UNIVERSITI PUTRA MALAYSIA

EFFECTIVNESS OF SILT PIT AS A SOIL, WATER AND NUTRIENT CONSERVATION METHOD IN NON-TERRACED OIL PALM PLANTATIONS

MOHSEN BOHLULI

EFFECTIVNESS OF SILT PIT AS A SOIL, WATER AND NUTRIENT CONSERVATION METHOD IN NON-TERRACED OIL PALM PLANTATIONS

By

MOHSEN BOHLULI

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

November 2014

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

EFFECTIVNESS OF SILT PIT AS A SOIL, WATER AND NUTRIENT CONSERVATION METHOD IN NON-TERRACED OIL PALM PLANTATIONS

By

MOHSEN BOHLULI

Novamber 2014

Chairman: Christopher Teh Boon Sung, PhD.

Faculty: Agriculture

Oil palm plantation activities have expanded to include marginal lands such as steep land areas. The problems of steep lands are soil erosion, loss of fertilizers, poor soil water storage and low productivity. In Malaysia, optimum yield production can be achieved by a combination of land area expansion and yield intensification. Silt pit is one of the best management ways to increase oil palm production in steep lands through soil, water and nutrient conservation. The main objective of this study was to evaluate the effectiveness of various dimensions of silt pit to conserve soil, water and nutrients in a non-terraced oil palm plantation. The effectiveness of silt pit as a soil, water and nutrient conservation method was also compared against control which had no conservation practices. Two field experiments were set up in oil palm sites at Tuan Mee in Sg.Buloh, Selangor and Felda Tekam in Pahang. Each field experimental design had five treatments with three blocks (replications). The treatments were control (no silt pit) and four silt pit sizes with different volume and opening areas including: H1 (1×3×1 m), H2 (1.5×3×1 m), H3 (2×3×1 m) and H4 (2×3×0.5 m). Soil samples were taken once every two months for a year at each site. Each sampling set included the soil outside, sediments and below the sediment inside the silt pit. The soil samples were analyzed for soil chemical and physical properties which were: soil pH, cation exchange capacity, Ca, Mg, K, N, P and total C. Soil physical analysis included bulk density, aggregate stability, dry aggregation and soil water retention. Soil water content was measured daily up to 0.90 m from soil surface. Analysis of variance (ANOVA) was used with split-split block experimental design. In Tuan Mee H1 conserved more soil water content in oil palm active root zone compared with other treatments. This is because pits with smaller opening area had bigger W:F ratio which caused higher lateral water infiltration through silt pit's walls than water percolation through silt pit's floor area. Among the silt pits, the narrowest pit showed the best effect to improve soil chemical parameters inside and outside of the pit in Tuan Mee.

This is because the silt pit with narrower opening area helped the water head to be higher than other wider pits and redistributed dissolved nutrients in top soil. Nonetheless, the same amount of trapped nutrients inside the pit would be leached over a smaller floor area. Hence, the nutrients are concentrated over a smaller soil area in narrow silt pit compared with other treatments. In Tuan Mee silt pits were not able to affect soil physical characteristics. That was because soil physical parameters change slower than soil chemical characteristics and it will take more time to see significant changes on soil physical properties. Silt pits were not effective in terms of soil water content, soil chemical and physical properties improvement in Tekam because there were no run-off and sediments to be trapped in silt pits as sources of redistributed water and nutrients into the soil.

Abstrak tesis yang dibentangkan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan ijazah untuk ijazah Doktor Falsafah

KEBERKESANAN SILT PIT SEBAGAI TANAH, AIR DAN NUTRIEN DAN PEMULIHARAAN KAEDAH TANPA TERES BAGI PERLADANGAN KELAPA SAWIT

Oleh

MOHSEN BOHLULI

November 2014

Pengerusi: Christopher Teh Boon Sung, PhD.

Fakulti: Pertanian

Aktiviti penanaman kelapa sawit telah diperluaskan termasuk kawasan tanah marginal seperti kawasan tanah curam. Kira-kira satu per tiga daripada kawasan semenanjung Malaysia adalah terdiri daripada kawasan berbukit-bukau. Masalah bagi kawasan tanah curam adalah seperti hakisan tanah, kehilangan baja, masalah penyimpanan air tanah dan produktiviti rendah. Di Malaysia, pengeluaran hasil optimum dapat dicapai dengan gabungan perluasan tanah dan peningkatan hasil yang intensif. Silt pit adalah salah satu cara pengurusan yang terbaik untuk meningkatkan pengeluaran kelapa sawit di tanah curam melalui tanah, air dan pemuliharaan nutrien. Matlamat utama kajian ini adalah untuk menilai keberkesanan pelbagai dimensi silt pit untuk memelihara tanah, air dan nutrien dalam ladang kelapa sawit bukan teres. Keberkesanan silt pit sebagai tanah, air dan pemuliharaan nutrien juga dibandingkan dengan kawalan yang tidak mempunyai amalan pemuliharaan. Dua kawasan eksperimen telah dijalankan di kawasan kelapa sawit di Tuan Mee di Sg.Buloh, Selangor dan Felda Tekam di Pahang. Setiap reka bentuk eksperimen di ladang mempunyai lima rawatan dengan tiga blok (replikasi). Rawatan kawalan (tiada silt pit) dan empat saiz silt pit dengan jumlah dan pembukaan kawasan-kawasan yang berlainan termasuk: H1 (1 × 3 × 1 m), H2 (1.5 × 3 × 1 m), H3 (2 × 3 × 1 m) dan H4 (2 × 3 × 0.5 m). Sampel tanah telah diambil sekali setiap dua bulan dalam setahun di setiap kawasan. Setiap set termasuk pensampelan tanah di luar, sedimen dan sedimen di dalam silt pit. Sampel tanah dikaji untuk kimia tanah dan fizikal tanah: pH tanah, kapasiti pertukaran kation, Ca, Mg, K, N, P dan jumlah C. Analisis fizikal tanah adalah termasuk ketumpatan pukal, kestabilan agregat, agregat kering dan pengekalan air tanah . Kandungan air tanah diukur secara harian sehingga 0.90 m dari permukaan tanah. Analisis varians (ANOVA) digunakan dengan split-split block reka bentuk eksperimen. Di Tuan Mee H1 menyimpan lebih banyak kandungan air tanah di zon akar aktif kelapa sawit berbanding dengan rawatan lain. Ini kerana pit yang mempunyai kawasan pembukaan yang lebih kecil mempunyai nisbah W: F yang besar menyebabkan penyusupan air yang lebih tinggi melalui dinding sisi silt pit itu daripada serapan air melalui kawasan lantai silt pit ini. Antara silt pit, pit yang paling sempit menunjukkan kesan yang terbaik untuk memperbaiki parameter kimia tanah di dalam dan di luar pit di

Tuan Mee. Ini kerana silt pit dengan kawasan pembukaan sempit membantu permulaan air lebih tinggi daripada pit lain yang lebih luas dan pengagihan nutrien terlarut di tanah atas. Namun demikian, jumlah nutrien yang sama terperangkap di dalam pit itu akan terlarut lesap di kawasan lantai yang lebih kecil. Oleh itu, nutrien adalah pekat di kawasan tanah yang lebih kecil dalam silt pit sempit berbanding rawatan lain. Di Tuan Mee, silt pit tidak dapat memberi kesan kepada ciri-ciri fizikal tanah. Itu adalah kerana tanah parameter fizikal menukar secara perlahan daripada ciri-ciri kimia tanah dan ia akan mengambil lebih banyak masa untuk melihat perubahan yang besar ke atas sifat-sifat fizikal tanah. Silt pit tidak berkesan dari segi kandungan air tanah, kimia tanah dan peningkatan ciri-ciri fizikal di Tekam. Tanah di Tekam telah dilindungi dengan baik oleh perlindungan vegetatif yang tinggi dan cerun yang rendah. Oleh itu, tidak ada larian air dan sedimen yang terperangkap dalam silt pit sebagai sumber agihan air dan nutrien ke dalam tanah.

