ANALYSIS OF IN-SITU SPECTRAL REFLECTANCE AND VEGETATION INDICES OF SAGO PALMS FOR EMPIRICAL ESTIMATION OF STRUCTURAL ATTRIBUTES: IMPLICATIONS FOR ESTIMATION USING WORLDVIEW-2 IMAGERY

Meriam M. SANTILLAN[a*], Jojene R. SANTILLAN[b], Michelle V. JAPITANA[a]

[a] Division of Geodetic Engineering, College of Engineering and Information Technology, Caraga State University, Ampayon, Butuan City, Philippines; Tel: +63-85-3412296; E-mail: mmsantillan@carsu.edu.ph

[b] Research Laboratory for Applied Geodesy and Space Technology, Training Center for Applied Geodesy and Photogrammetry, University of the Philippines, Diliman, Quezon City, Philippines; Tel: +63-2-9818500 ext. 3147; E-mail: jrsantillan@up.edu.ph

KEY WORDS: Sago palm, spectral reflectance, vegetation indices, WorldView-2

Abstract: In the Philippines, the commercial utilization of sago palm (*Metroxylon sagu*) as a significant source of starch that can be converted into flour, lactic acid, ethanol and biodegradable plastics, are increasing. Along with this comes the need to determine the location and distribution of these palms, and to ascertain whether there is enough supply of sago to drive and sustain a large scale sago starch industry. This situation calls for opportunities for the adoption of existing remote sensing (RS)-based techniques for mapping of the sago palm in RS images and to empirically estimate sago palm structural characteristics that could provide information on the amount of starch that could be extracted from a sago stand. We present in this paper the results of our study that aims to analyze relationships between in-situ spectral reflectance and vegetation indices with sago palm structural attributes that are indicative of sago starch contents such as age, number of leaves, plant height and diameter-at-breast-height (dbh). In-situ measurements of spectral reflectance and structural characteristics were conducted in 58 sago palm-rich sites located in the eastern part of Mindanao Island in southern Philippines. The sites represent the four major growth stages of sago palm: rosette, bole formation, inflorescence, and fruit-ripening. Sago palm spectral reflectance curves within the 345 - 1045 nm wavelength range were collected at the sago sites using an Ocean Optics USB4000 Field VIS-NIR spectrometer. The spectral reflectance curves were then resampled to match the spectral response of Bands 1-8 of the WorldView-2 sensor. From the resampled reflectance curves, the WV2 bands where different growth stages of sago can be discriminated were identified. Correlation analysis was then conducted to determine whether relationships exist between the band reflectance values and computed vegetation indices (NDVI, RVI, DVI) with the measured structural characteristics, and to provide insight as to whether the use of images acquired by the WorldView-2 sensor is a feasible way of estimating sago structural attributes. Results suggest that it is possible to discriminate sago palms in rosette and inflorescence stages from those in bole formation and fruit ripening stages in the WV2 bands 6, 7 and 8. On the other hand, sago palms in bole formation and fruit ripening stages cannot be discriminated from each other in these three bands. However, the spectral reflectance values in bands 1 and 2 indicate separability between the two growth stages. These results imply that if images were to be acquired by WV2, sago palms at different growth stages can be discriminated on the image based on spectral information alone. Results of correlation analysis revealed that WV2 band reflectance values and VIs are highly correlated with sago palm structural attributes. However, the degree of correlation is not consistent throughout the growth stages. In general, most of the sago palm structural attributes have better correlation with VIs. These results lead to the insight that it is possible to estimate sago palm structural attributes by utilizing spectral information to compute VIs from a WV2 imagery.

INTRODUCTION

The sago palm (*Metroxylon Sagu* Rottb.) has been described as human kinds' oldest food plant (Avé, 1997). It has a trunk which contains starch and used as a staple food for humans in South-East Asia (Flach, 1997). It is now grown commercially in Malaysia, Indonesia and Papua New Guinea for production of sago starch and/or conversion to animal food or fuel ethanol (McClatchey et al., 2006).

In the Philippines, especially in the province of Agusan del Sur, the sago palm is considered a staple food source and utilized for its wide industrial purposes. Aside from food, the potential of sago palms as a source of important starch by-products such as lactic acid that are used for producing biodegradable plastics (Shibata et al., 2007) has drawn increasing interest recently.

