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DEVELOPMENT OF VARIABLE RATE TECHNOLOGY GRANULAR FERTILIZER APPLICATOR FOR OIL PALM PLANTATIONS

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By

TAJUDEEN ABIODUN ISHOLA

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the requirement for the degree of Doctor of Philosophy

May 2013

Dedicated to

My Parents

My Wife and Children

My Brothers, sisters and all my kinsmen

Abstract of the thesis presented to the senate of Universiti Putra Malaysia, in fulfilment of the requirements for the degree of Doctor of Philosophy

DEVELOPMENT OF VARIABLE RATE TECHNOLOGY GRANULAR FERTILIZER APPLICATOR FOR OIL PALM PLANTATIONS

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May 2013

Chairman: **Assoc. Prof. Ir. Azmi bin Dato Yahya, PhD**
Faculty : **Engineering**

Currently, in the Malaysian oil palm plantation, fertilizer is applied manually or mechanically at a uniform rate without due consideration to nutrient variability. Excessive application of this fertilizer leads to contamination of ground water by increasing its mineral contents to value that is above the world health organization (WHO) limit for safe drinking water. On the other hand, a variable rate technology (VRT) fertilizer applicator promotes Green Engineering practice by encouraging reduction in excessive fertilizer application, land degradation, pollution through leaching and volatilization among others. It could also increase crop yield and profit. Unfortunately, GPS-based VRT fertilizer application could not be successfully implemented in the oil palm plantation due to tree canopy cover that hinders GPS signal reception.

A novel radio frequency identification (RFID) based VRT fertilizer applicator for band application of granular fertilizer on oil palm plantation was designed, developed

and evaluated. The VRT fertilizer applicator has a 1.20 ton capacity hopper, two 1.88 kg/s capacity rotary valves, two 3.33 kW @ 2850 rpm centrifugal blowers and a 5.46 kg/s @ 30 rpm screw conveyor. The VRT fertilizer applicator was mounted on a 51 kW @ 2600rpm four wheel drive (4WD), four wheel steer (4WS) universal prime mover specially designed for oil palm plantation terrain. In addition, a graphical user interface written in Visual C++ 6.0 was developed to provide a digital chart for the selection of a configuration of the VRT fertilizer applicator during field operation.

Extensive laboratory calibrations were conducted on the individual sensors and machine components that make up the VRT system of the VRT fertilizer applicator. The calibrated sensors were used in the calibration of the screw conveyor, rotary valves and centrifugal blowers of the machine system. LabVIEW 2011 program was used in collecting data and saving it in real time in the computer hard disc. Factorial analysis was used to study the effects of the screw conveyor speed, rotary valve speed and the centrifugal blower speed and their interactions on the discharge rate of fertilizer. Mathematical expressions relating the fertilizer discharge rate to the screw conveyor speed, rotary valves speed, centrifugal blower speed and fertilizer bulk density and repose angle was developed using multiple linear regression analysis. The results of the test were used in programming the graphical user interface in Visual C++ 6.0. Furthermore, field tests were conducted in order to determine the response time of the VRT system, the field performance and the fertilizer distribution uniformity of the VRT fertilizer applicator.

An application table which contained the geo-position of each tree; the corresponding RFID code and the amount of fertilizer to be applied on each tree was developed and stored in the database of the computer system on the VRT fertilizer applicator. The

RFID reader on the VRT fertilizer applicator detected the RFID code of each tree, sent the code to the LabVIEW 2011 program which related the information to the database and triggered the control system to discharge the right amount of fertilizer to the required palm tree.

An evaluation test was conducted to validate the previously developed mathematical expression for fertilizer discharge rate. The application assembly of the VRT applicator has 99.28 % and 99.09 % accuracy on the right side and left side respectively of discharging the set application rate. It took 2 to 3 seconds for the VRT applicator to respond to changes in application rate depending on the magnitude of the change. The distribution uniformity test resulted in coefficient of variation (CV) range of between 6.51 % and 10.94 % which were within the acceptable percentage range specified by ASABE standards. Furthermore, the VRT fertilizer applicator has a field capacity of 7.22 ha/h and 7.71 ha/h with field efficiencies of 0.54 and 0.52 at the travelling speed of 4.43 km/h and 4.92 km/h, respectively. At field speed of 4.92 km/h the field capacity and field efficiency of the VRT fertilizer applicator were 1.67 times and 1.49 times respectively higher than those of the (uniform rate) UR fertilizer applicator at 6 km/h. It is expected that the use of RFID technology will serve as alternative for tree crops where tree canopy has hindered proper application of GPS-based precision agriculture practices.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi syarat ijazah Doktor Falsafah.

