Monitoring potassium levels in peat-grown pineapple using selected spectral ratios

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A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract. *In this study, we assessed the biophysical changes within pineapple (var. MD2) in response to different potassium (K) rates using a hyperspectral approach. K deficiency was detected at 171 days after planting. Shortage of K also exhibited a shift in red edge towards shorter wavelengths between 500-700 nm. In addition, spectral ranges of 430 nm and 680 nm, as well as 680-752 nm were found to be most effective in differentiating spectral response to varying K rates. Three vegetation indices, i.e. Normalized Pigment Chlorophyll Index (NPCI), Plant Senescence Index (PSRI) and Red-edge Vegetation Index (RVSI) were found to best describe K treatment effects on pineapple canopy reflectance. This study could be extended further to include pineapple varieties other than MD2, and also key nutrients, such as N and P, for better fertilizer management in peat-grown pineapple.*

Keywords. *K response, spectral indices, pineapple canopy reflectance.*

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Introduction

Suboptimal soil fertility is one of the key factors affecting pineapple growth and yield in Malaysia. This is mainly due to the fact that pineapple in Malaysia is largely cultivated on peat and not mineral soils as in other producer countries like Thailand and the Philippines. Cultivation on peat brings upon nutrient leaching problem which rarely occurs on mineral soils. This problem is most evident with potassium (K), a very mobile nutrient that is more prone to washout especially in the tropical region where precipitation can be as high as 3500 mm (Ahmed et al., 2005; Ahmed et al., 2013). In addition, low clay content and absence of mineral matter in peat makes K fixation very difficult even with abundant exchangeable K in the soil (Ahmed et al., 2007). Pineapple deficient of K can have problems such as reduced fruit mass, lesser fruit aroma, and decreased slip production which usually leads to leaf tip death and necrosis (Hawkesford et al., 2012).

Given the severity of K leaching on peat, many pineapple plantations have resorted to excessive fertilizer application to compensate low K recovery, which may eventually get washed out from the soil and contaminate ground water and environment (Zhao et al., 2006). The traditional approach of monitoring plant nutritional status, i.e. detailed sampling followed by laboratory chemical analyses, is economically and environmentally challenging given the large plantation acreage. The use of non-destructive remote sensing tools is a promising approach to compliment the monitoring of plant nutritional status. These tools have the ability to assess nutrient deficiency and the accompanying changes in biophysical and biochemical properties within crops. Studies of physiological alterations caused by nutrient stress can be effectively ascertained by comparing the spectral reflectance of healthy and nutrient-deficient plants. Stressed plants generally show a higher reflectance at the Photosynthetic Active Radiation (PAR) region (400-700 nm) and a much lower reflectance at the Near-Infra Red (NIR) region (700-1200 nm) (Xu et al., 2007). In a study conducted by Selvaraja et al. (2013), it was reported that reflectance ratios of 400-428 nm, 520-703 nm and 739-924 nm wavelength correlated strongly with K content in oil palm leaves.

With these reflectance ratios, vegetation indices that best describes crop nutritional status can be determined. Despite the abundance of studies on vegetation indices, an improvement of K-specific indices and its efficiency have not been a major focus of researchers in the past. This work was aimed at evaluating how vegetation indices correspond to different K rates in pineapple. Moreover, pineapple variety MD2 is a new hybrid which may not be suited to local peat soil and its response to fertilizer input could be different from that of other varieties. Hence, this work has the potential to improve fertilizer recommendation by optimizing K use in pineapple cultivation. This is timely give the ever increasing cost of K fertilizer.

Materials and Methods

Experimental

The work was conducted at an open farm space within Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The area has a relative humidity ranging from 73 to 81% and a mean temperature of up to 27˚C from October, 2014 to January, 2015. All suckers of MD2 variety were pre-treated with fungicide before being potted on raised beds in double row, spaced at 0.6 x 0.6 m on the bed and 0.9 m apart within row in a randomized complete block design. Four different levels of K were applied as Muriate of Potash (60% K). Treatments comprised the following: K0 (control with no fertilizer), K1 (256 kg ha^{-1}), K2 (366 kg ha^{-1}) and K3 (476 kg ha^{-1}). Fertilizer K was applied in three splits at 3-, 5- and 8-month after planting. Other nutrients were applied adequately for all pots either via broadcast (Nitrogen = 110 kg ha^{-1}, Phosphorus = 50 kg ha^{-1}).

