UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF AN AUTOMATED MECHANICAL VALVE FOR VARIABLE RATE KNAPSACK SPRAYER

SITI MARIAM SHAMSI

FK 2017 117

DESIGN AND DEVELOPMENT OF AN AUTOMATED MECHANICAL VALVE FOR VARIABLE RATE KNAPSACK SPRAYER

By

SITI MARIAM SHAMSI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

April 2017

I wish to dedicate this thesis to Allah, his messenger Muhammad S.A.W and my beloved family

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

DESIGN AND DEVELOPMENT OF AN AUTOMATED MECHANICAL VALVE FOR VARIABLE RATE KNAPSACK SPRAYER

By

SITI MARIAM SHAMSI

April 2017

Chairman: Muhammad Razif Bin Mahadi @ Othman, PhD
Faculty: Engineering

Rice is a major crop in Malaysia that provides source of nutrition to the national population. Although rice farmers generally recognize the importance of fertilizer for supplying crops with essential nutrients needed for sustaining high yield, they often do not apply fertilizer at the right time and in the right amount to get a high return on their investment. The problem can be solved through precision farming; whereas sensors, navigation systems and machinery are integrated into a system called Variable Rate Applicator (VRA). So, the spraying will be done according to the needed soil and can practices the precision farming concept by the smallholder farmers. The design concept of VRA knapsack sprayer takes an idea from the shower diverter, which it can control from which outlet the liquid will flow through. Hence, the type fertilizer of fertilizer that can be applied by using the VRA knapsack sprayer is liquid forms. The VRA knapsack sprayer will spray the fertilizer based on desired application. For example, when the applicants arrive at the certain area that doesn't need to apply the fertilizer, the valve will remain close. However, the pump will still running and the fertilizer will continuously flow and accumulates the pressurize fertilizer. In order to prevent the handle switch from blowing out, another line as a back flow line was proposed. The back flow was used when the main valve is closed to flow the fertilizer back to the tank. The valve will be controlled by the stepper motor in order to open and close the valve based on the desired application. The controller was designed to make sure it can be used suitably for the all knapsack type because the mechanism of the controller stand-alone without the disturbance from the operation of the knapsack itself. The mechanism of the controller was tested to open and close at the designated zone which is for zone A and C was set up as 90° of opening of valve while for zone B and D was set up as 45° opening of valve. It shows the controller successfully open and close based on the desire application with the average error of fertilizer application rate 1.38% and 0.92% respectively. The VRA knapsack sprayer was also compared with the normal knapsack to determine its efficiency. It shows the reduction of fertilizer used up to 27.3 % compared using the normal knapsack and it can help farmers to practice the precision farming concepts and saving the usage of fertilizers. So, a VRA knapsack sprayer that is small enough to be handled by a farmer and come with some intelligence has successfully been developed.

