

# Mapping of soil test-based spatial fertilizer recommendations for paddy and maize using GIS, GPS and STCR approaches in a micro-watershed of Karnataka, India

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A case study was undertaken at the Honnavalli micro-watershed of Hassan district, Karnataka, India, to prepare digital maps for site-specific fertilizer recommendations for the major crops (paddy and maize) using STCR approach. The map shows that the recommended dose of N fertilizer for paddy is 148, 111, 82, 54, 26, –8, –67 and –108 kg ha<sup>-1</sup> for the soil available N status <200, 200–250, 250–280, 280–325, 325–375, 375–425, 425–500 and >500 kg respectively. Similarly, for maize it is 290, 286, 283, 281, 279, 276, 268 and 259 kg ha<sup>-1</sup> for <250, 250–275, 275–300, 300–325, 325–350, 350–400, 400–500 and >500 kg ha<sup>-1</sup> respectively. Therefore, the study has implications on reducing consumption of fertilizers (24–45% for N; 12–15% for P and 8–32% for K), thereby reducing the cost of cultivation besides achieving higher nutrient use efficiency.

**Keywords:** Fertilizer recommendations, micro-watershed, paddy, maize, soil nutrients, targeted yield.

THE share of India in the global degraded land area is about 10% (ref. 1). This is largely due to anthropogenic misuse of the soil through non-scientific, indiscriminate and non-sustainable intensive usage of agricultural inputs such as fertilizers<sup>2</sup>. Consequently, poor nutrient use efficiency (30–60%) has been reported in major cereal crops at the national and global levels, besides increasing the cost of the import of fertilizers<sup>3</sup>. Hence, there is a need for the adaptation of suitable practices for fertilizer applications and other operations. To achieve higher nutrient use efficiency and better crop yield, fertilizer recommendation approaches should consider crop needs and the existing soil nutrient pool<sup>4</sup>. The desired balance of nutrients in the soil can be achieved by soil test-based fertilizer recommendations, which also ensure an increase in the efficiency of fertilizer use<sup>5</sup>.

Among various approaches, the target yield-based concept (soil test crop response (STCR) approach) is used for fertilizer recommendation and mapping. This approach is more scientific, fully quantitative, and highly situation-specific (soil–crop–climate)<sup>6</sup>. The yield target can be decreased or increased based on the economic resources of the farmers and the availability of fertilizers. Such fertilizer adjustment equation for obtaining specific yield targets for crops provide the actual balance between soil-available and fertilizer nutrients<sup>7</sup>. Since fertilizer is a costly input, soil test-based fertilizer application considering the target yield of specific crops and soil test values reduce the total amount of fertilizer applied and economizes its usage by avoiding wastage due to over and under-application<sup>8</sup>.

In this background, site-specific agriculture/farming consisting of remote sensing, a global positioning system (GPS) and geographical information system (GIS) can be of use for the assessment and management of soil fertility<sup>9–11</sup>. 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<sup>12,13</sup>. Therefore, to understand the soil's spatial and temporal variability, physico-chemical properties and geo-statistics for specific applications, remote sensing and GIS are the best tools<sup>14</sup>. This helps the farmers identify the right input at the right amount, which not only avoids wastage of inputs but also reduces pollution due to excessive use of inputs. Further, the concept of grid-based fertility assessment and fertilizer recommendation will help supply nutrients according to the crop demand to improve its growth and yield. With this background, we considered the important crops of the study region, viz. paddy which occupies an area of 81.5 ha and maize of 33.5 ha under the Honnavalli micro-watershed in Karnataka, India. These two crops are largely grown with a wide range of fertilizer levels and nutrient use efficiency<sup>15</sup>. Hence, an effort was made to delineate the soil fertility status and fertilizer recommendation mapping to provide balanced nutrition

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through soil test-based fertilizer recommendation using the GIS technique coupled with the STCR approach for sustainable crop production in the study area.

