

Spatial Variability and Site-specific Integrated Nutrient Management Practices for Maize Production in the Bankanahalli Micro-watershed, Karnataka

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ABSTRACT

The present study was conducted in the Bankanahalli micro-watershed of the Dudda sub-watershed, Mandya district, Karnataka, covering an area of 489 ha, to evaluate soil nutrient variability and develop Site-Specific Nutrient Management (SSNM) strategies for sustainable maize production. A detailed soil survey was carried out using Quick Bird satellite imagery (0.5 m resolution) and a grid sampling technique (320 m × 320 m), from which 45 surface soil samples (0-15 cm) were analyzed for available nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O). The spatial variability of soil nutrients was quantified using semivariogram models and ordinary kriging interpolation in ArcGIS 10.5 to generate thematic fertility maps. Nitrogen availability ranged from 120.06-564.93 kg ha⁻¹, phosphorus from 16.42-84.17 kg ha⁻¹ and potassium from 24.24-236.88 kg ha⁻¹, showing distinct fertility gradients across the watershed. Based on these maps, a field experiment was conducted with 12 treatments in a randomized block design (RCBD) to assess the influence of various nutrient management strategies like UAS package of practices, LRI based NMP-I and NMP-II, green manuring (Sunhemp), mulching and intercropping with green gram on maize growth, yield and economics. Results revealed that T₁₁ (green manuring with Sunhemp followed by maize + mulching under NMP-II) recorded the highest plant height (218.53 cm), leaf area index (3.90), kernel yield (8660.79 kg ha⁻¹), stover yield (9177.16 kg ha⁻¹) and total biomass (23,074.24 kg ha⁻¹). Economic analysis showed the highest net return (Rs.155,462 ha⁻¹) and B:C ratio (3.57) with T₇: Maize + Green gram intercrop with T₃. The study clearly establishes that spatial nutrient mapping combined with integrated nutrient management practices significantly enhances crop productivity, soil fertility and profitability, offering a viable framework for precision nutrient management and sustainable agriculture in semi-arid micro-watersheds.

Keywords : Geostatistical analysis, Maize, Micro-watershed, Site-specific nutrient management, Spatial variability

LAND and soil are the vital natural resources for the survival of life on the earth. The natural resources assessment is pre-requisite for the assessment of productivity of land and sustainability of the ecosystem. In the era of climate variability, soil degradation and resource-intensive agriculture, for achieving sustainable crop productivity while

maintaining soil health is a significant challenge. The declining trend in soil fertility, coupled with imbalanced nutrient application, has made it imperative to adopt more site-specific and resource-efficient strategies. The, nutrient management becomes a cornerstone of sustainable agriculture, as it directly influences both the physical condition

of the soil and the yield potential of crops (Shukla *et al.*, 2020).

The Bankanahalli micro-watershed, situated in Karnataka, represents a typical semi-arid agro-ecological region with undulating terrain and varying soil types. Micro-watersheds serve as ideal units for implementing location-specific interventions. Nutrient variability within a micro-watershed is often high due to differences in soil type, slope and land use. Therefore, site-specific nutrient management, aided by LRI data is particularly crucial in such landscapes (Patil *et al.*, 2022). GIS is a powerful tool for collecting, storing, transforming and displaying spatial data from the real world. It can be used for producing a soil fertility map of an area, which will help in formulating balanced fertilizer recommendations. Therefore, to understand the soil’s spatial and temporal variability, physico-chemical properties and geostatistics for specific applications, remote sensing and GIS are the best tools.

The objective of nutrient management practices is to apply the ‘4R’ nutrient stewardship principle (right source, right rate, right time and right place) to minimize nutrient losses and enhance nutrient-use efficiency (Ladha *et al.*, 2020). Practices such as green manuring and mulching are particularly effective in restoring soil structure and microbial diversity. For instance, incorporation of sunhemp (*Crotalaria juncea*) as green manure contributes organic matter and biologically fixed nitrogen, significantly enhancing post-harvest soil quality (Kumar *et al.*, 2023).

MATERIAL AND METHODS

Study Area Description

The study area of Bankanahalli micro-watershed (Dudda sub-watershed), located between 12°35’ 6.863" to 12°36’56.68" N and 76° 45’ 13.14" to 76° 46’ 23.722" E with an area of 489 ha situated in Mandya taluk, Mandya district of Karnataka, India (Fig. 1). The major cropping sequence