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Christopher Teh Boon Sung, for the continuous support of my Ph.D study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Ph.D study.

Besides my supervisor, I would like to thank the rest of my supervisor committee: Prof. Dr. Ahmad Husni Mohd Hanif and Prof. Dr. Zaharah A. Rahman, for their encouragement, insightful comments, and hard questions.

I would also like to thank Mr. Goh Kah Joo from Applied Agriculture Research (AAR) Sdn. Bhd and staff of AAR for providing the required materials, their value advices and comments.

I would like to thank managements and staff of Federal Land Development Authority (Felda), Tuan Mee estate and Felda Tekam plantation, , for providing the experimental sites and supports with workers and comments. I am indebted to them for their help.

My sincere thank also goes to the laboratory and supporting staff at the Dept. of Land Resource Management, Universiti Putra Malaysia for their help during my study and research.

My high appreciation goes to Universiti Putra Malaysia for giving me an opportunity to do my PhD in Malaysia.

Last but not the least, I would like to thank my family: my parents for giving birth to me at the first place and my brothers and sister for supporting me spiritually throughout my life.

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

Christopher Teh Boon Sung, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Ahmad Husni Mohd Hanif, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Zaharah A.Rahman, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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: Christopher Teh Boon Sung

Signature:
Name of Member of Supervisory Committee: Ahmad Husni Mohd Hanif

Signature:
Name of Member of Supervisory Committee: Zaharah A.Rahman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APOC	American Palm Oil Council
ARS	Agricultural Research Service's
CEC	Cation Exchange Capacity
EFB	Empty Fruit Bunches
FAO	Food and Agriculture Organization of the United Nations
FFB	Fresh Fruit Bunches
H	Pressure head
H1	1×3×1 m silt pit treatment
H2	1.5×3×1 m silt pit treatment
H3	2×3×1 m silt pit treatment
H4	1×3×0.5 m silt pit treatment
I	Pore-connectivity
IS	Inside the Silt Pit
K	Unsaturated hydraulic conductivity
K_s	Saturated hydraulic conductivity
K_{ij}^{A}	Components of dimensionless anisotropy tensor
LSD	Least Significant Difference
MPOB	Malaysian Palm Oil Board
MWD	Mean Weight Diameter
n	Number of fractions
NWP	Netherlands Water Partnership
OS	Outside the Silt Pit
Q_r	Residual water content
Q_s	Saturated water content
RBT	Average weight of fresh fruit bunches

RCBD	Randomized Completely Block Design
S	Sink term
S_p	Slope of the soil water retention curve at a point halfway between θ_r and θ_s
SAS	Statestical Analytical System
Sed	Trapped Sediments
SWRC	Southwest Watershed Research Center
t	Time
TBS	Number of fresh fruit bunches
USDA	U.S. Department of Agriculture
VAM	Vesicular Arbuscular Mycorrhizas
W	Soil total weight
W_i	Weight of aggregates between two sieves
W:F	Wall-to-floor area ratio
WOCAT	World Overview of Conservation Approaches and Technologies
WUE	Water Use Efficiency
X_i	Average size between two fractions
α and n	Empirical coefficients of the hydraulic functions in soil water retention
$\lvert h \rvert$	Pressure
θ	Volumetric water content
$\theta(h)$	Water content
θ_s	Saturated water content
θ_r	Residual water content
Θ	Dimensionless normalized volumetric soil water content

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The demand for edible vegetable oils is expected to double from 120 to 240 million t yr^{-1} from 2009 to 2050 (Corley, 2009). Among the major vegetable oils, palm oil has the lowest production cost and highest productivity; therefore, it will cause an increase in oil palm plantation area by up to 12 million ha (or about 300,000 ha yr^{-1}) over the next 40 years. If all land expansion takes place in Malaysia and Indonesia, land area of oil palm would increase by 140% from 8.4 in 2007 to 20.4 million ha in 2050 (FAO, 2008). However, only 7.8 million ha (23%) of the land area of Malaysia are classified as suitable land for long term agricultural activities, and 18.3 million ha (56%) must remain as forests (Lee and Panton,1971). But it was reported by MPOB (2012) that only oil palm area have reached 5 million ha in 2011, a 3% increase compared to 4.85 million ha in 2010.

The lack of more suitable agricultural lands has caused oil palm plantation activities to inevitably expand into marginal lands, such as steep land area. The main problems of steep lands are soil erosion, loss of fertilizers and poor soil water storage. Agricultural activities and cultivation on steep slopes can severely increase soil erosion. Soil erosion in association with heavy rains could cause barren lands after few years (Pratt and Gwynne, 1978; Pomeroy and Service, 1986; Kjekshus, 1997).

The longer and steeper the slope, the higher the erosion and the run-off. Run-off washes out the applied fertilizers as solution or in complex form with soil particles. Accelerated soil erosion on steep slopes would result in soil fertility reduction, fresh and ground water pollution and other environmental hazards. Soil erosion reduces oil palm production not only by decreasing soil fertility and its organic matter content but also by reducing soil water infiltration, soil water content and soil water holding capacity. Hartemink (2006) reported that the erosion under natural forests is less than 1 t ha^{-1} yr^{-1} while the maximum soil erosion under oil palm plantations is 78 and 28 t ha^{-1} yr^{-1} for Oxisols and Ultisols, respectively.

Moreover, oil palm is planted in tropical regions where rainfall is approximately uniform throughout the year. Despite an average annual rainfall of over 2500 mm in many areas in Malaysia (Dale 1959), there is still water shortage for oil palms (Goh et al., 1994). Oil palm needs adequate amount of water as it grows quickly and has a high biomass, fruit and oil production. Oil palm requires 1300-1500 mm of water annually, and matured oil palms must be irrigated by 300-350 L day^{-1} water per palm during the dry period. However, providing 1500 mm of water for oil palm growth on rain-fed oil palm plantations or steep slopes needs much more rain because the majority of precipitation is lost as runoff. Insufficient soil water content is critical during 24 (flowers sex selection), 18 (floral abortion) and 6 (pollination) months before fruit maturity of oil palm. Water stress causes more number of male flowers, less number of fruits in each fresh fruit bunch and less oil content (Gawankar et al., 2003).

In Malaysia, optimum yield production can be increased by a combination of land area expansion and yield intensification. Management is said to be often more important than soil type in determining the yield potential of oil palm at a given site (Goh et al., 1994). Removing the limitations and deficits of oil palm plantations through agronomic management can increase the oil palm production immediately through increasing the bunch weight and oil content of fruits. Furthermore, agronomic practices constantly increase the oil palm production via extending the weight of bunches. This is because production of a ripe bunch from floral initiation takes 3 to 4 years before harvesting (Donough et al., 2006). However, newly planted oil palms are not productive for first 1-3 years. Therefore, yield intensification would be cheaper, faster and more beneficial than developing new oil palm plantations. Application of soil and water conservation practices (terracing and silt pits) and oil palm residue mulches (empty fruit bunches, pruned oil palm fronds and Eco-mat) are the most common methods of oil palm yield intensification which have been practiced for several decades in Malaysia.

Terraces are constructed with the purpose of reducing run-off and soil erosion across the hill slopes (Troeh et al., 2004; Morgan, 2005). Despite significant effects of terracing to reduce run-off and erosion for slopes of 6-20º (Abo Hammad et al., 2006), on gentler slopes, terracing loses its efficiency and should be replaced by other conservation practices (Corley and Thinker, 2003). Despite of advantages of terracing, soil compaction and removing of fertile layer of top soil during construction of terraces reduce soil productivity (Hamdan et al., 2000). Compaction and removing of soil layers across terraces cause negative effects on soil physical properties, such as reduction of hydraulic conductivity, aggregate stability and water retention capacity (Ramos et al., 2007). Hill terracing is not recommended on sandy, shallow soil or soil with high fraction of stones (Troeh et al., 2004). Negative effects of terracing on soil productivity have forced some oil palm plantations to employ mulches and silt pits on non-terraced slopes.

