MAPPING OF *SUBAK AREA* BOUNDARIES AND SOIL FERTILITY FOR AGRICULTURAL LAND CONSERVATION

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DOI: 10.21163/GT_2022.172.17

ABSTRACT:
Soil fertility is the most crucial aspect of the sustainability of agricultural land productivity. As an agricultural country, Indonesia is closely related to agricultural activities and soil fertility. This scientific paper analyzed the boundary of *subak*, soil fertility condition, which will later be used as a guide for agriculture land conservation. *Subak* is a traditional Balinese farmer organization that aims to manage water irrigation and rice cropping patterns in paddy fields. Boundary *subak* agricultural land is determined by participatory mapping method, involving farmers. Soil fertility data were analyzed through field and laboratory surveys. The condition of the limiting factors for soil fertility in each mapping unit is then used as the basis for managing and conserving agricultural land. The result showed that area of *subak* in agriculture land is 2,177.33 ha divided into 65 Subaks. Soil fertility status in each Subak is grouped into two soil fertility statuses (medium and high). Therefore, it is necessary to carry out integrated soil conservation, such as returning plant residues into the soil periodically and adding organic matter and fertilizers containing P and K elements in single fertilizers and compound fertilizers. Adding P and K compound fertilizers is needed to support optimal land productivity and increase the CEC value of the soil. Types of organic matter can be applied to the soil by returning crop residues, manure, and composting.

Key-words: *GIS, Conservation, Mapping, Soil Fertility, Subak, Bali-Indonesia.*

1. INTRODUCTION

Subak is a traditional Balinese farmer organization that primarily aims to manage water irrigation and rice cropping patterns in paddy fields (Sumiyati et al., 2017; W. Windia et al., 2018). Subak is a traditional organization that is already known abroad. As an organization that deals with conventional irrigation systems, *Subak* also has a unique attraction for tourists, namely terraced rice fields, generally composed of terraced rice fields or terraces resembling unsized steps; this view presents tourists with both local and local. Furthermore, foreign countries visit Bali (Suasih et al., 2018). United Nations Education, Scientific, and Cultural Organization (UNESCO), on June 12, 2012, designated Subak as a world cultural heritage in the cultural landscape category.

One of the challenges currently facing *Subak* is the shrinking of irrigated paddy fields due to conversion to non-agricultural activities. In the last five years, rice fields in Bali have decreased by more than 1000 ha/year (Windia & Wiguna, 2013). Land conversion occurs in many urban areas because it is triggered by land prices that continue to soar, so farmers in urban areas are very tempted by very high price offers. The land-use change is thought to be due to the low productivity of agricultural land, one of which occurred in *Subak* in Sawan District, Buleleng Regency, Bali-Indonesia Province.

In agriculture, especially in plant cultivation, soil conditions and their management are essential factors determining whether the growth and yield of plants to be cultivated are optimal. This is because the soil is a production factor that acts as a growing medium for plants, a supplier of nutrients, and a water supply indispensable for plant growth (Subedi, 2018). Therefore, the ability of the soil to support plant growth will be determined by the state of soil fertility. As far as fertility is concerned, soil productivity can be improved and enhanced by specific technological inputs.

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Soil fertility is the ability of the ground to provide balanced amounts of nutrients for plant growth and production. Planting crops can cause the loss of essential nutrients in the soil because, during harvesting, essential nutrients are transported out of the land, mainly if they are cultivated continuously (Kome et al., 2019; Bayu, 2020; Prabakaran et al., 2021). Thus, soil fertility will decrease until it reaches a state where the addition of nutrients through fertilization is necessary to obtain profitable agricultural products.

The boundaries of the *subak* agricultural area are not currently available spatially. The data is essential, especially in the management of *subak* agricultural land, irrigation arrangements, and the distribution of fertilizer subsidies by the government so that they are right on target and in the right location. *Subak* land mapping and quantification of soil properties were carried out using a Geographic Information System (GIS). Previous researchers used GIS technology to map landslide hazards (Diara et al., 2022; Trigunasih & Saifulloh (a), 2022), monitor changes in vegetation index and urban air quality (Sunarta & Saifulloh, 2022), as well as spatial analysis of relationships between flooding and soil infiltration in urban areas (Trigunasih & Saifulloh (b), 2022). We use GIS to analyze and map the spatial distribution of agricultural subaks, and soil properties, which are used as the basis for future *subak* land conservation.

