SMAP AND SENTINEL-1 DATA ASSIMILATION TO IMPROVE SUGARCANE GROWTH MONITORING

Apimook Phusiripaiboon[1] and Anuphao Aobpaet[2]
Kasetsart University, 50 Phahonyothin Road, Ladyao, Chatuchak, Bangkok 10900, Thailand,
Email: apimook.ph@ku.th[1], fengaha@ku.ac.th[2]

KEYWORDS: SMAP, Soil moisture, Sentinel-1, Polarisation

ABSTRACT: Soil moisture dramatically affects crop growth and agricultural productivity. There are many instruments to measure soil moisture but just a few to measure the large area. The SMAP satellite is NASA's first mission designed to measure soil moisture worldwide. This research aims to study the potential of soil moisture data from the SMAP satellite and the averages backscatter of VH and VV polarisation from the Sentinel-1 satellite to compare the time-series trend of a one-hundred sugarcane plot. The time-series data is between August 2020 and July 2021. We extract soil moisture data using the L2 SM_SP: Soil Moisture (Sentinel Radar, Radiometer) data of SMAP with one-kilometre resolution and VH and VV averages backscatter polarisation of the synthetic aperture radar (SAR) system of the Sentinel-1 satellite. The fact revealed that soil moisture changes correspond to rainfall and other factors such as sunlight and irrigation. In the SAR pre-processing, we average the backscatter value of polarisation data with/without terrain correction to determine its difference in data preparation which we found slightly different. Then the soil moisture data and the averages backscatter of VH and VV polarisation were used to monitor the time-series trend of the sugarcane plot. It found that both data were positively correlated to significantly monitor sugarcane's growth at $r = 0.435$ and $r = 0.443$, respectively. When analysing the relationship in each sugarcane plot area, without outliers, that is, deviations from other values so much so that it caused the suspicion that a different mechanism caused it. The significance level is approximately $r = 0.800$, which is a high correlation level. We conclude that the soil moisture data had potential and could support the monitoring of sugarcane growth and the average backscatter of SAR polarisation data enabling planning and management of the sugarcane industry.

1. INTRODUCTION

The agricultural sector has been crucial to Thai society for a long time because it helps improve Thailand's economy, especially sugarcane that has been processed into sugar and other alternative energy sources. Thailand is the second-largest sugar exporter in the world. However, most agricultural households still have production problems. It was partly due to the lack of knowledge of farmers and lack of systematic planning and management. The provision of timely, reliable, accurate and high-resolution satellite remote sensing data are essential to facilitate a transition from parcel-level decision-making towards precision agriculture (Khabbazan et al., 2019). Previous studies clearly show the strong response of dual-polarization (VV and VH) to rice phenology and cropping system by using Sentinel-1 SAR data. The low and high backscattering values are noticed at the vegetative and maturity stages, respectively (Minh et al., 2019). Including, we envision soil moisture as a primary control on many hydrological phenomena, especially runoff formation, soil evaporation, and plant transpiration. Knowledge of soil moisture is therefore essential for applications such as weather forecasting and agricultural product monitoring. Several studies now show that soil moisture can be measured by satellites. The most crucial mission is NASA's Soil Moisture Active/Passive (SMAP) (Entekhabi et al., 2014), thus together with the VH and VV polarisation backscatter averages from the Sentinel-1 satellite to monitor sugarcane growth.

2. DATA PREPARATION

2.1 Data from SMAP satellites

This study extracted soil moisture data from the L2 SM_SP: Soil Moisture (Sentinel Radar, Radiometer) product of the 1 km SMAP satellite, radiometer wavelength and 1.41 GHz 1.26 GHz L-band radar. The satellite's orbital orientation is ascending direction with the (sensing time) from 6 a.m. to 6 p.m. It was recorded every 2-3 days (Earth orbit) using 13 SMAP satellite images covering the Khon Kaen province. The temporal data is between August 2020 and July 2021, and we acquired them from Earth Data Search (https://search.earthdata.nasa.gov/search). The acquired satellite image data is a file saved in sequential format. A multidimensional array is also known as HDF5 files that do not contain terrestrial coordinate system information. We use soil moisture data at a resolution of 1 kilometre to determine the coordinates and process the satellite imagery. A Python script developed with the Geospatial Data Library (GDAL) in the Quantum GIS program produces a Detailed Image Data File (TIFF) with a UTM grid coordinate system: EPSG 4326 WGS 84 is obtained. After that, the image data file will be created as time-series data between August 2020 and July 2021. We then processed the spatial data (Shapefile) of sugarcane planting plots in Khon Kaen Province to extract soil moisture values from 100 sugarcane plots of SMAP satellite images in the study area.

