



RESEARCH ARTICLE

Fertiliser recommendation maps based on soil test crop response for important crops of Upparapalli village of Tirupati district, Andhra Pradesh

Abhinav Aditya Das¹, G P Leelavathy^{2*}, B Vajantha³, G Prasad Rao⁴ & M V S Naidu¹

¹Department of Soil Science, S. V. Agricultural College, Acharya N. G. Ranga Agricultural University, Tirupati 517 502, Andhra Pradesh, India

²Department of Soil Science, Institute of Frontier Technology, Regional Agricultural Research Station, Acharya N. G. Ranga Agricultural University, Tirupati 517 502, Andhra Pradesh, India

³Department of Soil Science, Agricultural Research Station, Perumallapalle, Acharya N. G. Ranga Agricultural University, Tirupati 517 505, Andhra Pradesh, India

⁴Department of Information Technology, Electronics and Communication, Andhra Pradesh Space Application Centre, Government of Andhra Pradesh, Vijayawada 520 010, Andhra Pradesh, India

*Correspondence email - gp.leelavathi@angrau.ac.in

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Abstract

The soil test crop response (STCR) approach facilitates precise estimation of fertiliser needs for a given season and site by considering the baseline soil nutrient levels and the crop's response in terms of nutrient absorption and yield performance. Efficient nutrient management is essential for sustaining crop productivity while minimising environmental impacts in modern agriculture. However, conventional blanket fertiliser recommendations often fail to account for spatial variability in soil fertility, leading to nutrient overuse, reduced fertiliser-use efficiency and long-term soil degradation. This study integrates geographic information system (GIS)-based soil fertility mapping with STCR targeted-yield equations to generate precise, site-specific fertiliser recommendations for Upparapalli village in the Tirupati district of Andhra Pradesh. A total of 200 geo-referenced surface soil samples (0–15 cm), collected using a 170 m grid, were analysed for available nitrogen (N), phosphorus (P) and potassium (K). Spatial variability maps for N, P₂O₅ and K₂O were created using the inverse distance weighting (IDW) interpolation method in ArcGIS 10.3 and crop-specific fertiliser requirements were computed for rice, groundnut and sugarcane using STCR equations. The results revealed substantial heterogeneity in soil nutrient distribution across the village, underscoring the limitations of uniform fertiliser application. Overall, the integration of GIS with STCR proved highly effective in promoting site-specific nutrient management, reducing input costs and preventing nutrient losses to the environment. The approach offers a scalable and scientifically robust framework for precision nutrient management in regions with similar soil and climatic conditions, contributing to sustainable agricultural intensification and improved soil health.

Keywords: ArcGIS; fertiliser recommendation maps; inverse distance weighted interpolation; nutrient-use efficiency; precision agriculture; soil test crop response (STCR)

Introduction

Crop production and food security have become pressing global concerns, particularly as inherent climatic variability and the rapidly rising demand for food pose significant risks to human well-being (1). Global food requirements are projected to rise by nearly 60 % by 2050 to sustain the expanding population (2). In 2017 alone, an estimated 770 million people- almost one-tenth of the global population-faced severe food insecurity (3). Under the continually shifting fertiliser management strategies used across India, a single, generalised fertiliser recommendation cannot meet the needs of diverse soil systems. Fertiliser consumption has risen sharply over the past decades; the use of N, P and K nutrients increased from 0.07 Mt in 1951–52 to over 28 Mt by 2010–11. Likewise, the per-hectare application rate grew from less than 1 kg in 1951–52 to about 135 kg in 2010–11 (4). However, despite higher fertiliser inputs, nutrient use efficiency has steadily declined- from 16 kg of food grain produced

per kg of NPK applied in the 1970s to 8 kg in the 1990s and to nearly 6 kg at present-primarily due to emerging deficiencies of secondary and micronutrients (5).

During the Green Revolution, it became evident that conventional fertiliser recommendations required refinement to match diverse soil fertility levels and achieve economically viable crop yields. This led to the development of the soil test crop response (STCR) approach, a scientific method that integrates soil test values, crop response to applied nutrients and targeted yield concepts to formulate precise fertiliser recommendations (6). Soil test crop response involves targeted yield-based recommendations, calibration experiments and fertiliser prescription equations (7).

Sugarcane, rice and groundnut all require balanced and adequate nutrition for sustained productivity. However, the fertiliser production capacity in India remains insufficient to meet national nutrient demands. This mismatch between supply and requirement

is expected to widen in the coming years (8). Furthermore, the region of research often relies on blanket fertiliser recommendations that fail to consider variations in soil fertility, nutrient status and yield potential across farms. Enhancing nutrient-use efficiency and achieving the next level of productivity gains will require location-specific nutrient management strategies tailored to individual fields.

Considering these difficulties, spatially explicit fertiliser recommendation frameworks based on STCR principles offer a promising pathway toward precision nutrient management. The present study was conducted in Upparapalli village of Tirupati district with the objective of generating crop-specific fertiliser recommendation maps using geospatial tools. The majority of farmers in India still follow the blanket recommendation of fertilisers, which is often more or less than the actual crop demand. Nutrient release patterns of applied chemical fertilisers generally do not match the crop demand due to the faster release of nutrients, which often leads to nutrient deficiencies and imbalances over time.

Materials and Methods

Location and extent

The Upparapalli village is located in Pakala mandal of Tirupati district, Andhra Pradesh. The village covers a total area of 922.8 ha, out of which 621.44 ha of land is agricultural land, whereas 301.36 ha of land is non-agricultural. It is located within 13° 28' 25" to 13° 26' 25" North latitude and 79° 7' 11" to 79° 4' 16" East longitude with an elevation of 361 m (1184 ft). As it is near the Bay of Bengal, the village has a tropical climate and is very humid. Summers are very long and hot and the monsoon season is associated with a lot of rain and low temperatures. Winters are less severe and there is a marked decrease in the temperature. The location map of the study area is presented in Fig. 1. The summer period occurs between February to June and the temperatures rise gradually to a peak in May, with temperatures at the lowest from 26.4 °C to the highest of 36.4 °C. The monsoon season is between June and October and the winter season is between December to February, with temperatures of 16.8 °C to 17.5 °C. The coldest month of the year is normally December. January and February receive little rainfall and the greatest rainfall occurs in October with 6 to 162 mm because the North-East monsoon is the richest in rainfall in Tirupati district.

Database creation and organisation

The cadastral and base maps of Upparapalli village were created using ArcGIS v 10.3, a geographic information system (GIS)-based software used for database building and the preparation of numerous themed maps. These maps were generated by the Andhra Pradesh Space Application Centre (APSAC), Vijayawada and used in the study.

Delineation of the study area

The agricultural land of Upparapalli village was mapped using mandal boundaries and a geo-referenced toposheet. Data for the study area were extracted as a subset for further analysis. The geo-referencing process of the 57003 toposheet is illustrated in a flow diagram in Fig. 2, created using ERDAS Imagine software, while the procedure for merging the toposheets is shown in a flow diagram in Fig. 3.

Ground truth data collection

A preliminary survey of the study area was carried out by travelling through Upparapalli village, which includes three hamlet villages: Mallelacheruvupalli, Gollapalle and Ramireddugaripalle. Representative soil areas were identified by covering the survey numbers of farmers' fields in the region. Global positioning system (GPS) readings were taken at each sampling location using a 170 m grid. Information about crops and cropping systems practised in the village's agricultural land was gathered through interactions with local farmers. A total of 200 geo-referenced composite surface soil samples (0–15 cm) were collected across Upparapalli village, which spans a total area of 922.8 ha, including 621.44 ha of agricultural and 301.36 ha of non-agricultural land. These samples were collected by covering the survey numbers of farmers' fields.

Soil analysis

The soil samples collected were air-dried in the shade, crushed using a wooden hammer and sifted through 2 mm and 0.5 mm sieves (for organic carbon analysis). The prepared soil samples were subsequently analysed using standard methods. The available nitrogen was determined by the alkaline potassium permanganate method (9). The available phosphorus content was determined by extracting the soil with 0.5 M NaHCO₃, pH 8.5 and estimated by developing blue colour using ascorbic acid as reductant at 660 nm and available potassium in the soils was extracted by neutral normal ammonium acetate and determined by the flame photometer (10, 11).

Fertiliser recommendation maps

The fertiliser recommendations developed using fertiliser adjustment equations from STCR can be displayed in the form of a spatial fertiliser recommendation map by linking the information with soil fertility maps. The fertiliser recommendation maps for different management zones in terms of nitrogen, phosphorus and potassium were derived by the inverse distance weighting (IDW) interpolation method in a GIS environment. In general, the soils having low category values are recommended with 30 % more than the recommended doses and the soils having high category values of nutrients with 30 % less than the usual recommended doses. The usage of STCR-based recommendations is more useful for getting a targeted yield approach. The recommended dose of fertilisers for rabi rice is 120-60-40 kg N-P₂O₅-K₂O ha⁻¹, for rabi groundnut is 20-40-50 kg N-P₂O₅-K₂O ha⁻¹ and for sugarcane is 224-112-112kg N-P₂O₅-K₂O ha⁻¹. The area under the fertiliser recommendation ranges of available N, P and K had arrived through thematic maps. The actual N, P₂O₅ and K₂O fertiliser nutrient recommendations were derived using the fertiliser adjustment equations based on the targeted yield approach developed by the soil test-based fertiliser application, Department of Agriculture, Hyderabad (12).

