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Utilising GIS-based spatial land resource analysis for subsidised fertiliser allocation in Jombang Regency, Indonesia

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Highlights
- There is a large gap between the subsidised fertiliser demand and its allocation.
- So far, the calculation of the demand has been based on standard rice field areas only.
- A new perspective takes into account GIS-based multi-land resource data.
- Spatial data need to focus on standardised areas, cropping patterns, and soil N, P, K status.
- This novel approach enables a more precise determination of the local demand.

Abstract: A subsidised fertiliser policy is a clear option to increase rice production and maintain farmer benefits. It has proven to be costly and hence needs to be effectively calculated. This research proposes the use of advanced multidisciplinary techniques to precisely estimate annual fertiliser demands for food production, based on the local field conditions and crop characteristics. Time-series satellite imageries (Landsat 8 Surface Reflectance of Operational Land Imager) were analysed to identify the annual cropping patterns, delineate agricultural field boundaries, and estimate land area. Monitoring and data collection on cropping patterns were conducted using normalised difference vegetation index (*NDVI*) data. The corrected rice field maps and cropping patterns were validated through field inspections. Subsequently, soil sampling and analysis were performed to determine precise fertiliser doses for each crop during each planting season. Finally, a fertiliser demand allocation map was created to inspect the results visually. A case study conducted in Jombang Regency, East Java Province, Indonesia, highlighted a gap of approximately 5.91 Mg urea and 1.02 Mg NPK in fertiliser demand measured using this study method as compared to the current subsidised fertiliser allocation. This gap could lead to an ineffective use of the fertiliser subsidy budget, which could jeopardise achieving the national food production target. Therefore, this study urges government stakeholders to implement the proposed method to maintain national food security in the country.

Keywords: fertiliser demand, fertiliser subsidy, food security, land resources, precision farming

INTRODUCTION

To support national food security, the Indonesian government is also making efforts to improve the subsidised fertiliser governance. These include digitalising the distribution and redemption of subsidy, as well as compiling data on fertiliser subsidy recipients to ensure more targeted allocation. The mechanism for proposing subsidised fertiliser allocation will use land area data registered in the Simluhtan database, which includes information by name and address

(Kementerian Koordinator Bidang Perekonomian, 2022; Kementerien Pertanian, 2022). Despite the long-standing implementation of the fertiliser subsidy policy, recurring issues have not been resolved. The proposed demands and the government's allocations still differ significantly, leading to either a shortage or surplus of fertiliser. This mismatch has occurred every year until now, especially during the rice planting season, which begins in early November and reach its peak in December–January (Sarwani, 2022).

Spatially derived land resource information is crucial for advancing precision agriculture, prioritising tailored input usage based on data and production insights. This approach aims to enhance efficiency, productivity, and profitability across the agricultural supply chain (Whelan and Taylor, 2013; Adi *et al.*, 2021). Geographical Information System (GIS) technology has the potential to enhance agricultural sustainability by integrating the spatial dimension of agriculture into agricultural policies. In addition, GIS's potential to promote evidence-based, informed decision-making is growing. There is an increased need for the integration of GIS in policy and decision-making to accurately determine fertiliser demand on a national scale to support agricultural sustainability (García-Berná *et al.*, 2020; Weiss, Jacob and Duveiller, 2020; Mathenge, Sonneveld and Broerse, 2022; Liu *et al.*, 2023).

Until now, the determination (calculation) of subsidised fertiliser demands in Indonesia has relied solely on a map of standard rice field areas (*SRFA*) derived from statistical yearbook data. As a result, it is unsurprising that shortages of subsidised fertiliser occur during the peak rice planting season. This issue most likely arises because the calculations of fertiliser demand for a particular area do not consider the main influencing factors, such as the type of crops planted and cropping patterns, which can vary significantly between fields and across different seasons each year. Additionally, the soil fertility status, especially the N, P, and K nutrient status, has not been considered in calculations. Therefore, a new perspective is needed – one that formulates the amount of subsidised fertiliser demand by incorporating the multi-source data of land resources, as explained above, and processing it using GIS technology. By employing this method, it is expected that crop productivity can be increased, and the main causes of the scarcity of subsidised fertilisers in Indonesia can be overcome. Information on these spatial land resources is necessary not only for determining the accurate fertiliser demand but also to implement a precision farming system that provides sustainable high productivity (Weiss, Jacob and Duveiller, 2020; Mathenge, Sonneveld and Broerse, 2022; Liu *et al.*, 2023).

Jombang Regency is one of the main rice-producing areas in East Java. However, along with the rapid development of industrial and residential areas, many rice fields have changed their function. Therefore, accurate data on standard rice field area, cropping patterns, and soil nutrient status must be updated for determining accurate subsidised fertiliser demand, especially for such staple food crops as rice, maize, and soybeans. To support this effort, a study is needed to create a model for calculating the amount of subsidised fertiliser required for the regency. This model would serve as a basis for submitting fertiliser requirements to the provincial and ministerial levels. It is expected that the determination of fertiliser demand per season based on the land resources approach in Jombang Regency, East Java Province, can serve as a new framework that could be applied in other provinces, ultimately becoming a standard model for calculating the national fertiliser demand. In this context, the current study proposes a model for calculating subsidised fertiliser demand in Jombang Regency, based on land resource data and applying GIS technology.

MATERIALS AND METHODS

STUDY AREA

A case study determining fertiliser demand was conducted in Jombang Regency, East Java Province, Indonesia. Geographically, the study site is in 7°20'–7°46' S and 112°03'–112°27' E, in the eastern part of Java Island (Fig. 1). Jombang Regency's annual rainfall ranges from 1,686 mm to 2,570 mm. The air temperature ranges between 27 and 33°C. The peak of average rainfall occurs in January, whereas the lowest precipitation occurs in August and September. Based on the analysis of rainfall data, the research area is classified as a C3 agro-climatic zone, where the wet period (rainfall >200 mm per month) lasts for 5–6 consecutive months and the dry period (rainfall <100 mm per month) lasts for 4–6 months (Oldeman, 1975).

The total area of paddy fields in the regency is about 40,613 ha, accounting for about 36.2% of its total administrative area (ATR/BPN, 2019). The dominant landform groups in Jombang Regency are alluvial, volcanic, and tectonic, which developed from alluvium, volcanic, and sedimentary deposits. Paddy fields formed from alluvium deposits in the form of dust and clay with a fine soil texture are spread across the central part of Jombang Regency (north and south of the Brantas River), covering an area of 13,573 ha (30.12%) (Noya *et al.*, 1992; Santosa, 1992).

MATERIALS AND DATA

This study utilised soil characteristics as primary data to determine soil nutrient status, serving as a basis for estimating fertiliser demand. Field soils were characterised based on soil samples that were collected during a soil survey. A total of 85 representative soil samples were collected compositely at a depth of 0–20 cm, representing the parent material, land management practices (e.g. cropping patterns and terraces), and paddy field typology. Soil was sampled using a soil auger, and sample geographic locations were recorded using the Avenza Maps application. Soil sampling locations are presented in Figure 2. These soil sampling points formed the basis for determining the soil nutrient status distribution using GIS, taking into consideration the typology of rice fields (Sukarman, Setyorini and Ritung, 2012; Prasetyo and Thohiron, 2013; Liu *et al.*, 2023).

