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Comparative Assessment of Panchakavya and DAP-Based Nutrient Management on Soil Properties, Yield Attributes and Grain Elemental Composition of Selected Pulse Crops in Tamil Nadu, India

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Abstract

Nutrient management practices can influence the mineral composition and safety of pulse grains. A three-year field study (2022–2024) was conducted in Ottapidaram, Thoothukudi, Tamil Nadu, to compare organic (Panchakavya) and conventional inorganic (DAP) nutrient-management practices in red cowpea, horse gram, black gram, and green gram. Grain elemental composition (25 elements) was determined using ICP-MS, while soil properties, germination, seed count, and 50-seed weight were evaluated annually. Grains from the DAP-treated plot generally showed lower concentrations of several potentially hazardous elements, including As, Cd, Cr, Mn, Mo, Pb, and Tl, along with lower K, Na, and Fe. Green gram from the organic plot showed markedly higher Cd levels, highlighting the importance of verifying the quality of organic inputs. A significant difference across the 25-element profile was observed for red cowpea, but not for the other crops. Overall, neither nutrient-management system was consistently superior in terms of grain safety or nutrient density. The findings emphasize the need for source verification of organic inputs and replicated studies to assess their effects on pulse grain quality and safety.

Introduction

Pulses are an essential component of the Indian food system, contributing significantly to dietary protein, fibre, and essential micronutrients, particularly iron, zinc, and folate. India is the world's largest producer and consumer of pulses, highlighting their importance in food and nutritional security. Major pulse crops, including black gram (*Vigna mungo*), green gram (*Vigna radiata*), cowpea (*Vigna unguiculata*), and horse gram (*Macrotyloma uniflorum*), are widely cultivated under rainfed conditions, particularly in the semi-arid regions of Tamil Nadu. In Thoothukudi district, these short-duration legumes are important components of dryland agricultural systems, where soil fertility and nutrient-management practices may influence crop productivity and grain nutritional quality.

Concerns over the long-term sustainability of intensive chemical fertilization, coupled with rising consumer demand for pesticide- and residue-free food, have renewed interest in traditional organic nutrient sources. Panchakavya, a fermented liquid preparation of five cattle-derived products (dung, urine, milk, curd, and ghee) blended with jaggery, banana, and other additives, is among the widely promoted organic biostimulants in South Indian natural-farming systems. A substantial body of field research has reported that Panchakavya foliar sprays improve growth, nodulation, yield attributes, and seed quality in black gram, green gram, lentil, and other legumes relative to unfertilized controls, and that in several trials they perform comparably with, or better than, inorganic NPK application (Kumar, 2011; Britto & Girija, 2007; Devi *et al.,* 2016; Aswal *et al.,* 2025).

The sustainability of intensive cropping systems is under increasing scrutiny due to declining soil fertility, over-dependence on chemical fertilizers, and stagnation in crop productivity (Kansanga *et al.,* 2019; Gollin *et al.,* 2021). Continuous application of inorganic fertilizers, although effective in increasing yields in the short term, has been associated with long-term soil degradation, nutrient imbalance, and reduced biological activity (Onte *et al.,* 2025). This trend has raised concerns over the future viability of such systems, as they have become increasingly reliant on costly external inputs. Therefore, the development of alternative nutrient-management strategies that maintain crop productivity while improving soil health is a critical need in modern agriculture (Onte *et al.,* 2025).

At the same time, diammonium phosphate (DAP) remains a widely used source of phosphorus for pulse cultivation in India owing to its high nutrient content (18% N, 46% P_2O_5) and ready availability. Phosphatic fertilizers manufactured from rock phosphate are a recognized, though variable, source of cadmium (Cd) and other trace-metal contaminants entering agricultural soils; the Cd content of commercial DAP depends heavily on the geological source of the parent rock phosphate (Mortvedt & Osborn, 1982; Niño-Savala *et al.,* 2019; Guo *et al.,* 2016). DAP manufactured from low-cadmium rock phosphate can carry a substantially lower Cd load than single superphosphate or unprocessed rock phosphate, and can even reduce the bioavailable fraction of soil Cd through phosphate-induced immobilization. Conversely, organic manures derived from cattle are not automatically free of heavy metals: feed additives, mineral licks, and regional soil or forage contamination can result in measurable Cd, Pb, As, Cu, and Zn residues in cattle dung, urine, and, by extension, in dung- and urine-based preparations such as Panchakavya (Nicholson *et al.,* 1999; Xiong *et al*., 2019; Cerit *et al.,* 2007).

