UNIVERSITI PUTRA MALAYSIA

SPECTRAL APPROACHES TO NUTRIENT STRESS DETECTION IN PINEAPPLE CULTIVATION ON A TROPICAL PEAT SOIL

CHONG YEN MEE

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By

CHONG YEN MEE

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SPECTRAL APPROACHES TO NUTRIENT STRESS DETECTION IN PINEAPPLE CULTIVATION ON A TROPICAL PEAT SOIL

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CHONG YEN MEE

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Chairman: Associate professor Siva Kumar Balasundram, PhD
Faculty: Agriculture

Pineapple in Malaysia is largely cultivated on peat which has resulted in problems including poor drainage, low fertility, subsidence and irreversible drying which rarely occurred on mineral soil. Hence, replenishment of nutrients and organic matter to soil through rational fertiliser application is part of the precision agriculture practices to enhance soil quality and crop productivity. To further avoid excessive application of fertilisers, a study was conducted to measure the reflectance changes of nutrient stress induced by nitrogen (N) and potassium (K) deficiencies, using a spectroradiometer. While other parameters such as growth measurement including height, leaf width and leaf number were made at 45, 135 and 225 days after planting, alongside with leaf nitrogen content measurement with hand-held Minolta SPAD-502 chlorophyll meter. Four different levels of nitrogen and potassium were applied to the pot as Urea (46 % N) and Muriate of Potash (60 % K_2O) respectively. All suckers of MD2 variety were pre-treated with fungicide before potted on raised beds in double row, spaced 0.6 m x 0.6 m on the bed and 0.9 m apart within row in a randomised complete block design. The fertilisers were applied at three split periods of 3-, 5- and 8-month after planting [N0 (control with no fertiliser added); N1 (369 kg/ha); N2 (528 kg/ha); N3 (686 kg/ha); K0 (control with no fertiliser added); K1 (256 kg/ha); K2 (366 kg/ha); K3 (476 kg/ha). Other fertilisers were applied equally for all pots either *via* broadcast or micronutrient fertiliser spray. In this study, several published indices were used to evaluate their capabilities to quantify leaf N concentration of pineapple grown under four contrasting levels of N & K. Results showed that different vegetation indices were found most useful depending on crop phenology. The three indices, the Narrow Band Normalised Difference Vegetation Index (NBNDVI), Greenness Index (GI) and Nitrogen Reflectance Index (NRI) performed better at differentiating N rates from mid to advanced growth stages. While the Normalised Difference Red Edge Index (NDRE) performed equally well but at more advanced growth stage and the Normalised Difference Vegetation Index (NDVI) was the least performing index with greater sensitivity to N stress in young plant rendering it

ineffective in present study focusing on mid to advance growth stages of pineapple. On the other hand, K deficiency tested reported three out of six indices evaluated in this study to be effective at differentiating K rates across varying growth stages. The Normalised Pigment Chlorophyll Index (NPCI) and Plant Senescence Reflectance Index (PSRI) were found to be useful throughout the entire study period, while the Red Edge Vegetation Stress Index (RVSI) only showed minimal differences between K rates. The other three indices including NDRE, NDVI and NBNDVI were found to be ineffective in K study. Additionally, canopy reflectance of K-deficient pineapple also exhibited a shift of red edge towards shorter wavelengths of 500-700 nm as often observed in the absence of N. The results ascertained that canopy and leaf reflectance changes are important indicators of fertiliser application. The changes of canopy and leaf reflectance may show whether the plant has received sufficient nutrients, so that fertiliser can be applied at appropriate amount without being wasted.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENDEKATAN SPEKTRA DALAM MENGESAN TEKANAN NUTRIEN DI PENANAMAN NANAS ATAS TANAH GAMBUT