Satellite imageries were utilised as secondary data to identify annual cropping patterns, agricultural field boundaries, and land area. The cropping patterns in the study area were identified using Landsat 8 Surface Reflectance of Operational Land Imager (OLI) images at 30 m spatial and 16-day temporal resolution (path/row 118065 and 119065) from January 2018 to June 2019 (1.5 years). The precise field boundary was digitised from current satellite images of Bing Maps.

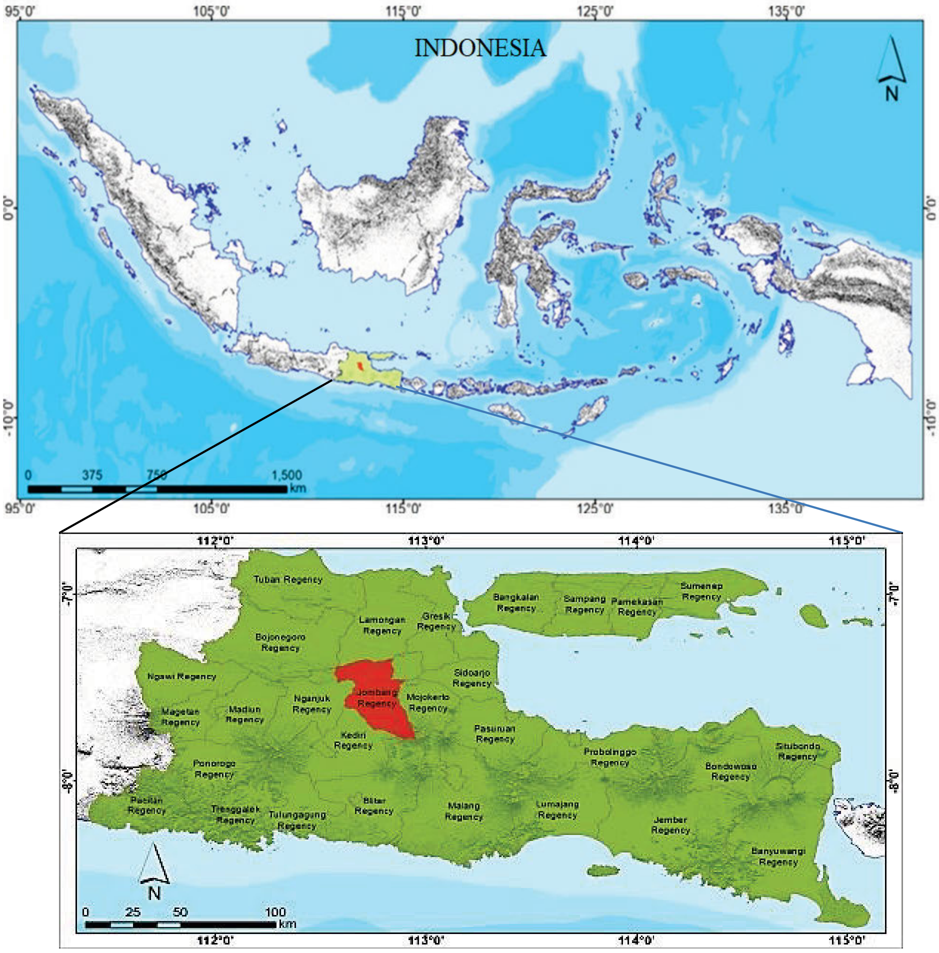


Fig. 1. Geographic location of the study area, Jombang Regency, East Java Province, Indonesia; source: own elaboration

Fig. 2. Soil sampling map; source: own elaboration

VALIDATION OF RICE FIELDS

The corrected rice field maps and cropping patterns were validated in the field. Validation of rice fields through ground truthing involved field extension officers using the Avenza Map. The accuracy of the rice field spatial data was evaluated by comparing the corrected rice field data with real field conditions, both spatially and in tabular form. This comparison was carried out using a correlation/unification process known as a confusion matrix. The accuracy results are presented in the form of a confusion matrix, which describes the relationship between actual conditions in the field and the corrected paddy field data expressed as percentages and Kappa coefficient values. Mapping accuracy was calculated using the following formula (Congalton, 1991; Jensen, 1996; Fielding and Bell, 1997):

$$MA = \frac{X_{\text{crpixel}}}{X_{\text{crpixel}} + X_{\text{opixel}} + X_{\text{copixel}}} \tag{1}$$

where: MA = mapping accuracy, X_{crpixel} = number of corrected class X, X_{opixel} = number of class X that enter other classes (omission), X_{copixel} = number of additional class X from other classes (commission).

The calculation results were then expressed in tabular form as a confusion matrix. In the ideal case, all non-diagonal elements of the confusion matrix calculation are all zero, indicating there was no error in the results (misclassification). The Kappa coefficient value was calculated based on Equation (2):

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum(X_{i+} \cdot X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} \cdot X_{+i})} \tag{2}$$

where: K = coefficient of accuracy, N = number of observations, r = the number of rows in the matrix, X_{ii} = number of observations in row i and column i, X_{i+} = number of marginal in row i, X_{+i} = number of marginal in column i.

The criteria for the accuracy of the correction results for paddy fields are based on the modified classes proposed by Forbes, Rossister and van Wambeke (1983), namely:

a) high precision, if it has a purity of ≥85%;
b) medium precision, if it has a purity of (50–85%);
c) low precision, if it has a purity of <50%.

The accuracy of the classification of correction results used the Kappa coefficient (Landis and Koch, 1977) with the following criteria:

a) high accuracy, if it has a coefficient ≥0.75;
b) medium accuracy, if it has a coefficient (0.40–0.75);
c) low accuracy, if it has a coefficient <0.40.

CROPPING PATTERN

In the current study, monitoring and data collection on cropping patterns were conducted using the moderate resolution imaging spectroradiometer (MODIS) to analyse the normalised difference vegetation index (*NDVI*) data (Wahyunto and Heryanto, 2006; Setiawan *et al.*, 2014; Ardiansyah, Subiyanto and Sukmono, 2015; Chen *et al.*, 2018; Li *et al.*, 2023). Apart from correcting the paddy field boundaries, cropping patterns in the paddy fields were also identified. The cropping pattern identification process was carried out using the open-source Quantum Geographic Information System (QGIS) software, version 3.22. The *NDVI* data for 1.5 years was stacked into a single dataset, with the first layer representing early January 2018 sequentially continuing until the final layer in June 2019 (Fig. 3).

