experimental procedures were approved by the Committee of Experimental Animal Care.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the study's design, data collection, analysis, decision to publish, or manuscript preparation.

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