The fertiliser adjustment equations based on STCR were given in equation 1–9.

STCR equation for rice (Target yield = 60 q ha⁻¹):

$$FN = 4.53 T - 0.51 SN \quad (\text{Eqn. 1})$$

$$FP 205 = 2.12 T - 2.06 SP \quad (\text{Eqn. 2})$$

$$FK 20 = 2.35 T - 0.21 SK \quad (\text{Eqn. 3})$$

STCR equation for groundnut (Target yield = 22 q ha⁻¹):

$$FN = 3.69 T - 0.36 SN \quad (\text{Eqn. 4})$$

$$FP 205 = 1.32 T - 0.71 SP \quad (\text{Eqn. 5})$$

$$FK 20 = 2.54 T - 0.12 SK \quad (\text{Eqn. 6})$$

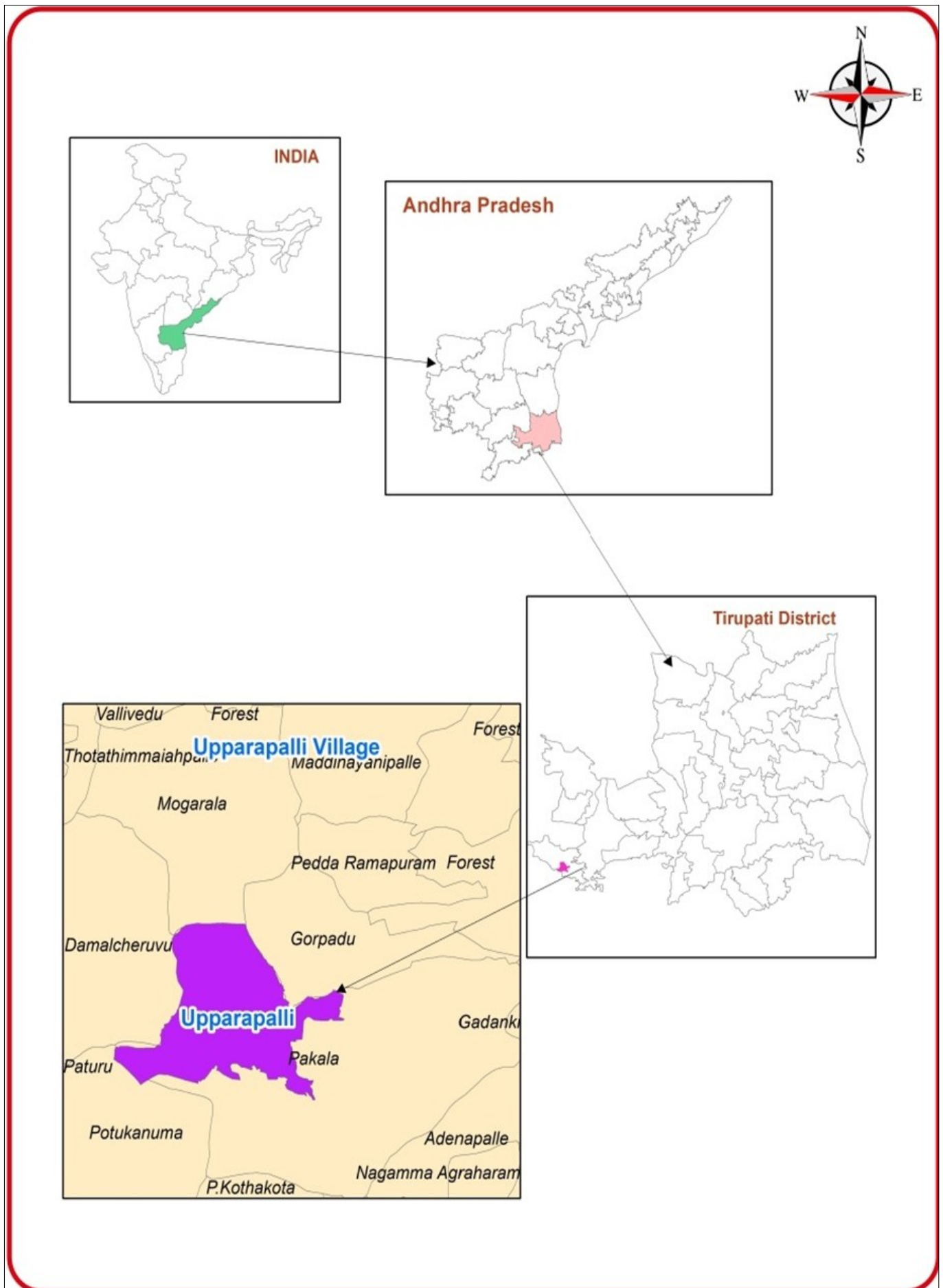


Fig. 1. Location map of Upparapalli village, Tirupati district, India.

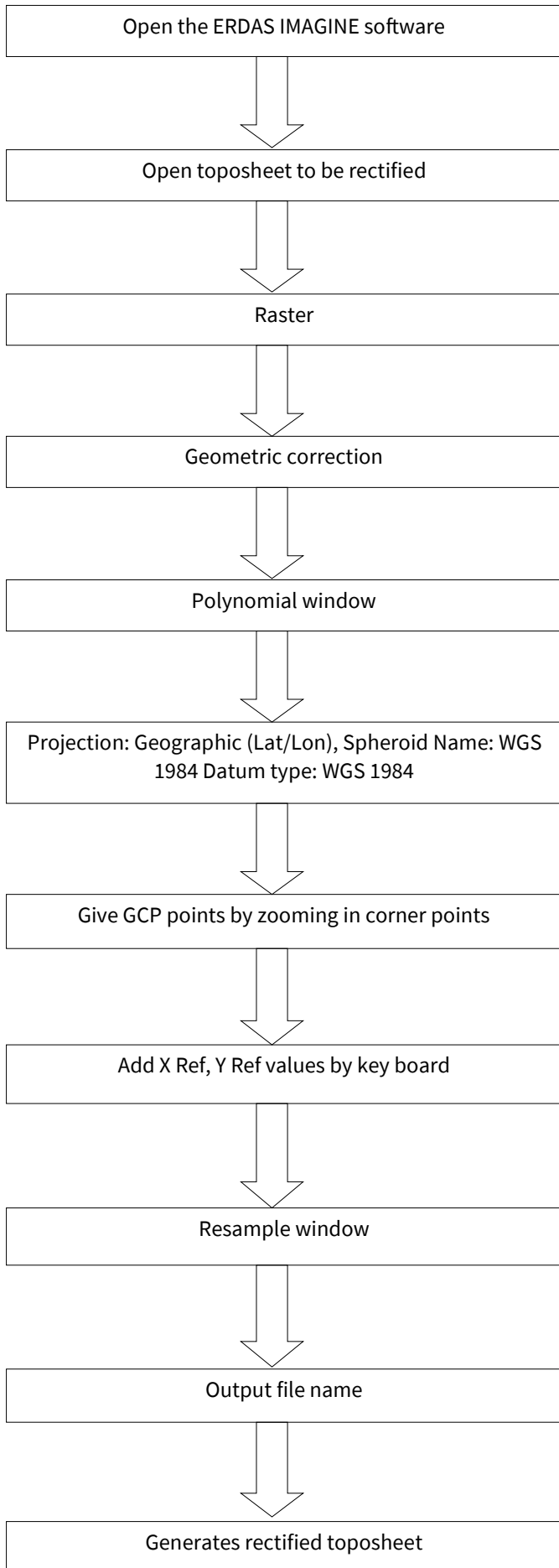


Fig. 2. Flow diagram of rectification of toposheets in ERDAS Imagine 15.