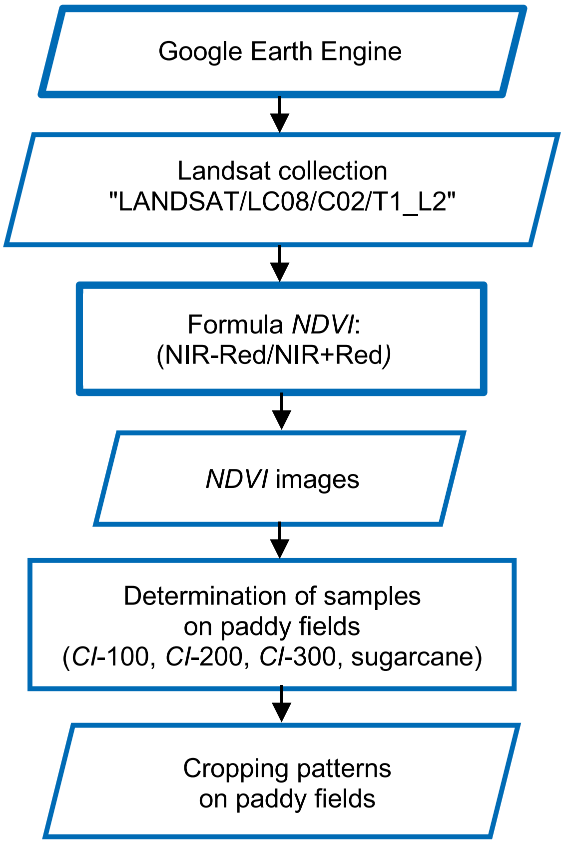


Fig. 3. Research flowchart in identifying cropping patterns in rice field areas; *NDVI* = normalised different vegetation index, LANDSAT/LC08/C02/T1_L2 = dataset contains atmospherically corrected surface reflectance and land surface temperature derived from the data produced by the Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) instruments, NIR = spectral channel in the red wavelength range (channel 4 for Landsat 8), RED = spectral channel in the near-infrared wavelength range (channel 5 for Landsat 8), *CI* = cropping index; source: own elaboration acc. to Wahyunto and Heryanto (2006), Setiawan *et al.* (2014), Ardiansyah, Subiyanto and Sukmono (2015), Chen *et al.* (2018), and Li *et al.* (2023)

SOIL NUTRIENT STATUS

The nutrient status of nitrogen, phosphorus, and potassium (NPK) in the soil was determined based on the results of soil laboratory analysis. The selected soil parameters included percent of N-total (Kjeldahl), P_2O_5 (phosphorus pentoxide), K_2O (potassium oxide) concentration (extracted using 25% hydrochloric acid (HCl)), and percentage of soil texture (pipette) (Eviati *et al.*, 2023). Criteria for determining the NPK nutrient status are presented in Table 1 (Husnain, Kasno and Rochayati, 2016).

Table 1. Criteria for N, P, and K status

Status of NPK nutrients	Assessment criteria		
	N-total (%)	P_2O_5	K_2O
		mg·(100 g)$^{-1}$	
Low	0.20	<20	<10
Medium	0.20–0.50	20–40	10–20
High	>0.50	>40	>20

Explanations: NPK = nitrogen, phosphorus, and potassium, P_2O_5 = phosphorus pentoxide, K_2O = potassium oxide.
Source: Husnain, Kasno and Rochayati (2016).

FERTILISER DEMAND

The NPK fertiliser demand at each soil sample location was estimated using a plant nutrient balance approach. This approach considers the nutrient status of N (total), potential P, and potential K as the basis for NPK demand estimation. The demand for NPK for every 1 Mg of rice grain is 17.5 kg of N, 3 kg of P, and 17 kg of K (Dobermann and Fairhurst, 2000). For this study, the productivity targets for paddy, maize, and soybeans were 8, 10, and 1.5 Mg·ha^{-1}, respectively. The subsidised fertiliser used included NPK (15:15:15), urea, and KCl.

Fertiliser demand at the soil sampling location was extrapolated into 2-dimensional field polygon data. The extrapolation process considered a unique combination of soil type, parent material, land management, field biology, and NPK status to form a land unit. The annual fertiliser demand for each land unit was then calculated based on the identified cropping patterns. The annual fertiliser demand for particular land units was the basis for calculating the annual total fertiliser demand in Jombang Regency. A 2-D digital map that includes information on fertiliser demand per sub-district in the Jombang Regency was also generated during the analysis. Management of spatial data on fertiliser demand used the GIS concept (Fig. 4).

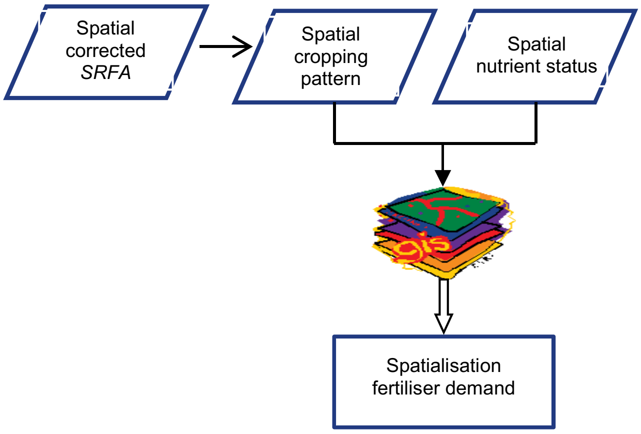


Fig. 4. The flow of spatialisation of fertiliser demand; *SRFA* = standard rice field areas; source: own elaboration

RESULTS AND DISCUSSION

STANDARD RICE FIELD AREA

The results of field verification (ground truthing) to test the accuracy of the correction results for the distribution of rice fields based on the purity of each delineation are presented in Table 2. It showed that the correction for rice fields had an overall accuracy of 100% and a Kappa coefficient (K) of 1.0. In the current study, the Kappa coefficient was rated as high accuracy (Landis and Koch, 1977), and the overall accuracy was rated as high precision (Forbes, Rossister and van Wambeke, 1983). These results suggest that the corrected *SRFA* data are suitable for further research and applicable for various practical uses.

Based on data from ATR/BPN (2019), standard rice fields areas (*SRFA*) Jombang Regency account for 40,669 ha. The validation results revealed that Jombang Regency's rice fields cover an area of 45,465 ha (Tab. 3). This result is 4,796 ha greater than the *SRFA* data reported by ATR/BPN (2019). This significant discrepancy is likely due to the less intensive verification process in the preparation of the SRFA, which did not include the participation of extension officers familiar with the distribution of rice fields in target villages. According to the 2020 agricultural statistical data, the *SRFA* in Jombang Regency was 48,446 ha (BPS Jombang, 2019). The difference of 8,000 ha was most likely due to land used for sugarcane, which was until 2020 was still recorded as rice fields, although it had actually transitioned to dryland use. Therefore, in determining the amount of subsidised fertiliser needed, the corrected rice field area of 45,465 ha was used. Following these results, Rwanga and Ndambuki (2017) performed a study using remote sensing and GIS techniques with two Landsat satellite images (Landsat 8 OLI/TIRS) to map land-use and land-cover areas. They found an overall classification accuracy of 81.7% and a Kappa coefficient of 0.72, indicating substantial accuracy; hence, the classified image was deemed suitable for further study.

