MAPPING OF SOIL pH AND NPK NUTRIENTS ON PEAT AGRICULTURAL LAND IN KALAMPANGAN VILLAGE, PALANGKA RAYA CITY

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ABSTRACT

Soil pH and macronutrient (Nitrogen, Phosphorus, Potassium - NPK) availability are critical factors influencing agricultural productivity, particularly in peatland regions like Kalampangan Village, which faces challenges of acidic soils and potentially low nutrient levels. This study aimed to map the spatial distribution of soil pH and NPK content across agricultural land in Kalampangan Village using field measurements with a 5-Pin Soil Sensor Probe RS485. The Inverse Distance Weighted (IDW) interpolation method was employed to generate spatial distribution maps from 45 sampling points. The results revealed significant spatial variability in soil pH, with a substantial portion of the agricultural land exhibiting acidic to slightly acidic conditions. Furthermore, the analysis indicated generally low levels of nitrogen, phosphorus, and potassium. The discussion explores the factors contributing to these conditions, including the inherent acidity of peat soils, peat depth variations, and nutrient dynamics influenced by pH. The generated maps provide crucial spatial information for targeted soil management interventions, enabling precise application of ameliorants and fertilizers to optimize soil conditions and enhance agricultural sustainability and productivity in this peatland ecosystem.

Key words: Soil sensor, soil acidity, peat agricultural, soil fertility.

INTRODUCTION

Soil is a crucial natural resource for agriculture, providing a medium for plant growth and the basis for food production. Soil quality, which is influenced by a variety of physical, chemical and biological factors, directly impacts agricultural productivity and food security (Suleman & Rajamuddin, 2016). Among the very important soil chemical parameters is pH (Santoso et al., 2022) and the availability of macronutrients Nitrogen (N), Phosphorus (P), and Potassium (K), which play a vital role in various plant physiological processes (Manurung et al., 2022). Nitrogen plays a role in vegetative growth, specifically leaf formation and leaf green color. Phosphorus is essential for the development of the root system, the formation of seeds, fruits, and flowers. Meanwhile, Potassium plays a role in stem strengthening and sustainable growth. Soil NPK content analysis is important to determine the appropriate external NPK fertilizer dosage according to plant needs. Maintaining the availability of NPK nutrients in soil requires an understanding of the method of measuring the nutrient content (Kumar et al., 2024).

Sub-ideal soil pH conditions, either too acidic or too alkaline, can cause various problems for plant growth, including affecting the availability of NPK nutrients (Fajeriana, 2024). Extreme pH can interfere with nutrient uptake, cause poisoning of certain elements, and inhibit the activity of beneficial soil microorganisms (Huda et al., 2023). Deficiencies or excesses of NPK can also have a negative impact; for example, nitrogen deficiency causes stunted growth and yellowing of leaves, phosphorus deficiency inhibits root development and flowering, while potassium deficiency decreases plant resistance to disease and drought (Suntoro et al., 2024). This problem has the potential to reduce crop yields, increase fertilization costs, and have a negative impact on the farmer economy.

Kalampangan Village is one of the areas with significant agricultural activities. However, the characteristics of the soil in this region, especially those dominated by peatlands (Yulianti et al., 2023), have the potential to cause problems related to soil pH that tends to be acidic with a value range of 4 to 6 and the availability of low NPK nutrients (Lestari et al., 2018). In addition, improper agricultural practices such as improper and unbalanced fertilization, then burning of peatlands to clear harvest residues can also affect the availability of nutrients. Therefore, mapping the pH and NPK conditions of the soil in Kalampangan Village is very important. It is crucial foundations for peatland improvement, although it does not directly change soil conditions. An accurate spatial understanding of pH distribution allows for precise and cost-effective application of ameliorants to areas in need. Similarly, NPK mapping identifies nutrient deficiencies for targeted fertilization only where they are needed, preventing wasteful use of fertilizers and reducing negative impacts on the environment. The combination of these two maps is an important diagnostic tool in designing holistic improvement strategies, considering the interaction between pH and nutrient availability, so that peatland management is more focused and sustainable.