In anticipation of the emergence of sago starch industry in the country, more particularly in Mindanao, mapping the location and distribution of this palm becomes necessary in order to determine the total area coverage as well as to determine the suitable sites and conditions to ensure balance between increase in utilization and production rates for both food and other by-products. This determination of the location and distribution of the sago palm calls for opportunities for the adoption of existing remote sensing (RS)-based techniques for mapping of the sago palm in RS images and to empirically estimate sago palm structural characteristics that could provide information on the amount of starch that could be extracted from a sago stand.

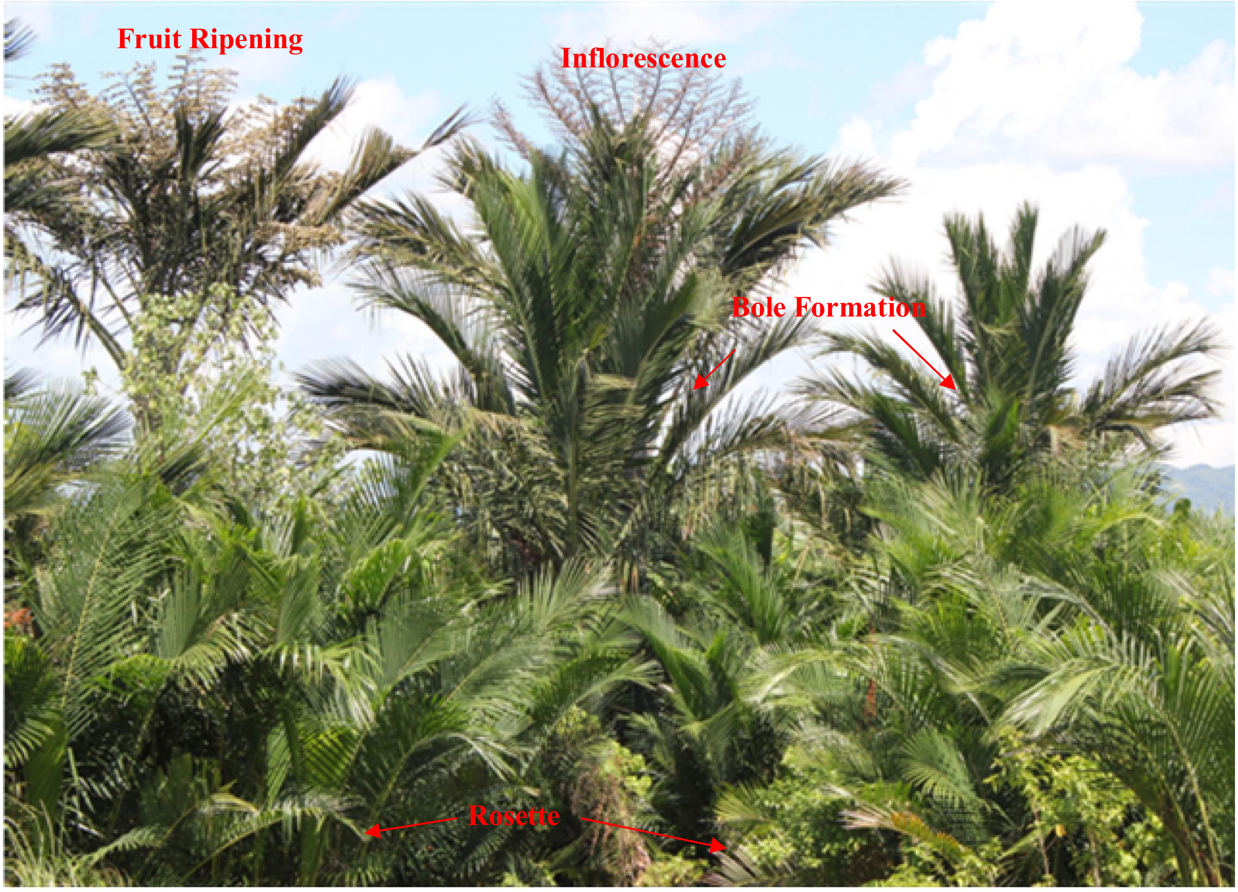
The objective of this study is to analyze relationships between in-situ spectral reflectance and vegetation indices with sago palm structural attributes that are indicative of sago starch contents such as age, number of leaves, plant height, and diameter-at-breast-height (dbh). By matching the measured in-situ spectral reflectance with the 8 multispectral bands of the WorldView-2 (WV2) sensor, this study aims to explain the correlations between the measured structural attributes with the WV2-resampled spectral reflectance and with the computed vegetation indices in order to provide insight as to whether imagery acquired by the WV2 sensor is useful in estimating sago palm structural attributes.

