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Evaluation of nutrient uptake patterns and nutrient budgeting of *Kharif* crops

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Abstract
A two rainy season *kharif* experimentation (2023-2024) were carried out at ICAR-Indian Institute of Millets Research, Hyderabad, India.This study focuses on evaluating the nutrient uptake patterns of *kharif* pulses and (green gram and soybean), and foxtail millet with the aim of developing sustainable cropping strategies to enhance productivity and soil health in rainfed and semi-arid regions. Experiment was laid out in RCBD with 8 replications and 4 treatments. Results revealed that soybean has 4.05 times, 45.1 and 60.2% higher grain N-P-K concentration than foxtail millet grain (1.31-0.31- 0.83%). Soybean has 4.75 times, 64.1 and 85.6% higher grain N-P-K uptake than foxtail millet grain (14.2-3.40-9.07- kg ha^{-1}). Mean while, haulm N, concentration and uptake were highest in green gram whereas P-K concentration and uptake were highest in soybean by 68.4, 18.4% and 89.2 and 34.0% than foxtail millet straw (0.19 and 1.06% concentration and 4.00 and 22.30 kg ha^{-1}) uptake. Soil cultivated after soy bean and green gram has positive nitrogen, phosphorous and potassium balance than foxtail millet during both the years of study. Positive balance of N (75.17 and 74.91 kg $ha^{-1)}$ was obtained with green gram and soybean cultivation compared foxtail millet (-21.54), soybean also has neutral P balance (-0.02 kg ha^{-1}). Soybean has higher K gain (37.93 kg ha^{-1}) than green gram and foxtail millet.

Keywords: Soybean, green gram, foxtail millet, nutrient balance, nutrient uptakes

Introduction
A two rainy season field experimentation (2023-2024) were carried out at ICAR-Indian Institute of Millets Research, Hyderabad, India, to evaluate nutrient uptake patterns of *kharif* crops. Experiment was laid out in RCBD with 3 treatments and 8 replications. Green gram (*Vigna radiata* L.), an important pulse crop, is widely cultivated for its high protein content (20-25%) and short duration, making it ideal for crop rotations and intercropping systems. Its ability to fix atmospheric nitrogen through symbiosis with *Rhizobium* spp. improves soil fertility and reduces dependence on chemical fertilizers. Foxtail millet (*Setaria italica* L.) is one of the oldest cultivated millets, valued for its climate resilience, low input requirement, and adaptability to marginal lands. Rich in minerals, dietary fiber, and antioxidants, it serves as a health-promoting cereal while contributing to crop diversification in dryland ecosystems. Soybean (*Glycine max* L.) is a globally significant oilseed and pulse crop, containing about 40% protein and 20% oil. It plays a crucial role in human nutrition, livestock feed, and industrial uses, while also improving soil nitrogen status through biological nitrogen fixation. Nutrient budgeting, which accounts for all nutrient inputs and outputs (harvest removal, leaching, losses), provides an essential tool for assessing nutrient balances and guiding site-specific nutrient management strategies. Comparative evaluation of nutrient uptake patterns among these crops helps identify their relative nutrient demands and their roles in cropping system sustainability.

Materials and Methods
Field experiments were carried out for two consecutive *kharif* seasons of 2023 and 2024 at ICAR-Indian Institute of Millets Research (IIMR), Rajendra nagar, Hyderabad, Telangana state, India. The experimental site was situated at 17.19°N latitude and 78.23°E longitude at an elevation of 542 meters above mean sea level. As per Köppen-Geiger climate classification, it

has a steppe climate (BSh). During the experimental period (July-october), a rainfall of (15 rainy days) and 184.4 (19 rainy days) was received during 2023 and 2024. The experimental clay loam soil was non-saline (EC: 0.15 dS m⁻¹) neutral soil pH (7.18) was rated as low for organic carbon (0.38 and 0.41%), available nitrogen (198 and 206.4 kg ha⁻¹), medium for available phosphorus (18.0 and 20.0 kg ha⁻¹) and potassium (250.0 and 272 kg ha⁻¹). Field experiment with three treatments (soybean, green gram and foxtail millet) replicated eight times was set up in randomized complete block design (RCBD). The experimental field for green manure crop was prepared by running a rotavator and soybean, green gram and foxtail millet were sown using a seed rate of 60, 22 and 10 kg ha^{-1} on 2nd July and 27th June during 2023 and 2024. Recommended dose of fertilizer was applied to the crop before ploughing that got incorporated with rotavator running. Nutrient (N, P and K) concentration (%) in plant samples was estimated as per standard procedures and nutrient uptake (kg/ha) was arrived at by multiplying nutrient concentration with dry matter of weeds (kg ha^{-1})/100. The apparent balance of nitrogen, phosphorus, and potassium (N, P and K) was determined by considering the initial available nutrient status of the soil at sowing along with nutrients added on input side. The total nutrient uptake by the crop (grain and straw) considered as output was then subtracted from this sum to obtain the apparent nutrient balance for each treatment. Net gain or loss of nutrients after harvest of crops for both the seasons (*kharif* and *rabi*) during both the years were worked out by subtracting expected balance from initial balance

Data were subjected to statistical analysis as per the procedures outlined by Gomez and Gomez (1984). Treatment means were compared using the critical difference (CD) at 5% level of significance.