This study aims to map the soil pH and NPK nutrients on agricultural land in Kalampangan Village through field measurements using the Soil Sensor 5 Pin Probe RS485 (ComWinTop, NPKPHCTH-HMI043, China). This tool successfully detects soil nutrients that are not much different from the results of laboratory tests (Kumar et al., 2024). Kumar et al conducted a study on CAES land samples and showed that the laboratory Nitrogen value was 55 kg acre^{-1} and the sensor value was 30 kg acre^{-1}, the laboratory Phosphorus value was 6.6 kg acre^{-1} and the sensor value was 6 kg acre^{-1}, while the laboratory Potassium value was 82.2 kg acre^{-1} and the

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sensor value was 72 kg acre^{-1}. The results of this research are expected to provide useful information for farmers in land management, for local governments in the formulation of agricultural policies, and contribute to the development of science in the field of soil science. With this research, readers can find out the area of agricultural land in Kalampangan village that requires special attention. This is intended so that plant growth and crop yields will increase.

MATERIAL AND METHODS

Description of the study area

Kalampangan Village has an area of 5000 hectares. Land use in Kalampangan Village is dominated by yards (3.544 Ha), followed by plantations (1.000 Ha) and settlements (420 Ha). It has been designated by the government as one of the main food safety buffer villages and producers of agricultural products in Central Kalimantan (BPS, 2024). Geographically, Kalampangan Village is located between the coordinates 114º 00'18" − 144º02'42 East Longitude and 2º 16'48" − 2º20'24" South Latitude. Since the 1980s, a significant portion of peatland in Kalampangan, exceeding 3 meters in depth, has been transformed into agricultural land by local farmers. Their primary crops include sweet corn, kale, spinach, mustard greens, chilies, long beans, eggplant, and cucumber. Consequently, this area and its vicinity are increasingly recognized as a valuable natural site for studying tropical peatland agriculture and ecological restoration efforts in peatland ecosystems (Yulianti et al., 2023).

The condition of agricultural land in Kalampangan Village is dominated by peatland dengan kedalaman 4 meter (Yulianti et al., 2023). This is because geologically, Kalampangan Village, which is part of the Sebangau District in Palangka Raya City, has surface deposits predominantly composed of Quaternary alluvium. This alluvium consists of peat dark to blackish brown (paludal deposits); loose sand, yellowish colour, fine-coarse grained, unbedded (fluvial deposits); clay grey to brownish colour, very soft, locally containing plant remains (tidal area); kaolinite clay, yellowish white, plastic. The thickness of this unit ranging from 50 to 100 meters. The older geological formation is the sedimentary deposit of the Dahor Formation, estimated to be Middle Miocene to Pliocene in age and generally composed of non-compacted sedimentary rocks such as conglomerate, sandstone, and claystone, with an estimated thickness of 300 meters (Nila et al., 1995) .

The topographic conditions in Kalampangan Village are predominantly characterized by lowlands with flat slopes, which ranges from 0% to 3%. The altitude of this area is in the range of 14 to 18 meters above sea level. Kalampangan has a tropical climate with two main seasons, namely the rainy season (November−Februari) and the dry season (Juni−September). The average temperature ranges from 24º to 34º Celsius, and the average annual rainfall is between 2000 and 3000 mm (P. R. BPS, 2024).

Soil Sensor 5 Pin Probe RS485 NPKPHCTH-HMI043

This Soil Sensor (Figure 1 and Table 1) can be used to measure soil pH and NPK. Data collection is carried out by sticking the sensor feet into the ground and the results will be displayed on the HMI touch screen.

Soil pH Reference

Table 2 below presents the typical pH range for various soil types. An understanding of soil pH is of paramount importance in agricultural and horticultural practices due to its direct influence on nutrient availability for plants.