Evaluation of fertility status to assess and monitor soil fertility is essential to identify deficiencies or obstacles in terms of nutrients possessed by the land. One way that is often used to assess the soil's fertility is through soil analysis or soil testing. Soil analysis or testing is a relatively more objective approach to determining soil fertility status. Assessment of soil fertility status is essential because if no fertilization action is under the soil's needs over time and land use, then soil fertility will decrease. This research was conducted to know the spatial distribution of *Subak* land, analyze soil fertility status, and provide recommendations for land conservation based on soil fertility properties.

2. STUDY AREA

The case study of this research is administratively located in Sawan District, Buleleng Regency, Bali, Indonesia. Geographically, Sawan Regency is located at 8° 5' 14" - 8° 14' 45" South Latitude and 115° 6' 55' - 115° 11' 1" East Longitude (**Fig. 1**). This is because it has varied topography and slopes. *Subak* agriculture stretches widely from the upstream area with an altitude of > 2000 m asl to the northern coastal area with an altitude of < 5 m asl. The slope of the slope also varies, from flat (0-8%) to very steep (> 45%). Rainfall in the upstream area reaches > 2500 mm/yr, while in coastal areas, it ranges from 1000-1500 mm/yr.

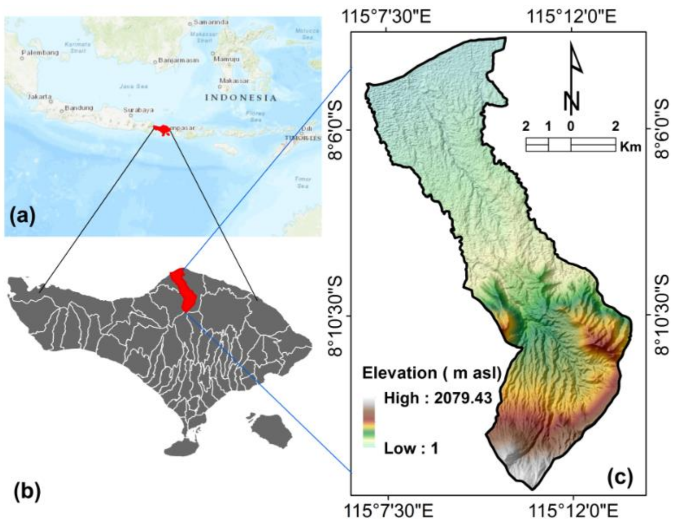

Fig.1. The research location is viewed from a low scale (left, a and b), the research location appears to be on a larger scale (right).

The *subak* area in this study focuses on wetlands ie rice fields. Based on field observations, the period of the rice cropping pattern on the land is 2 times a year, depending on the conditions of the availability of rainwater and irrigation. This condition is assumed to affect the chemical variability and soil fertility of *subak* agricultural land. On steep slopes to steep, it was easily leaching nutrients due to being washed away by rainwater in the upstream to downstream areas.

3. DATA AND METHODS

3.1. Tools and Materials

The materials used to analyze soil samples in the laboratory are chemical substances as reagents for soil analysis. The materials used for analysis in the laboratory include HCl 25%, NH_4OAc pH 7 1N, 80% alcohol, 50% NaOH, concentrated H_2SO_4, liquid paraffin, concentrated H_3PO_4, $K_2Cr_2O_7$, $FeSO_4$ 1N, DPA, Whatman 42 filter paper, an indicator of methyl red and aqua dust. The maps are the image of the research area from Google Earth in 2020, a slope map, a land map, subak map. The tools needed in this research are: tools in the laboratory include an oven, pH meter, Erlenmeyer, pipette, burette, Kjeldahl flask, and Kjeldahl distillation device. The tools needed in the field include a Belgian drill, dagger, meter, plastic bag, label paper, Garmin Montana 6.80 Hand GPS and stationery.