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

REKABENTUK DAN PEMBANGUNAN AUTOMATIK INJAP MEKANIKAL UNTUK KADAR BOLEH UBAH (VRA) PENYEMBUR GALAS

Oleh

SITI MARIAM SHAMSI

April 2017

Pengerusi: Muhammad Razif Bin Mahadi @ Othman, PhD
Fakulti: Kejuruteraan

Padi merupakan tanaman utama di Malaysia yang menyediakan sumber pemakanan kepada penduduk negara. Walaupun petani umumnya menyedari kepentingan baja untuk membekalkan tanaman dengan nutrien penting yang diperlukan untuk mengekalkan hasil yang tinggi, mereka sering tidak menggunakan baja pada masa yang tepat dan dalam jumlah yang betul untuk mendapatkan pulangan yang tinggi ke atas pelaburan mereka. Masalah ini boleh diselesaikan melalui pertanian jitu; dimana sensor, sistem dan peralatan navigasi disepadukan dalam sistem yang dipanggil Kadar Boleh Ubah Aplikator (VRA). Jadi, penyemburan akan dilakukan mengikut keperluan tanah dan boleh mengamalkan konsep pertanian jitu oleh para petani pekebun kecil. Konsep reka bentuk penyembur galas VRA diambil idea dari penyonsang pancuran, dimana ia boleh mengawal cecair yang akan keluar melaluinya. Oleh itu, jenis baja yang boleh digunakan dengan menggunakan penyembur galas VRA adalah dalam bentuk cecair. Penyembur galas VRA akan menyembur baja berdasarkan permohonan dikehendaki. Sebagai contoh, apabila pemohon tiba di kawasan tertentu yang tidak perlu untuk memohon baja, injap akan kekal tutup. Walau bagaimanapun, pam masih berjalan dan baja akan terus mengalir di dalam tangki dan baja bertekanan di kumpul. Untuk mengelakkan suis pemegang daripada pecah, satu aliran kembali telah dicadangkan. Aliran kembali digunakan apabila injap utama ditutup dan baja akan kembali ke tangki. Injap akan dikawal oleh motor pelangkah untuk membuka dan menutup injap berdasarkan aplikasi yang dikehendaki. Pengawal ini telah direka untuk memastikan ia boleh digunakan sesuai untuk jenis semua penyembur galas kerana mekanisme pengawal berdiri sendiri tanpa gangguan daripada pengendalian penyembur galas itu sendiri. Mekanisme pengawal telah diuji untuk membuka dan menutup di zon yang ditetapkan iaitu untuk zon A dan C telah ditetapkan sebagai 90 ° pembukaan injap manakala bagi zon B dan D telah ditetapkan sebagai 45 ° pembukaan injap. Ia menunjukkan pengawal berjaya membuka dan menutup dimana ralat purata kadar pembajaan untuk setiap bukaan adalah 1.38% dan 0.92%. Penyembur galas VRA juga telah dibandingkan dengan peneymbur galas biasa untuk menentukan kecekapan penyembur galas VRA. Keputusan menunjukkan pengurangan baja yang digunakan oleh penyembur galas VRA sehingga 27. 3% berbanding menggunakan penyembur galas biasa dan ia boleh membantu petani untuk

mengamalkan konsep pertanian jitu dan menjimatkan penggunaan baja. Jadi, penyembur galas VRA yang cukup kecil yang akan dikendalikan oleh seorang petani dan datang dengan beberapa kepintaran telah berjaya dibangunkan.

ACKNOWLEDGEMENTS

In the Name of God, Most Gracious, Most Merciful

I would like to express my full gratitude and praise to Allah who has guided me along the journey of completing this thesis study. Every person and detail that has come along of this work is a result of His blessings. My family, especially my parents, Shamshi Abd Wahab and Paridah Hamid have supported me along the way with their forbearance and countless efforts to get me through this undertaking journey such as providing me advices, financial support and much more that cannot be written down in a single page. I am forever indebted to them. They deserve my gratitude after Allah and His Messenger.

I wish to thank my committee members who were more than generous with their expertise and precious time. A special thanks to Dr. Muhammad Razif Bin Mahadi @ Othman, my committee chairman for his countless hours of reflecting, reading, encouraging, supporting, and most of all patience throughout the entire process. Thank you Dr. Aimrun Wayayok and Dr. Ahmad Fikri Abdullah for agreeing to serve on my committee.

Besides, I would like to thank Faculty of Engineering of University Putra of Malaysia which provided me a good environment and equipment in successfully completing this project. Furthermore, I would like to thank very helpful technicians, Mr. Anuar and Mr. Hamed for their unlimited support. I also would like to thanks my best friends, Devi Murni Tajudin, Kesuma Dewi Tajudin and Hassuhaida Abd Halim for their moral support and everything. Thank you very much.

