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Research Article

Evaluation of Calibration Method for Field Application of UAV-Based Soil Water Content Prediction Equation

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The objective of this study is to monitor the water content of soil quickly and accurately using a UAV. Because UAVs have higher spatial and temporal resolution than satellites, they are currently becoming more useful in remote sensing areas. We developed a water content estimation equation using the color of the soil and suggested a calibration method for field application. Since the resolution of the images taken by the UAV is different according to the altitude, the water content estimation formula is developed by using the images taken at each altitude. In order to calibrate the color difference according to lighting conditions, the calibration method using field data were proposed. The results of the study showed an altitude-specific estimation equation using RGB values of the UAV image through linear regression. The appropriate number of field data needed for calibration for site application of the estimation equation was found between 4 and 10. On-site application results of the proposed calibration method showed RMSE accuracy of 1.8 to 2.9%. Thus, the water content estimation and calibration method proposed in this study can be used in effectively monitoring the water content of soil using UAVs.

1. Introduction

The water content is an important factor affecting the strength and behavior of the soil. Monitoring the water content is also essential in determining the appropriate amount and timing of irrigation [1, 2]. Generally, sensors such as time-domain reflectometry (TDR) and frequency-domain reflectometry (FDR) are used to monitor the water content of soils. The TDR sensors can measure the water content with high accuracy, but they are expensive [3–7]. The FDR sensors, on the other hand, are inexpensive but require site-specific calibration [8–10]. Because of these problems, it is difficult to monitor the water content using sensors in a wide area.

Since the color becomes darker as the soil gets wet, many studies have been conducted to estimate the water content of the soil using the color of the soil [11–13]. As a method of monitoring the color of the soil, there is an observation using a satellite image. The method using the satellite image has the advantage of monitoring a wide area periodically. However, the cost of satellite images is high, and the reliability of the measured values is relatively low due to the low resolution.

Aerial photography using UAVs can be a proper alternative to satellite. UAVs are a cost- and time-effective tool in compared to traditional UAVs because they can provide high-resolution aerial images within a few hours and have short repletion times [14, 15]. UAVs are used for various areas because they are suitable for monitoring difficult terrain [16–18]. Moon et al. [18] had been classified land cover using aerial photography by UAVs. Park and Um [19] used UAVs to make a digital surface model (DSM) for surveying construction areas. Also, Jeong et al. [20] developed a monitoring system for civil works using UAVs. Niethammer et al. [21] and Stumpf et al. [22] had produced valuable digital terrain models of the landslide area in France by UAVs. Also, Rau et al. [23] used the UAV to observe landslides caused by typhoons. A number of studies are also underway to predict the water content of soil using UAVs. Park [24] performed a soil classification and characteristic analysis of the forest and reclaimed land soil through the digital image processing of UAV images. Chang and Hsu [25] estimated the soil water content using thermal infrared sensor-equipped UAVs.

When photographing with a UAV, the color of the picture changes depending on lighting conditions. When the water content is estimated by simply using the colors on the photograph without considering the color change due to lighting conditions, a large error may occur. Therefore, there is a need for a monitoring method capable of correcting the error caused by the difference in lighting conditions.

The purpose of this study is to use a UAV image to monitor the water content of the soil quickly and accurately. As mentioned earlier, as the ratio increases, the color of the soil becomes darker, so we want to predict the water content using the color of the soil shown in the picture. At this point, UAVs were used to obtain pictures of monitoring areas with more convenience. First, a water content prediction equation was developed using RGB values in soil photography. As the resolution of the UAV image varies according to the flight altitude, the accuracy of the predicted equation was compared by the flight altitude. Second, to improve accuracy, a method of calibration is proposed using field data because the colors of the UAV images change depending on the lighting conditions. The number of field data for proper calibration is proposed. Finally, to evaluate the applicability of the developed water content prediction method, the water content predicted by the UAV image was compared to the actual measured data.

2. Materials and Methods

2.1. Materials. Aerial photography and soil sampling were performed in the study area. The study area is located in Hwaseong-si, Gyenggi-do, South Korea (37°12′39.4″N, 126°39′31.4″E). There is a lake on the left side of the study area and a cropland on the right side. The study area is located in the west of Hwaseong City and faces the Yellow Sea. It is a flat plain with a low altitude of less than 50 m and a gentle slope of less than 5%. The average annual temperature in the study area is 12.3°C, and the annual precipitation is 1,226.5 mm. Figure 1 shows the location of the study area and the flight path of the UAV.

As a result of the particle size distribution test, the soil of the study area has 77.6% of sand (>0.05 mm) content, 17.2% of silt (0.002 to 0.05 mm) content, and 5.2% of clay (<0.002 mm) content. According to the United States Department of Agriculture soil classification method [26], the soil of the study area is classified as sandy loam.

2.2. Aerial Photography Using UAVs. We used Mavic Pro (DJI Co.), one of the commercial UAVs, to acquire aerial photographs of the soil surface. The Mavic Pro has a built-in 4000 × 3000 pixel camera for high-resolution images. Aerial photographs were taken at 150 m altitude, and the total flight distance is about 7400 m. The flight path is a one round trip to the study area, with a flight time of approximately 15 minutes and a flight speed of 8 m/s. The flight path is shown in Figure 1. Aerial photographs were taken five times during the period from February 2017 to January 2018 for the study area, and surface soil samples were taken after the photographs were taken.