## Materials and methods

### Study area

The Honnavalli micro-watershed (4B4B3T2c, which comes under the Nidnur sub-watershed), located in the Alur Taluk of Hassan district, Karnataka, is delineated and implemented by the Karnataka Watershed Development Project-II (SUJALA-III). The project has a total geographical area of 420 ha and lies between 12°56'4.176"–12°56'58.234"N lat. and 75°54'1.635"–75°54'55.337"E long. at 953 m amsl (refs 15, 16). This watershed belongs to the Argo-climatic Zone No. VII of Karnataka (Southern Transition Zone) and covers 14 taluks in 5 districts with an area of 1.22 m ha. The average minimum and maximum temperatures of this area range from 18.20°C to 29.12°C. The climate is hot, moist, sub-humid and annual rainfall ranges from 612 to 1054 mm. The soils in the micro-watershed are mostly Alfisols and Inceptisols in some parts.

### Methodology of mapping

A preliminary traverse of the entire watershed was carried out with the help of a cadastral map (1:4000 scale), satellite imagery (the merged data of Cartosat-1 (PAN), and Resourcesat-2 (LISS IV)), and Survey of India toposheets. The field boundaries and survey numbers given on the cadastral sheet were located on the ground by following permanent features like roads, cart tracks, canals, streams, tanks, etc. and the changes observed were incorporated on the cadastral map. A handheld receiver (GARMIN, Oregon 650 GPS, GeoVISTA Company, Hyderabad) was used to collect information regarding the geographical location of the ground-truth sites. We collected 105 composite surface (0–15 cm) soil samples during the second fortnight of May 2019 on 400 m grid intervals. The collected soil samples were processed, passed through a 2 mm sieve, and analysed for available nitrogen (N), phosphorus (P<sub>2</sub>O<sub>5</sub>), and potassium (K<sub>2</sub>O) and organic carbon according to the relevant procedures<sup>17–20</sup>. Using the data collected from different locations, the point feature showing the position of samples in MS Excel format was prepared and linked with the spatial data by 'join' option in ArcMap. The spatial and non-spatial databases developed were integrated for the generation of spatial distribution maps.

A base file consisting of data for the *X* and *Y* coordinates with respect to the sampling site location was created. A shape file (vector data) showing the outline of the Honnavalli micro-watershed area was created in ArcView 3.1. Using the database file in the project window, the *X*-field *X*-coordinates and *Y*-field *Y*-coordinates were selected.

The *Z* field was used for different nutrients. Using the Honnavalli micro-watershed shape file, from the 'surface menu' of ArcView spatial analyst, the 'interpolate grid option' was selected. Later, on the output menu 'grid specification dialogue' was selected to choose the Honnavalli micro-watershed grid extend. The map was reclassified based on ratings of the respective nutrients. After the map was prepared, it was clipped to the study area shape, and the final mapping was carried out and exported as .jpeg or .pdf format. By interpolating point data, soil spatial variability maps were prepared. Initially, the geo-referenced soil test results for available nitrogen (N), available phosphorus (P<sub>2</sub>O<sub>5</sub>), and available potassium (K<sub>2</sub>O) were plotted using ARC/Info software (<https://handwiki.org/wiki/Software:ArcInfo>). The interpolation technique used was ordinary kriging. The fertilizer recommendations developed using the fertilizer adjustment equations from STCR were displayed in the form of a spatial fertilizer recommendation map by linking the information with soil fertility maps.

### Fertilizer adjustment equations

The fertilizer recommendations were developed using the fertilizer equations of STCR and displayed in the form of a spatial fertilizer recommendation map by linking the information with soil fertility maps. The fertilizer recommendation maps for different management zones in terms of N, P and K were derived by the kriging interpolation method in the GIS environment<sup>21,22</sup>. The fertilizer adjustment equations developed by the All India Co-ordinated Research Project on STCR, University of Agricultural Sciences, Bengaluru, for the Southern Transitional Zone (zone-VII) were utilized for fertilizer recommendations<sup>6</sup>.

### STCR fertilizer adjustment equations

The fertilizer adjustment equations for paddy (5.0 tonne ha<sup>-1</sup>) are as follows:

$$FN = 5.343807T - 0.690865 SN$$

$$(KMnO_4-N) - 0.00125 OM,$$

$$FP_2O_5 = 1.89835T - 0.660225$$

$$SP_2O_5 (\text{brays } P_2O_5) - 0.0017 OM,$$

$$FK_2O = 4.055729T - 1.023547$$

$$SK_2O (NH_4OAC K_2O) - 0.00328 OM,$$

where FN, FP<sub>2</sub>O<sub>5</sub> and FK<sub>2</sub>O are fertilizers N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O (kg ha<sup>-1</sup>) respectively; *T* the yield target (tonne ha<sup>-1</sup>); SN, SP<sub>2</sub>O<sub>5</sub> and SK<sub>2</sub>O respectively, are the available nutrients, viz. alkaline KMnO<sub>4</sub>-N, Brays P<sub>2</sub>O<sub>5</sub> and NH<sub>4</sub>OAC-K<sub>2</sub>O (kg ha<sup>-1</sup>) and OM is the organic matter supplied through farmyard manure (FYM).