Figure 1. Soil Sensor 5 Pin Probe RS485 NPKPHCTH-HMI043

Table 1. Soil Parameters Measuring

Not	Measure item	Parameters
1	pH	Measuring range : 3−9 pH Accuracy : ± 0.3 pH Long-term stability : ≤5% year^{-1} Response time : ≤10s
2	N,P,K	Measuring range : 1−1999 mg kg^{-1} (mg L^{-1}) Resolution : 1 mg kg^{-1} (mg L^{-1}) Response time : 1s

Remarks : (CWT, 2024)

Table 2. pH Soil Parameters

	Very Acidic	Acidic	Slightly Acidic	Neutral	Slightly Alkaline	Alkaline
pH (H20)	<4.5	4.5−5.5	5.6−6.5	6.6−7.5	7.6−8.5	>8.5

Remarks : (PPT, 2005)

Data Analysis

Soil pH and NPK mapping was carried out using *Inverse Distance Weighted* (IDW) method with open source geospatial software QGIS 3.38 version Grenoble (Suntoro et al., 2024). Method *Inverse Distance Weighted* (IDW) is a geostatistical interpolation technique known for its simplest formulation, ease of understanding, and easy implementation. The interpolation method generally works on the assumption that adjacent points are more similar. *Inverse Distance Weighting* (IDW) specifically uses this principle by assuming that resemblance is inversely proportional to distance. The closer the distance between the points, the greater the influence in the calculation. IDW uses the distance inverse function for this calculation. The determination of the search radius and the power of the distance inverse function are very important in IDW. This method is ideal if there are at least 14 sample points that are well spread across the research area (Setianto & Triandini, 2015). In this research, 45 sampling points were established within the agricultural land area of residents in Kalampangan Village. Data acquisition was conducted directly in the field by inserting a Sensor 5 Pin Probe RS485 NPKPHCTH-HMI043 sensor into the soil. Subsequently, soil pH and NPK values were directly observable on the HMI touch screen of the instrument. IDW accuracy is affected by rank parameters p, the size of the search area, and the number of neighboring points (Setianto & Triandini, 2015).

$$Z_o = \frac{\sum_{i=1}^{N} z_i . d_i^{-n}}{\sum_{i=1}^{N} d_i^{-n}}$$

Where,
Z_o= The estimated z-value at point I
z_i = The observed value at point I.
d_i = The distance from the sample point to the point of estimation.
N = The distance-based weighting coefficient.
n = The sum of predictions generated for every validation case.

RESULT AND DISCUSSION

A. RESULT

A.1 pH Content

The results of the analysis showed that the distribution of pH values in the study area ranged from 4.71 to 8.19 (Figure 2). Based on the 45 data points depicted in Figure 2, 13 points exhibit a pH range of 4.7 to 5.5 (acidic), 12 points fall within the pH range of 5.7 to 6.5 (slightly acidic), 15 points present a pH range of 6.6 to 7.5 (neutral), and 5 points demonstrate a pH range of 7.7 to 8.4 (slightly alkaline).

A.2 Nitrogen Content

The results of nitrogen content analysis in agricultural peatland (Figure 3) showed values ranging from 0 to 52.99 mg kg^{-1}.

A.3 Phosphorus Content

The results of the analysis of phosphorus content in agricultural peatland showed a range of 0−167.98 mg kg^{-1} (Figure 4).

A.4 Potassium Content

The results of the analysis of potassium content in agricultural peatland in Kalampangan village showed a value in the range of 0−161.98 mg kg^{-1} (Figure 5).