To convert the photographed images into a digital elevation model (DEM), we used PhotoScan (Agisoft Co.), a 3D spatial information generation program. The processing procedure to build the DEM by PhotoScan includes four stages such as camera alignment, generating dense point cloud, mesh, and texturing. In the camera alignment stage, the program searches for common points on the photographs using GPS information and finds camera positions and calibration parameters. In generating the dense point cloud stage, the program calculates depth information for each camera and combines it into a single dense point cloud. Based on the point cloud information, the program generates a polygonal mesh model in building the mesh stage. Finally, the program generates an orthophoto or DEM by texturing on the surface of mesh.

Ground resolution of the image in this study is 0.09 m/pixel. The spatial resolution of a commonly used satellite image is from 1.5 (SPOT-6/7) to 30 (LANDSAT) m/pixel, and the temporal resolution is 16 days for LANDSAT and 1 to 3 days for SPOT-6/7. UAV, on the other hand, has a very high spatial resolution and high temporal resolution because it can be photographed whenever the weather is good. Since the UAV image had a lower price and a higher resolution than a satellite image, it was suitable for monitoring the soil surface.

2.3. Development and Validation of a Water Content Estimation Formula Using the Soil Color. Five fully saturated 40 cm × 30 cm sized soils were prepared with fully saturated soil (Figure 2). Each fan was dried for a certain time to adjust the water content. When soil photographs are acquired under indoor lighting and when the water content is high, the photograph is very bright due to the reflection of the light. Therefore, in order to minimize the effect of reflections on the high water content area during RGB extraction, outdoor photography was performed. Images were acquired at different altitudes to further confirm the effect of color change due to the altitude. The average RGB value of 20 points is extracted from each fan, the sample of the corresponding point is sampled, and the water content is measured and used for analysis.

In order to use the water content estimation formula, the lighting condition and the photographing condition should be the same between the image used at the time of development of the prediction formula and the image of the field to apply the prediction formula. It is possible to adjust the photographing conditions to be the same, but it is very difficult to adjust the lighting conditions to be the same. This is because the lighting condition at the time of

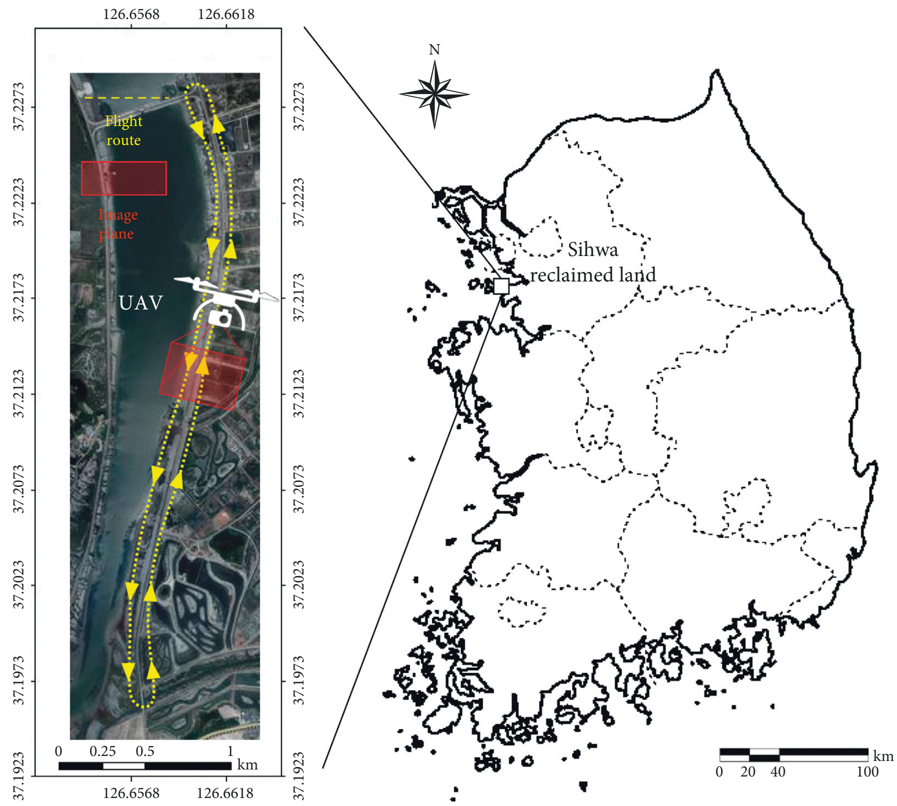


Figure 1: Location of the study area and the flight path of the UAV.

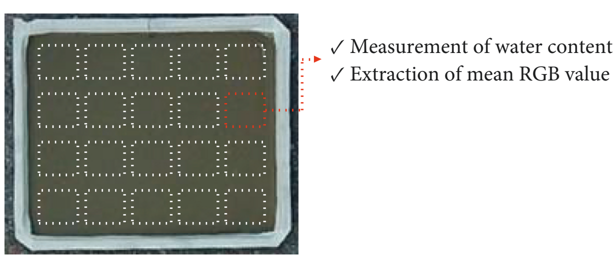


Figure 2: Soil sampling location for water content measurement and RGB value extraction.

photographing continuously changes according to weather conditions, time. It is possible to calibrate the color if the lighting conditions of the field can be accurately measured, but this is difficult to apply easily. Therefore, a convenient method is to collect soils at several sites in the field and measure the water content to perform calibration. The calibration method of the RGB color is summarized in Figure 3. It is possible to perform color correction of the photograph based on the result of extracting the color of the sampling point of the soil sample from the image acquired by the UAV. The more the soil sampling points used for calibration, the higher the accuracy. However, it is not efficient to sample so many points of soil. Therefore, the minimum number of soil samples that can improve the accuracy of color correction should be selected. In this study, RMSE was calculated by applying the water content estimation formula to the color corrected image after selecting several arbitrary points (1, 2, 4, and 10) among the soil at 168 sites acquired in the field. At this time, the RMSE changes depending on which point is arbitrarily selected. Therefore, the accuracy of the correction was evaluated by the average and standard deviation of the RMSE calculated by repeating the extraction 1000 times according to the number of the designated sampling.