**Table 1.** Soil test-based fertilizer recommendation for paddy in the Honnavalli micro-watershed, Karnataka, India

Soil range (kg ha <sup>-1</sup> )	Nitrogen			Soil range (kg ha <sup>-1</sup> )	Phosphorus			Soil range (kg ha <sup>-1</sup> )	Potassium		
	Area		Recommended N fertilizer (kg ha <sup>-1</sup> )		Area		Recommended P fertilizer (kg ha <sup>-1</sup> )		Area		Recommended K fertilizer (kg ha <sup>-1</sup> )
	(ha)	(%)			(ha)	(%)			(ha)	(%)	
<200	44	10	148	<5	84	20	91	<100	116	28	143
200–250	136	32	111	5–10	136	32	88	100–140	56	13	90
250–280	32	8	82	10–15	116	28	85	140–180	60	14	70
280–325	52	12	54	15–20	40	10	82	180–200	48	11	32
325–375	44	11	26	>20	44	11	46	200–225	28	7	-20
375–425	32	8	-8	-	-	-	-	225–250	32	8	-43
425–500	24	6	-67	-	-	-	-	>300	80	19	-90
>500	56	13	-108	-	-	-	-	-	-	-	-

The Fertilizer adjustment equations for maize (9.0 tonne ha<sup>-1</sup>) are as follows:

$$FN = 3.45T - 0.093 \text{ SN (KMnO}_4\text{-N)},$$

$$FP_2O_5 = 2.00T - 0.31 \text{ SP}_2O_5 \text{ (brays P}_2O_5\text{)}$$

$$FK_2O = 1.04T - 0.046 \text{ SK}_2O \text{ (NH}_4\text{OAC K}_2O\text{)}.$$

## Results and discussion

For site-specific nutrient management, ranges were derived and thematic maps were prepared for the Honnavalli micro-watershed. These maps were prepared using spatial variability of available soil N, P, and K and utilized to establish fertilizer recommendations for paddy and maize. The study area was classified into different fertility zones by considering the soil test values of the major available nutrients. The actual N, P and K fertilizer nutrient recommendations were derived using the fertilizer prescription equations based on the targeted yield approach for the Hassan district.

### Fertilizer recommendation map for paddy

The NPK fertilizer recommendations for paddy grown in various delineated zones of N, P and K were given based on the STCR equations. These equations consider the nutrient requirements for targeted yield as well as the nutrient status of fertilizer resources and soil native nutrients. The general recommendation of NPK dose for paddy is 100–50–50 (N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg ha<sup>-1</sup>) according to the University of Agricultural Sciences, Bangalore Recommendations, 2019 (<https://agriculturalextensionhome.files.wordpress.com/2020/06/uasopkannada.pdf>). Table 1 presents the spatial variability of available N, P and K status in the Honnavalli micro-watershed and the respective fertilizer recommendations for paddy.

### Nitrogen recommendations for paddy

The soil tested value of available N in the Honnavalli micro-watershed was divided into eight ranges for thematic map-

ping of the study area. The result depicts that the maximum 136 ha (32%) area falls under 200–250 kg ha<sup>-1</sup>, followed by 56 ha (13%) under >500 kg ha<sup>-1</sup>, 52 ha (12%) in the range 280–325 kg ha<sup>-1</sup>, 44 ha (11%) between 325 and 375 kg ha<sup>-1</sup>, 44 ha (10%) under <200 kg ha<sup>-1</sup>, 32 ha (8%) between 250 and 280 kg ha<sup>-1</sup>, 32 ha (8%) in the range 375–425 kg ha<sup>-1</sup> and the remaining 24 ha (6%) between 425 and 500 kg ha<sup>-1</sup>. The study recommends fertilizer N using the STCR targeted yield approach @ 148, 111, 82, 54, 26, -8, -67 and -108 kg ha<sup>-1</sup> for the areas of soil test value in the available N range <200, 200–250, 250–280, 280–325, 325–375, 375–425, 425–500 and >500 kg ha<sup>-1</sup> respectively (Figure 1 a). The proposed methodology and implications are in line with the findings of Raddy *et al.*<sup>21</sup>. Similarly, Ammal *et al.*<sup>23</sup> and Verma *et al.*<sup>24</sup> found maximum total N uptake by rice with N application using the STCR approach.