Oleh

CHONG YEN MEE

November 2017

Pengerusi: Profesor Madya Siva Kumar Balasundram, PhD
Fakulti: Pertanian

Sebahagian besar nanas di Malaysia ditanam di tanah gambut dan bukannya tanah mineral seperti mana di negara-negara pengeluar yang lain di rantau Asia Tenggara. Penanaman nanas di tanah gambut telah mendatangkan masalah termasuklah saliran miskin, kesuburan tanah yang rendah, penenggelaman serta pengeringan tidak berbalik yang jarang berlaku di atas tanah mineral. Oleh itu, penggantian semula nutrien dan bahan organik ke tanah melalui penggunaan baja yang rasional, adalah sebahagian daripada amalan ketepatan pertanian (*precision agriculture*) demi meningkatkan kualiti tanah dan produktiviti tanaman. Bagi mengelakkan penggunaan baja yang berlebihan, satu kajian mengaplikasi spektoradiometer telah dijalankan untuk mengukur perubahan pantulan tekanan nutrien akibat kekurangan nitrogen (N) dan kalium (K). Walaupun parameter lain seperti ukuran pertumbuhan, termasuklah ketinggian, kelebaran daun dan bilangan daun akan diambil pada 45, 135 dan 225 hari selepas penanaman, berserta ukuran kandungan nitrogen daun menggunakan SPAD-502 Minolta meter. Empat tahap nitrogen dan kalium telah dibubuh pada pot sebagai urea (46 % N) dan muriate of potash (60 % K). Kesemua tunas nanas varieti MD2 dirawat dengan racun kulat sebelum ditanam atas tapak bertimbun dalam dua barisan, berjarak 0.6 m x 0.6 m atas tapak, dan 0.9 m dalam barisan berbentuk blok rawak lengkap. Baja-baja dibubuh mengikut tiga tempoh berasingan pada 3-, 5- dan 8-bulan selepas penanaman [N0 (kawalan tanpa baja); N1 (369 kg/ha); N2 (528 kg/ha); N3 (686 kg/ha); K0 (kawalan tanpa baja); K1 (256 kg/ha); K2 (366 kg/ha); K3 (476 kg/ha)]. Baja lain turut dibubuh sama rata melalui semburan mikronutrien. Dalam kajian ini, beberapa indeks yang telah diterbitkan dinilai keupayaan mereka dalam mengukur kepekatan nitrogen daun nanas bawah empat rawatan N dan K. Keputusan mendapati indeks tumbuhan yang berlainan berguna bergantung pada fenologi tumbuhan. Ketiga-tiga indeks, Indeks Perbezaan Band Terpilih Vegetasi (NBNDVI), Indeks Kehijauan (GI) dan Indeks Refleksi Nitrogen (NRI) didapati berkesan dalam membezakan kadar N dari peringkat pertengahan hingga peringkat matang pertumbuhan. Walaupun Indeks Perbezaan Red Edge Vegetasi (NDRE)

berprestasi baik, namun hanya terhad kepada peringkat matang pertumbuhan. Manakala Indeks Perbezaan Vegetasi (NDVI) adalah indeks yang berprestasi kurang memuaskan dengan kepekaan yang lebih tinggi terhadap tekanan nutrien nitrogen pada peringkat pertumbuhan muda. Ini menyebabkan ia kurang berguna dalam kajian ini yang bertumpu pada peringkat pertengahan ke matang pertumbuhan nanas. Sebaliknya, kekurangan K yang diuji mendapati tiga daripada enam indeks berguna dalam membezakan kadar K sepanjang peringkat pertumbuhan. Indeks Nisbah Pewarnaan Klorofil (NPCI) dan Indeks Refleksi Penderiaan Tanaman (PSRI) didapati berguna sepanjang tempoh kajian. Manakala Indeks Tekanan Vegetasi (RVSI) hanya menunjukkan perbezaan yang sedikit antara kadar K. Tiga indeks lain termasuklah NDRE, NDVI dan NBNDVI, didapati tidak berkesan dalam kajian atas K. Selain itu, pantulan kanopi nanas bawah tekanan nutrient K juga memaparkan pergeseran red edge ke arah gelombang lebih pendek dalam lingkungan 500-700 nm, sebagaimana yang dilihat semasa tanpa N. Hasil kajian membuktikan bahawa perubahan pantulan kanopi dan daun adalah indikator penting dalam aplikasi baja. Perubahan pantulan kanopi dan daun akan menentukan sama ada tumbuhan menerima nutrien yang mencukupi, supaya baja dapat dibubuh pada kadar yang sesuai dengan tidak mensia-siakan.