THE SAGO PALM AND ITS GROWTH STAGES

According to McClatchey et al. (2006), the sago palm is widely distributed in Southeast Asia, Melanesia and islands in Micronesia and Polynesia. It can grow between 9-33 meters in height in tropical lowland forest and freshwater swamps. They are usually found near sea level but can be found 1–700 m with rainfall of 2000–5000 mm (80–200 in). Sago palms grow in a variety of soils (including well drained, poor quality sand and clay); together with a wide range of species found in lowland freshwater swamps and in traditional swidden gardens in lowland rain forests. The growth rate is rapid, exceeding 1.5 m (5 ft) per year in optimal conditions. Under good conditions, the sago palm can yield from 15–25 metric tons of air-dried starch per hectare (McClatchey et al., 2006).

The sago palm has 4 major growth stages (Figure 1): rosette, bole formation, inflorescence, and fruit ripening, with a seed-to-seed life of 11-12 years under optimum ecological conditions (Flach, 1997; McClatchey et al., 2006). Rosette stage (45 months from seeding) is a period characterized by relatively little growth. During this period the plant forms a total of about 90 fronds[1]. In the bole formation stage of 54 months, the bole elongates to maximum height and produces one frond per month. Plants during this stage have a total of about 24 fronds and 54 frond scars on the bole and are producing a high amount of starch. In the inflorescence stage of 12 months, the plant forms two fronds per month, the rate of starch accumulation starts to decrease, and the starch moves from the lower to the upper bole. It is in this stage that flowers emerge. Palms are harvested for starch during this and the next period. The fruit ripening stage of 24 months is the stage when the flowers have been converted into fruits. When the fruits have fully ripened, the plant's life cycle is completed because the starch in the trunk has already been exhausted to produce the seeds.

[1] In the text of Flach (1997) and McClatchey et al. (2006), the term used for “frond” is “leaf”. In this paper, we exchanged “leaf” with frond to refer to the part of the palm that holds the elongated leaves.



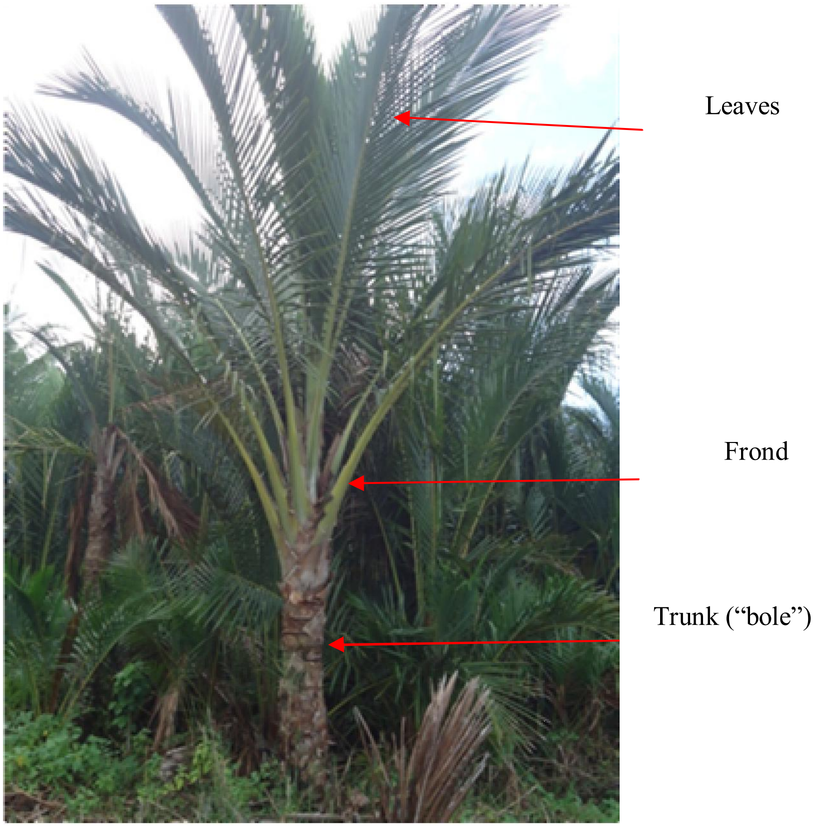


Figure 1. (a.) A cluster of sago palms showing different growth stages. (b) A sago palm in bole formation stage, with some of its parts indicated.