3.2. Methods and stages of research

This research was conducted using survey methods and soil test methods which were analyzed at the Laboratory of Soil and Environmental Sciences, Faculty of Agriculture, Udayana University. The chemical properties of the soil determined were Cation Exchange Capacity (CEC) and Base Saturation (NH_4OAc Extraction pH 7 1N), total P_2O_5 and total K_2O content (25% HCl), C-Organic content (Walkley and Black, 1934), pH (H_2O 1: 2.5), then the levels are determined based on the criteria for soil chemical properties (PPT, 1995). Determination of soil fertility status using technical instructions for evaluation of soil fertility-Indonesia (PPT, 1995). The criteria for assessing soil chemical properties are presented in **Table 1**.

Table 1.

Criteria of several chemical properties of the soil.

Criteria	Very Low	Low	Moderate	High	Very High
C Organic (%)	< 1.00	1.01-2.00	2.01-3.00	3.01-5.0	>5.00
P_2O_5 Bray I (ppm)	< 10	10-15	16-25	26-35	>35
P_2O_5 (ppm), Olsen, 1954	< 10	10-25	26-45	46-60	>60
K_2O (me/100 g)	< 0.1	0.1-0.2	0.3-0.5	0.6-1.0	>10
Base Saturation (%)	< 20	20-35	36-50	51-70	>70
CEC (me/100 g)	< 5	5-16	17-24	25-40	>40
pH	4.5-5.5 Sour	5.6-6.5 Bit Sour	6.6-7.5 Netral	7.6-8.5 Bit Base	>8.5 Alkaline/base

The stages of the research started with delineating the mapping unit, field survey, and soil analysis in the laboratory. Delineation of mapping units based on land map overlays, slope maps, and subak maps. Determination of subak boundaries is done by participatory mapping, involving farmer groups who own the land. Farmers have a main role in this activity, while researchers are GIS operators who direct the mapping of the boundaries of the subak area. From the results of overlaying several maps, a map of the mapping unit can be obtained, which is used as an observation unit in soil sampling. Making a unit mapping using a QGIS 3.22 LTR applications. The spatial distribution of mapping units is presented in the next sub-chapter. Field surveys are carried out by checking the correctness of the boundaries of the mapping unit, then adjusting to the conditions in the field. Furthermore, soil samples were taken with a depth of 0-30 cm in the mapping unit following the irrigation canal from upstream, middle, and downstream with a purposive sampling method and then composited. A Belgian drill and GPS assisted this soil sampling for geo-tagging the location.

Soil analysis in the laboratory was carried out after taking soil samples in the field. The chemical properties of the soil analyzed included pH, CEC, Base Saturation, K-total, P-total, and C-organic. The results of soil analysis are used to assess soil fertility status. After obtaining soil chemical properties data, tabulated using the QGIS 3.22 LTR application by entering soil chemical properties data into a table to make it easier to view soil chemical properties data and determine soil fertility status. Evaluation of fertility status is determined based on the chemical properties of the soil, which is matched with the criteria for soil fertility status (PPT, 1995). Determination of land conservation based on soil fertility status and limiting factors on low and medium soil fertility. After obtaining the results of laboratory analysis, a determination is made by classifying the status of soil fertility according to the criteria for assessing chemical properties (Sardiana et al., 2017; Siregar et al., 2021).

4. RESULTS AND DISCUSSIONS

4.1. Mapping of *Subak* Land

Subak is a community organization that regulates the irrigation system used in rice cultivation in Bali, Indonesia. Subak generally has a temple called *Pura Uluncarik* or *Pura Bedugul*, specially built by landowners and farmers. According to Balinese beliefs, the temple is dedicated to *Dewi Sri*, the goddess of prosperity and fertility. This irrigation system is managed by a traditional leader (*Pekaseh*), a farmer in Bali. The *subak* system has become one of the characteristics of Balinese society. This irrigation system develops under the influence of solid Hindu religious values . It forms a pearl of local wisdom, which allows farming communities in Bali to be in harmony with nature to obtain optimal yields (Windia & Wiguna, 2013). Based on the participatory mapping, the area of *Subak* land in Sawan District is 2,177.33 ha, which is divided into 65 *Subaks*. Subak with an area of 75-100 ha, there are 4 *Subaks*, including the Landahan Kerobokan, Guliang and Babakan Jagarag. *Subak* above 100 ha there is only one *Subak*, namely Kloncing with an area of 102.24 ha. The graph of the difference in the area of *Subak* from the mapping is presented in **Fig. 2**.

