UNIVERSITI PUTRA MALAYSIA

SPATIAL YIELD VARIATION AND SOIL N IN A MATURE OIL PALM PLANTATION : A CASE STUDY IN SABAH

TEE BEE HEOH

FP 2001 10

SPATIAL YIELD VARIATION AND SOIL N IN A MATURE OIL PALM PLANTATION: A CASE STUDY IN SABAH

TEE BEE HEOH

MASTER OF AGRICULTURAL SCIENCE
UNIVERSITI PUTRA MALAYSIA

2001

SPATIAL YIELD VARIATION AND SOIL N IN A MATURE OIL PALM PLANTATION: A CASE STUDY IN SABAH

By

TEE BEE HEOH

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Agricultural Science in the Faculty of Agriculture Universiti Putra Malaysia

May 2001

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Agricultural Science.

SPATIAL YIELD VARIATION AND SOIL N IN A MATURE OIL PALM PLANTATION: A CASE STUDY IN SABAH

By

TEE BEE HEOH

May 2001

Chairman : Dr. Anuar Abd. Rahim

Faculty : Agriculture

One of the major challenges in oil palm plantations in recent times is the lack of proper interpretation of yield maps for site-specific management, and the identification and understanding of the causal factors influencing the variability of oil palm yields. The ability to find and comprehend the soil factors influencing yield variabilities of oil palm will enable us to manage them more efficiently. A study was conducted in a mature oil palm plantation at Sri Kunak Estate, Tawau, Sabah, Malaysia with the objectives (i) to quantify and characterize the spatial and temporal yield variations of fresh fruit bunch (ffb) so as to determine the optimum management zones for oil palm plantations and create possible management zones for site-specific inputs (ii) to quantify and characterize the nature of spatial soil NH_4^+-N variation as influenced by long-term N fertilizer management (iii) to establish the inter-relationship between ffb yields and soil NH_4^+-N so as to develop optimum range of soil NH_4^+-N for optimum oil palm growth and production.

Two clusters of palms were selected; with and without N fertilizer applications for the past 10 years. Soil samples were analyzed for Total N, NH_4^+-N, NO_3^--N, exchangeable K, and pH. Fresh fruit bunch (ffb) yields were summarized on an annual basis. Relationship between ffb yields and selected soil properties were investigated using regression analysis. Response of ffb yields to soil NH_4^+-N was compared using 6 empirical fertilizer response models. Geostatistical analysis was used to characterize the spatial yield variations of ffb and soil NH_4^+-N.

Semivariance analysis revealed that within the plots, the increase in semivariance reached a peak at a range of about 2 to 3-palm distance, suggesting that the optimum management zone for oil palm plantations was 37 palms. Application of N could sustain ffb yields above 30 t ha^{-1} yr^{-1}. Long-term N fertilizer applications reduced the annual ffb yield fluctuations to between 35 and 45%.

The coefficient of variations (CVs) for both soil NH_4^+-N and NO_3^--N exceeded 30% even within each microsite of palm circle, interrow, frond heaps and harversters' path. Semivariance analysis revealed that the structure of variation of soil NH_4^+-N was controlled by the sampling design, experimental plot size, and previous planting practices. The maximum range of semivariance of soil NH_4^+-N was reached at 90 m and 10 m in area with and without N respectively, indicating that the application of N fertilizer induced its spatial variability in mature oil palm agroecosystem. The kriged soil map showed localized spots of high NH_4^+-N content, which corresponded to the palm circles where N fertilizer was applied. Long-term applications of N fertilizer caused significant movement of soil NH_4^+-

N, NO_3^--N, and exchangeable K to the lower soil depth, and decreased the soil pH to 3.7.

Approximately 64% of the yield variations of oil palm was explained by soil NH_4^+-N. The response of ffb yields in relation to soil NH_4^+-N was best described using the Linear-Plateau model followed by the Richards model. Maximum ffb yields predicted by the various models range between 250 kg palm^{-1} yr^{-1} for Linear-Plateau model and 258 kg palm^{-1} yr^{-1} for the square-root model. Four soil classes of deficiency, low, adequate, and high were delineated from the Linear-Plateau model for fertilizer recommendations as well as to monitor nutritional problems of oil palm. The model identified the adequate range of soil NH_4^+-N for optimum oil palm growth and production to be between 102 mg kg^{-1} and 130 mg kg^{-1}, with corresponding mean maximum annual ffb yield of 250 kg palm^{-1}. Nitrogen fertilizer is needed when a soil NH_4^+-N level is < 102 mg kg^{-1}. Consideration should be given to reduce fertilizer N applications when a soil NH_4^+-N level is > 130 mg kg^{-1}. The Linear-Plateau model was able to correctly diagnose 79% of the kriged cases.