PEMBANGUNAN SEBUAH APLIKATOR BAJA BERBUTIR DENGAN KADAR BOLEH UBAH TEKNOLOGI UNTUK LADANG KELAPA SAWIT

Oleh

TAJUDEEN ABIODUN ISHOLA

Mei 2013

Pengerusi : Prof. Madya Ir. Azmi bin Dato Yahya, PhD

Fakulti : Kejuruteraaan

Pada masa kini, diladang kelapa sawit Malaysia, baja digunakan secara manual atau mekanikal pada kadar seragam tanpa pertimbangan sewajarnya mengenai kepelbagaian nutrien. Potensi pembaziran dan penggunaan berlebihan baja ini mencemari air bawah tanah dan ia meningkatkan kandungan mineralnya melebihi had WHO bagi air minuman yang selamat untuk diminum. Sebaliknya, Teknologi Kadar Boleh Ubah (VRT) baja aplikator menggalakkan amalan Kejuruteraan Hijau dengan mengurangkan penggunaan baja yang berlebihan, kemusnahan dan pencemaran tanah melalui pengurasan dan pengewapan. Ia juga boleh meningkatkan hasil dan keuntungan. Malangnya, penggunaaan baja berasaskan GPS VRT tidak boleh dilaksanakan dengan jayanya dalam ladang kelapa sawit kerana kanopi pokok yang menutup dan menghalang penerimaan isyarat GPS.

Satu novel aplikator baja VRT berasaskan RFID untuk pengaplikasian baja berbutir di jalur antara baris di ladang kelapa sawit telah direka, dibangunkan dan dinilai. Aplikator baja VRT mempunyai kapasiti bin 1.20 tan, dua unit 1.88kg/s injap putar,

dua unit 3.33kW@2466rpm peniup empar dan5.46kg/s@30rpm skru penghantar. Aplikator bajaVRT akan dipasang pada 51kW@2600rpm 4WD4WS traktor yang direka khas untuk permukaan ladang kelapa sawit. Aplikator baja VRT telah direka untuk dicetuskan oleh sistem RFID. Di samping itu, sebuah grafik antara muka pengguna yang ditulis dalam Visual C + + 6.0 telah dibangunkan untuk menyediakan carta digital untuk pemilihan konfigurasi aplikator baja VRT semasa operasi di ladang.

Kalibrasi makmal untuk penentukuran bagi setiap sensor dan komponen mesin telah dijalankan secara meluas bagi membentuk sistem aplikator baja VRT. Sensor yang telah ditentukur telah digunakan dalam penentukuran skru penghantar, injap putar dan peniup empar bagi sistem mesin. Pengaturcara LabVIE2011 telah digunakan bagi pengumpulan dan penyimpanan data dalam cakera keras komputer secara masa sebenar. Analisis faktorial telah digunakan untuk mengkaji kesan kelajuan penghantar skru, kelajuan injap putar dan kelajuan peniup empar dan interaksi mereka pada kadar pelepasan baja. Satu ungkapan matematik berkaitan kadar pelepasan baja kepada kelajuan penghantar skru, putar injap kelajuan, kelajuan peniup empar dan ketumpatanpukalbaja dan sudut rehatnya telah dibangunkan dengan menggunakan analisis regresi linear berganda. Keputusan ujian ini telah digunakan dalam pengaturcaraan penggunaan grafik antara muka dalam Visual C + + 6.0. Tambahan pula, ujian ladang telah dijalankan untuk menentukan masa tindak balas sistem VRT, prestasi ladang dan keseragaman pertaburan baja oleh aplikator baja VRT.

Satu jadual penggunaan yang mengandungi kedudukan-geografi setiap pokok; kod RFID yang sepadan dengan jumlah baja yang akan digunakan pada setiap pokok telah dibangunkan dan disimpankan dalam pengkalan data sistem komputer bagi aplikator baja VRT. Pengimbas RFID yang terletak diatas aplikator baja VRT mengesan kod RFID pada setiap pokok dan menghantar kod tersebut kepada pengaturcara LabVIEW 2011 yang menghubungkaitkan maklumat kepada pengkalan data dan mencetuskan sistem kawalan bagi melepaskan kadar baja yang tepat mengikut keperluan pokok kelapa sawit.

Satu ujian penilaian telah dijalankan untuk mengesahkan ungkapan matematik yang dibangunkan sebelum ini bagi kadar pelepasan baja. Pemasangan aplikasi aplikator VRT mempunyai ketepatan 99.28% dan 99.09% di sebelah kanan dan sebelah kiri masing-masing, mengenai set pelepasan kadar penggunaan. Ia mengambil masa 2-3 saat untuk aplikator VRT untuk bertindak balas kepada perubahan dalam kadar permohonan bergantung pada magnitud perubahan. Ujian keseragaman pengagihan menunjukkan Pekali pelbagai Variasi(CV) di antara 6.51dan 10.94% dan ia adalah dalam julat peratusan yang bolehditerima mengikut piawaian yang ditetapkan oleh ASABE. Tambahan pula, kapasiti ladang,kecekapan ladang dan penggunaan bahan api aplikator baja VRT telah diperolehi. Aplikator VRT mempunyai kapasiti ladang 7.22ha/h dan 7.71ha/h dengan kecekapan ladang 0.54 dan 0.52 pada kelajuan perjalanan 4.43km/h dan4.92km/h, masing-masing. Pada kelajuan ladang 4.92 km/h, kapasiti ladang dan kecekapan ladang bagi aplikator baja VRT adalah masing-masing mempunyai 1.67 dan 1.49 kali ganda lebih tinggi dari aplikator baja kadar seragam yabg ianya pada 6 km/h. Adalah dijangkakan bahawa penggunaan teknologi RFID akan dapat digunakan sebagai alternatif untuk tanaman pokok di mana kanopi pokok telah menghalang peggunaan berasaskan-GPS dengan tepat bagi amalan pertanian presis.