METHODS

The methodology of the study involves (i.) in-situ spectral and structural measurements of sago palms in 4 growth stages, (ii.) re-sampling of the measured sago palm reflectance spectra to match the spectral bands of the WV2 sensor, and (iii.) statistical analysis of the correlations between resampled reflectance spectra and derived vegetation indices with sago palm structural attributes such as age, plant height, number of fronds and leaves, and diameter-at-breast-height (dbh).

In-situ Spectral Measurements

In-situ spectral measurements were carried out in the different sago palm-rich sites in Mindanao, Philippines (Figure 2) such as in Agusan del Norte, Surigao del Sur, and Agusan del Sur. Measurements were done in a sample of 58 sago palms which consisted of 23 in rosette, 23 in bole formation, 7 in inflorescence, and 5 in fruit ripening stages. There were few samples in inflorescence and fruit ripening stages as the sago palms in these stages are very tall making it very difficult to measure spectral reflectance.

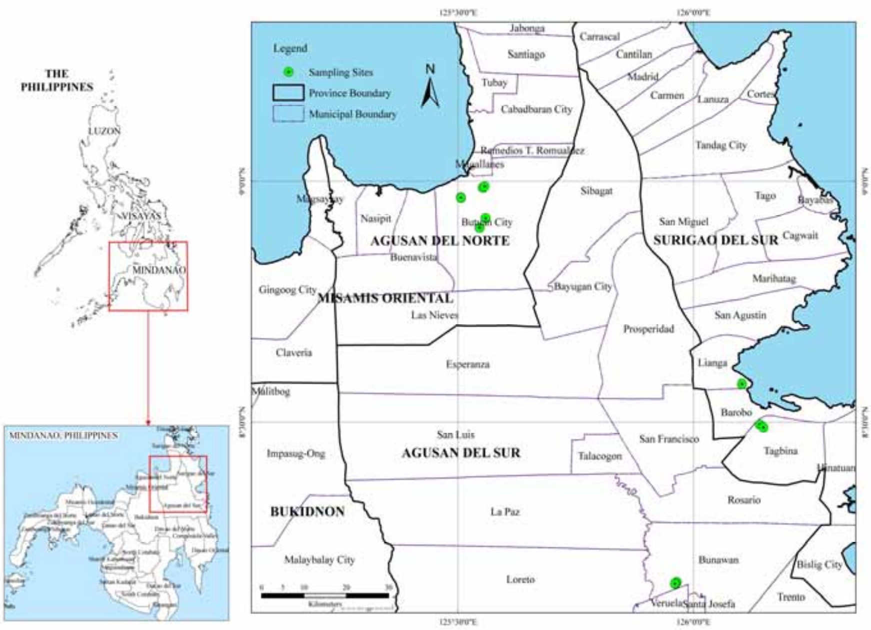


Figure 2: Map showing the location of sago palm-rich sites where in-situ spectral and structural measurements were carried out.

In-situ spectral reflectance of sago palm within 345 - 1045 nm wavelength range at different growth stages in 58 sampling sites were measured using an Ocean Optics USB4000 Field VIS-NIR spectrometer. For each sago palm, the measurement was done in five modes: one on top of the canopy, and four on the side of the canopy (i.e., at 45 degrees separation). At each mode, 25 spectral reflectance curves were gathered, the average of which represents the spectral reflectance of the sago palm at that sampling site. In each site, two kinds of measurements were taken: (i.) the amount of radiation reflected by the sago palm and (ii.) reflected radiation from a white reference panel (Ocean Optics LS1 diffused reflectance standard). Percentage spectral reflectance is obtained by dividing the measured sago reflected radiation with the measured reflected radiation from a white reference panel x 100%. Figure 3 illustrates the spectral measurements.