Despite the popularity of Panchakavya-based natural farming in Tamil Nadu, few field studies have directly compared the elemental and heavy-metal profiles of pulse grain produced under organic versus DAP-based regimes using a sensitive multi-element technique such as inductively coupled plasma mass spectrometry (ICP-MS) across more than a single season. The present study reports a three-year (2022–2024) side-by-side field comparison at Ottapidaram, Tamil Nadu, in which an organic plot managed with Panchakavya and an adjacent inorganic plot managed with DAP were used to grow four common pulse crops. The specific objectives were to: (i) compare soil physicochemical fertility indicators between the two management regimes over three years; (ii) compare seed germination, seed count, and test weight of the four pulse crops; and (iii) quantify and compare, using ICP-MS, the concentrations of 25 elements macro-minerals, essential trace elements, and non-essential/toxic heavy metals in grain harvested from each regime in each year.

2. Materials and Methods

2.1 Study site and experimental layout

The field experiment was conducted at Ottapidaram, Thoothukudi district, Tamil Nadu, India, for three consecutive cropping years (2022 - 2024). Two adjacent agricultural field plots, Survey Nos. 67/1A and Survey No. 67/1B, were selected for the study. Plot 67/1A had been maintained under organic management for approximately 10 years on uncultivated land prior to the experiment and was designated as the organic (Panchakavya) plot, whereas plot 67/1B was managed under a conventional inorganic nutrient-management system using Diammonium phosphate(DAP) and was designated as the inorganic plot. The plots were approximately 200 m apart to minimize potential cross-contamination through spray drift, surface runoff, or shared irrigation. Land-use details were documented and verified by the local Village Administrative Officer. Before sowing, baseline soil samples were collected from both field plots and analysed at the Kovilpatti Soil Testing Laboratory. In the organic field plot, preliminary land preparation involved manual removal of weeds, and grass cover on 6 October 2022.

2.2 Crops and field plot geometry

The four crops Black gram, Green gram Red cowpea, and Horse gram, were carried forward for grain elemental analysis. Sub-plots of 2 m × 10 m were used for the initial one-cent (~40 m²) plant-selection layout, and the main field plots measured 12.5 m × 16.2 m for Black gram , green gram, and horse gram and 10.2 m × 20 m for cowpea, with a 1 m bunded pathway separating adjacent field plots.

2.3 Seed source and germination testing

Seeds of all four crops were procured from local village growers; the Black gram seed lot used was certified organic. Germination capacity was assessed using the tray method with four trays (one per crop, 100 seeds per tray) on 16 October 2022, under ambient conditions (day temperature 27 °C; rainfall was recorded on the sowing day). The germination percentages were 98% for Black gram, 90% for Green gram, 80% for Cowpea, and 55% for Horse gram,

2.4 Nutrient management treatments

The organic field plot received Panchakavya prepared from cow manure, cow urine, jaggery, pulse/millet flour and field soil, fermented in water and applied as a foliar spray at 20 days after sowing. No DAP or synthetic pesticide was used. The inorganic plot received DAP according to crop recommendations and a need-based pesticide spray. No organic amendment was applied.

2.5 Soil sampling and analysis

Composite soil samples (0–15 cm) were collected annually from both plots and analyzed for N, P, K, S, Fe, Zn, Mn, Cu, B, EC, pH and organic carbon using standard laboratory methods.

2.6 Yield attributes

At harvest, total seed number per field plot and 50-seed test weight were recorded for Black gram, Green gram, Cowpea and Horse gram.

2.7 Grain elemental analysis

Grain samples were analyzed by ICP-MS following acid digestion for 25 elements (Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, Sr, Ti, Tl and Zn). Results were expressed as ppm/100 g grain. One composite sample per crop × treatment × year was analyzed.

2.8 Statistical Analysis

Mean, standard deviation, and percentage difference between the organic and DAP treatments were calculated from the three annual observations. Differences across the 25-element panel were assessed using paired t-tests and Wilcoxon signed-rank tests for each crop ($n = 25$) and for all crops combined ($n = 100$). Analyses were performed using Python 3, with statistical significance set at $p < 0.05$.

Because each crop × treatment × year × element represented a single determination, the statistical analysis was considered a screening-level comparison rather than a replicated experimental analysis.