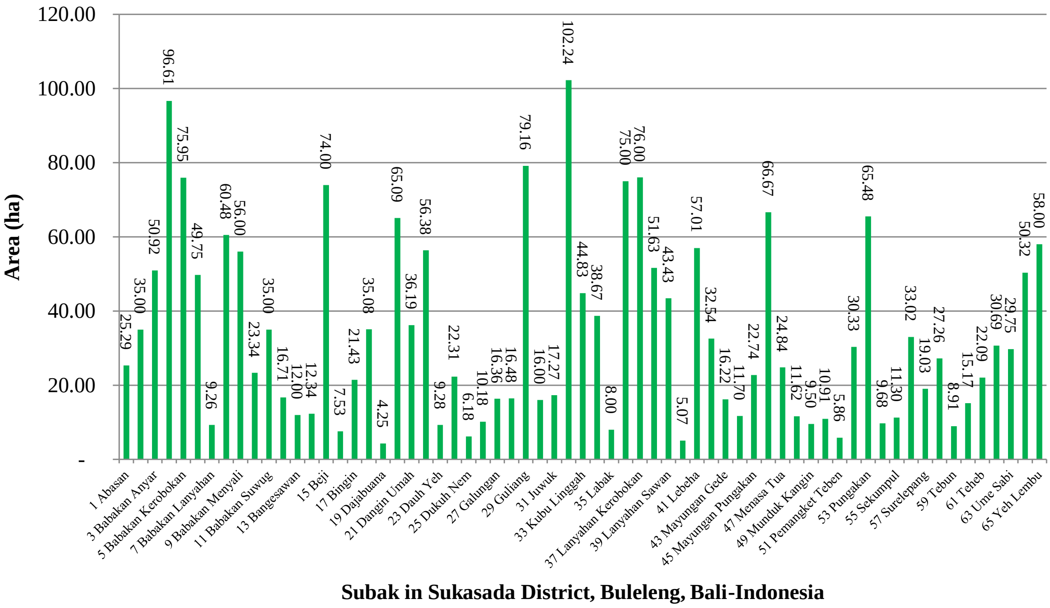

Fig. 2. The graph of the difference in the area from the mapping of Subak.

The boundaries of the *subak* area are determined based on irrigation canals and natural boundaries, namely rivers. *Subak* does not follow administrative boundaries because the subak area existed before the government set administrative boundaries, such as villages or sub-districts (Aryastana et al., 2020; Norken et al., 2016; Trigunasih & Saifulloh (c), 2022). Based on **Fig. 3**, the Tukad Sungsit (river) is a barrier between the Subak Beji area and Subak Dangin Yeh, which is spatially located on the north coast of Bali Province.

Fig. 3. Spatial distribution of Subak area as seen from the Bing World Imagery Satellite.

This research focuses on *Subak* rice fields (wetlands). Spatially, 65 Subaks in Sawan District are presented in **Fig. 4**. The northern coastal area contains Subak Labak, Beji, Dangin yeh Guliang, and Yangai with flat slopes (0-8%). The southern part has steep slopes (25-45% spatially), Subak Bingin, Bangesawan, and Galungan. The previous mapping of the *Subak* boundary was carried out by (Lanya & Manalu, 2021; Lanya et al., 2017; Lanya & Subadiyasa, 2016).

Protection of *Subak* land is essential to control land conversion into built-up land. The conversion of *Subak* land is not only detrimental to farmers. It is also detrimental to the tourism sector because *Subak* in Bali is not only for agricultural activities but also for a destination for tourist attraction (Budiasa et al., 2015; Norken et al., 2016; Sunarta et al., 2019; Sunarta et al., 2021), so Subak land resources need to be preserved. One of the sustainable S*ubaks* in Bali namely Subak Jatiluwih.