Canopy Reflectance Measurement and Leaf K Determination

Plant canopy reflectance was measured once every week for a period of one month after the second and third fertilizer applications. A handheld spectroradiometer (Field Spec Pro; Analytical Spectral Devices, Boulder, Co, USA) was used to take spectral measurements at a height of 50 cm above plant canopy and 25˚ field of view under favorable weather conditions between 11.00 and 14.00 local time in Malaysia. Every ten reflectance measurements were averaged and recorded as the value of reflectance per plant. At the same time, the instrument was calibrated against a reference panel alternately using a white spectralon board mounted on a tripod. Spectral readings were processed using ViewSpec™ and transferred to MS Excel for computation of six vegetation indices (formula summarized in Table 1). Following spectral measurements, three longest leaves or the D-leaves of the same plant for each treatment were sampled and brought to the laboratory for analysis. All samples were oven dried at 70˚C until the constant weights were obtained before determining dry weights. Then K was extracted from the tissues using the dry ash method and K concentration via atomic absorption spectrophotometry. All data were subjected to analysis of variance and Duncan's multiple range test. Normality of the distribution of standardized residuals for each variable was tested using Shapiro-Wilk test at the 0.05 level of significance.

Table 1: Spectral indices used in this study

Abbreviation	Index	Formulae	Reference
NPCI	Normalized Pigment Chlorophyll Ratio Index	(R680-R430)/(R680+R430)	Peñuelas et al.(1994)
NDVI	Normalized Difference Vegetation Index	(RNIR− RR)/(RNIR + RR), RNIR indicates 775–825 nm, RR indicates 650–700 nm	Rouse et al. (1973)
NBNDVI	Narrow-band Normalized Difference Vegetation Index	(R850− R680)/(R850 + R680)	Thenkabil et al. (2000)
PSRI	Plant Senescence Reflectance Index	(R680-R500)/R750	Merzlyak et al. (1999)
RVSI	Red-edge Vegetation Stress Index	[(R712+R752)/2]-R732	Merton and Huntington (1999)
NDRE	Normalized Difference Red Edge Index	(R790-R720)/(R790+R720)	Barnes et al. (2000)

Results and Discussion

The mean total K in pineapple leaves were compared across all treatments (Table 2). Results indicated that K concentration in pineapple leaves was significantly different at all three sampling dates ranging from 120 to 254 days after planting (DAP), with slight variation found in the K rates. K2 or the recommended rate by the plantation was found to be the optimum, and was easily differentiated from the rest. Among the six vegetation indices evaluated in this study, three indices were found to be the best for discrimination of K rates (Table 4). The three best indices were Normalized Pigment Chlorophyll Ratio Index (NPCI), Plant Senescence Reflectance Index (PSRI) and Red-edge Vegetation Stress Index (RVSI). Descriptive statistics of these indices are given in Table 3.

Table 2: Treatment effects on leaf total K

Treatment	First Sampling (120 DAP)	Second Sampling (233 DAP)	Third Sampling (254 DAP)
K0	0.63^{c}	0.63^{c}	0.62^{c}
K1	0.87^{b}	0.85^{b}	0.71^{c}
K2	1.45^{a}	1.45^{a}	1.37^{a}
K3	0.89^{b}	0.91^{b}	0.89^{b}

*Values followed by the same letters in the same column are not significantly different at p=0.05

Table 3: Descriptive statistics for the three best spectral indices at different growth stages

Date	**DAP**	**Min**	**Max**	**Mean**	**Std Error**	**CV (%)**
Normalized Pigment Chlorophyll Ratio Index (NPCI)						
14/1/2015	143	0.116	0.244	0.163	0.010	25
28/1/2014	157	0.108	0.306	0.214	0.010	27
4/2/2015	164	0.023	0.191	0.096	0.013	54
11/2/2015	171	0.065	0.351	0.182	0.018	40
18/2/2015	178	0.003	0.294	0.108	0.021	79
14/4/2015	233	0.004	0.207	0.071	0.015	84
28/4/2015	247	0.025	0.264	0.134	0.018	54
5/5/2015	254	0.016	0.195	0.069	0.013	75
Plant Senescence Reflectance Index (PSRI)						
14/1/2015	143	0.007	0.020	0.014	0.001	26
28/1/2015	157	0.040	0.075	0.061	0.002	14
4/2/2015	164	0.001	0.012	0.005	0.001	66
11/2/2015	171	0.003	0.037	0.017	0.002	56
18/2/2015	178	0.002	0.030	0.015	0.002	61
14/4/2015	233	0.0003	0.024	0.010	0.002	77
28/4/2015	247	0.004	0.034	0.013	0.002	61
5/5/2015	254	0.001	0.016	0.007	0.001	75