### Phosphorus recommendations for paddy

The soil-tested value of available P was divided into five ranges for thematic mapping of the study area. The result depicts that the maximum area of 136 ha (32%) falls under 5–10 kg ha<sup>-1</sup>, followed by 116 ha (28%) between, 10 and 15 kg ha<sup>-1</sup>, 84 ha (20%) under <5 kg ha<sup>-1</sup>, 44 ha (11%) under >20 kg ha<sup>-1</sup> and the remaining area of 40 ha (10%) between 15 and 20 kg ha<sup>-1</sup>. Using the STCR targeted yield approach, we recommend the fertilizer dosage for P at 91, 88, 85, 82 and 46 kg ha<sup>-1</sup> for the areas of soil test value in the available P range <5, 5–10, 10–15, 15–20 and >20 kg ha<sup>-1</sup> respectively (Figure 1 b). Similar results have been reported in other studies<sup>6,21,25</sup>.

### Potassium recommendations for paddy

The soil test value of available K was divided into seven ranges for thematic mapping of the study area. The result depicts that the maximum 116 ha (28%) area falls under <100 kg ha<sup>-1</sup>, followed by 80 ha (19%) under >300 kg ha<sup>-1</sup>, 60 ha (14%) in the range of 140–180 kg ha<sup>-1</sup>, 56 ha (13%) between 100 and 140 kg ha<sup>-1</sup>, 48 ha (11%) under 100–140 kg ha<sup>-1</sup>, 32 ha (8%) between 225 and 250 kg ha<sup>-1</sup> and

the remaining 28 ha (7%) area between 200 and 225 kg ha<sup>-1</sup>. Using the STCR targeted yield approach, we recommend the fertilizer dosage for K @ 143, 90, 70, 32, -20, -43 and -90 kg ha<sup>-1</sup> for the areas of soil test value in the available K ranges <100, 100–140, 140–180, 180–200, 200–225, 225–250 and >300 kg ha<sup>-1</sup> respectively (Figure 1 c). A similar approach was followed by Raddy *et al.*<sup>21</sup>. The results suggest that we can considerably save fertilizer application to paddy; N by 45%, P by 12% and K by 32% over blanket method of application in the study area. These results conform to the findings of Biradar *et al.*<sup>26</sup> that there is an increase in grain yield of paddy and wheat due to

site-specific nutrient management over the blanket application with an improved use efficiency of about 24%. Basavaraj *et al.*<sup>6</sup> reported that, besides saving on fertilizers, the STCR targeted yield approach produced a higher yield of paddy (4.16 tonne ha<sup>-1</sup>) compared to blanket application practice (3.90 tonne ha<sup>-1</sup>). Ammal *et al.*<sup>23</sup> observed that balanced and need-based fertilizers application according to crop demand might have increased its growth and development, which ultimately enhanced crop yield under STCR.

