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Improvement of growth and yield of chickpea (*Cicer arietinum* L.) through deep-placed nitro-phosphate briquettes under semi-arid conditions

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Abstract
Chickpea productivity in semi-arid agroecosystems is frequently constrained by suboptimal nutrient availability, rapid nutrient losses from surface-applied fertilizers, and low fertilizer-use efficiency. In this context, nutrient deep-placement technologies, particularly nitro-phosphate (NP) briquettes, have emerged as promising alternatives to conventional fertilization. The present investigation was undertaken during the rabi season of 2018-19 at Mahatma Phule Krishi Vidyapeeth, Rahuri, to elucidate the influence of deep-placed NP briquettes on the growth dynamics and yield performance of chickpea (*Cicer arietinum* L.). The experiment was executed in a randomized block design comprising eight nutrient-management treatments, including conventional recommended fertilizer dose (RDF), graded NP briquette levels, and an unfertilized control. Growth parameters (plant height) and key yield attributes (pods plant^{-1}, pod weight plant^{-1}, grain weight plant^{-1}, and hundred-seed weight) were quantified, followed by assessment of grain, straw, and biological yields. Deep placement of NP briquettes exerted a pronounced and consistent improvement in vegetative growth and yield attributes relative to straight fertilizers. The 130% RDF applied through NP briquettes recorded the highest plant height, pod number, pod and grain weights, and ultimately the maximum grain yield (36.05 q ha^{-1}) and harvest index. Notably, 85% RDF through briquettes produced yields statistically comparable to 100% RDF via conventional fertilizers, indicating substantial enhancement in nutrient-use efficiency. Overall, the investigation substantiates the agronomic superiority of NP briquette deep placement in augmenting growth and yield in chickpea under semi-arid rainfed conditions. The technology demonstrates considerable potential for reducing fertilizer inputs while maintaining or improving productivity, thereby contributing to more sustainable and resource-efficient pulse cultivation.

Keywords: Chickpea productivity, nitro-phosphate briquettes, deep fertilizer placement, growth and yield attributes, nutrient-use efficiency

1. Introduction
Chickpea (*Cicer arietinum* L.) is a nutritionally dense legume crop and an essential component of pulse-based farming systems across semi-arid environments, providing a major source of plant protein, minerals and dietary fibre for millions of people (Arriagada *et al*., 2022) [1]. Advances in chickpea genomics and breeding have greatly broadened the scope for improving productivity and stress resilience; for example, the draft genome published by Varshney *et al*. (2014) [16] highlighted key genetic resources for trait enhancement. Despite these advances, actual farm-level yields remain well below the crop's potential due to suboptimal nutrient management, erratic rainfall and soil fertility constraints in rainfed regions (Arriagada *et al*., 2022) [1].
Nutrient management is a critical determinant of chickpea productivity in semi-arid Vertisol systems because nutrient losses following fertilizer application are substantial, particularly for nitrogen (N) and phosphorus (P). Losses through volatilization, denitrification, runoff and soil fixation often lead to poor synchrony between nutrient supply and crop demand, thereby reducing fertilizer-use efficiency and limiting yield expression (Linquist *et al*., 2013) [4]. These challenges underscore the need for improved nutrient-delivery strategies that enhance root-zone nutrient availability and minimize loss pathways.

Deep placement of fertilizers, including nitrogen supergranules or compacted NPK briquettes, has been widely documented as an effective strategy to increase fertilizer-use efficiency by reducing gaseous and leaching losses and by maintaining higher subsurface nutrient concentrations for longer periods (Wu *et al.*, 2017) [17]. Across rice-based systems, deep placement has consistently enhanced N recovery efficiency and grain yield, as reported by Wu *et al.* (2017) [17] in subtropical by Li *et al.* (2021) [3], who demonstrated significant improvements in nitrogen-use efficiency and reductions in greenhouse gas emissions with deep-placed N fertilizers. These mechanisms—enhanced NH_4^+ retention and prolonged nutrient availability in deeper soil layers—have also been attributed to N-P briquettes used in transplanted rice (Savant & Stangel, 1998) [12], highlighting their potential utility in other crop systems.