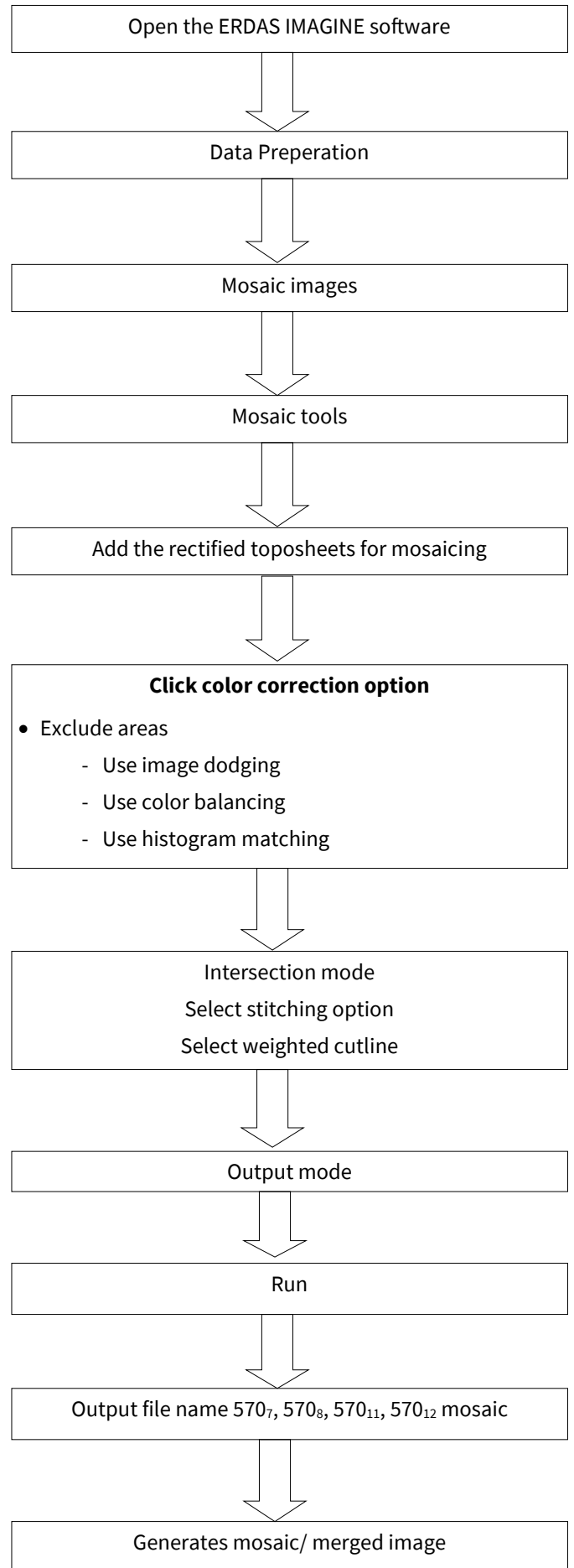


Fig. 3. Flow diagram of mosaicing (merging) of the toposheets in ERDAS Imagine 15.

STCR equation for sugarcane (Target yield = 110 t ha⁻¹):

$$FN = 5.4T - 1.25SN \quad (\text{Eqn. 7})$$

$$FP205 = 1.80T - 4.73SP \quad (\text{Eqn. 8})$$

$$FK20 = 1.7T - 0.33SK \quad (\text{Eqn. 9})$$

Where, T= Target yield, SN= Soil nitrogen, SP= Soil phosphorus, SK= Soil potassium.

Results and Discussion

Fertiliser recommendation ranges were determined and thematic maps were developed to enable site-specific nutrient management for Upparapalli village. The spatial variability of available nitrogen, phosphorus and potassium was analysed using these maps, which were then applied to formulate fertiliser recommendations for rice, groundnut and sugarcane.

Fertiliser recommendation maps for rice

In the traditional method, the research territory is a homogenous unit, with the needs of nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) in rice being 120, 60 and 40 kg ha⁻¹, respectively. The natural variability of nutrients within a field, however, may lead to over-application or under-application of fertilisers with the same quantity applied to the whole area. This practice translates to high input prices and poor quality of soil and decreased efficiency of fertilisers (13). The yield of the rice crop for the rabi season was 143.36 ha. To attain these sustainable yields, it is important to adopt

a more precise method of application of fertilisers that is adapted to specific sections of the fields. The field must be treated at different rates of applying fertilisers due to the differences in soil fertility (14). The IDW technique can be used to create fertility maps, which can be used to subdivide the field into different zones of management areas based on spatial differences in soil fertility (15). Nitrogen, phosphorus and potassium fertiliser recommendations for rice were based on the equations of STCR of each of the nutrient status classes. These formulas were generated based on the nutrient needs to attain the desired crop production and the current amount of nutrients in the available fertiliser, as well as in the native soil (16). Table 1 presents the spatial variability of the available nitrogen, phosphorus and potassium and the role of the said fertiliser in rice growing in relation to the specifications in Upparapalli village is visualised in Fig. 4–6.

The spatial nitrogen recommendation map of rice in Upparapalli village has five categories that are based on the availability of nitrogen. The highest area, 51.10 % (317.56 ha), is in the <150 kg ha⁻¹ class, then 26.78 % (166.40 ha) in the 151–200 kg ha⁻¹ classification, 6.51 % (40.46 ha) in the 201–250 kg ha⁻¹ classification and 1.80 % (11.18 ha) in the >300 kg ha⁻¹ classification. The amount of nitrogen recommended to feed these categories is 169, 144, 126, 107 and 71 kg ha⁻¹ respectively. Comparing the application of these doses of nitrogen with the RDF (Recommended Doses of Fertilisers) of 120 kg ha⁻¹, it is observed that application of the nitrogen is reduced significantly, other for the recommended application of nitrogen of 150 kg ha⁻¹, 151–200 kg ha⁻¹ and 201–250 kg ha⁻¹.

Table 1. Soil test-based fertiliser recommendation for rice crop in Upparapalli village

Available nitrogen				Available phosphorus				Available potassium			
Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended nitrogen (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended phosphorus (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended potassium (kg ha ⁻¹)
< 150	317.56	51.10	169	< 25	16.39	2.64	110	< 250	133.96	21.56	76
151–200	166.40	26.78	144	26–35	113.37	18.24	87	251–300	145.73	23.45	58
201–250	85.84	13.81	126	36–45	189.09	30.43	66	301–350	160.99	25.90	48
251–300	40.46	6.51	107	46–55	183.64	29.55	43	351–400	103.01	16.58	38
> 300	11.18	1.80	71	> 55	118.95	19.14	18	> 400	77.75	12.51	19

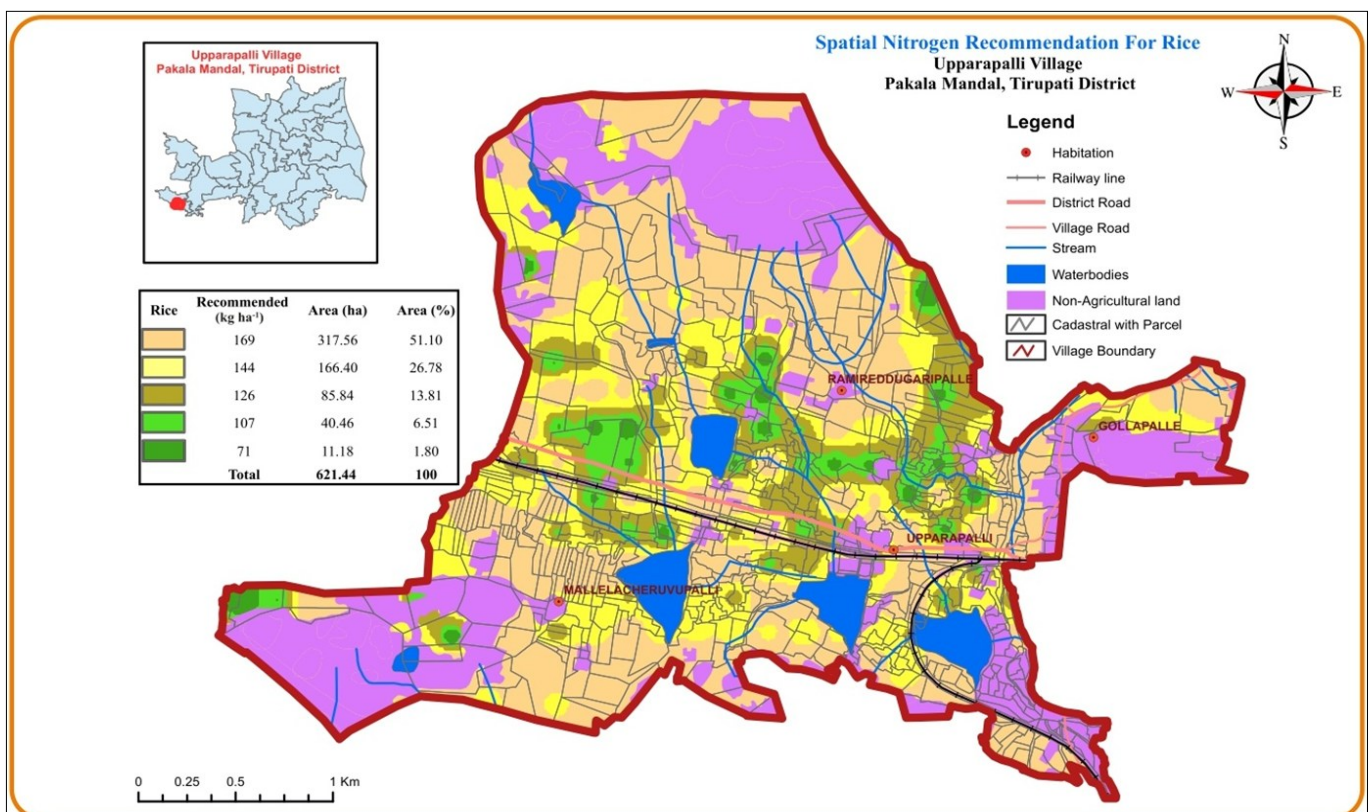


Fig. 4. Spatial nitrogen recommendation map for rice Upparapalli village, Pakala mandal, Tirupati district.