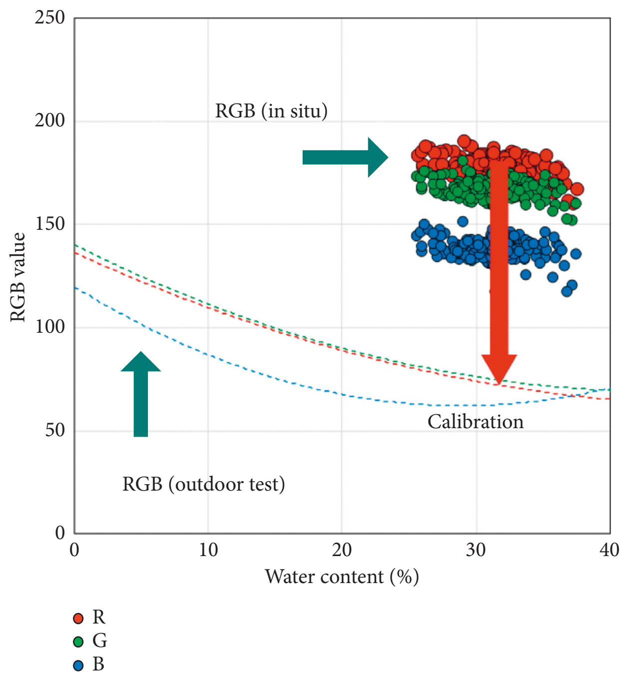
The water content estimation formula was verified using the images taken from the SH reclaimed land. After aerial photographing, the surface soil was sampled and the water content was measured. Sampling locations and methods are summarized in Figure 4. Total 215 soil samples in 5 different times (2017.02.08, 2017.03.14, 2017.04.20, 2017.05.26, and 2018.01.18) were collected for verification of the water content estimation formula.

3. Results and Discussion

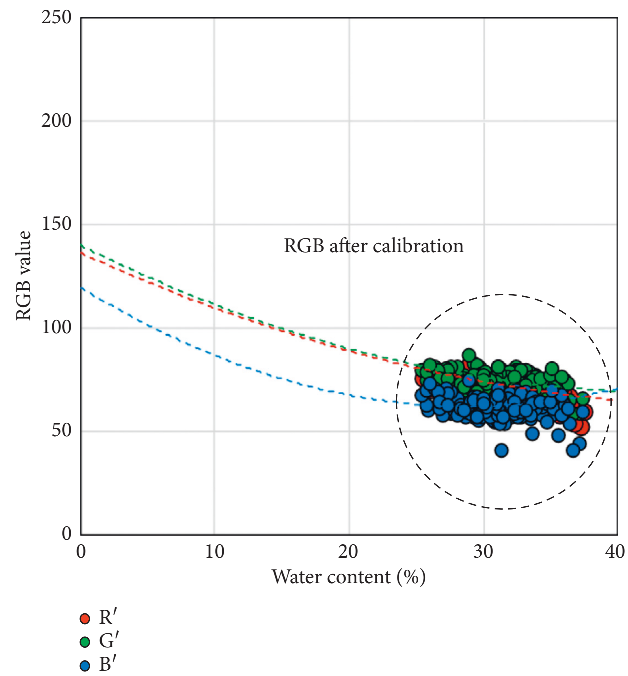
3.1. Development of the Water Content Estimation Formula Using the Soil Color. The aerial photographs of the soil surface layer obtained by using the UAVs are shown in Figure 5.

Immediately after aerial photographing, 20 samples were taken from the surface layer of the soil, and the water content was measured. The aerial photographs taken at each altitude were enlarged to extract the color information at the point where the water content was measured. The average water content of each fan was 1.1, 7.4, 18.4, 24.2, and 30.8%.

The water content obtained from the five planes and the RGB values of the measurement points are shown in

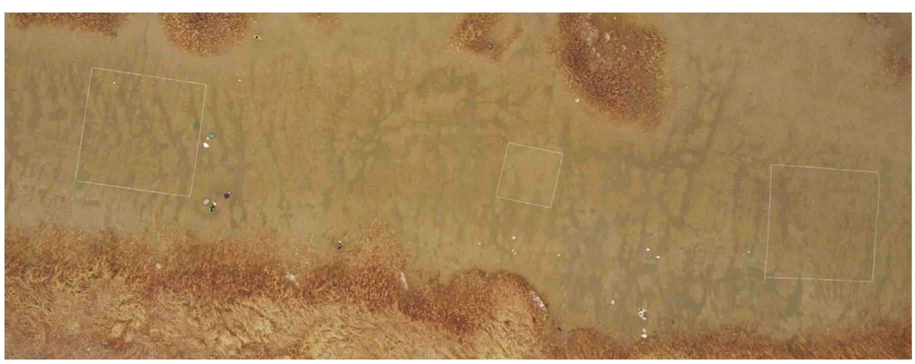


(a)

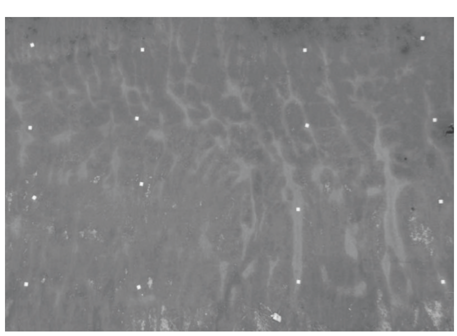


(b)

FIGURE 3: Calibration of RGB for the water content estimation formula: (a) before calibration; (b) after calibration.