Empty fruit bunches (EFB) have been applied as a mulch and fertilizer because of their high nutrient concentration and ability to conserve high soil water content in top soil. One tonne of EFB has been estimated to supply an equivalent of 7.0, 2.8, 19.3 and 4.4 kg of urea, phosphate, rock, muriate of potash and kieserite, respectively (Singh et al., 1999). Application of different rates of EFB has been frequently studied. Zin and Tarmizi (1983) recommended 30-50 and 50-100 t ha^{-1} y^{-1} of EFB. Loong et al. (1987), Jantaraniyom et al. (2001) and Etta et al. (2007) reported 37, 35 and 40-60 t ha^{-1} yr^{-1} of EFB as suitable rates, respectively.

Along with the ability of EFB to increase soil nutrient and soil water content, it has a fast decomposition rate. Zaharah and Lim (2000) found that EFB lost 50 and 70% of its dry matter due to decomposition in 3 and 8 months after application, respectively. However, application of EFB could only be implemented on field that are near oil palm mills because of difficulties of storage and high expenses of transportation and field application of the bulky EFB (Teh et al., 2011).

Difficulties of application of EFB motivated the development of Eco-mat. Eco-mat is a compressed EFB in the form of carpet-like material (Yeo, 2007). Therefore, field application, transportation and storage of Eco-mat are easier and cheaper than EFB.

Pruned oil palm frond is another oil palm residue which is commonly used as mulch in oil palm plantations. Stacking the pruned fronds on the soil surface will reduce soil erosion and run-off. The decomposed fronds are a source of nutrients release into the soil. Husin et al. (1987) determined that one tonne of applied pruned frond on soil surface released 7.5, 1.0, 9.8 and 2.8 kg of N, P, K and Mg, respectively. Although pruned oil palm fronds provide high amount of nutrients (Chan et al., 1980), they are less effective to reduce run-off and soil erosion and to increase soil water content compared with other soil and water conservation practices in non-terraced oil palm plantations (Moradi et al., 2012).

Silt pit is one of the recommended soil-water conservation methods in Malaysia (Teh et al., 2011). Goh et al. (1994) mentioned that maximum oil palm yield production in Malaysia can be increased by yield intensification through land management practices, such as silt pits. Silt pits are long, narrow and deep close-ended trenches which are dug between oil palm planting rows to hold surface run-off during rainy days.

Silt pits function by reducing soil erosion, controlling run-off and sedimentation, increasing oil palm yield through supplying more water specially during dry weather, protecting and increasing soil fertility through reduction of nutrient loss and redistribution of eroded nutrients back into the soil. Silt pit redistributes collected water and nutrients into the oil palm root zone rather than being lost through deep percolation. Figure 1.1 shows the function of silt pit to collect run-off and sediments and redistribute water and nutrients into the soil of non-terraced slopes of oil palm plantations.

Although silt pit has been practiced for several decades in oil palm plantations, there are few studies about the soil and water improvement through this method specially in comparison with other practices in nutrient and water conservation efficacy. It is commonly believed that the larger and deeper silt pit would increasingly store and return more water (Luna, 1989; National Institute of Agricultural Extension Management, 2010). However, silt pit must be able to capture maximum run-off and also redistribute collected water into the oil palm shallow active root zone rather than the water being lost through deep percolation through the floor of pit. The water must be also stored for longer time to be used by oil palms during dry periods. Hence, the main questions in this study are: how does the silt pit size (dimensions) affect the effectiveness of pits to conserve soil water and nutrients? Is the larger and deeper the silt pit, the better?

Effectiveness of a silt pit size was evaluated by determining how much improvement the silt pit doing to the soil in terms of: trapping sediments and run-off (controlling soil erosion), increasing soil water content, improving soil chemical (C, N, P, K, Ca, Mg, CEC and pH) and soil physical properties.

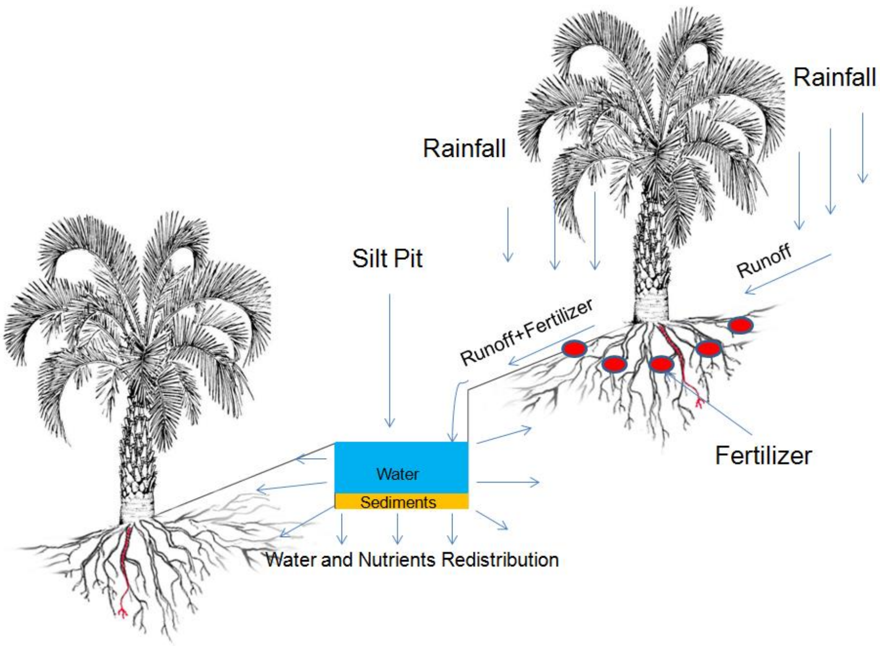

Figure 1.1. Silt pits collect the run-off and sediments flowing over the slope and redistribute the collected water and nutrients into the root zone of oil palms in non-terraced slopes of oil palm plantations.

1.2 Objectives of Study

The main objectives of this study were:

1) To evaluate the effectiveness of silt pit on soil and water conservation in two non-terraced oil palm plantations,

2) To evaluate the effectiveness of silt pit on improvement of soil nutrients content and soil chemical properties in terms of: increasing C, N, P, K, Ca, Mg, CEC and pH in two non-terraced oil palm plantations,

3) To evaluate the effectiveness of silt pit on soil physical properties in two non-terraced oil palm plantations,

4) To determine the effect of various silt pit dimensions on their ability to conserve soil, water and nutrients in these two non-terraced oil palm plantations, and

5) To expand the findings of this study on soil water holding time of silt pits on other slopes, through simulations of different silt sizes by HYDRUS 2D model.

Abo Hammad, A.H., Borresen, T. and Haugen, L.E. 2006. Effects of rain characteristics and terracing on runoff and erosion under the Mediterranean. *Soil and Tillage Research* 87: 39-47.

ADB. 2008.Rainwater Harvesting Handbook. Assessment of best practices and experience in water harvesting. Tunis-Belvedere, Tunisia: African Development Bank.

Acosta-Martinez, V., Reicher, Z., Bischoff, M. and Turco, R.F. 1999. The role of tree mulch and nitrogen fertilizer on turfgrass soil quality. *Biology and Fertility of Soil* 29: 55-61.

Ahenkorah Y., Halm B. J., Appiah M. R., Akrofi G. S. and Yirenkyi J. E. K. (1987). Twenty year's results from a shade and fertilizer trail on amazon cocoa (*Theobroma Cacao)* in Ghana. *Experimental Agriculture* 23: 31-39.

Allan, W. 1965. The African husbandman. Oliver & Boyd, Edinurgh.

American Palm Oil Council. 2004. Sustainable palm oil practices. Retrieved 2011 from http://www.americanpalmoil.com/sustainable.html.

Anderson J. M. and Ingram J. S. I. (1993). Tropical soil biology and fertility: a handbook of methods. GAB International, Wallingford, UK, pp.221.

APOC, American Palm Oil Council. 2003-2004. Sustainable practices. Retrieved 2014 from http://www.americanpalmoil.com/sustainable-water.html.