2.2 Data from SENTINEL-1 satellites

This study uses SAR image data of the Level-1 Ground Range Detection (GRD) satellite system, Sentinel-1, high resolution, pixel size 10 m x 10 m, C-band wavelength, 5.405 GHz, in Interferometric Wide swath mode (IW) at dual-polarization VH (vertical transmission and receive horizontal signals) and VV (vertical transmission and reception). Ascending satellite orbits are recorded every 12 days using 25 images of SAR image data covering the Khon Kaen Province region. The temporal baseline of the data is between August 2020 and July 2021, getting from AFS Data Search (https://search.asf.alaska.edu/#/). After that, we performed the pre-image processing of satellite images in ESA's Sentinel Application Platform (SNAP) program. Typically, the pre-processing steps will divide into radiometric correction and geometric correction step by step. The pre-processing consists of seven steps (Filipponi, 2019): 1) Apply Orbit File is adjusting orbit data such as satellite position information and orbital velocity data 2) Thermal Noise Removal will reducing the effect of soil noise between subsections 3) Border Noise Removal is to modify the start time of the sampling in order to replace the edge of the image in the curvature of the earth which is necessary for level 1 satellite products 4) Calibration will adjust the accuracy of the backscatter for more accurate conversion of the satellite image intensity to sigma value 5) Speckle filtering is to reduce the preliminary scattering noise and we applied a Lee filter of 5 x 5 m in this research 6) Terrain correction is to correct a satellite image that has some geometric distortions such as distance and topography, which is deviating from the reality on the soil of the earth 7) Linear to-from dB is to process the reflection coefficient (Backscatter) to change the ratio of the reflected wave power to the transmitted wave power (Incident wave) is a unit of measure decibels (dB). After data pre-processing, the satellite images will be created as time-series data between August 2020 and July 2021 and then processed together with the spatial data (Shapefile) of sugarcane planting plots in Khon Kaen Province to extract the mean VH and VV polarisation reflections from 100 sugarcane plots of Sentinel-1 SAR satellite images at the study area.

2.3 Field Data

At Nongruea district, Khon Kaen Province, Thailand, as shown in Figure 1, the sugarcane field observation area shows the physical growth characteristics of sugarcane and the characteristics of sugarcane planting areas that change in each period from August 2020 to July 2021. There is essential data to validate the VH and VV polarisation average backscatter data from the Sentinel-1 satellites at the date of receiving different data for monitoring sugarcane growth. This research aims to study the potential of soil moisture data from the SMAP satellite to analyse the averages backscatter of VH and VV polarisation from the Sentinel-1 satellite, so the reference from field data will enhance the correct and accuracy of sugarcane growth monitoring. The most concern is that the knowledge of growth stages should be accounted for investigating. We can improve it in future monitoring to use the same area data validation.

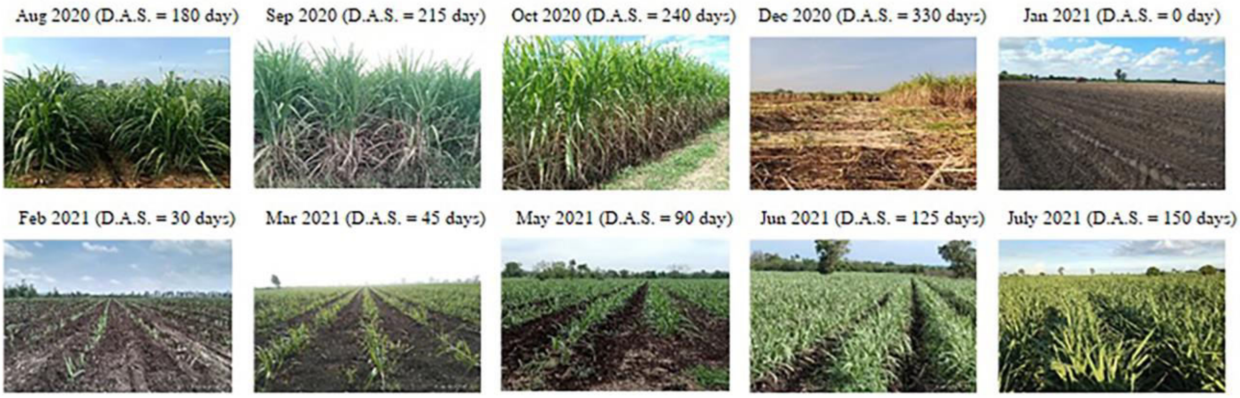


Figure 1 The sugarcane field observation area at Nongruea district, Khon Kaen Province, Thailand (Ketsrirat A., 2021)