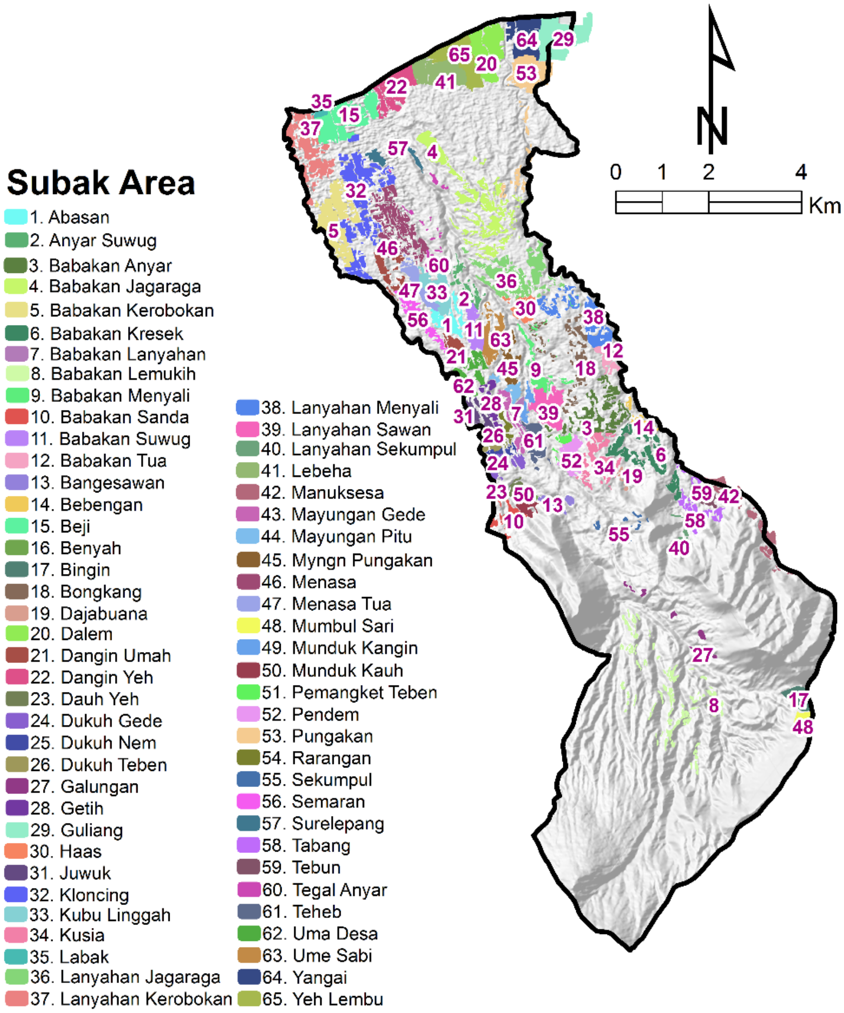

Fig. 4. Spatial distribution of the Subak land.

Subak Jatiluwih, located in Penebel District, Tabanan Regency (8°22'6.68"S, 115° 8'12.64"E), has become one of the role models in the management of Subak rice fields in Bali (**Fig. 5**). Apart from being an agricultural activity, the Subak land is a mainstay tourist destination in Bali, which domestic and foreign tourists know. The *Subak* area is located on a steep slope, but water availability for each rice field is still met. This condition is due to managing irrigation water with one inlet and one outlet system, which the *Subak* organization has managed. Even though it is on a steep slope, Subak Jatiluwih is safe from erosion and landslides. This condition is due to the terracing system on sloping land. Terraces can minimize runoff due to high rainfall, retain coarse material from upstream areas and minimize sedimentation.

The traditional *Subak* land conservation efforts can be duplicated in other areas by considering each region's local wisdom. This research reviews conservation actions through agricultural land management based on soil fertility conditions. Effective management is right on target and in the right location to be effective and efficient. With the findings in this study, practitioners in agriculture carry out land management (especially in terms of chemistry) with different chemical compositions of fertilizers. Based on the soil fertility conditions that have been analyzed in each land unit.

Fig. 5. Map of Subak Jatiluwih rice fields (left) sourced from the Tabanan Regency Agriculture Service, Natural panorama of Subak Jatiluwih terraces (right), sourced from https://www.klook.com.

