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DETECTION OF SOIL WATER CONTENT IN TEA (*Camellia sinensis*) PLANTATION THROUGH SPATIAL ANALYSIS USING AGRIRADAR TECHNOLOGY IN BOGOR, WEST JAVA

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ABSTRACT

Soil water content is a critical parameter for plants that influence nutrient absorption, plant growth, and plant metabolism. In tea (*Camellia sinensis*), soil water content must be monitored regularly. This study aims to develop a rapid and spatially approach to detect soil water content using Agriradar technology. The agriradar technology integrates radar sensing and multispectral imaging in the aerial vehicle (UAV) to generate spatial data across plantation areas. This device is able to detect soil water content so that spatial-based data is obtained from the area passed by the drone. Experiments were carried out by taking a case studies on tea plantations. This research was conducted from January-May 2025 in tea plantations located in Bogor, West Java, Indonesia. The results of this study indicate that soil water levels ranged from 22% to 25%, which is below the optimal limit of 30% required for optimal tea growth. Furthermore, soil water content below 10% are associated with inhibited shoot development and increased risk of plant mortality. The integration of Agriradar technology into precision agriculture practices can support cultivation management and improve fresh yield of the tea plantation.

Key words: Plantation; Precision; Radar; Tea; Water

INTRODUCTION

Soil water content (SWC) is a necessary parameter in tea plantation and must be available during the growth and development of the tea plant (Yin *et al.,* 2023). Water is indispensable for plant because it used in digestion, photosynthesis, mineral translocation, tissue expansion, and transpiration (Wulansari *et al.,* 2022). The changes of the SWC can affect the yield and the quality of tea shoots. Tea (*Camellia sinensis*) is a water-demanding crop and is highly susceptible to drought stress. Morris (2023) reported that drought stress induces several physiological and biochemical adaptations in *Camellia sinensis*, including stomatal closure to reduce transpiration, increased abscisic acid (ABA) production as a stress-signaling mechanism, and enhanced root penetration into deeper soil horizons to improve water acquisition under limited moisture conditions. Insufficient rainfall (<60 mm week^{-1}) restricts nutrient decomposition and uptake by tea plants, resulting in slower vegetative growth. Extended drought periods exceeding 2 months can cause severe growth disturbances and considerable reductions in yield as a consequence of decreased shoot development (Wulansari *et al.,* 2022). Therefore, its cultivation is best suited to regions with relatively high and well-distributed annual rainfall.

The most favorable land conditions for tea plantation is moderately acidic soils (pH 4.5–5.5), nutrient-rich and well-drained, loam soils textured, elevations of 1,000–2,500 masl, slopes of 5–20°, annual rainfall ranging from 1,200 to 2,500 mm, mean annual temperatures between 18-25 °C, and relative humidity of 70–80% (Mwesige *et al.,* 2026). In Indonesia, tea plantations are generally established on rainfed upland areas, where water availability primarily depends on precipitation and mostly located in west java. Soil water content in each region varies, even in the same plantation it could be different. Each soil has different water holding capacity according to the soil chemical, physical, and biological properties (Wulansari *et al.,* 2022). SWC determined by multiple factors such as soil texture, soil density, and structure, weather, soil biological activity, roots exudate, and climate conditions, also complex interactions occurring within the soil–plant–atmosphere (Rasheed *et al*., 2022).

Assessing variations in soil water content is vital for supporting agricultural decision-making and improving understanding of soil–water interactions under fluctuating climatic conditions. Soil water content influence the land managements, such a planting time, fertilizer, herbicides, and pesticides application, and irrigation (Rasheed *et al.,* 2022). Nonetheless, investigations into soil moisture dynamics using spatial analysis, and the influence of contrasting management strategies, are still scarce. Pramudita *et al.* (2022) state that SWC can be measured by two methods : direct and indirect. Gravimetric is a direct method by take the soil sample from a certain location and measure the differences between fresh and dried weights. Indirect method are developed based on physical behavior such as resistive, capacitive, time domain reflectometry, and electromagnetic wave.

Tea plantations typically cover extensive areas with heterogeneous environmental conditions, resulting in substantial spatial variability in soil water content. Consequently, monitoring soil moisture through direct sampling methods is often labor-intensive, time-consuming, and challenging to implement across the entire plantation area. Therefore, technologies capable of accurately estimating soil water content over large spatial scales are required. Agriradar using remote sensing methods is efficient alternatives for monitoring soil moisture dynamics across extensive tea plantation areas (Pramudita *et al.,* 2022). This study aims to assess the spatial distribution of soil water content in tea plantations in Bogor, West Java, using Agriradar technology. The generated information is expected to provide a reliable reference for land management decisions and support more effective and precision agriculture practices.