3. METHODOLOGY

3.1 SMAP Image Data Analysis

In this research, we highlight the importance of large-area soil moisture data extracted from SMAP satellite imagery. As we all know, there are many instruments to measure soil moisture, such as tensiometers are devices that measure soil moisture tension. They sealed water-filled tubes with a porous ceramic tip at the bottom and a vacuum gauge at the top. Another example is Time Domain Reflectometry (TDR), a newer tool that sends an electrical signal through steel rods placed in the soil and measures. The signal return to estimate soil water content (Cregg, 2003), but it is just a few to measure the large area and analyse the soil moisture in the past in the sugarcane planting area, especially Khon Kaen Province. According to the data from January 2018 to July 2021, the change was analysed with the previous monthly rainfall.

3.2 Sentinel-1 SAR Image Data Analysis

The VH and VV averages backscatter polarisation data of Sentinel-1 SAR imagery were previously used to monitor plant growth characteristics. SAR data are generally sensed with a varying viewing angle greater than 0 degrees, resulting in images with some distortion related to side-looking geometry. Thus, the geometric representation of the image will be as close as possible to the real world. We question how necessary terrain correction is if terrain corrections are intended to compensate for these distortions. We average the backscatter value of polarisation data with and without terrain correction, which is one of the seven steps in pre-processing images to determine its difference in data preparation and the analysis of the effect of monthly rainfall on the average polarisation reflection.

3.3 Analysis of Satellite Image Data on Sugarcane Growth Monitoring

This study aims to study the potential of SMAP satellite soil moisture data for feasibility analysis in combination with the VH and VV polarisation averages from Sentinel-1 satellites in the growth monitoring of sugarcane. It took the soil moisture and polarisation values from SMAP and Sentinel-1 satellites to compare the time-series trend of one-hundred sugarcane plots in Nongruea district, Khon Kaen province. The time-series data is between August 2020 and July 2021 to analyse the data's potential and correlation direction to monitor sugarcane growth.

3.4 Statistical Correlation Analysis

This study used correlation analysis to measure the degree of linear correlation between the two variables. In order to know how much the variables studied are related and what direction the relationship is (Wongsaichue, 2013). The average soil moisture and the average backscatter polarisation change according to the growth period of sugarcane plants. By testing the linear correlation, we calculate using the Pearson Correlation Coefficient as shown in Equation 1. The analysis results are presented through the correlation coefficient (r) between two variables whose values are 1.00 to 1.00. If the value is closer to 1, the two variables have a very high degree of correlation. For the sign before the correlation coefficient, it indicates the direction of the relationship. If the value is negative ($r < 0$), the two variables are negatively correlated. Explain that if the value of one variable increases, the other variable decreases. On the other hand, if it is positive ($r > 0$), the two variables are positively correlated. Explain that if the value of one variable increases, the other variable will also increase (Wongsaichue T., 2013).

$$r = \frac{[1/(N-1)][\sum XY - \{(\sum X)(\sum Y)/N\}]}{S_x S_y} \quad (1)$$

where: r = Pearson Coefficient
N = number of the pairs of the variable
$\sum XY$ = sum of values of the paired variables
$\sum X$ = sum of the x variables
$\sum Y$ = sum of the y variables
S or SD = standard deviation

