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Mapping soil nutrients and texture for the pilot project of glutinous rice variety Pulut Siding (MR 47) in Langkawi Island, Malaysia

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Abstract The soil nutrient and texture status in four rice areas, namely Kg. Ayer Hangat, Kg. Batu Duyung, Kg. Baru/Teluk, and Kg. Ulu Melaka on Langkawi Island, Malaysia was successfully analysed using Geographic Information System (GIS) techniques. The results indicated no significant variations in organic carbon, cation exchange capacity (CEC), and conductivity among the study areas. However, distinctive differences were observed in soil chemical features, including pH values, total nitrogen, available phosphorus, and exchangeable potassium—specifically, the rice fields in Kg. Ayer Hangat exhibited a significantly lower pH (4.68) compared to Kg. Batu Duyung (5.23) and Kg. Baru/Teluk (5.09). Total nitrogen content was notably higher in Kg. Ayer Hangat (0.18). Available phosphorus showed significant variations, with Kg. Batu Duyung recorded the highest (37.32 mg/kg) and Kg. Ayer Hangat is the lowest (15.25 mg/kg). Exchangeable potassium levels were markedly higher in Kg. Ulu Melaka (0.53 cmol(+)/kg) compared to Kg. Ayer Hangat (0.29 cmol(+)/kg), while Kg. Batu Duyung and Kg. Baru/Teluk recorded lower levels (0.19 cmol(+)/kg and 0.08 cmol(+)/kg, respectively). Furthermore, Soil Taxonomy (ST) was employed to categorize soils, with the majority falling under hydrologic soil group A, primarily sandy loam types. Kg. Ayer Hangat, however, was categorized under hydrologic soil group C (sandy clay loam). The study suggests that additional research may be conducted to assess the practical implementation of soil nutrient mapping and texture in small plantation systems. This could potentially bridge the gap between research findings and practical applications.

Keywords: Soil fertility, Rice, Global positioning system, Geographic information system

Introduction

Aimrun *et al.* (2011) found that soil management is essential, including grid-soil sampling and mapping nutrients when a field lacks

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fertilization information. Describing the spatial variability of soil fertility across a field has been difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced. The collection of soil samples by using GPS is significant for preparing thematic soil fertility maps (Mishra *et al.*, 2013; Mandal *et al.*, 2023). Similarly, a Geographical Information System (GIS) is a potential tool used for easy access, retrieval, and manipulation of voluminous data of natural resources often challenging to handle manually. This technology enables the analysis of crop yield estimates, soil conditions and ensures precision in agricultural practices (Jamru *et al.*, 2023).

It facilitates manipulation of spatial and attribute data useful for handling multiple data of diverse origins (Mandal and Sharma, 2009). The geostatistical method is a spatial distribution and variability analysis method. For the production of mapping of soil chemical analysis data, methods data interpolation using IDW (Inverse Distance Weighted) technique was chosen because this method can produce a significant soil nutrients mapping (Eltaib *et al.*, 2002). Data interpolation methods using techniques IDW is a well-known spatial interpolation (Lee *et al.*, 2016) to determine soil fertility status then the graphic editor of ArcView was applied to produce soil nutrient spatial distribution map, which describes the precision of the algorithm and distribution range of soil nutrients (Yang and Zhang, 2008). The research finding aimed to conduct soil nutrient and texture mapping for identified planting sites in Langkawi Island, specifically for the glutinous rice variety Pulut Siding (MR 47).

Materials and methods

Study area and soil sampling

This study was conducted in four separate locations for the glutinous rice variety Pulut Siding (MR 47) pilot project which is in Langkawi Island, Malaysia. The soil samples were collected at Kg. Ayer Hangat has longitude coordinates 6025'26.3"N and latitude 99049'01.05"E, covering an area of 12.84 hectares. Kg. Batu Duyung is located at longitude coordinates 6025'08.1"N, latitude 99048'25.4"E, covering an area of 3.36 hectares—location Kg. Baru/Teluk is located at longitude coordinates 6020'57.0"N, latitude 99014'29.7"E, covering an area of 13.58 hectares. While the location of Kg. Ulu Melaka is located at longitude coordinates 6021'10.4"N and latitude 99045'4602"E, which covers an area of 9.18 hectares. Location maps are shown in Figure 1.

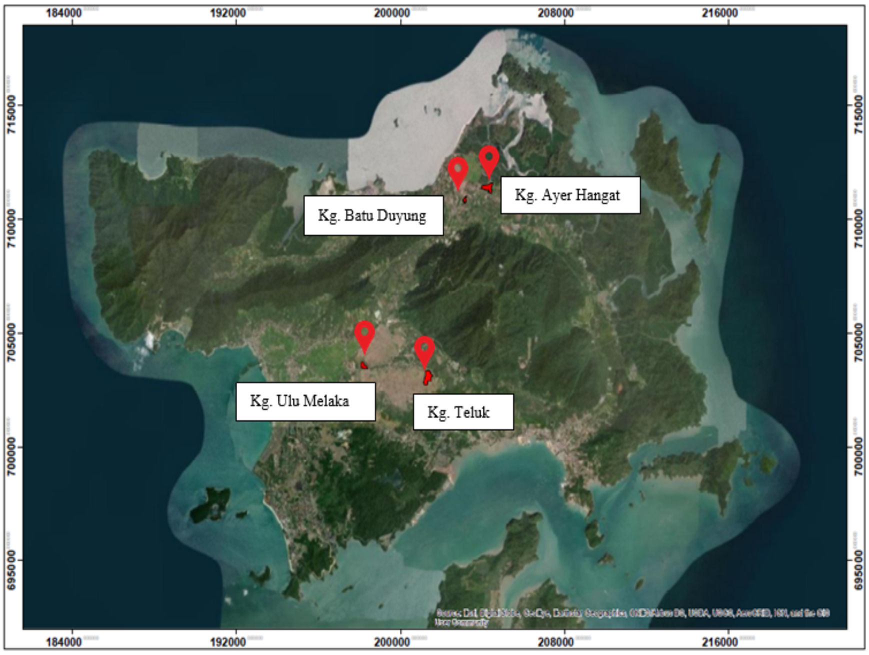

Figure 1. Study area (Kg. Ayer Hangat, Kg. Batu Duyung, Kg. Baru/Teluk and Kg. Ulu Melaka)

The soils were sampled at depths from 0-20 cm using a 200 m x 200 m grid system. The latitude and longitude of sampling sites were recorded with the help of a differential Global Positioning System (GPS). To prepare samples and determine soil properties (pH, CEC, total nitrogen, organic carbon, available P, exchangeable K, and conductivity) and texture (soil texture) in soil, this study used standardised methods. Then, data were computed into GIS software to generate maps of nutrient concentration and overlaid to produce a nutrient status map. Soil fertility maps were prepared using ArcGIS version 10.5.5 software to interpolate soil samples by Inverse Distance Weighting (IDW) interpolation technique, which enabled visualization in the form of raster and vector maps for the spatial distribution of soil nutrient and texture status. Variables of total N and organic carbon are measured in percentage (%), available P is measured in mg/kg, exchangeable K and CEC are measured in cmol (+)/kg, and conductivity is measured in µS/cm.