MATERIALS AND METHODS

Overview of the study area

This research conducted from January-May 2025, filed data collection conducted in April 2025. The study area extends across Cisarua and Megamendung Districts, Bogor Regency, West Java, Indonesia, and is geographically situated between 6.6606450°–6.7046070° S and 106.9685990°–106.9979300° E. The plantation covers approximately 477.15 ha. Consist of 3 afdeling (A, B, C) with 36 blocks. Climatic conditions in the study area include mean air temperatures ranging from 16 to 25°C and annual rainfall of approximately 2.896–3.070 mm, providing suitable environmental conditions for the growth and production of tea (*Camellia sinensis*). Geologically, the study area is characterized by volcanic formations dominated by breccia and lava originating from Mount Kencana and Mount Limo. The geological substrate also includes older volcanic deposits associated with Mount Pangrango, comprising volcanic materials and basaltic lava flows. Topographically, the plantation is divided into flat to steep. The steepest terrain, occupies the smallest proportion of the afdeling, covering only 1.14 ha. Its extensive area, combined with variations in topography and environmental conditions, makes it a representative site for investigating the spatial distribution of soil water content (Figure 1).

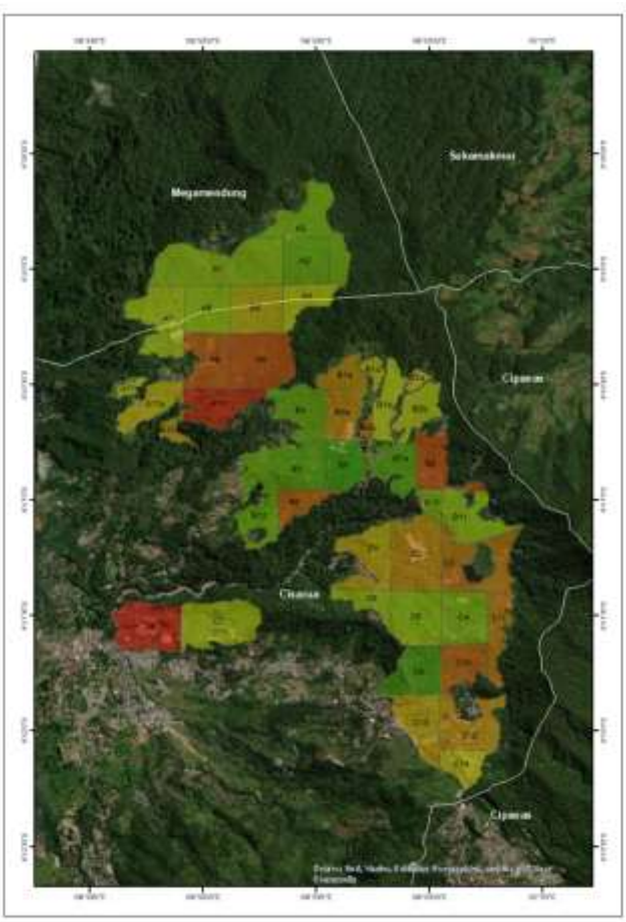
(a)

(b)


Figure 1. (a) Location of study area; (b) Land condition in study area

Agriradar : radar-drone for soil water content

This study use remote sensing technology called Agriradar to measure the soil water content. According Pramudita *et al.* (2022), the Agriradar system employs radar technology to estimate soil water content based on the interaction of electromagnetic waves with the soil surface. As electromagnetic waves propagate across media boundaries, variations in soil dielectric properties affect the characteristics of the reflected radar signals, enabling the estimation of soil moisture levels. Experimental results have shown that this method achieves an accuracy of approximately 96% in soil water content detection. For large-scale data acquisition, the radar sensor is integrated with a hexacopter UAV platform, which allows efficient collection of soil moisture information over broad areas. During operation, the UAV is flown at a nearly constant altitude to maintain consistent radar signal strength reaching the ground surface and to enhance measurement accuracy and spatial coverage (Figure 2).