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This thesis submitted to the senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follow:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

TAJUDEEN ABIODUN ISHOLA

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CHAPTER I

INTRODUCTION

1.1 Background of study

Oil palm (*Elaeis guineensis*) produces the highest amount of oil among the perennial oil yielding crops. It is a major commodity and the vegetable oil that gives the highest profit in Malaysia. In 2011, oil palm formed 37 % of the Gross Domestic Product (GDP) for the agricultural sector (Figure 1). Crude palm oil production in Malaysia increased by 1.92 million tonnes in 2011 when compared to 2010. Oil palm cultivation has expanded to diverse soil and terrain due to its productivity. Between 2007 and 2011, the planted area for oil palm in Malaysia increased from 4.3 million hectares to 5.0 million hectares (Department of Statistics, Malaysia, 2012). The expansion and growth of the oil palm plantation comes with a corresponding increased need for labour to work in the plantations.

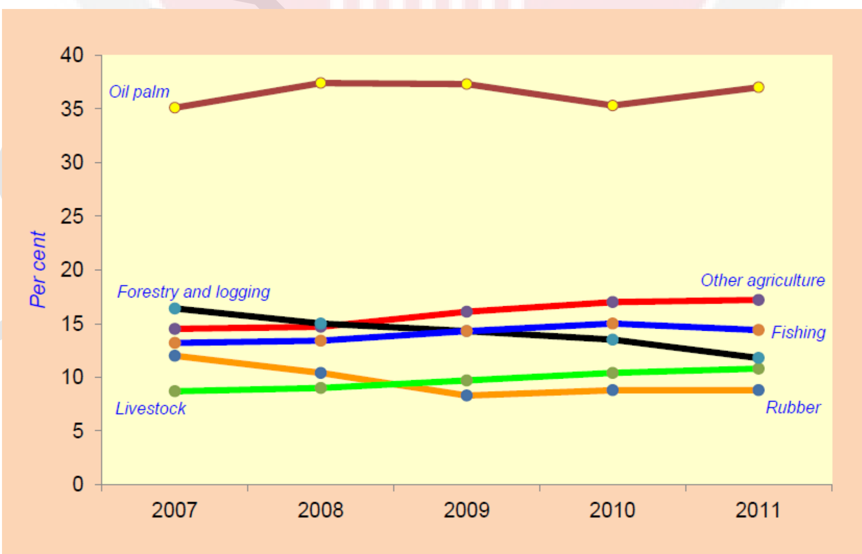

Figure 1. Percentage share of GDP for agriculture sector in Malaysia.
(Source: Department of Statistics, Malaysia, 2012)

Unfortunately, the Malaysian oil palm plantation is heavily dependent on foreign workers. However, in 2011, the number of foreign workers in agriculture and the plantation decreased by 9.3 % when compared to 2010 (Department of Statistics, Malaysia, 2012). Presently, 80 % of the labour force in the plantation are foreign workers. Out of the total foreign workers employed in the plantations, 78 % are Indonesians (Kamisan, 2012). The skilled workers especially the Indonesian workers who are familiar with the oil palm terrains are becoming scarce to get. One of the reasons is that the Indonesian oil palm industries are now offering improved conditions of service to their workers by increasing salary, provision of schools and health care services in order to stem the migration of the workers to Malaysia. On the other hand, new incentives and subsidies are now introduced by the Malaysian oil palm plantations to recruit and retain the skilled workers. The current cost of hiring a skilled worker is on the increase due to the new policy imposed by the Indonesian government to guarantee better welfare for workers in the Indonesian oil palm plantations. It is against this backdrop that it was suggested that the Malaysian oil palm plantations should adopt modern technologies and implement mechanisation in their operations. This has become imperative if they want to sustain their competitiveness and productivity (Kamisan, 2012).