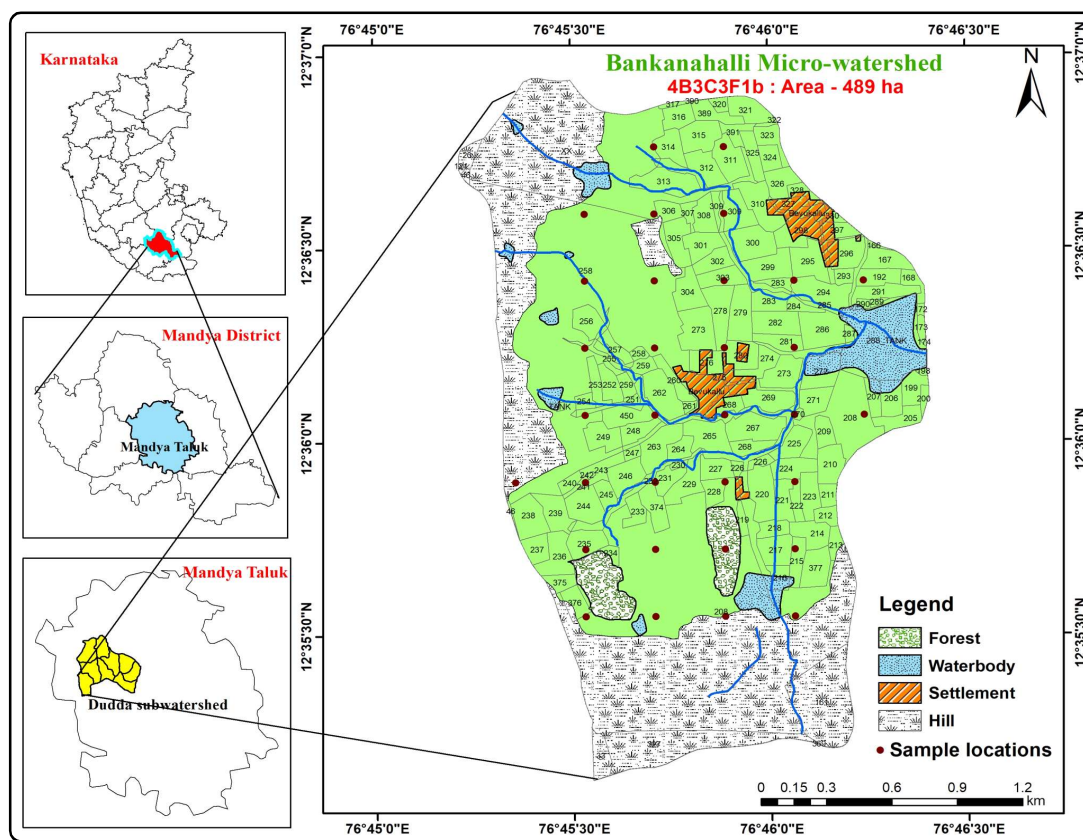


Fig. 1 : Location map of study area

focused in this area is cereals followed by pulses. The micro-watershed's primary landforms are midlands and undulating uplands. The soils, are sandy loam to sandy clay loam. The watershed is typical of Karnataka's southern dry zone (Zone 6), which has a semi-arid tropical climate and modest rainfall (633.91 mm), mainly from the southwest monsoon with a 120-day LGP.

Initial Status of Soil Properties

In order to analyse the soil properties, a detailed soil survey of Bankanahalli micro-watershed was conducted using quick bird satellite imagery with 0.5m spatial resolution and overlay on cadastral maps with a scale of 1:7920. The grid sampling technique was applied at an interval of 320 m x 320 m and collected 45 surface soil samples. The collected samples were processed and analysed by adopting standard procedures (Liu *et al.*, 2006).

Spatial Variability Assessment and Generation of Thematic Maps

The spatial variability of soil nutrients (N, P₂O₅ and K₂O) was assessed using a geostatistical approach. Experimental semivariogram models were developed to quantify the spatial dependence and suitable theoretical models were fitted based on the lowest RMSE, nugget, P- sill and major range.

The best fitted semivariogram models were then used for ordinary kriging interpolation in ArcGIS 10.5 to generate thematic maps. These thematic maps provided a visual representation of nutrient distribution and delineated zones of very low, low, medium, high and very high fertility zones based on nutrient status of the area, which formed the basis for site-specific nutrient management.

Field Experiment on Nutrient Management Strategies

Within the micro-watershed, one representative farmer's field was identified to capture small-scale spatial variability of soil fertility. The field was selected based on criteria such as soil type, cropping history, topography and accessibility. This

field was assumed to represent the variability pattern of the micro-watershed due to its central location and mixed soil fertility status.

A systematic soil sampling was conducted in the selected field. Surface soil samples (0-15 cm) were collected and each sample was air-dried, sieved (2 mm) and analyzed in the laboratory for Available nitrogen (Alkaline KMnO₄ (Subbiah and Asija, 1956)), Available phosphorus (Olsen *et al.*, 1954), Available potassium (Hanway and Heidel, 1952).

With three replications and twelve treatments, the experiment was set up using a randomized block design (RCBD). The treatments included: T₁: UAS Package of practices, T₂: LRI based NMP-I *i.e.* L, M, H approach, T₃: LRI based NMP-II *i.e.* VL, L, M, H, VH approach, T₄: GM (Sunhemp) *fb* Maize with T₂, T₅: GM (Sunhemp) *fb* Maize with T₃, T₆: Maize + Green gram intercrop with T₂, T₇: Maize + Green gram intercrop with T₃, T₈: Maize + mulching (Green leaf/crop residue) with T₂, T₉: Maize + mulching (Green leaf/crop residue) with T₃, T₁₀: GM (Sunhemp) *fb* Maize + mulching (Green leaf/crop residue) with T₂, T₁₁: GM (Sunhemp) *fb* Maize + mulching (Green leaf/crop residue) with T₃, T₁₂: Absolute control.

Here, fertilizers were applied based on nutrient categories based on the soil nutrient status by taking into consideration threshold values listed in Table 1, as indicated by the Nutrient Management Plan (NMP-I & II), which indicates the L, M, H (Low - High) approach and the VL, L, M, H, VH (Very low - Very high) approach, respectively.

To evaluate best nutrient management plan for crop productivity, Growth parameters like plant height, number of leaves per plant, leaf area and leaf area index, total dry matter production were computed. Yield and economics were recorded after harvest.

RESULTS AND DISCUSSION

Spatial Variability of Soil Properties in Bankanahalli Micro-Watershed

Spatial variability maps were generated using ordinary kriging with semivariogram modelling to

TABLE 1
Thresholds for categorization of nutrients and Fertilizer requirement multiplication factors for different nutrient availability levels

Nutrient	Very Low	Low	Medium	High	Very High
Nitrogen(N (Kg ha ⁻¹))	<140	140-280	280-560	560-700	>700
Phosphorus (P ₂ O ₅ , (Kg ha ⁻¹))	<11.45	11.45-22.90	22.91-57.25	57.26-91.60	>91.60
Potassium(K ₂ O, (Kg ha ⁻¹))	<72.3	72.3-144.6	144.7-337.4	337.5-674.8	>674.8
Multiplication factors fertilizer recommendation under different nutrient availability levels (N, P ₂ O ₅ , K ₂ O)	RDF × 1.67	RDF × 1.33	RDF × 1.00	RDF × 0.67	RDF × 0.33

(Source : DSS for crop based nutrient management and soil health, Sujala-III, Watershed Development Department, GoK, Bengaluru)

visualize the distribution of soil nutrients in the Bankanahalli micro-watershed. The maps categorized soil nutrients into distinct fertility zones ranging from low to high, thereby enabling the identification of target areas for site-specific nutrient management.