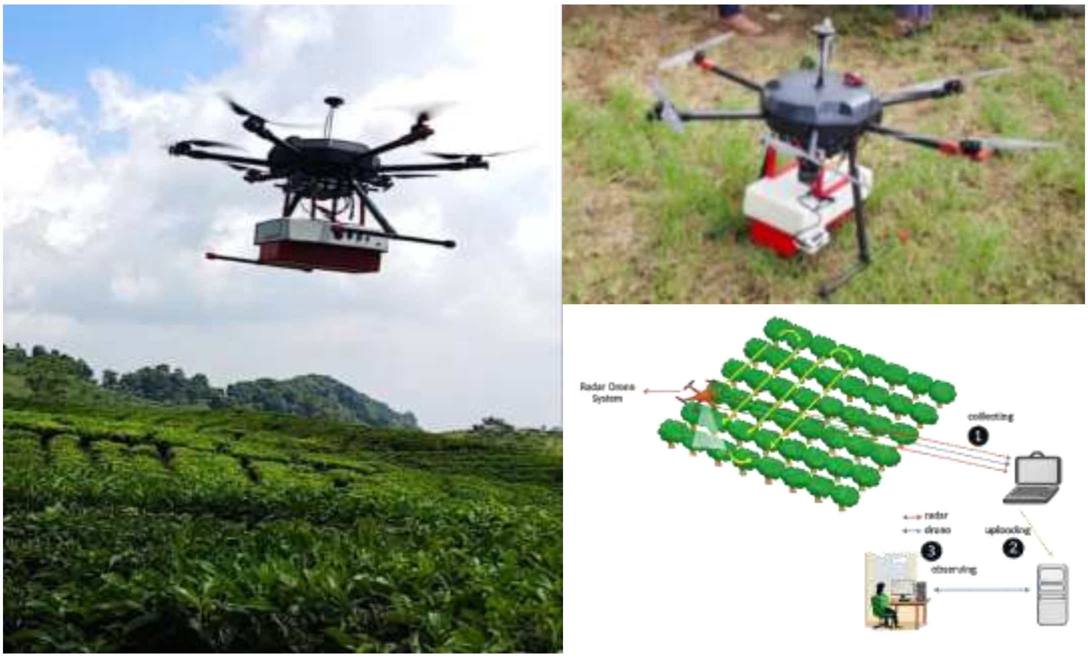


Figure 2. Illustration of Agriradar technologi implementation to measure soil water content

RESULTS AND DISCUSSION

The measured soil water content reflects the soil's capacity to retain water under critical moisture conditions. Higher soil water content indicates a greater potential of the soil to store and supply water to plants during periods of drought, such as the dry season (Hermawan, 2004 *cit* Wulansari *et al.,* 2022). According Ladanyi *et al.* (2021) Soil water content (SWC) in mineral soil can be categorized into 5 classes : very low (20%), low (20-30%), moderate (30-50%), and high (50-80%), and very high (>80%). Plant water uptake is significantly restricted when available water content drops below 30%. At levels below 20%, water is tightly bound to soil particles and can no longer be accessed by plant roots, resulting in severe water stress and eventual plant death (Ladanyi *et al.,* 2021). Nevertheless, the optimal water availability and drought tolerance threshold vary among plant species. In the tea plantation, soil water content below 30% generally constrains the growth of tea plants, whereas moisture levels lower than 15% may lead to plant death as a consequence of critical water deficiency (Rezamela & Dalimoenthe, 2016).

Water scarcity has a significant negative impact on tea plantations, leading to production declines of approximately 20–30% relative to normal conditions. In addition, every 100 mm reduction in monthly precipitation may decrease tea yield by 30–90 kg ha^{-1} (Wijeratne *et al.,* 1996 cit Rezamela & Dalimoenthe, 2016). The typical signs of drought stress in tea plants are identified by the leaves were wilting and curled (deformed), most branches died, the leaf water content decrease, and chlorophyll concentration decreased (Guo *et al*., 2017). The spatial variability of soil water content across the study area is influenced by differences in topography, soil properties, vegetation characteristics, and land management practices. Variations in slope position, soil texture, organic matter content, and plant water uptake can lead to heterogeneous soil moisture distribution, even within the same tea plantation. (Western *et al.,* 2002; Wulansari *et al.,* 2022).