Statistical analysis

Data were analyzed using analysis of variance (ANOVA) of SAS 9.4. Mean comparisons were subjected to using the Duncan Multiple Range Test if significant.

Results

Map of soil fertility status in Kg. Ayer Hangat

Soil pH

The soil pH value for the study area is between 4.5 to 4.9, and the mean soil pH is 4.7. A pH value of 4.5-4.6 is 2.85 hectares from the entire study area, a pH value of 4.6-4.7 is 5.41 hectares, while a total of 4.58 hectares represents a pH value of 4.7-4.9 (Figure 2).

Organic carbon

The value of organic carbon for the study area is between 1.2 to 1.4%, and the average organic carbon of the soil is 1.3%. Organic carbon, with a value between (1.2-1.3%) covers the study area of 9.64 hectares, while the value of organic carbon (1.3-1.4%) is 3.20 hectares from the entire study area (Figure 3).

CEC

The value of soil CEC for the study area is between 12.0 and 17.6 cmol(+)/kg, and the average soil CEC is 15.9 cmol(+)/kg. For CEC value (12.0-16.0 cmol(+)/kg) is 3.87 hectares from the entire study area, and as much as 8.97 hectares represents CEC value (16.0-17.6 cmol(+)/kg) (Figure 4).

Total nitrogen (N)

The total N value for the study area is between 0.12 and 0.26%, and the average total N of the soil is 0.18%. The total value of N (0.12-0.16%) is 3.88 hectares from the entire study area, and as much as 5.30 hectares represents the total value of N (0.16-0.20%), while the total value of N over> 0.20% covers the study area of 3.66 hectares (Figure 5).

Available phosphorus (P)

The soil available P value for the study area is between 12.0 and 18.0 mg/kg, and the average soil available P is 15.3 mg/kg. The available P value (12.0-15.0 mg/kg) is 5.18 hectares from the entire study area, and as much as 2.41 hectares represents available P value (15.0-16.0 mg/kg) while 5.25 hectares is available P value (16.0-18.0 mg/kg) (Figure 6).

Exchangeable potassium (K)

The soil exchangeable K value for the study area is between 0.19 and 0.38 cmol(+)/kg, and the average soil exchangeable K value is 0.29 cmol(+)/kg. For the value of exchangeable K (0.19-0.20 cmol(+)/kg) is 0.78 hectares from the entire study area, as much as 6.11 hectares represents the value of exchangeable K (0.20-0.30 cmol(+)/kg) and as much as 5.95 hectares represents the value of exchangeable K (0.30-0.38 cmol(+)/kg) (Figure 7).

Conductivity

The soil conductivity value for the study area is between 0.14 to 0.19 µS/cm and the average conductivity value is 0.17 µS/cm. For the conductivity value (0.14-0.15 µS/cm) is 1.17 hectares from the entire study area, as much as 4.16 hectares represents the conductivity value (0.15-0.18 µS/cm) and as much as 7.51 hectares represents the conductivity value (0.18-0.19 µS/cm) (Figure 8).

Soil texture

The entire soil in the study area is composed of sandy clay loam type soil texture (Figure 9). This classification is based on the USDA Soil Texture Triangle which refers to the percentage composition of sand (diameter 2.00-0.05 mm), silt (diameter 0.05-0.002 mm) and clay (diameter smaller than 0.002 mm).