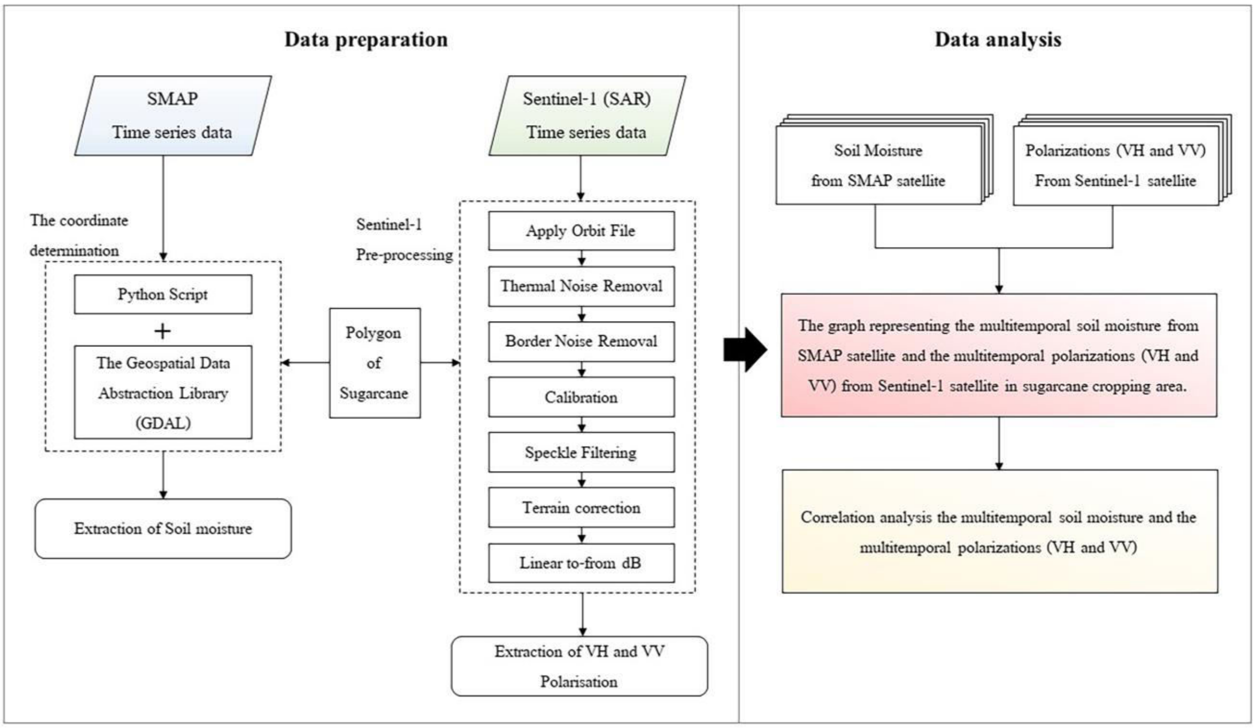


Figure 2 The research procedures and methods flow chart

4. RESULTS AND DISCUSSION

4.1 Spatial variability of the soil moisture values from SMAP satellites.

Soil moisture values from SMAP satellite imagery back each year in the sugarcane planting area. As shown in Figure 3A, Khon Kaen Province can reach the highest mean soil moisture level of four years during the rainy season in Thailand (May-October) in 2018. The highest mean soil moisture level was in July and September, with about 0.44 m^3/m^3 analysed with historical monthly rainfall from the rain gauge station of the Royal Irrigation Office 6, Khon Kaen Province, as shown in Figure 3B. It was found that in 2018, the monthly rainfall was highest in July. It accounts for 0.2308 percent of the total annual rainfall of about 1,096.90 mm, indicating a significant correlation. However, in May-June 2020, rainfall decreased by 0.0152 percent, but the mean soil moisture increased by 0.0473 m^3/m^3, indicating that the change in soil moisture still depends on other factors and sunlight and irrigation.

