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Research Article
Mapping Nutrient Status in Oil Palm Plantation Using Geographic Information System

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Abstract
Background and Objective: In oil palm plantation, the fertilization is the most prominent for nutrient status evaluation and costly manageable input in oil palm cultivation. At this moment, the economic significance of nutrient management for oil palm, acquisition of accurate and timely information about its agronomy is becoming a critical issue for realization of the best management strategies. Hence, the objective of study was to map nutrient status in oil palm plantation in Selangor, Malaysia by using Geographic Information System (GIS) technique. **Materials and Methods:** To prepare samples and determine macronutrients concentration (nitrogen, phosphorus, potassium, magnesium and calcium) in leaf and in soil, this study had used the standardised methods. Then, leaf and soil nutrients data were computed into GIS software to generate maps of macronutrients concentration and overlaid to produce oil palm nutrient status map. **Results:** The results found nitrogen concentration is classified as optimum in leaf and in soil. Potassium concentration is classified as high in leaf and deficiency in soil. Magnesium and calcium concentrations are classified as moderate in leaf and deficiency in soil, whilst phosphorus is classified as deficiency in leaf and in soil. Overall, blocks of 0.231, 0.302, 0.304 and 0.305 represent the highest level of nutrient status. The oil palm nutrient status map obtaines the majority of plantation area is classified as deficiency with total area of 95.6 ha (76%) and about 30.2 ha (24%) is moderate. **Conclusion:** Low amount of nutrients show the nutrient status in this plantation area is unbalance.

Key words: Geographic information system, mapping, nutrient status, oil palm

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Nutrient status in oil palm plantation is usually maintained through applications of fertilizer, lime, organic materials and the addition of legume in the cropping system or combination of these[1,2]. A good knowledge of nutrient status will allow the development of nutrient management plans, such as nutrient rates, sources, timing and application to achieve the best agronomic, economic and environmental objectives. The costs of fertilizers have increased over the years from USD 110-150 ha^{-1} in 1990s to more than USD 700 ha^{-1} in 2008, mainly due to the increase in fertilizer prices[3,4]. Due to the economic significance of nutrient management for oil palm, acquisition of accurate and timely information about its agronomy is critical for realization of the best management strategies. Most of nutrient status evaluation in Malaysian oil palm plantations is obtained manually via block surveys and time consuming. Thus, rapid and accurate technique to evaluate nutrient status is necessary to be established for large-scale agriculture crops such as oil palm industry at this moment.

Geographic Information System (GIS) technique and technology have enabled precision agriculture to quantify large scale spatial and temporal variability, which contributes to efficient trouble shooting during crop production[5,6]. In most cases, the ability to pin down crop nutrient problems and launch timely intervention strategies can result in higher profitability. The usage of GIS in conjunction with growth simulation models have become increasingly recognized as powerful tools for estimating crop nutrient status and yield[7] Nutrient status evaluation is contingent upon the ability to identify the key agronomic variable. The previous studies have found the GIS technique can be used to map the nutrient status for wheat[8,9], sugar[10], potato[11], corn[12] and oil palm[13-15]. However, study on use of GIS technique to understand oil palm nutrient status is still limited until now. This present study is part of an ongoing effort to develop GIS protocol for sustainable oil palm nutrient management. Hence, the main focus of this study is to map nutrient status in oil palm plantation using GIS. There are 5 major macronutrients that used in this study such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca) elements.

MATERIALS AND METHODS

Study area: The study was carried out at UKM oil palm plantation which located in Bangi, Selangor, Malaysia (Fig. 1).