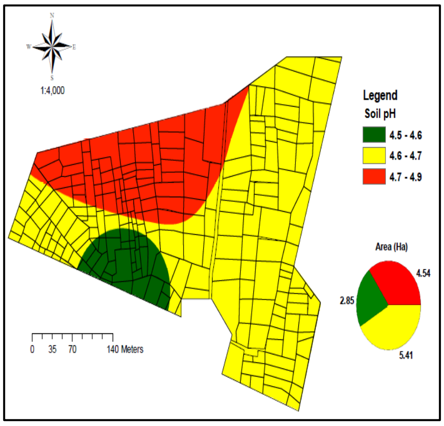

Figure 2. Soil pH distribution map in Kg. Ayer Hangat

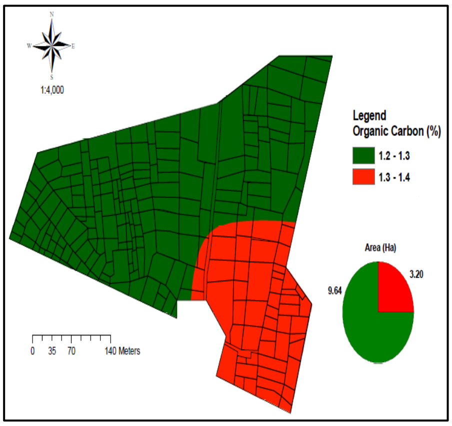

Figure 3. Organic Carbon distribution map in Kg. Ayer Hangat

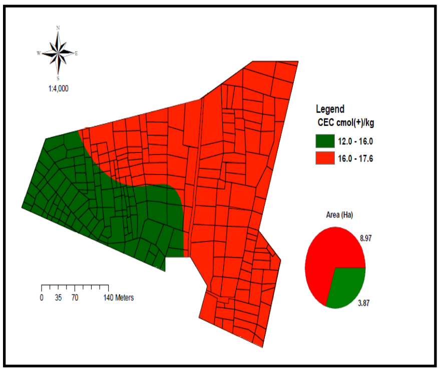

Figure 4. CEC distribution map in Kg. Ayer Hangat

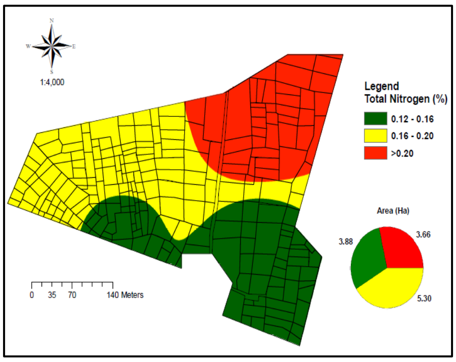

Figure 5. Total Nitrogen distribution map in Kg. Ayer Hangat

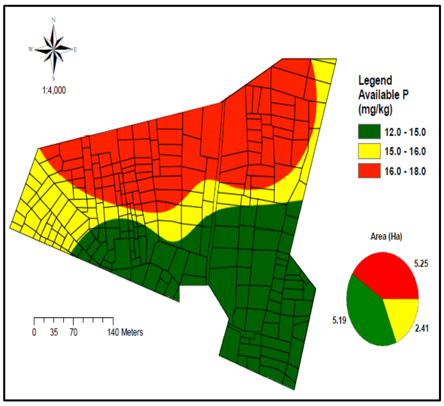

Figure 6. Available P distribution map in Kg. Ayer Hangat

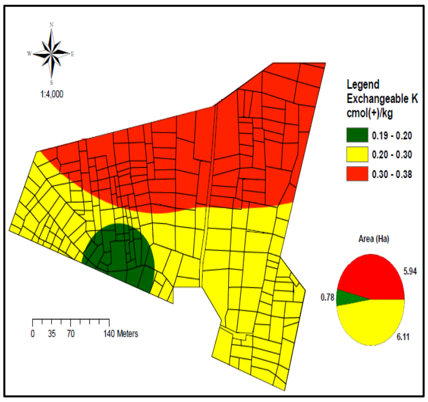

Figure 7. Exchangeable K distribution map in Kg. Ayer Hangat

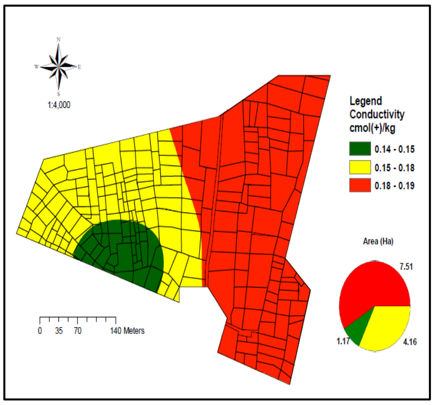

Figure 8. Conductivity distribution map in Kg. Ayer Hangat

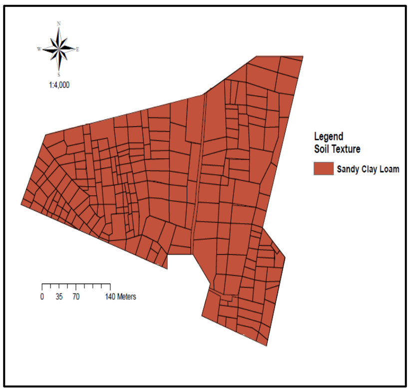

Figure 9. Soil texture distribution map in Kg. Ayer Hangat

Map of soil fertility status in Kg. Batu Duyung

Soil pH

The soil pH value of the soil for the study area is between 4.98 and 5.55 and the average soil pH is 5.27. The pH value of 4.98-5.00 is only 0.10 hectares of the entire study area, the pH value of 5.00-5.40 is as much as 1.66 hectares while as much as 1.60 hectares the area represents the soil pH value of 5.40-5.55 (Figure 10).

Organic carbon

The organic carbon value for the study area is between 0.59 and 0.95% and the average organic carbon of the soil is 0.79%. Organic carbon with a value between (0.59-0.70%) covers the study area of 1.12 hectares, while, the value of organic carbon (0.70-0.80%) covers the study area of 0.79 hectares and the value of organic carbon (0.80-0.95%) is 1.45 hectares from the entire study area (Figure 11).

CEC

The value of CEC for the study area is between 7.0 and 15.0 cmol(+)/kg and the average soil CEC is 11.4 cmol(+)/kg. For CEC value (7.0-10.3 cmol(+)/kg) is 1.14 hectares from the entire study area while 1.12 hectares represents CEC value (10.3-11.7 cmol(+)/kg) and soil CEC value (11.7-15.0 cmol(+)/kg) is 0.80 hectares of the entire study area (Figure 12).

Total nitrogen (N)

The total N value for the study area is between 0.10 and 0.12% and the average total N of the soil is 0.10%. The total value of N (0.10-0.11%) is 2.46 hectares from the entire study area and as much as 0.90 hectares represents the total value of N (0.12%) (Figure 13).

Available phosphorus (P)

The available P value for the study area ranged from 36.0 to 38.8 mg/kg and the average available P was 37.3 mg/kg. The available P value (36.0-37.0 mg/kg) is 2.56 hectares from the entire study area, and as much as 0.80 hectares represents the available P value (37.0-38.8 mg/kg) (Figure 14).

Exchangeable potassium (K)

The exchangeable K value of soil for the study area is between 0.14 and 0.22 cmol(+)/kg, and the average exchangeable K value is 0.19 cmol(+)/kg. For the value of exchangeable K (0.14-0.18 cmol(+)/kg) is 1.40 hectares of the entire study area, as much as 1.96 hectares represents the value of exchangeable K (0.19-0.22 cmol(+)/kg) (Figure 15).

Conductivity

The soil conductivity value for the study area is between 22.0 to 120.0 μS/cm, and the average conductivity value is 51.2 μS/cm. The conductivity value (22.0-48.0 μS/cm) is 1.22 hectares from the entire study area, as much as 1.04 hectares represents the conductivity value (49.0-79.0 μS/cm) and as much as 1.10 hectares represents the conductivity value (80.0-120.0 μS/cm) (Figure 16).

Soil Texture

The entire soil in the study area is comprised sandy loam type soil texture (Figure 17). This classification is based on the USDA Soil Texture Triangle, which refers to the percentage composition of sand (diameter 2.00-0.05 mm), silt (diameter 0.05-0.002 mm), and clay (diameter smaller than 0.002 mm).