The typology of rice fields in Jombang Regency was dominated by irrigated rice fields (85.23%), and the remainder were rain-fed rice fields (14.77%). Details of the standard area of rice fields from the validation of Jombang Regency are presented in Table 4 and their distribution in Figure 5.

Table 2. Matrix of accuracy test of rice fields in Jombang Regency

Type of land	Rice field	Non-rice field	Total	Accuracy (%)	Kappa coefficient
	field verification				
Rice field	40	0	40	100	1.0
Non-rice field	0	10	10	100	1.0
Total	**40**	**10**	**50**	**100**	**1.0**

Source: own study.

Table 3. Details of the standard area of rice fields from validation results in Jombang Regency, East Java

Sub-district	Area of rice fields (ha)		
	acc. to BPS (2019)	standard rice field area (2019)	satellite image analysis (2020)
Bandar Kedung Mulyo	2,113	2,191	2,462
Bareng	3,191	1,963	2,894
Diwek	2,961	1,968	2,213
Gudo	2,580	2,051	2,470
Jogo Roto	1,746	1,414	1,514
Jombang	1,693	1,233	1,718
Kabuh	2,352	2,666	3,459
Kesamben	3,715	2,929	3,528
Kudu	1,542	1,135	1,258
Megaluh	1,853	2,094	2,307
Mojoagung	2,221	2,031	1,394
Mojowarno	3,885	3,735	3,286
Ngoro	3,092	2,179	2,525
Ngusikan	1,224	735	1,016
Perak	2,010	1,413	1,769
Peterongan	1,891	1,761	1,788
Plandaan	2,308	2,638	2,651
Ploso	1,970	1,718	1,881
Sumobito	3,379	2,848	3,038
Tembelang	2,260	1,865	2,220
Wonosalam	460	101	74
Total	**48,446**	**40,669**	**45,465**

Source: own study.

Table 4. Matrix used to test the accuracy of cropping patterns in Jombang Regency

Cropping index	Field verification				Total	Accuracy (%)
	CI-100	*CI*-200	*CI*-300	sugar-cane		
CI-100	6	1	0	0	7	86
CI-200	0	6	1	0	7	86
CI-300	0	0	7	0	7	100
Sugarcane	0	0	0	7	7	100
Total (producer)	**6**	**7**	**8**	**7**	**28**	**93**

Explanation: *CI* = cropping index.
Source: own study.

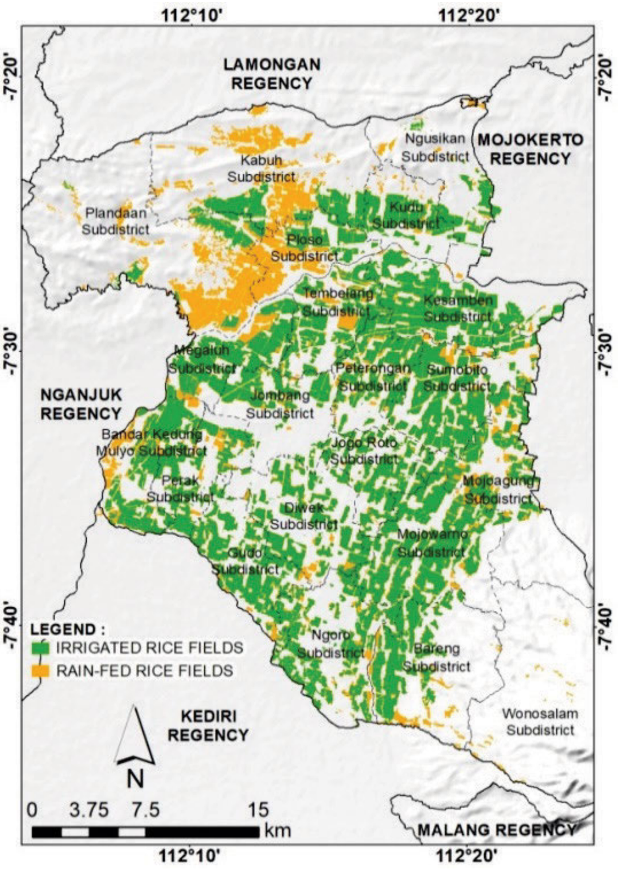


Fig. 5. The validated standard area of rice fields in Jombang Regency, East Java; source: own study

CROPPING PATTERN

In crop cultivation, cropping patterns are a key factor in determining the need for fertilisers. Therefore, identifying cropping patterns in real-time is essential to prevent misallocation of fertilisers and support the achievement of food security through precision agriculture. In the current study, cropping patterns were determined by sampling for each cropping index (*CI*) for rice and sugarcane to capture the *NDVI* signatures representative of each cropping pattern in paddy fields. Each sample involved nine pixels, with the mean *NDVI* value used to create the cropping pattern (Chen *et al.*, 2018). The *NDVI* value from each sample was processed using Excel software to analyse the graphic pattern (Figs. 6 and 7).

The graph for *CI*-100 rice shows a peak within a period <120 days (rice growth) and a regular increase in *NDVI* values until reaching the maximum. The *CI*-200 rice graph shows two peaks for <240 days and a regular increase in *NDVI* values until reaching their maxima. Meanwhile, the *CI*-300 rice graph shows three peaks throughout the year (360 days), with steady increase in *NDVI* values until reaching their maxima (Fig. 6).

For sugarcane, the graph shows the growth from June 2018 to June 2019, and the *NDVI* value increases regularly until it reaches the maximum value and then decreases (Fig. 7).

The results of field verification (ground truthing) to test the accuracy of the cropping pattern distribution (Tab. 4) based on the purity of each delineation showed that the cropping pattern correction results had a purity of 93% and a Kappa coefficient of 0.9 (high). Meanwhile, Chen *et al.* (2018) carried out a study aimed at developing a new approach to identify major cropping patterns for soy-maize, soy-cotton, soy-pasture, soy-fallow, fallow-cotton, and single crop, using MODIS *NDVI* time-series data in the state of Mato Grosso, Brazil. This study revealed that the new approach was successful and enabled to identify and map cropping patterns with an accuracy of 73%.

Interviews with farmers helped to collect information about which crops to plant after rice or what cropping patterns farmers would apply in the growing season (GS) the following year. The results showed that rice was planted in the first growing season (GS1), the second growing season (GS2), and the third growing season (GS3). Maize, tobacco, and horticultural commodities (watermelon) were grown in GS2 and GS3. Rice fields in the research area generally had *CI*-300 with several cropping patterns but *CI*-200 of rice dominated (76.0%) Jombang Regency, and the cropping pattern of rice-paddy-maize had a wide distribution (21,598 ha). Meanwhile, *CI*-300 of rice was spread over an area of 5,049 ha, or 11.1% of the standard rice field area. Details of cropping patterns in Jombang Regency are presented in Table 5.