Overall the result of SWC ranging from very low to moderate, around 13%-35% (Figure 3.). This condition indicates that soil moisture in the study area is inadequate to sustain optimal tea growth, potentially limiting plant development and productivity. The precipitation and temperature in the last 7 days during the field data collection (April 29-30, 2025 was 36,08 mm and the temperature 25,11°C, and in the previous weeks it ranged from 24,10-130,58 mm and 24,62-25,56°C (Table 1.). The ideal rainfall for tea plantation was the ten-year average includes no more than two dry months (<60 mm rainfall) and no completely rainless months (Santoso *et al*., 2006 *cit* Wulansari *et al.,* 2022). The daily precipitation estimated for tea was 1.24–2.68 mm at temperatures ranging from 10°C to 28°C (Chang and Wu, 1971 *cit* Wulansari *et al.,* 2022). On an annual precipitation, tea plants require approximately 917 mm, equivalent to 917 liters per year or 2.51 liters per day (Chapagain and Hoekstra, 2007 *cit* Wulansari *et al.,* 2022).

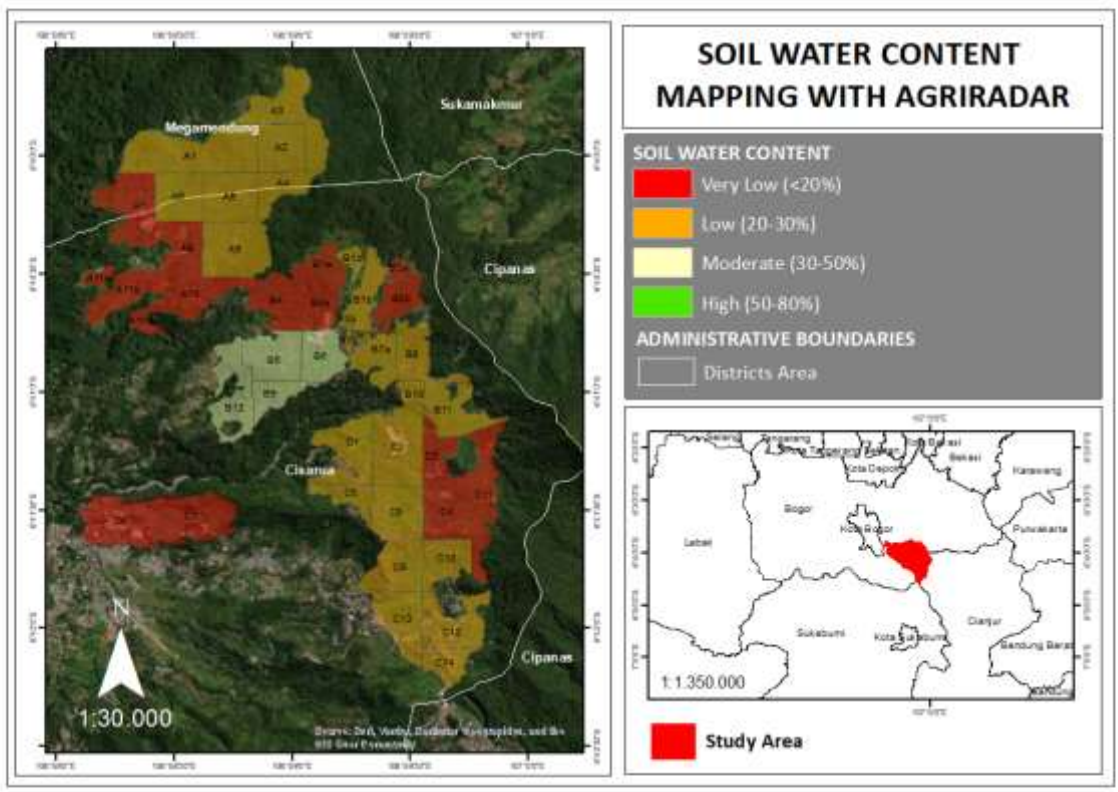


Figure 3. Spatial mapping of soil water content in study area

Table 1. Climate condition in the study area during the filed data collection

Month	Week	Relative Humidity (%)	Precipitation (mm)	Temperature (°C)
March	1	87,88	130,58	25,22
	2	88,77	25,30	24,85
	3	90,73	29,45	24,62
	4	90,42	24,10	24,82
April	1	87,93	43,51	25,03
	2	85,62	58,77	25,56
	3	89,57	36,08	25,11
	4	86,93	28,25	25,32

Source : https://power.larc.nasa.gov/data-access-viewer/

From the climate condition, this study area was favorable for tea cultivation. In contrast, the measured soil water content showed suboptimal water availability for tea plants. Since water supply from the precipitation is sufficient, the low soil water content suggests that the soils in the study area have a limited capacity to retain the water. Slope 15–25% (moderately steep) predominates the study area, accounting for 267.81 ha. The second largest category is slope 8–15% (sloping), which covers 201.14 ha. Based on slope dataset, the topography of study area can be categorized as hillocky and rolling (Sukarman *et al.*, 2017). Topography controls the redistribution of water across landscapes and is one of the primary factors influencing spatial patterns of soil moisture (Western *et al.,* 2002). Sloping lands are highly susceptible to soil erosion and water loss, distribution of SWC differs at the top, middle, and bottom of the slope due to the differences in water flow and moisture accumulation (Hu *et al.,* 2023).