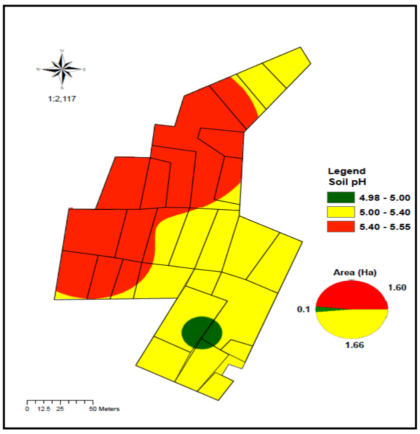

Figure 10. Soil pH distribution map in Kg. Batu Duyung

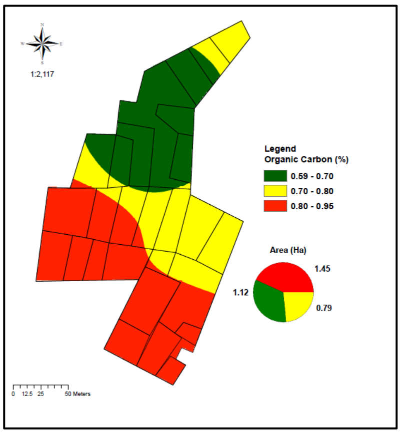

Figure 11. Organic Carbon distribution map in Kg. Batu Duyung

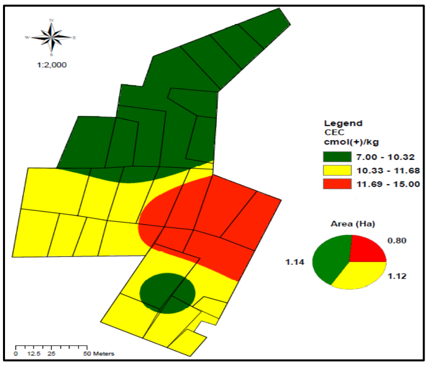

Figure 12. CEC distribution map in Kg. Batu Duyung

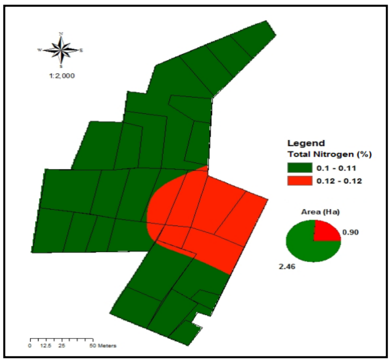

Figure 13. Total Nitrogen distribution map in Kg. Batu Duyung

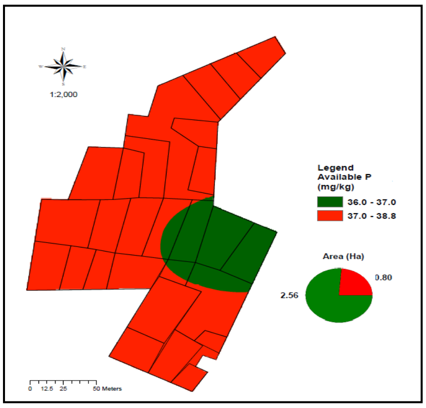

Figure 14. Available P distribution map in Kg. Batu Duyung

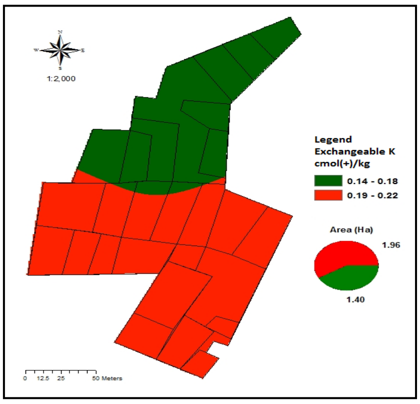

Figure 15. Exchangeable K distribution map in Kg. Batu Duyung

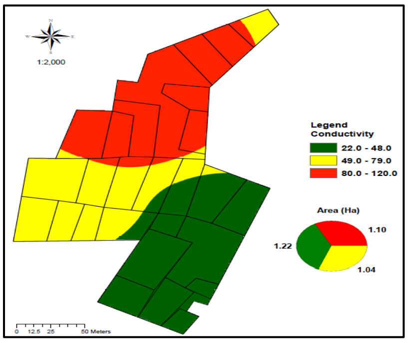

Figure 16. Conductivity distribution map in Kg. Batu Duyung

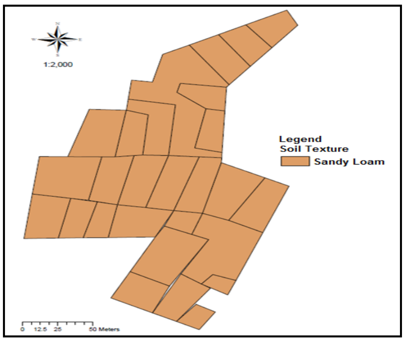

Figure 17. Soil texture distribution map in Kg. Batu Duyung

Map of soil fertility status in Kg. Baru/Teluk

Soil pH

The soil pH value for the study area is between 4.7 and 5.3, and the average soil pH is 5.1. A soil pH value of 4.7-5.0 is only 3.52 hectares from the entire study area, a soil pH value of 5.1-5.3 is as much as 10.06 hectares from the entire study area (Figure 18).

Organic carbon

The organic carbon for the study area is between 0.72 and 1.22% and the average organic carbon of the soil is 1.06%. Organic carbon, with a value between (0.72-1.00%) covers the study area of 2.75 hectares, while, organic carbon value (1.01-1.22%) is 10.83 hectares from the entire study area (Figure 19).

CEC

The soil CEC value for the study area is between 4.0 and 18.0 cmol(+)/kg, and the average soil CEC is 13.8 cmol(+)/kg. For CEC value (4.0-16.0 cmol(+)/kg) is 7.51 hectares from the entire study area while 6.07 hectares represents CEC value (16.0-18.0 cmol(+)/kg) (Figure 20).

Total nitrogen (N)

The total N value for the study area is between 0.10 and 0.13% and the average total N of the soil is 0.12%. For the total value of N (0.10-0.11%) is 7.91 hectares from the entire study area and as much as 5.67 hectares represents the total value of N (0.12-0.13%) (Figure 21).

Available phosphorus (P)

The available P value for the study area ranged from 34.8 to 36.8 mg/kg and the average available P is 35.8 mg/kg. For available P value (34.8-

36.0 mg/kg) is 7.37 hectares from the entire study area, and as much as 6.21 hectares represents available P value (36.1-36.8 mg/kg) (Figure 22).

