INTEGRATION OF PRECISION AGRICULTURE STRATEGIES TO IMPROVE COCOA PRODUCTIVITY AND QUALITY

TEE YEI KHENG

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INTEGRATION OF PRECISION AGRICULTURE STRATEGIES TO IMPROVE COCOA PRODUCTIVITY AND QUALITY

By

TEE YEI KHENG

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Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

INTEGRATION OF PRECISION AGRICULTURE STRATEGIES TO IMPROVE COCOA PRODUCTIVITY AND QUALITY

By

TEE YEI KHENG

November 2019

Chair : Siva Kumar Balasundram, PhD
Faculty : Agriculture

Cocoa industry faces challenges such as high input costs and low cocoa productivity despite pest and disease problem. Currently, cocoa is managed conventionally using labour in farm management, however, more effective production systems need to be identified to increase competitiveness of cocoa supply chain and to sustain high demand in the grinding industry. Thus, precision strategies are built upon modern system approaches which aim to transform the cocoa production system towards low input, high efficiency and sustainable cocoa production. So far, there is no research focus on applying precision technology in the cocoa production chain in Malaysia. In this research, the studies were designed at three different stages of cocoa production system, from young cocoa seedlings at the nursery to mature cocoa trees and finally cocoa bean quality, targeting the issues faced by the cocoa industry at each of the production stages through precision cocoa management. Remote sensing was applied to determine the reflectance in young cocoa seedlings subjected to N and K deficiency and the study was supported with physical (height, girth and leaf area) and physiological (plant net photosynthesis, transpiration rate and chlorophyll content) data as plants developed. A total of 72 grafted cocoa seedlings with clone MCBC10 were planted in the greenhouse. The seedlings were six months old after sowing with three treatments (T1: complete nutrients of nitrogen, phosphorus and potassium; T2: nitrogen deficiency; T3: potassium deficiency) arranged in a randomized complete block design. From this study, hyperspectral reflectance showed that plants with nutrient deficiency had higher reflectance at the visible range of 550 nm while plants with complete fertilizers achieved the highest peak of reflectance in the near-infrared 700-2500 nm ranges. Cocoa seedlings with nitrogen and potassium deficiency showed a shift in the red edge with greater reflectance at 675-750 nm. Nitrogen deficiency had the most pronounced effects on growth, net photosynthesis, transpiration rate and chlorophyll content at young cocoa seedlings. The output of the study was able to detect seedlings with nutrient deficiency at early stages in order to ensure seedlings planted by the smallholders are in healthy condition. A multivariate geospatial approach was used to quantify the spatial and temporal variability of soil properties, cocoa pod borer infestation rate and cocoa fresh bean weight at two different commercial planting

systems of mature cocoa. From the study, precision cocoa farm management helped to increase crop yield by 58.8 and 51.1% at cocoa-gliricidia and cocoa-coconut, respectively, might be due to the effective pest control in the critical zone and site-specific fertilization, especially during high peak harvesting season of cocoa. During harvesting, bean quality is an important factor that influences for higher pricing and the quality is affected by the maturity stages during harvesting. Hence, this study was carried out to determine the optimum harvest period for cocoa using a non-destructive method of multi-parametric sensor. From this study, flavonol accumulated as cacao pods developed, however, chlorophyll and nitrogen balance index declined as pods reached maturity at four months after pod emergence. Post-harvest bean quality tests indicated that pods harvested at the mature stage of four months after pod emergence met the standards certified by the Malaysian Standard and the bean quality is as good as beans harvested at the ripe stage of five months after pod emergence.

Abstraktesis yang dikemukakankepadaSenatUniversiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENERAPAN STRATEGI PERTANIAN PERSIS DALAM PENINGKATAN PRODUKTIVITI DAN KUALITI KOKO

Oleh

TEE YEI KHENG

November 2019

Pengerusi : Siva Kumar Balasundram, PhD
Fakulti : Pertanian

Industri koko menghadapi pelbagai cabaran seperti kos input pertanian yang tinggi dan produktiviti koko yang rendah selain serangan serangga dan penyakit. Sehingga hari ini, koko masih diurus menggunakan cara konventional dengan menggunakan sumber tenaga buruh dalam pengurusan aktiviti ladang koko. Akan tetapi, satu sistem yang lebih efektif perlu dikenalpasti supaya dapat meningkatkan persaingan dalam rangkaian sektor pengeluaran koko bagi memastikan kelestarian permintaan koko yang tinggi dalam industri hiliran koko. Oleh itu, strategi persis telah dibina atas sistem pengeluaran moden yang bertujuan untuk mengubah sistem pengeluaran koko ke arah input kos rendah, tahap efisien yang tinggi serta pengeluaran koko yang lestari. Setakat ini, tiada kajian yang fokus kepada aplikasi teknologi persis dalam pengeluaran koko di Malaysia. Pada peringkat muda anak benih koko, makro-nutrien seperti nitrogen dan potasium merupakan elemen yang akan mempengaruhi pertumbuhan, penampilan dan yang paling penting adalah hasil tanaman koko selepas anak benih tersebut ditanam di ladang. Walaubagaimanapun, simptom kekurangan makro-nutrien yang ditunjukkan melalui fizikal anak benih adalah lambat dan analisis nutrien mengambil masa yang panjang. Oleh itu, objektif kajian ini adalah untuk mengesan perubahan pada spektrum pancar, pertumbuhan pokok dan ciri-ciri fisiologi antara pokok koko yang diberikan nutrien lengkap dan pokok koko yang mengalami kekurangan nutrien yang spesifik seperti nitrogen dan potasium. Anak benih tersebut berumur enam bulan selepas biji koko disemai dengan aplikasi tiga rawatan (T1: nutrien lengkap dengan nitrogen, fosforus dan potasium; T2: kekurangan nitrogen; T3: kekurangan potasium) di mana anak benih koko disusun dalam rekabentuk blok secara rawak.Melalui kajian ini, refleksi '*hyperspectral*' menunjukkan pokok yang mengalami kekurangan nutrien mempunyai bacaan spektrum pancar yang lebih tinggi pada lingkungan spektrum 550 nm manakala pokok koko dengan nutrien lengkap mempunyai spektrum pancar yang tinggi pada inframerah dalam linkungan 700–2500 nm. Pokok yang mengalami kekurangan nitrogen mempunyai kesan yang ketara pada pertumbuhan pokok, fotosintesis, kadar transpirasi dan kandungan klorofil pada anak benih koko. Seterusnya, satu pendekatan menggunakan '*geospatial*' untuk menganalisa variasi '*spatial*' dan '*temporal*' telah dijalankan dengan tumpuan kajian pada ciri-ciri tanah,

tahap serangan ulat pengorek buah koko dan hasil berat basah koko pada dua sistem tanaman komersil koko dengan tanaman pokok koko matang. Hasil kajian menunjukkan pengurusan persis koko telah meningkatkan hasil koko sebanyak 58.8% dan 51.1% bagi plot koko-gliricidia dan koko-kelapa masing-masing. Semasa aktiviti penuaian, kualiti biji koko merupakan satu faktor penting untuk mendapatkan harga yang tinggi dan kualiti biji koko dipengaruhi oleh tahap kematangan buah semasa penuaian. Daripada kajian ini, flavonol berkumpul semasa tumbesaran buah koko, akan tetapi, kandungan klorofil dan '*nitrogen balance index*' menurun semasa buah koko mencapai kematangan pada empat bulan selepas pembentukan buah. Ujian biji koko lepas tuai menunjukkan buah yang dituai pada tahap kematangan empat bulan selepas pembentukan buah telah mencapai piawaian pensijilan sebagaimana yang ditentukan di dalam Piawaian Malaysia. Manakala kualiti biji koko yang dituai sebulan lebih awal adalah sama kualiti dengan biji koko yang dituai pada peringkat cukup masak, iaitu lima bulan selepas penghasilan buah.

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I certify that a Thesis Examination Committee has met on 21 November 2019 to conduct the final examination of Tee Yei Kheng on her thesis entitled "Integration of Precision Agriculture Strategies to Improve Cocoa Productivity and Quality" 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 Doctor of Philosophy.

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

Viacheslav I. Adamchuk, PhD
Associate Professor
Faculty of Agriculture and Environmental Sciences
McGill University
(External Examiner)

ZURIATI AHMAD ZUKARNAIN, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

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

Abdul Rashid Mohamed Shariff, PhD
Professor Sr Gs
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Phebe Ding, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
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Signature: _____
Name of Member of Supervisory Committee: Prof. Sr Gs Dr. Abdul Rashid Mohamed Shariff C. Eng.