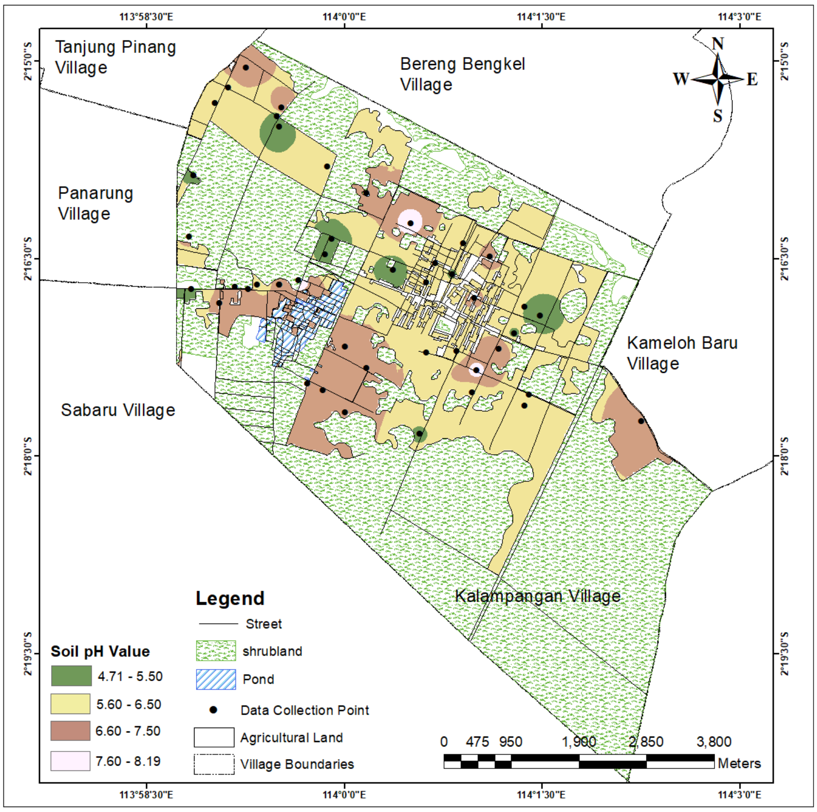

Figure 2. Distribution of pH of peat agricultural land in Kalampangan village, Palangka Raya city

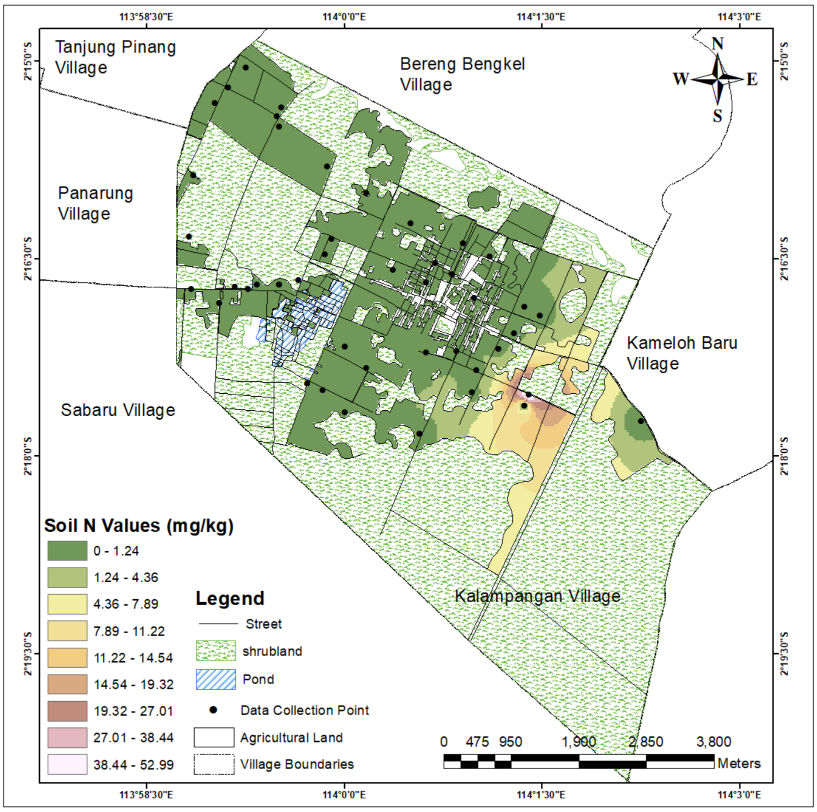

Figure 3. Distribution of nitrogen (N) in peat agricultural land in Kalampangan village, Palangka Raya city