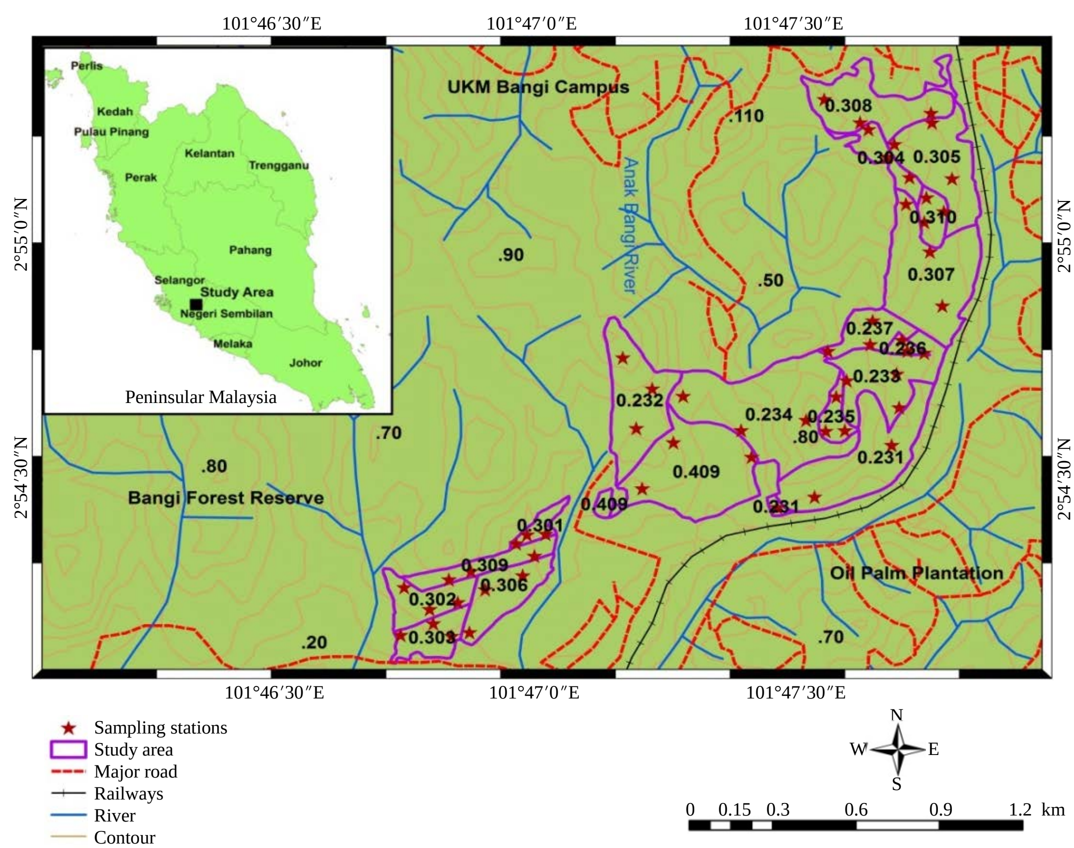

Fig. 1: Location of the study area

Table 1: Classification of macronutrients concentration in soil and in leaf for mature palms

Nutrients	Deficiency	Moderate	Optimum	High
*Nitrogen in soil (%)	0.08-0.12	0.12-0.15	0.15-0.25	>0.25
*Available phosphorus in soil (mg kg^{-1})	10-25	25-40	40-60	>60
**Available potassium in soil (mg kg^{-1})	<78.2	78.2-156.4	156.4-312.8	>312.8
**Available calcium in soil (mg kg^{-1})	<150	150-270	270-380	>380
#Available magnesium in soil (mg kg^{-1})	<18	18-36	36-54	>54
##Nitrogen in leaf (%)	<2.30	2.30-2.40	2.40-2.80	>3.00
##Phosphorus in leaf (%)	<0.14	0.14-0.15	0.15-0.18	>0.25
##Potassium in leaf (%)	<0.75	0.75-0.90	0.90-1.20	>1.60
##Magnesium in leaf (%)	<0.20	0.20-0.25	0.25-0.40	>0.70
##Calcium in leaf (%)	<0.25	0.25-0.50	0.50-0.75	>1.00

Sources: *Goh and Chew[38], **Young and Brown[39], #Rossiter and van Wambeke[40] and ##Von Uexkull and Fairhurst[41]

The plantation had 18 blocks with total area of 125.8 ha. The palms had been in mature phase (more than 6 years from planting) and fertilized with standard fertilizer program adopted by most commercially operated oil palm in Malaysia. The total annual rainfall was about 1951 mm per year with the minimum rainfall of about 75 mm per month occurring in February and maximum rainfall of 276 mm per month in November.