Although such evidence is extensive for cereals, studies on fertilizer briquette deep placement in pulses remain limited. Legumes typically have deeper root systems, different phenological nutrient demands and often experience water stress under rainfed conditions, meaning that nutrient delivery dynamics may differ markedly from those observed in rice or upland cereals. Therefore, empirical assessments are needed to evaluate whether nitro-phosphate (NP) briquette technologies can improve nutrient-use efficiency, nutrient uptake and yield in chickpea under semi-arid, rainfed conditions (Naveen *et al.*, 2024) [7].

The present investigation was undertaken to address this knowledge gap using a field experiment conducted at MPKV Rahuri during rabi season. The study evaluated graded levels of recommended dose of fertilizer (RDF), supplied either fully through conventional fertilizers or partially through NP briquettes (24:24:0), with the remaining P and K applied through straight fertilizers. Specifically, the experiment aimed to: (i) assess the influence of NP briquette deep placement on chickpea growth, yield attributes and yield; (ii) quantify macro- and micronutrient uptake in grain and straw. These findings are expected to support evidence-based nutrient management recommendations for improving productivity and resource-use efficiency in chickpea-based cropping systems.

2. Material and Methods

2.1 Fertilizer Application

Fertilizer treatments were applied according to the nutrient regimes defined for each experimental plot. In the straight-fertilizer treatment (T_2), the full recommended dose of 25:50:30 kg $N:P_2O_5:K_2O$ ha^{-1} was applied at sowing using urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O). For briquette-based treatments (T_3-T_8), nitrogen and a portion of phosphorus were supplied through nitro-phosphate (NP) briquettes containing 24:24:0 $N:P_2O_5:K_2O$, each briquette weighing 2.6 g. The remaining P_2O_5 and all K_2O were supplemented using SSP and MOP, respectively, according to treatment-specific nutrient requirements (Table 1).

Straight fertilizers were applied through drill placement at sowing, whereas NP briquettes were supplied using deep placement two days after sowing to ensure localized and sustained nutrient availability within the crop root zone (Figure 1). Treatment-wise briquette quantities were calculated on a plot and hectare basis to maintain accurate dose application.

2.2 Seed and Sowing

Genetically pure seed of chickpea (*Cicer arietinum* L.) variety 'Phule Vikram' was procured from the Seed Cell, Mahatma Phule Krishi Vidyapeeth, Rahuri (Table 2). Sowing was carried out on 15 December 2018 at a spacing of 30 × 10 cm using the recommended seed rate of 75 kg ha^{-1}. 'Phule Vikram' is an early-maturing, high-yielding cultivar released in 2016, characterized by a tall plant architecture suitable for mechanical harvesting, resistance to Fusarium wilt, and superior yield performance under both timely and late sown conditions.

Table 1: Details of Experimental trails

No of Treatments	Treatment details
T_1	Control
T_2	100% RDF (25:50:30 N, P_2O_5, K_2O kg ha^{-1}) through conventional straight fertilizer
T_3	55% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)
T_4	70% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)
T_5	85% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)
T_6	100% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)
T_7	115% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)
T_8	130% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)

Table 2: The details of treatments

Crop and Variety	:	Chickpea - *Phule Vikram*
Design	:	Randomized Block Design
No of Treatments	:	8
No of replications	:	3
No of plot	:	24
Plot size	:	Gross= 6.0 x 4.20 m^2, Net = 5.40 x 3.60 m^2
Sowing date	:	15/12/2018
Soil	:	Medium black soil
Spacing	:	30 x 10 cm

2.3 Crop Management

2.3.1 Gap Filling and Thinning

Gap filling was performed at 8 days after sowing (DAS) to ensure uniform plant establishment. Thinning was conducted at 15 DAS to maintain one healthy seedling per hill.

2.3.2 Weed Management

A single hand weeding operation was carried out at 30 DAS to maintain weed-free conditions during early crop growth.

2.3.3 Irrigation

An initial irrigation was applied immediately after sowing using the flood method to ensure proper seed germination. Subsequently, drip irrigation was provided at weekly intervals until 14 February 2019 to maintain adequate soil moisture for vegetative and reproductive growth.

2.3.4 Plant Protection

Gram pod borer (*Helicoverpa armigera*) was managed using a two-stage protection schedule. A foliar spray of 5% neem seed kernel extract (NSKE) was applied at early flowering, followed by Emamectin benzoate 5 SG at 200 g ha^{-1} during pod development to suppress larval infestation and minimize pod damage.