Signature: _____
Name of Member of Supervisory Committee: Assoc. Prof.Dr. Phebe Ding

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
TE	Trace elements
NIR	Near-infrared
VNIR	Visible near infrared
SWIR	Short-wave infrared
PPFD	Photosynthetic photon flux density
VPD	Vapor pressure deficit
RCBD	Randomised complete block design
DMRT	Duncan's multiple range test
PSII	Photosystem II
CPB	Cocoa pod borer
MCB	Malaysian Cocoa Board
GNSS	Global positioning system
GIS	Geographical information system
ADSI	Average damage severity index
SCL	Sclerotic layer
ME	Mean error
MSE	Mean squared error
RMSSE	Root mean square standardized error
EDA	Exploratory data analysis
ESD	Extreme studentized deviate
RF	Red fluorescence
FRF	Far-red fluorescence
ANTH	Anthocyanin
FLAV	Flavonol
CHL	Chlorophyll
NBI	Nitrogen balance index
FB	Fully brown
PP	Partly purple
FP	Fully purple
UPLC	Ultra performance liquid chromatography
UV	Ultraviolet
CHS	Chalcone synthase
CHI	Chalcone isomerase
F3H	Flavanone-3-hydroxylase
FLS	Flavonol synthase
FI	Fermentation index

CHAPTER 1

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an understorey forest species belonging to the family of Malvaceae which is planted extensively in Africa, America, Asia and Oceanic countries, including Indonesia, Malaysia and the Philippines. Cocoa beans are primarily processed to produce semi-finished products such as cocoa mass, butter, cakes and powder, which are used as ingredients in the manufacture of food, beverages and chocolates. With increasing demand of chocolates and cocoa semi-finished products, cocoa becomes the third major commodity in Malaysia after palm oil and rubber. Cocoa was introduced to Malaysia as a commercial crop in 1950 and was one of the crops for agricultural diversification in the Second Malaysia Plan (1971–1975). Cocoa has been cultivated extensively in Malaysia from 123,855 ha in 1980 to 414,236 ha in 1989 due to the unprecedented high cocoa prices (Lee 2013).

Unfortunately, the cocoa industry faces disconcerting scenarios with a tremendous decline in planted area from 393,465 ha in 1990 to 190,127 in 1995 and as of 2017, the cocoa planted area was reduced to 17,554 ha. Cocoa bean production declined from 250,000 tonnes in 1990 to 1,029 tonnes in 2017. However, there is an apparent uptrend in the cocoa grinding industry and is expected to grow further in future between 350,000 to 400,000 tonnes. It is believed that the major gap between the supply of low bean production and high demand of bean grinding is caused by poor world cocoa prices, severe infestation of cocoa pod borer (CPB), escalating production costs, labor constraints and competition of land use from oil palm cultivation (Lee et al. 2013).
As an industrial crop, cocoa trees can be planted in monoculture or intercropped with other economical crops such as coconut, durian, oil palm and rubber with favorable commodity prices to increase income of smallholders. Currently, cocoa is planted by smallholders on an average of one hectare of land and cocoa is managed conventionally using labor for manuring, pruning, weeding and harvesting. However, the aging smallholder population and labor constraints are causing the failure in well managed cocoa farms. In this aspect, efforts need to be focused in increasing cocoa productivity and maintaining high quality of cocoa beans with lower environmental impacts. For Malaysia to revitalize agricultural sectors, the government realizes the importance of creating a comprehensive overhaul in production agriculture by adopting smart farming or precision agriculture in order to move forward. Precision agriculture is believed to offer solutions to the problems faced by the cocoa industry.

Precision agriculture is a modern integrated technology that allows site- and time-specific agriculture practices. Application of precision agriculture in cocoa production is regarded as a game changer in the cocoa industry. The main targets of precision agriculture include cocoa productivity, labor constraints and sustainable green environment of cocoa planting. Technologies such as global positioning system (GNSS), geographical information system (GIS), proximal and remote sensing might be able to provide new levels of intelligent management for agriculture so as to

improve efficiency in crop and soil testing, fertilization, pest and disease control and harvesting efficiencies. Precision agriculture has been well adopted in developed economies such as United States of America, Canada and the European Union. A study by Lambert and Lowenberg-DeBoer (2000) confirmed that 63% of the farmers obtained profits and showed a payoff after adoption of precision agriculture. In the long run, farmers benefit from the precision farm management as cropping becomes more profitable. Maximized resource allocation based on optimal fruiting densities in the farm will save farmers money and labor, and eventually, increase product quality.

In 2016, the Malaysian government identified an opportunity to increase the competitiveness of Malaysian cocoa smallholders by targeting the challenges incurred along the cocoa production chain, from young cocoa seedling stage at the nursery to bean quality through precision technology under 11th Malaysian Plan (2016–2020). The five year program aimed transforming the cocoa upstream industry using various innovative approaches in cocoa field management and production system. The government believes that precision cocoa farm management has a strong potential to be scaled up in the future, and this study identified strategies in three key production stages of cocoa. In this context, precision agriculture should provide solutions to sustainable cocoa production. Questions that remain unanswered include; What caused the tremendous decline in cocoa planting area and bean production in Malaysia? What should be the most effective solution to increase cocoa productivity while conserving the ecological biodiversity in cocoa planting and thus, create sustainable development of cocoa production in Malaysia? In this study, it is crucial to scientifically validating the concept of adopting remote sensing and site-specific crop management to test the null hypothesis proposed in this study, i.e. uniform management or conventional methods are the optimal strategy to increase cocoa productivity and bean quality, considering variations are homogenous. While the alternative hypothesis is proposed if the variability can be identified and quantified using precision techniques with rapid and non-destructive methods to increase cocoa productivity and bean quality, then precision cocoa management can be employed in attempts to refute the proposed null hypothesis.

This dissertation shows how precision agriculture techniques can be applied at three production stages of cocoa; from young cocoa seedlings at the nursery to mature cocoa trees at the field and finally the cocoa beans harvested from the pods to improve the cocoa productivity and bean quality. The organizational of the thesis is as follows. Chapter 1 of the thesis comprised history and current scenario of cocoa industry in Malaysia, background of the challenges being faced by the industry, justifications on the reason to shift conventional to precision farming in cocoa management and objectives of the study. Chapter 2 provides literature review of the cocoa as one of the important commodities in Malaysia, existing technologies applied in the farm for cocoa sustainability and comparison between conventional and precision approach in field management. Methods carried out in each production system were outlined below to Chapter 3, 4 and 5 (Figure 1). Lastly, Chapter 6 presented the significant and summarized conclusions from each of the studies and recommendations of research for the future.

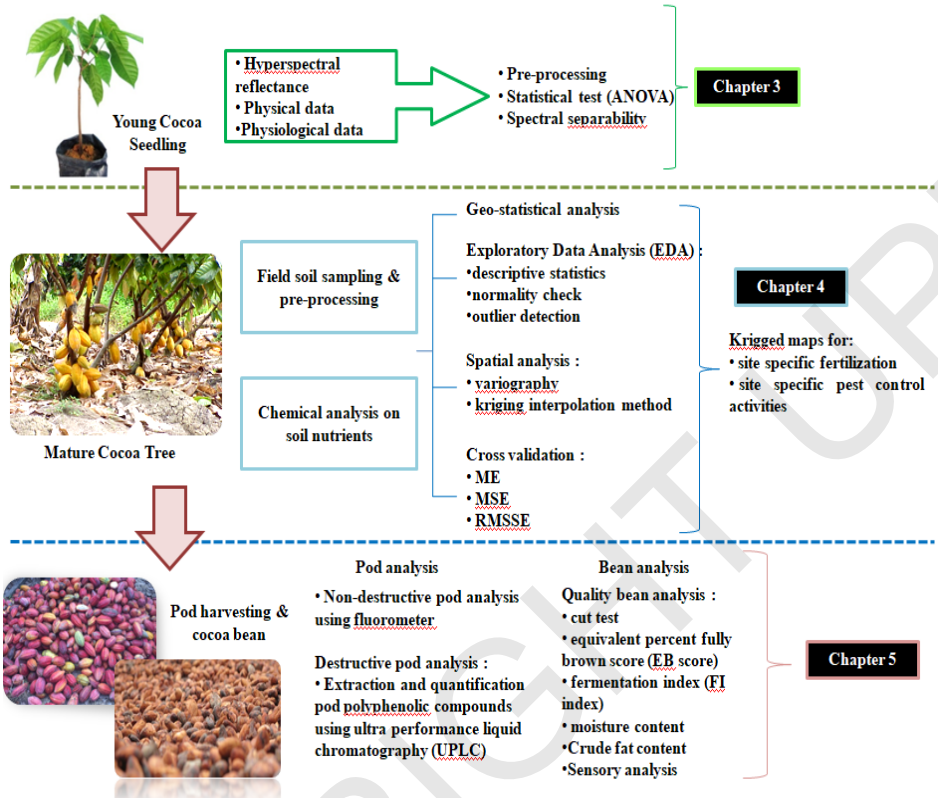

Figure 1: Organizational flow chart of the study

Overall, general objective of the study was to identify precision strategies that can be applied in three main production stages of cocoa with the aims to increase the cocoa productivity and bean quality. Thus, the specific objectives of this study were:

1. To quantify the spectral reflectance response of cocoa to different levels of nitrogen and potassium.
2. To quantify the spatial and temporal variability of soil nutrient, cocoa yield and cocoa pod borer (CPB) infestation under integration system of cocoa-gliricidia and cocoa-coconut.
3. To determine the optimum harvest period of commercial cocoa based on fluorescence indices during cocoa pod development.

REFERENCES

Adams, M. L., Norvell, W. A., Peverly, J. H., Philpot, W. D. (1993). Fluorescence and reflectance characteristics of manganese deficient soybean leaves: Effects of leaf age and choice of leaflet. In *Plant Nutrition: from Genetic Engineering to Field Practice*, ed. N. J. Barrow, pp. 261-264. Kluwer Academic Publishers: Dordrecht.