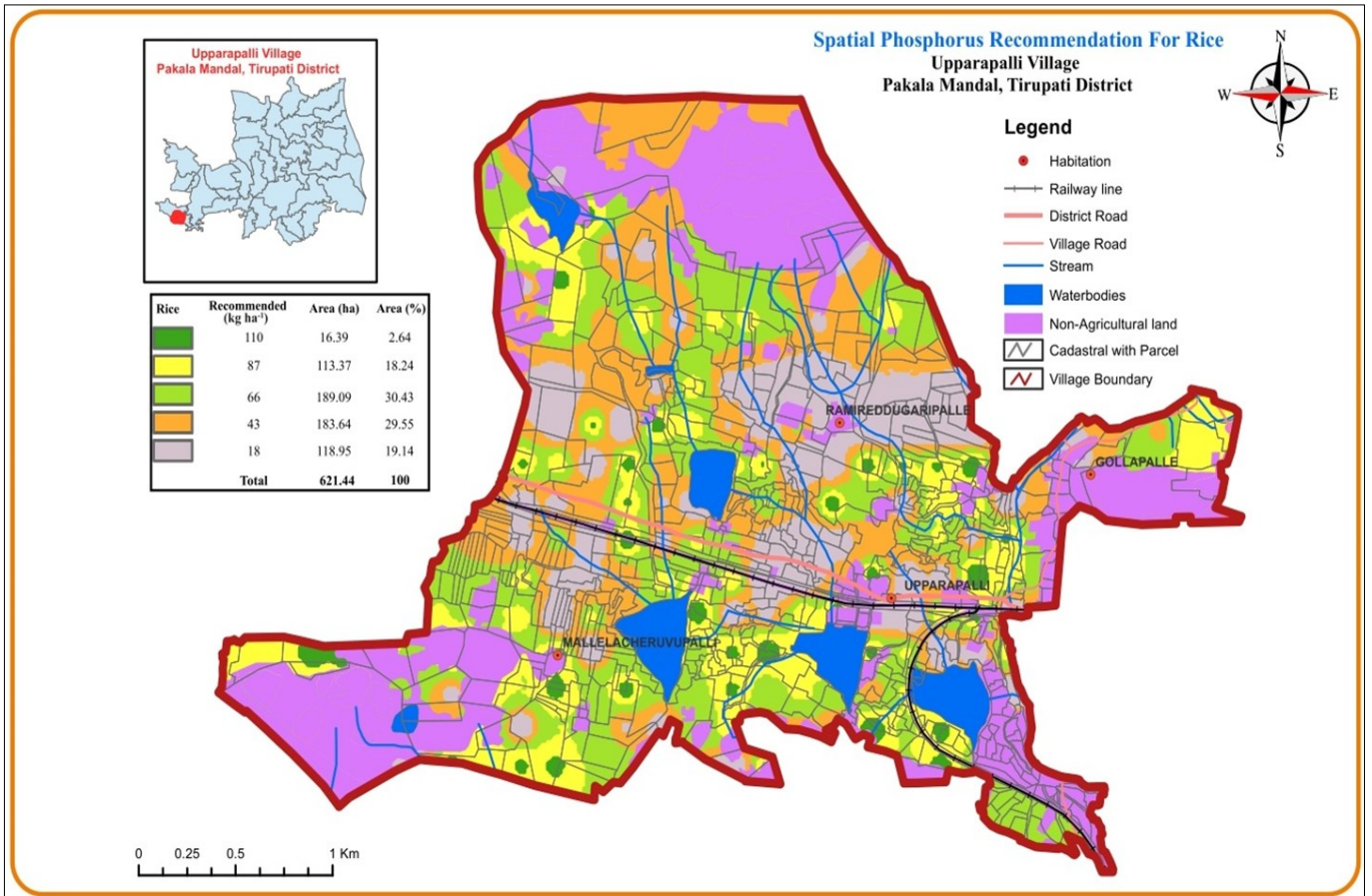


Fig. 5. Spatial phosphorus recommendation map for rice Upparapalli village, Pakala mandal, Tirupati district.

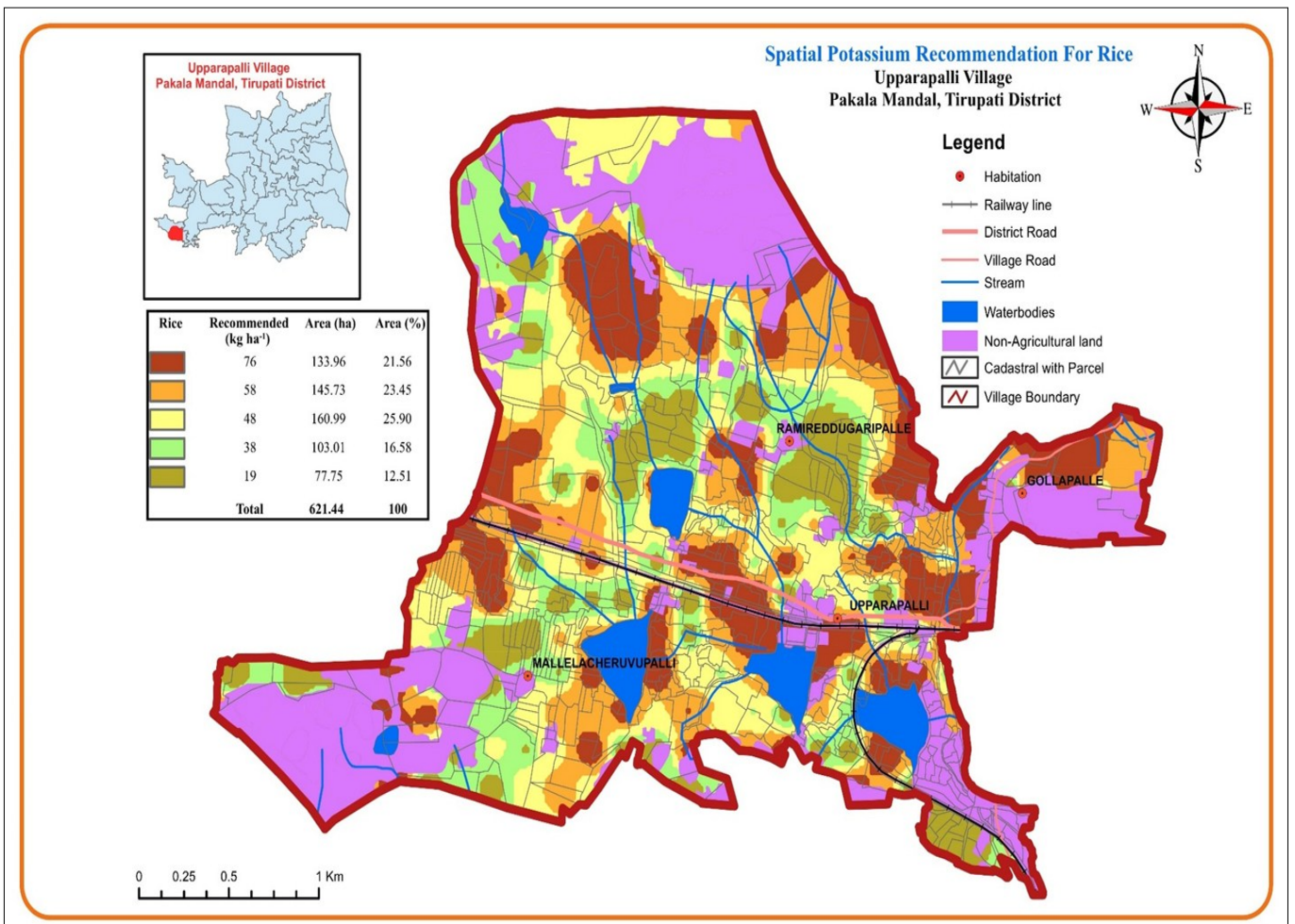


Fig. 6. Spatial potassium recommendation for rice Upparapalli village, Pakala mandal, Tirupati district.

The phosphorus recommendation map for rice in the Upparapalli village is classified into five categories depending on the phosphorus available. The highest percentage, 30.43 % (189.09 ha), is in the 36–45 kg ha⁻¹ category, then 29.55 % (183.64 ha) in the 46–55 kg ha⁻¹ category, 19.14 % (118.95 ha) in the >55 kg ha⁻¹ category, 18.24 % (113.37 ha) in the 26–35 kg ha⁻¹ category and 2.64 (16.39 ha) in the <25 kg ha⁻¹ class. The phosphorus doses that are recommended in these categories are 110, 87, 66, 43 and 18 kg ha⁻¹ respectively. Implementation of these recommendations will lead to a substantial decrease in the amount of phosphorus fertiliser application in comparison with the RDF of 60 kg ha⁻¹, with the exception of the <25, 26–35 and 36–45 kg ha⁻¹ categories, where added phosphorus is greater than the general amount.

The potassium recommendation map of rice in Upparapalli village categorises the village into five regions according to the availability of potassium. The bulk 25.90 % (160.99 ha) is in the 301–350 kg ha⁻¹ range and then 23.45 % (145.73 ha) in the 251–300 kg ha⁻¹ range, 16.58 % (103.01 ha) in the <250 kg ha⁻¹ range and 12.51 % (77.75 ha) in the >400 kg ha⁻¹ range. These categories of potassium are recommended 19, 38, 48, 58 and 76 kg ha⁻¹, respectively. The application of potassium fertiliser decreases significantly throughout the village when compared to the overall application of 40 kg ha⁻¹ except at the 251–300 and 301–350 kg ha⁻¹ groups, where higher potassium levels are suggested than the common dose, which is 40 kg ha⁻¹.