3. Results

3.1 Soil Physico-Chemical Properties (2022 to 2024)

Table 1 summarises the soil test results for both plots over the three study years. Soil pH remained more alkaline in the organic plot (8.3–8.6) than the DAP plot (6.7–7.2) throughout the study, and organic carbon declined over the three years in both plots but remained consistently higher in the organic plot in 2023 and 2024. Available potassium (K) was higher in the organic plot in two of the three years, while available phosphorus (P) was consistently, and often substantially, higher in the DAP plot, as expected given its direct phosphatic input.

Table 1. Soil physico-chemical properties of the organic (Panchakavya) and DAP-treated Plots, Ottapidaram 2022–2024.

Parameter	2022 Org.	2022 DAP	2023 Org.	2023 DAP	2024 Org.	2024 DAP
N (kg ha^{-1})	87	67	109	98	74	77
P (kg ha^{-1})	2.5	3	5	2	7.1	12.5
K (kg ha^{-1})	224	213	330	350	245	191
S (kg ha^{-1})	–	–	127.0	260.0	9.19	9.19
Fe (mg kg^{-1})	1.95	3.26	–	–	2.00	1.94
Zn (mg kg^{-1})	0.19	0.25	–	–	2.95	2.87
Mn (mg kg^{-1})	3.03	2.12	–	–	0.16	0.18
Cu (mg kg^{-1})	0.25	0.47	–	–	0.24	0.30
B (mg kg^{-1})	–	–	–	–	0.28	0.32
EC (dS m^{-1})	0.16	0.11	0.20	0.20	0.20	0.09
pH	8.3	6.7	8.6	7.20	8.6	7.2
O.C. (%)	–	–	1.38	1.01	0.39	0.12

Note: – indicates parameter not recorded in that year.

3.2 Seed count and test weight

Seed count per plot (Table 2) and 50-seed test weight (Table 3) were generally higher in the organic plot than in the DAP plot for Black gram , Green gram and cowpea across the three years, whereas horse gram showed smaller and less consistent differences

Table 2. Seed count per plot, organic (Panchakavya) vs. DAP plots, 2022–2024.

Crop	2022 Org.	2022 DAP	2023 Org.	2023 DAP	2024 Org.	2024 DAP
Black gram	250	175	252	140	336	252

Crop	2022 Org.	2022 DAP	2023 Org.	2023 DAP	2024 Org.	2024 DAP
Green gram	452	350	640	600	440	440
Cowpea	100	56	110	82	125	101
Horse gram	50	40	70	40	70	30

Table 3. Fifty-seed test weight (g), organic (Panchakavya) vs. DAP plots, 2022–2024.

Crop	2022 Org.	2022 DAP	2023 Org.	2023 DAP	2024 Org.	2024 DAP
Black gram	3	2.90	3	2.85	3	2.85
Green gram	2	1.90	2	1.90	2	1.95
Cowpea	4	3.80	4	3.85	4	3.90
Horse gram	1	0.95	1	0.90	1	0.95

3.3 Grain elemental profile by ICP-MS

The three-year mean ± SD concentrations of all 25 elements (ppm per 100 g) for the four pulse crops are presented in Tables 4–7. Across the four crops, grains from the DAP-treated plot showed lower mean concentrations of arsenic (−73%), cadmium (−100%), chromium (−68%), manganese (−91%), molybdenum (−97%), lead (−68%), thallium (−75%), sodium (−45%), potassium (−18%), and iron (−31%) than grains from the organic plot. In contrast, grains from the DAP-treated plot showed higher mean concentrations of silver (+30%), strontium (+45%), calcium (+15%), magnesium (+14%), titanium (+16%), and zinc (+25%). Selenium and cobalt were also higher in the DAP-treated grain, although their concentrations in the organic samples were generally close to the quantification limit.

The large difference observed for cadmium was mainly associated with the unusually high values recorded in organic green gram, as discussed in Section 3.4.

Paired comparison of the three-year mean concentrations across the 25-element panel showed a statistically significant difference between the organic and DAP-treated profiles for red cowpea (paired $t = -2.31$, $p = 0.030$; Wilcoxon signed-rank $p = 0.003$), but not for horse gram ($p = 0.97$ and 0.63), black gram ($p = 0.47$ and 0.79), or green gram ($p = 0.86$ and

0.35). When all four crops were pooled (n = 100 element–crop pairs), the overall difference was not statistically significant (paired t = −1.26, p = 0.21; Wilcoxon signed-rank p = 0.063). Overall, the observed elemental differences were predominantly crop- and element-specific rather than consistently associated with either nutrient-management regime.