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I certify that a Thesis Examination Committee has met on 20 November 2017 to conduct the final examination of Chong Yen Mee on her thesis entitled "Spectral Approaches to Nutrient Stress Detection in Pineapple Cultivation on a Tropical Peat Soil" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Mohamed Hanafi bin Musa, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Osumanu Haruna Ahmed, PhD
Professor
Faculty of Agriculture and Food Science (Bintulu Campus)
Universiti Putra Malaysia
(Internal Examiner)

Mohamadu Boyie Jalloh, PhD
Senior Lecturer
Universiti Malaysia Sabah
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 29 January 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Siva Kumar Balasundram, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Ahmad Husni Mohd Haniff, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

____
(ROBIAH BINTI YUNUS, PhD)
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature:	
Name of Chairman of Supervisory Committee:	Associate professor Dr. Siva Kumar Balasundram

Signature:	
Name of Member of Supervisory Committee:	Associate professor Dr. Ahmad Husni Mohd Haniff

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CHAPTER 1

INTRODUCTION

In recent years, there has been an increasing interest in understanding fertiliser management in relation to crop nutrient needs. Established crops are confined to a particular compound and therefore are dependent upon the characteristics of the environment they occupy. These environmental characteristics such as temperature, moisture and soil quality are known to play important roles in crop growth and reproduction. However, unsustainable agricultural practices and intensive cropping have resulted in rapid nutrient washout which render the soil infertile for crop (Mafongoya et al., 2006). This has eventually affected crop performance with problems like stunted growth, reduced shoots and roots growth depending on the severity of deficiency (Hawkesford et al., 2012).

In view of all that have been mentioned so far, it seemed that replenishment of nutrients and organic matter to soil through rational fertiliser application is a good precision agriculture practice in enhancing soil quality and crop productivity. Environmental pollution resulted from excessive fertiliser inputs is fast becoming a great concern where nutrient applied above the crop requirement often leached through soil and contaminate ground water (Zhao et al., 2006). Recently it has been found that excessive inorganic fertiliser especially that of nitrogen (N) will lead to higher emission of greenhouse gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2) across different agricultural systems (Wang et al., 2011; Linquist et al., 2012).

Considering the fact that crop is generally sensitive to changes of the surrounding environment especially stress imposed upon them due to unfavourable condition, it is paramount to monitor crop nutritional status on real time basis so that fertilisation regime can be adjusted accordingly. Traditionally, time-consuming and expensive laboratory analyses as well as detailed sampling have dominated the market. Recent development of science and technology especially in the field of remote sensing has brought upon the improved and more up-to-date remote sensing tools which are found to be both economically and environmentally feasible at large scale. These remote sensing tools are proven effective in assessing crop biochemical properties changes triggered by stressors like pest and disease, water deficit and nutrient scarcity. In this respect, spectral parameters including leaf pigment content, water status, leaf area index (LAI) are often gauged as useful indicators of crop stress physiology.

Studies of nutritional status of crop revealed how the interactions of different environmental factors contributing to the alteration of the plant features. It is recalled that crop responds to environmental changes through structural modifications especially that of architecture and morphology for continued survival. These long-term adaptation responses usually manifest in the alterations of leaf size, number and thickness, as well as development of special features like extended root system and modified architecture for better access to limited nutrients and water in soil (Hiradate et al., 2007). However, these internal metabolic and growth responses are unable to provide ultimate protection and adverse effects caused by the constraints especially concerning vegetative growth and yield are common in plant.

From these perspectives, it is noted that while there have been many studies done on crop nutritional status and effects on crops, few have explored the crop nutrient demand at different growth stage. This information is crucial as it can be related to nutrient application in field and also its associated crop yield. In addition to common spectral tools such as SPAD meter, extensive research using more advanced remote sensing techniques such as hyperspectral sensor Spectroradiometer also needs to be conducted in gathering more details of the plant functional properties alterations to better address the nutrient deficiency problem in plant.