The results demonstrate the potential of integrating spatial and temporal stability of ffb yields from multi-year yield data to classify management zones for site-specific oil palm management particularly for fertilizer application. Soil testing is a useful diagnostic tool for assessing N nutritional problems and N fertilizer recommendations of oil palm. Geostatistical analysis is useful to illustrate their spatial inter-relationship.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebegai memenuhi keperluan untuk ijazah Master Sains Pertanian.

VARIASI RUANG HASIL DAN N TANAH DI SEBUAH LADANG KELAPA SAWIT: SATU KAJIAN DI SABAH

Oleh

TEE BEE HEOH

Mei 2001

Pengerusi : Dr. Anuar Abd. Rahim

Fakulti : Pertanian

Salah satu cabaran tanaman kelapa sawit pada masa kini ialah kekurangan pengalaman untuk menafsirkan peta hasil untuk pengurusan secara ‘site-specific’, pengenalpastian dan pemahaman punca faktor yang mempengaruhi variasi hasil kelapa sawit. Satu kajian telah dijalankan di sebuah ladang kelapa sawit di estet Sri Kunak, Tawau, Sabah, Malaysia. Objektif kajian ini adalah untuk: (i) mengukur dan mencirikan variasi ruang dan ‘temporal’ bagi menentukan saiz pengurusan ladang yang optima untuk tanaman kelapa sawit, dan mengenalpasti zon pengurusan untuk input spesifik (ii) mengukur dan mencirikan variasi NH_4^+-N tanah akibat daripada pembajaan N yang berterusan (iii) menghubungkaitkan antara hasil kelapa sawit dengan kandungan NH_4^+-N tanah, menentu julat optimum kandungan NH_4^+-N tanah untuk tumbesaran dan pengeluaran optimum kelapa sawit.

Dua kumpulan pokok kelapa sawit dipilih untuk kajian ini, dengan pembajaan N, dan tanpa pembajaan N untuk 10 tahun yang lepas. Sampel tanah dianalisis untuk jumlah N, NH_4^+-N, NO_3^--N, tukarganti K, dan pH tanah. Hasil kelapa sawit dilapur berdasarkan hasil tahunan. Hubungan hasil kelapa sawit dengan unsur-unsur terpilih tanah dikait melalui analisis regrasi. Tindakbalas hasil kelapa sawit terhadap kandungan NH_4^+-N tanah dibanding dengan 6 model tumbesaran. Geostatistik digunakan untuk mengkaji variasi ruang hasil kelapa sawit dan NH_4^+-N tanah.

Analisis semivariogram menunjukkan di dalam plot, 'semivariance' meningkat dengan peningkatan jarak sehingga mencapai jarak genting pada jarak 2 hingga 3 pokok. Ini bermakna zon pengurusan optimum untuk tanaman kelapa sawit ialah 37 pokok. Pembajaan N dapat mengekalkan hasil kelapa sawit 30 tan ha^{-1} $tahun^{-1}$ di samping mengurangkan variasi hasil kelapa sawit kepada 35-45%.

Pekali variasi untuk kandungan NH_4^+-N dan NO_3^--N dalam tanah melebihi 30% walaupun di antara 'micro-site'. Analisis 'semivariance' menunjukkan struktur variasi NH_4^+-N tanah dikawal oleh rekabentuk pensampelan, saiz plot eksperimen, dan amalan penanaman. Julat maksimum 'semivariance' untuk NH_4^+-N ialah 90 m bagi kawasan dengan pembajaan N dan 10 m bagi kawasan tanpa pembajaan N. Ini menunjukkan pembajaan N meningkatkan variasi ruang NH_4^+-N tanah dalam agroekosistem kelapa sawit. Peta interpolasi menunjukkan NH_4^+-N tanah berkumpul setempat di mana baja N ditabur. Pembajaan N berterusan

mengakibatkan pergerakan NH_4^+-N, NO_3^--N dan K tukarganti tanah ke horizon tanah yang lebih dalam. Ia juga menurunkan pH tanah kepada 3.7.