APOC. 2010. American Palm Oil Council, Palm Oil development and performance in Malaysia. MPOB and APOC Presentation to USITC Washington DC.

Atmaja and Hendra. 2007. Soil moisture content in soil conservation technique of ridge terace and silt pit in oil palm plantation PTPN VII Rejosari, Lampung. IPB, Bogor Agricultural University.

Baba Amte Centre. 2007. National rural employment guarantee act watershed works manual: for people's empowerment. Samaj pragati sahayog for ministry of rural development, government of India.

Bharad, G.M., Bathkal, B.G., Nagdeve, M.B., Kohale, S.K., Ingle, S.N., Gawande, R.L., Mahorkar, V.K., and Kayande, K.S. 1991. Watershed approach in rainfed agriculture. Res. Bulletin, Dr. Punjabrao Deshmukh Vidyapeeth, Akola.

Banabas, M., Turner, M. A., Scotter, D. R., and Nelson, P. N. 2008. Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. *Austlian Journal of Soil*, 46: 332–339.

Barbhuiya A.R., Arunachalam A., Pandey H.N., Arunachalam K., and Khan M.L. 2008. Effects of anthropogenic disturbance on soil microbial biomass C, N and P in a tropical rainforest ecosystem of Assam, northeast India. *Malaysian Journal of Soil Science*, 12: 31-44.

Basehart, H. W. 1972. Traditional history and political change among the Matengo of Tanzania. *Journal of the International African Institute*, Vol.XIII, 4: pp. 87-97.

Bescansa, P., Imaz, M.J., Virto, I., Enrique, A. and Hoogmoed, W.B. 2006. Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research*, 87: 19-27.

Bilotta, G. S., and Brazier, R. E. 2008. Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research*, 42: 2849–2861.

Black, G.R. and Hartge, K.H. 1986. Bulk Density. In Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Ed. Klute, A., 2nd edition, Madison, Wisconsin USA: *American Society of Agronomy-Soil Science Society of America*.

Bouyoucos G. L. 1935. The Clay ratio as a criterion of susceptibility of soil to erosion. *American Socity of Agronomy*, 27: 738 – 741.

Bremner, J.M., Mulvaney, C.S. 1982. Nitrogen-Total. In: A.L. Page, R.H. Miller (Eds). Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp. 595-624.

Breure, C.J. 2003. In Oil palm – Management for large and sustainable yields (Fairhurst & Härdter, eds). PPI/PPIC-IPI, Singapore, pp. 59-98.

Brogan S., Gerow T., Gregory J.D., Gueth M., Hamilton R., Hughes K.M., Swartley W. and Swift L. 2006. North Carolina forestry best management practices manual to protect water quality. North Carolina Division of Forest Resources.

Bruijnzeel, L.A. 1990. Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. Humid Tropics Programme, IHP-UNESCO, Paris, and Vrije Universiteit, Amsterdam, p. 224.

Buckingham, E. 1907. Studies on the movement of soil moisture. *Bulletin 38, USDA*, Bureau of Soils, Washington, DC.

Budianta, D., Wiralaga, A.Y.A. and Lestari, W. 2010. Changes in soil chemical properties of Ultisol applied by mulch from empty fruit bunches in an oil palm plantation. *Journal of Tropical Soils,* 15(5): 111-118.

Buresh, R.J., Smithson, P.C. and Hellums, D.T. 1997. Building soil phosphorus capital in Africa. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (eds) Replenishing Soil Fertility in Africa. *Soil Sience Society of America*, Madison,Wisconsin, pp. 111-149.

C.H. Umana and C.M. Chinchilla. 1991. Symptomatology associated with water deficit in oil palm. *ASD oil palm papers*.

Chan, K.W., Watson, I. and Lim, K.C. 1980. Use of oil palm waste material for increased production. In *Proceedings of the Conference on Soil Science & Agriculture Development in Malaysia.* Kuala Lumpur, April 10-12, 1980, Pushparajah E., Chin S.L. (Eds.), Incorporated Society of Planters, pp. 213-242.

Chaney, K. and Swift, R.S. 1984. The influence of organic matter on aggregate stability in some British soils. *Soil Science* 35: 223-230.

Chauhan B.S. 2008. Environmental studies. Social Issues and the environment. An imprint of Laxmi Publications. University Science Press.

Chaves, M.M. and Oliveira, M.M. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *Journal of Experimental Botanic,* 42: 1-16.

Cheng, S., Hong, X.C., Hong, B.S. Xin, T.L. and Young, X. 2011. Growth and physiological responses to water and nutrient stress in oil palm. *Aferican Journal of Biotechnology,* 10(51): 10465-10471.

Chim, L. T., 1974. A note on soil erosion study at Tawau hills forest reserve. *Malaysian Natural Journal,* 27: 20-26.

Comte, I., Colin, F., Whalen, J.K., Grünberger, O. and Caliman, J.P. 2012. Agricultural practices in oil palm plantations and their impact on hydrological changes, nutrient fluxes and water quality in Indonesia: A review. In Donald L. Sparks, editor: Advances in Agronomy, 116: 71-124

Corley, R.H.V. 2009 How much palm oil do we need. *Environmental science & policy*, 12: 134-139.

Corley, R.H.V. and Tinker, P.B. 2003. The Oil Palm. 4th edition. Oxford: Blackwell Science Ltd., P. 562.

Dale, W. L. 1959. The rainfall of Malaya - Part I. *Journal of Tropical Geography,* 13: 30-32.

Dalvi V.B., Nagdeve M.B., and Sethi L.N. 2009. Rain water harvesting to develop non-arable lands using continuous contour trench (CCT). Assam University. *Journal of Science and Technology: Physical Sciences and Technology*, 4: 54-57.

Daniel, J. G., and A. Kulasingam .1974. Problems arising from large scale forest cleaning for agricultural use - The Malaysian experience. *Malaysian Froster*, 37 (3): 152-160.

Davidson, L. 1991. "Management for efficient, cost effective and productive oil palm plantations. In *Proceedings of the Conference at PORIM International Palm Oil Conference,* September 9-14, 1991.

Donough, C.R., C. Witt, T. Fairhurst, W. Griffiths, and A.G. Kerstan. 2006. intensification in oil palm plantations. In *Proceedings of the 5th International Planters Conference 2006*, Incorporated Society of Planters, Kuala Lumpur.

Donough C.R., Witt C., and Fairhurst T.H. 2009. Yield intensification in oil palm plantations through best management practice. *Better Crops*, 93 (1):12-14.

Durfrene, E., Dubos B., Rey H., Quencez P., and Savgier B., 1992. Changes in evapotranspiration from an oil palm stand (Elaeis Guineensis Jacq) exposed to seasonal soil water deficits. Acta Oecologica, 13: 299-314.

Dufrene, E. and Saugier, B. 1993. Gas exchange of oil palm in relation to light, vapour pressure deficit, temperature and leaf age. *Functional Ecolog,y* 7: 97-104

Ekanade O. 1987. Small-scale cocoa fFarmers and environmental change in the tropical rain forest regions of south-western Nigeria. *Journal of Environmental Management,* 25: 61-70.

El-Swaify S.A., Dangler E.W. and Armstrong C.L., 1982. Soil erosion by water in the tropics. Research Extension Seris 024. University of Havaii.

Emerson, W.W. and Greenaland D.J. 1990. Soil aggregates-formation and stability. In M.F. de Boodt, M.H.B. Hayes and A. Herbillon (eds.) *Soil colloids and their associations in aggregates.* New Yourk: Plenum Press, pp. 485-511.

Etta, C.E., Nkongho, R.N., Timti, I.N. and Nebane, C.N. 2007. Effects of empty fruit bunch mulching applied as organic manure on the yield of oil palms, planted on lateritic sandy soils of Pamol, Ndiane Estate, Camerron. In *Proceeding of PIPOC 2007, International Palm Oil Congress (Agriculture, Biotechnology and Sustainability),* pp. 625-638.

Evans, J. 1992. Plantation Forestry in the Tropics, 2nd edn. Clarendon Press, Oxford.