In Malaysia, large amounts of the oil palm are planted on Ultisols and Oxisols. These soils have low base saturation, low cation exchange capacity, high aluminium concentration, high acidity and low fertility level. The yield of oil palm is highly dependent on the availability of optimum nutrient (Tarmizi, 2001). In order to sustain the high productivity of the oil palm, the nutrient shortfall of the soil has to be augmented with addition of fertilizer. Fertilizer application is quite imperative for a successful oil palm production. It constitutes a major factor for productivity and the highest operational cost in well managed plantations. However, the price of fertilizer is quite erratic in Malaysia (Goh et al., 2009). The price of imported fertilizer increased by 5.4 % between 2011 and 2012 in Malaysia (Department of Statistics, Malaysia, 2012). The increasing price of fertilizer is becoming prohibitive for some oil palm plantations. As such, strict measures are being taken to avoid wastage and improper timing of fertilizer application.

Mature oil palm trees have feeding roots that spread around them. These roots cover about the same area as the tree canopy. In addition, there are interpenetrating roots which are most dense along the rows of the oil palm trees (Tarmizi, 2001). Hence, broadcasting of fertilizer around the oil palm reduces leaching losses because more roots come in contact with the nutrient and absorb it. Cut palm fronds are laid in rows in between the oil palm trees. This practice enhances the activities of microbes, prevents soil moisture loss and improves the effectiveness of the fertilizer. Therefore, application of fertilizer right on top of the stack of fronds along the alternate rows will promote its absorption because more roots will be able to come in contact with it (Tarmizi, 2001).

The current popular method of fertilizer application in the Malaysian oil palm plantation is the manual method. Only a few plantations use the commercially available uniform rate mechanical fertilizer applicator. The manual method of fertilizer application is more favoured because of claims that the uniform rate mechanical applicator tends to waste fertilizer during operation. This comes from the fact that there is no speed feedback mechanism on the uniform rate mechanical applicator to adjust the fertilizer application rate proportionately to actual travel speed of the machine. Hence, fertilizer could likely be wasted when travelling uphill and when slowing down to turn at the headland in the plantation. Moreover, the band placement of fertilizer on top of the stack of old oil palm fronds on either side of the machine path that is required in the plantation is not fully fulfilled by the mechanical fertilizer spreader. It leaves some fertilizer along the machine path which is easily washed away by runoff water or by human, animal and machine traffic on the machine path.

Aerial fertilizer application in oil palm plantations with peat soils and steeply sloping land was investigated by Caliman et al. (2002). It was asserted that the cost of using aerial application could be up to five times more expensive than the cost of manual fertilizer application. They recommended that mechanical fertilizer application using tractor mounted fertilizer spreader would be appropriate for flat mineral soils in terms of reduced labour requirement, even spread and speed of application.

Fertilizer application systems in oil palm plantations are based on "Field Average". Soil cores are collected throughout an oil palm plantation and mixed into a composite sample. This sample is then analysed to determine unique fertilizer recommendation and fertilizer is applied to the whole oil palm plantation according to this result. This method disregards the needs of individual oil palm based on their size, age, or the variability of soil properties. The application of fertilizer without due consideration to what is actually required could lead to wastage and environmental pollution. The excess of the fertilizer applied could find their way to nearby rivers and streams by leaching or surface run off. In addition, there is the possibility of volatilisation and land degradation by erosion (Wittry and Mallarino, 2004; Wahid et al., 2005; Cugati et al., 2006; Kim et al., 2006 and Ah Tung et al., 2009). A study was conducted to examine the watershed quality of Tebrau River, Johor, Malaysia

(Zainudin et al., 2010). The water from the river was classified as polluted because it had 25 mg L^{-1} concentration of Ammoniacal Nitrogen. This concentration is within the polluted water category of the Malaysian Interim National Water Quality Standards (INWQS). The contamination was found to have come from fertilizers used in the oil palm plantations along the course of the river. Likewise, water from Bekok River, Johor, Malaysia was found to have a pH value of 2.5 which was low for potable water by INWQS standards (Rui and Fulazzaky, 2011). The Iron and Aluminium concentration were 110 mg L^{-1} and 290 mg L^{-1} respectively. The seepage of excess fertilizer from the oil palm and rubber plantation around the river channel was suspected to be the cause of the pollution. Also, a study was conducted to estimate the level of ground water contamination due to fertilizer application in the oil palm plantation in Sabah, Malaysia (Ah Tung et al., 2009). The leaching of Nitrogen and Potassium nutrients from Ammonium Chloride and Muriate of Potash fertilizers and their consequent effects on the quality of ground water during the monsoon season was investigated. It was observed that when application rates of Nitrogen and Potassium exceeded the optimum, there was a resultant negative effect on the ground water quality. The Nitrogen in the form of Ammonium was more than the WHO limit of 0.5 mg L^{-1} concentration while the Potassium went above the 12 mg L^{-1} WHO concentration limit for safe potable ground water.