NITROGEN (N), PHOSPHORUS (P), AND POTASSIUM (K) NUTRIENT STATUS

The soil sample analysis showed that rice fields in Jombang Regency have low N status, high P status, whereas K status varies from low to high (Tab. 6) (Dobermann and Fairhurst, 2000). The presence of low N cannot be separated from the unstable nature of N in the soil, as it easily changes and is lost through volatilisation, leaching, or changing its form to become unavailable to plants (Qiu *et al.*, 2022). The high P levels indicate significant P accumulation in the soil. The P is likely derived from the parent material and the long-term application of inorganic P fertilisers. Typically, plants absorb only about 25–30% of the P applied as fertiliser. In addition, due to its low solubility, P becomes fixed by other elements in the soil, forming complex compounds (Rivaie *et al.*, 2008; Penn and Camberato, 2019). Meanwhile, K content varied from low to high in the soil at the study site; this is most likely related to the influence of the parent soil material, land position, and the source of irrigation water (Kasno *et al.*, 2021). The distribution and area for each combination of N, P, and K nutrient status are presented in Table 6, and the spatial distribution is presented in Figure 8.

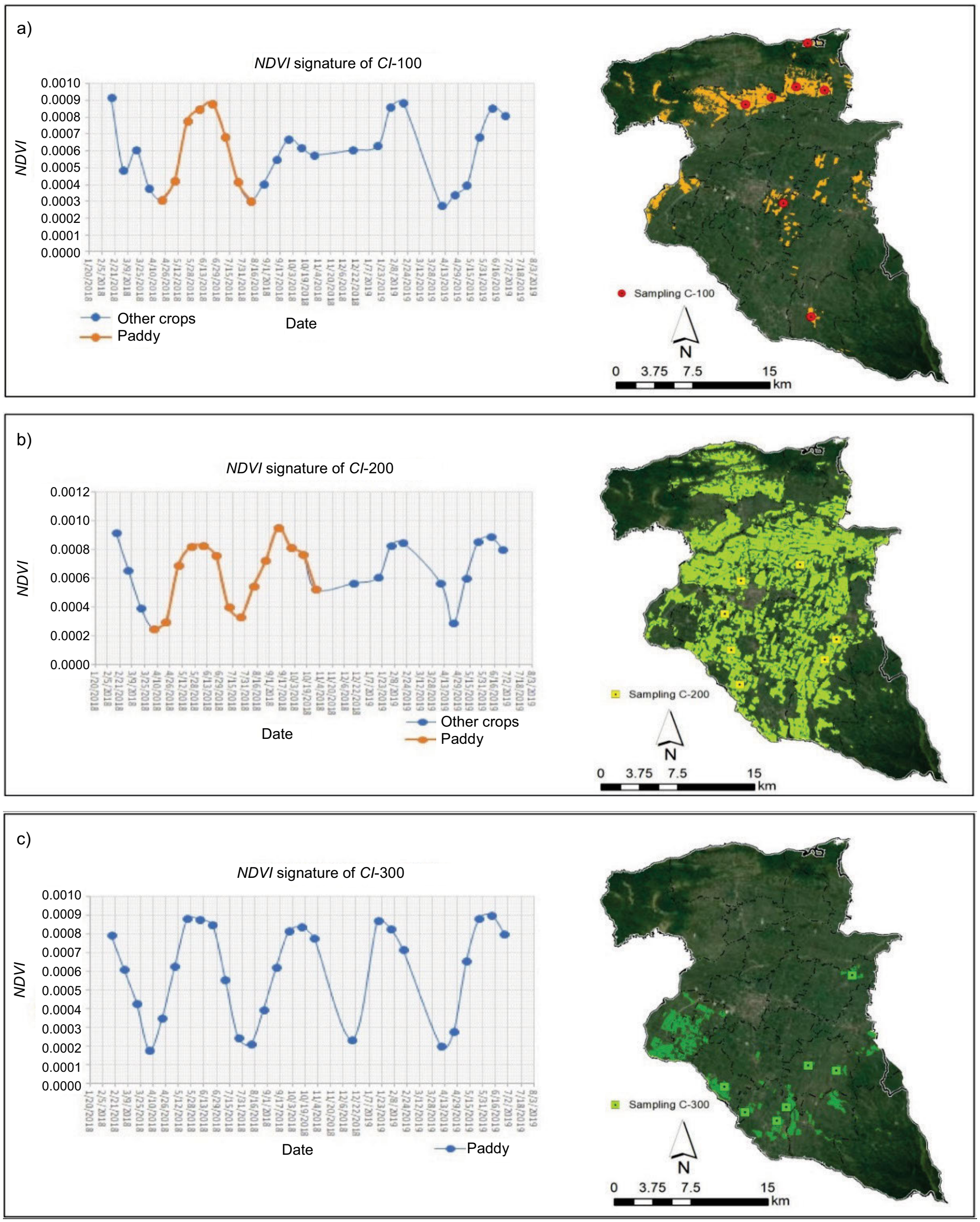


Fig. 6. Pattern of normalised different vegetation index (*NDVI*) for different cropping index (*CI*) of rice: a) *CI*-100, b) *CI*-200, c) *CI*-300; source: own study

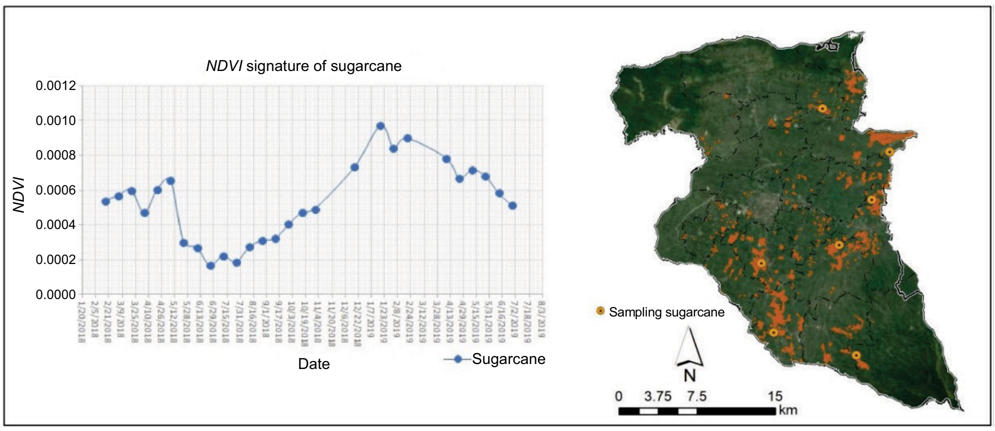


Fig. 7. Pattern of normalised different vegetation index (*NDVI*) for cropping index (*CI*) of sugarcane; source: own study

Table 5. Details of cropping patterns on rice fields in Jombang Regency, East Java

