UNIVERSITI PUTRA MALAYSIA

SPATIAL DISTRIBUTION OF SOIL NITROGEN, PHOSPHORUS AND POTASSIUM IN BLACK PEPPER CULTIVATION IN SARAWAK, MALAYSIA

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By

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April 2018

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Black pepper in Sarawak is cultivated on hilly topography due to natural land formation which provide good water drainage. Nitrogen, phosphorus and potassium are mostly insufficient due to nutrients loss subsequent to leaching and surface runoff. A study combining the use of global positioning system (GPS) and geographic information system (GIS) was conducted in selected black pepper farm in Bintulu (NL and SM), Kapit (SA), Sri Aman (AM), Serian (SR) and Kuching (BA and SK), Sarawak with the intention to determine soil physicochemical, conceivable correlation and spatial distribution using ordinary Kriging interpolation method to scrutinise distribution of N, P and K in various topography and farm background. A total of 416 soil samples were analysed for organic carbon, soil texture, soil pH, total N, available P, K, Ca, Mg, Fe and Mn. It was found that all soils was dominant rocks of sandstone, shales, limestone and alluvium. Generally, OC (2.02 to 5.04%) increased from Kuching <Serian <Sri Aman <Kapit <Bintulu and the soil pH was considered to be extremely acid to very strongly acidic. The availability of Fe was higher in NL (6×10^{-2} to 3.4×10^{-1} g kg^{-1}) when compared to six other farms. Ultimately, P (5×10^{-6} to 7×10^{-3} g kg^{-1}) and K (3×10^{-2} to 1.1×10^{-1} g kg^{-1}) availability were been found to be strongly affected by high Fe concentration as compared to N. Lack of P explained by the formation of Fe-P complexes while K could have been leached out and replaced by Fe^{3+} which is very common in many tropical soils. The relationship between soil properties showed a positive correlation between OC with Mn, N, P, K, Ca and Mg which indicated an upsurge in the soil properties. Presence of OC as a soluble chelating agent, retained nutrients in the soil system. The negative correlation between soil pH against Fe, P, K, Ca and Mg have caused leaching out of cations in following order K >Ca >Mg and replaced by Fe. The spatial correlation of N, P and K for seven farms were modelled through isotropic which indicated linear, spherical, exponential and Gaussian. This prediction was acceptable with lower value obtained through leave-one-out validation method that provides mean error (-0.0329 to 0.0052) close to zero and unbiased prediction. Ordinary Kriging interpolation mapped showed the distribution of N to be affected by topography, soil texture and OC. As for P and K, the distribution was affected by Fe fixation, fertilizer application technique and soil acidity. Availability of N, P and K in those farms can be improved through annual lime application, mulching and growing of cover crops around black pepper poles which are seldom practised due to production cost and low awareness among farmers. It can be concluded that the availability of N, P and K in the research areas were affected by various factors such as soil mineralogy, topography, improper soil and land management (i.e. bare soil, absence of terracing and insufficient application of lime).