Concerns about environmental degradation, population growth and resource scarcity has resulted in the employment of engineering technologies to meet the need of current generation without creating side effects that can hinder the needs of the future generation. In other words, collectively taking care of the objectives of prosperity, environment and the society. This new concept of engineering is called Green Engineering. It is defined as incorporating sustainability factor in engineering where optimum energy and resources are used to make products and practices that are feasible, economical, environmentally friendly and benign to human health. Recently, a new technology known as Variable Rate Technology (VRT) emerged. The VRT concept encourages treating oil palm with actual fertilizer rates for site-specific oil palm needs. It advances the benefits of applying different rate of fertilizer in different grids of the same plantation in order to obtain optimum pH and/or fertility values over the entire plantation. With this new VRT, grid or zone sampling is employed to determine the soil fertility variability of the plantation and fertilizers at variable rates are applied onto each of these grids or zones. VRT fertilizer application can be described as a way of implementing Green Engineering in fertilizer application. This is because it satisfies the following principles of Green Engineering: Minimizing depletion of natural resources (soil); striving to prevent wastage (fertilizer) and possessing system components that maximize energy and efficiency. Furthermore, it is economical because it has the potential to reduce cost of production while increasing yields (Chan et al., 2002; Zhang et al, 2007). It is environmental-friendly and sustainable due to the fact that the hazards of soil degradation as a result of excessive fertilizer application is eliminated (Norton et al., 2005).

Essentially, a VRT fertilizer applicator consist of a Geographic Information System (GIS) fertilizer prescription map, Global Positioning System (GPS) device, a volume or mass flow sensor for the fertilizer rate controller, an actuator valves and a microcontrollers or embedded computer program. Fertilizer prescription maps which indicate fertilizer requirement are generated from yield maps, soil maps, crop nutrient levels, aerial images or maps of soil electrical conductivity. The GPS position coordinates is indicated by the GPS device. Upon a user command, the microcontrollers or embedded computer program reads the GPS coordinates, calculates the correct application rate through a formula or algorithm with reference to the prescription map and then translates the correct rate into actual fertilizer output through the actuators or valves (Schueller, 1992; Ehsani et al., 2009). VRT granular fertilizer applicators are used to apply small dry granules of fertilizer or bio-solids. Spinner discs spreader and pneumatic applicator are the two main technologies for granular fertilizer application. For the spinner discs type, a hopper is used to hold the fertilizer and a conveyor chain carries the fertilizer granules from the hopper to the spinner discs mechanism. The rate of fertilizer is altered by using a controller to adjust the speed of the conveyor chain or by adjusting the opening of the gate between the hopper and the conveyor chain (Ehsani et al., 2009). For the pneumatic applicator, hydraulically driven fluted rollers are used to meter fertilizer materials from a storage hopper that is positioned centrally into air tubes. A centrifugal fan is hydraulically driven by hydraulic power from a prime mover to produce airflow for the discharging air tubes. Mounted on the prime mover are a controller for the metering device, a GIS software package installed on a computer and a Differential Global Positioning System (DGPS) receiver to provide the VRT capability for both the spinner discs spreader and pneumatic applicator (Fulton et al., 2003). However, these VRT systems are only suitable for broadcast fertilizer application on fields planted with cereals and vegetable crops where discharging mechanism is well above the height of the crop. In order to use some of them for tree crops like citrus, these variable rate fertilizer spreaders were modified by placing baffle plates in front of the spinner disc so as to deflect the fertilizer particles under the tree in a banded pattern (Cugati et al., 2006). In the oil palm plantation where the target area of fertilizer application is on the piles of oil palm frond which is within the 4 to 12 meter width stretch on either side of the fertilizer applicator path, it is not appropriate because the discharging mechanism were not designed for this.

Some studies have been done to assess the advantages of using VRT fertilizer application over the uniform rate fertilization. Wittry and Mallarino (2004) applied phosphorus fertilizer to corn and soybean by using uniform rate and VRT fertilizer applicators. It was observed that the VRT application was able to apply up to 41 % less phosphorus and reduced the soil-test phosphorus variability compared to uniform rate applicator. It was also asserted that the loss of phosphorus to surface water was reduced. In a separate study, variable rate phosphorus application was compared with the uniform rate application of phosphorus. The variable rate method resulted in 27 % reduction in the amount of fertilizer applied (Norton et al., 2005). In addition, experiments were done to study variable rate fertilization for maize for two consecutive years. It was observed that variable rate fertilization was able to increase maize yield up to 33 % and the amount of fertilizer used was reduced by up to 32 % lesser than that of uniform rate fertilization. In essence, it was suggested that variable rate fertilizer application could be more economically feasible while maintaining high yield (Zhang et al, 2007).

1.2 Problem Statement

The manual method of fertilizer application in the oil palm plantation is inefficient due to low human output capacity for fertilizer application. Unfortunately, there is growing shortage of human labour in the oil palm plantations in Malaysia (Kamisan, 2012). Moreover, both the manual and the uniform rate mechanical fertilizer application do not consider the variability in the soil and oil palm nutrient status across the plantation. There is a tendency of excessive or under-application as the case may be. The solution lies in the use of VRT fertilizer applicator. However, it was pointed out that the commercially available variable rate fertilizer spreaders are for cereals and vegetable crops. For oil palm trees which can grow up to 20 m high, practical methods of using sensors to relate the tree attributes to fertilizer requirement on-the-go have not yet been found. Furthermore, the oil palm tree canopy cover hinders the reception of GPS signal under the oil palm. Hence, GPS-based or sensor based VRT fertilizer application could not be successfully implemented in the oil palm plantation (Wahid et al., 2004).