Fairhurst, T.H. and Mutert, E. 1999. Interpretation and management of oil palm leaf analysis data. *Better Crops International,* 13(1): 48-51.

FAOSTAT. 2011. http://faostat.fao.org.

FAOSTAT. 2008. ResourcesSTAT. Food and agriculture organization of the united nations, Rome, Italy.

Fauziah, C.I., Jamilah, I. and Syed Omar, S.R. 1997. An evaluation of cation exchange capacity methods for acid tropical soils. *Pertanica Journal of Tropical Agriculture*. SCI. 20(2/3).

Feller C., Fritsch E., Poss R. and Valentin C. 1991. Effect de la texture sur le stockage et la dynamique des matieres organiques dans quelques sols frrugineux et ferralitique (Afrique de l'Ouest, en particulier). *Cahiers ORSTOM,* série Pédologie 25: 25-36.

Ferwerda, J.D. 1977. Oil palm. In: Alvim, P.deT. and Kozlowski, T.T. (eds) Ecophysiology of tropical crops. Academic Publishers, New York, pp. 351–382.

Filho W. L. 2012. Climate change and the sustainable use of water. Springer Heidelberg Dordrecht London New York. ISSN, 1610-2010.

Fisher, R.F. and Binkley, B. 2000. Ecology and management of forest soils (3rd Edition) Wiley, New York. p. 489.

Food and Agriculture Organisation of the United Nations (FAO). 2002. 'Small-scale palm oil processing in Africa', Chapter 3, FAO Agricultural Services Bulletin 148, accessible at: http://www.fao.org/DOCREP/005/y4355e/y4355e03.htm, accessed in 2010.

Foong, S.F. and Lee, C.T. 2000. Increasing oil palm productivity with irrigation – felda's experience, in *Pushparajah, E (Ed.) Proceedings of the International Planters Conference*, Plantation Tree Crops in the New Millennium: The Way Ahead. The Incorporated Society of Planters, Kuala Lumpur, pp. 227-301.

Foster, H.L. 2003. Assessment of oil palm fertilizer requirements. In *Proceedings* of Oil Palm: Management for Large And Sustainable Yields (Fairhurst, T. and Hardter, R., eds.). Potash and Phosphate Institute (PPI), Potash and Phosphate Institute Canada (PPIC) and Int. Potash Inst. (IPI), Singapore, pp. 231-257

Foster H.L. and Chang K.C., 1997. Seasonal fluctuation in oil palm leaf nutrient levels. *MARDI Research Bulltain*, 5 (2): 74-90

Foster, H.L., and Goh, H.S. (1997). Fertilizer requirement of oil palm in west Malaysia. In *international Development in Oil Palm* (Newall W. ed.) Incorporated Society of Planters, Kuala Lumpur.

Gachene et al. 1997. Soil erosion effects on soil properties in a highland area of central Kenya. *Soil Science Society of America Journal,* 61: 559-564.

Gawankar, M.S; Devmore, J.P; Jamadagni, B.M; Sagvekar, V.V; Khan, H.H. 2003. Effect of water stress on growth and yield of Tenera oil palm, *Journal of Applied Horticulture*, 5(1): 39-40.

Goh, K.J., Chew, P.S. and Teo, C.B. 1994. Maximising and maintaining oil palm yields on commercial scale in Malaysia. In *Chee, K.H. (ed.) International Planters Conference on Management for Enhanced Profitability in Plantations*. Kuala Lumpur, 24–26 October 1994. ISP, pp.121–141.

Goh, K.M. 2004. Carbon sequestration and stabilization in soils: Implications for soil productivity and climate change. *Soil Science and Plant Nutrition,* 50: 467-476.

Government of Rajasthan. 2008. Derail project report. Rural development and Panchyati Raj department. Watershed Development and soil Conservation Department Rajasthan, Jaipur.

Gray B.S. and Hew C.K. 1968. Cover crop experiments in oil palms on the West Coast of Malaysia. In P.D. Turner (Ed.), Oil palm developments in Malaysia. Inc. Soc. Planters, Kuala Lumpur.

Hamdan, J., Burnham, C.P. and Ruhana, B. 2000. Degradation effect of slope terracing on soil quality for *Elaeis quineensis* Jacq. (oil palm) cultivation. Land degradation and development, 11: 181-193

Hashim M., Ibrahim A.L., Marghany M., Ahmad S., and Okuda T. 2008. Assessment of impact on landscape development to ecological service avlues and goods in malaysia lowland tropical rainforest using integrated remote sensing and GIS techniques. The International Archives of the Photogrammetry, Remote Sensing and Spacial Information Sciences. Vol. XXXVII (B7): 1403-1414.

Hartemink, A.E. 2006. Soil erosion: Perennial crop plantations. In *Encyclopedia of Soil Science,* ed. R. Lal, New York, USA: Taylor & Francis Publisher, pp. 1613-1617.

Havlin J.L., Tisdale, S.L., Beaton, J.D. and Nelson W.L. 2011. Soil fertility and fertilizers. New Delhi: PHI.

Heady H.F. 1975. Rangeland management. McGraw-Hill Book Company. New York.

Hemptinne, J. and Ferwerda, J.D. 1961. Influence des précipitations sur les productions du palmier à huile (Elaeis, Jacq.). Oléagineux 16(7):431-437.

Henson, I.E. 1994. Environment impacts of oil palm plantations in Malaysia. PORIM Occasional, p.33.

Henson, I.E. and Harun, M.H. 2005. The influence of climatic conditions on gas and energy exchanges above a young oil palm stand in north Kedah, Malaysia. *Journal of Oil Palm Research,* 17: 73-91.

Hill Region. Himalayan ecology. ENVIS Bulletin 14 (1)

Hill, R.D. 1982. Agriculture in the Malaysian region. Budapest, Hungary: Akademiai Kiado.

Hille, D. 1998. Environmental soil physics . San Diego, USA: Academic Press, p. 771.

Hudson, B.D. 1994. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation,* 49(2): 189-194.

Huntington, T.G. 2003. Available water capacity and soil organic matter. In *Proceeding of Encyclopaedia of Soil Science,* ed. R., Lal, New York: Marcel Dekker, pp. 139-143.

Husin, M., Zakaria Z.Z., Hassan, A.H. 1987. Potentials of oil palm by-products as a raw materials for agro-based industries. In *Proceeding of the 1985 PORIM National Symposium on Oil Palm By-products for Agro-Based Industries.* Kuala Lumpur, 5-6 Nov, 1985, PORIM, pp. 7-15.

International Board for Soil Research and Management. 1991. Evaluation for sustainable land management in the developing world. IBSSRAM Proceeding, No. 12, Vol. 1. IBSRAM, Bangkok.

Itani, J. 1998. Evaluation of an indigenous farming system in the Matengo highlands, Tanzania, and its sustainability. *African Study Monograph*, 19(2): 55-68.

Jabatan Kerja Raya. 2014. Schedule of rates for the supply of all labour, materials, tools, plants, appliances and everything else necessary for the erection and completion Retrieved 2014 from https://www.jkr.gov.my/ckub/a_main/images/pdf/LUM%20SUM%2009.pdf

Jalani, S., Cheah, S.C., Rajanaidu, N. and Darus, A. 1997. Improvement of oil palm through breeding and biotechnology. IAOCS 74: 1451-1455.

Jantaraniyom, T., Exsomtramage, T., Nilnond, C. and Tongkum, P. 2001. Effect of empty fruit bunches mulching on yield, soil moisture and leaf nutrient contents of oil palm. *Songklanakarin Journal of Science and Technology*, 23 (Suppl.): 679-689.

Jenkinson D.S. 1988. Soil organic matter and its dynamics. In: Wild, A. (ed) Russell's Soil Conditions and Plant Growth. Longman, Harlow, pp. 564-607.

Jones, L.H. 1997. The effect of leaf pruning and other stresses on sex determination in the oil palm and their representation by a computer simulation. *Journal of Biology*, 187: 241-260.

Joshi H.B. 1983. Troup's silviculture of Indian trees. Controller of Publications, Delhi 4: 345.

Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. Soil physics. John Wiley & Sons, New York.

Kallarachal, J., Jeyakumar, P. and George, S.J. 2004. Water use of irrigated oil palm at three different arid locations in peninsular India. *Journal of Oil Palm Research* 16: 45-53.

Kamphorst, A. 1987. A small rainfall simulator for the determination of soil erodibility. *Netherlands Journal of Agricultural Science*, 35: 407-415.

Kayombo,R., Ellis-Jones, J. and Martin, H.L. 1999. Indigenous conservation tillage system in East Africa with an example of their evaluation from South West Tanzania. Kaumbutho P G and Simalenga T E (eds), Conservation tillage with animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa, pp. 89-107.

Kemper, W.D. and Rosenau, R.C. 1986. Aggregate stability and size distribution. In: Klute A, editor. Methods of soil analysis. Part 1. Physical and mineralogical methods. Madison, WI. pp. 425-42.

Kirchmann, H. and Gerzabek, M.H. 1999. Relationship between soil organic matter and micropores in a long-term experiment at Ultuna, Sweden. *Journal of Plant Nutrition and Soil Science*, 162(5): 493-498.

Kjekshus, H. 1977. Ecology control and economic development in East African history.Villiers Publications, London.

Khaleel, R., Reddy, K.R. and Overcash, M.R. 1981. Changes in soil physical properties due to organic waste applications: A review. *Journal of Environmental Quality* 10(2): 133-141.

Khalid, H., Zin, Z.Z. and Anderson, J.M. 2000. Decomposition processes and nutrient release patterns of oilpalm residues. *Journal of Oil Palm Research,* 12(1): 46-63.

Kladivko, E.J. 1994. Residue effects on soil physical properties. In Managing Agriculture Residues, ed. P.W. Unger, Boca Raton, USA: Lewis Publishers, pp. 123-162.

Lal, R. 1979. Physical properties and moisture retention characteristics of some Nigerian soils. Geoderma 1: 127-139.

Lal, R., and B. Okigbo, 1990. Assessment of soil degradation in the southern states of Nigeria working paper No. 39. Washington D.C., USA. : World Bank. Environment Department Sector Policy and Research Staff.

Lal, R. and Shukla, M. 2004. Principles of soil physics. New York, USA: Marcel Dekker, p. 682.

Law, C.C. 2006. Changes in soil water profile due to different soil water conservation practices in an oil palm estate. Final year project, Universiti Putra Malaysia.

Lee PC and WP Panton. 1971. ‘First Malaysia plan land capability classification Rreport’. Economic Planning Unit, Prime Minister’s Dept, Malaysia.

Lehmann, J. and Schroth, G. 2003.Trees, crops and soil fertility. CAB international, pp 151-166.

Lim, K.H. 1989. Soil erosion control under mature oil palms on slopes. In *Proceedings of PORIM International Development Conference,* Kuala Lumpur. Sukaimi, J., Zakaria, H.Z.Z., Paranjothy, K., Darus, A., Rajanaidu, N. Cheah, S.C., Wahid, M.B., Hensom, I.E. and Dolmat, H.M.T. (eds.). pp. 191-198.

Lim, K.C. and Zaharah, A.R. 2000. Decomposition and N & K release by oil palm empty fruit bunches applied under mature palms. *Journal of Oil Palm Research*, 12(2): 55-62.

Loong, S.G., Nazeeb, M. and Letchumanan, A. 1987. Optimizing the use of EFB mulch on oil palm on two different soils. In *Proceedings of the 1987 International Oil Palm/Palm Oil Conference: Progress and Prospects-Agriculture.* Kuala Lumpur, Malaysia, Jun 23-26, 1987, Abdol Halim,. H., Soon, C.P., Wood, B.J. and Pushparajah, E. (eds.), pp. 605-639.

Lord, S., and Clay, J. 2006. Environmental impacts of oil palm—Practical considerations in defining sustainability for impacts on air, land and water. In *International Planters Conference on Higher Productivity and Efficient Practices for Sustainable Agriculture*, The Incorporated Society of Planters, Putrajaya.

Luna, R.K. 1989. Plantation and practice os silviculture. Khanna Bandhu, Dehradun, pp 371-372.

McLaren, R.G. and Cameron, K.C. 1996. Soil science 2nd edition Oxford University Press, London.

Madhu M., Raghunath B., Tripathi K.P., Sam M.J., Chandran B., Mohanraj R., and Haldoria B. 2011. Vegetative barrier with contour staggered trenches for resource conservation in new tea plantations of the Nilgiris, India. *Indian Journal of Soil Conservation*, 39 (1): 33-36.

Madhu M., and Trioathi K.P. 1997. Soil and water conservation practices in tea at Nilgiris: Some Facts. *Indian Farming (India)*, 47 (1): 33-36.

Maena, L. M., Thong, K. C., Ong, T. S., and Mokhtaruddin, A. M. 1979. Surface wash under mature oil palm. In *Proceedings of the Symposium on Water Agriculture in Malaysia* (E. Pushparajah, Ed.), pp. 203–216. Malaysian Society of Soil Science, Kuala Lampur.

Malesu, M.M., Oduor, A.R., Odhiambo, O.J. 2007. Green water handbook. Rainwater harvesting for agricultural production and ecological sustainability. Nairobi: The world Agroforestry Centre.

Malley, Z. J. U., Kayombo, B. Willcocks, T. J. and P. W. Mtakwa. 2004. Ngoro: an indigenous, sustainable and profitable soil, water and nutrient conservation system in Tanzania for sloping land. *Soil Tillage Research*, 77: 47 – 58.

Malmer A. 1996. Hydrological effects and nutrient losses of forest plantation establishment on tropical rainforest land in Sabah, Malaysia. *Journal of Hydrology*, 174: 129-148.

National Institute of Agricultural Extension Management, Ministry Agriculture, Government of India. www.manage.gov.in, Last accessed 2010

Manivanna S., Rajendran V. and Ranghaswami M.V. 2010. Effect of In-situ moisture conservation measures on fruit and nut quality of cashew (Anacardium Occidentale) in lateritic soils of Goa. *Indian Jurnal of Soil Conservation*, 38 (2): 116-120.

McLean, E.O. 1982. Soil pH and lime requirement. In Methods of Soil Analaysis: Part 2- Chemical and Microbiological Properties, eds. A.L. Page, R.H. Miller and D.R. Keeney, Madison, Wisconsin, USA: American Society of Agronomy-Soil Science Society of America, pp. 199-224.

Mishra T.k., singh A.K., and Banerjee S.K. 2002. Response of conservation measures on the growth of planted species and improvement in soil properties in a degraded area. In *proceeding of12th ISCO conference*. Beijing.

Mite, F., Carrillo, M. and Josė. 1999. Fertilizer use efficiency in oil palm is increased under irrigation in Ecuador. Better Crops International, May 1999, 13(1): 30-32.

Moradi A., Christopher T.B.S., Goh K.J., Hanif A.H.M., and Fuziah C.I. 2012. Evaluation of four soil conservation practices in a Non-Terraced oil palm plantation. *Agronomy Journal* ,104 (6): 27-40.

Morgan, R.P.C. 2005. Soil erosion and conservation. 3rd edition, Oxford: Blackwell Publishing, P. 304.

MPOB. 2014. Oil palm and the environment. Official Protal of Malaysian Palm Oil Board 2014. http://www.mpob.gov.my/palm-info/environment/520-achievements

Murtilaksono K., Darmosarkoro W., Sutara E.S., Siregar H.H., Hidayat Y., and Yusuf M.A. 2011. Feasibility of soil and water conservation techniques on oil palm plantation. *Journal of Agriculture Science*, 33 (1).

Murtilaksono K., Darmosarkoro W., Sutara E.S., Siregar H.H., and Hidayat Y. 2009. Effort to increase oil palm production through application technique of soil and water conservation. *Jurnal Tanah*, 14(2): 135-140.