The spectral reflectance curves were then resampled to match the spectral response of Bands 1-8 of the WorldView-2 sensor (Table 1). WV2 is a commercial high resolution satellite that provides 8 spectral sensors in the visible to near-infrared range. Each sensor is narrowly focused on a particular range of the electromagnetic spectrum that is sensitive to a particular feature on the ground, or a property of the atmosphere (Digital Globe, 2009).

The resampling was done so that it will be possible to compute the vegetation indices (VIs) as well as to correlate the resampled band values and the VIs to the measured structural attributes. Vegetation indices such as Normalized Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and Difference Vegetation Index (DVI) were computed using the resampled reflectance values corresponding to the Red and Near-infrared 1 (NIR1) bands (band 5 and band 7, respectively). The following equations were used in computing the VIs:

$$NDVI = (Band\ 7 - Band\ 5) / (Band\ 7 + Band\ 5) \quad (1)$$

$$RVI = (Band\ 7 / Band\ 5) \quad (2)$$

$$DVI = (Band\ 7 - Band\ 5) \quad (3)$$

Figure 3. Illustration of the in-situ spectral measurements.

Table 1. The 8 multispectral bands of WV2 sensor (Digital Globe, 2009).

Band No.	Band Name	Wavelength Range, nm
1	Coastal blue	400-450
2	Blue	450-510
3	Green	510-580
4	Yellow	585-625
5	Red	630-690
6	Red Edge	705-745
7	Near infrared 1	770-895
8	Near infrared 2	860-1040

Structural Measurements

Each spectral measurement of a sago palm is paired with structural measurements. Standard forest measurement techniques were employed to measure the sago palm structural attributes that include dbh, plant height, number of fronds and leaves, and age. Dbh was determined using a measuring tape. Plant height was measured using a clinometer while the number of fronds and number of leaves per frond were determined by counting. The age of sago palm was determined by employing the method of McClatchey et.al. (2006) by counting the fronds and frond sheet marks.

Correlation Analysis

Bivariate correlation analysis was employed to relate the resampled WV2 band reflectance values and vegetation indices with the measured structural attributes. This aims to determine whether strong relationships exist between the band reflectance values and the VIs with the measured structural characteristics, and to evaluate whether the use of images acquired by the WorldView-2 sensor is a feasible way of estimating sago structural attributes. WV2 is a commercial high resolution satellite that provides 8 spectral sensors in the visible to near-infrared range. Each sensor is narrowly focused on a particular range of the electromagnetic spectrum that is sensitive to a particular feature on the ground, or a property of the atmosphere (Digital Globe, 2009).

RESULTS AND DISCUSSION

Average Reflectance of Sago Palms

Figure 3 shows the graph of the average reflectance values (matched to the eight bands of the WV2 sensor), of the sampled sago stands at various growth stages. At bands 6, 7, and 8, sago palm at rosette and inflorescence stages have the highest reflectance values compared to the sago palms at bole formation and fruit ripening stage. In terms of separability between each growth stage, it appears from the average reflectance values that it is possible to discriminate sago palms in rosette and inflorescence stages from those in bole formation and fruit ripening stages in bands 6, 7 and 8. On the other hand, sago palms in bole formation and fruit ripening stages cannot be discriminated from each other in these three bands. However, the spectral reflectance values in bands 1 and 2 indicate separability between the two growth stages. These results imply that if images were to be acquired by WV2, sago palms at different growth stages can be discriminated on the image based on spectral information alone.