Spatial Distribution of Available Soil Nutrients (N, P₂O₅ and K₂O)

The spatial distribution of available nitrogen (kg ha⁻¹) in the soils of the Bankanahalli micro-watershed (Fig. 2) represents that, nitrogen availability varies widely from 120.06 to 564.93 kg ha⁻¹ and has been grouped into three fertility classes: 120.06-264.86 (shown in red), 264.87-378.26 (shown in yellow) and 378.27-564.93, (shown in green). The northern and north-eastern portions of the watershed are dominated by the red zone, indicating low nitrogen status and suggesting severe nutrient deficiency that could limit crop growth unless supplemented with fertilizers or organic manures. The central belt of the watershed mainly falls under the yellow zone, representing medium nitrogen levels, where moderate fertilizer application may be required to sustain productivity. In contrast, the southern and southwestern regions are covered predominantly in green, reflecting relatively medium to high nitrogen content in the soil, which is favourable for crop production with lesser external nitrogen inputs. This indicates that while some regions require nitrogen supplementation, others need judicious application to prevent nutrient

imbalance and losses (Chaudhari *et al.*, 2019; Ravikumar *et al.*, 2021 and Priya *et al.*, 2022).

Spatial distribution of soil phosphorus levels were represented in Fig. 3 and they are categorized into three concentration ranges. The phosphorus concentration is divided into three color-coded classes: red (16.42-31.92) represents areas with low phosphorus content, indicating nutrient-poor soils that may require fertilizer supplementation for crop growth; yellow (31.93-46.06) represents moderate phosphorus levels, suggesting soils that can moderately support plant productivity without major amendments and green (46.07-84.17) indicates high phosphorus availability, signifying nutrient-rich soils that can sustain vegetation and agriculture effectively without additional phosphorus input. Overall, phosphorus showed strong spatial variability, with low to moderate availability in uplands and very high levels in southern cultivated fields, necessitating rational input management to avoid further imbalance (Chaudhari *et al.*, 2019).

Spatial distribution of soil potassium (K) content (Fig. 4), categorized into three concentration ranges. The potassium concentration is represented by three color classes: red (24.24-104.37) indicates low potassium levels, suggesting soils that are nutrient-deficient and may hinder crop growth due to inadequate potassium availability; yellow (104.38-140.64) represents moderate potassium