(a)

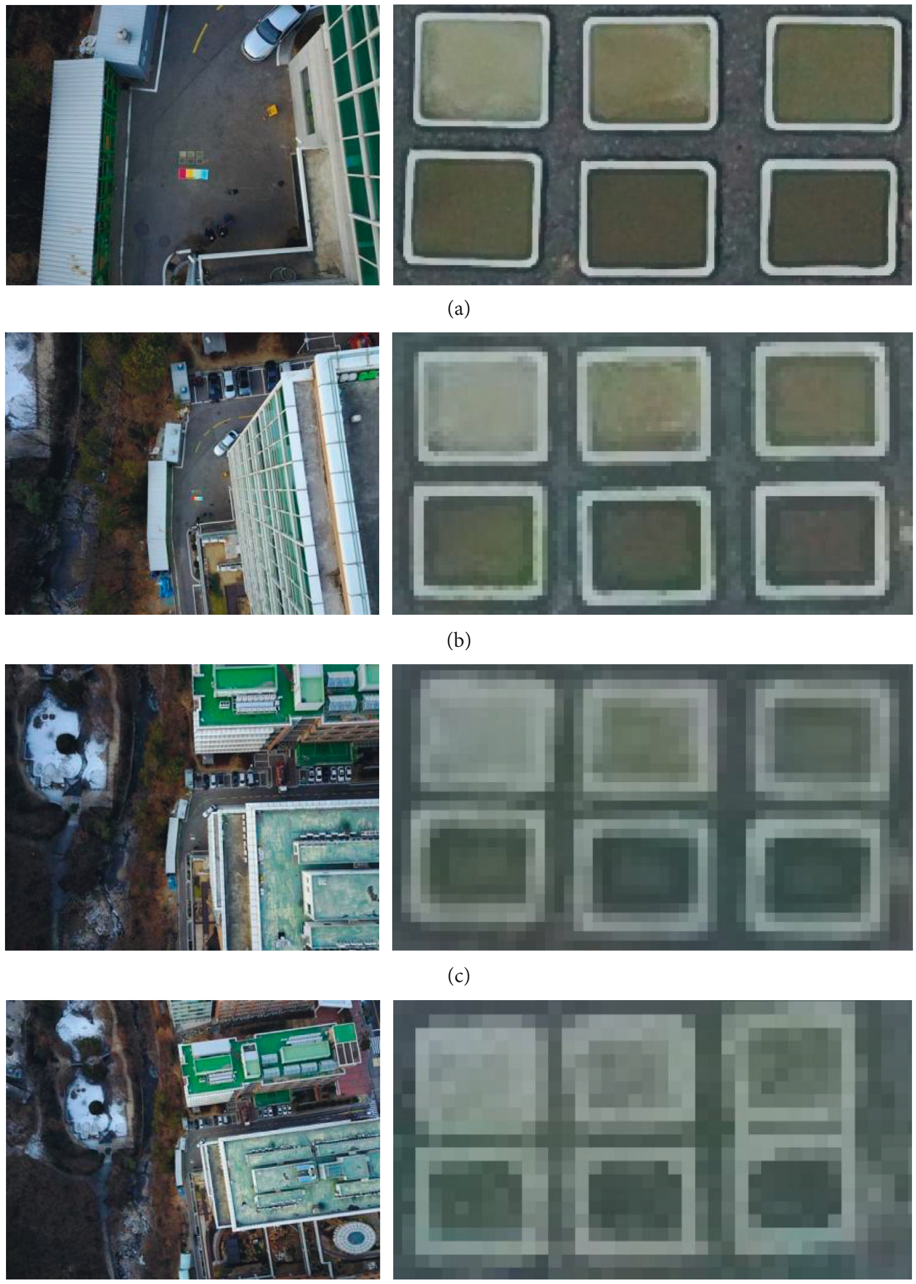


(b)

(c)

FIGURE 4: Soil sampling method in this study: (a) selection of sampling areas; (b) sampling location; (c) topsoil sampling.

Figure 6. As the water content increases, the RGB value tends to decrease exponentially. The change of the RGB value according to the water content was large when the altitude was high. The deviation of RGB values according to the water content ratio was not great up to 100 m, but it increased sharply at higher altitudes. This phenomenon is believed to



(a)

(b)

(c)

(d)

FIGURE 5: Aerial photographs of the soil surface using the UAV. Altitude: (a) 20 m; (b) 50 m; (c) 100 m; (d) 150 m.

be caused by the decrease in the resolution of aerial photographs as altitude increases. Therefore, it is desirable to use the aerial photographs obtained in the low altitude area when constructing the correlation formula between the water content and the RGB value.