Table 4. Mean ± SD elemental concentration (ppm/100 g, 3-year data, 2022–2024) in Red Cowpea (Vigna unguiculata) grain: organic (Panchakavya) vs. DAP plot.

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Ag	11.2	0.95	12.37	0.85	+10.4
Al	5823.33	621.66	1717.63	2198.64	-70.5
As	570.67	13.32	136.98	12.71	-76
Ba	61.63	3.28	43.27	1.53	-29.8
Be	-0.87	0.06	-1.23	0.15	-42.3
Ca	44663	1454.57	28565.99	9107.41	-36
Cd	-1.32	0.06	-3.27	0.05	-147.1
Co	-0.5	0	-1.32	0.16	-163.3
Cr	43.9	1.37	15.3	1.1	-65.1
Cu	58.2	2.11	44.9	0.7	-22.9
Fe	53926.67	2501.92	58407.5	43097.4	+8.3
K	80765.67	4043.85	73555.67	2203.18	-8.9
Mg	51465.67	8594.16	47082.8	34906.14	-8.5
Mn	30399.73	37364.58	1695.9	2103.75	-94.4
Mo	6.34	0.73	0.5	0.53	-92.1
Na	30072.33	3833.81	13901.67	1270.21	-53.8
Ni	-2.14	0.03	-1.58	0.33	+26.3
Pb	5.87	0.64	4.63	0.15	-21
Sb	-10.55	0.93	-11.73	0.61	-11.2

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Se	-1.87	0.06	-1.77	0.55	+5.4
Sn	61.57	5	44.53	0.59	-27.7
Sr	767.93	8.08	753.63	29.92	-1.9
Ti	21213.97	26789.72	4172.5	57.32	-80.3
Tl	55.43	12.9	66	0.56	+19.1
Zn	46803.33	5033.37	47425	4445.38	+1.3

Table 5. Mean ± SD elemental concentration (ppm/100 g, 3-year data, 2022–2024) in Horse Gram (Macrotyloma uniflorum) grain: organic (Panchakavya) vs. DAP plot.

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Ag	27.93	4.93	23.3	0.92	-16.6
Al	516.13	55.3	558.07	30.17	+8.1
As	450.7	28.77	153.67	10.52	-65.9
Ba	47.13	7.03	49.03	5.27	+4
Be	24.03	1.52	-2.4	0.2	-110
Ca	17671.03	3292.79	44921.59	16191.8	+154.2
Cd	-1.63	0.06	-3.43	0.32	-109.8
Co	-1.57	0.29	-1.5	0.07	+4.5
Cr	-1.27	0.32	15.93	1.55	+1357.9
Cu	44.2	1.46	45.17	1	+2.2
Fe	58618.33	6263.98	26663.63	34346.89	-54.5
K	63061	9631.57	47207	5505.68	-25.1
Mg	61752.67	6627.37	75843.17	2139.02	+22.8
Mn	2085.73	2736.97	584.93	67.27	-72

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Mo	1.72	0.37	0.44	0.62	-74.4
Na	40075.33	24554.61	13074.67	11101.5	-67.4
Ni	-2.95	0.6	-1.62	0.42	+45.1
Pb	5.21	0.7	4.13	0.41	-20.7
Sb	-11.33	0.95	-14.12	0.48	-24.6
Se	-2.93	0.58	-1.67	0.11	+43
Sn	47.33	6.86	56.17	10.05	+18.7
Sr	545.3	18.47	450	19.63	-17.5
Ti	572.77	50.17	4683.63	530.25	+717.7
Tl	809.57	73.55	69.63	6.49	-91.4
Zn	25546.67	864.82	55167	7073.36	+115.9

Table 6. Mean ± SD elemental concentration (ppm/100 g, 3-year data, 2022–2024) in Black gram (Vigna mungo) grain: organic (Panchakavya) vs. DAP plot.