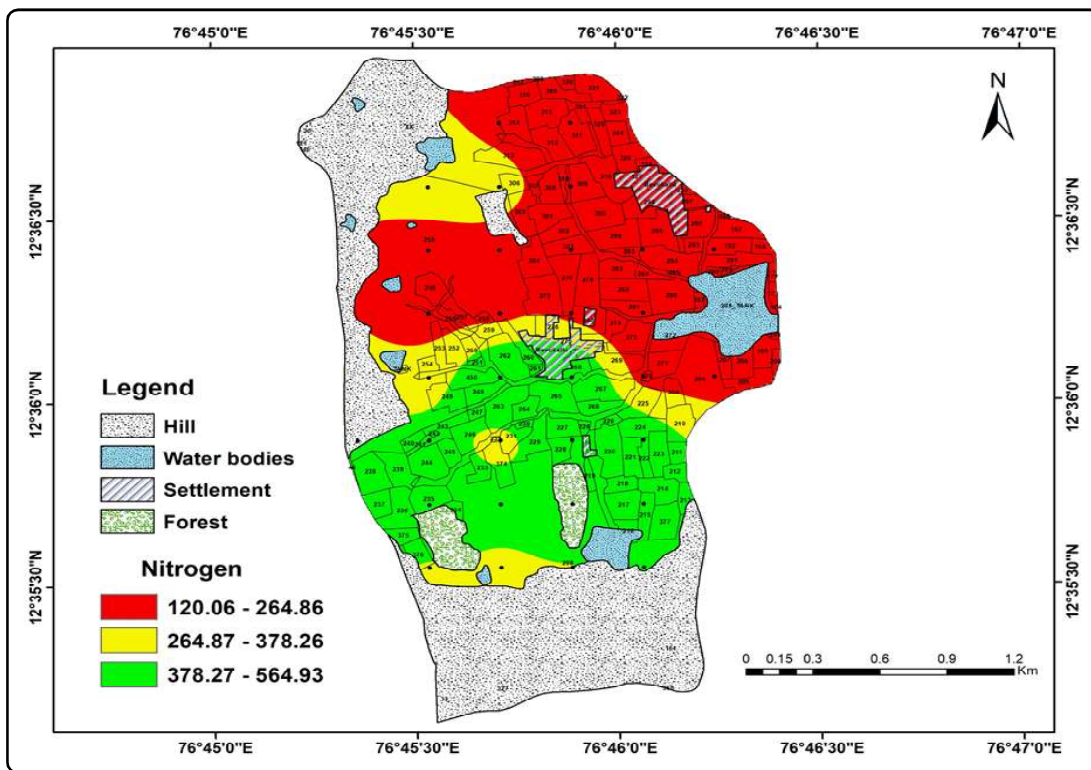


Fig. 2: Distribution of nitrogen in Bankanahalli micro-watershed

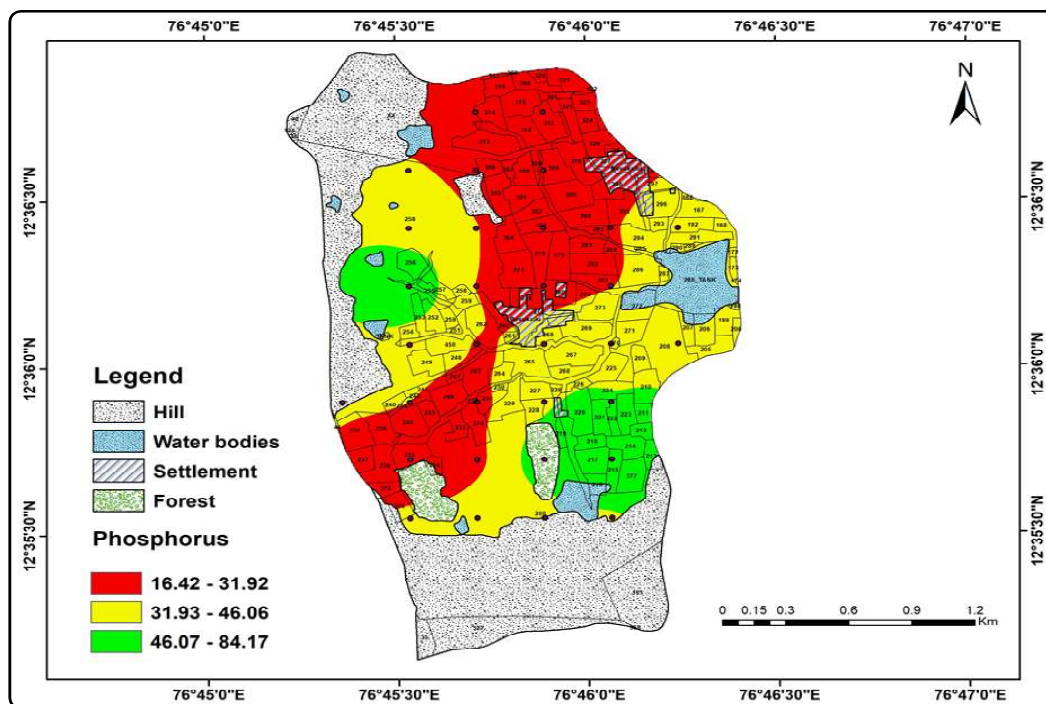


Fig. 3: Distribution of phosphorus in Bankanahalli micro-watershed

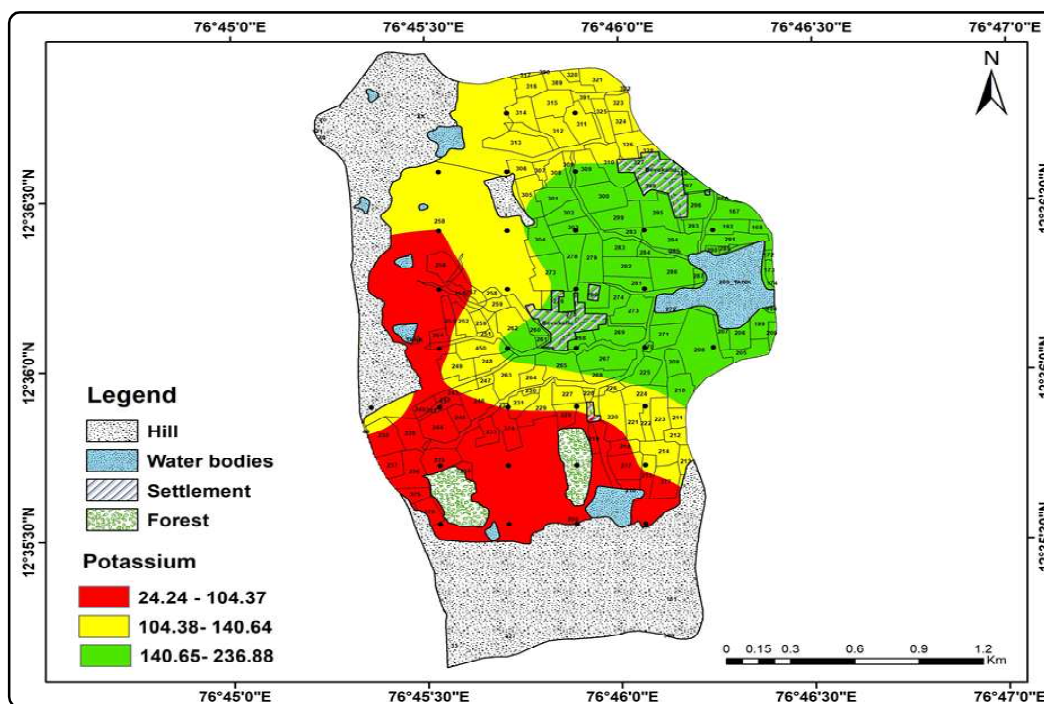


Fig. 4: Distribution of potassium in Bankanahalli micro-watershed

levels, which can support average agricultural productivity but may still benefit from periodic fertilization and green (140.65-236.88) shows high potassium content, indicating fertile soils with sufficient potassium to promote strong plant root development and overall vigor. The map reveals that southern and southwestern regions (in red) have lower potassium levels, possibly due to erosion or over-cultivation, while eastern and central areas (in green) show higher fertility, often coinciding with forested and low-lying zones that favor nutrient accumulation and retention (Priya *et al.*, 2022).

Field Experiment Results of Different Nutrient Management Plans

Growth Parameters

Plant Height

The data revealed significant variation in maize plant height under different nutrient management practices at all growth stages (Table 2). Among the treatments, T₁₁ (green manuring with sunhemp *fb* maize + mulching with T₃) recorded the maximum plant height at 30 DAS (59.18 cm), 60 DAS (195.82 cm),

90 DAS (216.75 cm) and at harvest (218.53 cm). This was on par with T₁₀ (green manuring with sunhemp *fb* maize + mulching with T₂), which exhibited plant height of 58.55, 195.35, 212.16 and 214.86 cm at the respective stages, but it was consistently lower than T₁₁.