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

TABURAN RUANGAN NITROGEN, FOSFORUS DAN KALIUM DALAM TANAH DALAM PENANAMAN LADA HITAM DI SARAWAK, MALAYSIA

Oleh

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Lada hitam ditanam di Sarawak pada topografi berbukit kerana pembentukkan tanah secara semulajadi yang menyediakan saliran air yang baik. Nitrogen, fosforus dan kalium selalunya rendah akibat kehilangan nutrien oleh larut lesap dan larian permukaan. Satu penyelidikan menggabungkan penggunaan sistem kedudukan sejagat (GPS) dan sistem maklumat geografi (GIS) dijalankan di kawasan ladang lada hitam terpilih di Bintulu (NL dan SM), Kapit (SA), Sri Aman (AM), Serian (SR) dan Kuching (BA dan SK), Sarawak dengan tujuan untuk menentukan fisiokimia tanah, korelasi yang mungkin dan taburan ruangan menggunakan kaedah interpolasi Kriging biasa untuk meneliti taburan N, P dan K pada pelbagai topografi dan latar belakang kawasan. Sejumlah 416 sampel tanah digunakan untuk analisis karbon organik, tekstur tanah, pH tanah, jumlah N, ketersediaan P, K, Ca, Mg, Fe dan Mn. Didapati semua tanah adalah batuan dominan batu pasir, syal, batu kapur dan alluvium. Umumnya, OC (2.02 to 5.04%) meningkat dari Kuching <Serian <Sri Aman <Kapit <Bintulu dan pH tanah dianggap teramat berasid ke sangat berasid. Ketersediaan Fe adalah lebih tinggi di NL (6 X 10^{-2} to 3.4 X 10^{-1} g kg^{-1}) dibandingkan dengan enam ladang yang lain. Pada akhirnya, ketersediaan P (5 X 10^{-6} to 7 X 10^{-3} g kg^{-1}) dan K (3 X 10^{-2} to 1.1 X 10^{-1} g kg^{-1}) adalah dipengaruhi oleh kandungan Fe yang tinggi berbanding dengan N. Kekurangan P dijelaskan melalui pembentukkan Fe-P yang kompleks manakala K berkemungkinan larut lesap dan diganti oleh Fe^{3+} yang biasa berlaku di kebanyakkan tanah tropika. Hubungan di antara sifat tanah menunjukkan kolerasi positif di antara OC dengan Mn, N, P, K, Ca dan Mg yang menunjukkan kenaikan mendadak sifat tanah. Kehadiran OC sebagai pelarut agen kelat, menyimpan nutrien di dalam sistem tanah. Kolerasi negatif di antara pH tanah terhadap Fe, P, K, Ca dan Mg telah mengakibatkan larut lesap kation mengikut order K >Ca >Mg dan diganti oleh Fe. Sekaitan ruang N, P dan K untuk tujuh ladang telah dimodelkan secara isotropi yang mana menunjukkan linear, sfera, eskponen dan Gaussan. Ramalan ini diterima dengan nilai rendah yang diperolehi melalui kaedah pengesahan tinggal-satu-keluar yang memberikan min ralat (-0.0329 to 0.0052) menghampiri kosong dan ramalan saksama. Interpolasi Kriging biasa dipeta menunjukkan taburan N dipengaruhi oleh topografi, tekstur tanah dan OC. Untuk P dan K, taburan adalah bergantung kepada pengikatan Fe,

teknik pembajaan dan keasidan tanah. Ketersediaan N, P dan K di Kawasan ladang tersebut boleh diperbaiki secara pengapuran tahunan, sungkupan dan penanaman penutup bumi di sekitar sokongan lada hitam yang jarang diamalkan kerana kos pengeluaran dan tahap kesedaran yang rendah dalam kalangan petani. Kesimpulannya, ketersediaan N, P dan K di dalam kawasan penyelidikan adalah dipengaruhi oleh banyak faktor seperti mineralogi tanah, topografi, pengurusan tanah dan kawasan yang tidak betul (tanih dedah, ketiadaan teres dan kekurangan penggunaan kapur).

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Last but not least, a postgraduate journey is not how fast we can finish the study, but how well we understand and value the knowledge and giving back to the society. Time is just a number, but the experience and knowledge is priceless.

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:

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Declaration by graduate student

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LIST OF ABBREVIATIONS

%	Percent
<	Less than
>	Greater than
AA3	AutoAnalyzer 3
AAS	Atomic absorption spectrometer
AE	Absolute error
AME	Absolute mean error
ANOVA	Analysis of variance
C/N	Carbon to nitrogen ratio
Ca/K	Calcium to potassium ratio
Ca/Mg	Calcium to magnesium ratio
CEC	Cation exchange capacity
CV	Coefficient of variation
GIS	Geographic information system
GPS	Global positioning system
IDW	Inverse distance weighting
K-S	Kolmogorov-smirnov test
LW	Lower
MD	Middle
ME	Mean error
MPB	Malaysian Pepper Board
n	Sample size
^{o}	Degree
^{o}C	Degree Celsius
OM	Organic matter
PA	Precision agriculture
P-P	Probability-probability plot
Q-Q	Quantile-quantile plot
RMSE	Root mean squared error
RMSS	Root mean square standardised
rpm	Revolutions per minute
RS	Remote sensing
TE	Trace element
UP	Upper

CHAPTER 1

INTRODUCTION

1.1 Research Background

Black pepper (*Piper nigrum* L.) berries are commonly used as food seasoning due to their pungent smell. Such superiority has impacted to the production of the berries and has augmented shift in the cultivation of the land, especially in Sarawak, East Malaysia. Sarawak recorded 16,093 ha of black pepper area in the year 2015 with a total production of 22,500 MT and the production has ascended to 23,000 MT in the year 2016 (Malaysian Pepper Board, 2017). Increment in the production is closely related to the black pepper farm areas where sufficient nutrient absorption can lead to an increased in yield. Sufficient nitrogen (N), phosphorus (P) and potassium (K) may provide high-quality berries and prolong of black pepper cultivation (Ann, 2012; Srinivasan *et al.*, 2007).