The STCR approach increased rice yield by 11.5 % relative to conventional methods of applying fertilisers in the Mancheril district of Telangana (17). The integration of farmyard manure (FYM) with NPK fertilisers under a targeted yield strategy was shown to improve nutrient use efficiency in a rice-rice system (18). Fertiliser application based on STCR-targeted yield treatments was found to significantly enhance the available N, P and K status of the soil compared to other fertilisation methods (19). The STCR approach aimed at targeted yields of 65 and 55 q ha⁻¹ proved to be the most effective strategy for maximising productivity in aerobic rice, surpassing both the PoP and LMH approaches (20). The STCR approach led to significant reductions in fertiliser use, saving 45 % nitrogen, 12 % phosphorus and 32 % potassium compared to the blanket application method (21).

The average soil test values from the field experiment (194 kg N, 22 kg P and 182 kg K) were found to correspond to 126 kg ha⁻¹ of N, 44 kg ha⁻¹ of P₂O₅ and 78 kg ha⁻¹ of K₂O for achieving a rice yield of 50 q ha⁻¹ in an inceptisol (22). It was also observed that no fertiliser application of N, P, or K was necessary when the nutrient requirement (NR) derived from fertiliser adjustment equations for 40 and 50 q ha⁻¹ rice yields resulted in zero, according to the same study. A targeted paddy yield of 40 q ha⁻¹ was successfully obtained, showing a 38.24 % yield increase over the local check (30.02 q ha⁻¹)

(23). Soil test crop response studies with rice variety ADT 43 showed that at initial soil available NPK levels of 200, 10 and 250 kg ha⁻¹, the fertiliser requirement to achieve a target yield of 60 t ha⁻¹ was 233 kg ha⁻¹ of N, 100 kg ha⁻¹ of P₂O₅ and 107 kg ha⁻¹ of K₂O through fertiliser application alone (24).

Fertiliser recommendation maps for groundnut

In the conventional approach, the nitrogen requirement for groundnut in the study area was estimated to be 20 kg ha⁻¹, assuming the area as homogeneous. Likewise, the phosphorus and potassium requirements were set at 40 kg ha⁻¹ and 50 kg ha⁻¹, respectively. The yield of groundnuts for the rabi season was a total of 152 ha. Fertiliser recommendations for groundnut, based on the spatial variability of nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) availability, are provided in Table 2 and depicted in Fig. 7–9.

The nitrogen recommendation map for groundnut in Upparapalli village classifies the area into four distinct categories based on nitrogen availability. The largest proportion, 39.28 % (244.13 ha), falls in the 101–150 kg ha⁻¹ range, where a nitrogen dose of 35 kg ha⁻¹ is recommended. The second largest, 26.78 % (166.40 ha), falls into the 151–200 kg ha⁻¹ range, with a recommended dose of 19 kg ha⁻¹. A further 22.12 % (137.47 ha) of the area exceeds 200 kg ha⁻¹, requiring only 4 kg ha⁻¹ and 11.82 % (73.44 ha) of the area falls below 100 kg ha⁻¹, for which the recommendation is 59 kg ha⁻¹. Compared to the RDF of 20 kg ha⁻¹, the nitrogen application is significantly reduced in most areas, except for the < 100 and 101–150 kg ha⁻¹ ranges as implicated by STCR, which require more nitrogen than the standard dose.

The phosphorus recommendation map for groundnut in Upparapalli village divides the area into five categories based on phosphorus availability. The largest share, 79.12 % (491.68 ha), falls into the > 35 kg ha⁻¹ range, with a recommended phosphorus dose of 2 kg ha⁻¹. The next largest, 11.81 % (73.38 ha), falls in the 31–35 kg ha⁻¹ range, requiring 6 kg ha⁻¹. Other smaller areas, 6.43 % (39.99 ha), 2.08 % (12.94 ha) and 0.56 % (3.45 ha), fall under the 26–30 kg ha⁻¹, 21–25 kg ha⁻¹ and < 20 kg ha⁻¹ categories, with recommended doses as of by STCR were 9, 13 and 18 kg ha⁻¹, respectively. In comparison to the RDF of 40 kg ha⁻¹, phosphorus application in the area is significantly reduced.

The potassium recommendation map for groundnut in Upparapalli village divides the area into seven categories based on potassium availability. The largest area, 29.09 % (180.75 ha), falls in the > 350 kg ha⁻¹ range, with a recommended potassium dose of 6 kg ha⁻¹. The next largest, 25.91 % (160.99 ha), is in the 301–350 kg ha⁻¹ range, requiring 17 kg ha⁻¹. Additional areas, 23.45 % (145.73 ha), 13.82 % (85.89 ha), 6.25 % (38.86 ha), 1.40 % (8.73 ha) and 0.08 % (0.49 ha), fall within the 251–300 kg ha⁻¹, 201–250 kg ha⁻¹, 151–200 kg ha⁻¹, 101–150 kg ha⁻¹ and < 100 kg ha⁻¹ categories, with recommended doses of 23, 29, 35, 41 and 45 kg ha⁻¹, respectively.

Table 2. Soil test-based fertiliser recommendation for groundnut crop in Upparapalli village

Available nitrogen				Available phosphorus				Available potassium			
Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended nitrogen (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended phosphorus (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended potassium (kg ha ⁻¹)
< 100	73.44	11.82	59	< 20	3.45	0.56	18	< 100	0.49	0.08	45
101–150	244.13	39.28	35	21–25	12.94	2.08	13	101–150	8.73	1.40	41
151–200	166.40	26.78	19	26–30	39.99	6.43	9	151–200	38.86	6.25	35
> 200	137.47	22.12	4	31–35	73.38	11.81	6	201–250	85.89	13.82	29
				> 35	491.68	79.12	2	251–300	145.73	23.45	23
								301–350	160.99	25.91	17
								> 350	180.75	29.09	6

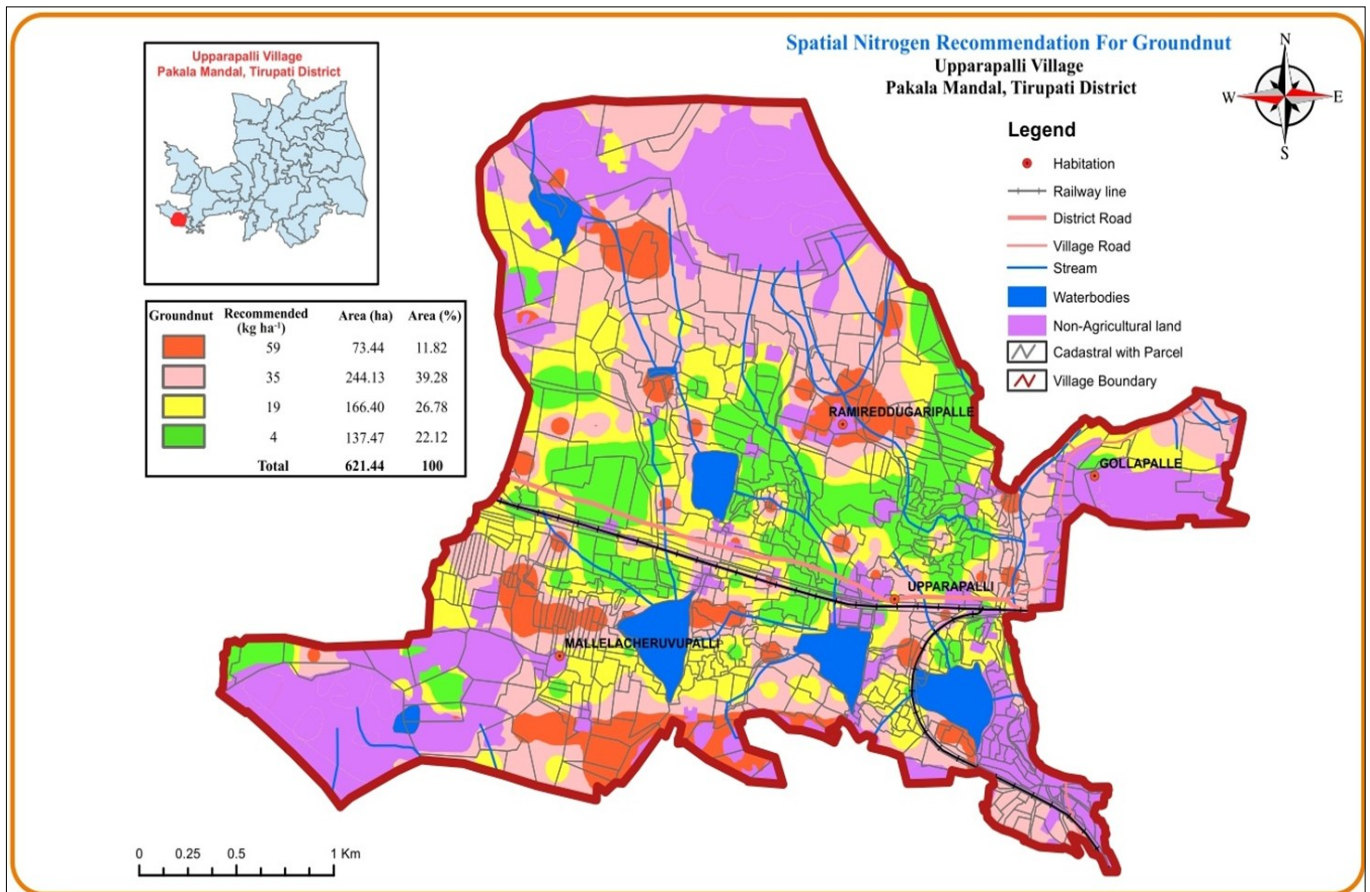


Fig. 7. Spatial nitrogen recommendation map for groundnut Upparapalli village, Pakala Mandal, Tirupati district.