4.2. Land Unit Mapping

Land units (LU) are delineated based on the slope and soil type. The soil types in the research location include brown regosol, gray brown regosol, and yellowish-brown latosol (**Fig. 6a**). The slopes at the study site ranged from 0-8%, 8-15%, 15-25%, and 25-45% (**Fig. 6b**). As well as the green map, which shows the spatial distribution of *Subak* land in Sawan District (**Fig. 6c**). Based on the overlay, the land unit (**Fig. 6d**) can be obtained, which is used as a working map in soil sampling and a basis for determining Subak land management through soil fertility analysis. The land unit is the basis for the researchers' consideration in analyzing soil fertility data because the soil sample represents the condition of the soil properties in the field. The soil formation is influenced by parent material, slope, climate, and others (Jáuregui et al., 2018; Minasny et al., 2008; Phillips, 2017). The basis for taking soil samples using Land units has also been carried out by previous researchers (Sardiana et al., 2017; Beisel et al., 2018).

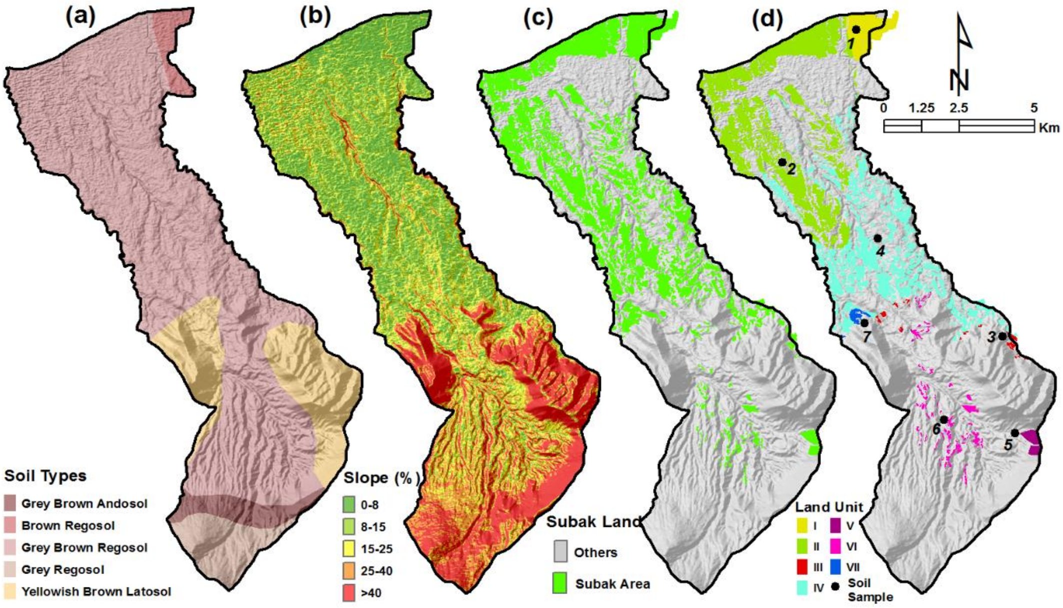

Fig 6. Thematic map of soil types (a), slope (b), Subak area (c), land units and soil sampling location on field (d).

4.3. Mapping of Soil Fertility

The chemical properties of the soil in this study consisted of CEC, base saturation, organic matter, total P, total K, and pH as supporting data on soil fertility status (**Table 2**).

Table 2.

The results of the analysis of soil chemical properties through the Laboratory and Adjustment to Soil Fertility.

LU	CEC (me/100 g)	Base Saturation (%)	C-Organic (%)	P_2O_5 (mg/100g)	K_2O (mg/100 g)	pH H2O	Soil Fertility
I	22.62 (M)	99.04 (VH)	4.03 (H)	50.79 (H)	143.31(VH)	6.64 (N)	Moderate
II	27.42 (H)	95.99 (VH)	3.68 (H)	37.01 (M)	202.93 (VH)	6.50 (N)	High
III	26.47 (H)	93.33 (VH)	3.70 (H)	50.99 (H)	142.28 (VH)	6.66 (N)	High
IV	26.38 (H)	96.55 (VH)	3.81 (H)	91.11 (VH)	47.98 (H)	6.55 (N)	High
V	19.32 (M)	93.33 (VH)	3.60 (H)	49.32 (H)	107.38 (VH)	6.30 (BS)	Moderate
VI	27.49 (H)	91.05 (VH)	3.75 (H)	36.91 (M)	118.47 (VH)	6.60 (N)	High
VII	28.77 (H)	93.75 (VH)	6.79 (VH)	21.83 (M)	13.48 (L)	6.58 (N)	Moderate

Data Source: Laboratory Analysis, 2021:(L)Low, (M)Medium, (H)High, (VH)Very High, (N)Neutral, (BS)Base.