Exchangeable potassium (K)

The exchangeable K value of soil for the study area is between 0.10 and 0.12 cmol(+)/kg, and the average exchangeable K value is 0.10 cmol(+)/kg. For the value of exchangeable K (0.10-0.11 cmol(+)/kg) is 9.10 hectares of the entire study area, as much as 4.48 hectares represents the value of exchangeable K (0.12 cmol(+)/kg) (Figure 23).

Conductivity

The soil conductivity value for the study area is between 23.0 to 121.0 µS/cm and the average conductivity value is 49.3 µS/cm. The conductivity value (23.0-50.0 µS/cm) is 8.63 hectares of the entire study area, as much as 4.95 hectares represents the conductivity value (50.0-121.0 µS/cm) (Figure 24).

Soil texture

Figure 25 shows that the entire soil in the study area is composed of sandy loam type soil texture. This classification is based on the USDA Soil Texture Triangle, which refers to the percentage composition of sand (diameter 2.00-0.05 mm), silt (diameter 0.05-0.002 mm) and clay (diameter smaller than 0.002 mm).

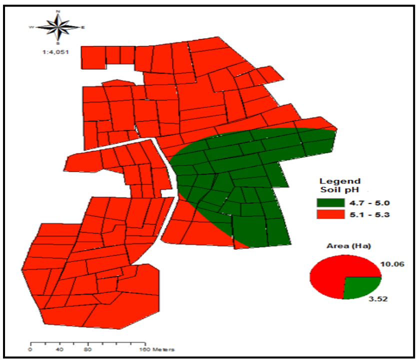

Figure 18. Soil pH distribution map in Kg. Baru/Teluk

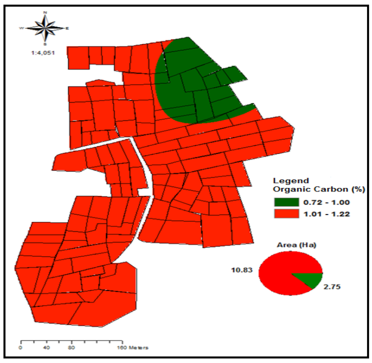

Figure 19. Organic Carbon distribution map in Kg. Baru/Teluk

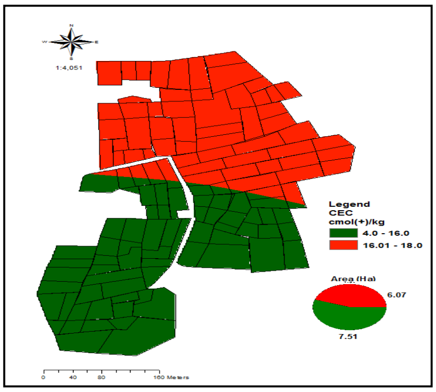

Figure 20. CEC distribution map in Kg. Baru/Teluk

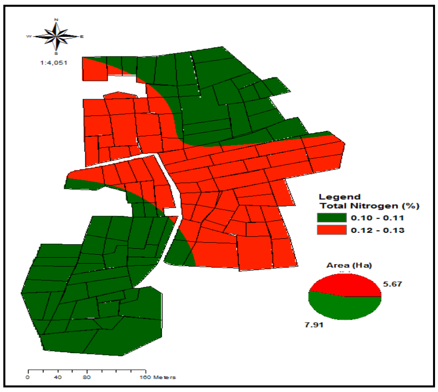

Figure 21. Total Nitrogen distribution map in Kg. Baru/Teluk

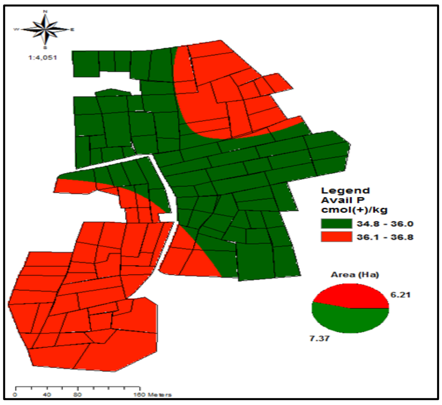

Figure 22. Available P distribution map in Kg. Baru/Teluk

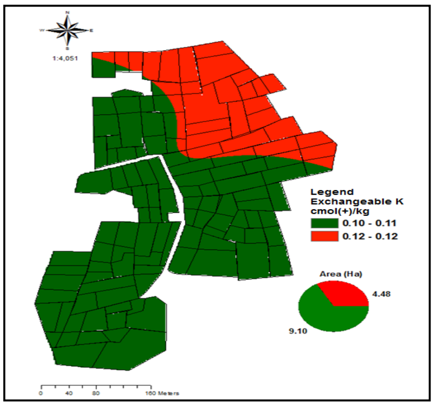

Figure 23. Exchangeable K distribution map in Kg. Baru/Teluk

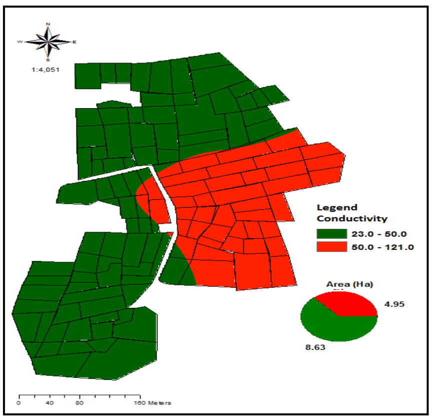

Figure 24. Conductivity distribution map in Kg. Baru/Teluk

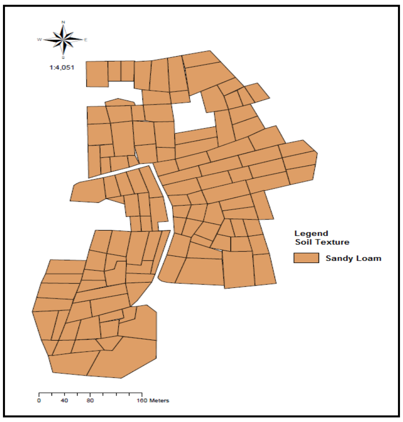

Figure 25. Soil texture distribution map in Kg. Baru/Teluk

Map of soil fertility status in Kg. Ulu Melaka

Soil pH

The soil pH value for the study area is between 4.9 and 5.2, and the average soil pH is 5.0. For the soil pH value of 4.9-5.0 is only 3.26 hectares from the entire study area, the soil pH value of 5.0-5.2 is 5.92 hectares from the entire study area (Figure 26).