The study area categorized as a sloping land so that makes the soil water content was low, due to high run off. Soil water content in afdeling "A" and "C" dominated by low class, and the remaining small area is very low. Agriradar measurement result of Soil Water Content in Afdeling "A" and "C" ranging from 20,4% to 27,8% and 15,9% to 24,1%, showing relatively homogeneous fluctuations across the dataset. In Afdeling "B" the dataset more fluctuating, ranging from 18,7% to 35,1%. From that data we can conclude that the study area needs more treatment to improve soil water content, because when SWC lower than 30% the plant nutrient uptake restricted even we adding some an-organic fertilizer. For rapid solution, we can apply fertilizer by foliar spray.

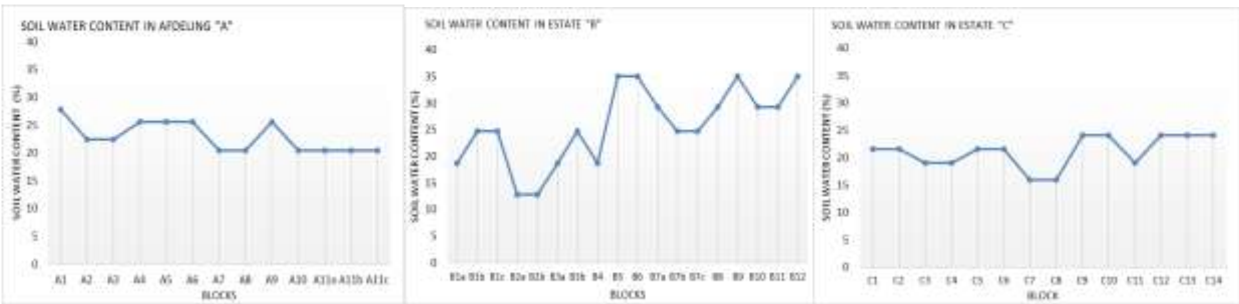


Figure 4. Soil water content in each Afdeling

In order to improve the soil's capacity to retain and store water, the application of amendments or mulching is necessary. Mulching is widely used to conserve water by reducing surface evaporation, moderating soil temperature fluctuations, promoting nocturnal condensation, minimizing soil erosion, and improving water infiltration and retention, particularly when organic or permeable mulch materials are used. (Ramos *et al.,* 2024). Mulch material may consist of organic substance such as crop residue or straw like commonly used in tea plantation after tea pruning. In other way, we can also improve soil properties through adding organic fertilizer. Decomposed organic material inputs can affect the soil aggregate stability, improve soil and pore structure, which affects soil water retention, moreover organic materials also decreased soil wettability and ability to retain water because the structure of organic material is similar to the sponge (Eden *et al.,* 2017). The implementation of conservation agriculture practices, such as minimizing mechanical soil disturbance, maintaining soil cover with organic mulch or crop residues can improve soil water retention and strengthen soil resistance to drought condition (Abdallah *et al.,* 2021). In the sloping area, well designed terrace can protect the soil from erosion and water loss by increasing infiltration rates and decreasing run off (Arnaez *et al.,* 2015).

CONCLUSION

Spatial analysis of soil water content using Agriradar technology ranged from very low to moderate, around 13%-35% with predominantly classified as very low and low classes (<20% and 20-30%). Low soil water content can disturb the plant growth and decreasing the productivity, leading to physiological and morphological symptoms such as leaf curling, wilting, chlorophyll reduction, and other drought-related stress responses. This condition influenced by the topography of study area, which consists of sloping land. Consequently, although water supply from rainfall was considered adequate, the soil has limited ability to absorb and retain the water. Therefore, strategies such as organic mulching, organic matter amendments, conservation agriculture, and terracing should be considered to enhance soil water retention and improve water availability for tea plants

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