Leaf analysis: Leaf blades from frond No. 17 were sampled for this study. According to Pahan[16] this frond gave a better accuracy about nutrient concentration than another frond. A total of fifty four leaves samples from selected mature palms were collected for nutrient concentration determination. The concentration of N in the leaf was determined by semi-micro Kjeldahl method[17]. The concentrations of K, Mg and Ca in the leaf were determined by the wet digestion method[18].

Soil analysis: The soil where the leaves were sampled were sampled for soil nutrient concentration analyses. Composites soil samples were taken from depth (0-15 cm) around the oil palm tree. The concentration of N in the soil was determined by semi-micro Kjeldahl method[17]. The available nutrients (K, Mg and Ca) in the soil were determined in acid acetate-acetic ammonium filtrates by inductive coupled plasma-mass spectometry, respectively[19]. The availaible P concentration was determined by molybdate-blue colorimetric method[20] from Spectrophotometer Ultraviolet Model Vis UV 1201.

GIS analysis: Oil palm nutrient data, recorded as the nutrients concentration in leaf and in soil were obtained from laboratory analysis. Data of each variable was computed subsequently into attribute table of polygon or block and projected to Kertau RSO Malaya meter coordinate. The GIS analyses were performed on ArcGIS Ver. Ten software using standard protocols. The conversion of vector (polygon) to raster map was conducted for the classification and overlay processes. The maps of nutrients concentration were classified based on the reference model of critical nutrient for mature palms and overlaid to produce the oil palm nutrient status map (Table 1). The overlay process applied the maximum limitation method to evaluate crop nutrient status based on the lowest class and macronutrients were used as the critical limitation to rank the class. While, for analysis of variance, this study had used IBM SPSS Statistic 19 software package. The conceptual framework of overall methodology followed is illustrated in Fig. 2.

RESULTS

Leaf nutrients concentration: The highest concentration of leaf N is found at block 0.301 with a mean and SD of 2.75±0.06% and the lowest level is at block 0.236 with a mean and SD of 2.18±0.06%. Leaf N concentration showed the majority of study area is classified as optimum class with total area of 115.7 ha (92%) (Fig. 3a). Leaf P concentration in study area is classified as deficiency class (Fig. 3b). The highest concentration of leaf K is found at block 0.306 with a mean and SD of 3.84±0.00% and the lowest level is at block 0.232 and 0.236 with a mean and SD of 0.61±0.01%. Leaf K concentration showed the majority of study area is classified as high class with total area of 47.8 ha (38%) (Fig. 3c).

The highest concentration of leaf Mg is found at block 0.310 with a mean and SD of 0.62±0.00% and the lowest level is at block 0.237 with a mean and SD of 0.10±0.04%. Leaf Mg concentration showed the majority of study area is classified as moderate class with total area of 60.4 ha (48%) (Fig. 3d). The highest concentration of leaf Ca is found at block 0.303 with a mean and SD of 0.68±0.15% and the lowest level is at block 0.305 with a mean and SD of 0.37±0.14%. Leaf Ca