Nitrogen concentration (%) and uptake (kg ha^{-1}) by by seed/grain and haulm or straw

Data regarding N concentration and uptake by grain/seed of *kharif* crops during both the years of study are given in Table 1. Data shows that soybean has recorded significantly higher N concentration than green gram and foxtail millet grain during both the years of study. On mean basis soybean (5.31%) and green gram (3.22%) seeds have 4.05 and 2.46 times higher N than foxtail millet grain (1.31%).

On mean basis, soybean (66.7 kg ha^{-1}) seed N uptake was 1.79 and 4.75 times higher than the green gram seeds (37.1 kg ha^{-1}) and foxtail millet grain (14.2 kg ha^{-1}) uptakes. Further, green gram seed N uptake was 1.61 times higher seed uptake than the grain N uptake by foxtail millet.

Nitrogen concentration and uptake by haulms / straw of different *kharif* crops was presented in Table 1. Among the crops, green gram haulms have higher N concentration than the soybean whereas the least in fox tail millet straw during both the years of study. On mean basis green gram (2.51%) haulms have 1.5 and 5.98 times% more N than soybean haulms (1.67%) and foxtail millet stover (0.42%). On mean basis green gram (54.4 kg ha^{-1}) has 1.36 and 6.48 times more N uptake by haulm than soybean haulms (40.1) and fox tail millet straw (8.39).

Kouelo *et al.* (2013) reported that *Mucuna pruriens* has nitrogen uptake by grain (149.4 kg N ha⁻¹). *Centrosema pubescens* has higher N uptake by straw (88.4 kg ha⁻¹).

Table 1: Nitrogen concentration (%) and uptake in grain and straw (kg ha^{-1}) of *kharif* crops

Treatment	Grain				Straw			
	N (%)		N uptake (kg ha^{-1})		N (%)		N uptake (kg ha^{-1})	
	2023	2024	2023	2024	2023	2024	2023	2024
Green gram	3.19	3.26	35.4	38.8	2.48	2.55	52.5	56.4
Soybean	5.27	5.35	63.8	69.5	1.64	1.70	39.3	40.9
Foxtail millet	1.29	1.33	13.5	14.9	0.39	0.45	7.97	9.80
Mean	2.58	2.65	29.5	32.4	1.00	1.06	40.1	45.5
S.Em±	0.06	0.08	0.78	1.51	0.01	0.02	0.36	0.46
CD (p = 0.05)	0.17	0.24	2.39	4.57	0.03	0.05	1.10	1.41
CV (%)	6.13	8.63	7.49	17.54	5.51	8.80	12.37	13.51

Phosphorous concentration (%) and uptake (kg ha^{-1}) by seed/grain and haulm/straw

P concentration and uptake by seed/ grain of different *kharif* crops are presented in Table 2. Among the crops, soybean recorded significantly superior grain phosphorous concentration and uptake than green gram seed and foxtail millet grain during both the years of study. On mean basis soybean (0.39% and 5.58 kg ha⁻¹) seeds have 28.5% and 45.1% more P concentration and 38.8 and 64.1% higher uptake than green gram (0.35% and 4.02 kg ha⁻¹) and foxtail millet grain (0.31% and 3.40 kg ha⁻¹).

P concentration and uptake by haulm or straw of *kharif* crops during both the years of study were presented in Table 2. Among the crops, soybean crop recorded significantly higher phosphorous concentration and uptake in haulm than green gram haulms and foxtail millet straw during both the years of study. Foxtail millet recorded the lowest values during both the years. On mean basis, soybean (0.32% and 7.57 kg ha^{-1}) haulms have 18.5 and 68.4% more P and 29.6 and 89.2% higher P uptake than green gram haulms (0.27% and 5.84 kg ha^{-1}) and foxtail millet straw (0.19% and 4.00 kg ha^{-1}). Results obtained in our study were similar to findings of Singh *et al.* (2008) [15] pearl millet recorded the highest phosphorus uptake (26.1 kg ha⁻¹) while, green gram registered the lowest P uptake (21.9 kg ha⁻¹).