### Fertilizer recommendations for maize

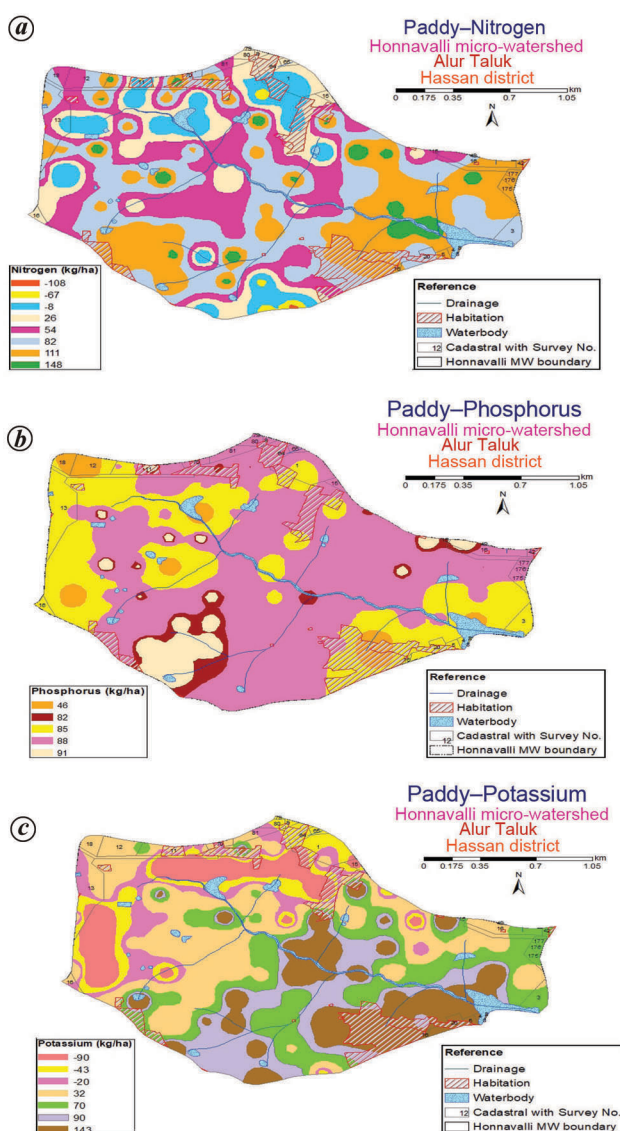
The general recommendation of NPK fertilizers dose for maize is 100–50–25 (N–P<sub>2</sub>O<sub>5</sub>–K<sub>2</sub>O kg ha<sup>-1</sup>) under rainfed conditions according to the University of Agricultural Sciences, Bangalore Recommendations, 2019 (<https://agriculturalextensionhome.files.wordpress.com/2020/06/uaspokannada.pdf>). Table 2 presents the spatial variability of available N, P and K status in the Honnavalli micro-watershed and the respective fertilizer recommendations for maize.

### Nitrogen recommendations for maize

The soil-tested value of available N in the Honnavalli micro-watershed was divided into eight ranges for thematic mapping of the study area. The result depicts that the maximum 180 ha (43%) area falls under <250 kg ha<sup>-1</sup>, followed by 52 ha (12%) under >500 kg ha<sup>-1</sup>, 44 ha (10%) in the range 400–500 kg ha<sup>-1</sup>, 32 ha (8%) between 250 and 275 kg ha<sup>-1</sup>, 32 ha (8%) between 300 and 325 kg ha<sup>-1</sup>, 32 ha (8%) between 350 and 400 kg ha<sup>-1</sup>, 24 ha (6%) between 325 and 350 kg ha<sup>-1</sup> and the remaining 20 ha (5%) between 275 and 300 kg ha<sup>-1</sup>. Using the STCR targeted yield approach, we recommend the fertilizer dosage for N @ 290, 286, 283, 281, 279, 276, 268 and 259 kg ha<sup>-1</sup> for the areas of soil test value of available N range <250, 250–275, 275–300, 300–325, 325–350, 350–400, 400–500 and >500 kg ha<sup>-1</sup> respectively (Figure 2 a). Thus 24% of N fertilizer can be saved using the STCR approach compared to the blanket application. Kumar *et al.*<sup>27</sup> reported similar results. Basavaraj *et al.*<sup>6</sup> noticed that this approach to fertilizer application improves the yield (77.97 q ha<sup>-1</sup>) in maize compared to blanket application (66.77 q ha<sup>-1</sup>) by fulfilling the real demands of crop and soil.