I certify that a Thesis Examination Committee has met on 21 April 2017 to conduct the final examination of Siti Mariam binti Shamsi on her thesis entitled "Design and Development of an Automated Mechanical Valve for Variable Rate Knapsack Sprayer" 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:

Khalina binti Abdan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Samsuzana binti Abd Aziz, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Darius El Pebrian, PhD
Senior Lecturer
Universiti Teknologi MARA
Malaysia
(External Examiner)

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

Date: 4 September 2017

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:

Muhammad Razif Bin Mahadi @ Othman, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ahmad Fikri Abdullah, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: 26/9/17

Name and Matric No: Siti Mariam binti Shamsi (GS 37536)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of
Chairman of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

Signature: _____
Name of
Member of
Supervisory
Committee: _____

TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MADA	Muda Agricultural Development Authority
KADA	Kemubu Agricultural Development Authority
IADA KERIAN	Kerian Integrated Agricultural Development Area
IADA BLS	Barat Laut Selangor Integrated Agricultural Development Area
IADA P.Pinang	Pulau Pinang Integrated Agricultural Development Area
IADA Seberang Perak	Seberang Perak Integrated Agricultural Development Area
IADA KETARA	Northern Terengganu Integrated Agricultural Development Area
IADA Kemasin Semerak	Kemasin Semerak Integrated Agricultural Development Area
PITCOS©	Precision Irrigation Tertiary Canal off-take Structure
ViRaS	Virtual rainfall stations with Radar-derived Rainfall data
ANOVA	Analysis of variance
SPSS	Statistical package for the social science
FAO	Food and Agriculture Organization
UN	United Nations
PF	Precision Farming
GIS	Geospatial Information System
GNSS	Global Navigation Satellite Systems
VRT	Variable Rate Technology
VRA	Variable Rate Applicator
EC	Electrical conductivity
GPS	Global Positioning System
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
DC	Direct Current
LCD	Liquid Crystal Display
PMW	Pulse Width Modulation
RTK	Real Time Kinematics
MARDI	Malaysian Agricultural Research and Development Institute

CHAPTER 1

INTRODUCTION

1.1 Background

Food and Agriculture Organization of the United Nation (FAO) estimates the number of population will reach 9.6 billion people in 2050. This will impose a great challenge to the agriculture sector to provide sufficient food. An increase of 70 % in food production is estimated at 2050, and this target has to be achieved despite the limitations in agricultural land availability, the increase in fresh water demand (agriculture uses 70 % of freshwater supply in the world) and other factors that are unpredictable, such as the effect of climate change as reported recently by the United Nations (UN) may result in changes to seasonal events in the life cycle of plants and animals.

Similar to other Asian countries, rice is a major crop in Malaysia that provides the source of nutrition to the population. Rice cultivation applies about 9.81% of all fertilizers used in the region as shown in Figure 1.1. Although rice farmers generally recognize the importance of fertilizer for supplying essential nutrients vital to crops growth and sustaining high yield, more often than not the applications are done unsystematically. Because of that, the operational cost remains high and fertilizer usage is more than it is actually needed.

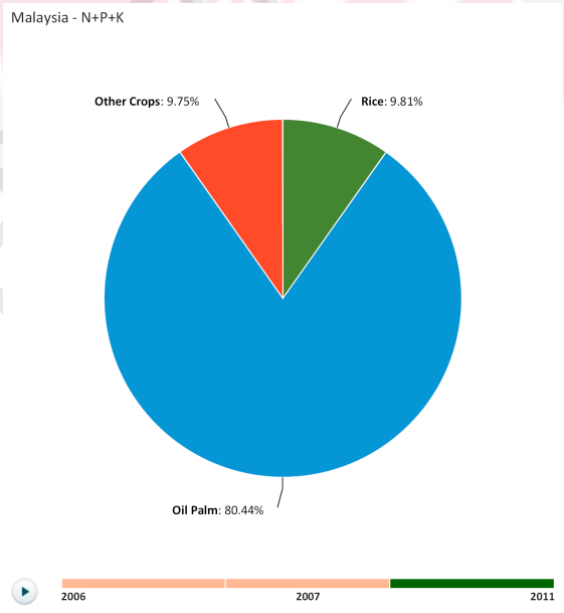

Figure 1.1: Total fertilizer use by crop in Malaysia
(Assessment of Fertilizer Use by Crop at the Global Level 2011, knoema.com)

One way to address these issues and improve the quality and quantity of agricultural production is by implementing sensing technology. Hence, farm management is integrated with technology. This is also known as precision farming.