Adams, M. L., Philpot, W. D. and Norvell, W. A. (1999). Yellowness index: an application of spectral 2nd derivatives to estimate chlorosis of leaves in stressed vegetation. *International Journal of Remote Sensing* 20: 3663-3675.

Adamson, G. E., Lazarus, S. A., Mitchell, A. E., Prior, R. L., Cao, G. H., Jacobs, P. H., Kremers, B. G., Hammerstone, J. F., Rucker, R. B., Ritter, K. A. and Schmitz, H. H. (1999). HPLC method for the quantification of procyanidins in cocoa and chocolate samples and correlation to total antioxidant capacity. *Journal of Agricultural and Food Chemistry* 47:4184-4188.

Adeyeye, E. I., Akinyeye, R. O., Ogunlade, I., Olaofe, O. and Boluwade, J. (2010). Effect of farm and industrial processing on the amino acid profile of cocoa beans. *Food Chemistry* 118: 357-363.

Afoakwa, E. O., Peterson, A. and Fowler, M. (2007). Factors influencing rheological and textural qualities in chocolate – A review. *Trends in Food Science and Technology* 18: 290-298.

Afoakwa, E. O. (2010). Chocolate Science and Technology. Wiley-Blackwell Publishers: Oxford, UK.

Afoakwa, E. O., Peterson, A., Fowler, M. and Ryan, A. (2008). Flavor formation and character in cocoa and chocolate: a critical review. *Critical Reviews in Food Science and Nutrition* 48:840–57.

Afolayan, O. S. (2016). Soil-plant properties degradation in aged cocoa farms in Southwest Nigeria. *Nigerian Journal of Agriculture, Food and Environment* 12(4): 194-199.

Agati, G. and Tattini, M. (2010). Multiple functional roles of flavonoids in photoprotection. *New Phytologist* 186: 786–793.

Alara, O. R., Abdurahman, N. H., Ukaegbu, C. I., Hassan, Z. and Kabbashi, N. A. (2018). Dataset on LC-Q- TOF/MS tentative identification of phytochemicals in the extract of *Vernonia amygdalina* leaf through positive ionization. *Data in Brief* 21: 1686 – 1689.

Albert, L. S. C. and Azhar, I. (2010). Estimating cocoa wet bean loss caused by cocoa pod borer using bootstrap resampling method. *Malaysian Cocoa Journal* 6: 1-12.

Allwood, J. W., Chandra, S., Xu, Y., Dunn, W. B., Correa, E. Hopkins, L., Goodacre, R., Tobin,A.K., Bowsher, C. G. (2015). Profiling of spatial metabolite distributions in wheat leaves under normal and nitrate limiting conditions. *Phytochemistry* 115: 99–111.

Almoosawi, S., Fyfe, L., Ho, C. and Al-Dujaili, E. (2010). The effect of polyphenol-rich dark chocolate on fasting capillary whole blood glucose, total cholesterol, blood pressure and glucocorticoids in healthy overweight and obese subjects. *British Journal of Nutrition* 103: 842–850.

Alverson, W. S., Whitlock, B.A., Nyffeler, R., Bayer, C. and Daum, D. (1999). Phylogeny of the core Malvales: evidence from ndhF sequence data. *American Journal of Botany* 86: 1474–1486.

Amusan, O. A. and Amusan, F. O. (2006). The impact of soil quality on cocoa yield in Nigeria.*Geo-Environment and Landscape Evolution* 98: 443 – 453.

Anita-Sari, I., Susilo, A. W. and Setyawan, B. (2016). Chromatographic identification of leaf color characteristics on fine flavor and bulk cacao as selection indicator. *Pelita Perkebunan* 32: 1–9.

AOAC. (2000). *Official Methods of Analysis of AOAC International*, 17th edition. Gaithersburg, MD, USA.

Aprotosoaie, A. C., Luca, S. V. and Miron, A. (2016). Flavor chemistry of cocoa and cocoa products-an overview. *Comprehensive Reviews in Food Science and Food Safety* 15: 73-91.

Arétouyap, Z., Njandjock Nouck, P., Nouayou, R., Ghomsi Kemgang, F. E., Piépo Toko, A. D. and Asfahani, J. (2016). Lessening the adverse effect of the semivariogram model selection on an interpolative survey using kriging technique. *SpringerPlus* 5: 1-11.

Artés, F. (2002). Analysing Changes in Fruit Pigments, pp. 248-282. Woodhead Publishing Limited: Cambridge.

Askne, J. I. H., Fransson, J. E. S., Santoro, M., Soja, M. J. and Ulander, L. M. H. (2013). Model-based biomass estimation of a hemi-boreal forest from multitemporal TanDEM-X acquisitions. *Remote Sensing* 5(11): 5574–5597.

Ayala-Silva, T. and Beyl, C. A. (2005). Changes in spectral reflectance of wheat leaves in response to specific macronutrient deficiency. *Advances in Space Research* 35: 305–317.

Aziz, N. A., Omar, W., Kassim, R. and Kamarudin, N. (2012). Remote sensing measurement for detection of bagworm infestation in oil palm plantation. *MPOB Information Series* 589: 1511-7871.

Azman, I., Mohd Arif, S. and Mohd Noor, M. (2003). The production costs of oil palm fresh fruit bunches: The case of independent smallholders in Johor. *Oil Palm Industry Economic Journal* 3(1): 1-7.

Balasundram, S. K., Husni, M. H. A. and Ahmed, O. H. (2008). Application of geostatistic tools to quantify spatial variability of selected soil chemical properties from a cultivated tropical peat. *Journal of Agronomy* 7: 82-87.

Balasundram, S. K., Memarian, H. and Khosla, R. (2013). Estimating oil palm yields using vegetation indices derived from QuickBird. *Life Science Journal* 10(4): 851– 860.

Baloch, P. A., Moizuddin, M., Imam, M., Abro, B. A., Lund, J. A. and Solangi, A. H. (2004). Effect of NPK fertilizers and farmyard manure on nut production of coconut (*Cocos nucifera* L.). *Asian Journal of Plant Sciences* 3(1): 91-93.

Bartley, B. G. D. (2005). *The Genetic Diversity of Cacao and Its Utilization*. Wallingford: CABI Publishing.Baud, S. and Lepiniec, L. (2010). Physiological and developmental regulation of seed oil production. *Progress in Lipid Research* 49: 235–249.

Bernaert, H., Blondeel, I., Allegaert, L. and Lohmueller, T. (2012). Industrial treatment of cocoa in chocolate production: health implications. In *Chocolate and health*, eds. R. Paoletti, A. Poli, A. Conti and F. Visioli, pp. 17-30. New York: Springer.

Blackmer, T. M. and Schepers, J. S. (1995). Use of a chlorophyll meter to monitor N status and schedule fertigation of cron. *Journal of Production Agriculture* 8: 56-60.

Bonvehi, S. J. and Coll, V. (2002). Factors affecting the formation of alkylpyrazines during roasting treatment in natural and alkalinized cocoa powder. *Journal of Agricultural and Food Chemistry* 50: 3743-3750.

Booij, R., Kreuzer, A. D. H., Smit, A. L. and van der Werf, A. (1996). Effect of nitrogen availability on dry matter production, nitrogen uptake and nitrogen interception of Brussels sprouts and leeks. *Netherlands Journal of Agricultural Science* 44: 3–9.

Borlaug, N. E. (2000). Ending world hunger. The promise of biotechnology and the threat of antiscience zealotry. *Plant Physiology* 124: 487-490.

Bragazza, L. and Freeman, C. (2007). High nitrogen availability reduces polyphenol content in Sphagnum peat. *Science of the Total Environment* 377: 439-443.

Bruinsma, J. (2009). The Resource Outlook to 2050: By How Much Do Land, Water and Crop Yields Need to Increase by 2050? Expert Meeting on How to Feed the World in 2050, Food and Agriculture Organization of the United Nations, Economic and Social Development Department.

Cakirer, M. S., Ziegler, G. R. and Guiltinan, M. J. (2010). Seed color as an indicator of flavonol content in *Theobroma cacao* L. In *Chocolate, Fast Foods and Sweeteners: Consumption and Health*, ed. M. R. Bishop, pp. 257-270. Nova Science Pub. Inc.: New York.

Cartelat, A., Cerovic, Z. G., Goulas, Y., Meyer, S., Lelarge, C., Prioul, J. L., Barbottin, A., Jeuffroy, M. H., Gate, P., Agati, G. and Moya, I. (2005). Optically assessed contents of leaf polyphenolics and chlorophyll as indicators of nitrogen deficiency in wheat (*Triticum aestivum* L.). *Field Crops Research* 91:35–49.

Carter, G. A. and Knapp, A. K. (2001). Leaf optical properties in higher plants: linking spectral characteristics to stress and chlorophyll concentration. *American Journal of Botany* 88: 677-684.

Cartus, O., Santoro, M. and Kellndorfer, J. (2012). Mapping forest aboveground biomass in the northeastern United States with ALOS PALSAR dual-polarization L-band. *Remote Sensing of Environment* 124: 466–478.

Cathcart, R.J. and C.J. Swanton, 2003. Nitrogen management will influence threshold values of green foxtail (*Setaria viridis*) in corn. *Weed Science* 51: 975- 986.