Organic carbon

The organic carbon of soil for the study area is between 0.52 and 1.14%, and the average organic carbon of the soil is 0.81%. Organic carbon with a value between (0.52-0.71%) covers the study area of 2.54 hectares, while organic carbon value (0.72-1.00%) is 5.36 hectares, and organic value of carbon (1.01-1.14%) is 1.28 hectares from the entire study area (Figure 27).

CEC

The soil CEC value for the study area is between 6.0 and 14.0 cmol(+)/kg and the average soil CEC is 8.25 cmol(+)/kg. For CEC value (6.0-10.0 cmol(+)/kg) is 7.33 hectares from the entire study area, while 1.85 hectares represents CEC value (10.0-14.0 cmol(+)/kg) (Figure 28).

Total nitrogen (N)

The total N value for the study area is between 0.10 and 0.13% and the average total N of the soil is 0.12%. The total value of N (0.10-0.11%) is 4.03 hectares of the entire study area, and as much as 5.15 hectares represents the total value of N (0.12-0.13%) (Figure 29).

Available phosphorus (P)

The available P value for the study area ranged from 33.7 to 37.4 mg/kg, and the average available P was 35.5 mg/kg. The available P value (33.7-35.0 mg/kg) is 3.15 hectares of the entire study area, and as much as 6.03 hectares is representative of available P value (35.0-37.4 mg/kg) (Figure 30).

Exchangeable potassium (K)

The exchangeable K value of soil for the study area is between 0.42 to 0.66 cmol(+)/kg, and the average exchangeable K value is 0.53 cmol(+)/kg. For the value of exchangeable K (0.42-0.45 cmol(+)/kg) is 2.80 hectares from the entire study area, as much as 3.93 hectares represents the value of exchangeable K (0.46-0.50 cmol(+)/kg) and as much as 2.45 hectares represents the value of exchangeable K (0.51-0.66 cmol(+)/kg) (Figure 31).

Conductivity

The soil conductivity value for the study area is between 22.0 to 31.0 µS/cm, and the average conductivity value is 25.3 µS/cm. The conductivity value (22.0-25.0 µS/cm) is 5.27 hectares from the entire study area, as much as 3.13 hectares represents the conductivity value (25.0-30.0 µS/cm) and as much as 0.78 hectares represents the conductivity value (30.0-31.0 µS/cm) (Figure 32).

Soil texture

The entire soil in the study area is composed of sandy loam-type soil texture. This classification is based on the USDA Soil Texture Triangle, which refers to the percentage composition of sand (diameter 2.00-0.05 mm), silt (diameter 0.05-0.002 mm) and clay (diameter smaller than 0.002 mm) as show in Figure 33.