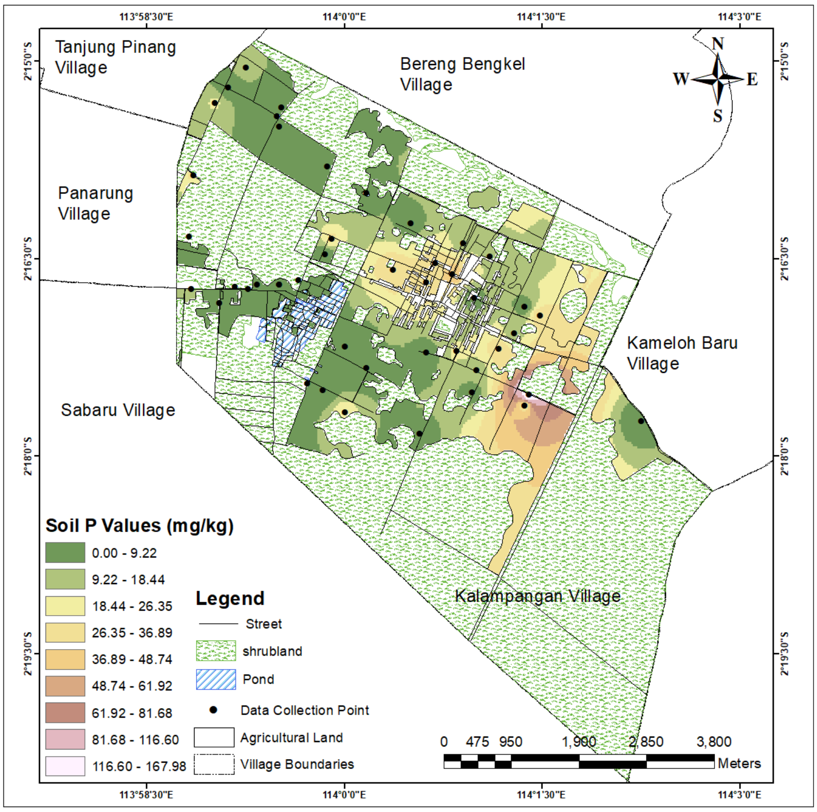

Figure 4. Distribution of phosphorus (P) in peat agricultural land in Kalampangan village, Palangka Raya city

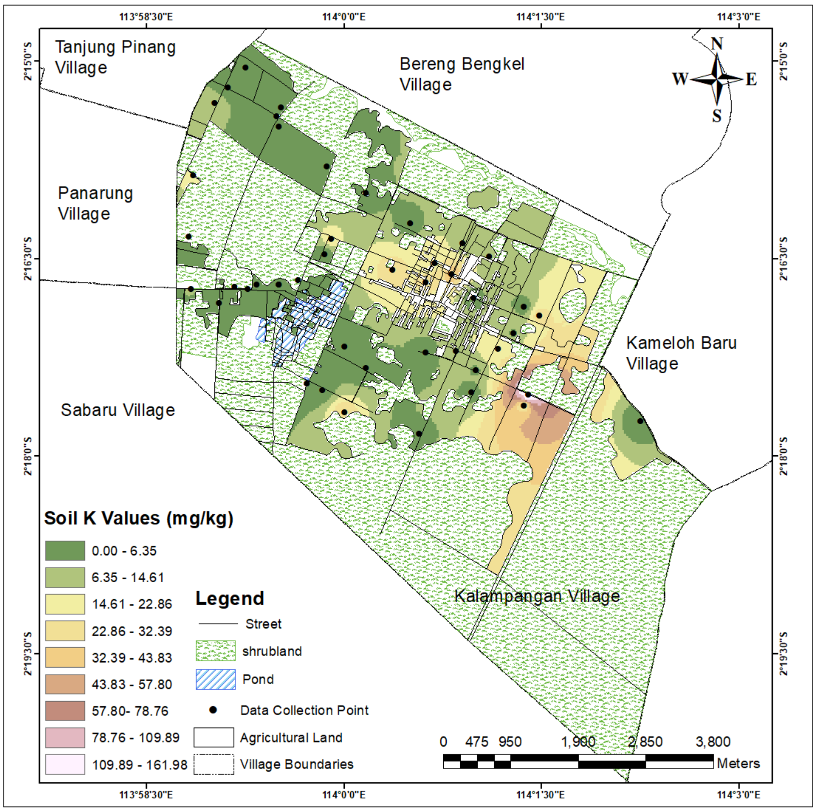

Figure 5. Distribution of potassium (K) in peat agricultural land in Kalampangan village, Palangka Raya city