1.3 Research Objectives

The general objective of this research is to design and construct a Variable Rate Technology (VRT) fertilizer applicator for the oil palm plantation.

The specific objectives are:

1. To develop instrumentation and control system on a prime mover upon which the VRT fertilizer applicator is to be mounted.

2. To formulate and validate a mathematical relationship for the machine and fertilizer parameters of the VRT fertilizer applicator.

3. To develop a Graphical User Interface in Visual C++ 6.0 for the selection and customization of the VRT fertilizer applicator configuration.

4. To evaluate the application accuracy of the VRT fertilizer applicator.

1.4 Scope of Study

The research project covered the design calculations and engineering drawings of the components of a pneumatic VRT fertilizer applicator for the oil palm plantation. The VRT fertilizer applicator was fabricated, instrumented, calibrated in the laboratory and tested in the field. Only band application of dry granular inorganic fertilizers used for matured oil palm trees that are three years and above was considered.

However, the research project did not include the development of the technology for the determination of oil palm nutrient deficiency and fertilizer requirement. For the purpose of testing the fertilizer applicator, the results obtained from the current practice of using foliar analysis in the determination of oil palm fertilizer need was used. Nevertheless, there is an on-going research on the development of simpler and faster method of determination of oil palm fertilizer need in Universiti Putra Malaysia. A provision for mixing two or more types of granular fertilizer was not included in the design of the VRT fertilizer applicator. Likewise, liquid and slurry fertilizer application was not part of the scope of the research project. A GIS digital map that contains the plane coordinates of each oil palm tree in the oil palm plantation was expected to be available. Notwithstanding the GIS digital map, the VRT fertilizer applicator developed could still function perfectly.

REFERENCES

Ah Tung, P. G., Yusoff, M. K., Majid, N. M., Joo, G. K. and Huang, G. H. (2009). Effect of N and K Fertilizers on Nutrient Leaching and Groundwater Quality under Mature Oil Palm in Sabah during the Monsoon Period. American Journal of Applied Sciences 6(10): 1788 -1799.

Allaire, S. E., and Parent, L. E (2004). Physical properties of granular organic-based fertilisers. Part1: static properties. Biosystems Engineering 87(1): 79 -87.

Ampatzidis, Y. G., Vougioukas, S. G., Bouchtis, D. D. and Tsatsarelis, C. A. (2009). A yield mapping system for hand-harvested fruits based on RFID and GPS location technologies: field testing. Precision Agriculture 10: 63 -72.

Ampatzidis, Y. G. and Vougioukas, S. G. (2009). Field experiments for evaluating the incorporation of RFID and barcode registration and digital weighing technologies in manual fruit harvesting. Computers and Electronics in Agriculture. 66: 166 – 172.

ASABE Standards. (2003). S296.5: General terminology for traction of agricultural traction and transport devices and vehicles. . St. Joseph, Mich. ASABE.: 1 - 5.

ASABE Standards. (2009). S341.4: Procedure for measuring distribution uniformity and calibrating granular broadcast spreaders. St. Joseph, Mich. ASABE. USA

Bogballe (2003). Bogballe M1 trend user manual and spare part catalogue.

Caliman, J. P, Togatorop E, Martha B and Samosir R. (2002). Aerial fertilization of oil palm. Better Crops International 16(2).

Camacho-Tamayo, J. H., Barbosa, A. M., Perez, N. M., Leiva, F. R. and Rodriguez, G. A. (2009). Operational characteristics of four metering systems for agricultural fertilizers and amendments. Engenharia Agricola, Jaboticabal 29(4): 605 - 613.

Chan, C. W., J. K. Schueller, W. M. Miller, J. D. Whitney and J. A. Cornell. 2004. Error sources affecting variable rate application of nitrogen fertilizer. Precision Agriculture. 5(6): 601 – 616.

Chan, C. W., J. K. Schueller, W. M. Miller, J. D. Whitney, T. A. Wheaton and J. A. Cornell. 2002. Error sources on yield-based fertilizer variable rate application maps. Precision Agriculture. 3(1): 81 – 94.

Cugati, S. A., Miller, W. M., Schueller, J. K., Schumann, A. W., Buchanon, S. M. and Hostler, H. K. 2007. Benchmaking the dynamic performance of two commercial variable-rate controllers and components. Transactions of ASABE. 50(3): 795 – 802.

Cugati, S. A., Miller, W. M, Schueller, J. K, and Schumann, A. W. (2006). Dynamic characteristics of two commercial hydraulic flow-control valves for a variable-rate granular fertilizer spreader. ASABE Paper No. 061071. St. Joseph, Mich.: ASABE.: 1 - 10.