Macronutrients are crucial to support crop growth where N take part in the photosynthesis and formation of berries. Phosphorus is important in supporting root formation, especially in immature crop and K for fruit development (George *et al.*, 2005). In black pepper farm area, providing sufficient nutrients through fertilizer application is vital in sustaining the crop. Due to different soil mineralogy and topography, the amount of fertilizer varies slightly. In Sarawak, the fertilizer suggested for use is 12:12:17:2+TE (TE; trace element) during the immature phase (<24 months after planting) at the rate between 80 and 200 g/vine every two months (Paulus *et al.*, 2011). This amount can be twice to thrice the immature rate after reaching the matured phase with greater monthly rate. The greater amounts required during the matured phase have become a limiting factor to small-scale farmers as the cost for resources increased. Alternatively, farmers become solely depended on organic fertilizer to cover the increase in cost.

Application of fertilizer to the crop is done by adding fertilizer on soil surface or known as the broadcasting technique. This practice has been used immensely due to fast and non-labour intensive compared to other methods (e.g. strip fertilization). The practised may be inefficient to provide nutrients for the crop as it was subjected to various transportation leeway such as movement through leaching in the soil profile and runoff after rainfall (Peñuela *et al.*, 2015). These incidents have limited nutrient availability to the crop and massive deficiencies of the nutrients can be perceived across the farm with abnormality crop growth such as stunted, defoliation, infestation by small insect (e.g. ant) and look-alike disease symptom (e.g. leave shape of mosaic viruses). This limitation has impacted crop productivity which later caused enormous yield reduction and a short lifespan of the crop (Hamza *et al.*, 2014).

Ultimately, the fate of N, P and K become more erratic as it was also affected by other factors such as hilly topography and conservative farm management (e.g. improper land establishment). In hilly areas, a slope of more than 25^o inclined to suffer nutrient deficiencies (Peng and Wang, 2012). Minimal land establishment, for example direct planting black pepper cutting on bare soil surface will eventually affect soil fertility by increasing the tendency for soil erosion to occur that transfer top soil to a more stabilise area (e.g. downward, lower area or nearest river). Coarse soil texture becomes another factor holding and retaining nutrient ions (Tahir and Marschner, 2017). Amendments with organic matter can provide negative exchangeable site which hold the ion from the crops (Pal and Marschner, 2016). Good land conservation practices, for example, constructing terrace along the slope, intercropping with deep rooted crops to stabilise the soil structure, growing cover crop to protect soil surface and provide a drain for water movement after rainfall have become means to control the movement and retained the nutrient in soil colloids (Tanaka *et al.*, 2009). This has fastened nutrient movement and become unpredictable to sustain crop and soil fertility. Moreover, management of nutrients availability should be very specific to only the affected area and should be corrected to improve and increase crop growth.

Precision agriculture (PA) is widely implemented in the agricultural sector especially in major industrial crops such as oil palm and paddy in Malaysia (Chong *et al.*, 2017). The farm area can be easily managed due to site-specific indicators which provide better management than conventional methods. Conventional methods improve nutrient availability but also increase production cost with greater tendency to pollute the environment. Meanwhile, the use of PA can be an effective solution for black pepper farm area cultivated on hilly area through collection of global positioning system (GPS) data, sampling and analysis of nutrients (e.g. N, P and K) and integrated use of geographic information system (GIS) data through geospatial analysis (Mondo *et al.*, 2012). This may provide a baseline data on the availability of nutrient in the soil where areas with lesser, greater or moderate nutrient availability can be identified. Beside nutrient management, soil and crop management can be predicted accordingly and help in planning a way to improve soil fertility, land conservation and crop sustainability.

The availability of N, P and K can be interpolated by generating maps with different nutrient concentration to give detail information on each part of the farm area (Adekayode *et al.*, 2014). This can provide a better understanding on the distribution, movement and fate of the nutrients after application or during season changing (e.g. wet and dry season) especially in hilly topography. Intensive use of organic manure with greater concentration of iron (Fe) limit the availability of P and K by tightly bounding to P and replacing exchangeable site with trivalent cation which promotes leach out K (de Campos *et al.*, 2016; Uzoho *et al.*, 2016). Integrating use of GPS and GIS may help in decision making especially in directing which part of the farm area need more nutrient or management in term of correcting soil pH, improving nutrient retention by providing negative charge substance, improving water retention and avoiding waterlogged. Apparently, PA helps in managing the crop by providing what is necessary and avoiding excessive amount and reducing environmental problem, such as eutrophication caused by deposition of N and P into the river (Huang *et al.*, 2017; Nguyen and Marschner, 2013).

1.2 Objectives

The objectives of this research were to determine the:

i. Soil physicochemical properties of the black pepper farms in Bintulu, Kapit, Sri Aman, Serian and Kuching.
ii. Correlation of selected soil properties cultivated with black pepper cultivation.
iii. Spatial distribution of N, P and K through ordinary Kriging method.

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