Patil Shirish S. et al., (2013) stated that precision farming (PF) is a management philosophy that utilized scientific data, information technology and advanced mechanization in order to increase profit, decrease operational cost and provide sustainable environmental impact. The core concept is based on novel and complete system approach which depends on integration of various technologies. Some of these Geospatial Information System (GIS), Global Navigation Satellite Systems (GNSS), computer modeling, and multispectral ground based imaging, airborne and satellite remote sensing system, field robotics, variable rate technology, and advanced information processing for timely in-season crop management. Precision farming aims to achieve the following objectives: increased productivity and sustainability, a better yield quality, effective and efficient pest and nutrient management, energy, water and soil conservation, and surface and ground water conservation. The application of precision agriculture enables farmers to reduce wastage but at the same time optimizing their profit.

Environmental preservation is also a major concern in the developed countries while at the same time given preference to high yield with high usage of inputs such as fertilizers and pesticides. In addition to sustaining a high yield, precision farming was also used as a measure to preserve the environment. Total fertilizer nutrient (N+P+K) consumption in 2013 was 5.4 million metric tonnes and expected to maintain or increase by the end of 2016 (Liri, 2015). However, with regular use and consistently, these chemicals not only increase production costs, but also increase the environmental threat in terms of soil and groundwater contamination (Yamin et al., 2016).

Variable Rate Technology (VRT) is a vital component in precision farming. It involves the use of past and/or real site-specific information in applying the required amount of an agricultural input such as herbicides, fertilizers, and pesticides at a specific site within the farm. Technically, the development of the hardware and software for variable rate application of agricultural inputs is a vital aspect in the development of precision farming technology.

VRT provides a means of applying fertilizer only in amounts and locations where they are needed (Wollenhaupt et al., 1993). The basic logic of VRT fertilizer application is addition of more fertilizers to higher productivity areas and reduction in fertilizer application to low productivity areas (Smith, 1998). Agronomically, targeted application of fertilizer is deployed in variable-rate application of fertilizer based on prehistoric soil test data and other related databases. Economically, variable-rate systems provide a mean for fertilizer dollars to be used on areas with higher productivity within a field where they will provide a better response rather than having an unlikely feedback. Environmentally, variable-rate systems aid helps in preventing over-application of fertilizer where the consequences could lead to environmental degradation.

1.2 Research problems

Spatial variability of nutrients in soil exists even in a small farm such as a one hectare field. This means any farm should have an uneven fertility potential (Radite et al., 2010). These problem can be solved through precision farming; whereas sensors, navigation systems and machinery are integrated into a system called Variable Rate Applicator (VRA). VRA in PF emphasis on optimizing input such as fertilizer. Once hone in to the soil requirement, the yield will be maximized. However in rice farming there is a further challenge towards implementing this concept. For instance, wet soil and standing water depth during growing season preventing the use of heavy machinery as they would rather sink and stuck in the field. In fact, the constraint to practicing precision farming in rice is not feasible due to lacking of VRA compatible devices.

In Malaysia, majority of the rice farmers have never used soil or plant testing to adjust fertilizer applications, in other words PF concept has not been practiced. Shahrina et.al (2014) mentioned that the average income earned by paddy farmers in Malaysia is RM1400.00 per month which is considerably low where farmers are less advantaged to invest in PF concept.