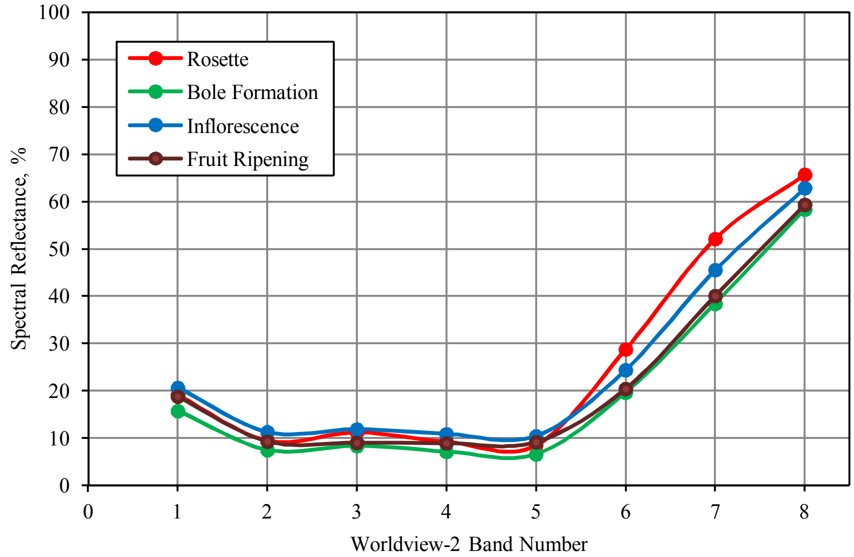
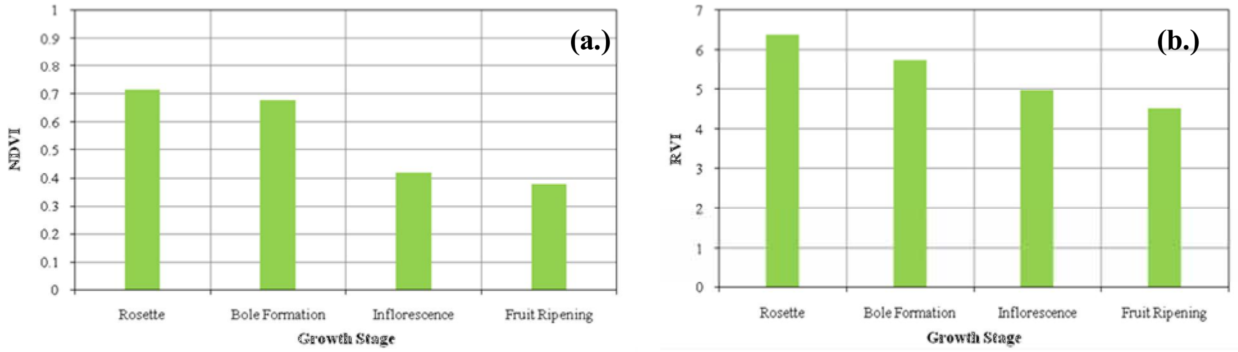


Figure 3: Average reflectance of sago palms at different growth stages, matched to the 8 bands of the WV2 sensor.

Vegetation Indices of Sago Palms

Shown in Figure 4 are the three different vegetation indices of the sago palms that were computed using the average spectral reflectance of sago palms corresponding to Bands 5 and 7.



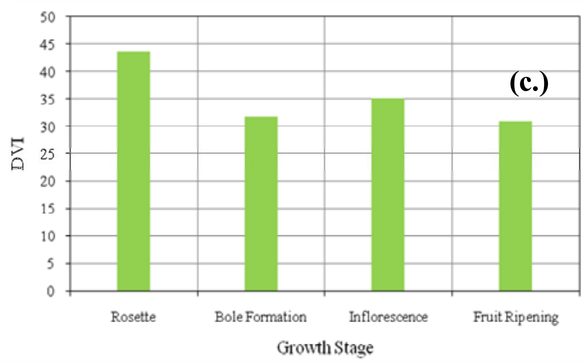


Figure 4: Average NDVI, RVI and DVI of the sago palms at different growth stages. The VIs were computed using the resampled reflectance corresponding to Bands 5 and 7 of the WV2 sensor.

The graphs generally show that the NDVI, RVI and DVI are inversely proportional to the growth stage of sago palms. This means that values of these indices decreases as the sago palm develops to its final growth stage. Among the three VIs, the RVI shows a more realistic pattern of decreasing VI from rosette to fruit ripening stages. This pattern correctly corresponds to how the number of fronds decreases through time. It can be recalled that during the rosette stage, the sago palm has the most number of fronds and leaves, and hence it is greener and reflects more in the near infrared (NIR) region. The number of fronds goes down to 24 during the bole formation stage indicating the number of leaves have decreased, and hence lower reflectance in the NIR region that leads to lower RVI. These results would indicate that vegetation indices can be a good indicator of sago palm growth stage.