2.4 Soil Sampling for N and P Movement

To evaluate the spatial movement of nitrogen and phosphorus from NP briquettes, soil samples were collected at two crop stages: 30 DAS and 45 DAS. Samples were drawn from four positions relative to the briquette placement point to assess horizontal and vertical nutrient dispersion:

- 15 cm horizontal × 15 cm vertical (15H-15V)
- 15 cm horizontal × 30 cm vertical (15H-30V)
- 30 cm horizontal × 15 cm vertical (30H-15V)
- 30 cm horizontal × 30 cm vertical (30H-30V)

Samples were analyzed to determine the localized availability of N and P within the rooting zone.

2.5 Post-Harvest Observations
2.5.1 Number of Pods per Plant
At harvest, pods from five pre-tagged plants within each plot were collected and counted to determine the mean number of pods plant^{-1}.

2.5.2 Pod Weight per Plant
All pods harvested from the five sampled plants were weighed individually, and the average pod weight per plant was calculated.

2.5.3 Grain Weight per Plant
Grains obtained from the sampled plants were weighed using an analytical balance, and mean grain weight plant^{-1} was determined.

2.5.4 Hundred-Seed Weight
From the composite grain sample of each net plot, 100 seeds were randomly selected and weighed to determine the 100-seed weight.

2.5.5 Grain Yield
Grain yield was recorded after sun-drying the harvested produce for one week, followed by threshing and cleaning. The plot-level grain weight was converted to q ha^{-1} using the standard hectare conversion factor.

2.5.6 Straw Yield
Dried stalks and empty pods were weighed to estimate straw yield plot-^{1}, and values were converted to q ha^{-1}.

2.5.7 Biological Yield
Biological yield was calculated as the sum of grain and straw yields.

2.5.8 Harvest Index
Harvest index (HI) was computed according to Salisbury and Ross (1986):

$$HI(\%) = \frac{\text{Grain Yield}}{\text{Grain Yield} + \text{Straw Yield}} \times 100$$

2.6 Statistical Analysis
Experimental data were analyzed using the Analysis of Variance (ANOVA) procedure appropriate for a Randomized Block Design (RBD) as described by Panse and Sukhatme (1985) [10]. Treatment means were compared using the Critical Difference (CD) at the 5% significance level, and Standard Error of Mean (SEm) values were calculated for all measured parameters. Graphical and tabular representations were prepared for clarity and interpretation of treatment effects.

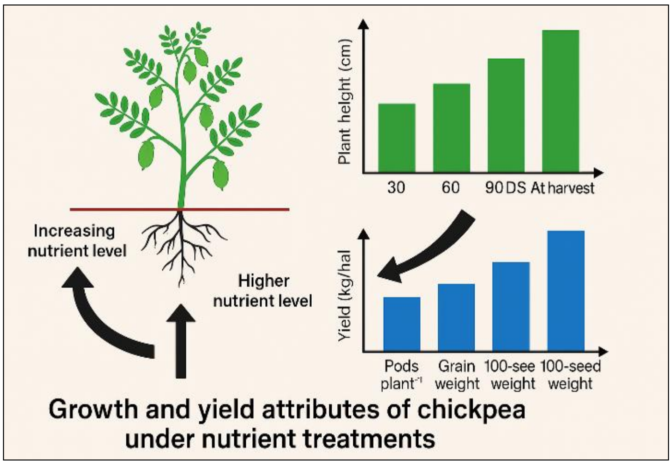

Fig 1: Conceptual Diagram of Treatment Structure and Nutrient Application Method

3. Results and Discussion
3.1 Plant Establishment and Growth
3.1.1 Plant population
Initial stand (20 DAS) across treatments showed a mean population of 3168.70 plants ha^{-1} (95.06%), and final population at harvest was 3144.27 plants ha^{-1} (93.17%). No significant differences among nutrient-management treatments were observed (Table 3). This uniformity in stand confirms that variations in fertilizer source or dose did not influence emergence or survival, thereby validating comparisons of subsequent growth and yield parameters. Maintaining a uniform plant stand is critical in fertilization trials to ensure that differences in yield or growth are due to treatment effects rather than population variability (Mohan *et al*., 2019) [5].