The machinery costs also be one of the key factor in improving the profitability of a farm. On many farms 30-40% of the fixed costs can be allocated to farm machinery. If labor is included, the figure can be as high as 60-65%. On some farms labor and machinery costs may reach a staggering 90% (Andrew, 2000).

However, the most critical operation requiring mechanization is therefore spraying of chemicals. It needs for mechanization is as high as 80.76% that spraying operation currently done by the farmers is not only laborious and tiring but also poses significant threat to the health of the farmers due to their prolonged exposure to the chemicals during application.

Most of the farm areas in Malaysia own by smallholders is within five to 10 acres. The small areas may not be suitable for large machinery and in fact small and portable machinery are more convenient. In general, this project is aimed in adopting PF based on cheaper, convenient, and easy to be operated and handle.

1.3 Objective of the study

The main objective of this study was to design, fabricate, and develop a new, inexpensive and convenient VRA knapsack sprayer to be attached to the common knapsack for agricultural works. The VRA knapsack sprayer is basically a device equipped with a controller system that would be able to perform spray with accuracy as required by its respective zone. The following are the specific objectives of the study;

1. To design and develop an automatic mechanical valve for variable rate knapsack sprayer.

2. To evaluate spray performance of the developed automatic mechanical valve at various degree of opening outlet.

1.4 Scope of the study and limitations

In developing this device, the project assumed that the actual fertilizer mapping was done prior to application, through methods such as electrical conductivity (EC) reading, GIS and remote sensing. Therefore, this research using the electric knapsack sprayer and focused only on the development of the controller device. The study concentrated on the design for flow control, integration with positional tracking on the ground based on Global Positioning System (GPS) signal versus a pseudo map that described the target fertilizer zone.

1.5 Thesis layout

This thesis consists of five chapters and are summarized as follows:

a) Chapter 1 explain about the concept of VRA in PF and how the technology and in pursuant of it, the sprayers role in VRA. It also includes the aim and objectives and general overview of the research.

b) Chapter 2 presents the literature review. This chapter review the implication of serving precision farming, technologies behind it and also the reviews the background of variable rate application system researches.

c) Chapter 3 discusses about the proposed method that will be required to design the sprayer. In this chapter the necessary dynamic characteristics of the sprayer components are determined. It explains about the development of the global positioning system, integration between map data and the GPS and performance evaluation of the sprayer mechanism.

d) Chapter 4 gives the results of calibrating each components. It evaluates the performance of the system.

e) Chapter 5 summarizes the conclusion, recommendations and suggestions on how the systems can be improved to suit with the desired application. The closure of this chapter ends with suggestion for future improvements of this research.

REFERENCES

Aimrun. W., Amin. M.S.M, Ezrin. M.H, Mastura. M (2011). Paddy soil properties and yield characteristics based on apparent electrical conductivity zone delineation for a humid tropical rice farm. *African Journal of Agricultural Research, Vol. 6(23)*, pp 5339-5350

Ajay. V. R., S. m. Deshmukh, (2015). Design and evaluation of map-based control system for application of fertilizer. *International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) volume 4*, Issue 4

Alam, M. M., C. Siwar, M. W. Murad, R. I. Molla and M. E. b. Toriman (2010). "Socioeconomic profile of farmer in Malaysia: study on integrated agricultural development area in North-West Selangor". *Agricultural Economics and Rural Development, 7(2)*, 249-226

Ali, A.-S., M. Altarawneh and E. Altahat (2012). "Effectiveness of agricultural extension activities". *American Journal of Agricultural and Biological Sciences, 7(2)*, 194-200

Amin MSM, MK Rowshon and W Aimrun, (2011). *Paddy Water Management for Precision Farming of Rice*. In Chapter 6, Current issues of Water Management, Dr. Uli Uhligh (Ed.), ISBN: 978-953-307-413-9. InTech Open Access

Andrew. L. (2000). *Farm Machinery: Selection, Investment and Management*. Farming Press