The change of the coefficient of determination between water content and RGB according to altitude is shown in Figure 7. As a result of the determination of the coefficient of determination, the coefficient of determination of the B value was relatively low compared to the values of R and G, and the deviation was also large. The coefficient of determination is high at the altitude of 100 m from the whole water content range (1.1~30.8%), but at higher altitudes, the coefficient of determination is greatly decreased. In the middle water content ratio (18.4%~24.2%) and the high water content ratio (24.2~30.8%), the overall coefficient of determination decreased with increasing altitude.

The estimated regression equation of the water content (ω) using the RGB value of the soil surface layer by altitude is as follows. Table 1 shows the values of a, b, c, and d for altitude:

$$\omega = aR + bG + cB + d. \quad (1)$$

As the shooting altitude increases, the resolution of the picture is lowered, so the distribution of the RGB values of the surface layer varies. For this reason, coefficients of the

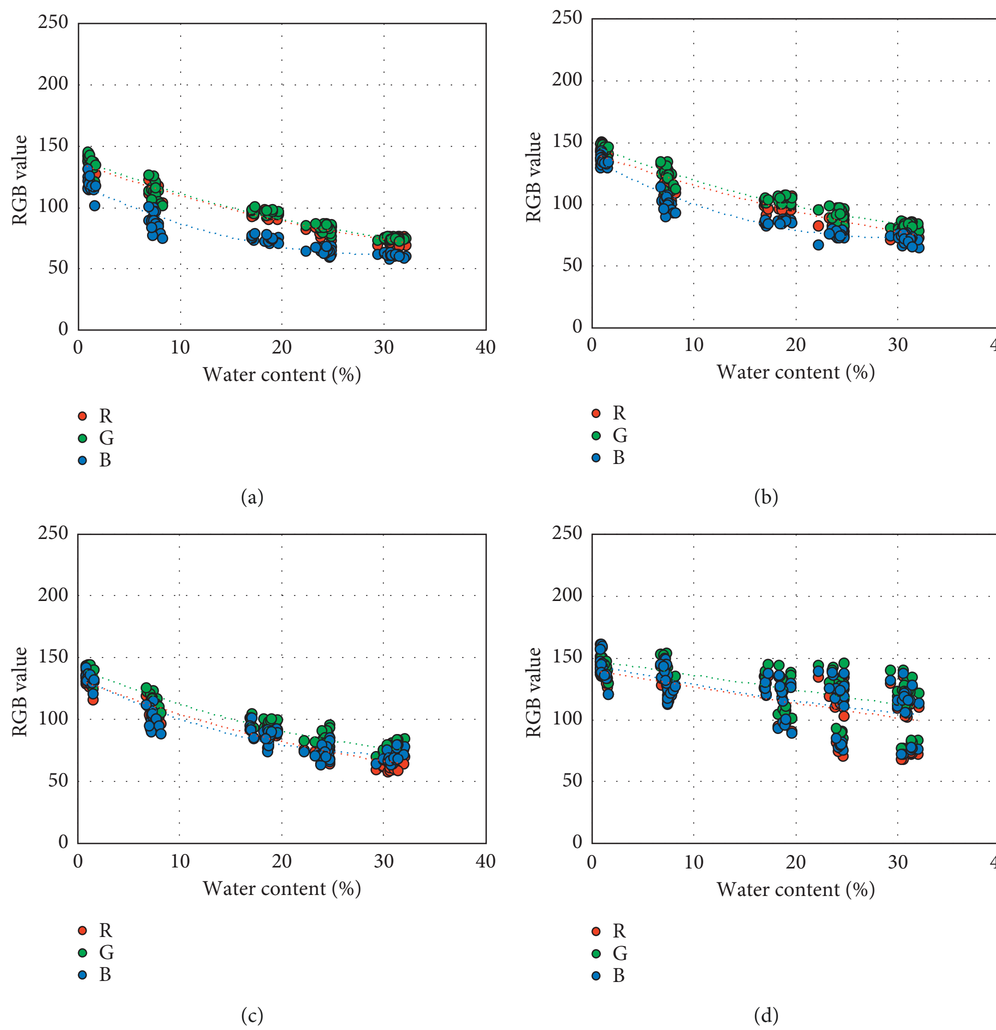


Figure 6: Variation of RGB values according to the water content. Altitude: (a) 20 m; (b) 50 m; (c) 100 m; (d) 150 m.

water content estimation formula using RGB values are calculated differently according to the shooting altitude. The accuracy of the water content estimation formula at each shooting altitude was evaluated by RMSE. The water content estimation formula derived from the photographs taken at 20, 50, and 100 m altitude showed high accuracy with RMSE of 3%. The RMSE was found to be somewhat higher in the water content estimation equation derived from the photograph taken at 150 m altitude because the resolution of the photograph was low. Overall, the lower the shooting altitude, the higher the accuracy of the water content estimation equation. Therefore, the water content estimation equation of 20 m is used for later field application verification and field application.

3.2. Validation of the Water Content Estimation Formula Using the Soil Color. There are considerations that must be considered before using the estimation equation given in equation (1). That is, the lighting conditions at the site and the place where equation (1) was developed may not coincide. If the lighting conditions are different, the colors of the soil surface may differ, even if they are soil of the same water content. To solve this problem, after taking soil from the site after the shooting, calibration should be performed using the color information and the water content of the sampling point. In Park's study [24], one point of field data was used for calibration in estimating the water contents using UAV images. However, even if the calibration is carried out, the accuracy of the calibration changes depends on the point at which the soil sample obtained in the field is sampled. There is a difference as shown in Figure 8 according to the data used for the correction of the RGB values of the data set. Figures 8(a) and 8(c) show the case where the correction is not performed properly and Figure 8(b) the case where the appropriate correction is made. If the soil collected for calibration in a large area of the topsoil is well represented by the whole soil as shown in Figure 8(b), the accuracy of the estimation equation is high. However, as shown in Figures 8(a) and 8(c), the accuracy is greatly reduced when the soil in a particular area is used for correction in the whole soil.