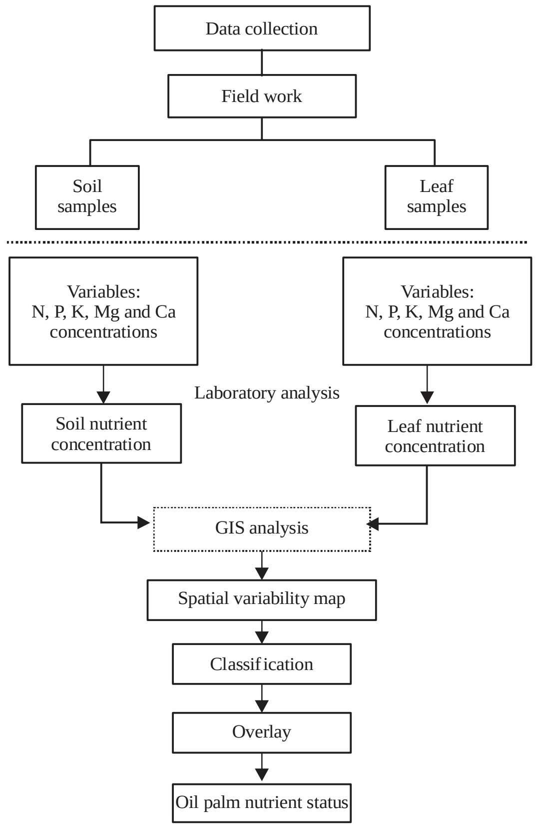

Fig. 2: Conceptual framework of the research methodology

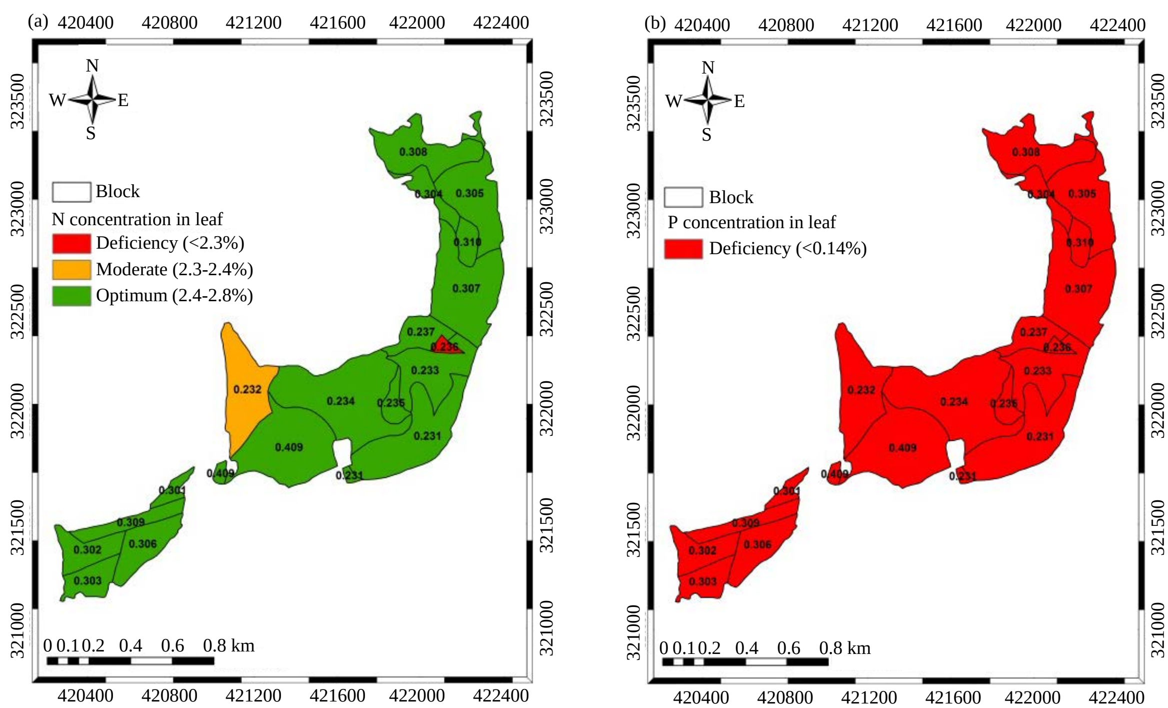

Fig. 3(a-e): Continue

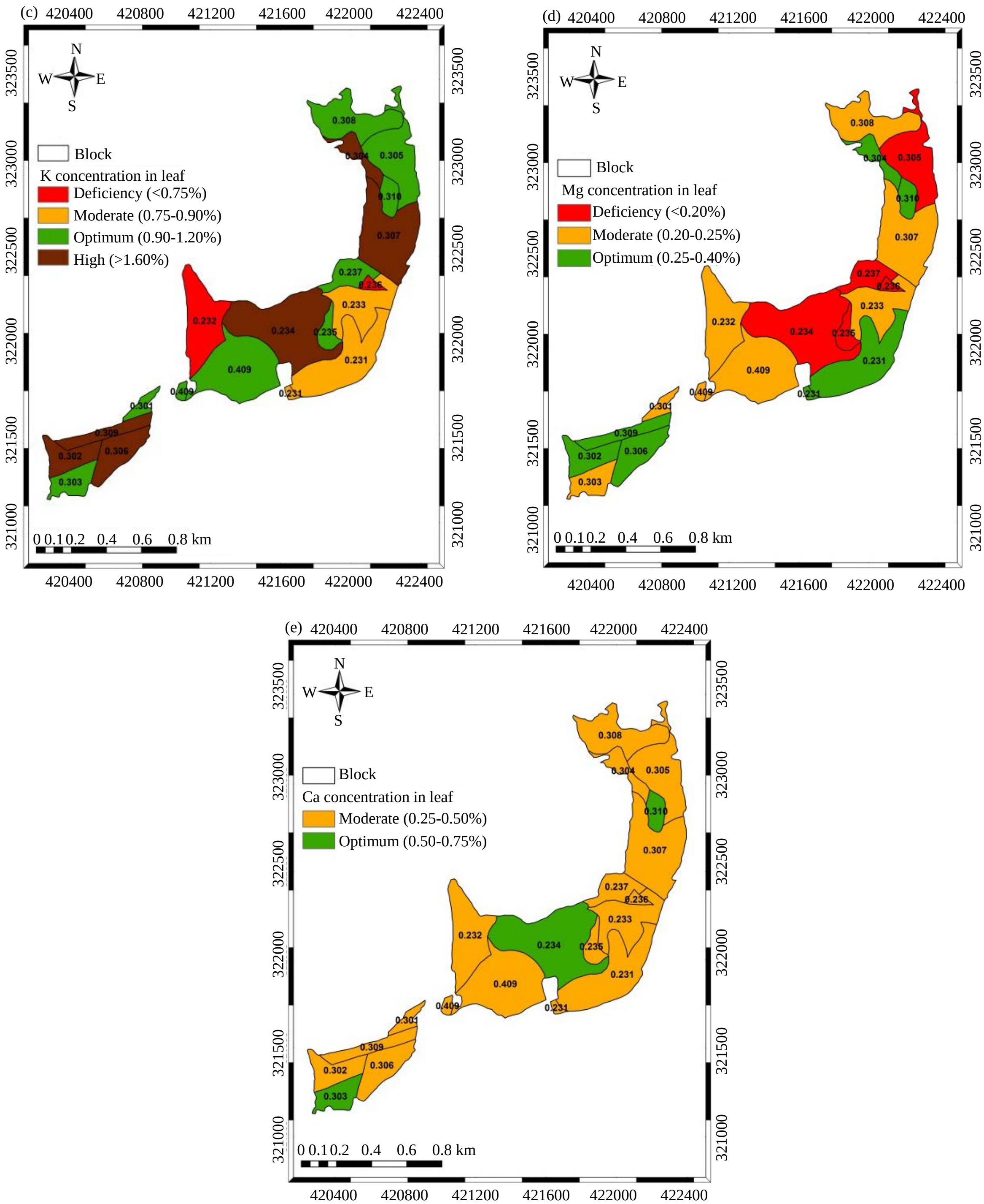

Fig. 3(a-e): Leaf nutrients concentration for (a) N, (b) P, (c) K, (d) Mg and (e) Ca

concentration showed the majority of study area is classified as moderate class with total area of 101.9 ha (81%) (Fig. 3e).

Soil nutrients concentration: The highest concentration of soil N is found at block 0.308 with a mean and SD of 0.21±0.04% and the lowest level is at block 0.236 with a mean and SD of 0.06±0.01%. Soil N concentration showed the majority of study area is classified as optimum class with total area of 100.6 ha (80%) (Fig. 4a). Soil P concentration in study area is classified as deficiency class (Fig. 4b). The highest concentration of soil K is found at block 0.310 with a mean and SD of 376.0±55.58 mg kg^{-1} and the lowest level is at block 0.231 with a mean and SD of 55.7±4.74 mg kg^{-1}. Soil K concentration showed the majority of study area is classified as deficiency class with total area of 60.4 ha (48%) (Fig. 4c). The highest concentration of soil Mg is found at block 0.304 with a mean and SD of 110.7±4.21 mg kg^{-1} and the lowest level is at block 0.232 with a mean and SD of 8.7±0.30 mg kg^{-1}. Soil Mg concentration showed the majority of study area is classified as deficiency class with total area of 94.3 ha (75%)