Table 3: Plant count of chickpea as influenced by different treatments

Treatment	Initial plant count		Final plant count	
	ha$^{-1(-00)}$	Per cent	ha$^{-1(-00)}$	Per cent
T_1- Control	3168.70	95.06	3158.42	94.75
T_2-100% RDF (25:50:30 N, P_2O_5, K_2O kg ha^{-1}) through conventional straight fertilizer	3209.85	96.30	3148.13	91.36
T_3-55% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3168.70	95.06	3168.70	91.36
T_4-70% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3148.13	94.44	3106.98	95.06
T_5-85% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3148.12	94.44	3137.84	95.06
T_6-100% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3148.13	94.44	3127.55	90.12
T_7-115% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3168.70	95.06	3148.13	93.21
T_8-130% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	3189.28	95.68	3158.42	94.44
S.E m ±	92.63	2.78	85.43	1.68
C.D. at 5%	NS	NS	NS	NS
General Mean	3168.70	95.06	3144.27	93.17

RDF: Recommended Dose of Fertilizer; RDN: Recommended Dose of Nitrogen; DAS: Days After Sowing; S.Em ± Standard Error of Mean; C.D. at 5% Critical Difference at 5% level of significance; NP Briquettes: Nitro-Phosphate Briquettes; ha^{-1} Per hectare.

3.1.2 Plant height

Plant height increased progressively from 30 DAS (mean 14.68 cm) to harvest (mean 52.72 cm) (Table 4). Nutrient management significantly influenced height at all growth stages. The 130% RDF treatment via nitro-phosphate (NP) briquettes with supplementary P and K registered the highest harvest height (56.00 cm), about 7.9 cm greater than the unfertilized control (48.13 cm). Treatments with 115% RDF via briquettes were similar; the control remained the lowest.

Enhanced plant height under deep-placed briquette treatment likely results from sustained nutrient availability in the root zone, enabling continuous uptake throughout vegetative growth. Similar findings have been reported in other crops where deep or band placement of NPK increased vegetative growth compared with broadcast applications (Nkebiwe, 2016; Nakachew, 2024) [8, 6]. Moreover, deep placement reduces early nutrient loss by volatilization or surface runoff, improving nutrient-use efficiency and promoting robust growth (Nakachew *et al*., 2024) [6]

Thus, the superior plant height in 130% RDF-briquette treatment supports the hypothesis that deep-placement briquette fertilization fosters improved root-zone nutrient supply and vegetative growth under semi-arid conditions.

Table 4: Mean Plant height of chickpea as influenced by different treatments

Treatment	Plant Height (cm)			
	30 DAS	**60 DAS**	**90 DAS**	**At Harvest**
T_1- Control	13.50	42.00	47.00	48.13
T_2-100% RDF (25:50:30 N, P_2O_5, K_2O kg ha^{-1}) through conventional straight fertilizer	14.37	46.83	52.37	52.77
T_3-55% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	14.10	45.00	49.67	49.67
T_4-70% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	14.43	44.67	52.50	52.50
T_5-85% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	14.57	46.93	52.83	52.83
T_6-100% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	15.13	48.17	54.83	54.83
T_7-115% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	15.30	47.67	55.00	55.00
T_8-130% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	16.00	50.17	56.00	56.00
S.E m ±	0.46	1.44	1.00	1.20
C.D. at 5%	1.39	4.36	3.02	3.63
General Mean	14.68	46.43	52.53	52.72

RDF: Recommended Dose of Fertilizer; RDN: Recommended Dose of Nitrogen; DAS: Days After Sowing; S.Em ± Standard Error of Mean; C.D. at 5% Critical Difference at 5% level of significance; NP Briquettes: Nitro-Phosphate Briquettes; ha^{-1} Per hectare.

3.2 Yield Attributes

3.2.1 Number of pods, pod weight, grain weight, 100-seed weight

All yield-attributing traits were significantly influenced by nutrient management (Table 5). The mean pods per plant was 52.85; the 130% RDF (briquette) treatment produced the highest pods per plant (61.37), while control had the least. Pod weight per plant (26.07 g), grain weight per plant (23.67 g) and 100-seed weight (26.04 g) also peaked under 130% RDF-briquette.

These results suggest that a sustained supply of nutrients via deep-placed briquettes supports both formation of reproductive sinks (pods) and effective filling (seed weight). Previous work in other crops has shown that localized deep placement of NPK reduces nutrient losses (fixation, leaching, volatilization) and improves nutrient availability during critical stages, resulting in enhanced yield components (Tapkeer, 2017; Owusu, 2024; Zhu, 2019) [14, 9, 18].