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Ag	24.4	1.06	40.97	6.4	+67.9
Al	424.1	2.34	3008.63	3913.89	+609.4
As	454.37	10.3	147.53	7.52	-67.5
Ba	84.87	3.1	80.47	6.77	-5.2
Be	-22.31	29.35	-3	0.53	+86.6
Ca	44487	1679.79	27863.02	21346.72	-37.4
Cd	-39.09	52.06	-3.07	0.68	+92.2
Co	-5.56	0.55	-1.29	0.11	+76.7
Cr	15.57	0.55	17.33	1.68	+11.3

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Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Cu	58.23	7.17	44.67	0.86	-23.3
Fe	25441	33624.04	20965.4	27254.34	-17.6
K	45799	5497.88	55328.13	42752.62	+20.8
Mg	47013.67	6131.41	52654.67	41056.84	+12
Mn	17774.63	30022.82	2146.53	2700.64	-87.9
Mo	0.5	0.45	0.75	0.69	+49.7
Na	10437.33	13015.83	10323.33	5350.47	-1.1
Ni	2.27	0.06	-5.19	6.41	-329.1
Pb	4.45	0.21	4.51	0.59	+1.3
Sb	-54.03	1.5	-17.4	0.84	+67.8
Se	-16.97	4.87	-1.5	0.1	+91.2
Sn	29.53	88.64	48.97	5.45	+65.8
Sr	501.77	20.67	1662.73	2156.64	+231.4
Ti	483.63	35.14	17147.6	22093.06	+3445.6
Tl	161.25	227.49	52.07	5.6	-67.7
Zn	47126	4970.81	16831.67	14315.86	-64.3

Table 7. Mean ± SD elemental concentration (ppm/100 g, 3-year data, 2022–2024) in Green gram (Vigna radiata) grain: organic (Panchakavya) vs. DAP plot.

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Ag	33.13	0.5	49.47	5.35	+49.3
Al	12921.67	16682.79	14644.23	24139.45	+13.3
As	-27.5	5.22	-42.13	2.57	-53.2
Ba	6.87	28.81	57	7.88	+730.1

Element	Org. mean	Org. SD	DAP mean	DAP SD	% diff (DAP vs Org.)
Be	-0.63	0.25	-0.77	0.45	-21.1
Ca	25490	1714.73	50381.93	38094.99	+97.7
Cd	17409	5674.25	-3.37	0.2	-100 †
Co	-22.8	0.69	-2.83	0.51	+87.6
Cr	127.03	1.4	10.84	0.53	-91.5
Cu	5.1	0.37	2.97	0.56	-41.7
Fe	45287	6129.05	20729.33	7370.34	-54.2
K	46685	4881.71	16761	4516.38	-64.1
Mg	57793	4749.25	73143	14826.02	+26.6
Mn	391.23	56.37	324.37	28.05	-17.1
Mo	165.5	61.56	4.34	0.15	-97.4
Na	49803	7801.69	35104.03	26975.14	-29.5
Ni	4.08	0.39	2.64	0.59	-35.3
Pb	456.03	59.12	137.1	101.92	-69.9
Sb	-12.4	1.05	-11.8	0.72	+4.8
Se	5.88	0.58	4.56	0.65	-22.5
Sn	6.55	0.49	5.29	0.11	-19.2
Sr	468.17	72.95	435.9	17.08	-6.9
Ti	566.3	65.78	448.23	22.77	-20.8
Tl	52.3	5.63	81.13	6.24	+55.1
Zn	14568.67	24243.86	48512.07	6533.73	+233

Section 3.4 and 4.4: the organic-field plot cadmium value for Green gram is a consistent, order-of-magnitude outlier relative to all other Cd readings in the dataset and is flagged for confirmatory re-analysis.

3.4 The Green gram cadmium result

Cadmium concentrations in Green gram grain from the organic (Panchakavya) 2022, 2023 and 2024, respectively, indicating an apparent increase over the three-year period. In comparison, the corresponding Diammonium phosphate(DAP) field plot values were −3.26,3.25 and −3.60 ppm/100 g, indicating concentrations at or below the quantification limit. No other crop–treatment combination showed Cd concentrations of a similar magnitude. As each annual value was obtained from a single composite sample analyzed once, these results should not be considered a definitive food-safety finding. Nevertheless, the repeated detection across three consecutive years warrants further investigation and independent confirmatory analysis using replicated sampling, duplicate digestion and certified reference materials before any definitive conclusion is drawn.

4. Discussion

4.1 Soil fertility and yield attributes

The higher soil organic carbon and comparable or higher available potassium observed in the organic field plot may be associated with the continued use of organic inputs and their contribution to soil organic matter and nutrient cycling. In contrast, the higher available phosphorus in the Diammonium phosphate (DAP) treated plot is consistent with the direct contribution of phosphorus through Diammonium phosphate (DAP) application. The generally higher seed count and test weight observed in the organic field plot for Black gram, Green gram and Cowpea are broadly comparable with previous reports showing favorable yield responses to Panchagavya-based nutrient management in pulse crops (Ali *et al*., 2011; Britto & Girija, 2007; Kumar, 2011; Aswal *et al.,* 2024). However, these comparisons should be interpreted cautiously because the present study involved a single organic and a single Diammonium phosphate (DAP) treated plot without within-treatment field replication. Therefore, the observed differences describe the performance of the two plots during the study period rather than providing definitive evidence of treatment effects.