Chapman, S. C. and Barreto, H. J. (1995). Using a chlorophyll meter to estimate specific leaf nitrogen of tropical maize during vegetative growth. *Agronomy Journal* 89: 557-562.

Cheeseman, E. E. (1944). Notes on the nomenclature, classification and possible relationships of cocoa populations. *Tropical Agriculture* 21: 144–159.

Chemura, A., van Duren, I. and van Leeuwen, L. M. (2015). Determination of the age of oil palm from crown projection area detected from worldview-2 hyperspectralremote sensing data: the case of Ejisu-Juaben district, Ghana. *ISPRS Journal of Photogrammetry and Remote Sensing* 100: 118–127.

Chen, J. Y., Wen, P. F., Kong, W. F., Pan, Q. H., Wan, S. B. and Huang, W. D. (2006). Changes and subcellular localizations of the enzymes involved in phenylpropanoid metabolism during grape berry development. *Journal of Plant Physiology* 163:115- 127.

Chong, K. L., Kasturi, D. K., Christine, P. and Tan, K. P. (2017). A review of remote sensing applications for oil palm studies. *Geo-spatial Information Science* 20(2): 184-200.

Christensen, L. K., Jorgensen, R. N. (2003). Spatial reflectance at sub-leaf scale discriminating NPK stress characteristics in barley using multiway regression (N-PLS). ASAE Annual International Meeting, Las Vegas, Nevada, USA. July 27-30.

Cilia, C., Panigada, C., Rossini, M., Busetto, L., Amaducci, S., Boschetti, M., Picchi, V. and Colombo, R. (2014). Nitrogen status assessment for variable rate fertilization in maize through hyperspectral imagery. *Remote Sensing* 6(7): 6549-6565.

Close, D. C. and Christoper, L. B. (2003). The ecophysiology of foliar anthocyanin. *Botanical Review* 69: 149–161.

Close, D. C., Beadle, C. L., Brown, P. H. and Holz, G. K. (2000). Cold-induced of photoinhibition affects establishment of *Eucalyptus nitens* (Deane and Maiden) Maiden and *Eucalyptus globules* Labill. *Trees* 15: 3241.

Conant, R. T. and Paustian, K. (2002). Spatial variability of soil organic carbon in grassland: implications for detecting change at different scales. *Environmental Pollution* 116: 127-135.

Cooper, K. A., Donovan, J. L., Waterhouse, A. I. and Williamson, G. (2008). Cocoa and health: a decade of research. *British Journal of Nutrition* 99: 1–11.

Curran, P. J., Dungan, J. L. and Peterson, D. L. (2001). Estimating the foliar biochemical concentration of leaves with reflectance spectrometry: testing the Kokaly and Clark methodologies.*Remote Sensing Environment* 76: 349–359.

Curran, P., Dungan, J., Macler, B. and Plummer, S. (1991). The effects of a red leaf pigment on the relationship between red edge and chlorophyll concentration. *Remote Sensing Environment* 35: 69-76.

Czedik-Eysenberg, A., Arrivault, S., Lohse, M. A., Feil, R., Krohn, N., Encke, B., Nunes-Nesi, A., Fernie, A. R., Lunn, J. E., Sulpice, R. and Stitt, M. (2016). The interplay between carbon availability and growth in different zones of the growing maize leaf. *Plant Physiology* 172, 943–967.

Dai, T. B., Cao, W. X. and Jing, Q. (2001). Effects of nitrogen form on nitrogen absorption and photosynthesis of different wheat genotypes. *Chinese Journal of Applied Ecology* 12: 849–852.

Dai, T. B., Cao, W. X., Sun, C. F., Jiang, D. and Jing, Q. (2003). Effect of enhanced ammonium nutrition on photosynthesis and nitrate reductase and glutamine synthetase activities of winter wheat. *Chinese Journal of Applied Ecology* 14: 1529–1532.

Das, P. K., Geul, B., Choi, S. B., Yoo, S. D. and Park, Y. I. (2011). Photosynthesis-dependent anthocyanin pigmentation in Arabidopsis. *Plant Signal Behavior* 6: 23-25.

Daughtry, C. S. T., Walthall, C. L. Kim, M. S. Brown de Colstoun, E. and McMurtrey III, J. E. (2000). Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. *Remote Sensing Environment* 74: 229-239.

de Lima Rhein, A. F. and de Almeida Silva, M. (2017). Nitrogen doses on physiological attributes and yield of sugarcane grown under subsurface drip fertigation. *Journal of Plant Nutrition* 40(2): 227-238.

Degenhardt, A., Engelhardt, U. H., Winterhalter, P., Ito, Y. (2001). Centrifugal precipitation chromatography − a novel chromatographic system for fractionation of polymeric pigments from black tea and red wine. *Journal of Agricultural and Food Chemistry* 49: 1730-1736.

Delgado, R., Martín, P., del Álamo, M. and González, M. R. (2004). Changes in the phenolic composition of grape berries during ripening in relation to vineyard nitrogen and potassium fertilisation rates. *Journal of the Science of Food and Agriculture* 84: 623-630.

Desavathu, R. N., Nadipena, A. R. and Peddada, J. R. (2018). Assessment of soil fertility statusin Paderu Mandal, Visakhapatnam district of Andhra Pradesh through geospatial techniques. *The Egyptian Journal of Remote Sensing and Space Sciences* 21: 73–81.

Di Gioia, F., Simonne, E. H., Gonnella, M., Santamaria, P., Gazula, A. and Sheppard, Z. (2011). Assessment of ionic interferences to nitrate and potassium analyses with ion-selective electrodes. *Communications in Soil Science and Plant Analysis* 41: 1750-1768.

Djoussé, L., Hopkins, P. N., North, K. E., Pankow, J. S., Arnett, D. K. and Ellison, R. C. (2011). Chocolate consumption is inversely associated with prevalent coronary heart disease: the National Heart, Lung and Blood Institute Family Heart Study. *Clinical Nutrition* 30: 182–187.

Englhart, S., Keuck, V. and Siegert, F. (2011). Aboveground biomass retrieval in tropical forests − the potential of combined X- and L-band SAR data use. *Remote Sensing of Environment* 115(5): 1260–1271.

Ersus, S. and Yurdagel, U. (2007) Microencapsulation of anthocyanin pigments of black carrot (*Daucuscarota* L.) by spray drier. *Journal of Food Engineering* 80: 805-812.

Espinosa, J., Mite, F., Cedeno, S., Barriga, S. and Andino, J. (2006). GIS-based site-specific management of cocoa. *Better Crops* 90: 36 – 39.

Fatimah M., A., Bala, B. K., Alias, E. F., Abdulla, I. (2015). Modelling boom and bust of cocoa production systems in Malaysia. *Ecological Modelling* 309: 22-32.

Flint, S. D., Jordan, P. W. and Caldwell, M. M. (1985). Plant protective response to enhanced UV-B radiation under field conditions: leaf optical properties and photosynthesis. *Journal of Photochemistry and Photobiology A* 41: 95–99.

Foody, G. M., Cutler, M. E., McMorrow, J., Pelz, D., Tangki, H., Boyd, D. S. and Douglas, I. (2001). Mapping the biomass of bornean tropical rain forest from remotely sensed data. *Global Ecology and Biogeography* 10(4): 379–387.

Fowler, M. S. (2009). Cocoa beans: from tree to factory. In *Industrial Chocolate Manufacture and Use*, ed. S. T. Beckett. 4th ed., pp 10-48. Oxford: Blackwell Publishing.

Francis, A., Kelvin, L., Sapiyah, S., Nuraziawati, M. Y. and Mohamad Jaafar, H. (2005). Development of planting material programme in the Malaysian Cocoa Board: progress and achievement. In Proceedings of the 4th Malaysian International Cocoa Conference, Sunway Pyramid Convention Centre, Kuala Lumpur. 18-19 July 2005, Sabah: Malaysian Cocoa Board. p. 59-63.

Franco, R., Oñatibia-Astibia, A. and Martínez-Pinilla, E. (2013). Health benefits of methylxanthines in cacao and chocolate. *Nutrients* 5: 4159-4173.

Frankel, E. N. (1996). Potential health benefits of grape and wine antioxidants. In Medically, Is Wine Just Another Alcoholic Beverage, ed. C. S. Stockley, pp. 45-49. Proceeding of the wolf Blass Foundation International wine and health conference.

Frederick, N. N., Frieke, M. B. V. C. and Robert, D. W. (2019). Delineation of cocoa agroforests using multiseason sentinel-1 SAR images: A low grey level range reduces uncertainties in GLCM texture-based mapping. *International Journal of Geo-information* 8: 179 – 204.

Garriga, M., Retamales, J. B., Romero-Bravo, S., Caligari, P. D. S. and Lobos, G. A. (2014). Chlorophyll, anthocyanin and gas exchange changes assessed by spectroradiometry in *Fragaria chiloensis* under salt stress. *Journal of Integrative Plant Biology* 56(5): 505-515.

Gee, G. W. and Bauder, J. W. (1986). Particle-size analysis. In *Methods of Soil Analysis*, ed. A. Klute, pp. 383-411. American Society of Agronomy: Madison, Wisconsin, USA.