CEC is one of the chemical properties of the soil that is closely related to the availability of nutrients for plants and is an indicator of soil fertility. The higher the CEC of the soil, the greater the ability of the soil to absorb and exchange nutrients. Based on the soil analysis results, the soil's CEC value at the research site, according to the assessment criteria used, is classified as high to moderate (**Fig. 7a**). The higher the pH value of the soil, the higher the CEC value of the soil. On the other hand, hydrolysis does not occur at low pH values, so the soil's CEC value is low (Nadeau & Sullivan, 2015).

Based on the analysis results of the base saturation value in each land units at the research location, the observed criteria are classified as very high (**Fig. 7b**). Base saturation is related to releasing these cations into the soil solution. The higher the cation saturation, the easier it is to release the cation into the soil solution. In other words, the more readily available the cation is to plants (Utomo et al., 2016). The high value of base saturation at the research site reflects that there are still many basic cations in the soil.

Based on the results of the C-Organic analysis of the soil in each land unit in the research location, it was classified as high to very high criteria (**Fig. 7c**). Giving organic matter into the soil not only adds nutrients to plants but also creates conditions suitable for plant growth and can improve water holding capacity, facilitate root penetration, improve aeration, increase soil pH, CEC, and nutrient uptake (Meimaroglou & Mouzakis, 2019; Wei et al., 2020). One of the primary sources of soil organic matter is plant debris that is returned to the soil. Adding organic matter into the soil will liberate the elements it contains, such as N, P, K, Ca, Mg, and so on, and increase its availability for plants (Antonkiewicz et al., 2019). Soil organic matter plays a vital role in exchanging cations and, at the same time, providing nutrients for plants. Soils with high organic matter have a higher CEC than soils with low organic matter (Wei et al., 2020). Organic matter can increase the adsorption capacity and cation exchange capacity. This can happen because the weathering of organic matter will produce humus (organic colloid), a source of negative soil charge, so it has a surface that can hold nutrients and water.

Based on the P-Total value of the soil in each land unit, it is classified as medium, high to very high criteria (**Fig. 7d**). The availability of P in the soil is closely related to soil acidity (soil pH). According to (Basha, 2020; Sirsat et al., 2017), most soils with a maximum total P-value can be found at a neutral pH range between 6.0 – 7.0, so the availability of P will decrease if the pH is below 6.0 or above 7.0. According to (Montaño et al., 2021; Papangelou & Mathijs, 2021), the form of equilibrium is in the form of fixation or dissolution with other nutrients. P in soil is found in various compounds, most of which are unavailable to plants. Most of the fertilizer applied to the soil cannot be utilized by plants because it has reacted with cations, so the efficiency of P fertilization is generally low to very low.

Based on the results of the K-Total analysis of the soil in each land unit in the research location, it was included in the criteria of very high, high to low (**Fig. 7e**). The high value of soil CEC can affect the soil solution to be able to release potassium and can reduce the potential for leaching of potassium in the soil (Nakhli et al., 2017). The K-Total value of the soil at the research site, which is included in the very high, high, and low criteria, is because the CEC value at the research location is classified as high to moderate. A high soil CEC value can increase the soil's ability to hold K nutrients so that the soil solution is slow to release K nutrients and reduce leaching potential. The straw, the rest of the harvest, is also the primary source of K and Si (Silicate). About 80% of plants' nutrient K is contained in the straw. Therefore, returning crop residues to the soil can slow down the impoverishment of K and Si nutrients. Returning crop residues to paddy fields has the potential as K fertilizer, either in fresh form, composted, or burned. According to (Si et al., 2018), in addition to replacing K fertilizer at a specific dose, straw also plays an essential role in improving the productivity of paddy fields, increasing fertilization efficiency, and ensuring production stability.