B. DISCUSSION

B.1 pH Content

The pH value of the soil in the study area is diverse. Based on the 45 data points, 55.56% of the sampled area exhibits soil pH values categorized as acidic and slightly acidic. On the map (Figure 2), these areas are indicated by green and yellow hues. Peat soil exhibits acidity due to its inherent acidic organic matter content (humus) (A'idah et al., 2018). Subsequently, 33.33% of the area identified by the brick-red coloration in Figure 2 is categorized as having a neutral soil pH. This conditions favorably influence soil microorganism activity, thereby enhancing organic matter decomposition and nutrient provision for plants (Huda et al., 2023). Neutral soil pH in the study area was seen mostly near the pond (Figure 2). 11.11% of the area indicated by the white coloration in Figure 2 presents an alkaline soil pH. Alkaline soil conditions can decrease the availability of essential plant nutrients, especially phosphorus and certain micronutrients (Santoso et al., 2022). This variability in soil pH values can be attributed to several factors, one of which may be the application of agricultural lime (dolomite) to agricultural land in order to elevate soil pH levels.

In addition, it can also be caused by the non-uniform peat depth in the study area. The range of peat depth in the study area was more than 3 meters (Yulianti et al., 2023). The thickness of peatland ranging from 50 to 100 meters (Nila et al., 1995). The depth of peat exerts a significant influence on soil pH. Surface layers tend to exhibit higher acidity due to the accumulation of organic acids resulting from the decomposition of recent litter and the leaching of bases by precipitation. In areas with a thin peat layer overlying mineral soil, the overall soil pH is more strongly influenced by the chemical properties of the underlying mineral substrate. Where this mineral soil has a higher pH (for instance, calcareous soils), the pH of the thin overlying peat layer is less likely to be as acidic compared to thick peat deposits. Conversely, sites with thick peat layers are predominantly characterized by the inherent chemical properties of the peat itself. Consequently, the soil pH in such areas tends to be highly acidic and more uniform throughout the peat profile, with minimal influence from the underlying mineral soil (Widijayakusumah, 2022). pH that is too low (acidic) or too high (alkaline) can inhibit the absorption of nutrients, even causing poisoning (Puspita Sari, 2023). On the agricultural land of Kalampangan village, rice plants have not been able to grow because of the pH condition of the soil. So that the crops planted by farmers are spinach, chili, eggplant, mustard greens, kale, and long beans. Food crops such as carrots, potatoes, radishes or tuber-type food crops tend to be rarely planted because they are difficult to grow.

B.2 Nitrogen, Phosphorus, and Potassium Content

The nitrogen, phosphorus, and potassium content in the agricultural peatland of Kalampangan Village is measurably low. The nitrogen content of the soil is lower than the phosphorus and potassium content. This disparity in nitrogen content can be primarily attributed to the complex and pH-sensitive nature of the nitrogen cycle within the soil. Unlike phosphorus and potassium, which have more stable availability mechanisms, nitrogen undergoes various transformations such as organic matter mineralization, nitrification, denitrification, and biological fixation, each operating optimally within specific pH ranges. Extreme pH conditions, whether excessively acidic or alkaline, can significantly hinder the crucial processes of mineralization and nitrification, consequently reducing the readily available inorganic nitrogen for plant uptake.