Correlations of WV2 Band Reflectance and VIs with Structural Attributes

Table 2 summarizes the computed correlation coefficients between WV2 band reflectance and VIs with sago palm structural attributes.

Table 2. Computed correlation coefficients between WV2 band reflectance and VIs with sago palm structural attributes. Values in bold are the highest correlation coefficients.

(a) Rosette Stage	WV2 Spectral Bands								VIs		
Structural Attributes	*Band 1*	*Band 2*	*Band 3*	*Band 4*	*Band 5*	*Band 6*	*Band 7*	*Band 8*	*NDVI*	*RVI*	*DVI*
number of leaves	0.33	0.38	0.31	0.30	0.30	0.35	**0.44**	0.41	0.21	0.24	**0.45**
dbh	0.18	0.19	0.08	0.14	0.18	0.21	**0.33**	0.28	**0.44**	0.40	0.35
plant height	**0.36**	0.33	0.15	0.20	0.25	0.24	0.34	0.35	0.22	0.22	**0.35**
age	0.11	0.13	0.11	0.07	0.05	0.21	**0.32**	0.25	0.41	**0.47**	0.37

(b) Bole Formation Stage	WV2 Spectral Bands								VIs		
Structural Attributes	*Band 1*	*Band 2*	*Band 3*	*Band 4*	*Band 5*	*Band 6*	*Band 7*	*Band 8*	*NDVI*	*RVI*	*DVI*
number of leaves	-0.05	0.10	0.06	0.13	**0.17**	-0.11	-0.06	-0.15	-0.13	**-0.24**	-0.08
dbh	0.14	0.06	-0.13	-0.10	0.04	0.12	**0.25**	0.24	0.24	**0.29**	0.26
plant height	**0.22**	0.16	-0.01	0.06	0.19	0.04	-0.10	0.04	**-0.37**	-0.28	-0.13
age	-0.21	-0.04	0.24	0.24	0.06	-0.15	**-0.30**	-0.29	-0.44	**-0.47**	-0.33

(c) Inflorescence Stage	WV2 Spectral Bands								VIs		
Structural Attributes	*Band 1*	*Band 2*	*Band 3*	*Band 4*	*Band 5*	*Band 6*	*Band 7*	*Band 8*	*NDVI*	*RVI*	*DVI*
number of leaves	0.20	**0.20**	0.28	0.24	0.24	0.12	0.19	0.08	**-0.18**	-0.08	0.12
dbh	-0.24	-0.12	0.34	0.29	0.02	-0.40	**-0.63**	-0.45	-0.46	-0.55	**-0.62**
plant height	-0.53	-0.24	0.38	0.25	-0.06	-0.83	-0.79	**-0.88**	-0.73	-0.54	**-0.76**
age	0.06	0.39	**0.79**	0.74	0.56	-0.36	-0.50	-0.50	**-0.91**	-0.77	-0.65

(d) Fruit Ripening Stage	WV2 Spectral Bands								VIs		
Structural Attributes	*Band 1*	*Band 2*	*Band 3*	*Band 4*	*Band 5*	*Band 6*	*Band 7*	*Band 8*	*NDVI*	*RVI*	*DVI*
number of leaves	0.11	0.03	**-0.38**	-0.34	-0.18	-0.22	-0.10	-0.08	-0.02	**0.35**	-0.07
dbh	0.46	0.50	0.50	**0.57**	0.56	0.52	0.53	0.34	-0.20	-0.35	**0.50**
plant height	0.60	0.66	0.82	**0.86**	0.81	0.70	0.62	0.54	-0.39	**-0.82**	0.53
age	-0.17	-0.15	-0.28	-0.14	-0.07	-0.41	-0.45	**-0.52**	**-0.93**	-0.65	-0.57

At the rosette stage, the correlation coefficients values for the WV2 bands and derived vegetation indices and that of the structural properties of sampled sago stands at rosette stage are all positive. This may indicate that the increase in WV2 band values and VIs would mean increase in the values of the structural attributes. The number of leaves is highly correlated with Band 7 and DVI. The dbh is closely associated to Band 7 and NDVI. Band 1, band 8 (NIR 2) and DVI band are highly associated to the plant height of the sampled sago at rosette stage. The estimated age of the sago palms at rosette stage is highly correlated to band 7 and RVI band. It can be noticed, however, that structural attributes are better correlated with VIs than the WV2 band values.