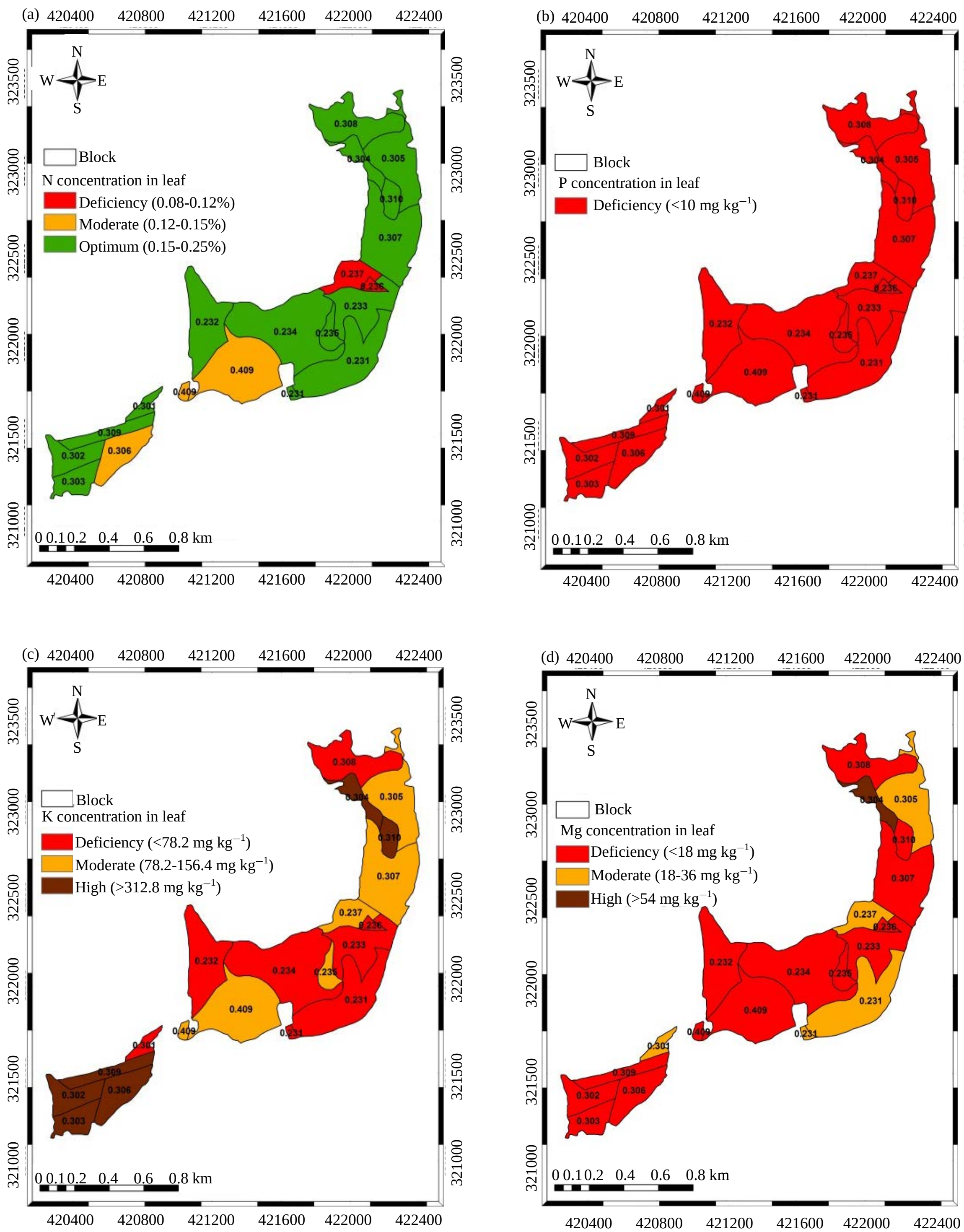

Fig. 4(a-e): Continue

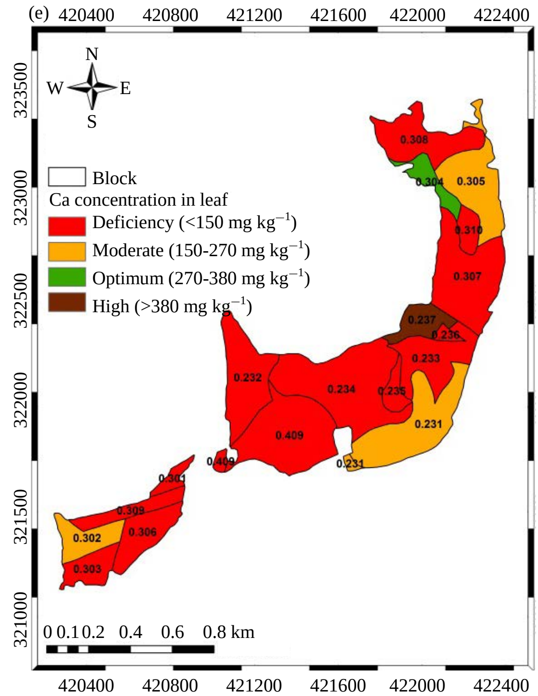

Fig. 4(a-e): Soil nutrients concentration for (a) N, (b) P, (c) K, (d) Mg and (e) Ca

(Fig. 4d). The highest concentration of soil Ca is found at block 0.237 with a mean and SD of 551.2±97.73 mg kg^{-1} and the lowest level is at block 0.309 with a mean and SD of 18.3±10.62 mg kg^{-1}. Soil Ca concentration showed the majority of study area is classified as deficiency class with total area of 93.1 ha (74%) (Fig. 4e).

DISCUSSION

Based on results of study, leaf N concentration in study area is found to be within the optimum level. Nitrogen is a prominent in chlorolphyll, protein and enzyme productions[21]. It is also involved in leaf area, leaf color and leaf production rate. The concentration of N in leaf is influenced by age of crop. Tarmizi and Tayeb[22] report the deficiency of N in leaf is rare found at the mature palms. Hence, the palms in study area which have aged more than 12 years after planting had an optimum leaf N concentration. The deficiency of leaf N in study area is mostly caused by loss of nutrients via erosion, especially on the hill areas. Leaf P concentration in study area is within the range of deficiency level. Phosphorus is important in the crop growth and fruit quality production[23]. High amounts of Al and Ca are the predominant factor that reduce the P adsorption by palms in study area. Leaf K concentration is found high in study area. Potassium is prominent in the crop metabolism and chlorophyll molecules during the photosynthetic activity[24]. The sufficient of K in the soil may increase the crop health from diseases and dry season[25]. High amounts of leaf K in study area cause the reduction of Mg adsorption by palms so as the concentration of Mg in the leaf is low.

Leaf Mg concentration is found moderate in study area. Magnesium is a basic element in chlorophyll and important for photosynthetic efficiency. It also acts to manage phosphate metabolism, respiration and enzyme activator[26]. The deficiency of leaf Mg in study area can be contributed to leaf by low Mg concentration in soil or an unbalance between Mg and Mg^{2+} cation in soil. High amounts of leaf K and Ca in study area also contributes to Mg concentration in leaf by the depletion of Mg adsorption by palms. Another studies also find the deficiency of Mg often occurres at sandy and acidic soils[27]. Leaf Ca concentration is found moderate in study area. Calcium is involved in the cell structural element, root development and crop meristematic activity[28]. Based on another studies, the concentration of Ca in leaf can be influenced by soil pH and Mg concentration[29,30]. In this study, leaf Ca concentration is moderate due to low pH and Mg concentration in leaf.