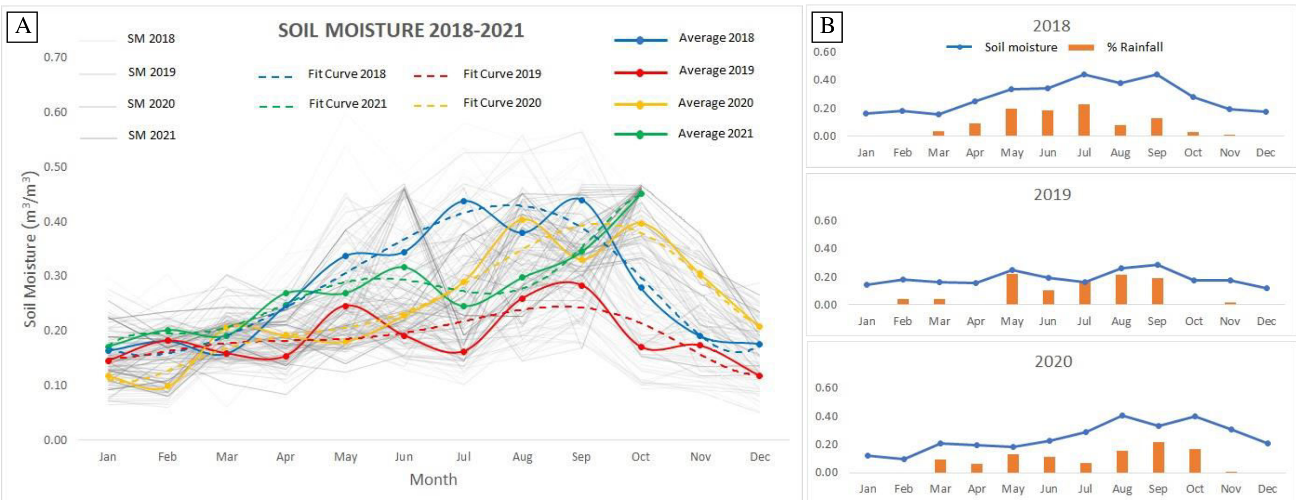


Figure 3 (A) The soil moisture values from SMAP satellite and (B) the average soil moisture and monthly rainfall.

4.2 Spatial variability of the polarisation values from the Sentinel-1 satellite.

The validation of VH and VV polarisation average backscatter data from Sentinel-1 satellites at the date of receiving different data in 100 sugarcane planting areas, Khon Kaen Province, with and without terrain correction, as shown in Figure 4A. It can be seen that the polarisation variance from satellite imagery with and without terrain correction is quite distinct. The result shows that pre-processing of satellite imagery is necessary to provide more accurate average backscatter polarisation extracted from satellite imagery. Furthermore, from examining the effect of historical monthly rainfall on the average backscatter polarisation as shown in Figure 4B, it was found that the polarisation tends to increase and decrease in one direction, with historical monthly rainfall showing a significant correlation. However, it can be noted that the polarisation level has dropped slightly after September 2020, April and June 2021, with the monthly rainfall higher than October. 2020, May and July 2021 represents some noise that has occurred.