A positive correlation was observed between band 5 and the number of leaves of the sampled sago palms at bole formation stage. Band 7 is positively correlated with dbh but negatively correlated with the estimated age of the sago palms at bole formation stage. Plant height is positively correlated to band 1 but negatively correlated to NDVI band. The number of leaves and the estimated age of the sago palms are negatively correlated to RVI band but positively correlated to the dbh of sago palms at bole formation stage.

It is at the inflorescence stage that the highest correlations were observed between the WV2 bands and derived vegetation indices and that of the structural properties. Significant results were observed between band 3 and estimated age, band 7 and dbh, band 8 and plant height, NDVI and age, DVI and dbh, and DVI and plant height, respectively. It is remarkable to note that the correlation coefficient value for the association of age to NDVI and band 3 are 0.91 and 0.79 (at $p < 0.05$), respectively. Plant height's correlation to band 8 and DVI is -0.87 and -0.76 (at $p < 0.05$), respectively.

The estimated age of sago palms at fruit ripening stage is strongly correlated to NDVI with a correlation coefficient value of -0.91 (at $p < 0.05$). The estimated age of sago stands at this stage is also highly associated to band 8. Plant height is positively correlated to band 4 (0.86) but negatively correlated to RVI band (-0.82). Dbh are positively correlated to both band 4 and DVI band.

It appears from results of the correlation analysis that WV2 bands and VIs that are highly correlated in a certain growth stage would not necessarily have the same high correlation in another growth stage. For example, number of leaves in rosette stage is highly correlated with DVI but this does not hold true in bole formation, inflorescence and fruit ripening changes. In fact, in bole formation, number of leaves is more correlated with RVI. However, in general most of the sago palm structural attributes have better correlation with VIs.

CONCLUSIONS

We presented in this paper an analysis of the relationships between sago palm structural attributes with in-situ spectral reflectance that were resampled to match the spectral bands of the WV2 sensor. It was shown, through the visual analysis of the resampled spectral reflectance curves, that if images were to be acquired by WV2, sago palms at different growth stages can be discriminated on the image based on spectral information alone. Another important finding is that in general most of the sago palm structural attributes have better correlation with VIs.
These results lead to the insight that it is possible to estimate sago palm structural attributes by utilizing spectral information to compute VIs from a WV2 imagery.
One of the limitations of this research is the few number of samples of spectral and structural measurements. It is for this reason that the study focused only on describing the patterns and relationships between WV2 band values, VIs and the structural attributes. Presently, more measurements are being taken to improve the results presented in this paper. Steps are also being taken in using the in-situ spectral and structural measurements in generating estimation algorithms of sago palm structural attributes that will hopefully be applicable to WV2 imagery of sago palms.

ACKNOWLEDGEMENT

This work is an output of *Project II.2-Biophysical, Structural and Spectral Characterization of the Sago Palm and Its Environment* which is funded by the Philippine Council for Industry, Energy and Emerging Technology Research and Development of the Department of Science and Technology (PCIEERD-DOST). We thank the following personnel and students of the College of Engineering and Information Technology of the Caraga State

University for their assistance during the in-situ measurements namely, Engr. Arnold G. Apdohan, Arthur M. Amora, Linbert Cutamora, Dylan Dikraven Galavia and Cherry Bryan G. Ramirez.

REFERENCES

Avé, J.B., 1977. Sago in insular South-East Asia: historical aspects and contemporary use. In: Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July, 1976. (K. Tan ed.), pp. 21-30.

Digital Globe, 2009. The Benefits of the 8 Spectral Bands of WorldView-2, Digital Globe White Paper, August 2009.

Flach, M., 1997. Metroxylon sagu Rottb. - Promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetics and Crop Plant Research, Gatesleben/International Plant Genetic Resources, Rome, Italy.

McClatchey, W., Manner, H.I., Elevitch, C.R., 2006. *Metroxylon amicarum*, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawaii. <http://www.traditionaltree.org>.

Shibata, K., Flores, D.M., Kobayashi, G., 2007. Direct l-lactic acid fermentation with sago starch by a novel amylolytic lactic acid bacterium, Enterococcus faecium. Enzyme and Microbial Technology, 41, pp. 149-155.