The low nitrogen content can caused by several other factors, namely the nature of nitrogen which is easily lost because it is soluble in water. High rainfall or over-irrigation can dissolve nitrates and take them out of the plant's root zone, so nitrogen is lost from the soil (Puspita Sari, 2023). Then the evaporation of nitrogen in the form of ammonia into the air due to the pH of the soil is not ideal and the temperature is high. And finally, the denitrification process is carried out by microorganisms in anaerobic conditions. In waterlogged soil conditions, these microorganisms convert nitrates into nitrogen gas and nitrogen oxides, which are then lost to the atmosphere. The combination of these factors often works together and causes the soil to have a low nitrogen content, which can ultimately negatively impact crop growth and crop yields (Bachtiar & Ura', 2022). For example, nitrogen-deficient plants will experience stunted growth, yellowing leaves, small leaf size, and reduced number of saplings (Rellam et al., 2017). In Figure 3, it can also be seen that the higher nitrogen content than other areas in ranges from 4.36–27.01 mg/kg. In the data collection area, there is a dragon fruit orchard that has just been fertilized. So that the nitrogen content of the soil tends to be higher than other agricultural land.

The phosphorus availability within the soil is also influenced by soil pH conditions. Optimal phosphorus availability occurs within a normal pH range of 6.6 to 7.5. Under acidic conditions (pH < 6.6), the increased solubility of aluminum and iron ions leads to phosphorus fixation as insoluble aluminum and iron phosphate compounds. Conversely, under alkaline conditions (pH > 7.5), phosphorus tends to be bound by calcium, forming calcium phosphate compounds with similarly low solubility (Dariah et al., 2015). Consequently, soil conditions with extreme pH values can impede phosphorus uptake by plant roots. In figure 3, there is an area of study that has a higher phosphorus content than other area in range 36.89 to 167.98 mg/kg. This indicates that not all agricultural land in Kelampangan village shows a very low soil phosphorus content. This can happen due to the treatment of farmers to their fields in fertilizing, good drainage, dolomite application to regulate soil pH, and other factors. Phosphorus deficiency can cause plants to experience impaired growth, impaired flower and fruit formation, reddish-purple leaves, and low seed and fruit production (Suntoro et al., 2024).

The value range of potassium is also classified as a low number for soil phosphorus content. Low potassium content can occur due to pH soil, excessive irrigation, high rainfall, improper use of fertilizers, and so on (Suntoro et al., 2024). The availability of potassium (K) in soil is not directly governed by soil pH but is rather indirectly influenced through its impact on the soil's cation exchange capacity (CEC). The CEC, representing the soil's ability to retain positively charged ions (cations) including potassium (K^+), is modulated by soil pH. Specifically, at low (acidic) pH levels, the negative charge on the surface of clay particles and organic matter, which constitute the primary cation retention sites, tends to decrease. This reduction in negative charge diminishes the soil's capacity to retain potassium and other cations, thereby increasing the potential for potassium loss through leaching. Conversely, high (alkaline) pH conditions generally lead to an increase in CEC, which can enhance potassium retention. However, this increased CEC at alkaline pH can also augment the retention of other base cations (such as calcium, magnesium, and sodium), which may, in certain instances of high concentration, compete with potassium for uptake by plant roots (Solly et al., 2020).

CONCLUSION

This study successfully mapped the spatial distribution of soil pH and NPK nutrient levels across agricultural land in Kalampangan Village, a crucial step towards informed peatland management. The findings reveal a considerable heterogeneity in soil pH, with a significant portion of the area exhibiting acidic to slightly acidic conditions, typical of peatlands. While neutral and slightly alkaline zones were also observed, likely influenced by factors such as liming and varying peat depths, the prevalence of acidic pH poses challenges for nutrient availability. Furthermore, the analysis indicates generally low levels of nitrogen, phosphorus, and potassium across the surveyed agricultural areas. Low nitrogen is attributed to the dynamic nature of the nitrogen cycle and susceptibility to loss through leaching, volatilization, and denitrification, exacerbated by sub-optimal pH. Phosphorus availability is constrained by both acidic and alkaline conditions due to fixation with aluminum/iron and calcium, respectively. Potassium levels, while not directly pH-dependent, are indirectly affected by pH-induced changes in cation exchange capacity and potential competition with other cations. These spatial insights into soil pH and NPK status provide a vital diagnostic tool for targeted interventions, enabling farmers and local authorities to implement precise amelioration and fertilization strategies, thereby promoting sustainable agricultural practices and enhancing crop productivity in this peatland region.

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