Sub-district	Cropping pattern											Total
	RVM	RVT	RMV	RMM	RMS	RRV	RRM	RRR	RRT	RTF	RTM	
Bandar Kedung Mulyo	–	–	439	88	–	87	683	1,164	–	–	–	2,462
Bareng	–	–	–	6	–	–	2,168	719	–	–	–	2,894
Diwek	–	–	–	–	–	–	2,136	77	–	–	–	2,213
Gudo	–	–	–	–	–	–	1,939	531	–	–	–	2,470
Jogo Roto	–	–	–	312	156	–	1,007	–	39	–	–	1,514
Jombang	–	–	–	–	1	527	1,169	21	–	–	–	1,718
Kabuh	–	2	–	–	–	–	–	–	3,457	–	–	3,459
Kesamben	–	–	–	–	–	–	3,510	17	–	–	–	3,528
Kudu	–	71	119	20	13	29	285	–	–	109	612	1,258
Megaluh	–	–	–	42	–	1,548	717	–	–	–	–	2,307
Mojoagung	–	–	–	279	–	–	914	201	–	–	–	1,394
Mojowarno	–	–	–	27	–	–	2,987	272	–	–	–	3,286
Ngoro	–	–	–	–	–	549	1,174	802	–	–	–	2,525
Ngusikan	47	121	–	175	–	–	661	–	–	–	12	1,016
Perak	–	–	–	–	–	70	613	1,087	–	–	–	1,769
Peterongan	–	–	15	82	22	–	1,669	–	–	–	–	1,789
Plandaan	46	888	410	–	36	1,016	123	–	–	15	116	2,651
Ploso	–	1,186	8	23	–	284	379	–	–	1	–	1,881
Sumobito	–	–	166	–	188	6	2,544	135	–	–	–	3,038
Tembelang	–	–	–	–	–	107	2,113	–	–	–	–	2,220
Wonosalam	–	–	–	10	–	–	42	23	–	–	–	74
Total	**94**	**2,267**	**1,158**	**1,064**	**415**	**4,223**	**26,834**	**5,049**	**3,496**	**125**	**740**	**45,465**

Explanations: RVM = rice-veges-maize, RVT = rice-veges-tobacco, RMV = rice-maize-veges, RMM = rice-maize-maize, RMS = rice-maize-soybean, RRV = rice-rice-veges, RRM = rice-rice-maize, RRR = rice-rice-rice, RRT = rice-rice-tobacco, RTF = rice-tobacco-fallow, RTM = rice-tobacco-maize.
Source: own study.

FERTILISER DEMAND

Subsidised fertiliser is expected to encourage farmers to adopt fertilisation technology, thereby boosting productivity and income (Kasiyati and Santosa, 2010). However, due to the actual size of rice fields, cropping patterns and soil NPK status are not considered when calculating fertiliser demand within farmer groups, imbalances frequently occur – resulting in shortages for some farmers, while others experience surpluses. By using GIS, which is based on spatial data of paddy fields, cropping patterns, and soil NPK status, it is expected that fertiliser requirements per planting season in Jombang Regency can be estimated. In China, research has shown that the supply and demand structure for chemical fertilisers in a province is primarily influenced by factors such as the application of chemical fertilisers and yield. At the provincial level, key drivers for applying chemical fertiliser include soil type, crop variety, fertility period of crops, and the growing urbanisation trend. However, this study had limitations because relied on the statistical yearbook and singular data (Qu *et al.*, 2022). They neither use observation data nor consider impact factors, such as land use types or cropping patterns.

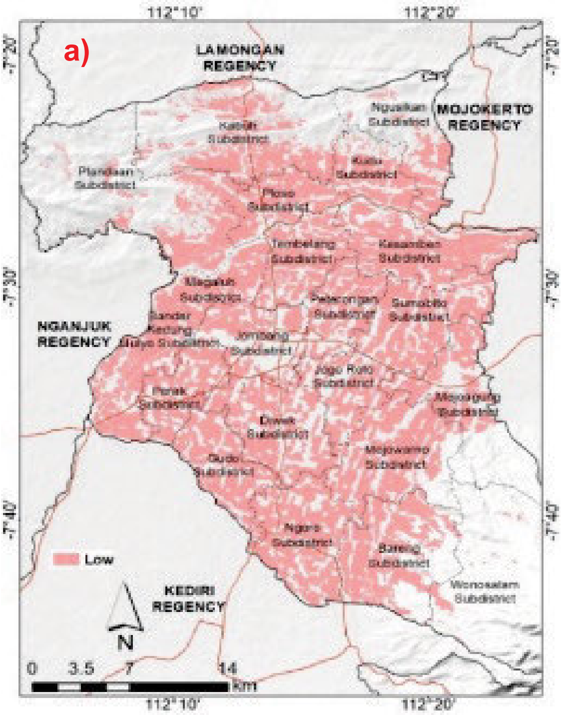
Based on the nutrient status of N, P, and K and soil texture, the urea requirement for rice is estimated around 250–300 kg·ha^{-1} and NPK (15:15:15) around 150–200 kg·ha^{-1}; the urea requirement for maize is around 200–250 kg·ha^{-1} and NPK (15:15:15) ranges from 250 to 275 kg·ha^{-1}; while NPK (15:15:15) for soybeans ranges from 120 to 150 kg·ha^{-1} and K ranges from 12.45 to 24.89 kg·ha^{-1} (Tab. 7). The results of the data analysis show that in a single year, the demand for fertiliser for rice, maize, and soybeans in Jombang Regency was 17,993 Mg of N, equivalent to 32,089 Mg of urea; 3,382 Mg of P_2O_5; and 3,387 Mg of K_2O was equivalent to 22,542 Mg of NPK (15:15:15), and 4 Mg of KCl (Tab. 8).

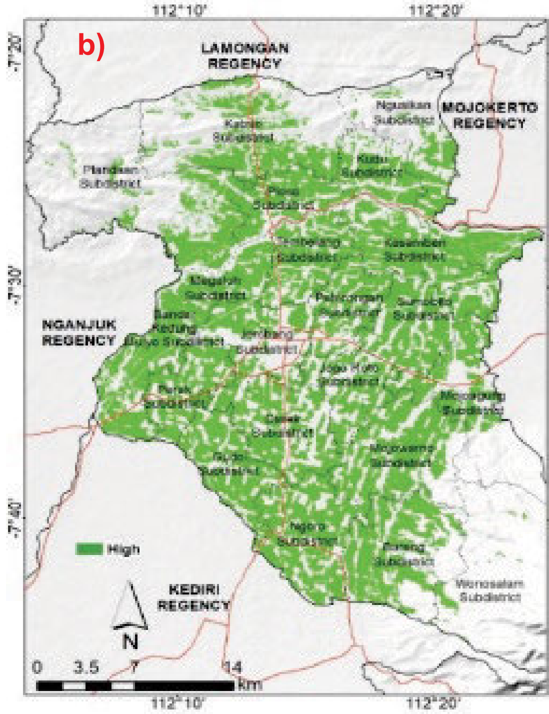
In the first growing season (GS1), all 45,465 ha of rice fields were planted with rice (Tab. 7). Rice planting started from the 4th week of November and continued until the 1st week of December in GS1. The analysis showed that fertiliser demand in GS1 was 7,033 Mg of N, which is equivalent to 12,819 Mg of urea, 1,136 Mg of P_2O_5, and 1,136 Mg of K_2O, which is equivalent to 7,573 Mg of NPK (15:15:15). Fertiliser demand figures in GS1, GS2, and GS3 are presented in Table 8, while the spatial distribution of fertiliser in GS1 is presented in Figure 9a. Meanwhile, in GS2, the