### Phosphorus recommendations for maize

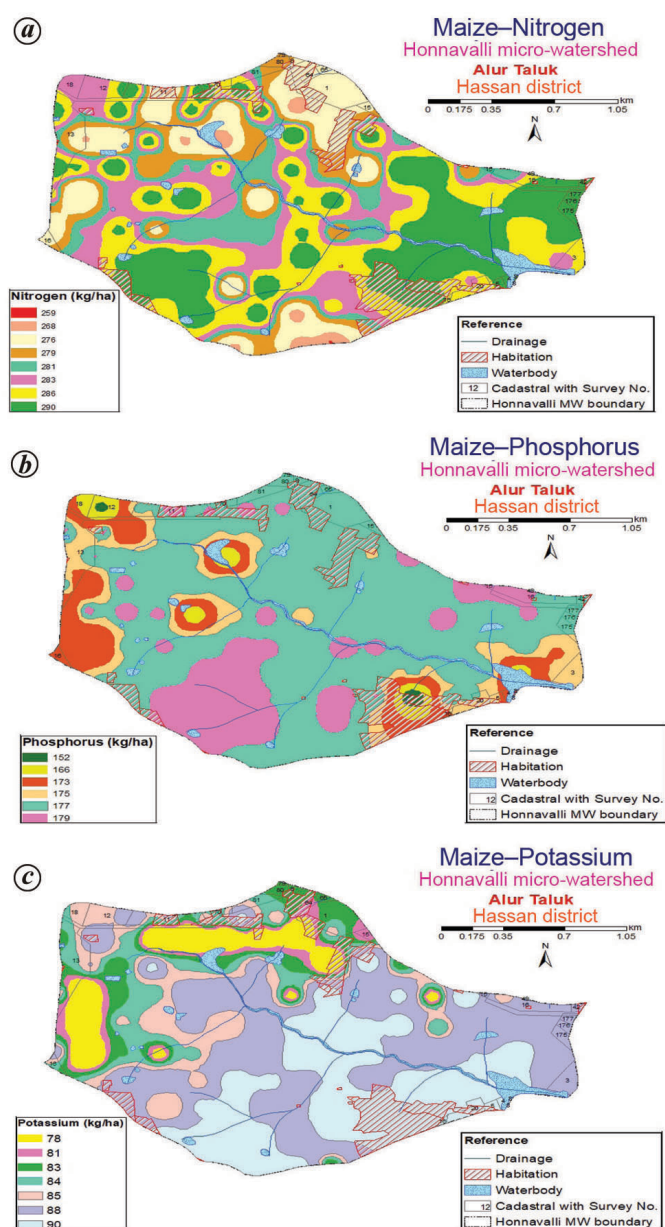
The soil test value of available P in the micro-watershed was divided into six ranges for thematic mapping of the study area. The result depicts that the maximum area of 132 ha (31%) falls under 5–10 kg ha<sup>-1</sup>, followed by 116 ha (28%) between 10 and 15 kg ha<sup>-1</sup>, 84 ha (20%) under <5 kg ha<sup>-1</sup>, 40 ha (10%) between 15 and 20 kg ha<sup>-1</sup>, 32 ha



**Figure 1.** a, Spatial nitrogen fertilizer recommendation map for paddy in the Honnavalli micro-watershed, Karnataka, India (prepared by using the ArcGIS platform). b, Spatial phosphorus fertilizer recommendation map for paddy in the Honnavalli micro-watershed (prepared using the ArcGIS platform). c, Spatial potassium fertilizer recommendation map for paddy in the Honnavalli micro-watershed (prepared using the ArcGIS platform).

**Table 2.** Soil test-based fertilizer recommendation for maize in the Honnavalli micro-watershed

Soil range (kg ha <sup>-1</sup> )	Nitrogen		Recommended N fertilizer (kg ha <sup>-1</sup> )	Soil range (kg ha <sup>-1</sup> )	Phosphorus		Recommended P fertilizer (kg ha <sup>-1</sup> )	Soil range (kg ha <sup>-1</sup> )	Potassium		Recommended K fertilizer (kg ha <sup>-1</sup> )
	Area (ha)	(%)			Area (ha)	(%)			Area (ha)	(%)	
<250	180	43	290	<5	84	20	179	<100	112	27	90
250–275	32	8	286	5–10	132	31	177	100–140	64	15	88
275–300	20	5	283	10–15	116	28	175	140–180	60	14	85
300–325	36	8	281	15–20	40	9	173	180–200	44	10	84
325–350	24	6	279	20–50	16	4	166	200–250	28	7	83
350–400	32	8	276	>50	32	8	152	250–300	32	8	81
400–500	44	10	268	–	–	–	–	>300	80	19	78
>500	52	12	259	–	–	–	–	–	–	–	–



**Figure 2.** *a*, Spatial nitrogen fertilizer recommendation map for maize in the Honnavalli micro-watershed (prepared using the ArcGIS platform). *b*, Spatial phosphorus fertilizer recommendation map for maize in the Honnavalli micro-watershed (prepared using the ArcGIS platform). *c*, Spatial potassium fertilizer recommendation map for maize in the Honnavalli micro-watershed (prepared using the ArcGIS platform).