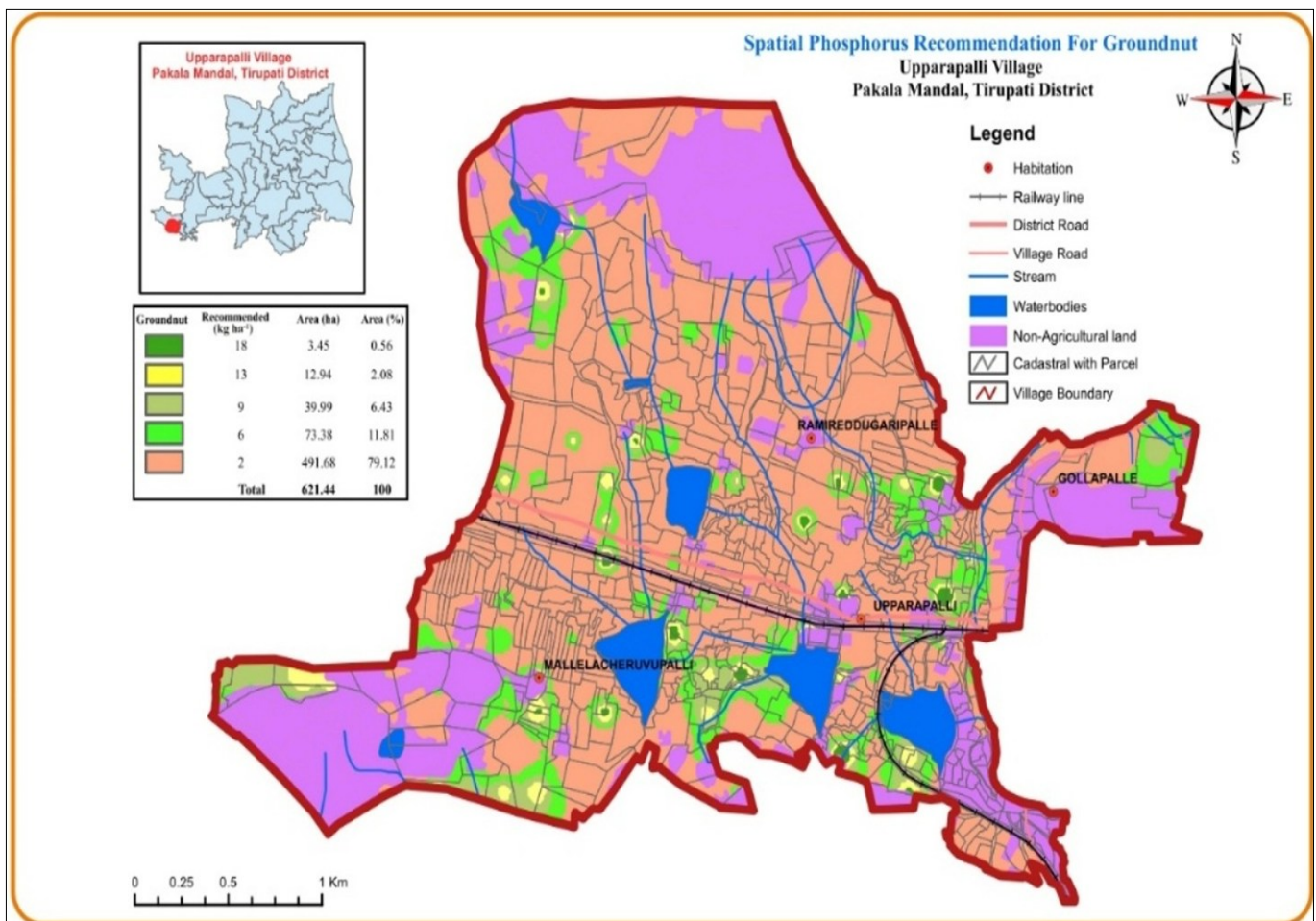


Fig. 8. Spatial phosphorus recommendation map for groundnut Upparapalli village, Pakala mandal, Tirupati district.

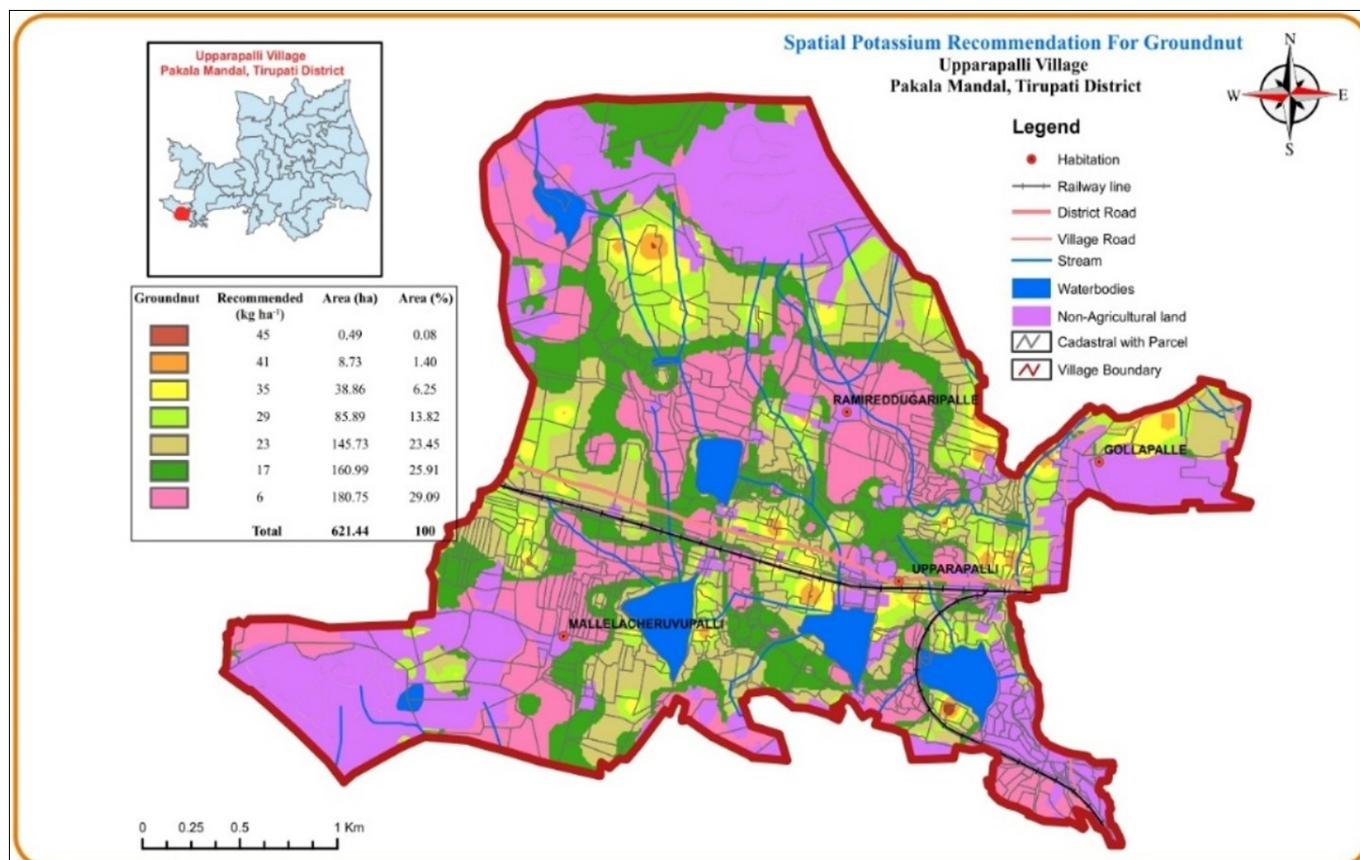


Fig. 9. Spatial potassium recommendation map for groundnut Upparapalli village, Pakala mandal, Tirupati district.

Compared to the general potassium recommendation of 50 kg ha⁻¹, the STCR recommendations indicate a substantial reduction in potassium fertiliser application, except in areas with < 100 and 101–150 kg ha⁻¹, where more potassium is required than the RDF.

Groundnut yields and growth parameters were significantly higher when the STCR equation was applied with a target yield of 25 q ha⁻¹ compared to the recommended dose of fertiliser (RDF) (25). Yield and income improvements for groundnut farmers in the Alfisols of the Tamiraparani region were achieved when STCR-based fertiliser recommendations were combined with 75 % STCR, 3 kg ha⁻¹ of rhizobium, 20 kg ha⁻¹ of humic acid and 3 t ha⁻¹ of poultry manure (T₈) (26). The STCR-IPNS approach targeting 30 q ha⁻¹ was found to outperform conventional farmer practices, leading to an average yield gain of 9 % (27). Additionally, 40.8 % of the area required no P fertilisation, 49.1 % required only 50 % of the recommended P₂O₅ and just 26.6 % of the study area required 60 % of the recommended K application based on STCR at the RBK level (28).