Giacometti, J., Jolić, S. M. and Josić, D. (2015). Cocoa processing and impact on composition.In *Processing and Impact on Active Components in Food*, ed. V. R. Preedy, pp. 605-612. London/Waltham/San Diego: Academic Press.

Gianquinto, G., Orsini, F., Fecondini, M., Mezzetti, M., Sambo, P. and Bona, S. (2011). A methodological approach for defining spectral indices for assessing tomato nitrogen status and yield. *European Journal of Agronomy* 35: 135-143.

Gitelson, A. A. and Merzlyak, M.N. (1994). Spectral reflectance changes associated with autumn senescence of *Aesculus hippocastanum* and *Acer platanoides* leaves. Spectral features and relation to chlorophyll estimation. *Journal of Plant Physiology* 143, 286-292.

Gitelson, A. A., Merzlyak, M. N. and Lichtenthaler, H. K. (1996). Detection of red edge position and chlorophyll content by reflectance measurements near 700 nm. *Journal of Plant Physiology* 148: 501-508.

Gocowski, J. and Oduwole, S. (2003). Labor Practices in the Cocoa Sector of Southwest Nigeria with a Special Focus on the Role of Children. STCP/IITA Monograph IITA, Ibadan: Nigeria.

Gorai, A. K. and Kumar, S. (2013). Spatial distribution analysis of groundwater quality index using GIS: a case study of Ranchi municipal corporation (RMC) area. *Geoinformatics & Geostatistics: An Overview* 1(2): 1-11.

Gould, K. S. (2004). Nature's swiss army knife: the diverse protective roles of anthocyanins in leaves. *Journal of Biomedicine and Biotechnology* 5:314-320.

Grotewold E. (2006). The genetics and biochemistry of floral pigments. *Annual Review of Plant Biology* 57: 761–780.

Guyot, S., Marnet, N. and Drilleau, J. (2001). Thiolysis−HPLC characterization of apple procyanidins covering a large range of polymerization states. *Journal of Agricultural and Food Chemistry* 49: 14-20.

Hakkinen, S. (2000). Flavonols and Phenolic Acids in Berries and Berry Products, Ph.D. dissertation, Faculty of Medicine, Kuopio, Finland.

Hammerstone, J. F., Lazarus, S. A., Mitchell, A. E., Rucker, R. and Schmitz, H. H. (1999). Identification of procyanidins in cocoa (*Theobroma cacao*) and chocolate using high-performance liquid chromatography/mass spectrometry. *Journal of Agricultural and Food Chemistry* 47: 490-496.

Harini, S. and Fang, Q. (2013). A spatially disaggregated areal interpolation model using light detection and ranging-derived building volumes. *Geographical Analysis* 45: 238-258.

Hartemink, A. E. (2005). Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystems: A review. *Advances in Agronomy* 86:227-253.

Hawkesford, M., Horst, W., Kichey, T., Lambers, H., Schjoerring, J., Moller, I. S. and White, P. (2012). Functions of macronutrients. In *Marschner's Mineral Nutrition of Higher Plants*, eds. Marschner, H. and P. Marschner, pp. 135-189. Academic Press: San Diego, USA.

Heim, K. E., Tagliaferro, A. R. and Bobilya, D. J. (2002). Flavonoid antioxidants: chemistry, metabolism and structure-activity relationships. *Journal of Nutritional Biochemistry* 13: 572–584.

Helmi, S., Rozita, O., Haya, R., Ling, A. S. C. and Halim, H. (2016). The efficiency of cocoa specific compound fertilizer on cocoa productions. *Malaysian Cocoa Journal* 9(1): 79-85.

Heloir, M. C., Fournioux, C., Barbier, M., Jeandet, P. and Bessis, R. (1998). Endogenous polyamines concentrations in juvenile, adult and micropropagated grapevine (*Vitis vinifera* L. cv. Pinot noir). *Vitis* 37: 61-62.

Hermann, J. H. (2013). Precision in Crop Farming - Site-specific Concepts and Sensing Methods: Application and Results. Springer Dordrecht Heidelberg: London, New York.

Ho, A. D. and Yu. C. C. (2015). Descriptive statistics for modern test score distributions: skewness, kurtosis, discreteness and ceiling effects. *Educational and psychological measurement* 75(3): 365-388.

Hoffmann, H., Nieto, H., Jensen, R., Guzinski, R., Zarco-Tejada, P. and Friborg, T. (2016). Estimating evaporation with thermal UAV data and two-source energy balance models. *Hydrology and Earth System Sciences* 20 (2): 697–713.

Hörtensteiner, S. (2006). Chlorophyll degradation during senescence. *Annual Review of Plant Biology* 57:55-77.

Husain Jahit. (2005). Pertanian Bioteknologi Mampu Beri Hasil Lumayan, Berita Harian. Retrieved on Mac 11, 2009 from http://ms.wikipedia.org/wiki/Pertanian_tepat.

ICCO (2007). Quarterly bulletin of cocoa statistics. Vol. XXXIII, No. 1, Cocoa Year 2006/2007. International Cocoa Organization.

CCO (International Cocoa Organization). Fine or flavor cocoa. Retrieved on 2017, January 3 from https://www.icco.org/about-cocoa/fine-or-flavour-cocoa.html

ICCO (International Cocoa Organization). Growing of cocoa. Retrieved on 2013, March 26 from https://www.icco.org/about-cocoa/growing-cocoa.html.

ICCO (International Cocoa Organization). Pests and diseases. Retrieved on 2015, April 10 from https://www.icco.org/about-cocoa/pest-a-diseases.html

ICCO (International Cocoa Organization). Production of cocoa beans. Retrieved on 2018, May 31 from https://www.icco.org/statistics/productionandgrindings/production.html

Jahurul, M. H. A., Zaidul, I. S. M., Norulaini, N. A. N., Sahena, F., Jinap, S., Azmir, J., Sharif, K. M., Mohd Omar, A. K. (2013). Cocoa butter fats and possibilities of substitution in food products concerning cocoa varieties, alternative sources, extraction methods, composition and characteristics. *Journal of Food Engineering* 117: 467–76.

Jalil, A. B. M. M. and Ismail, A. (2008). Polyphenols in cocoa and cocoa products: is there a link between antioxidant properties and health? *Molecules* 13: 2190–2219.

Jinap, S. and Dimick, P. S. (1990). Acidic characteristics of fermented and dried cocoa beans from different countries of origin. *Journal of Food Science* 55(2): 547-550.

Joanna, O., Ewa, N. and Dorota, Ż. (2015). The content of polyphenolic compunds in cocoa beans (*Theobroma cacao* L.), depending on variety, growing region, and processing operations: A review. *Critical Reviews in Food Science and Nutrition* 55 (9): 1176 – 1192.

Kadow, D., Bohlmann, J., Phillips, W. and Lieberei, R. (2013). Identification of main fine or flavour components in two genotypes of the cocoa tree (*Theobroma cacao* L.). *Journal of Applied Botany and Food Quality* 86: 90-98.

Kang, K. M., Kim, D. J., Kim, S. H. and Moon, W. M. (2016). Doppler velocity characteristics during tropical cyclones observed using ScanSAR raw data. *IEEE Transactions on Geoscience and Remote Sensing*54: 2343–2355.

Keller, M. (2005). Deficit irrigation and vine mineral nutrition. *American Journal of Enology and Viticulture* 56: 267-283.

Kelm, G. L. M., Hammerstone, J. F., Beecher, G., Cunningham, D., Vannozzi, S. and Prior, R. L. (2002). Fractionation of polymeric procyanidins from lowbush blueberry and quantification of procyanidins in selected foods with an optimized normal-phase hplc−ms fluorescent detection method. *Journal of Agricultural and Food Chemistry* 50: 4852-4860.

Kerstetter, R. A. and Poetig, R. S. (1998). The specification of leaf identity during shoot development. *Annual Review of Cell and Developmental Biology* 14: 373-398.

Khairul Bariah, S. (2014). Effect of fermentation duration using shallow box on pH, equivalent percent fully brown and flavour attributes of Malaysian cocoa beans. *Journal of Applied Science and Agriculture* 9(11): 104-108.

Kho, L. K., and Jepsen, M. R. (2015). Carbon stock of oil palm plantations and tropical forests in Malaysia: a review. *Singapore Journal of Tropical Geography* 36 (2): 249–266.

King, N., Seiler, J., Fox, T. R. and Johnsen. K. (2006). The short-tem effects of fertilization on loblolly pine photosynthesis and biomass. In: Conner KF, editor. Proceedings of the 13th Biennial Southern Silvicultural Research Conference. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, p. 113–116.

Knekt, P., Järvinen, R., Seppänen, R., Heliovaara, M., Teppo, L., Pukkala, E. and Aromaa, A. (1997). Dietary flavonoids and the risk of lung cancer and other malignant neoplasms. *American Journal of Epidemiology* 146: 223–230.

Kratzer, U., Frank, R., Kalbacher, H., Biehl, B., Wöstemeyer, J., Voigt, J. (2009). Subunit structure of the vicilin-like globular storage protein of cocoa seeds and the origin of cocoa- and chocolate-specific aroma precursors. *Food Chemistry* 113: 903–913.

Lambert, D. and Lowenberg-Deboer, J. (2000). Precision Agriculture Profitability Review. Site Specific Management Center: Purdue, USA.