(8%) under  $>50 \text{ kg ha}^{-1}$  and the remaining minimum area of 16 ha (4%) between 20 and  $50 \text{ kg ha}^{-1}$ . Using the STCR targeted yield approach, the recommended fertilizer dosages for P are @ 179, 177, 175, 173, 166 and  $152 \text{ kg ha}^{-1}$  for the areas of soil test value in the available P range  $<5$ , 5–10, 10–15, 15–20, 20–50 and  $>50 \text{ kg ha}^{-1}$  respectively (Figure 2 b). Hence, 12% of P fertilizer can be saved using the STCR approach compared to the existing blanket application. Dhillon *et al.*<sup>28</sup> and Arvind Verma *et al.*<sup>29</sup> also reported significantly higher grain yield per cob due to the site-specific application of nutrients. Singh *et al.*<sup>30</sup> and Srijaya *et al.*<sup>31</sup> reported that this approach helped in achieving more than 80% yield in different crops. Khurana *et al.*<sup>7</sup> also found this approach to reduce the load of excessive nutrients on the environment.

### Potassium recommendations for maize

The micro-watershed was divided into seven ranges for thematic mapping of the study area based on the soil test value of available K. The result depicts that the maximum 112 ha (27%) area falls under  $<100 \text{ kg ha}^{-1}$ , followed by 80 ha (19%) under  $>300 \text{ kg ha}^{-1}$ , 64 ha (15%) in the range  $100\text{--}140 \text{ kg ha}^{-1}$ , 60 ha (14%) between 140 and  $180 \text{ kg ha}^{-1}$ , 44 ha (10%) under  $180\text{--}200 \text{ kg ha}^{-1}$ , 32 ha (8%) between 250 and  $300 \text{ kg ha}^{-1}$  and the remaining 28 ha (7%) area between 200 and  $250 \text{ kg ha}^{-1}$ . Using the STCR targeted yield approach, we recommend the fertilizer dosage for K @ 90, 88, 85, 84, 83, 81 and  $78 \text{ kg ha}^{-1}$  for the areas of soil test value of available K ranges  $<100$ ,  $100\text{--}140$ ,  $140\text{--}180$ ,  $180\text{--}200$ ,  $200\text{--}250$ ,  $250\text{--}300$  and  $>300 \text{ kg ha}^{-1}$  respectively (Figure 2 c). Hence, 8% of K fertilizer can be saved using the STCR approach compared to blanket application. Likewise, Biradar<sup>32</sup> obtained a higher grain yield ( $9.77 \text{ tonne ha}^{-1}$ ) of maize and growth attributing characters with the application of nutrients by site-specific nutrient management (SSNM) through fertilizers for a targeted yield of  $10 \text{ tonne ha}^{-1}$ . Further, he reported that the magnitude of the increase in maize grain yield using SSNM over recommended dose of fertilizers and farmers' fertilizer practices was 28.6%.

### Conclusion

Soil test-based application of plant nutrients ensures their application in proportion to the magnitude of the deficiency, and the correction of nutrient imbalance in the soil helps harness the synergistic effects of balanced fertilization. The generated fertilizer recommendation maps using the ArcGIS platform would help farmers and researchers in the precise management of nutrients (N, P and K). The results of this study also provide site-specific nutrient recommendations for both paddy and maize in the Honnavalli micro-watershed and have great implications for

the saving of fertilizers N: 45%, P: 15% and K: 32% for paddy, and N: 24%, P: 12% and K: 8% for maize. Therefore, this approach could reduce the excessive use of fertilizers, thereby reducing the cost of inputs for small and marginal farmers. The results of this study could also be replicated in other parts of India with similar soil and climatic characteristics for maintaining crop yield, soil health and nutrient balance.

*Conflicts of interest:* The authors declare that they have no conflict of interest.

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