Chan. C. W. (2013). Precision farming: The way forward in mechanized agriculture. *Research Inaugural Lecture*, 978-967-936-613-6

Chan. C. W. (2008). Field evaluation of two machine navigation systems for variable rate application. *J. Trop. Agric. and Fd. Sc. 36(1)*, 135– 143

Chen. H. T, Z. Ying-zi, H. Shoy-yin, J. Wen-yi, O. Bin-lin, D. Guo-qiang, Z. Ji-cheng, (2015). Design and experiment of slave computer control system for applying variable-rate liquid fertilizer. *Journal of Northeast Agricultural University. Vol. 22, No. 2*, 73-79

Clark, R.L., and McGuckin, R.L., (1996). Variable rate application equipment for precision farming. Written for presentation at the Beltwide Cotton Conference

Ehtesham. F., M. Loghavi, (2012). Design, development and field evaluation of a map-based variable rate granular fertilizer application control system. *Agricultural Engineering International: CIGR Journal, 14(4)*, 255-261

Essays, UK. (November 2013). Famous Fertilizer Used In Malaysia

Marketing Essay. Retrieved from https://www.ukessays.com/essays/marketing/famous-fertilizer-used-in-malaysia-marketing-essay.php?cref=1

Ezrin MH, MSM Amin, SK Bejo, W Aimrun (2013). Development of on-the-go soil nutrigen mapping system for site specific management. *Journal of the Institution of Engineers, Malaysia (IEM) VOL 74(1)*

Fulton, J. P., S. A. Shearer, S. F. Higgins, M. J. Darr, and T. S. Stombaugh, (2005). Rate response assessment from various granular VRT applicators. *Transactions of the ASAE 48(6)*, 2095-2103

Honglei. J, F. Xianzhen, Q. Jiangtao, L. Xinhui, (2014). Research and application of variable rate fertilizer applicator system based on a DC motor. *International Federation for Information Processing. CCTA 2013, Part II, IFIP AICT 420*, pp. 381-391

J. F. Reyes, Wilson. E, Daniel. C, Rodrigo. O, (2015). Field testing of an automatic control system for variable rate fertilizer application. *Computers and Electronics in Agriculture 113*, 260-265

Joao. R. S. M, C. D. Raimo, R. R. da. C. Cavalcanti, M. A. Montezuma, E. A. C. de Souza, (2016). Study of an electromechanical system for solid fertilizer variable rate planting. *African Journal of Agricultural Research. Vol. 11(3)*, pp. 159-165

John K. Schueller, Min. W. W. (1994). Spatially-variable fertilizer and pesticide application with GPS and DGPS. *Computers and Electronics in Agriculture 11*, 69-83

Lang. C, W. Jinwu, S. Yeqiong, X. Xiaohuan, (2011). Design and development control system for deep-fertilization variable liquid fertilizer applicator. *Second International Conference on Digital Manufacturing & Automation*

Liang. C, Xi. Wang, (2010). Variable-rate fertilization control system based on fuzzy PID control strategy. *International Conference on Electrical on Control Engineering*

Liu, Z. et al., 2014. A simple assessment on spatial variability of rice yield and selected soil chemical properties of paddy fields in South China. *Geoderma, 235-236*, pp.39–47

Malaysia Agricultural Directory and Index (2013)/2014), *Agriquest Sendirian Berhad*, Kuala Lumpur

Mad Nasir. S, Nurul Nadia. R, Alias. R & Zainalabidin. M (2015). The impact of fertiliser subsidy and new variety of paddy on malaysian paddy/rice industry. *Pertanika J. Soc. Sci. & Hum. 23 (S)*, 1 – 10

Man, N. (2009). "Factors affecting the decision making in off farm

employment among paddy farmers in Kemasin Semerak". *Pertanika Journal of Social Sciences & Humanities 17(1)*, 7-15