4.2 Macro-Mineral Content of Grain

Calcium, magnesium, zinc, strontium and titanium showed higher mean concentrations in Diammonium phosphate (DAP) investigated grain, whereas potassium, sodium and iron were higher in organically managed grain. Thus, neither nutrient-management regime showed a consistent pattern of higher elemental concentrations across the overall mineral profile. The observed differences varied among elements and crops, with a statistically significant overall difference detected only for cowpea in the paired analysis. Such crop- and element-specific variation may reflect differences in nutrient uptake and partitioning associated with crop species, soil properties and interactions among nutrients. However, given the absence of within-treatment field replication in the present study, these observations should be interpreted as descriptive differences rather than definitive treatment effects

4.3 Toxic and Non-Essential Elements

Across the four crops, arsenic, chromium, lead, thallium, manganese and molybdenum showed lower mean concentrations in Diammonium phosphate(DAP) treated grain than in organically managed grain. This observation indicates that the elemental response was not uniformly higher under inorganic fertilization. The behavior of trace elements in agricultural systems can vary considerably with fertilizer composition, soil properties, source materials and their interactions with plant nutrient uptake. In particular, the cadmium content of phosphate fertilizers can vary substantially depending on the geological source of the phosphate rock, and the effects of phosphate application on Cd availability may therefore differ among fertilizer sources and soil conditions (Mortvedt & Osborn, 1982; Niño-Savala *et al*., 2019). Organic inputs derived from cattle are also not necessarily free from trace metals. Previous studies have reported detectable concentrations of Cd, Pb, Cu and Zn in cattle feed, manure and related organic materials, with levels influenced by feed composition, mineral supplementation, soil conditions and environmental sources (Nicholson *et al*., 1999; Cerit *et al*., 2007; Xiong *et al*., 2012). In the present study, the generally lower concentrations of several trace elements in DAP-treated grain, together with the unusually high Cd concentrations observed in organic green gram, highlight the importance of the source and composition of nutrient inputs. However, because the present study involved a single plot per treatment and the Cd result was based on a single composite sample per year, these findings should be interpreted cautiously and should not be generalized to organic or inorganic farming systems without replicated and source-verified studies.

4.4 Limitations

This study has four principal limitations that should be considered when interpreting the findings. First, the comparison involved a single organic field plot and a single diammonium phosphate (DAP)-treated field plot rather than a randomized, replicated field design. Therefore, plot-level differences unrelated to nutrient management, including inherent soil heterogeneity and the long-term management history of Plot 67/1A, cannot be statistically separated from potential treatment effects.

Second, each ICP-MS elemental value represents a single composite-sample determination for each crop, treatment, and year. Thus, the reported standard deviations represent year-to-year variation only, and no independent field or analytical replicate error term was available. Accordingly, the paired statistical analyses should be interpreted as exploratory, screening-level comparisons rather than definitive tests of treatment effects.

Third, several elements were detected at or near the practical limit of quantification, resulting in negative background-subtracted values for some observations. Such values should be interpreted as concentrations at or below the quantification limit, and small differences involving these elements should therefore be interpreted cautiously.

Fourth, the unusually high and consistent cadmium concentrations observed in organic green gram across all three years require independent confirmation. Because these measurements were based on single composite samples without analytical replication or certified reference-material verification, the Cd findings should be regarded as preliminary and should not be considered conclusive until confirmed by replicate digestion, independent analysis, and appropriate reference-material validation.

5. Conclusion

Over three years, neither organic nor diammonium phosphate (DAP) management produced a uniformly higher grain elemental profile across the four pulse crops. The organic plot showed relatively higher soil organic carbon, potassium, seed count, and test weight, whereas the DAP-treated plot showed higher available phosphorus. Elemental responses were crop- and element-specific, with a statistically significant difference in the 25-element profile observed only for red cowpea. The unusually high Cd concentrations observed in organic green gram require confirmatory analysis. Future studies should use replicated field trials, analytical replicates, and certified reference materials to validate and further evaluate these findings.

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