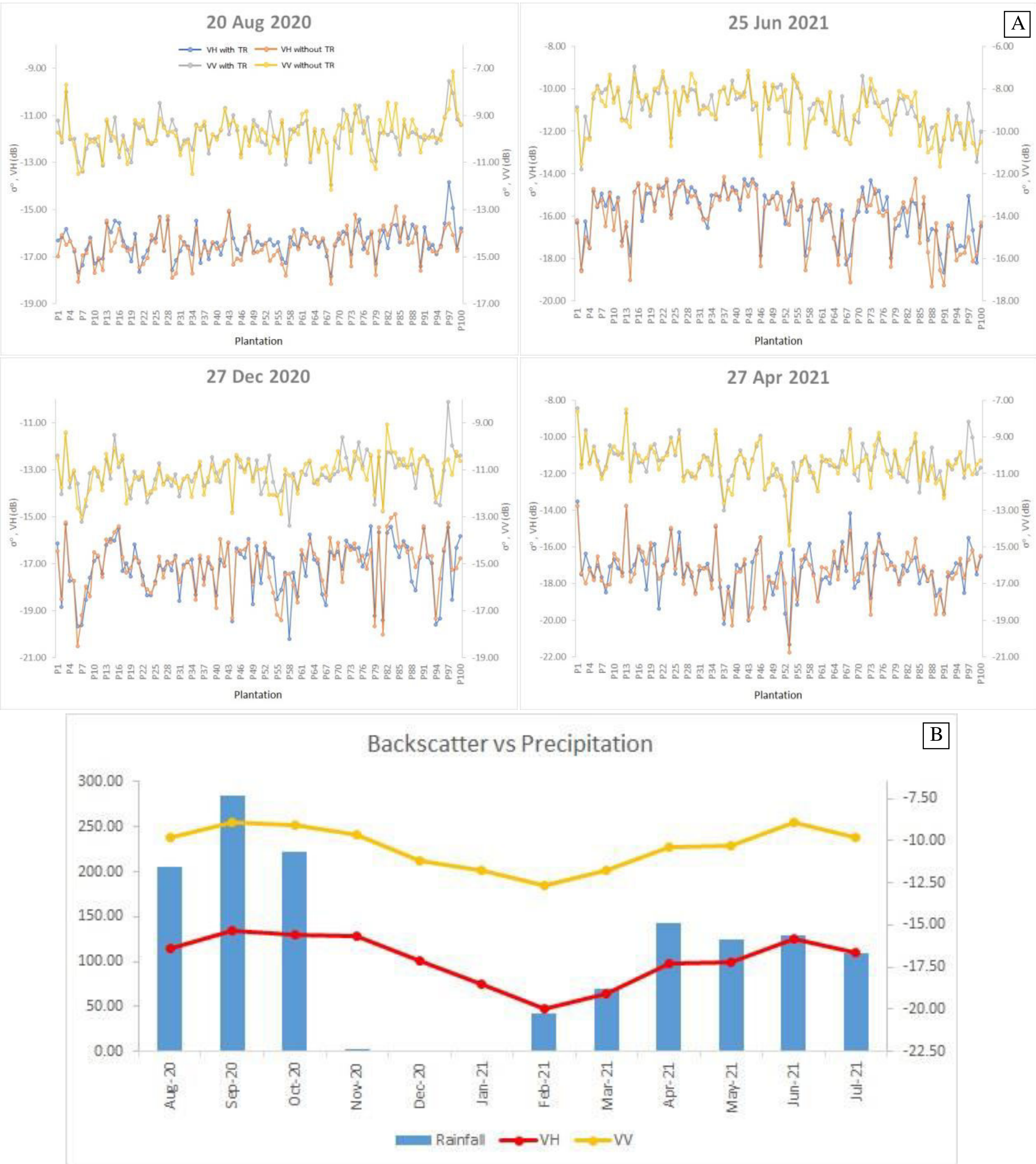


Figure 4 (A) The average of VH and VV backscatter polarisation from Sentinel-1 satellite with/without terrain correction and (B) The average of backscatter polarisation and monthly rainfall.

4.3 Effects of soil moisture and polarisation values on sugarcane growth monitoring

Fig. 5A and 5B shows a graph of soil moisture values from SMAP and polarisation values of VH and VV from Sentinel-1 that change with the data obtained to date. That is to say, changes according to the growth period of sugarcane in the sugarcane planting area of Khon Kaen Province with amounting to 100 plots, showing that in the 2020 sugarcane planting cycle, the averages soil moisture content and the average polarisation will gradually increase to the highest level in September. The mean maximum soil moisture content was about 0.44 m^3/m^3, and the highest mean VH and VV polarisation were about -15.35 dB and -8.92 dB, respectively.