Importantly, in pulse crops like chickpea, adequate P and N during pod initiation and grain filling are essential for pod set and seed development — conditions that deep placement helps stabilize by maintaining root-zone nutrient supply during moisture-nutrient stress periods, common in semi-arid climates. This aligns with broader recommendations for nutrient management in pulses, where precise fertilization timing and placement can enhance yield and resource-use efficiency (Thiyagarajan *et al*., 2003; Shah, 2025) [15, 13]

3.3 Yield and Harvest Index

3.3.1 Grain, Straw, and Biological Yield

Mean grain yield across treatments was 27.56 q ha^{-1}, but varied significantly. The 130% RDF-briquette treatment recorded the highest grain yield (36.05 q ha^{-1}), straw yield (42.30 q ha^{-1}), and biological yield (78.36 q ha^{-1}) (Table 6).

Remarkably, the 85% RDF via briquettes yielded comparably to 100% RDF via conventional fertilizers, indicating possible fertilizer savings of ~15% without loss of yield. This suggests improved fertilizer-use efficiency under briquette-based nutrient delivery.

Deep placement of fertilizers (granular or briquetted) has been widely documented to increase yield and nutrient-use efficiency across diverse crops, by reducing surface losses (volatilization, runoff) and improving nutrient retention and uptake (Nkebiwe, 2016; Chen, 2022; Radhika, 2013) [8, 2, 11]. Furthermore, recent studies on fertilizer deep placement in cereals have shown yield improvements and enhanced nitrogen-use efficiency with deep placement compared to broadcast fertilization (Li *et al*., 2021; Chen *et al*., 2022) [3, 2].

Our findings extend this evidence to a legume crop under semi-arid, rainfed conditions, demonstrating that deep-placed NP briquettes can yield similar or better productivity with lower or comparable fertilizer input — an agronomically and environmentally desirable outcome.

3.3.2 Harvest Index

Harvest index (HI) ranged from 38.80% (control) to 46.01% in the 130% RDF-briquette treatment (Table 6). The increased HI under briquette treatment suggests improved partitioning of assimilates towards grain, rather than vegetative parts.

This improvement likely reflects that sustained nutrient supply during reproductive phases, due to slow-release and root-zone localization of nutrients from briquettes, supports efficient source-to-sink translocation. Comparable effects — improved harvest index under deep placement — have been previously observed in cereals where deep-fertilization enhanced biomass partitioning and yield (Zhu *et al*., 2025; Wu, 2017) [19, 17].

Table 5: Yield attributing characters as influenced by different treatments

Treatment	No. of pods plant^{-1}	Weight of pods plant^{-1} (g)	Grain weight plant^{-1} (g)	100 seed weight (g)
T_1- Control	38.27	17.30	14.73	20.23
T_2-100% RDF (25:50:30 N, P_2O_5, K_2O kg ha^{-1}) through conventional straight fertilizer	54.63	23.17	20.30	24.08
T_3-55% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	46.93	20.63	17.70	22.92
T_4-70% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	52.87	22.40	19.70	23.47
T_5-85% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	54.13	23.20	20.27	24.03
T_6-100% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	56.47	23.77	21.23	24.28
T_7-115% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	58.13	25.20	22.73	24.80
T_8-130% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	61.37	26.07	23.67	26.04
S.E m ±	1.48	0.75	0.71	0.52
C.D. at 5%	4.48	2.28	2.14	1.58
General Mean	52.85	22.72	20.04	23.73

RDF: Recommended Dose of Fertilizer; RDN: Recommended Dose of Nitrogen; DAS: Days After Sowing; S.Em ± Standard Error of Mean; C.D. at 5% Critical Difference at 5% level of significance; NP Briquettes: Nitro-Phosphate Briquettes; ha^{-1} Per hectare.

Table 6: Yield and harvest index of chickpea as influenced by different treatments

Treatment	Yield (q ha^{-1})			Harvest index (%)	Yield increase over RDF (%)
	Grain	Straw	Biological yield		
T_1- Control	14.55	22.94	37.49	38.80	-
T_2-100% RDF (25:50:30 N, P_2O_5, K_2O kg ha^{-1}) through conventional straight fertilizer	29.07	37.92	66.99	43.40	-
T_3-55% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	21.76	31.82	53.58	40.60	-
T_4-70% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	24.53	32.89	57.42	42.72	-
T_5-85% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	28.11	35.93	64.05	43.91	-
T_6-100% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	32.35	39.04	71.40	45.32	15.47
T_7-115% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	34.02	40.17	74.19	45.85	17.02
T_8-130% of RDF (RDN through briquettes; remaining P_2O_5 & K_2O through conventional straight fertilizer)	36.05	42.30	78.36	46.01	24.01
S.E m ±	0.80	1.01	1.79	0.21	-
C.D. at 5%	2.41	3.07	5.43	0.63	-
General Mean	27.56	35.38	62.93	43.33	-