Soil N concetration in study area is optimum. A high N concentration is associated with the nitrification process, organic fertilizer application and legume, whilst a low N concentration is due to the nutrients are leached from soil, so

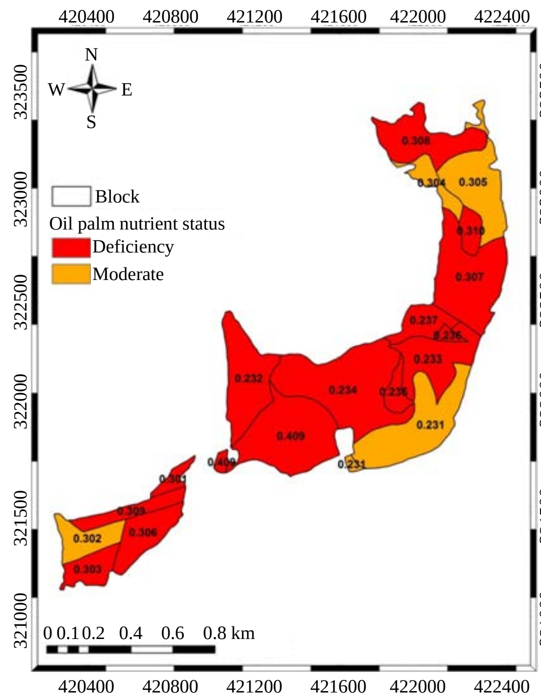

Fig. 5: Oil palm nutrient status map in the study area

as the fertilizer application is not effective. Slope factor affects the efficiency of N adsorption by crop with loss nutrients through runoff and erosion processes[31-33]. According to Ilori *et al*.[2] the deficiency of N concentration can be caused by the insufficient of fertilizer, poor drainage and erosion. Soil P concentration in study area is found to be within the deficiency level. Low amount of P in study area is normally associated with high of Al concentration, erosion and the insufficient of phosphate fertilizer. Soil K concentration in study area is found to be within the deficiency level. The concentration of K is influenced by soil pH. At low pH, the adsorption of K element by the palms run slowly, thus K concentration is found high in the soil. A low K concentration in soil may be associated with the presence of Ca and Mg elements in the cation exchange process. Soil Mg concetration in study area is found to be within the deficiency level. A low Mg concentration indicates low amount of Mg^{2+} exchange able cation in soil of study area (<0.30 meq/100 g). For the optimum Mg concentration in soil, Tinker and Smilde[34] have highlighted the Mg/K exchange able ratio should be more than 2 meq/100 g to avoid Mg deficiency in the soil. Plaster[35] reports the characteristic of clay holds Ca stronger than Mg element, so as the presence of Mg is low in the soil. Soil Ca concentration in study area is found to be within the deficiency level. The low pH and cation exchange capacity cause low amount of soil Ca in study area. A strong bonding between Ca and clay makes the element does not leach easily from soil, thus Ca concentration is higher than Mg in the soil[36,37].

The nutrient status map is produced from overlaying macronutrients concentration in leaf and in soil. Figure 5 showed the majority of study area is classified as deficiency class with total area of 95.6 ha (76%) and about 30.2 ha (24%) is moderate. Block 0.231, 0.302, 0.304 and 0.305 represent the highest level of nutrient status for oil palm, while the others blocks are within the deficiency level. This result indicates the fertilization management in study area is unbalance.

CONCLUSION

Overall, GIS assists the analyst to evaluate oil palm nutrient status faster and better result than conventional method. Hence, the usage of GIS technique for sustainable oil palm nutrient management is highly appropriate. Block 0.231, 0.302, 0.304 and 0.305 represent the highest level of nutrient status. Oil palm nutrient status map revealed the majority of study area is classified as deficiency class and needed to improve the fertilization application and management practices. Low amount of nutrients showed the nutrient status fertilization, especially in dose and time of fertilization is carried out. Furthermore, the placement of fertilizer has to be concerned very carefully by the planters, so as the efficiency of fertilizer may be achieved. The palms have to be fertilized around the active roots to make sure the nutrients may be adsorped by the crop effectively.

SIGNIFICANCE STATEMENT

This study revealed a study on mapping of nutrient status in oil palm plantation. The GIS technique has been applied in this study to quantify large scale spatial and temporal variability which contributes to efficient trouble shooting during crop production.

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