Accuracy can vary depending on the choice of calibration data when applying the water content estimation

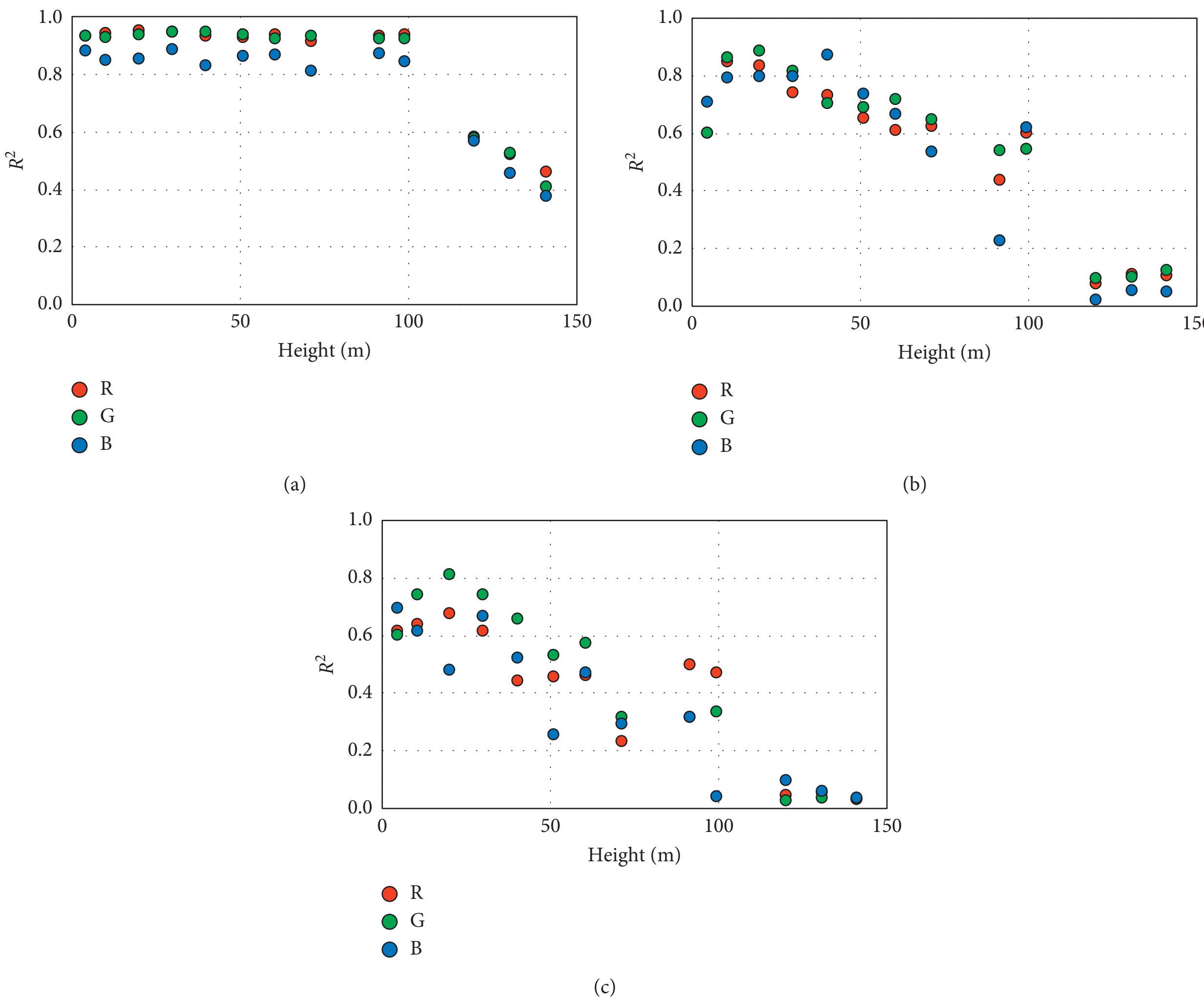


Figure 7: Change of coefficient of determination between the water content and RGB values according to the altitude. Water content range: (a) 1.1~30.8%; (b) 18.4~24.2%; (c) 24.2~30.8%.

Table 1: Coefficient of the water estimation formula using RGB values.

Altitude		20 m	50 m	100 m	150 m
Coefficient	*a*	−0.339	−0.105	−0.709	−1.187
	b	−0.361	−0.409	−0.027	0.909
	c	0.264	0.061	0.319	−0.026
	d	65.2	66.4	55.3	43.5
R^2		0.96	0.94	0.96	0.47
RMSE (%)		2.21	2.74	2.26	7.87

formula in the field. Therefore, the distribution of RMSE according to the selection of data was confirmed by using 168 data points obtained in the field in order to verify how the accuracy according to the selection of correction data varies. The accuracy of the correction may also depend on the number of selected data. To take this into consideration, 1, 2, 4, and 10 randomly selected from 168 data were selected and corrected by the average value. The proposed procedure was repeated 10,000 times to estimate RMSE and estimate the expected value and reliability of RMSE. The probability density function of RMSE according to the number of data selections is shown in Figure 9. Table 2 summarizes average and standard deviation of RMSE according to the number of correction data.