Manjeet. S, K. Amandeep, S. Ankit, P. K. Mishra, S. Karun, (2012). Development and evaluation of an experimental machine for variable rate application of granular fertilizers. *Sixth International Conference on Sensing Technology (ICST)*

Mohd Syaifudin. A.R., Mohd Sharil Shah. M.G., Teoh. C.C., Mohamad Aufa. B., Mohd Nadzim. N., Fakrul Radzi. F.Z., Mohamad Najib. M.Y., Fairol Zamzuri. C.S., Abu Hassan. D., and Mohd Haffiez. A.S. (2016). Variable rate application of fertilizer in rice precision farming. *International Conference on Agricultural and Food Engineering*

Mohd Tohit Bin Liri, (2015). The Malaysian Fertilizer Market. Fertilizer Industry Association of Malaysia.

Ning. S, Xu. T, Song. L, (2015). Development of a variable rate fertilization control system based on DC motor for use on granular fertilizer applicator. *Fifth International Conference on Communication Systems and Network Technologies*

P. A. S. Radite, W. Hermawan, B. Budiyanto, A. Azis, (2010). Development of variable rate fertilizer applicator module based on 8-bit embedded system. *AFITA 2010 International Conference, the Quality Information for Competition Agricultural Based Production System and Commerce*

Paddy Statistics of Malaysia (2013), Department of Agriculture Peninsular Malaysia, 2014. ISSN: 1985-2770

Patil Shirish S. and Satish A. Bhalerao, (2013). Precision farming: The most scientific and modern approach to sustainable agriculture. *Int. Res. J. of Science & Engineering, Vol.1 (2)*, 21-30

Patrick Heffer, (2013). Assessment of Fertilizer Use by Crop at the Global Level 2010-2010/11. International Fertilizer Industry Association (IFA)

Shahrina. M. N, Shuhaida. M. N, Moho. S. M. S (2014). Innovation diffusion of new technologies in the malaysian paddy fertilizer industry. *2nd World Conference on Business, Economics and Management - WCBEM 2013. Procedia - Social and Behavioral Sciences 109*, 768 – 778

Smith, J. (1998). Enhancing Environmental Stewardship via Site-Specific Agriculture. *Fluid Journal 6*, 10-12

Use of Remote Sensing and GIS technologies in Precision Farming for Rice Crop in Malaysia (July – December 2001) Newsletter of the Malaysian Centre for Remote Sensing, (MACRES) ISSN 1511-1806

Waleed, A. R. M. and MSM Amin and G.A Halim, ARM Shariff, W.

Aimrun (2009). Calibrated radar-derived rainfall data for rainfall-runoff modeling. *European Journal of Scientific Research, 30(4)*, Pp. 608-619. ISSN 1450-216X; ESSN: 1450-2-2X

William.D (2009), Article of Economic Time, International Crop Research Institute for Semi-Arid Tropics, (ICRISAT)

Wollenhaupt, N.C., R.P. Wolkowski, and H.F. Reetz. (1993). Variable-rate fertilizer application: update and economics. *In Proceedings 21st North Central Extension-Industry Soil Fertility Conference. Potash and Phosphate Institute, Manhattan, Kansas, 9*, 139-150

Yamin et al., (2016) Vrt liquid fertilizer applicator for soil nutrient management. *Jurnal Teknologi (Sciences & Engineering) 78:1–2*, 73–78

Yazid Abdullah (2014). PITCOS – Precision Irrigation tertiary Canal Off-take Structure, unpublished

Ying. J. Y, Zhen. Y. G, Shu. H. Z. (2013). Variable rate fertilization system based on ARM and its realization. *Applied Mechanics and Materials*, 303-306, 1465A

Zainalabidin. M, Rika. T, Mad Nasir S. and Ismail .A .L (2016). Paddy Farmers' Sustainability Practices in Granary Areas in Malaysia. *Resources, 5, 17*; doi:10.3390/resources5020017