Kira-kira 64% daripada variasi hasil kelapa sawit boleh dihubungkaitkan dengan NH_4^+-N tanah. Tindakbalas hasil kelapa sawit terhadap kandungan NH_4^+-N tanah paling sesuai diciri dengan model 'Linear-Plateau', diikuti dengan model Richards. Hasil maksimum berjulat antara 250 kg pokok^{-1} tahun^{-1} untuk model 'Linear-Plateau', dan 258 kg pokok^{-1} tahun^{-1} untuk model punca-kuasa dua. Empat kelas tanah telah ditakrifkan daripada model 'Linear-Plateau' untuk mengesyorkan pembajaan dan pengawasan masalah nutrien kelapa sawit, iaitu, kekurangan, rendah, optimum, dan tinggi. Julat NH_4^+-N tanah yang sesuai untuk tumbesaran pokok kelapa sawit ialah antara 102 mg kg^{-1} dan 130 mg kg^{-1}, dengan purata maksimum hasil tahunan 250 kg pokok^{-1}. Pembajaan N diperlukan untuk kawasan yang mengandungi NH_4^+-N tanah < 102 mg kg^{-1}. Untuk kawasan > 130 mg kg^{-1} NH_4^+-N, pertimbangan perlu diberi untuk mengurangkan kadar baja N. Model 'Linear-Plateau' dapat mendiagnosis dengan betul 79% kes kriging.

Keputusan ini menunjukkan potensi mengintegrasi kestabilan ruang dan 'temporal' hasil kelapa sawit dengan data tahunan untuk pengurusan secara 'site-specific' dengan mengklasifikasikan zon pengurusan yang berlainan, terutama untuk pembajaan. Pengujian tanah berguna untuk mengenalpasti masalah nutrien tanah dan juga untuk mengesyorkan pembajaan N untuk kelapa sawit. Analisis geostatistik berguna untuk mengambarkan hubungkaitnya secara ruang.

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. Anuar Abd. Rahim, the chairman of the advisory committee, and Mr. Goh Kah Joo, co-supervisor for suggesting the research topic, invaluable guidance, encouragement, and constructive ideas throughout the study. Sincere thanks also go to the other members of the supervisory committee, Assoc. Prof. Dr. Zaharah A. Rahman, and Dr. Muhamad Radzali Mispan for their constructive remarks and reviews of the thesis.

I wish to express my sincere gratitude to Applied Agricultural Research (AAR) Sdn. Bhd., for contributing the oil palm yield trial data, hospitality, and fieldwork facilities at Sri Kunak Estate, Tawau, Sabah. Thanks also go to the staff and other employees at AAR especially Mr. Teo Chor Boo for assisting in the collection of soil samples and sending them to Peninsular Malaysia. The study also form parts of AAR's research towards the adoption of precision farming in oil palm plantations.

I would like to express my sincere gratitude to all the staff members, and laboratory technicians of Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia.

I also wish to take this opportunity to express my sincere thanks to all my friends who have supported in one way or the other towards the completion of the thesis.

Lastly, I am most grateful to my beloved mother, sisters and brother for their sacrifices and moral support throughout the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The oil palm, *Elaeis guineensis,* Jacq., a native to the swamps of West Africa, was introduced to Malaysia in 1875 (Arnott, 1963) as an ornamental plant. The expansion of the oil palm industry started in the late 1960s under the crop diversification plan. From 55,000 hectares in 1960, the area under the crop has increased more than sixty fold to a total of 3.3 million ha in 1999. Approximately 50% of the total arable land in Malaysia is cultivated with oil palm. Malaysia is currently the world's largest producer and exporter of palm oil. In 1999, the country produced 10.5 million tonnes of crude palm oil and through the export of palm oil products, it contributed RM 19.2 billion in gross revenue (MPOB, 2000).

However, since 1975, the substantial increase in oil palm areas has not matched its productivity in terms of fresh fruit bunch (ffb) yields. The average ffb yields had remained in a range of 18-22 t ha^{-1} yr^{-1} for the past 20 years (MPOB, 2000). This yield is well below the theoretical yield potential of 44 t ha^{-1} yr^{-1} (Tinker, 2000). Many of the interacting factors that influence the yield trend have been identified and quantified by various researchers in the industry such as Foster *et al.* (1985a), Kee *et al.* (1994) and Goh and Teo (1997). Goh *et al.* (2000a) contended that "increased field size or management unit, generalized agricultural inputs and monitoring, declining management standards, lack of skilled workers and poor understanding of agronomy, exacerbated by the planting of oil palm on soil and climatic conditions previously deemed as marginal or unsuitable and the replanting of the rubber and cocoa on hilly, poor soils to oil palm are among the causal factors causing the dismal yield performance".