Table 6. Details of combination of rice fields' N, P, and K status in Jombang Regency, East Java

Sub-district	N, P, and K status (ha)			Total
	LHL	LHM	LHH	
Bandar Kedung Mulyo	799	1,580	83	2,462
Bareng	2,718	175	–	2,894
Diwek	985	1,228	–	2,213
Gudo	1,464	1,006	–	2,470
Jogo Roto	670	844	–	1,514
Jombang	779	775	164	1,718
Kabuh	–	1,227	2,233	3,459
Kesamben	720	1,765	1,042	3,528
Kudu	–	175	1,083	1,258
Megaluh	–	998	1,309	2,307
Mojoagung	685	412	297	1,394
Mojowarno	3,233	53	–	3,286
Ngoro	1,945	580	–	2,525
Ngusikan	3	87	926	1,016
Perak	1,155	615	–	1,769
Peterongan	214	1,266	309	1,789
Plandaan	–	537	2,114	2.651
Ploso	–	68	1,813	1,881
Sumobito	6	1,877	1,155	3,038
Tembelang	–	1,196	1,024	2,220
Wonosalam	5	36	34	74
Total	**15,380**	**16,500**	**13,586**	**45,465**

Explanations: N = nitrogen, P = phosphorus, K = potassium, LHL = N low, P high, K low, LHM = N low, P high, K medium, LHH = N low, P high, K high.
Source: own study.





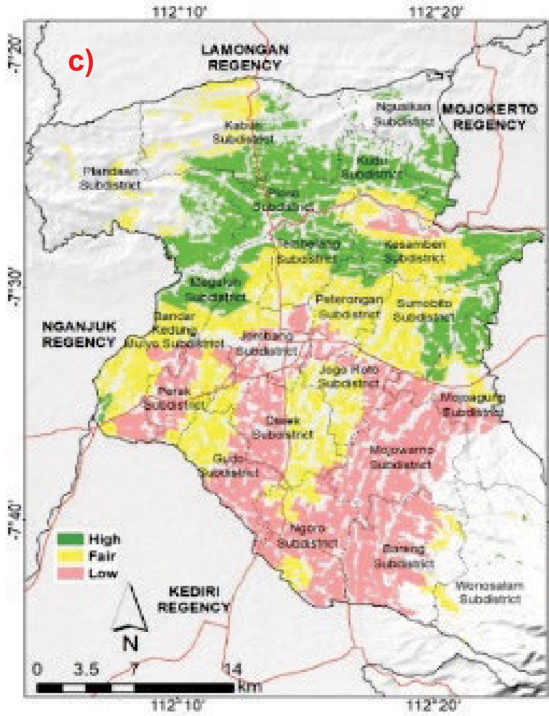


Fig. 8. Nutrient status of rice fields in Jombang Regency, East Java: a) nitrogen status, b) phosphorus status, c) potassium status; source: own study

rice fields cultivated for rice accounted for 39,603 ha and 2,637 ha for maize. Planting in GS2 started from the 4th week of March and continued until the 1st week of April. The analysis showed that fertiliser demand for rice in GS2 amounted to 6,094 Mg of N, equivalent to 11,088 Mg of urea, 993 Mg of P_2O_5, and 993 Mg of K_2O, equivalent to 6,617 Mg of NPK (15:15:15). While, for maize, 372 Mg of N is equivalent to 594 Mg of urea, 98 Mg of P_2O_5 and 98 Mg of K_2O are equivalent to 655 Mg of NPK (15:15:15). The spatial distribution of fertiliser demand in GS2 is presented in Figure 9b.

Table 7. Fertiliser needs for each crop according to nutrient status and soil texture

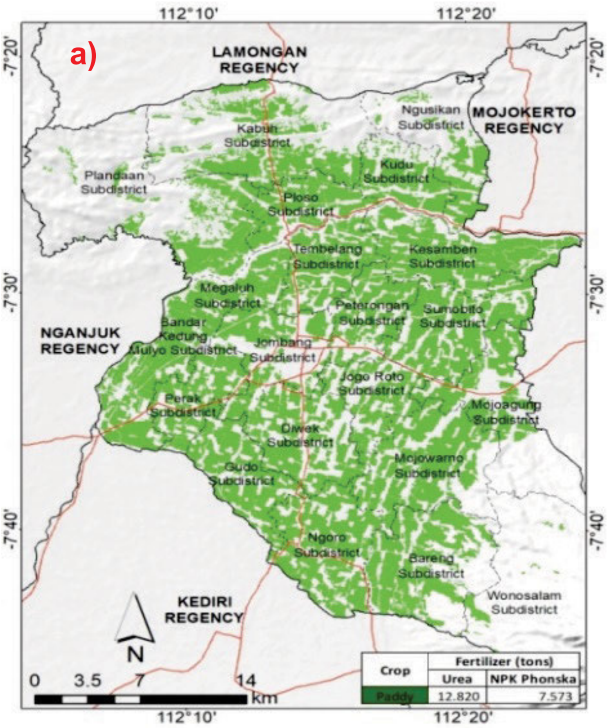
Nutrient status			Soil texture	Crop					
				rice		maize		soybean	
N	P	K		urea	NPK 15:15:15	urea	NPK 15:15:15	NPK 15:15:15	KCl
				$kg \cdot ha^{-1}$					
Low	high	low	fine	225	200	250	300	120	50
		med		250	150	275	250	120	25
		high		250	150	275	250	120	–
		low	medium	275	200	275	275	150	55
		med		300	150	275	250	150	–
		high		300	150	275	250	150	–

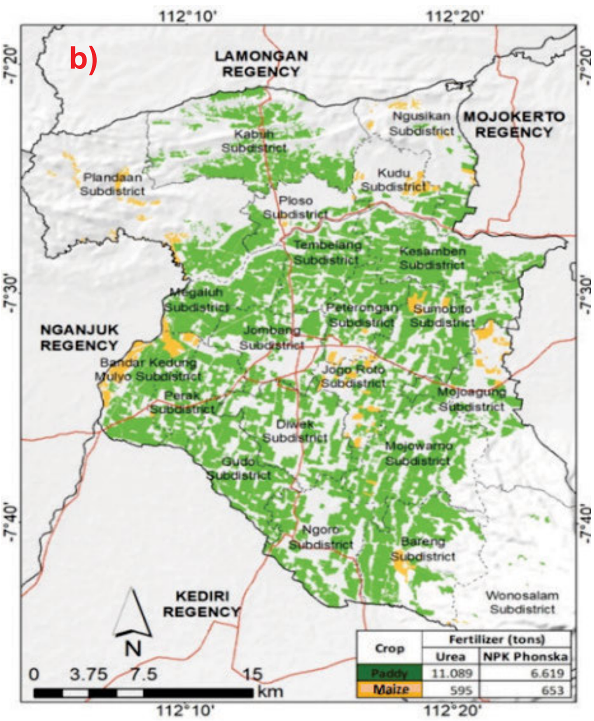
Explanations: N = nitrogen, P = phosphorus, K = potassium, KCl = potassium chloride, med = medium.
Source: own study.