Lee, C. H. (2013). Planting cocoa – Challenges and Realities. Retrieved on 2017, September from www.ipicex.com/doc1/2012/onral/planting cocoa-challenges and reality in Malaysia.pdf.

Lee, C. H., Lamin, K., Ramba, H., Maisin, N and Bakar, S. (2013). Cocoa Planting Manual: Sustainable Cocoa. Malaysia: Malaysian Cocoa Board.

Lee, D. W. and Kevin, S. G. (2002). Why leaves tum red: pigments called anthocyanins probably protect leaves from light damage by direct shielding and by scavenging free radicals. *Journal of American Science* 90: 1–6.

Lee, J. and Schwartz, S. J. (2006). Handbook of Food Science, Technology and Engineering, Pigments in Plant Foods. CRC-Taylor and Francis: New York.

Lee, M. T. (2006). Agricultural practices towards a sustainable cocoa economy. Proceedings 15th International Cocoa Research Conference, 9-14 October 2006, San Jose, Costa Rica.

Liaghat, S. and Balasundram, S. K. (2010). A review: The role of remote sensing in precision agriculture. *American Journal of Agricultural and Biological Sciences* 5(1): 50-55.

Li, H. D., Lin, J., Zhang, J. C., Zhang, X. C., Zhang, L. and Wang, Z. (2008). Spatial variability of soil organic carbon and total nitrogen based on small watershed scale. *Journal of Nanjing Forestry University (Natural Sciences Edition)* 32: 38–42.

Lillesand, T., Kiefer, R. W. and Chipman, J. (2015). Remote Sensing and Image Interpretation, 7th Edn. Wiley: New York.

Liu, D., Wang, Z., Zhang, B., Song, K., Li, X., Li, J. and Duan, H. (2006). Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region, Northeast China. *Agriculture, Ecosystems and Environment*113: 73-81.

Liu, L., Wang, J., Huang, W., Zhao, C., Zhang, B. and Tong, Q. (2004). Estimating winter wheat plant water content using red edge parameters. *International Journal of Remote Sensing* 25: 3331-3342.

Liu, W., Zhu, D. W., Liu, D. H., Geng, M. J., Zhou, W. B., Mi, W. J., Yang, T. W. and Hamilton, D. (2010). Influence of nitrogen on the primary and secondary metabolism and synthesis of flavonoids in *Chrysanthemum morifolium* Ramat. *Journal of Plant Nutrition* 33: 240-254.

Mackey, B. G., Mullen, I. C., Baldwin, K. A., Gallant, J. C., Sims, R. A. and McKenney, D. W. (2000). Towards A Spatial Model of Boreal Forest Ecosystem; The Role of Digital Terrain Analysis. Terrain Analysis - Principles and Applications; New York, American.

Mahlein, A. K., Steiner, U., Hillnhütter, C., Dehne, H. W. and Oerke, E. C. (2012). Hyperspectral imaging for small-scale analysis of symptoms caused by different sugar beet diseases. *Plant Method* 8:3.

Mariotti, M., Ercoli, L. and Masoni, A. (1996). Spectral properties of iron deficient corn and sunflower leaves. *Remote Sensing Environment* 58: 282–288.

Marschner, H. (1995). Mineral Nutrition of Higher Plants. 2nd edition. London etc., Academic Press.

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants. 3rd ed., pp. 178–189. Academic Press: London, UK.

Mattivi, F., Guzzon, R., Vrhovsek, U., Stefanini, M. and Velasco, R. (2006). Metabolite profiling of grape: flavonols and anthocyanins. *Journal of Agricultural and Food Chemistry* 54: 7692–7702.

MCB (Malaysian Cocoa Board). (2010). Malaysian Cocoa Statistics 2010. Malaysia: Malaysian Cocoa Board.

MCB (Malaysian Cocoa Board). (2013). Cocoa Planting Manual. MCB: Malaysia.MCB (Malaysian Cocoa Board). Importation of dried bean and cocoa products. Retrieved on 2018, August 17 from http://www.koko.gov.my.

MCB (Malaysian Cocoa Board). (2018). Malaysian cocoa statistics. Retrieved on February 12, 2018 from http://www.koko.gov.my//.

McClure, J. W. (1975). Physiology and functions of flavonoids. In *The Flavonoids*, ed. J. B. Harborne, T. J. Mabry. and H, Mabry, pp. 970–1055. Chapman and Hall Ltd: London, UK.

Mellor, D. D., Sathyapalan, T., Kilpatrick, E. S., Beckett, S. and Atkin, S. L. (2010). High-cocoa polyphenol-rich chocolate improves HDL cholesterol in Type 2 diabetes patients. *Diabetic Medicine* 27: 1318–1321.

Merzlyak, M. N. and Chivkunova, O. B. (2000). Light-stress-induced pigment changes and evidence for anthocyanin photoprotection in apples. *Journal of Photochemistry and Photobiology B: Biology* 55:155–163.

Meyer, B., Biehl, B., Said, M. B. and Samarakoddy, R. J. (1989). Post harvest pod storage: a method of pulp preconditioning to impair strong nib acidification during cocoa fermentation in Malaysia. *Journal of the Science of Food and Agriculture* 48: 285-304.

Michael, O. A., Thomas C., Paul, A. A., David, O. Y. and Kingsley, J. T. (2017). Demucilaging freshly stored seeds of cocoa (*Theobroma cacao* L.) improves seedlings emergence and growth. *Journal of Botany* 2017: 1-10.

Miletic, N., Popović, B., Mitrović, O. and Kandić, M. (2012). Phenolic content and antioxidant capacity of fruits of plum cv. 'Stanley' (*Prunus domestica* L.) as influenced by maturity stage and on-tree ripening. *Australian Journal of Crop Science* 6: 681-687.

Mohd Mustafa, M. M., Salim, H., Olagunju, O and Ramle, K. (2017). ToT and HRD competencies and its relationship to extension agents' performance among cocoa smallholders. *IOSR Journal of Agriculture and Veterinary Science* 10(12): 14-21.

Mokolobate, M. S. and Haynes, R. J. (2002). Increases in pH and soluble salts influence the effect that additions of organic residues have on concentrations of exchangeable and soil solution aluminium. *European Journal of Soil Science* 53(3): 481-489.

Motamayor, J. C., Risterucci, A. M., Lopez, P. A., Ortiz, C. F. and Moreno, A. (2002) Cacao domestication I: the origin of the cacao cultivated by the Mayas. *Heredity* 89: 380–386.

Munoz-Huerta, R. F., Guevara-Gonzalez, R. G., Contreras-Medina, L. M., Torres-Pacheco, I., Prado-Olivarez, J. and Ocampo-Velazquez, R. V. (2013). A review of methods for sensing the nitrogen status in plants: Advantages, disadvantages and recent advances. *Sensors* 13: 10823-10843.

Mustafa, M., James Ansley, R., Jacob, A. P., Fekede, W. and Charles, M. R. (2013). Remote monitoring of wheat streak mosaic progression using sub-pixel classification of Landsat 5 TM imagery for site-specific disease management in winter wheat. *Advances in Remote Sensing* 2: 16-28.

Nair Prabhakaran, K. P. (2010). Cocoa (*Theobroma cacao* L.). In *The Agronomy and Economy Of Important Tree Crops Of The Developing World*, ed. K.P. Nair Prabhakaran, pp. 131-180. Heidelberg, New York, London: Elsevier.

Ndoumou, D. O., Ndzomo, G. T. and Djocgoue, P. F. (1996). Changes in carbohydrate, amino acid and phenol contents in cocoa pods from three clones after infection with *Phytophthora megakarya* Bra. and Grif. *Annals of Botany***77**: 153-158.

Neill, S. and Gould, K. S. (2003). Anthocyanins in leaves: light attenuators or antioxidants? *Functional Plant Biology* 30: 865–873.

Neilson, A. P., Sapper, T. N., Janle, E. M., Rudolph, R., Matusheski, N. V. and Ferruzzi, M. G. (2010). Chocolate matrix factors modulate the pharmacokinetic behavior of cocoa flavan-3-ol phase II metabolites following oral consumption by Sprague-Dawley Rats. *Journal of Agricultural and Food Chemistry* 58: 6685–6691.

Nicola, C., Martin, B. W., Mark, S. F. and Ian, D. F. (2018). Hyperspectral imaging for non-destructive prediction of fermentation index, polyphenol content and antioxidant activity in single cocoa beans. *Food Chemistry* 258: 343-351.

Niemenak, N., Rohsius, C., Elwers, S., Ndoumou, D. O. and Lieberei, R. (2006). Comparative study of different cocoa (*Theobroma cacao* L.) clones in terms of their phenolic sand anthocyanins contents. *Journal of Food Composition and Analysis* 19: 612-619.

Norasma, C. Y. N., Shariff, A. R. M., Jahanshiri, E., Amin, M. S. M., Khairunniza-Bejo, S. and Mahmud, A. R. (2013). Web-based decision support system for paddy planting management. *Pertanika Journal of Science and Technology* 21(2): 343 – 364.

Novak, V. and Vidovic, J. (2003). Transpiration and nutrient uptake dynamics in maize (*Zea mays* L.). *Ecological Modelling* 166: 99-107.