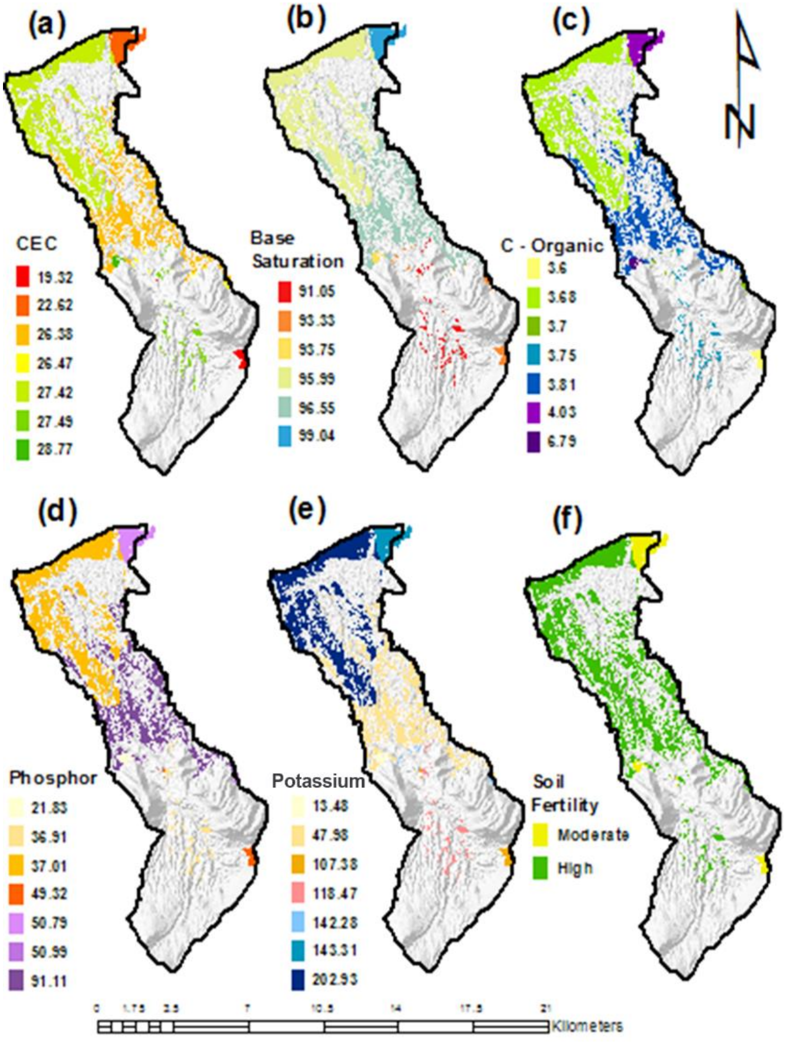

Fig 7. Spatial distribution of the CEC map (a), Base Saturation (b), Soil Organic Mater (c), Phosphor (d), Potassium (e) and Soil fertility status (f).

The limiting factors for soil fertility status (**Fig. 7f**) found at the research sites were CEC which was classified as moderate, P-Total, which was classified as moderate, and K-Total, which was classified as low. Therefore, it is necessary to carry out integrated soil management, such as regularly returning crop residues to the soil and adding organic matter and fertilizers containing P and K elements in the form of single fertilizers and compound fertilizers. Adding P and K compound fertilizers is needed to support optimal land productivity and increase the soil's CEC value. According (Chenu et al., 2019; Scotti et al., 2015). Types of organic matter can be applied to the soil by returning crop residues, providing manure, and compost. In addition to maintaining the content of organic matter in the soil, adding organic matter can also increase P nutrients in the soil.

5. CONCLUSIONS

The area of Subak land in Sawan District is 2,177.33 ha, divided into 65 Subaks. This research is one of the efforts to manage Subak land to survive sustainably. The conservation through soil fertility management on Subak land. The limiting factors for fertility status found at the research sites were CEC which was classified as moderate, P-Total, which was classified as moderate, and K-Total, which was classified as low. Therefore, it is necessary to carry out integrated soil conservation, such as regularly returning crop residues to the soil and adding organic matter and fertilizers containing P and K elements in the form of single fertilizers and compound fertilizers. Adding P and K compound fertilizers is needed to support optimal land productivity and increase the soil's CEC value. Types of organic matter can be applied to the soil by returning crop residues, providing manure, and compost. In addition to maintaining the content of organic matter in the soil, adding organic matter can also increase P nutrients in the soil.

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