Table 2: Phosphorous concentration (%) and uptake in seed or grain and haulm or straw (kg ha^{-1}) of different *kharif* crops

Treatment	Grain				Straw			
	P (%)		P uptake (kg ha^{-1})		P (%)		P uptake (kg ha^{-1})	
	2023	2024	2023	2024	2023	2024	2023	2024
Greengram	0.34	0.36	3.73	4.30	0.25	0.29	5.27	6.40
Soybean	0.42	0.47	5.08	6.08	0.29	0.34	6.85	8.29
Foxtail millet	0.29	0.33	3.06	3.74	0.17	0.21	3.43	4.56
S.Em±	0.010	0.006	0.178	0.192	0.004	0.015	0.198	0.366
CD (p = 0.05)	0.030	0.019	0.539	0.583	0.012	0.047	0.601	1.111
CV (%)	8.009	4.65	16.92	15.40	4.739	15.48	14.397	21.52

Potassium concentration (%) and uptake (kg ha^{-1}) by seed/grain and haulm/straw

Potassium (K) concentration and uptake by seed/grain of *kharif* crops during both the years of study were presented in Table 3. Among the crops, soybean seeds have significantly higher K concentration and uptake than green gram seeds and foxtail millet grain during both the years of study. On mean basis, soybean seeds (1.33% and 16.84 kg ha⁻¹) have 34.3 and 60.2% more K concentration and 46.8 and 85.6% higher uptake than green gram seed (0.99% and 11.47 kg ha⁻¹) and foxtail millet grain (0.83% and 9.07 kg ha⁻¹).

Potassium concentration and uptake by haulm/ straw of different *kharif* crops during both the years of study were presented in Table 3. Among the crops, soybean haulms have recorded significantly superior K concentration and uptake than green gram haulms and foxtail millet straw during both the years of study. Further, green gram haulms have significantly superior in K concentration and uptake than foxtail millet straw during both the years of study. On mean basis, soybean haulms (1.25%) have 5.0 and 18.4% higher K concentration and K uptake by 15.9 and 34.0% than green gram haulms (1.19 and 25.78 kg ha⁻¹) and foxtail millet straw (1.06% and 22.30 kg ha⁻¹). Further, green gram haulms have 12.2 and 15.6% higher K concentration and uptake than foxtail millet straw.

Legumes generally display higher potassium (K) concentration and uptake than millets due to their distinctive root morphology and physiological demands. Their deep and extensively branched root systems allow legumes to explore a broader soil volume and access both exchangeable and non-exchangeable soil K more effectively than the relatively shallow-rooted millets (Srinivasarao *et al.*, 2012; Fageria *et al.*, 2008) [16, 2]. Moreover, K is essential for nodule formation and optimal functioning of nitrogenase, since it regulates carbohydrate transport, osmotic balance, and the energy supply required for symbiotic N_2 fixation; consequently, legumes maintain elevated K concentrations to support this process (Reddy & Sreenivas, Marschner, 2012) [6]. Legumes also tend to produce greater vegetative biomass, allocating more K to leaves and stems compared to cereals or millets that primarily channel nutrients into grain. Their roots exude organic acids and acidify the rhizosphere during N_2 fixation, which enhances K solubilization and uptake (Neumann & Römheld, 2001) [11]. Coupled with a propensity for luxury consumption—absorbing more K than strictly necessary—these traits contribute to the generally higher K concentration and uptake observed in legumes versus millets (Mengel & Kirkby, 2001) [8].

Our results were in close conformity with findings of Joshi *et al.* (2020) [3] and Medhi *et al.* (2014) [7] for green gram and with Bathula *et al.* (2019) [1] for soybean.

Table 3: Potassium concentration (%) and uptake in seed or grain and haulm or straw (kg ha^{-1}) of different *kharif* crops

Treatment	Seed/ Grain				Haulm/Straw			
	K (%)		K uptake (kg ha^{-1})		K (%)		K uptake (kg ha^{-1})	
	2023	2024	2023	2024	2023	2024	2023	2024
Greengram	0.88	1.11	9.80	13.14	1.13	1.26	23.81	27.75
Soybean	1.19	1.48	14.44	19.23	1.22	1.29	28.52	31.25
Foxtail millet	0.75	0.92	7.83	10.31	1.01	1.11	20.46	24.14
S.Em±	0.032	0.023	0.451	0.561	0.016	0.020	0.857	0.877
CD (p = 0.05)	0.097	0.070	1.369	1.701	0.049	0.061	2.599	2.659
CV (%)	9.59	5.60	15.93	14.86	4.05	4.69	13.32	11.93

Soil Nutrient Balance Sheet

Nitrogen, phosphorous and potassium balance sheet in soils after harvest of of *kharif* crops was presented in Table 4.