The mean and standard deviation of RMSE decreased as the number of data for calibration increased. In the case of one-point correction, the value of RMSE is large and the deviation is large in each trial. As the number of data for calibration increases, the frequency at which a higher range RMSE decreases significantly. For 10-point calibration, the probability of RMSE less than 3% is about 55%, and the probability of RMSE more than 4% is about 1% and very high accuracy. As a result, the accuracy of the water content estimation equation increases with the number of correction data. It is possible to obtain very high accuracy when acquiring 10 or more data, but it is time-consuming to acquire a large amount of data in the field. Therefore, it is most reasonable to obtain 4~10 calibration data considering both accuracy and economic efficiency.

Figure 10 shows the results of applying the water content estimation formula to the aerial photographs taken using the

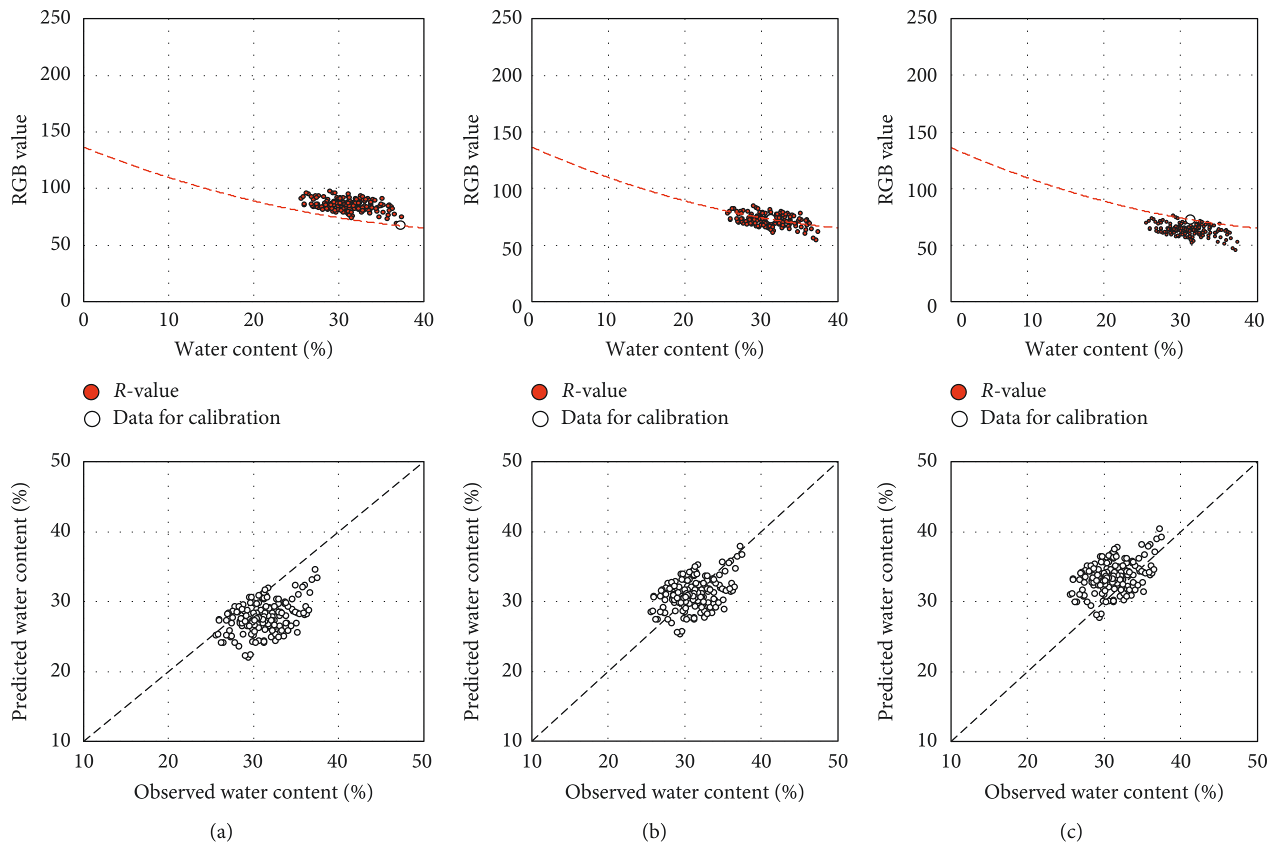


FIGURE 8: Accuracy change of the estimation result according to correction data selection: (a) case 1; (b) case 2; (c) case 3.