Comparatively, T₅ (green manuring *fb* Maize with T₃) showed significant improvement in plant height (56.17, 189.65, 205.32 and 207.54 cm) compared to the other treatments and its performance was statistically on par with T₁₀ and T₁₁ across all stages. Similarly, T₄ (green manuring *fb* Maize with T₂) followed the same trend, recording 55.12 cm, 188.12 cm, 202.67 cm and 205.02 cm at 30, 60, 90 DAS and harvest, respectively. Green manuring with sunhemp has been shown to improve soil organic matter, enhance microbial activity and supply a steady release of nitrogen, thereby supporting sustained plant height and dry matter accumulation in maize (Pattanaik *et al.*, 2020).

Number of Leaves

The data showed significant variation in the number of leaves of maize across different nutrient

TABLE 2
Effect of different nutrient management practices on plant height (cm) of maize
in Bankanahalli micro-watershed

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	45.60	42.49	44.04	155.03	151.91	153.47	169.87	163.49	166.68	171.03	164.65	167.84
T ₂	47.10	44.71	45.91	160.15	157.69	158.92	173.00	168.64	170.82	174.54	169.29	171.91
T ₃	48.25	45.86	47.05	164.04	161.58	162.81	175.23	170.87	173.05	176.23	171.42	173.83
T ₄	53.68	56.57	55.12	186.80	189.44	188.12	201.09	204.25	202.67	203.45	206.59	205.02
T ₅	54.72	57.61	56.17	188.33	190.97	189.65	203.74	206.90	205.32	205.97	209.11	207.54
T ₆	48.84	50.92	49.88	166.05	168.29	167.17	179.33	181.81	180.57	180.73	183.38	182.06
T ₇	49.96	52.04	51.00	169.87	172.11	170.99	182.60	185.08	183.84	183.73	186.38	185.06
T ₈	51.93	54.61	53.27	180.77	183.21	181.99	194.14	197.13	195.63	195.67	198.68	197.17
T ₉	52.24	54.92	53.58	181.00	183.44	182.22	195.98	198.97	197.47	197.47	200.48	198.97
T ₁₀	57.00	60.11	58.55	193.78	196.92	195.35	210.38	213.94	212.16	213.03	216.69	214.86
T ₁₁	57.63	60.74	59.18	194.25	197.39	195.82	214.97	218.53	216.75	216.70	220.36	218.53
T ₁₂	33.99	32.01	33.00	109.57	103.52	106.54	116.93	105.32	111.13	117.88	106.83	112.36
S.Em.±	1.79	1.79	1.79	5.32	5.30	5.31	7.61	7.80	7.69	7.54	7.51	7.52
C.D. (p=0.05)	5.26	5.26	5.26	15.61	15.54	15.56	22.32	22.89	22.56	22.12	22.02	22.07

TABLE 3
Effect of different nutrient management practices on number of leaves of maize
in Bankanahalli micro-watershed

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	7.53	7.13	7.33	10.20	9.80	10.00	10.40	10.00	10.20	8.33	7.72	8.02
T ₂	7.93	7.73	7.83	10.73	10.39	10.56	10.93	10.59	10.76	9.13	8.74	8.94
T ₃	8.00	7.80	7.90	11.07	10.73	10.90	11.27	10.93	11.10	9.47	9.07	9.27
T ₄	8.73	8.97	8.85	13.20	13.60	13.40	13.40	13.80	13.60	12.20	13.20	12.70
T ₅	8.80	9.04	8.92	13.27	13.67	13.47	13.47	13.87	13.67	12.27	13.29	12.78
T ₆	8.33	8.51	8.42	12.33	12.53	12.43	12.53	12.73	12.63	10.93	11.54	11.24
T ₇	8.40	8.58	8.49	12.40	12.60	12.50	12.60	12.80	12.70	11.00	11.62	11.31
T ₈	8.47	8.69	8.58	13.00	13.20	13.10	13.20	13.40	13.30	11.87	12.93	12.40
T ₉	8.60	8.82	8.71	13.07	13.27	13.17	13.27	13.47	13.37	12.00	13.00	12.50
T ₁₀	9.13	9.37	9.25	13.80	14.20	14.00	14.00	14.40	14.20	13.20	14.36	13.78
T ₁₁	9.20	9.44	9.32	14.20	14.60	14.40	14.40	14.80	14.60	13.60	14.77	14.18
T ₁₂	7.13	6.53	6.83	9.13	8.40	8.77	9.33	8.60	8.97	6.93	6.13	6.53
S.Em.±	0.31	0.31	0.31	0.59	0.58	0.58	0.59	0.58	0.58	0.62	0.65	0.64
C.D. (p=0.05)	0.91	0.91	0.91	1.72	1.70	1.71	1.72	1.70	1.71	1.82	1.92	1.87

management practices at all growth stages (Table 3). Among the treatments, T₁₁ (green manuring with sunhemp *fb* maize + mulching with T₃) recorded the maximum number of leaves at 30 DAS (9.32), 60 DAS (14.40), 90 DAS (14.60) and at harvest (14.18). This was closely followed by T₁₀ (green manuring with sunhemp *fb* maize + mulching with T₂), which recorded 9.25, 14.00, 14.20 and 13.78 leaves, respectively, across the corresponding stages.

Comparatively, T₅ (green manuring *fb* maize with T₃) recorded significantly higher number of leaves (8.92, 13.47, 13.67 and 12.78), followed by T₄ (green manuring *fb* maize with T₂) with 8.85, 13.40, 13.60 and 12.70 leaves at 30, 60, 90 DAS and harvest, respectively. Notably, the performance of T₅ and T₅ remained on par with T₁₀ and T₁₁, indicating that green manuring alone provided sufficient organic matter and nutrients to support optimum leaf production. The higher leaf production under these treatments can be attributed to the synergistic effects of green manuring, mulching and site-specific nutrient application, which enhanced nutrient supply,

improved soil health and promoted vigorous vegetative growth.

Similar improvements in maize leaf number and canopy development under integrated nutrient management were also reported by Reddy *et al.* (2018) and Bharathi *et al.* (2015).