Fertiliser recommendation maps for sugarcane

The nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) nutrient requirements of the sugarcane in the study area were pegged at 224 kg ha⁻¹ for nitrogen, 112 kg ha⁻¹ each of phosphorus and potassium. The yield of sugarcane in the rabi season was 90 ha. But, as indicated in Table 3 and in Fig. 10–12, the fertiliser

recommendations that were used in Upparapalli village were adjusted to consider the spatial heterogeneity of these nutrients.

The spatial nitrogen recommendation map of Upparapalli village classifies the area into four different classes according to the variability of the available nitrogen. Most of the area (98.20 % or 610.26 ha) is under the category of < 300 kg ha⁻¹ with a recommended nitrogen dose of 384 kg ha⁻¹. The smaller area (1.13, or 7.00 ha) is under the range of 301–325 kg ha⁻¹ with a recommended dose of 203 kg ha⁻¹. Even smaller ones (0.43, or 2.66 ha and 0.24, or 1.52 ha) fall into 326–350 kg ha⁻¹ and greater-than 350 kg ha⁻¹ ranges, which require 166 kg ha⁻¹ and 126 kg ha⁻¹ respectively. The recommendations with STCR indicate that there is a considerable decrease in the application of nitrogen fertilisers in most areas compared to the general recommendation, which is 224 kg ha⁻¹, excluding the range of less than 300 kg ha⁻¹ that demands more nitrogen than the RDF.

The phosphorus recommendation map of the sugarcane in the village of Upparapalli breaks down the area into five groups depending on the phosphorus available. The greatest percentage (79.12 or 491.68 ha) is in the category of > 35 kg ha⁻¹, where the recommended phosphorus dose is 15 kg ha⁻¹. Less land (11.81 % or 73.38 ha) is in the 31–35 kg ha⁻¹ range and the recommended dose is 42 kg ha⁻¹. The other categories (6.43 %, or 39.99 ha; 21–25 % or 12.94 ha; and 0.56 %, or 3.45 ha) are under the categories 26–30 kg ha⁻¹, 21–25 kg ha⁻¹ and < 20 kg ha⁻¹ with 66, 89 and 121 kg ha⁻¹, respectively.

Table 3. Soil test-based fertiliser recommendation for sugarcane crop in Upparapalli village

Available nitrogen			Available phosphorus				Available potassium				
Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended nitrogen (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended phosphorus (kg ha ⁻¹)	Range (kg ha ⁻¹)	Area (ha)	Area (%)	Recommended potassium (kg ha ⁻¹)
< 300	610.26	98.20	384	< 20	3.45	0.56	121	< 100	0.49	0.08	156
301–325	7.0	1.13	203	21–25	12.94	2.08	89	101–200	47.57	7.66	135
326–350	2.66	0.43	166	26–30	39.99	6.43	66	201–300	231.63	37.27	101
> 350	1.52	0.24	126	31–35	73.38	11.81	42	301–400	264.0	42.48	72
				> 35	491.68	79.12	15	> 400	77.75	12.51	31

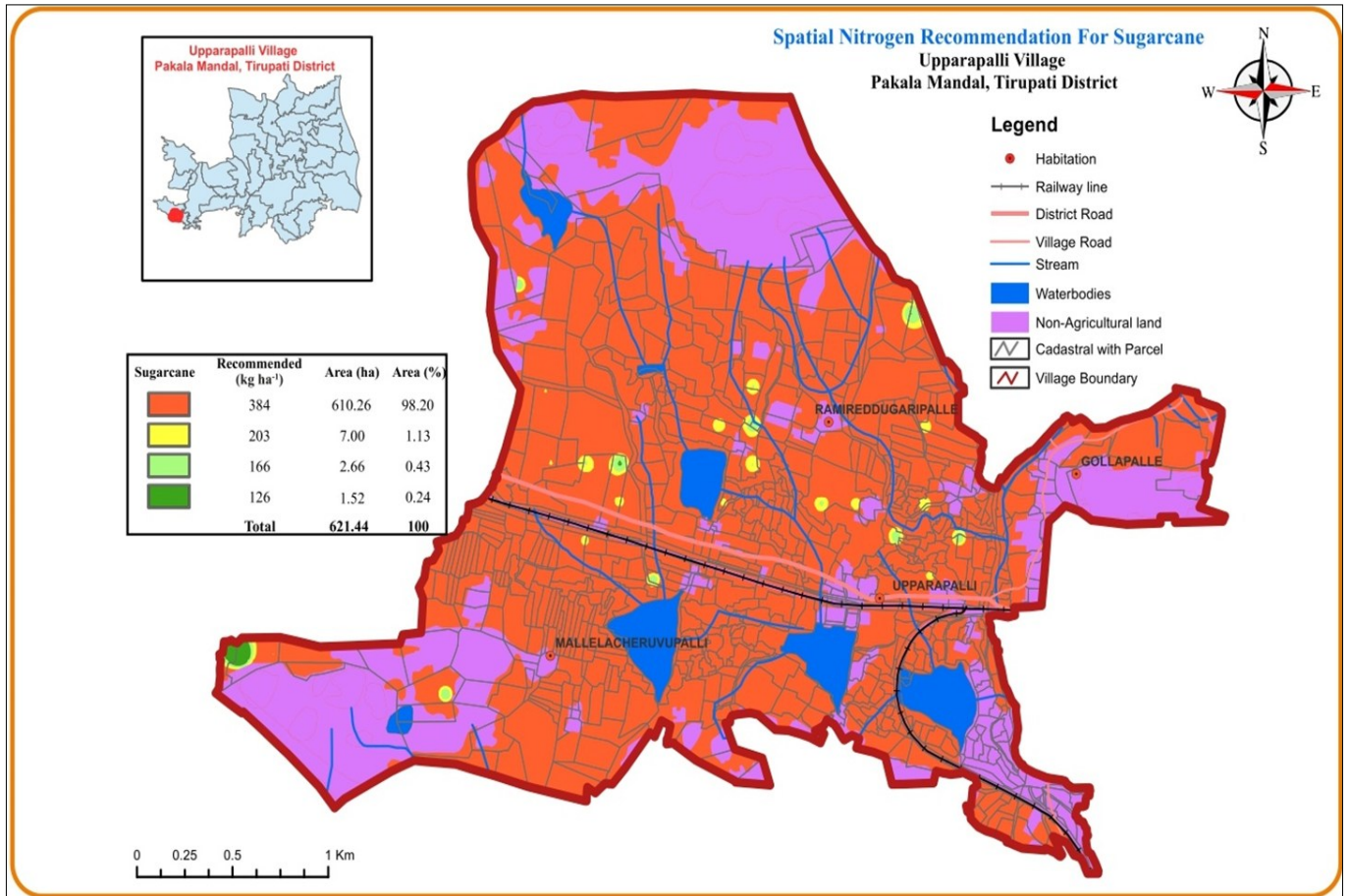


Fig. 10. Spatial nitrogen recommendation map for sugarcane Upparapalli village, Pakala mandal, Tirupati district.