Department of tatistics, Malaysia. (2012). Selected agricultural indicator. www.statistics.gov.my. Accessed 10/01/2013: 1 - 87.

Ehsani, R., Arnold, S., and Masoud, S. (2009). Variable rate Technology for Florida Citrus. AE 444, Agricultural and Biological Engineering Department, University of Florida. : 1 - 5.

Emdek Sdn Bhd (2012). Fertilizer Spreader catalogue.

Fulton, J. P., Shearer, S.A., Stombaugh, T.S. and Higgins, S.F. (2001). Pattern Assessment of a Spinner Disc Variable-Rate Fertilizer Applicator. ASAE Paper No. 01-1116. St. Joseph, Mich.: ASABE.: 1 - 21.

Fulton, J. P., Shearer, S. A., Chabra, G and Higgins, S. F. (2001). Performance asessment and model development of a variable-rate spinner-disc fertilizer applicator. Transactions of ASAE. 44(5): 1071 - 1081.

Fulton J. P., Shearer S. A., Stombough T. S and Higgin S. F. (2003). Comparison of variable-rate granular applicator equipment. ASABE Paper No. 031125. St. Joseph, Mich.: ASABE.: 1 - 16.

Fulton, J. P., Shearer, S. A., Higgins, S. F., Hancock, D. W and Stombaugh, T.S. (2005). Distribution pattern variability of granular VRT applicators. Transactions of ASABE. 48(6): 2053 - 2064.

Geonics Limited (2009). EM 38 meter catalogue.

Goh, K.J, Ng, P. H. C. and Lee, C. T (2009). "Fertilizer management and productivity of oil palm in Malaysia." Advanced Agroecological Research (AAR) Newsletter (October, 2009.): 1 - 24.

Gundogdu, M. Y. (2004). Design improvements on the rotary valve particle feeders used for obtaining suspended airflows. Powder Technology 139: 76 - 80.

Halliday, D., R. Resnick and J. Walker. 2010. Fundamentals of Physics. 9th Edition. John Wiley & Son’s publisher. Pp 57 – 78.

Hartsock N. J, Mueller. T. G., Thomas G. W., Barnhisel R. I, Wells K. L, and Shearer S. A. (2000). Soil Electrical Conductivity Variability. Proceedings of the 5th international conference on precision Agriculture: 1 - 7.

Jahis, S., Hitam, A., Ali, Z. M. and Nor, M. M. (2002). Mechanical fertilizer spreader for young palm. Malaysian Palm Oil Board (MPOB). Information Series(MPOB TT No. 135): 1 - 4.

Kamisan, R. (2012). Confronting the challenges of oil palm: How vulnerable will it be for the future. Proceedings of the 5th National Seminar on oil palm mechanisation, Bangi, Selangor, Malaysia. 23 - 24, October, 2012.: 20 - 36.

Kim, Y. J., Kim, H. J., Ryu, K. H and Rhee, J. Y. (2008). Fertiliser application performance of a variable-rate pneumatic granular applicator for rice production. Biosystems Engineering 100: 498 - 510.

Kim, Y. J., Yang, S.H and Rhee, J. Y. (2006). Development of a variable rate granule applicator and analysis of uniformity. ASABE Paper No. 061070. St. Joseph, Mich. ASABE.: 1 - 10.

Mandal, S., and Thakur, T. C. (2010). Design and development of subsoiler-cum-differential rate fertilizer applicator. Agricultural Engineering Internetaional: the CIGR Ejournal Vol. XII: 1 - 17.

McQuinn, E. A. (2004). Multi-variable rate dispensing system for agricultural Machine Patent No: EP 1023686 B1. http://www.google.com/patents. Accessed 26 /01 /2013

Miller, W. M., Schumann, A., J. D. Whitney and Buchanon, S. (2003). VRT citrus Test plots applications of grannular fertilizer. ASAE Paper No: 031127. St Joseph, Mich: ASAE: 1 - 15.

Monson, R. J. (1994). Closed-loop variable rate applicator. Patent No: EP0615682A1. http://www.google.com/patents. Accessed 26 /01 /2013

Nicolai, R., Ollerich, J. and Kelly, J. (2004). Screw auger power and throughput analysis. ASAE/CSAE Paper No: 046134. St Joseph, Mich: ASAE: 1 - 9.

Norton, E. R., Clark, L.J, and Borrego, (2005). Evaluation of variable rate fertilizer application in an Arizona cotton production system. Arizona Cotton Report.: 145 - 151.

Rankine, I. R. and Fairhurst, T. H. (1999). Immature. Field Handbook, Oil Palm Series. vol 2, First edition: 146 - 147.

Reumers, J., Tijskens, E., and Ramon, H (2003). Experimental characterization of the tangential and cylinderical fertiliser distribution pattern from a spinning disc: a parameter study. Biosystems Engineering 86(3): 327 - 337.