RDF: Recommended Dose of Fertilizer; RDN: Recommended Dose of Nitrogen; DAS: Days After Sowing; S.Em ± Standard Error of Mean; C.D. at 5% Critical Difference at 5% level of significance; NP Briquettes: Nitro-Phosphate Briquettes; ha^{-1} Per hectare.

3.4 Interpretation and Broader Implications

The study demonstrates that deep placement of NP briquettes especially at 130% RDF with supplementary basal P and K significantly improves vegetative growth, yield components, total yield, and harvest index in chickpea under semi-arid conditions (Figure 2).

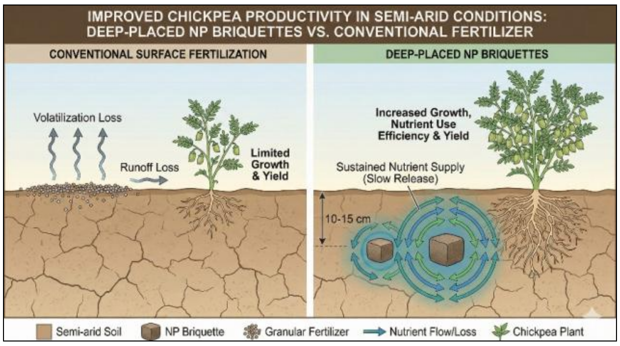

Fig 2: Mechanism of enhanced nutrient-use efficiency: Deep placement of NP briquettes reduces volatilization and runoff while increasing root-zone nutrient availability.

The enhanced performance under briquette treatments aligns with broader meta-analytic evidence that localized fertilizer application (deep, band or briquette) addresses common limitations of broadcast fertilization: nutrient losses, temporal mismatch with crop demand, surface volatilization, and poor recovery efficiency (Nakachew, 2016; Nkebiwe, 2016) [6, 8].

Moreover, recent research indicates that suitable fertilizer placement depth improves crop yield and nitrogen-use efficiency by reducing gaseous nitrogen losses and promoting deeper root uptake (Chen *et al.*, 2022; Zhu *et al.*, 2025) [2, 19]. These mechanisms likely operated in our experiment, particularly under drip irrigation and semi-arid climate, enabling sustained nutrient supply during vegetative and reproductive phases.

For pulse crops such as chickpea, which often grow on marginal soils with low fertility and under rainfed conditions, the adoption of briquette-based deep placement could offer a dual advantage: reducing fertilizer input and increasing yield and resource-use efficiency. This is particularly important given the limited fertilizer responsiveness of many pulses and their sensitivity to moisture-nutrient stress (Thiyagarajan *et al.*, 2020 & Shah, 2015) [15, 13].

In summary, the positive responses observed increased height, yield attributes, yield, and harvest index support the conclusion that NP briquette deep placement is a viable and effective nutrient management strategy for chickpea cultivation under semi-arid, rainfed conditions.

4. Conclusion

This study clearly demonstrates that deep placement of nitro-phosphate (NP) briquettes is an effective nutrient-management strategy for enhancing chickpea growth and productivity under semi-arid, rainfed conditions. NP briquette treatments ensured a sustained nutrient supply, which improved vegetative development, yield attributes, and final yields compared with conventional straight fertilizers. The 130% RDF briquette treatment consistently produced the highest plant growth, superior yield components, maximum grain and straw yield, and the greatest harvest index.

A key finding is that 85% RDF applied through briquettes performed on par with 100% RDF applied through straight fertilizers, indicating that briquette-based fertilization can save approximately 15% nutrients without reducing yield. This highlights the higher nutrient-use efficiency and economic advantage of deep-placed NP briquettes.

Overall, the results confirm that NP briquette deep placement is a practical, efficient, and sustainable approach for improving chickpea productivity in low-fertility, moisture-constrained environments. The technology offers a viable path toward higher yields, better fertilizer efficiency, and more resilient pulse production systems in semi-arid regions.

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