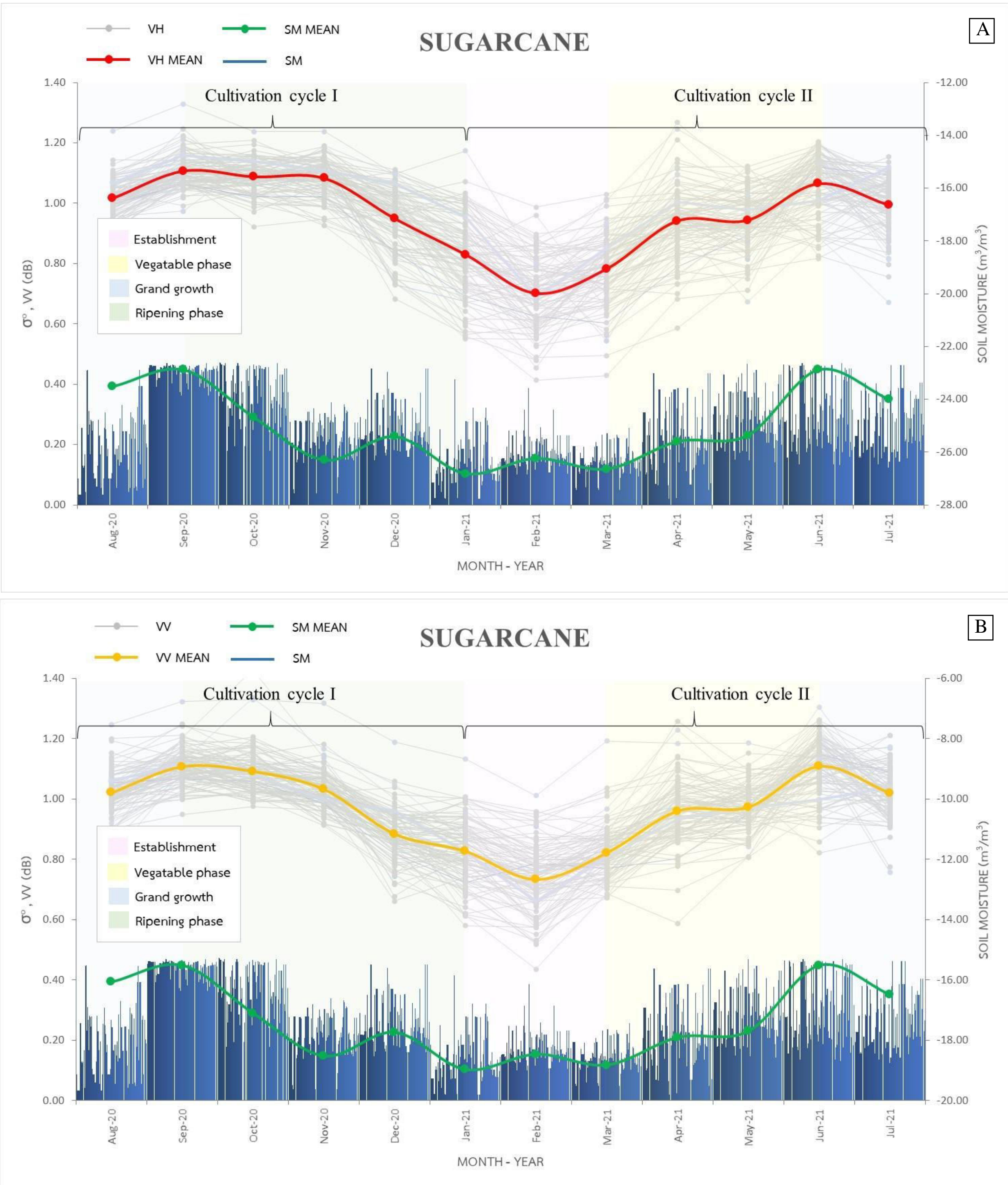
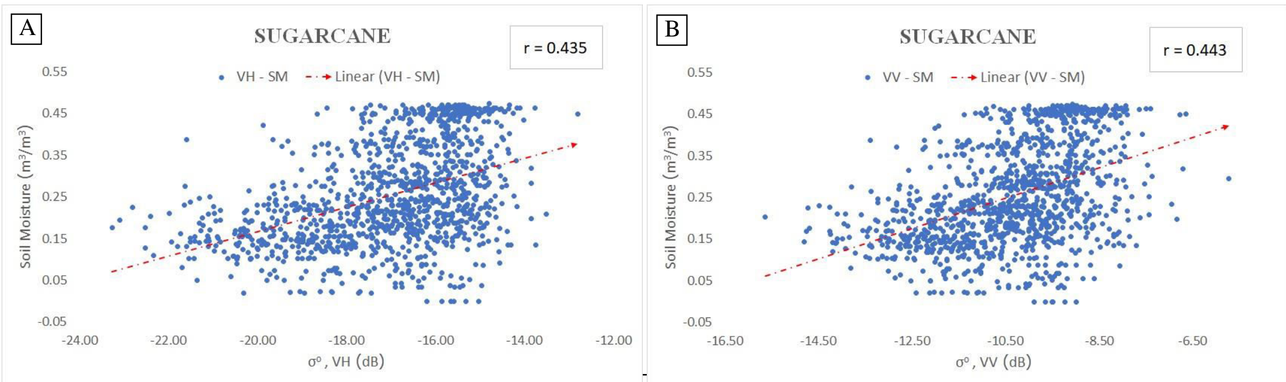


Figure 5 (A) Soil Moisture and VH Polarization and (B) Soil Moisture and VV Polarization.

Because it is the growth phase reaches its maximum, known as Grand growth (age 150-240 days), which is the period when sugarcane has a high water demand. To make the stems grow tall and form a dense thicket of leaves, it enters the Ripening phase (age 240-360 days). During this period, stem attachment slows down, and more sugar begins to accumulate in the stem. (Thai Encyclopedia for Youth, 2017). There is a decrease in water demand due to low water conditions making sugarcane sweeter (Mitr Phol Group, 2019) until the growth stops. This period is the harvesting season because sugar cane has the highest accumulation of sugar in the trunk. As a result, the averages soil moisture and averages polarisation gradually declined, respectively. With a mean soil moisture average of 0.26 m^3/m^3 in December, we found a VH and VV polarisation average of about -17.16 dB and -11.16 dB. Before entering the sugarcane cultivation cycle in 2021, which will plough the soil, remove old stumps, and level the area to be smooth to open the groove to facilitate planting and irrigation. And then started planting sugarcane, it is the so-called Establishment phase (age 0-60 days) results in the lowest mean soil moisture in January of about 0.14 m^3/m^3 and low VH and VV polarisation averages. Their peak in February was about -19.99 dB and -12.67 dB. A gradual increase in mean soil moisture and average polarisation levels after entering the stem and leaf growth stage, known as the vegetative phase (age 75-150 days), continues until the growth phase reaches its maximum and harvest.