Rissi, M. W. (2003). Adjustable spinner for a particulate material spreader. Patent No: US 6517281. http://www.google.com/patents. Accessed 26 /01 /2013.

Roberts, C. M. (2006). Radio frequency identification (RFID). Computers and Security 25: 18 – 26.

Rui, L. M. and Fulazzaky, M. A (2011). Assessment of Bekok river water quality status and its suitability for supporting the different uses: a review. Proceedings of international conference on Advanced Science, Engineering and Information Technology, Bangi, Selangor, Malaysia. 14 - 15, January, 2011.: 1 - 3.

Ruiz-Garcia, L. and Lunadei, L. (2011). The role of RFID in agriculture: Application, limitations and challenges. Computers and Electronics in Agriculture 79: 42 - 50.

Schueller, J. K. 1992. A review and integrating analysis of spatially-variable control of crop production. Fertilizer Research. 33: 1 – 34

Schueller, J. K., M. W. Wang. 1994. Spatially-variable fertilizer and pesticide application with GPS and DGPS. Computers and Electronics in Agriculture. 11(1): 69 – 83.

Schumann, A. W., Miller, W. M, Cugati, S. A , Hostler, H. K, and Buchanon, S. M. (2006). Optimizing variable rate granular fertilizer spreader performance for single-tree prescription zones. ASABE Paper No. 061073. St. Joseph, Mich.: ASABE. : 1 - 14.

Speicher, P. (1989). Broadcast spreader for pulverized materials. Patent No: US 4867381. http://www.google.com/patents. Accessed 26 /01 /2013.

Srivastava, A. K, Carrol, E. G, Roger P. R and Dennis R. B. (2006). Conveying agricultural materials. Engineering Principles of Agricultural Machine (2nd Edition): 491 - 524.

Stewart, C., Boydell, B. and McBratney, A. (2005). Precision decision for cotton: A guide to site –specific cotton crop management. The University of Sydney and Cotton Research and Development Corporation.: 32 - 66.

Su, V. H. (2011). Performance of economic comparison of manual and mechanized fertilizer applicationfor mature oil palms. Unpublished Bachelor of Engineering (Biological & Agricultural) thesis, Universiti Putra Malaysia: 24 - 28.

Svensson, J. E. T. (1994). Effects of constructional and operational variables on the mean mass flow of particulate fertilizer using a studded roller. Journal of Agricultural Engineering Research 59: 221 - 230.

Tarmizi, A. M. (2001). Nutritional requirements and efficiency of fertilizer use in Malaysian oil palm cultivation. Advances in Oil palm Research, Malaysian Palm Oil Board. 1: 411 - 440.

Tarmizi, A. M. and Mohammed, T. D. (2006). Nutrient demand of *Tenera* oil palm planted on inland soils of Malaysia. Journal of Oil palm Research 18: 204 - 209.

Valmar. 2012. Valmar product Catalog. www.valmar.com. Accessed 15/01/2013: 1 - 16.

Von Uexkull, H. R. (1991). The oil palm: fertilization management for high yield. International Potash Institute, Berne, Switzerland.: 1 - 6.

Wahid, B. O., Rahim, A. S., Tarmizi, A. M and Basri M. W (2004). Variable rate fertilizer applicator for oil palm. Malaysian Palm Oil Board (MPOB) Information Series (MPOB TT No 216): 1 - 4.

Wahid M. B, Abdullahi, S. N. A, and Henson, I. E. (2005). Oil palm - Achievements and potential. Plant Production Science. 8(3): 288 -297.

Wahid, O., Xaviar, A., Tarmizi, A. M. and Ibrahim, S (2002). Precision agriculture: Fertilizer management map. Part 1: Spatial and correlation analysis of yield and leaf nutrient. Malaysian Palm Oil Board (MPOB). Information Series (MPOB TT No. 128): 1 - 8.

Wittry D. J. and Mallarino, A. P. (2004). Comparison of uniform and variable rate phosphorus fertilizer for corn-soybean rotation. Agronomy Journal 96: 26 - 33.

Yu, Y., and Arnold, P. C (1996). The influence of screw feeders on bin flow patterns. Powder Technology 88: 81 - 87.

Zainudin, Z., Rahman, N. A., Abdullah, N. and Mazlan, N. F (2010). Development of water quality model for Sungai Tebraus using QUAL2K. Jouurnal of Applied Sciences **10**(21): 2748 - 2750.

Zhang S., Lan. Y., Li W. Hoffmann C., Xu Y and Ma C. (2007). Variable rate fertilization for maize and its effects based on the site-specific soil fertility and yield. ASAE Paper No. 071066. St. Joseph, Mich.: ASAE. : 1 - 9.

Zoz, F. M., and Grisso, R. D. (2003). Traction and tractor performance. ASAE Distinguished lecture # 27, Agricultural Equipment Technology Conference. Louisville, Kentucky, USA.: 1 - 47.