Leaf Area Index

The data indicated that leaf area index (LAI) of maize was significantly influenced by different nutrient management practices at all growth stages (Table 4). Among the treatments, T₁₁ (green manuring with sunhemp *fb* maize + mulching with T₃) recorded the maximum LAI at 30 DAS (1.64), 60 DAS (3.86), 90 DAS (3.90) and at harvest (3.37). This was followed by T₁₀ (green manuring with sunhemp *fb* maize + mulching with T₂) with corresponding values of 1.60, 3.77, 3.81 and 3.26, respectively, though slightly lower than T₁₁.

Treatments involving green manuring alone, such as T₅ (1.53, 3.59, 3.64 and 3.12, respectively) and

TABLE 4
Effect of different nutrient management practices on leaf area index of maize in Bankanahalli micro-watershed

Treatment	COC (Rs. ha ⁻¹)			Gross Returns (Rs. ha ⁻¹)			Net Returns (Rs. ha ⁻¹)			BC Ratio		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	0.97	0.95	0.96	2.30	2.28	2.29	2.34	2.33	2.33	2.22	2.21	2.21
T ₂	1.04	1.02	1.03	2.60	2.59	2.60	2.64	2.64	2.64	2.44	2.43	2.44
T ₃	1.10	1.08	1.09	2.61	2.60	2.61	2.65	2.65	2.65	2.58	2.57	2.57
T ₄	1.47	1.55	1.51	3.51	3.63	3.57	3.58	3.66	3.62	3.05	3.16	3.11
T ₅	1.50	1.55	1.53	3.55	3.64	3.59	3.59	3.70	3.64	3.05	3.18	3.12
T ₆	1.24	1.25	1.25	2.86	2.88	2.87	2.90	2.90	2.90	2.27	2.28	2.27
T ₇	1.26	1.27	1.27	2.91	2.92	2.92	2.94	2.94	2.94	2.31	2.32	2.31
T ₈	1.41	1.43	1.42	3.49	3.54	3.51	3.55	3.59	3.57	2.98	3.12	3.05
T ₉	1.42	1.43	1.43	3.49	3.55	3.52	3.56	3.62	3.59	2.99	3.13	3.06
T ₁₀	1.59	1.61	1.60	3.76	3.78	3.77	3.80	3.81	3.81	3.25	3.27	3.26
T ₁₁	1.63	1.65	1.64	3.85	3.87	3.86	3.89	3.90	3.90	3.36	3.37	3.37
T ₁₂	0.72	0.67	0.69	1.54	1.45	1.49	1.58	1.09	1.33	0.74	0.42	0.58
S.Em.±	0.08	0.05	0.05	0.19	0.13	0.12	0.19	0.16	0.11	0.15	0.13	0.11
C.D. (p=0.05)	0.22	0.14	0.14	0.57	0.39	0.36	0.55	0.47	0.33	0.44	0.39	0.32

T₄ (1.51, 3.57, 3.62 and 3.11, respectively), also recorded significantly higher LAI compared to other practices and were statistically on par with T₁₀ and T₁₁. Mulching-based treatments (T₈ and T₉) also maintained higher LAI values (3.05 and 3.06 at harvest, respectively), suggesting the positive role of organic residue recycling in sustaining canopy development. By contrast, the lowest LAI was observed in absolute control (T₁₂), with pooled values of 0.69, 1.49, 1.33 and 0.58 at 30, 60, 90 DAS and harvest, respectively. Sandhya Rani *et al.* (2021) reported that incorporation of green manures significantly increased nutrient bioavailability and leaf area development in maize.

Total Dry Matter Accumulation

The data revealed significant variation in total dry matter production of maize under different nutrient management practices at all growth stages (Fig. 5).

Among the treatments, T₁₁ (green manuring with sunhemp *fb* maize + mulching with T₃) recorded the maximum dry matter at 30 DAS (14.91 g plant⁻¹), 60 DAS (191.08 g plant⁻¹), 90 DAS (299.54 g plant⁻¹) and at harvest (415.34 g plant⁻¹). This was on par

with T₁₀ (green manuring with sunhemp *fb* maize + mulching with T), which exhibited 14.82, 187.80, 294.71 and 407.64 g plant⁻¹ at the respective stages, but was consistently lower than T₁₁.

Comparatively, T₅ (green manuring *fb* maize with T₃) also showed significant improvement in total dry matter accumulation (14.63, 183.90, 287.67 and 398.58 g plant⁻¹, respectively) and its performance was statistically on par with T₁₀ and T₁₁ across all growth stages. Similarly, T₄ (green manuring *fb* maize with T₂) followed a similar trend, recording 14.53, 182.00, 283.36 and 392.80 g plant⁻¹ at 30, 60, 90 DAS and harvest, respectively.

Importantly, T₈ (green manuring *fb* maize with T₂ + mulching) and T₉ (green manuring *fb* maize with T₃ + mulching) also recorded significantly higher dry matter values compared to the lower-input treatments. T₈ produced 14.00, 176.93, 275.99 and 386.16 g plant⁻¹, while T₉ recorded 14.06, 178.04, 277.53 and 387.34 g plant⁻¹ at the respective stages. Though slightly lower than T₄ and T₅, both treatments performed substantially better than T₁, T₂, T₃ and were statistically superior to the control (T₁₂). This suggests that the addition of mulching along