Olsen, S. R. and Sommers, L. E. (1982). Phosphorus. In *Methods of Soil Analysis Part 2 Chemical and Microbiological Properties*, ed. A. L. Page, pp. 403-430. American Society of Agronomy, Soil Science Society of America: Madison.

Olukayode, O. S., Blesing, L. O., Rotimi, A. D. and Oguntola, E. A. (2018). Assessment of plant health status using remote sensing and GIS techniques. *Advances in Plants and Agriculture Research* 8(6): 517–525.

Opoku, S. Y., Bhattacharjee, R., Kolesnikova-Allen, M., Motamayor, J. C., Schnell, R., Ingelbrecht, I., Enu-Kwesi, L. and Adu-Ampomah, Y. (2008). Genetic diversity in cocoa (*Theobroma cacao* L.) germplasm collection from Ghana. *Journal of Crop Improvement* 20(1): 73-87.

Oshunsanya, S., Oluwasemire, K. O. and Taiwo, O. (2017). Use of GIS to delineate site-specific management zone for precision agriculture. *Communications in Soil Science and Plant Analysis* 48(3): 565 – 575.

Owusu, M., Petersen, M. A. and Heimdal, H. (2012). Effect of fermentation method, roasting and conching condition on the aroma volatiles of dark chocolate. *Journal of Food Processing and Preservation* 36: 446-456.

Pacumbaba Jr., R. O. and Beyl, C. A. (2011). Changes in hyperspectral reflectance signatures of lettuce leaves in response to macronutrient deficiencies. *Advances in Space Research* 48: 32-42.

Pandey, P., Ge, Y., Stoerger, V. and Schnable, J. C. (2017). High throughput in vivo analysis of plant leaf chemical properties using hyperspectral imaging. *Frontier of Plant Science* 8:1348.Parry, M. A. J. and Hawkesford, M. J. (2010). Food security: increasing yield and improving resource use efficiency. *Proceedings of the Nutrition Society* 69: 592-600.

Patras, M. A., Milev, B. P., Vrancken, G. and Kuhnert, N. (2014). Identification of novel cocoa flavonoids from raw fermented cocoa beans by HPLC-MS. *Food Research International* 63: 353 – 359.

Peng, Z., Hayasaka, Y., Iland, P. G., Sefton, M., Hoj, P. and Walters, E. J. (2001). Quantitative analysis of polymeric procyanidins (tannins) from grape (*Vitis vinifera*) seeds by reverse phase high-performance liquid chromatography. *Journal of Agricultural and Food Chemistry* 49: 26-31.

Peter, H. D. and Andreas, C. B. (2015). Predicting total nitrogen, total phosphorus, total organic carbon, dissolved oxygen and iron in deep waters of Swedish lakes. *Environmental Modeling & Assessment* 20: 411–423.

Pick, T. R., Bräutigam, A., Schlüter, U., Denton, A. K., Colmsee, C., Scholz, U., Fahnenstich, H., Pieruschka, R., Rascher, U., Sonnewald, U. and Weber, A. P. M. (2011). Systems analysis of a maize leaf developmental gradient redefines the current C4 model and provides candidates for regulation. *Plant Cell* 23: 4208–4220.

Pierce, F. J. and Nowak, P. (1999). Aspects of precision agriculture. *Advances in Agronomy* 67: 1–86.

Pinelli, P., Romani, A., Fierini, E., Remorini, D. and Agati, G. (2013). Characterisation of the polyphenol content in the kiwifruit (*Actinidia deliciosa*) exocarp for the

calibration of a fruit-sorting optical sensor. *Phytochemical Analysis* 24: 460-466.

Poetig, R. S. (2003). Phase change and regulation of developmental timing in plants. *Science* 301: 334-336.

Prieto, J. A., Louarn, G., Perez-Pena, J., Ojeda, H., Simoneau, T. and Lebon, E. (2012). A leaf gas exchange model that accounts for intra-canopy variability by considering leaf nitrogen content and local acclimation to radiation in grapevine (*Vitis vinifera* L.). *Plant Cell Environment* 35: 1313-1328.

Puziah, H., Jinap, S., Sharifah, K. S. M. and Asbi, A. (1998). Changes in free amino acids, peptide-N, sugar and pyrazine concentration during cocoa fermentation. *Journal of the Science of Food and Agriculture* 78: 535-542.

Ramos, M. E. and Lagorio, M. G. (2006). A model considering light reabsorption processes to correct in vivo chlorophyll fluorescence spectra in apples. *Photochemical and Photobiological Sciences* 5: 508–512.

Ranjith, S. A. and Meinzer, F. C. (1997). Physiological correlates of variation in nitrogen-use efficiency in two contrasting sugarcane cultivars. *Crop Science* 37(3): 818-825.

Rascher, U., Liebig, M. and Luttge, U. (2000). Evaluation of instant light-response curves of chlorophyll fluorescence parameters obtained with a portable chlorophyll fluorometer on site in the field. *Plant Cell Environment* 23: 1397–1405.

Rein, D., Paglieroni, T. G., Wun, T., Pearson, D. A., Schmitz, H. H. and Gosselin, R. (2000). Cocoa inhibits platelet activation and function. *American Journal of Clinical Nutrition* 72: 30-35.

Rice-Evans, C. A., Miller, N. J. and Paganga, G. (1997). Antioxidant properties of phenolic compounds. *Trends in Plant Science* 2: 152–159.

Rodriguez-Campos, J., Escalona-Buendía, H. B., Orozco-Avila, I., Lugo-Cervantes, E. and Jaramillo-Flores, M. E. (2011). Dynamics of volatile and non-volatile compounds in cocoa (*Theobroma cacao* L.) during fermentation and drying processes using principal components analysis.*Food Research International* 44:250–258.

Roger, K. D. (1989). Effect of cocoa pod borer, *Conopomorpha cramerella*, on cocoa yield and quality in Sabah, Malaysia. *Crop Protection* 8(5); 332-339.

Römer, C., Wahabzada, M., Ballvora, A., Pinto, F., Rossini, M. and Panigada, C. (2012). Early drought stress detection in cereals: simplex volume maximization for hyperspectral image analysis. *Function of Plant Biology* 39: 878–890.

Rusconi, M. and Conti, A. (2010). *Theobroma cacao* L., the food of the goods: a scientific approach beyond myths and claims. *Pharmacological Ressearch* 61: 5–13.

Sanbongi, C., Osakabe, N., Natsume, M., Takizawa, T., Gomi, S., Osawa, T. (1998). Antioxidative polyphenols isolated from *Theobroma cacao*. *Journal of Agricultural and Food Chemistry* 46:452–457.

Sangita, P. I. and Smita, S. T. (2016). Review on toxicity assessment for carcinogenic soil contaminants. *The Pharmaceutical and Chemical Journal* 3(2): 139-144.

Sani, Y. and Jibril, E. (2010). A comparative study of nutrient cycling on soils under Daniella Oliveri and Chromolaena Odorata in the federal capital territory, Abuja, Nigeria. *American Journal of Scientific Research* 10: 26-33.

Santoso, H., Gunawan, T., Jatmiko, R. H., Darmosarkoro, W. and Minasny, B. (2011). Mapping and identifying basal stem rot disease in oil palms in North Sumatra with QuickBird imagery. *Precision Agriculture* 12(2): 233–248.

Savitzky, A. and Golay, M. J. E. (1964). Smoothing and differentiation of data by simplified least squares procedures. *Analytical Chemistry* 36: 1627–1639.

Scarpari, L. M., Meinhardt, L. W., Mazzafera, P., Pomella, A. W., Schiavinato, M. A., Cascardo, J. C. and Pereira, G. A. (2005). Biochemical changes during the development of witches' broom: the most important disease of cocoa in Brazil caused by *Crinipellis perniciosa*. *Journal of Experimental Botany* 56: 865–877.

Selvaraja, S., Balasundram, S., Vadamalai, G. and Husni, M. H. A. (2013). Site-specific disease management: A preliminary case with orange spotting in oil palm. Precision Agriculture 2013 - Papers Presented at the 9th European Conference on Precision Agriculture, ECPA 2013: 577-584.

Shabala, S. and Pottosin, I. I. (2010). Potassium and potassium-permeable channels in plant salt tolerance. *Signaling and Communication in Plants*: 87–110.

Shafri, H. Z., Hamdan, N. and Saripan, M. I. (2011). Semi-automatic detection and counting of oil palm trees from high spatial resolution airborne imagery. *International Journal of Remote Sensing* 32(8): 2095-2115.

Shemer, T. A., Harpaz-Saad, S., Belausov, E., Lovat, N., Krokhin, O. and Spicer, V. (2008). Citrus chlorophyllase dynamics at ethylene-induced fruit color-break: a study of chlorophyllase expression, post translational processing kinetics, and in situ intracellular localization. *Journal of Plant Physiology* 148:108–118.

Shen, J. P., Zhang, L. M., Guo, J. F., Ray, J. L. and He, J. Z. (2010). Impact of long-term fertilization practices on the abundance and composition of soil bacterial communities in Northeast China. *Applied Soil Ecology* 46(1): 119–124.

Sinclair, T. R. and de Wit, C. T. (1975). Photosynthate and nitrogen requirements for seed production by various crops. *Science* 189: 565–567.

Sinfield, J. V., Fagerman, D. and Colic, O. (2010). Evaluation of sensing technologies for on-the-go detection of macro-nutrients in cultivated soils. *Computers and Electronics in Agriculture* 70: 1-18.