4.4 Correlation between soil moisture value and polarisation value on sugarcane growth monitoring

By analysing the correlation between soil moisture data and polarisation data in 100 sugarcane plantations, as shown in Figures 6A and 6B, the soil moisture value and the VH and VV polarisation were positively correlated in the monitoring sugarcane growth significantly. Statistically, at r = 0.435 and r = 0.443, it means that if the soil moisture data or polarisation data is increased, the other level will also be increased. When analysing the transformed data by comparing the correlation coefficients with/without outliers in Tables 1 and 2, it shows the absence of outliers. There was a mean statistical significance at the r = 0.804 level, a very high correlation level, with an increase of approximately 0.306 percent in cases of abnormal values.



Sugarcane	Correlation coefficient	Coefficient difference

Figure 6 (A) Correlation between soil moisture and VH polarisation and (B) Correlation between soil moisture and VV polarisation.

Table 1 Comparison of the correlation coefficient between the soil moisture value and the VH backscatter polarisation value in case of outlier and without the outlier.

plantation	with outliers	without outliers	
1	0.448	0.853	0.405
2	0.370	0.809	0.435
50	0.440	0.786	0.346
60	0.324	0.863	0.339
65	0.361	0.776	0.415
70	0.494	0.771	0.277
Average	0.440	0.809	0.370

Sugarcane plantation	Correlation coefficient with outliers	Correlation coefficient without outliers	Coefficient difference
1	0.450	0.820	0.370
2	0.390	0.753	0.363
50	0.330	0.727	0.397
60	0.523	0.850	0.327
65	0.460	0.854	0.394
70	0.621	0.788	0.167
Average	0.556	0.799	0.243

Table 2 Comparison of the correlation coefficient between the soil moisture value and the VV backscatter polarisation value in case of outlier and without the outlier.

Table 3 The average soil moisture and backscatter of VH and VV polarisation of sugarcanes.

Age range (days)	Phase/Stage	Sugarcane SM (Unit : m^3/m^3)	Sugarcane VH (Unit : dB)	Sugarcane VV (Unit : dB)
0 - 60	**Establishment**	0.02 to 0.42	-23.27 to -14.58	-15.64 to -8.07
60 - 150	**Vegetable**	0.02 to 0.47	-21.31 to -13.51	-14.13 to -6.95
150 - 240	**Grand Growth**	0.03 to 0.47	-20.34 to -12.81	-12.42 to -6.78
240 - 360	**Ripening**	0.04 to 0.47	-21.70 to -12.81	-14.20 to -5.72
Minimum		0.02	-23.27	-15.64
Maximum		0.47	-12.81	-5.72

5. CONCLUSION

The soil moisture data from the SMAP satellite can use for analysing with the averages backscatter of VH and VV polarisation from the Sentinel-1 satellite to compare the time-series trend of a one-hundred sugarcane plot. The time-series data is between August 2020 and July 2021. We conclude the data as shown in Table 3. We found that the average soil moisture and backscatter of VH and VV polarisation have the lowest level in the Establishment phase (age 0-60 days) and the highest level in the Ripening phase (age 240-360 days), which is all the same period. Moreover, it shows that the soil moisture and polarisation data in 100 sugarcane plantations demonstrated a positive correlation in the sugarcane growth monitoring. By analysing the correlation between soil moisture data and polarisation data, it found that there was a very high correlation. The result revealed that soil moisture could also improve to determine the physical growth characteristics of sugarcane more effectively. In conclusion, we are able to clarify that the soil moisture data had potential and could support the monitoring of sugarcane growth of SAR polarisation data enabling planning and management of the sugarcane industry.

ACKNOWLEDGEMENTS

This work received research grants from Kasetsart University Research and Development Institute, KURDI. ASF DAAC 2020-2021 contains modified Copernicus Sentinel data 2020-2021, processed by ESA. We want to express our sincere thanks to Ms Chitayaporn Srithasri for her advice and assistance in data sources, including processing Sentinel-1 SAR satellite image data to be completed.

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