On mean basis, higher and positive balance of N (75.17 and 74.91 kg ha$^{-1)}$ was obtained with green gram and soybean cultivation compared foxtail millet (-21.54) this is mainly because legumes owing to their tap root system explores large volume of soil and an fix atmospheric N through bacterial symbiosis with *Rhizobium* residing in the root nodules often termed as BNF. In contrast, millets, like most cereals, are non-leguminous and rely solely on soil-available nitrogen, often leading to a negative N balance. Our results were corroborated with findigs of Peoples *et al.* (2009) [10] who reported that legumes contribute 30-200 kg N ha⁻¹ year⁻¹ through BNF, improving soil nitrogen status.

On mean basis, Soybean also neutral P balance (-0.02 kg ha⁻¹), while green gram and foxtail millet showed a moderate depletion (−5.76 and -2.24 kg ha⁻¹) on account of higher P depletion and limited capacity to mobilize unavailable P. Legumes due to their deep root system generally exhibit a positive phosphorus (P) balance compared to millets. They exude organic acids, such as citrate and malate, and phosphatase enzymes that solubilize bound soil phosphorus, making it more available for plant uptake. In addition, nitrogen fixation in legumes releases protons into the rhizosphere, lowering pH and enhancing P solubility. In contrast, millets often store a large proportion of phosphorus as phytic acid, a poorly bioavailable form, and lack strong biochemical mechanisms to mobilize soil-bound P, resulting in a comparatively lower P balance.

On mean basis, soybean has higher K gain (37.93 kg ha⁻¹) than green gram (23.45 kg ha⁻¹) due to its smaller biomass return as litter fall as compared to soybean. Fox tail millet showed a negligible gain (+1.57 kg ha⁻¹) because cereals remove significant amounts of K in grain and straw. Legumes generally maintain a higher potassium (K) balance compared to millets due to their deeper and more extensive root systems, which enable efficient K acquisition from deeper soil layers (Römheld and Kirkby, 2010) [11]. Biological nitrogen fixation in legumes improves soil structure and organic matter content, enhancing cation exchange capacity (CEC) and thereby increasing K retention in the soil (Sharma *et al.*, 2018) [12]. Additionally, legumes recycle significant quantities of K through their biomass and residue incorporation, which replenishes soil K reserves and reduces depletion (Singh *et al.*, 2019) [14]. In contrast, millets, though hardy, are often grown on marginal soils with low nutrient availability and tend to mine soil K without proportionate replenishment, leading to a lower overall K balance (Kumar *et al.*, 2014) [5].

Results obtained in our study where similar to findigs of Shukla *et al.* (2024) [13] whereas, the highest positive nitrogen balance observed under groundnut-maize (165 kg N ha⁻¹). Whereas, green gram-maize cropping system exhibited the lowest nitrogen uptake in grain (47.49 kg ha⁻¹) and straw (27.78 kg ha⁻¹)

Table 4: Soil nutrient balance sheet (N-P-K) of different *kharif* crops during 2023 and 2024

Treatment	Initial N-P-K (a)	N-P-K applied (b)	N-P-K uptake by crop (c)	Soil N-P-K status at harvest (d)	Apparent balance (a+b)-c= e	Net loss /gain (d-e)
2023						
Greengram	198.3-18-250	20-17.46-16.6	87.9-9.01-33.60	202.61-19.93-254.08	130.40 -26.45-233.00	72.21/ -6.53/21.08
Soybean	198.3-18-250	40-17.46-16.6	103.1-11.94- 42.96	207.55-21.79-259.17	135.20- 23.52-223.64	72.35 /-1.73/35.53
Foxtail millet	198.3-18-250	40-8.73-16.6	21.51- 6.50-28.29	194.56-16.88-238.70	216.79 -20.23-238.31	-22.23/-3.36/0.39
2024						
Greengram	206.4-20-272	20-17.46-16.6	95.2-10.68-40.88	209.33-21.79-273.5	131.20 -26.78-247.72	78.13/-4.99/25.82
Soybean	206.4-20-272	40-17.46-16.6	110.4-14.37-50.48	213.48-24.78-278.5	136.00 -23.09-238.12	77.48/1.69/40.33
Foxtail millet	206.4-20-272	40-8.73-16.6	24.7-8.31-34.44	200.85-19.30-256.9	221.70 -20.42-254.16	-20.85/-1.12/2.76

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