Table 8. Fertiliser demands (Mg) per planting season in Jombang Regency, East Java

Sub-district	GS1		GS2				GS3					
	rice		rice		maize		rice		maize		soybean	
	urea	NPK	urea	NPK	urea	NPK	urea	NPK	urea	NPK	NPK	KCl
	Mg											
Bandar Kedung Mulyo	761	423	579	329	151	156	348	199	197	205	–	–
Bareng	860	604	813	568	39	49	203	142	539	641	–	–
Diwek	664	381	664	381	–	–	23	12	534	558	–	–
Gudo	741	444	741	444	–	–	159	101	485	511	–	–
Jogo Roto	454	261	314	185	78	79	–	–	369	385	23	3
Jombang	451	297	451	296	–	–	6	4	246	300	–	–
Kabuh	889	519	888	518	–	–	–	–	–	–	–	–
Kesamben	867	489	867	489	–	–	4	3	285	325	–	–
Kudu	376	201	94	47	53	55	–	–	180	200	2	–
Megaluh	580	346	569	340	8	11	–	–	149	188	–	–
Mojoagung	419	245	333	201	72	72	59	36	294	310	–	–
Mojowarno	985	654	977	649	7	8	81	54	753	827	–	–
Ngoro	757	476	757	476	–	–	241	154	293	317	–	–
Ngusikan	288	152	193	99	37	44	–	–	197	210	–	–
Perak	529	323	529	323	–	–	326	207	153	159	–	–
Peterongan	460	279	425	256	24	26	–	–	365	390	3	1
Plandaan	684	397	303	171	82	103	–	–	64	80	4	–
Ploso	557	282	194	99	8	8	–	–	98	100	–	–
Sumobito	851	456	753	403	33	41	35	20	636	683	28	–
Tembelang	625	333	625	333	–	–	–	–	247	300	–	–
Wonosalam	21	11	19	10	2	3	7	3	12	13	–	–
Total	**12,819**	**7,573**	**11,088**	**6,617**	**594**	**655**	**1,492**	**935**	**6,096**	**6,702**	**60**	**4**

Explanations: GS1 = the first growing season, GS2 = the second growing season, GS3 = the third growing season, NPK = nitrogen, phosphorus, potassium (15:15:15), KCl = potassium chloride.
Source: own study.





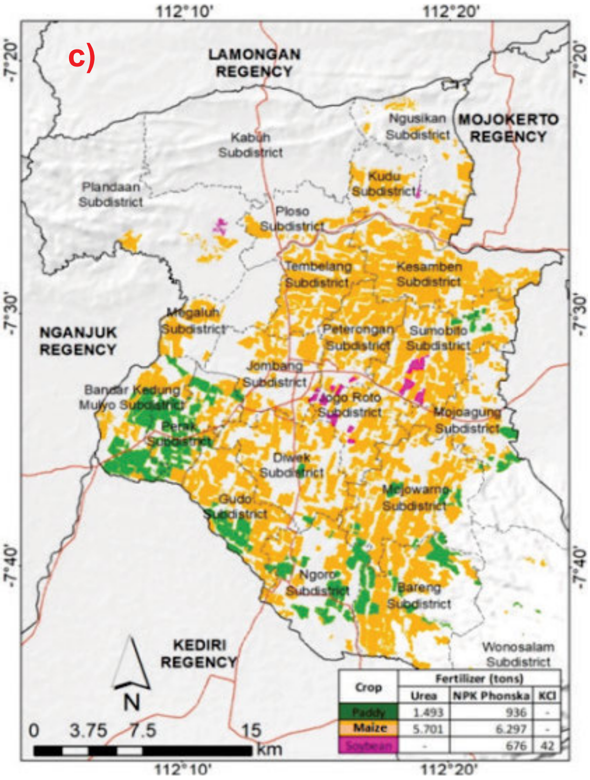


Fig. 9. The spatial distribution of fertiliser demand in three growing seasons: a) the first growing season (GS1) – rice, b) the second growing season (GS2) – rice-maize, c) the third growing season (GS3) – rice-maize-soybean; source: own study

In GS3, 5,049 ha of paddy fields were planted with rice, 28,731 ha with maize, and 415 ha with soybeans (Fig. 9c). Planting in GS3 started from the 4th week of July and continued until the 1st week of August. The analysis of fertiliser demand for GS3 rice showed 827 Mg of N equivalent to 1,492 Mg of urea, 140 Mg of P_2O_5, and 140 Mg of K_2O equivalent to 935 Mg of NPK (15:15:15), for maize, 3,658 Mg of N equivalent to 6,096 Mg of urea; 1,006 Mg of P_2O_5, and 1,006 Mg of K_2O are equivalent to 6,702 Mg of NPK 15:15:15. Meanwhile, for soybeans, the demand was 9 Mg of P_2O_5, 12 Mg of K_2O, or the equivalent of 60 Mg of NPK (15:15:15), and 4 Mg of KCl. This study has illustrated that more accurate formulation of the fertiliser demand should use a model that incorporates the main driving factors affecting the amount of fertiliser required by staple food crops in planting seasons each year, namely spatially standardised rice field areas, spatial data on cropping patterns, and spatial data on soil N, P, and K status.

CONCLUSIONS

The standard rice field area in Jombang Regency, East Java, has been delineated using a GIS approach with high accuracy, achieving a purity of 100% and a Kappa coefficient of 1.0. This suggests that the dynamic map of the spatial standard rice field area can be used as a base area map for planners and decision-makers for future planning and research.

Furthermore, the current study demonstrated that the proposed method effectively identified cropping patterns in rice fields with a high level of precision, achieving a purity of 93% and a Kappa coefficient of 0.9. Therefore, employing this novel approach would enable a more precise determination of subsidised fertiliser demand at the local level, with potential for broader applications in various other regions. Ultimately, such a model could be scaled up nationally to bolster precision agriculture initiatives and enhance food security. To operationalise this fertiliser demand calculation model, the rapid development of an application system is crucial. This system would ensure accurate targeting and facilitate policymakers in distributing fertilisers to farmers.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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