Skjemstad, J. O. and Baldock, J. A. (2008) Total and organic carbon. In *Soil Sampling and Methods of Analysis*, eds. M. R. Carter and E. G. Gregorich, pp. 225-238. Taylor and Francis: Boca Raton.

Smillie, R. M. and Hetherington, S. E. (1999). Photoabatement by anthocyanin shields photosynthetic systems from light stress. *Photosynthetica* 36: 451–463.

Smith, G. J. and Markham, K. R. (1998). Tautomerism of flavonol glucosides: relevance to plant UV protection and flower colour. *Journal of Photochemistry and Photobiology A* 118:99–105.

Snapir, B., Simms, D. M. and Waine, T. W. Mapping the expansion of galamsey gold mines in the cocoa growing area of Ghana using optical remote sensing. *International Journal of Applied Earth Observation and Geoinformation* 58: 225-233.

Solovchenko, A. E. and Schmitz-Eiberger, M. (2003). Significance of skin flavonoids for UV-B protection in apple fruits. *Journal of Experimental Botany* 54:1977–1984.

Stark, T., Bareuther, S. and Hofmann, T. (2005). Sensory-guided decomposition of roasted cocoa nibs (*Theobroma cacao*) and structure determination of taste-active polyphenols. *Journal of the Science of Food and Agriculture* 53: 5407–5418.

Stacey, K. F., Lark, R. M., Whitmore, A. P. and Milne, A. E. (2006). Using a process model and regression kriging to improve predictions of nitrous oxide emissions from soil. *Geoderma* 135: 107–117.

Steinberg, F. M., Bearden, M. M. and Keen, C. L. (2003). Cocoa and chocolate flavonoids: implications for cardiovascular health. *Journal of the American Dietetic Association* 103: 215-223.

Sub, A., Danner, M., Obster, C., Locherer, M., Hank, T. and Richter, K. (2015). Measuring Leaf Chlorophyll Content with the Konica Minolta Spad-502 Plus – Theory, Measurements, Problems, Interpretation. EnMAP Field Guides Technical Report, GFZ Data Services, Potsdam, Germany.

Sugiharto, B., Miyata, K., Nakamoto, H., Sasakawa, H. and Sugiyama, T. (1990). Regulation of expression of carbon-assimilating enzymes by nitrogen in maize leaf. *Plant Physiology* 92: 963–969.

Šulc, M., Kotíková, Z., Paznocht, L., Pivec, V., Hamouz, K. and Lachman, J. (2017). Changes in anthocyanidin levels during the maturation of color-fleshed potato (*Solanum tuberosum* L.) tubers. *Food Chemistry* 237: 981-988.

Sunoj, S., Igathinathane, C. and Visvanathan, R. (2016). Nondestructive determination of cocoa bean quality using FT-NIR spectroscopy. *Computer Electronic Agriculture* 124: 234-242.

Taiz, L. and Zeiger, E. (2010). Plant Physiology, pp. 67-86. Sinauer Associates Inc.; Sunderland, MA, USA.

Takos, A., Jaffe, F., Jacob, S., Bogs, J., Robinson, S. and Walker, A. (2006). Light-induced expression of a MYB gene regulates anthocyanin biosynthesis in red apples. *Journal of Plant Physiology* 142:1216–1232.

Tan, K. P., Kanniah, K. D. and Cracknell, A. P. (2013). Use of UK-DMC 2 and ALOS PALSAR for studying the age of oil palm trees in southern peninsular Malaysia. *International Journal of Remote Sensing* 34(20): 7424– 7446.

Tanaka, Y., Sasaki, N. and Ohmiya, A. (2008). Biosynthesis of plant pigments: anthocyanins, betalains and carotenoids. *Plant Journal* 54: 733–749.

Tarantino, E. (2004). Land cover classification of QuickBird hyperspectral data with an object-oriented approach. In *Management Information Systems*, ed. C. A. Brebbia, pp. 125-134. United Kingdom: WIT Press.

Tasnee, A., Sahaschai, K., Buree, B., Anan, P., Prateep, V. and Russell, Y. (2010). Site-specific nutrient management of irrigated rice in the central plain of Thailand. *Journal of Sustainable Agriculture*34(3): 258-269.

Thomas, G. W. (1982). Exchangeable cations. In *Methods of Soil Analysis Part 2 Chemical and Microbiological Properties*, eds. A. L. Page, R. H. Miller and D. R. Keeney, pp. 159-165. American Society of Agronomy, Soil Science Society of America: Madison, Wisconsin, USA.

Thompson, S. S., Miller, K. B., Lopez, A. S. (2007). Cocoa and coffee. In Food Microbiology Fundamentals and Frontiers, eds. M. P. Doyle, L. R. Beuchat, T. J. Montville, pp. 837-850. ASM Press: Washington, DC.

Thong, K. C. and Ng, W. L. (1978). Growth and Nutrient Composition of Monocrop Cocoa Plants on Inland Malaysian Soils. Preprint, International Conference on Cocoa and Coconut, Malaysia.

Torbica, A., Jovanovic, O. and Pajin, B. (2006). The advantages of solid fat content determination in cocoa butter and cocoa butter equivalents by the Karlshamns method. *European Food Research and Technology* 222(3-4): 385-391.

Tremblay, N., Wang, Z. and Bélec, C. (2010). Performance of Dualex in spring wheat for crop nitrogen status assessment, yield prediction and estimation of soil nitrate content. *Journal of Plant Nutrition* 33:57–70.

Ummi, K. I., Ida, I. M. and Ruzitah, M. S. (2011). Effect of pH on color behavior of *Brassica oleracea* anthocyanin. *Journal of Applied Sciences* 11(13): 2406-2410.

Wang, H., Hall, C. A. S., Cornell, J. D. and Hall, M. H. P. (2002). Spatial dependence and the relationship of soil organic carbon and soil moisture in the luquillo experimental forest, Puerto Rico. *Landscape of Ecology* 17: 671-684.

Wang, M., Zheng, Q., Shen, Q. and Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences* 14: 7370-7390.

Wang, Y.Q. and Shao, M.A. (2013). Spatial variability of soil physical properties in a region of the Loess Plateau of PR China subject to wind and water erosion. *Land Degradation and Development* 24(3): 296-304.

Webster, R. and Oliver, M. A. (2007). Geostatistics for Environmental Scientists. 2nd Edn, John Wiley and Sons: UK.

Winkel-Shirley, B. (2001). Flavonoid biosynthesis. A colorful model for genetics, biochemistry, cell biology and biotechnology. *Plant Physiology* 126: 485–493.

Winkel-Shirley, B. (2006). The biosynthesis of flavonoids, In The Science of Flavonoids, ed. E. Grotewold, pp. 71-95. New York, NY: Springer.

Wollgast, J. and Anklam, E. (2000). Polyphenols in chocolate: is there a contribution to human health?.*Food Research International* 33: 449–459.

Wollgast, J., Pallaroni, L., Agazzi, M. and Anklam, E. (2001). Analysis of procyanidins in chocolate by reversed-phase high-performance liquid chromatography with electrospray ionization mass spectrometric and tandem mass spectrometric detection. *Journal of Chromatography A* 926: 211-220.

Woodall, G. S. and Stewart, G. R. (1998). Do anthocyanins play a role in UV protection of the red juvenile leaves of Syzygium?.*Journal of Experimental Botany* 49: 1447-1450.

Wu, C., Niu, Z., Tang, Q. and Huang, W. (2008). Estimating chlorophyll content from hyperspectral vegetation indices, modelling and validation. *Agricultural and Forest Meteorology* 148: 1230-1241.

Xie, X., Pan, X. Z. and Sun B. (2012). Visible and near-infrared diffuse reflectance spectroscopy for prediction of soil properties near a copper smelter. *Pedosphere* 22: 351–366.

Young, A. M. (2007). Nature in the cacao: mysteries of pollination. In *The Chocolate Tree: A Natural History of Cacao*, ed. Young A. M, pp. 115-162. University Press of Florida: Florida.

Zhang, D. and Motilal, L. (2016). Origin, dispersal, and current global distribution of cacao genetic diversity. In *Cacao Diseases*, eds. B. Bailey and L. Meinhardt L. Springer, Cham.

Zhao, J., Liu, H. J., Sui, Y. Y., Zhang, X. Y. and Meng, K. (2006). Analysis for spatial heterogeneity of organic matter content and available nutrients in blacksoil

crop area with different scales. *Journal of Soil and Water Conservation* 20: 41–45.

Zhong, X. (1999). Physiological basis of tillering dynamics in rice (*Oryza sativa* L.) and its quantification. PhD Thesis, South China Institute of Botany, Chinese Academy of Sciences, Guangzhou, China.

Zhu, X. G., Long, S. P. and Ort, D. R. (2010). Improving photosynthetic efficiency for greater yield. *Annual Review of Plant Biology* 61: 235-261.

Ziegleder, G. (1990). Linalool contents as characteristic of some flavor grade cocoas. *Z Lebensm Unters Forsch* 191: 306–309.

Zwiggelaar, R. (1998). A review of spectral properties of plants and their potential use for crop weed discrimination in row-crops. *Crop Protect* 17: 189 – 206.