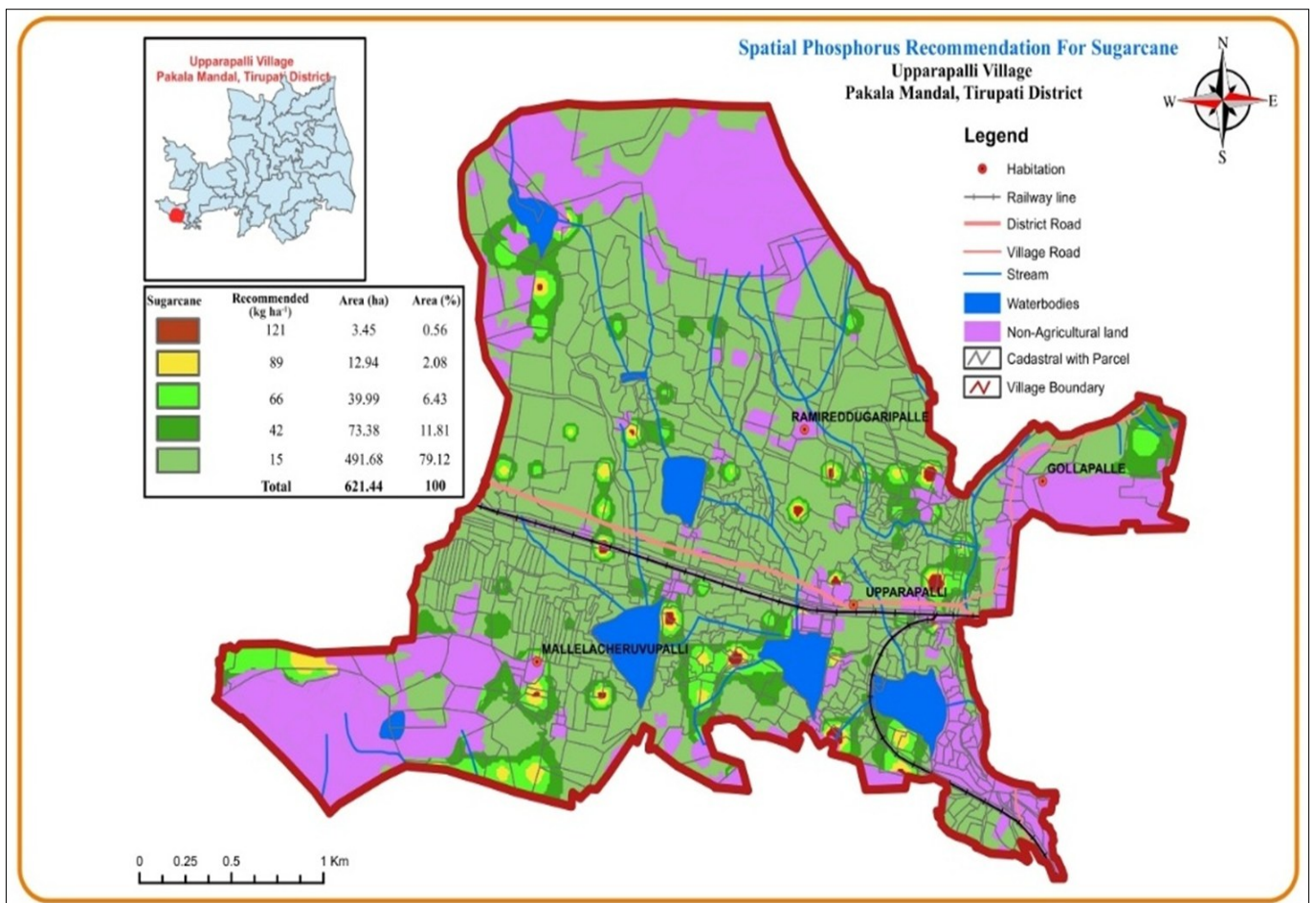


Fig. 11. Spatial phosphorus recommendation map for sugarcane Upparapalli village, Pakala mandal, Tirupati district.

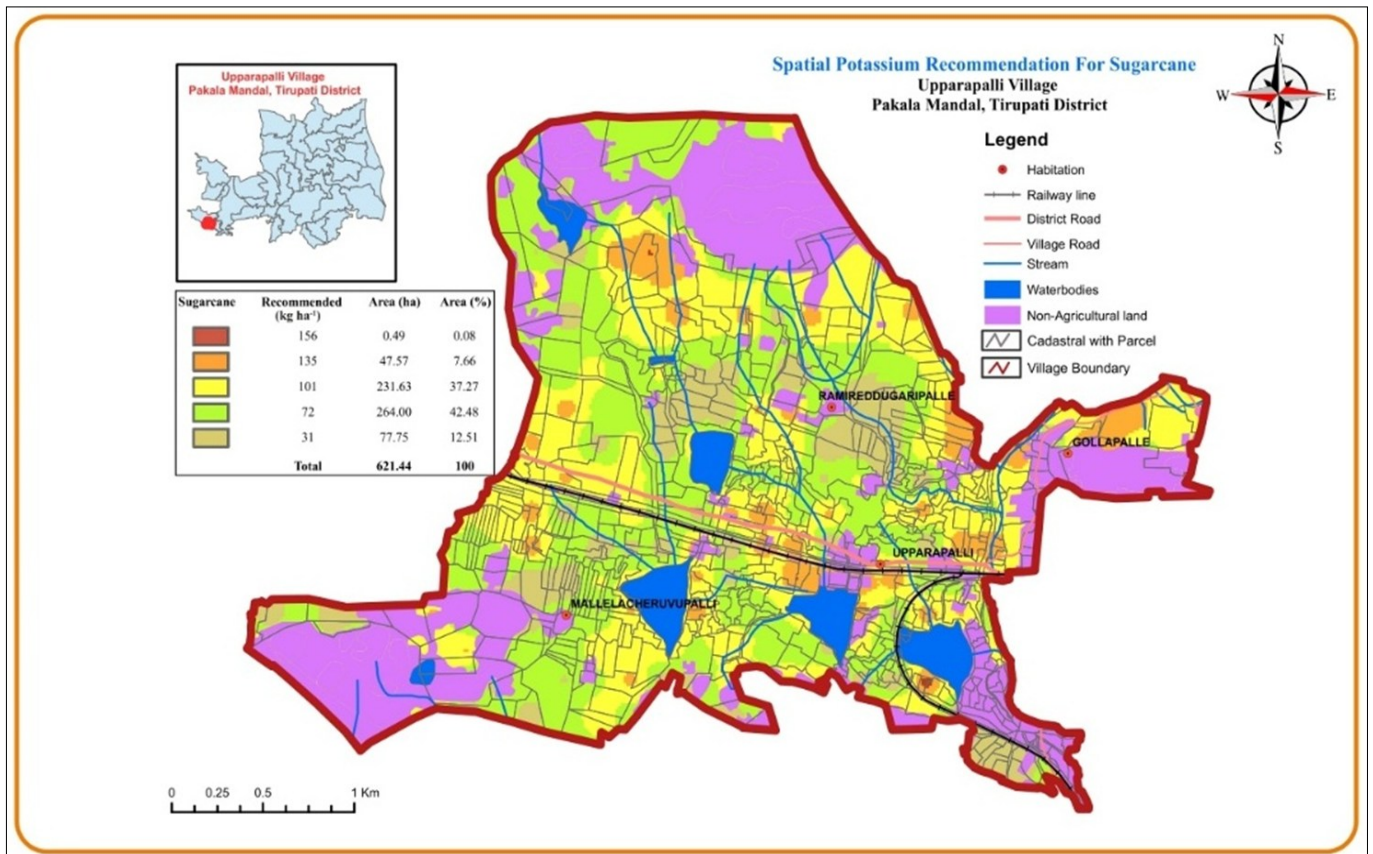


Fig. 12. Spatial potassium recommendation map for sugarcane Upparapalli village, Pakala mandal, Tirupati district.

Other than regions where less than 20 kg ha⁻¹ of available phosphorus is present and in which application is higher than the general recommendation, these specific recommendations by STCR reflect a marked reduction in the use of phosphorus fertiliser relative to the RDF of 112 kg ha⁻¹.

The potassium recommendation map of the Upparapalli village breaks the land into five categories according to the availability of potassium. The highest percentage (42.48 or 264.0 ha⁻¹) comprises the range between 301-400 kg ha⁻¹ and the recommended dosage of potassium is 72 kg ha⁻¹ in this range. There is a large percentage (37.27 %, or 231.63 ha⁻¹) that is classified in the range of 201-300 kg ha⁻¹ and that needs 101 kg ha⁻¹. Smaller categories (12.51 % or 77.75 ha; 7.66 %, or 47.57 ha; and 0.08 % or 0.49 ha) belong to larger classes (> 400 kg ha⁻¹, 135 kg ha⁻¹ and 156 kg ha⁻¹) with recommended doses of 31, 135 and 156 kg ha⁻¹, respectively. The spatially differentiated recommendations with STCR imply that the amount of potassium fertiliser needs to be significantly reduced, compared to the general potassium recommendation of 112 kg ha⁻¹, with the exception of the < 100 kg ha⁻¹ and 101-200 kg ha⁻¹ classes, which have higher needs than the RDF.

Application of fertilisers using the STCR equation at a 120 t ha⁻¹ target yield gave optimum yields of 121.5 t ha⁻¹ in plant crop I, 117.8 t ha⁻¹ at plant crop II and 114.2 t ha⁻¹ at the ratoon crop (29). The STCR strategy at 110 t ha⁻¹ increased yield by 1.0 % relative to the blanket treatment (100 % RDF) and by 3.7 % relative to the farmer practice (30). Experiments on preseasonal sugarcane (ratoon) showed that the application of residual FYM at 30 t ha⁻¹ saved 58.65 kg ha⁻¹ of N, 49.2 kg ha⁻¹ of P₂O₅ and 24 kg ha⁻¹ of K₂O for a 120 t ha⁻¹ yield target and 40.85 kg ha⁻¹ of N, 58.0 kg ha⁻¹ of P₂O₅ and 30.2 kg ha⁻¹ of K₂O for a 140 t ha⁻¹ target (31).

Conclusion

The fertiliser recommendation maps created in ArcGIS v10.3 and STCR equations help in encouraging site-specific nutrient use, where too much fertiliser is not applied to areas that do not need it and reasonable application is done in deficient areas. It showed that 30 kg P ha⁻¹ and 22 kg K ha⁻¹ were saved in groundnut fields and 45 kg P ha⁻¹ and 13 kg K ha⁻¹ were saved in sugarcane fields, without reducing yield. This type of precision farming reduces environmental pollution, nutrient runoff and conserves soil and water resources. Such outcomes are replicated in other areas having similar soils and climate conditions to maintain crop productivity and soil wellbeing.

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Authors' contributions

AAD conducted fieldwork at all locations, collected soil samples with precise GPS recording and analyzed and interpreted the data to prepare the maps. GPL outlined the research framework and provided essential resources, including methodology, equipment and chemicals and played a major role in drafting, reviewing, editing and correcting the manuscript. BV contributed chemicals and instruments and assisted with manuscript review and editing.

GPR contributed to the generation of fertilizer recommendation maps. MVSN assisted in revising and reviewing all analyzed data from the study. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflict of interests to declare.

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