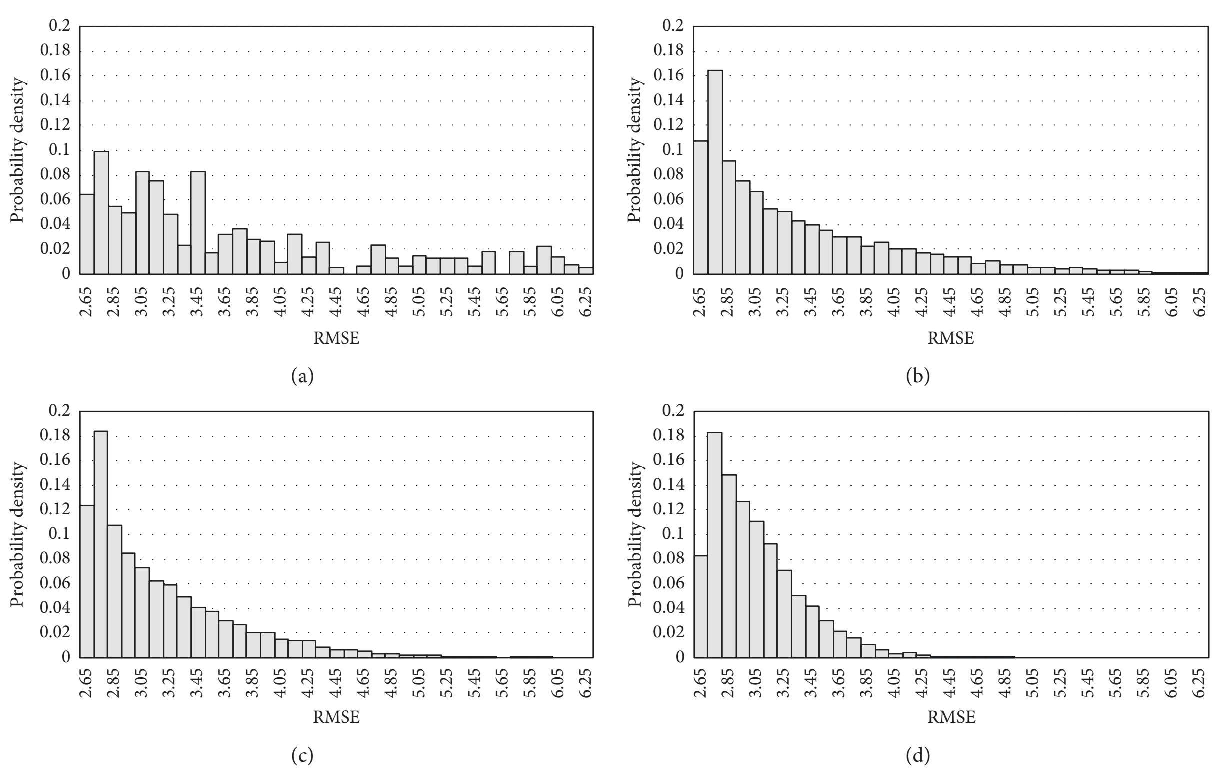


FIGURE 9: Probability density of RMSE according to calibration: (a) 1-point calibration; (b) 2-point calibration; (c) 4-point calibration; (d) 10-point calibration.

Table 2: Accuracy of the estimation equation according to the number of correction data.

	Number of data for calibration			
	1-point	2-point	4-point	10-point
Average	3.692	3.336	3.163	3.042
Standard deviation	0.971	0.692	0.503	0.316

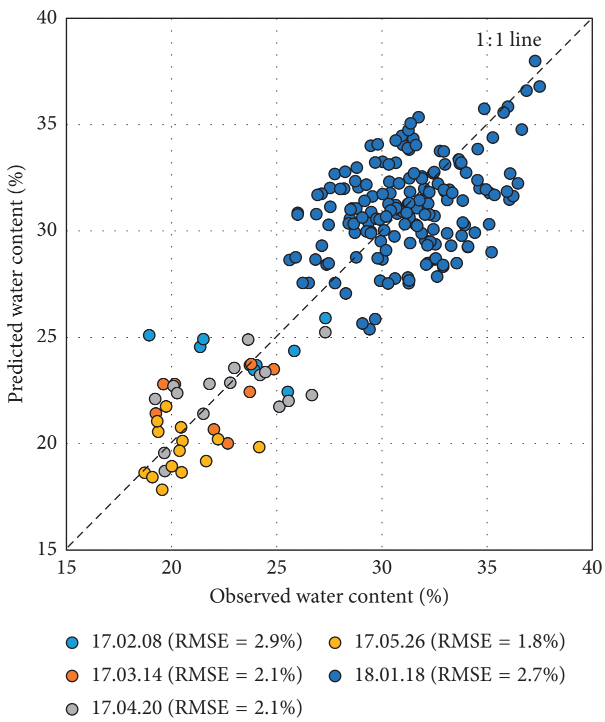


Figure 10: Comparison of observed/predicted water contents using the water content estimation formula.

UAV. The RMSE of the water content estimation equation is 1.8~2.9%, which predicts the water content of the soil surface relatively well. Therefore, if the calibration is performed by obtaining 4 to 10 calibration samples as shown above, the water content of the soil surface can be well-predicted by using the UAVs.

4. Conclusions

In this study, evaluation of the calibration method of the UAV-based soil water content prediction equation was examined. The following conclusions were obtained. The relationship between the soil water content and the soil color was investigated in aerial photographs taken at various altitudes. As a result, the RGB values decreased as the water content increased, and the RGB values varied greatly as the altitude increased. Therefore, the coefficient of determination between the RGB value and the water content decreased with increasing altitude. The linear regression analysis was used to predict the water content of the soil using the RGB values of aerial photographs. In order to apply the water content estimation formula using RGB values, color correction using soils sampled in the site should be performed. Accuracy of the water content estimation formula can vary greatly depending on which soil is selected as calibration data in the field. Therefore, 1, 2, 4, and 10 data were randomly selected based on the 168 calibration data obtained from the field, and then the correction was performed. Then, the accuracy was analyzed by comparing the respective RMSEs. The mean and standard deviation of RMSE decreased with the increasing number of calibration data. Considering accuracy and efficiency, it is reasonable to use 4 to 10 calibration data. The accuracy was confirmed by applying the proposed calibration method (4-point calibration) to 215 points at 5 points. The RMSE was 1.8~2.9%, which is considered to be highly applicable in the field.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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