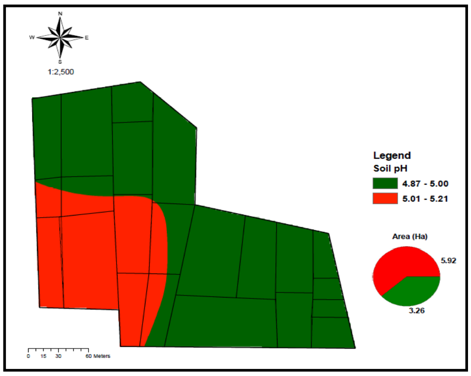

Figure 26. Soil pH distribution map in Kg. Ulu Melaka

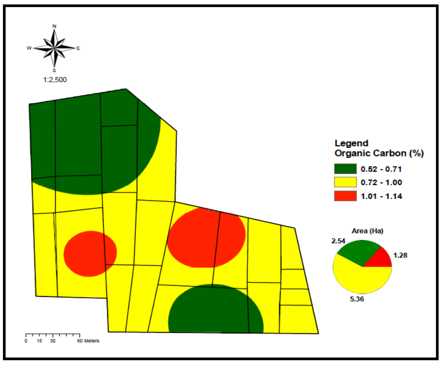

Figure 27. Organic Carbon distribution map in Kg. Ulu Melaka

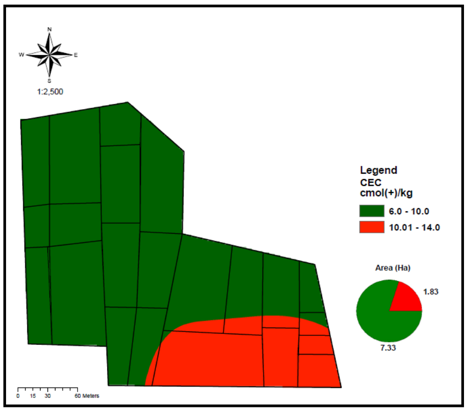

Figure 28. CEC distribution map in Kg. Ulu Melaka

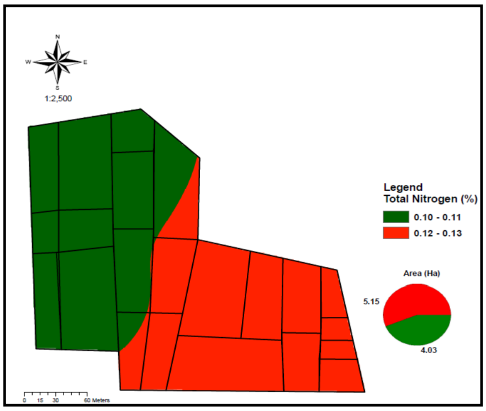

Figure 29. Total N distribution map in Kg. Ulu Melaka

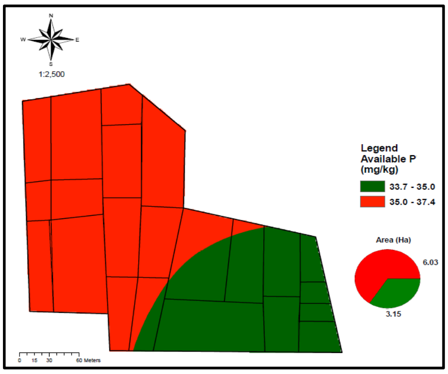

Figure 30. Available P distribution map in Kg. Ulu Melaka

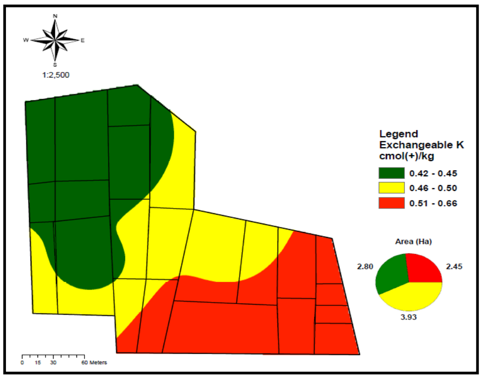

Figure 31. Exchangeable K distribution map in Kg. Ulu Melaka

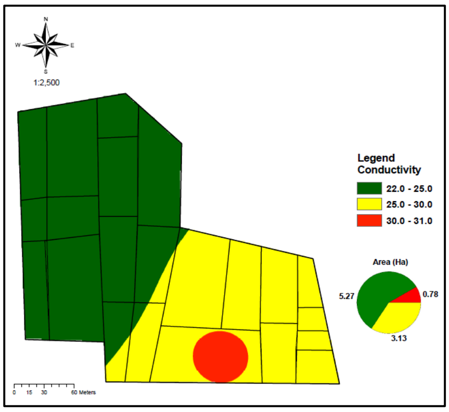

Figure 32. Conductivity distribution map in Kg. Ulu Melaka

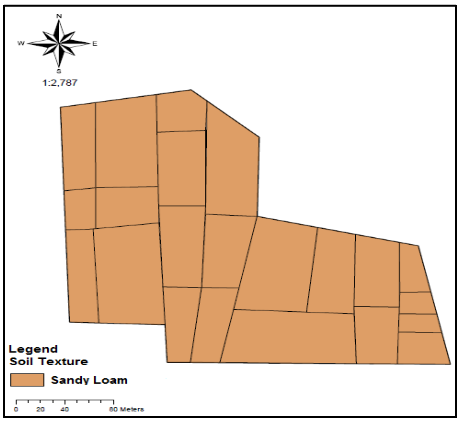

Figure 33. Soil texture distribution map in Kg. Ulu Melaka

Discussion

No significant difference in organic carbon, CEC, and conductivity among the study areas existed. However, a significant difference in soil chemical characteristics was observed in pH value, total N, available P, and exchangeable K. The results revealed that Kg. Ayer Hangat's rice field had a significantly lower pH value (4.68) than Kg. Batu Duyung (5.23) and Kg. Baru/Teluk (5.09). The average pH in the study area ranged from 4.68 to 5.23, slightly lower than the study area in Ajibode, Nigeria, with a range of 4.61 to 5.88 (Tobore *et al.*, 2021). The soil acidity might be attributed to the persistent application of inorganic fertilizers, particularly those containing nitrogen. Tobore *et al.* (2021) suggested that the observed acidity in the analyzed soils results from industrial waste discharge and widespread fertilizer application in the research area. The optimal pH range for rice fields, suggested by MARDI, is between 5.5 and 6.5 (Aishah *et al.*, 2010).

Additionally, the total N content in Kg. Ayer Hangat was significantly higher (0.18) compared to other locations in the study area. Nitrogen loss from the soil includes gaseous forms (N_2, N_2O, NO, and NH_3), losses through leaching, and nutrient loss during harvest (Safitri *et al.*, 2021). Phosphorus, a significant nutrient for crop growth (Yang *et al.*, 2023), was significantly higher in Kg. Batu Duyung (37.32 mg/kg) followed by Kg. Baru/Teluk (35.80 mg/kg) and Kg. Ulu Melaka (35.55 mg/kg). A study conducted in Beaumont, Texas, recorded a similar amount of available P at 36 mg/kg (Dou *et al.*, 2016). However, Kg. Ayer Hangat recorded the lowest available P (15.25 mg/kg), potentially due to losses through sediment-laden runoff (Pheav *et al.*, 2005).

Exchangeable K was significantly higher in Kg. Ulu Melaka (0.53 cmol(+)/kg) followed by Kg. Ayer Hangat (0.29 cmol(+)/kg), while Kg. Batu Duyung and Kg. Baru/Teluk recorded levels of exchangeable K at 0.19 cmol(+)/kg and 0.08 cmol(+)/kg, respectively. These results were lower than those found in a study by Tobore *et al.* (2021), which reported a range of 0.41 to 1.00 cmol(+)/kg. The reduced presence of potassium (K) in the soil may be attributed to factors such as the removal of plant biomass during harvesting, the adoption of intensive cropping practices, the cultivation of modern high-yield rice varieties, and the reduced or absence of potassium application (Sarkar *et al.*, 2017; Wihardjaka *et al.*, 2022).

Table 1. Characteristics of soil nutrients in study area

Locations	pH	Organic Carbon (%)	CEC (cmol(+)/kg)	Total N (%)	Available P (mg/kg)	Exchangeable K (cmol(+)/kg)	Conductivity (µS/cm)
Kg. Ayer Hangat	4.68 b	1.28 a	15.90 a	0.18 a	15.25 b	0.29 b	0.17 a
Kg. Batu Duyung	5.23 a	0.79 a	11.40 a	0.10 b	37.32 a	0.19 c	51.20 a
Kg. Baru/ Teluk	5.09 a	1.06 a	13.75 a	0.12 b	35.80 a	0.08 d	49.25 a
Kg. Ulu Melaka	4.98 ab	0.81 a	8.25 a	0.12 b	35.55 a	0.53 a	25.25 a
Mean Locations	5.00 *	0.97 ns	12.27 ns	0.13 *	29.53 *	0.27 **	32.63 ns
C.V.	4.64	25.04	37.28	21.75	29.20	22.97	108.49

Mean followed by * is significant at 0.05, Mean followed by ** is significant at 0.01

Soil Taxonomy (ST) is a categorization system formulated by the United States Department of Agriculture (USDA), classifying soils into 12 orders based on their physical, chemical, and biological attributes (Lee *et al.*, 2023; Soil Survey Staff, 2022). According to the USDA Soil Texture Triangle classification, three-quarters of the study locations fall under hydrologic soil group A, precisely the sandy loam type. This includes an area of 26.12 hectares in Kg. Batu Duyung, Kg. Baru/Teluk, and Kg. Ulu Melaka. However, in Kg. Ayer Hangat, the soil belongs to hydrologic soil group C, namely sandy clay loam, covering an area of 12.84 hectares.