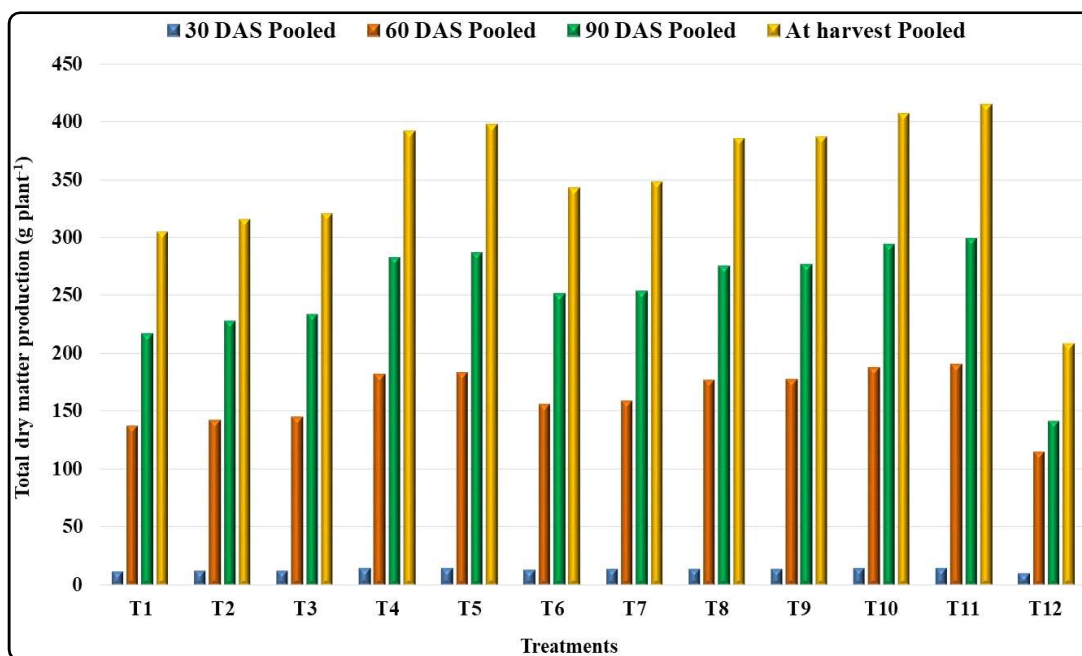


Fig. 5 : Effect of different nutrient management practices on total dry matter production of maize in Bankanahalli micro-watershed

with green manuring enhanced soil moisture conservation and nutrient uptake, thereby contributing to higher biomass production. Similar trends of enhanced photosynthesis and dry matter accumulation with green manure integration were reported by Gao *et al.* (2024).

Yield

Kernel Yield

The results showed that kernel yield of maize was significantly influenced by nutrient management practices (Fig. 6). The maximum kernel yield was recorded in T₁₁ (8660.79 kg ha⁻¹ pooled), which was on par with T₁₀ (8549.27 kg ha⁻¹), but significantly superior to all other treatments. These were followed by T₅ (7938.02 kg ha⁻¹) and T₄ (7788.21 kg ha⁻¹), which were statistically comparable to each other but inferior to T₁₀ and T₁₁. Treatments T₈ (7333.25 kg ha⁻¹) and T₉ (7402.06 kg ha⁻¹) also recorded higher kernel yields and were found to be on par. The lowest yield was observed in T₁₂ (2757.01 kg ha⁻¹), the absolute control. Similar results were obtained by Kushal *et al.* (2025) who studied on Effect of green manuring and different organic sources of nutrients on growth and yield of

maize in maize-cowpea cropping sequence. Enhanced source-sink relationship due to Green manuring + residue mulching improved soil structure and microbial activity, thereby boosting photosynthate production and ensuring higher assimilate flow into developing kernels (Essilfie *et al.* 2024).

Stover Yield

A similar trend was observed in stover yield, where the highest stover production was noted under T₁₁ (9177.16 kg ha⁻¹ pooled), which was on par with T₁₀ (9061.13 kg ha⁻¹) and both were significantly superior to all other treatments. These were followed by T₅ (8490.66 kg ha⁻¹) and T₄ (8392.05 kg ha⁻¹), which were statistically on par with each other. The next best group was T₈ (7986.50 kg ha⁻¹) and T₉ (8074.82 kg ha⁻¹), also found to be on par. The lowest stover yield was reported in T₁₂ (3227.82 kg ha⁻¹) (Fig. 6). The higher stover yields in T₁₀ and T₁₁ reflect better vegetative growth supported by improved root development, sustained nutrient availability and enhanced soil health due to organic residue addition (Abrol *et al.*, 2024 and Kumar *et al.*, 2021).

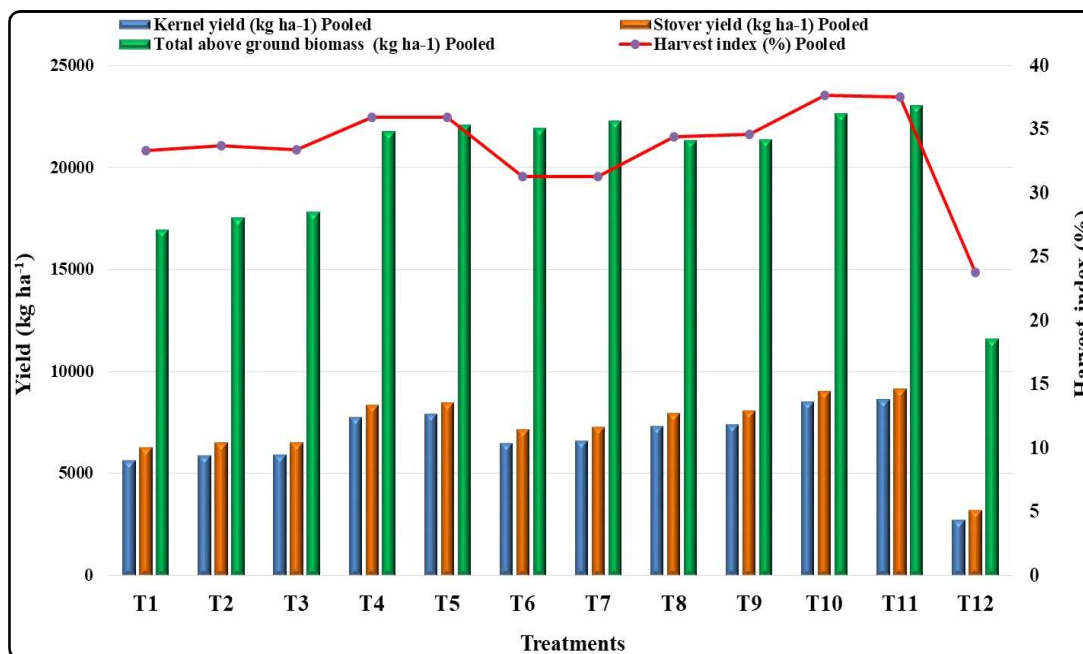


Fig. 6 : Effect of different nutrient management practices on yield and harvest index of maize in Bankanahalli micro-watershed

Harvest Index (HI)

The harvest index, which reflects the efficiency of assimilate partitioning into grain, was highest in T₁₀ (37.63%) and T₁₁ (37.51%), which were statistically on par and significantly superior to all other treatments. These were followed by T₄ (35.91%) and T₅ (35.92%), which were on par with each other, while T₈ (34.44%) and T₉ (34.60%) also showed comparable results (Fig. 6).