Table 3, con’t

Red-edge Vegetation Stress Index (RVSI)					
14/1/2015	143	-0.038	-0.021	-0.030	0.001	20
28/1/2015	157	-0.205	-0.116	-0.157	0.005	13
4/2/2015	164	-0.051	-0.028	-0.041	0.001	14
11/2/2015	171	-0.101	-0.007	-0.034	0.008	35
18/2/2015	178	-0.047	-0.023	-0.029	0.002	22
14/4/2015	233	-0.040	-0.019	-0.030	0.001	19
28/4/2015	247	-0.043	-0.009	-0.032	0.002	28
5/5/2015	254	-0.049	-0.028	-0.037	0.001	14

From Table 4, it is clear that the performance of vegetation indices were influenced by crop growth stage. Maximum differences in reflectance due to varied degree of K stress were observed at 157, 171 and 247 DAP for the three best indices mentioned above. The spectral range of 430-680 nm, as well as 680-752 nm showed the largest difference in crop response to K rates. Thus, these ranges are suitable in quantifying K stress in pineapple. The mean canopy reflectance of pineapple at 171 DAP was examined for reflectance patterns corresponding to different K treatments. Figure 1 shows the typical spectral reflectance of pineapple in response to K treatments, with striking similarity to that of N treatment effects (data not included in this paper). The reflectance is generally low in the visible spectrum, while K1 and K0 showed a much higher reflectance than the other two treatments. The reflectance started to rise rapidly in the near infrared region (700-1000 nm).

Table 4: Spectral vegetation indices across different treatments at different crop growth stages

	Growth Stage (DAP)							
Treatment	143	157	164	171	178	233	247	254
Normalized Pigment Chlorophyll Ratio Index (NPCI)								
K0	0.177^{ab}	0.134^{c}	0.037^{d}	0.118^{c}	0.014^{c}	0.013^{b}	0.040^{c}	0.042^{a}
K1	0.134^{b}	0.207^{b}	0.070^{c}	0.142^{bc}	0.076^{b}	0.039^{bc}	0.114^{b}	0.054^{a}
K2	0.197^{a}	0.253^{ab}	0.112^{b}	0.181^{b}	0.110^{b}	0.083^{b}	0.170^{a}	0.071^{a}
K3	0.144^{b}	0.261^{a}	0.165^{a}	0.285^{a}	0.231^{a}	0.149^{a}	0.214^{a}	0.107^{a}
Plant Senescence Reflectance Index (PSRI)								
K0	0.009^{d}	0.051^{c}	0.002^{b}	0.006^{c}	0.004^{c}	0.004^{b}	0.008^{b}	0.003^{a}
K1	0.012^{c}	0.059^{bc}	0.003^{b}	0.015^{b}	0.013^{b}	0.009^{ab}	0.011^{ab}	0.009^{a}
K2	0.018^{a}	0.071^{a}	0.006^{a}	0.028^{a}	0.025^{a}	0.018^{a}	0.012^{ab}	0.007^{a}
K3	0.015^{b}	0.064^{ab}	0.008^{a}	0.017^{b}	0.018^{ab}	0.010^{ab}	0.021^{a}	0.009^{a}
Narrow Band Normalized Difference Vegetation Index (NBNDVI)								
K0	0.872^{a}	0.688^{a}	0.869^{b}	0.773^{a}	0.845^{a}	0.853^{a}	0.850^{b}	0.902^{a}
K1	0.870^{a}	0.679^{a}	0.894^{a}	0.800^{a}	0.886^{a}	0.884^{a}	0.887^{a}	0.867^{a}
K2	0.880^{a}	0.777^{a}	0.896^{a}	0.802^{a}	0.872^{a}	0.880^{a}	0.890^{a}	0.884^{a}
K3	0.876^{a}	0.752^{a}	0.890^{ab}	0.788^{a}	0.891^{a}	0.892^{a}	0.895^{a}	0.869^{a}
Red-edge Vegetation Stress Index (RVSI)								
K0	-0.024^{a}	-0.135^{a}	-0.045^{b}	-0.052^{a}	-0.025^{a}	-0.036^{b}	-0.040^{b}	-0.033^{a}
K1	-0.026^{a}	-0.152^{ab}	-0.036^{a}	-0.030^{a}	-0.026^{a}	-0.028^{a}	-0.031^{ab}	-0.038^{a}
K2	-0.035^{b}	-0.174^{b}	-0.045^{ab}	-0.041^{a}	-0.035^{b}	-0.030^{ab}	-0.032^{ab}	-0.035^{a}
K3	-0.034^{b}	-0.165^{b}	-0.038^{ab}	-0.014^{a}	-0.032^{ab}	-0.027^{a}	-0.026^{a}	-0.040^{a}
Normalized Difference Vegetation Index (NDVI)								
K0	0.876^{a}	0.704^{a}	0.873^{b}	0.823^{a}	0.850^{a}	0.855^{a}	0.858^{b}	0.906^{a}
K1	0.874^{a}	0.695^{a}	0.899^{a}	0.844^{a}	0.892^{a}	0.886^{a}	0.895^{a}	0.871^{a}
K2	0.883^{a}	0.792^{a}	0.900^{a}	0.847^{a}	0.877^{a}	0.882^{a}	0.897^{a}	0.887^{a}
K3	0.879^{a}	0.767^{a}	0.893^{ab}	0.837^{a}	0.894^{a}	0.893^{a}	0.901^{a}	0.873^{a}
Normalized Difference Red Edge Index (NDRE)								
K0	0.225^{b}	0.097^{b}	0.232^{b}	0.292^{b}	0.221^{b}	0.229^{b}	0.221^{b}	0.325^{a}
K1	0.301^{a}	0.154^{a}	0.308^{a}	0.389^{a}	0.335^{a}	0.339^{a}	0.339^{a}	0.271^{a}
K2	0.280^{a}	0.185^{a}	0.336^{a}	0.365^{a}	0.297^{a}	0.320^{a}	0.328^{a}	0.291^{a}
K3	0.314^{a}	0.176^{a}	0.343^{a}	0.379^{a}	0.328^{a}	0.339^{a}	0.342^{a}	0.197^{b}