Fertiliser management remains one of the greatest challenges in maintaining crop production in agriculture. The common perception is that increased fertiliser input always results in higher crop yield, and that explains why farmers are willing to spend more on fertilisation and even ignore the risk of polluting the environment. However, studies showed that crop nutrient uptake relied very much on crop nutrient demand which vary across crop types and soil medium. Under this context, nutrient use efficiency of potassium (K) in pineapple cultivated on peat soil is low due to the nutrient rapid leaching in low clay and mineral content condition (Ahmed et al., 2005). On the other hand, nitrogen (N) content in peat is abundant but its uptake in pineapple depends on a range of factors including temperature, moisture and C/N ratio. This concurred with some findings that suggested recovery of N for most crops ranged from 40-60 % and a lot more are lost through leaching and volatilisation (Aulakh and Malhi, 2005).

Similar study on Oil Palm found a leaching loss of 1 to 1.6 % of N fertiliser applied to Oil Palm and a higher rate of K loss between 2.4 and 5.3 % at variable fertiliser application rate and may associate with factors including crop age, soil type and rainfall intensity. The uncertain amount of available N in peat has resulted in additional input of N applied to pineapple through fertilisation (Comte et al., 2012). Further to that findings, it is suggested that N Use Efficiency also correlates with crop nutritional status as well as the amount of N applied; where nitrogen uptake was slow in well-nourished crop and was more rapid in nitrogen-deficient crop. Conversely, K-deficient Olive plant was less ready in taking up K fertiliser applied (Fernández-Escobar et al., 2014). Besides, some findings suggested that crop nutrient needs change at different growth stages. In this case, nutrient use efficiency is closely linked to its growth capacity which deals directly with crop management practice, site-specific spatial variability and its genetic potential (Lemaire and Gastal, 2009). Therefore, it is now time to utilise remote sensing technique for continuous monitoring of the pineapple nutrient status across different growth periods to determine the crucial timing for nutrient application over different nutrient requirement in crop. Such move will minimise fertiliser input while maintaining pineapple yield at economic cost in the long run.

Pineapple (*Ananas comosus* L.) is largely cultivated on peat soil in Malaysia. This has resulted in restrained production of pineapple in the country as we faced several problems associated with peat soil characteristics such as poor drainage, low fertility and irreversibly drying (Ahmed et al., 2005). Other producer countries of the Southeast Asian regions can easily produce pineapple in bulk without these obstacles as the cultivation is all done on mineral soil. As reported by online statistics of Malaysian Pineapple Industry Board (MPIB), Malaysia ranked four in pineapple production right after Thailand, the Philippines and Indonesia (Ahmed et al., 2013). However, we are still able to improve our pineapple production through better crop management especially fertilisation in the plantation. This is in line with Malaysia's target of expanding the current 15,000 hectare of areas planted with pineapples to 24,000 hectare by year 2020. The move is expected to export Malaysian pineapple on a large scale to meet the demands in China as stated in an agreement signed by both countries in year 2013 (Zazali, 2014).

It is hoped that with better understanding of pineapple nutrient demand especially of nitrogen and potassium, we are then able to adjust fertilisation input in a manner that maximizes our pineapple growth potential as well as its yield and quality. Under this context, this study aims to determine spectral reflectance changes in the visible (380-720 nm) and infrared range (720-1500 nm) at different leaf N and K levels, and then develop spectral indices that indicate pineapple nutritional status along the growth cycle and ensure efficiency recovery of fertiliser applied in the pineapple field.

The current study undertaken with the objectives of studying leaf reflectance in response to four different leaf nitrogen (N) and potassium (K) levels ranged from 0 to 250 kg/ha across three planting ages of 3-, 5- and 8-month for pineapple (*Ananas comosus*) in pots. In doing so, spectral reflectance of healthy and nutrient-deficient plant are compared for pot trial following fertilisation scheme of local plantation estate, and subsequently validated in field. Furthermore, spectral indices corresponding to leaf N and K sufficiency as well as deficiency are also developed. The remote sensing tools utilised in developing the spectral indices for the assessment are Spectroradiometer and Greenseeker.

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