Soils in group A, which are sand, loamy sand, or sandy loam types, are known for minimizing runoff and facilitating rapid water absorption, even when thoroughly saturated (Minnesota Pollution Control Agency, 2023). Similar results were recorded by Swati Sucharita *et al.* (2023), where the soil in the field experiment was sandy loam, and the pH showed similar findings at 5.4, close to the sandy loam soils in Kg. Batu Duyung (5.23) and Kg. Baru/Teluk (5.09). According to the manual, group C comprises sandy clay loam soils, which exhibit low infiltration rates when fully saturated. These soils are mainly characterized by a layer that hinders the downward movement of water and a moderately fine to fine soil structure. Research conducted by Burbos and Lyn (2023) has shown similar responses to exchangeable K in Kg. Ayer Hangat, where both are recorded as sandy clay loam soils. According to their findings, they recorded an amount of exchangeable K at 40 ppm, equivalent to 0.10 cmol(+)/kg when converted, whereas the exchangeable K (cmol(+)/kg) in Kg. Ayer Hangat showed an amount of 0.29.

These findings are essential for establishing reliable information on soil nutrients and textures at the site. This mapping mechanism can be utilized as a graphical nutrient indicator based on targeted yield, particularly for rice. This approach is more desirable than conventional methods, where randomized samplings were carried out without a mapping mechanism. Therefore, this GIS mapping mechanism can be implemented in developing nutrient management strategies for intensive small plantation systems (Chatterjee *et al.*, 2015).

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References

Aimrun, W., Amin, M. S. M. and Nouri, H. (2011). Paddy field zone characterization using apparent electrical conductivity for rice precision farming. International Journal of Agricultural Research, 6:10-28.

Aishah, A. W., Zauyah, S., Anuar, A. R. and Fauziah, C. I. (2010). Spatial variability of selected chemical characteristics of paddy soils in Sawah Sempadan, Selangor, Malaysia. Malaysian Journal of Soil Science, 14:27-39.

Burbos, R. O. and Lyn, R. (2023). Physico-chemical assessment of rice soils in Quirino Province, Phillipines. International Journal of Biomedicine and Life Sciences, 8:110.

Chatterjee, S., Santra, P., Majumdar, K., Ghosh, D., Das, I. and Sanyal, S. K. (2015). Geostatistical approach for management of soil nutrients with special emphasis on different forms of potassium considering their spatial variation in intensive cropping system of West Bengal, India. Environmental Monitoring and Assessment, 187:1-17.

Dou, F., Soriano, J., Tabien, R. E. and Chen, K. (2016). Soil texture and cultivar effects on rice (*Oryza sativa*, L.) grain yield, yield components and water productivity in three water regimes. PloS ONE, 11:e0150549.

Eltaib, S. M., Soom, M. A. M., Hanafi, M. M., Shariff, A. R. M. and Wayayok, A. (2002). Spatial variability of N, P, and K in rice field in Sawah Sempadan, Malaysia. Songkhlanakharin Journal of Science and Technology, 24:321-328.

Jamru, L. R., Sharil, M. N. and Yusoh, M. P. (2023). Assessing the evolution of paddy cultivation in Kota Belud, Sabah using GIS and remote sensing techniques. Journal of the Malaysian Institute of Planners, 21:204-216.

Lee, D. -B., Kim, Y. -N., Sonn, Y. -K. and Kim, K. -H. (2023). Comparison of soil taxonomy (2022) and WRB (2022) systems for classifying paddy soils with different drainage grades in South Korea. Land, 12:1204.

Lee, S. H., Yoo, S. H., Choi, J. Y. and Engel, B. A. (2016). Effects of climate change on paddy water use efficiency with temporal change in the transplanting and growing season in South Korea. Irrigation Science, 34:443-463.

Mandal, A. K. and Sharma, R. C. (2009). Computerized database of salt affected soils for Peninsular India using GIS. Geocarto International, 24:65-85.

Mandal, H. R., Shah, S. K., Oli, B., Katel, S., Yadav, S. P. S., Pant, K. R., Lamshal, B. S., Kattel, S., Sah, S. and Yadav, B. (2023). Assessment of soil fertility status in Rupani Rural Municipality, Saptari, Nepal. AgroEnvironmental Sustainability, 1:111-121.

Minnesota Pollution Control Agency. (2023). Soil classification - Minnesota Stormwater Manual. Retrieved from https://stormwater.pca.state.mn.us/index.php?title=Soil_classification

Mishra, A., Das, D. and Saren, S. (2013). Preparation of GPS and GIS based soil fertility maps for Khurda district, Odisha. Indian Agriculturist, 57:11-20.

Pheav, S., Bell, R. W., Kirk, G. J. D. and White, P. F. (2005). Phosphorus cycling in rainfed lowland rice ecosystems on sandy soils. Plant Soil, 269:89-98.

Safitri, D. E., Ahmad, A. and Nathan, M. (2021). Study of soil management in rice fields in Bantimurung District Maros Regency. IOP Conference Series: Earth and Environmental Science, 807:042008. IOP Publishing.

Sarkar, I. U., Isalm, N., Jahan, A., Islam, A. and Biswas, J. C. (2017). Rice straw as a source of potassium for wetland rice cultivation. Geology, Ecology and Landscapes, 1:184-189.

Soil Survey Staff. (2022). Keys to Soil Taxonomy, 13th edition. USDA Natural Resources Conservation Service.

Swati Sucharita, Rautaray, S. K., Satapathy, M. R. and Nayak, R. K. (2023). Zinc fertilizer application improves growth, yield and profit of paddy (*Oryza sativa* L.) in a zinc deficient Inceptisol. ORYZA-an International Journal on Rice, 60:196-202.

Tobore, A., Senjobi, B., Ogundiyi, T. and Bamidele, S. (2021). Geospatial assessment of wetland soils for rice production in Ajibode using geospatial techniques. Open Geosciences, 13:310-320.

Wihardjaka, A., Harsanti, E. S. and Ardiwinata, A. N. (2022). Effect of fertilizer management on potassium dynamics and yield of rainfed lowland rice in Indonesia. Chilean Journal of Agricultural Research, 82:33-43.

Yang, M., Sakruaba, Y., Ishikawa, T., Ohtsuki, N., Kawai-Yamada, M. and Yanagisawa, S. (2023). Chloroplastic Sec14-like proteins modulate growth and phosphate deficiency responses in Arabidopsis and rice. Plant Physiology, 192:3030-3048.

Yang, Y. and Zhang, S. (2008). Approach of developing spatial distribution maps of soil nutrients. In: Li, D. (eds) Computer and computing technologies in agriculture, volume I. CCTA 2007. The International Federation for Information Processing, volume 258, Boston, Springer, pp.565-571.

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