Murtilaksono K., Siregar H.H., and Darmosarkoro W. 2007. Water balance model in oil palm plantation. *Jurnal Penelitian Kelapa Sawit*, 15 (1): 21-35.

Muslim A.S., Hidayat Y., and Sutarta E.S. 2008. Bund terraces and silt pits effectiveness to reduce overland flow and soil erosion in oil palm plantation area in Rejosari Management Unit. Institut Pertanian Bogor.

Ng, S.K. 1977. Review of oil palm nutrition and manuring – scope for greater economy in fertilizer usage. In: Earp, D.A. and Newall, W. (eds.) International Developments in Oil Palm. Malaysian International Agricultural Oil Palm Conference. Kuala Lumpur, 14– 17 June 1976. ISP, pp.209–233.

Ng, P. H. C., Chew, P. S., Goh, K. J. and Kee, K. K. 1999. Nutrient requirements and sustainability in mature oil palms—an assessment. The Planter 75: 331–345.

Netherlands Water Partnership. 2007. Smart water harvesting solutions. Examples of innovative, low-cost technologies for rain, fog, runoff water and groundwater.

Newman, E.I. 1997. Phosphorus blance of contrasting farming systems, past and present. Can food production be sustainable? *Journal of Applied Ecolocgy* 34: 1334-1347.

Noble, A.D., Moody, P., Ruaysoongnern, S., Liu Guodoa, Qi Zhiping and Berthelsen, S. 2003. Quantification of soil chemical degradation and its remediation in tropical australia, China and Thailand Pedosphere, 13(1).

Nye P. H. and Greenland D. J. 1960. The soil under shifring cultivation. Commonwealth Bureau of Soils, Harpenden, UK, pp. 144.

Ollagnier M., Lauzeral A., Olivin J. and Ochs R.1978). Evolution des Sols Sous Palmeraie Apres Defrichement de la Foret. *Oleagineux* 33: 537-547.

Olsen, S. R., and L. E. Sommers. 1982. Phosphorus. C. A. Mimic et al. (Ed.) Methods of soil chemical analysis, Part 2, Agronomy 9:403-430. American Society of Agronomy, Inc., Madison, WI.

Onweremadu, E.U., Aswalam, D.O. and Ibe, I.E. 2007. Changes in soil properties following application of composted sludge on an isohyperthermic kandiudult. *Research Journal of Environmental Taxicology,* 1(2): 62-70.

Page, S.E. and Rieley, J.O. 1998. Tropical peatlands: A review of their natural resource functions, with particular reference to Southeast Asia. *Int Peat Journal*, 8: 95-106.

Palat, T., Smith, B.G. and Corley, R. H. V. 2000. Irrigation of oil palm in southern Thailand. In *Procciding Of the International Planters Conference.* May 2000. Incorporated Society of Planters, Kuala Lumpur, pp.303-315.

Palm C. A., Giller K. E., Mafongoya P. L. and Swift M. J. (2001). Management of organic matter in the tropics: translating theory into practice. Nutrient Cycling in Agroecosystems, 61: 63-75.

de Preez C. C. and du Toit M. E. 1995. Effect of cultivation on nitrogen fertility of selected Agro-ecosystems in South Africa. *Fertilizer Research,* 42: 27-32.

Pieri C. (1989). Fertilite des Terres de Savanes. Ministere de la Cooperation et du Developpement and CIRAD-IRAT, Paris, p. 444.

Pomeroy, D., and M.W. Service 1986. Tropical ecology. Longman Group, Hong Kong.

PORIM. 1994. Environmental impacts of oil palm plantations in Malaysia. Palm Oil Research Institute of Malaysia.

Porwal M.C. 1997. Remote sensing analaysis of environmental resources for planning and development. S. B. Nangia. A P H Publishing Corporation. New Delhi. India.

Pradeepkumar T., Suma J. and Satheesan K.N. 2008. Management of horticultural crops. New India Publishing Agency.

Pradhan I.P., and Rajbans D. 1973. Effect of soil working on ravine afforestation. The Indian Forester. *A Pioneer Monthly Journal in Forestry Research and Education*, 99 (10)

Pratt D. J., and Gwynne M. D. 1978. Rangeland management and ecology in East Africa. Hodder and Stoughton, London.

de Ridder N. and van Kelulen H. 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). *Fertilizer Research,* 26: 299-310.

Rajshekar. 2009. Techniques for steeply sloping land. Rain water harvesting in the landscape. India Water Portal.

Rama Mohan Rao M.S., Adhikari R.N., Chittaranjan S., Chandrappa M. and Padmaiah M. 1993. Influence of conservation measures on water yield from catchments in the semi-arid tract of South India. *Journal of Hydrology*, (N.Z.) 31 (1): 23-38.

Ramos, M.C., Cots-Folch, R. and Martines-Casanovas, J.A. 2007. Effects of land terracing on soil properties in the Priorat region in Northeastern spain: A Multivariate analysis. Geoderma, 142: 251-261.

Rankine, I., and T.H. Fairhurst. 1999. Field handbook.Oil Palm Series,Vol 1, 2, & 3. Singapore: Potash & Phosphate Institute (PPI).

Rees, A.R. 1961. Midday closure of stomata in the oil palm Elaeis guineensis Jacq. *Journal of Experimental Botany,* 12: 129-146.

Rhoades, J.D. 1982. Cation exchange capacity. In: A.L. Page (ed.) Methods of soil analysis. Part 2: Chemical and microbiological properties (2nd ed.) Agronomy 9: 149-157.

Richards L.A. 1974. Pressure – Membrane apparatus – Construction and Use. *Agricultural Engineering,* 28: 451-454.

Roslan M.N. 2006. Effect of water stress on the physiological processes and water use efficiency in oil palm. Master’s thesis, Universiti Putra Malaysia.

Sanchez, P.A., Palm, C.A., Davey, C.B., Szott, L.T. and Russel, C.E. 1985. Tree crops as soil improvers in the humid tropics? In: Cannell, M.G.R. and Jackson J.E. (eds)

Attributes of Trees as Crop Plants. Institute of Terrestrial Ecology, Huntingdom, UK, pp. 79-124.

Sands, R. and Mulligan, D.R. 1990. Water and nutrient dynamics and tree growth. For Ecology Management, 30: 91-111.

Sawhney, B. L., and Paralange, J.Y. 1974. Two-dimentional water infiltration from a trench in unsaturared soils. *Soil Science Society of America Journal*, 38(6): 867-871.

Schubert R., Schellnhuber H.J., Buchmann N., Epiney A., Griebhammer R., Kulessa M., Messner D., Rah,storf S.,Schmid J. 2009.Future bioenergy and sustainable land use. German Advisory Council on Global Change (WBGU). First publishe by Earthscan in th UK and USA.

Schorth, G., Oliver, R., Balle, P., Gnahoua, G.M., Kanchanakanti, N., Leduce, B., Mallet, B., Peltier, R. and Zech, W. 1995. Alley cropping with *Gliricidia sepium* on a high base status soil following forest clearning: effects on soil conditions, plant nutrition and crop yield. Agroforestry Systems, 32: 261-276.

Sharma K.D., Pareek O.P. and Singh H.P. 1986. Microcatchment water harvesting for raising Jujube orchards in an arid climate. In: Transactions of ASEA 29 (1): 112-118.

Sheil, D., Casson, A., Meijaard, E., van Nordwijk, M. Gaskell, J., Sunderland-Groves, J. Wertz, K. & Kanninen, M. 2009. The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? Occasional Paper, No. 51. CIFOR, Bogor.

Shillington, K. 1989. History of Africa. Macmillan Press Ltd., London.

Simanton J.R., Weltz M.A., and Larsen H.D. 1991. Rangeland experiments to parameterize the water erosion prediction project model: vegetation canopy cover effects. *Journal of Range Management*, 44(3): 276-281.

Simunek J., Van Genuchten M.Th. and Sejna M. 2006. The HYDRUS software package for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably-saturated media. Technical Manual, Version 1.0, PC Progress, Prague, Czech Republic, p. 241.