Traditionally, the management of oil palm plantations is based on large-scale extensive agricultural practices. The general practice is to demarcate the plantations into similar management zones that are based on very general soil information, palm age, terrain, and available infrastructure for similar input. Currently, the typical management zone ranges between 40-100 ha (Chew and Anuar, 2000; Goh *et al*., 2000a). However, it is probably too large and the present fertilizer recommendations that are based on very general soil information may not be an effective way to reduce production cost and maximize profit; the most important factors towards sustainable oil palm production. Adequate N fertilizer management is of great importance as it is one of the macronutrients that forms the major item in the fertilizer bill. Excessive N fertilizer could result in a higher risk of nutrient losses through surface run-off (Maene *et al*., 1979; Kee *et al*., 2000), and leaching (Chang and Zakaria, 1987; Foong, 1993), which may contaminate ground water. Similarly, under estimation of fertilizer rates may restrict oil palm growth and lead to sub-optimal production.

Precision farming, defined as a spatial variable management in order to increase efficiency in the management of agricultural practices, productivity and profitability, and reduce the environmental impact, seems to offer some solutions to the above problems. However, the success and applicability of precision farming technique for oil palm plantations lies in the existence of manageable ffb yield variations (Goh *et al*., 2000a), which is the single most important factor influencing profit (Goh and Chew, 2000; Ong, 2000), and soil variations, which affect fertilizer input, the largest cost item in oil palm production (Kee and Chew, 1996). In other words, the real opportunity to optimize fertilizer inputs through site-specific management zoning lies in the understanding of the large variation that exists in the plantation. Proper management zoning, needs to take into account the spatial yield variations of ffb, and existing soil variability for optimum oil palm growth and production in conjunction with new technology tools. This includes proper interpretation of multiple-year yield maps, and identifying and understanding the causal factors affecting the yield variations of oil palm.

Therefore, the main objective of the study is to assess the variability of soils grown with oil palm in relation to yield variations of fresh fruit bunch at one of the selected oil palm plantations in Malaysia. The specific objectives are:

1. to quantify and characterize the spatial and temporal yield variations of ffb so as to determine the optimum management zones for oil palm plantations, as well as to create possible management zones for site-specific inputs

2. to quantify and characterize the nature of spatial soil NH_4^+-N variations as influenced by long term N fertilizer management

3. to establish the inter-relationship between ffb yields and soil NH_4^+-N so as to develop optimum range of soil NH_4^+-N for optimum oil palm growth and production

CHAPTER 2

LITERATURE REVIEW

2.1 Brief Overview of Oil Palm

Oil palm, *Elaeis guineensis* Jacq., belongs to the family of Palmae and the subfamily of Cocoidae. It is a perennial tree crop that originated in the swamps of West Africa. This is based on the observations of botanists and the findings of fossil pollen which resembled the oil palm pollen in Nigeria (Zeven, 1965). Oil palm is a C3 crop that is capable of transforming solar energy into dry matter and vegetable oil (palm oil). The latter is found in the fruitlets of fresh fruit bunch (ffb). Compared to other vegetable oil crops, oil palm is the most efficient converter of solar energy into dry matter. It can produce six times higher oil yield compared to rapeseed (Mielke, 1991). On the average, 3.6 tonnes of vegetable oil (crude palm oil) can be extracted from 1 ha of yield from ffb (Fairhurst and Mutert, 1999).

Oil palm can be cultivated over a wide range of tropical climatic conditions. It is best grown in the humid tropic region with high precipitation between 2000 and 2500 mm yr^{-1}, uniformly distributed throughout the year, with no month having rainfall below 100 mm. Wind speed less than 10 ms^{-1}; annual mean temperature between 26°C and 29°C; daily solar radiation between 16 and 17 MJ m^{-2} with sunshine hours exceeding 5 hours day^{-1} are required for optimum growth and production. The latter condition only holds true if the sunshine hours