The lowest HI was observed in T₁₂ (23.79%), highlighting the inefficiency of the control treatment in allocating biomass to economic yield. The higher HI under T₁₀ and T₁₁ indicates that these practices not only enhanced biomass production but also improved the efficiency of its partitioning into kernels Wang *et al.* (2025).

Economics

The economic evaluation of nutrient management practices is essential to determine their feasibility and profitability. Key components such as cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio provide a clear picture of economic

viability (Table 5). Assessing these parameters helps identify the most cost-effective and sustainable practice for farmers.

Gross Returns

Gross returns varied widely across treatments, with the highest value recorded in T₇ (Rs.215,994 ha⁻¹), which remained statistically on par with T₆ (Rs.211,766 ha⁻¹), T₁₁ (Rs.201,880 ha⁻¹), T₁₀ (Rs.199,282 ha⁻¹), T₅ (Rs.193,550 ha⁻¹) and T₄ (Rs.189,981 ha⁻¹). These higher returns were attributed to better crop yields under integrated nutrient management practices, which ensured an adequate supply of both macro- and micro-nutrients, leading to improved growth and productivity and mainly these treatments includes the returns from both maize and green gram yields.

In contrast, the lowest gross return was recorded in T₁₂ (Rs.64,571 ha⁻¹), which could be linked to poor nutrient supplementation and reduced yield potential.

Net Returns

Net returns followed a similar trend, with T₇ (Rs.155,462 ha⁻¹) showing the highest profitability,

TABLE 5
Effect of different nutrient management practices on economics of maize cultivation in Bankanahalli micro-watershed

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	48823	48823	48823	133260	130792	132026	84437	81969	83203	2.73	2.68	2.70
T ₂	49577	48402	48989	152488	137016	144752	102912	88614	95763	3.08	2.83	2.95
T ₃	49868	48402	49135	153519	138103	145811	103652	89701	96676	3.08	2.85	2.97
T ₄	55515	54621	55068	197034	182927	189980	141519	128306	134913	3.55	3.35	3.45
T ₅	55515	54952	55233	200763	186335	193549	145248	131384	138316	3.62	3.39	3.50
T ₆	60114	60454	60284	210392	213140	211766	150277	152686	151481	3.50	3.53	3.51
T ₇	60756	60309	60532	215128	216859	215994	154372	156550	155461	3.54	3.60	3.57
T ₈	60698	60542	60620	170085	172216	171151	109387	111674	110530	2.80	2.84	2.82
T ₉	60795	60212	60503	171674	173866	172770	110879	113655	112267	2.82	2.89	2.86
T ₁₀	67809	66802	67305	197272	201292	199282	129462	134491	131976	2.91	3.01	2.96
T ₁₁	67208	66802	67005	199839	203920	201879	132630	137118	134874	2.97	3.05	3.01
T ₁₂	33100	33100	33100	6961	59526	64571	36516	26426	31471	2.10	1.80	1.95

closely followed by T₆ (Rs.151,482 ha⁻¹), T₁₁ (Rs.134,875 ha⁻¹) and T₁₀ (Rs.131,977 ha⁻¹). These treatments outperformed others due to a balance between higher gross returns and moderate cultivation costs, ultimately enhancing the profitability margin. The lowest net returns were obtained in T₁₂ (Rs.31,471 ha⁻¹) because of its low gross returns despite minimal cultivation costs, proving that profitability is primarily yield-driven rather than cost-dependent. Treatments T₁ and T₂ also recorded moderate net returns owing to comparatively lower productivity.

Benefit-Cost Ratio (B:C)

The BC ratio highlighted the economic efficiency of treatments, where T₇ (3.57) and T₆ (3.51) recorded the highest values, indicating that every rupee invested yielded more than threefold returns. These treatments reflected the advantage of integrated nutrient management with residue incorporation, which improved input-use efficiency. On the contrary, T₁₂ (1.95) recorded the lowest BC ratio, showing that the returns were only marginally higher than the investment, making it the least profitable option. Treatments such as T₄ (3.45), T₅ (3.50), T₁₀ (2.96) and T₁₁ (3.01) also recorded favourable BC ratios, proving the superiority of integrated practices over sole fertilizer applications.

Although, the treatments like T₁₁ and T₁₀ recorded higher gross returns they are recorded lower BC ratio. It is mainly because of cost of paddy straw which is used for mulching in these two treatments that leads to increase in cost of production. If the paddy straw is readily available within the farmer field then the scenario of BC ratio will be changed and these treatments record higher BC ratio compared to other treatments.

The study demonstrated that soil nutrient availability in the Bankanahalli micro-watershed exhibits significant spatial heterogeneity, underscoring the importance of site-specific nutrient management. Among all treatments, green manuring with sunhemp followed by maize and mulching under NMP-II (T₁₁) proved superior in enhancing growth, yield and

profitability. Integrating organic amendments with balanced fertilizer use improved soil fertility, nutrient efficiency and crop performance. Therefore, adopting integrated and location-specific nutrient management strategies can ensure sustainable maize production and long-term soil health in semi-arid agroecosystems.

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