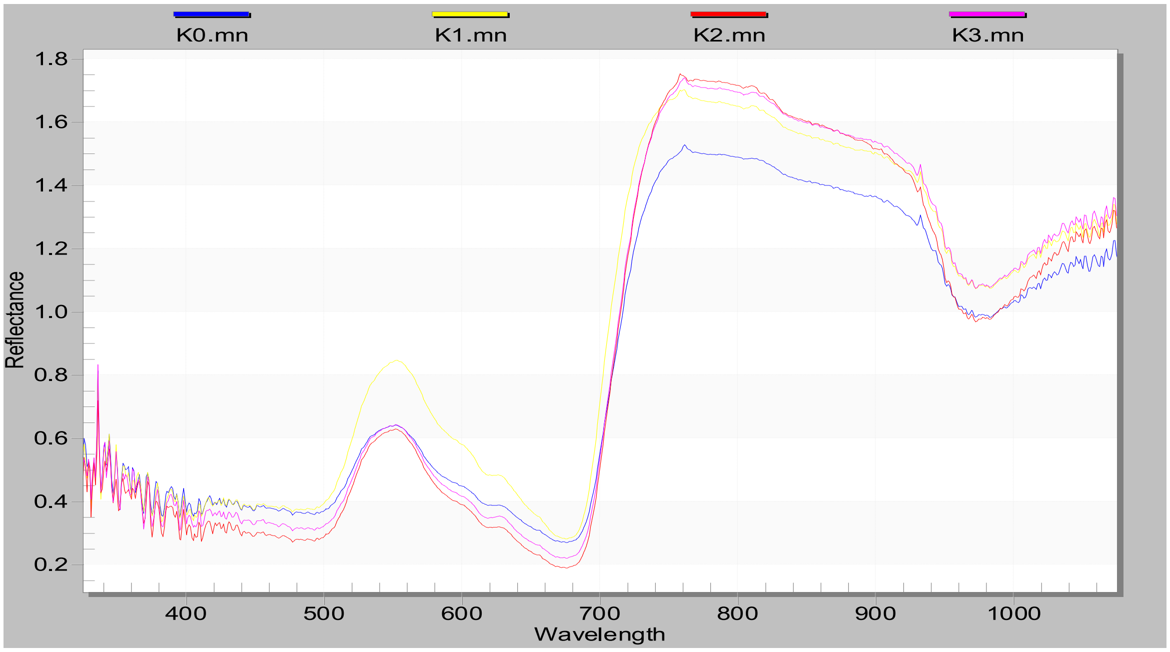

Figure 1: Canopy reflectance of pineapple under four rates of K at 171 days after planting

Conclusion

This work showed that K sufficiency/deficiency in pineapple can be effectively determined based on crop spectral response. Crop biophysical changes in response to different K rates were captured in the hyperspectral reflectance data. K deficiency with the highest variation was found at 171 DAP. Lack of K also showed a shift in the red edge towards shorter wavelengths between 500-700 nm. In addition, spectral range of 430-680 nm, as well as 680-752 nm were found to be most effective in differentiating spectral response of varying K rates. By identifying these wavelengths, three vegetation indices including Normalized Pigment Chlorophyll Index (NPCI), Plant Senescence Index (PSRI) and Red-edge Vegetation Index (RVSI) were found to be the best in describing K treatment effects on crop canopy reflectance. This study could be extended further to include pineapple varieties other than MD2, and also key nutrients, such as N and P, for better fertilizer management in peat-grown pineapple.

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