Singh, G., Kow, D.L., Lim, K.C. and Loong, S.G. 1999. Empty fruit bunches as mulch. In *Procciding of Oil Palm and the Environment: A Malaysian Perspective,* eds. G. Singh, K.H. Teo and L.K. David, Kuala Lumpur: Malaysia Oil Palm Growers' Council, pp. 171-183.

Singh R.K., Lama T.D., and Satapahy K.K. 2006. Treatment technologies for watershed development and management in North East.

Singh, G., Jalota, S.K. and Singh, Y. 2007. Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. *Soil and Tillage Research*, 97: 229-238.

Smith, G. 1989. The effects of soil water and atmospheric vapour pressure deficit on stomata1 behaviour and photosynthesis in the oil palm. *Journal of Experimental Botany*, 215: 647-651.

Smith, R. E., D. C. Goodrich, D. A. Woolhiser, C. L. Unkrich, and V. P. Singh., 1995. KINEROS-A kinematic runoff and erosion model. Computer models of watershed hydrology, pp. 697-732.

Soon, B.B.F. and Hoong, H.W. 2002. Agronomic practices to alleviate soil and surface runoff and soil losses in an oil palm estate. *Malaysian Journal of Soil Science,* 6: 53-64.

Speer W.S., 1963. Report to the government of Malaysia on soil and water conservation. Report no. 1788. Project TA/MAL/LA. Rome: FAO.

Stevenson F. J.and Cole M. A. 1999. Cycle of soil. John Wiley & Sons, New York, p: 427.

Swift, M.J., Heal, O.W. and Anderson, J.M. 1979. Decomposition in terrestrial ecosystems: Studies in ecology, V. 5, Oxford: Blackwell Scientific Publications, p. 372.

Talsma, T. 1969. Infiltration from semi-circular furrows in the field. *Australian Journal of Soil Research*, 7(3): 277-84.

Talsma, T. and Parlange, J.Y. 1972. One-dimentional vertical infiltration. *Australian Journal of Soil Research*, 10(2): 143-150.

Tambe S., Kharel Ghanashyam., Arrawatia M.L., Kulkarni H., Mahamuni K., and Ganeriwala A.K. 2012. Reviving dying springs: Climate change adaptation experiments from the Sikkim Himalaya. Mountain Research and Development, 32 (1): 62-72.

Tan, K.S. 1977. Efficient fertilizer usage for oil palm on inland soils. In: Earp, D.A. and Newall, S. (eds.) *International Developments in Oil Palm. Malaysian International Agricultural Oil Palm Conference*. Kuala Lumpur, 14–17 June 1976. ISP, pp.262– 288.

Tang M.K., Nazeeb M. and Loong S.G., 1999. An insight into fertiliser type and application methods in Malaysia Oil Palm Plantations. The Planter, Kuala Lumpur 75 (876): 115-137.

Teh, C.B.S. 1996. Soil aggregate stability: Its evaluation and relation to organic matter constituents and other soil properties. Master thesis of agricultural science. Universiti Putra Malaysia.

Teh, C.B.S. and Jamal, T., 2006. Soil physics analyses. Universiti Putra Malaysia Press, 1: p. 36.

Teh C.B.S., Goh K.J., Law C.C. and Seah T.S. 2011. Short-term changes in the soil physical and chemical properties due to different soil and water conservation practices in a sloping land oil palm estate. *Pertanika Journal of Tropical Agriculture Scince,* 34 (1): 41-62.

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. 2nd edition, Madison, Wisconsin USA: American Society of Agronomy-Soil Science Society of America, pp. 159-165.

Troeh, F.R., Hobbes, J.A. and Donahue, R.L. 2004. Soil and water conservation for productivity and environmental protection. 4th edition. Upper Saddle River, New Jersey: Prentice Hall, p. 656.

Tromble J.M. 1976. Semiarid rangeland treatment and rurface runoff. *Journal of Rangeland Management*, 29: 251-255.

Turner, P.D. and Gillbanks, R.A. 1974. Oil palm cultivation and management. incorporated society of planters, Kuala Lumpur.

UNEP (Editor). 2012. Sourcebook of alternative technologies for freshwater augmentation in Africa. Planting pits. Geneva: United Nations Environmental Program.

Van Bavel, C.H.M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Science Society of America Proceedings*, 17: 416-418.

Van Genuchten M.Th. 1980. A Closed-form equation for predicting the hydraulic conductivity of unsaturated soils. SSSA J. 44(5): 892-898.

Van Wambeke A. (1992). Soils of the tropics. McGraw-Hill, New York, p. 343.

Virendra K., Singh R.S., Singh P.K, and Singhvi B.S.M. 2007. Standardization of suitable soil and water conservation measures using remote sensing and GIS for small watersheds. *Journal of Agricultural Engineering*, 44 (2): 67-73.

Wakker, E., J de Rozario. 2004. Greasy Palms : The social and ecological impacts of large-scale oil palm plantation development in South East Asia , Friends of The Earth, London, UK

Wallis J.A.N. 1997. Intensified systems of farming in the tropics and subtropics. World Bank Discussion Paper No. 364. The World Bank Washington D.C. USA.

Walsh, L.M. and Beaton, J.D. 1973. Soil testing and plant analysis. Madison, Wis: Soil Science Society of America.

Wan Asma, I. 2006. Optimization of mulch mat production from oil palm empty fruit bunches and its effects on growth performance of Acacia hybrid seedlings on sandy tailings, PhD Thesis, University Putra Malaysia.

Warriar S.M. and Piggott C.J., 1973. Rehabilitation of oil palm by correction manuring based in leaf analysis. In Advance in Oil Palm Cultivation. Incorporated Society of Planters. Kuala Lumpur. Pp. 289-305.

Whitmore, T.C. 1985. Indigenous exploitation and management of tropical forest resources: an evolutionary continuum in forest-people interactions. Agriculture Ecosystems and Environment 63: 1-16.

Wichmeier W. H and Mannering J. V. 1965. Effect of organic matter content of the soil on infiltration. *Journal of Soil and Water Conservation*, 20.

Willis, R. G. 1966. The Fipa and related peoples of south-west Tanzania and north-east Zambia. In (D. Dorde ed.) Ethnographic Survey of Africa, p. 79. International African Institute, London.

Wingkis, R. 1998. Chemical composition of oil palm empty fruit bunch and its decomposition in the field, MSc. Thesis. Universiti Putra Malaysia.

WOCAT. 2007. Planting pits and stone lines. Niger – Tassa avec cordon pierreux. Oak Brook, IL: SWC Technology.

Woolhiser, D.A., Hanson, C.L., and Kuhlman, A.R., 1970, Overland flow on rangeland watersheds. *Journal of Hydrology (*New Zealand) 9(2): 336-356.

Woolhiser, D. A., R. E. Smith, and D. C. Goodrich. 1990. KINEROS: a kinematic runoff and erosion model: documentation and user manual. US Department of Agriculture, Agricultural Research Service.

Yeo, K.L. 2007. Processong empty fruit bunch (EFB) to fibre. In *Proceedings of Seminar on Ecomat Research and Promotion: Towards Enrichment of the Environment.* Beijing, China, 24-25 July, 2006, Organized by Beijing Municipal Bureau of Parks and Forestry, China and Malaysia Palm Oil Board, ed. Malaysian Palm Oil Board, pp. 38-39.

Yong Zhang, S., wen, J.L., Rong, Y. and Xue, X.C. 2009. Changes in soil aggregate, carbon and nitrogen storages following the conversion of cropland to alfalfa forage land in the marginal oasis of Northwest China. Environmental Management, 43: 1061-1070.

Zaharah, A.R. and Lim, K. C. 2000. Oil palm empty fruit bunch as a source of nutrients and soil ameliorant in oil palm plantations. *Malaysian Journal of Soil Science,* 4: 51-66.

Zin, Z. and Tarmizi, A.M. 1983. The use of palm oil industry by-product material. Workshop on Oil Palm Industry Technology Transfer. Problems and priorities. PORIM, pp. 121-131.

Zin, Z, Tarmizi A.M. and Khalid H. 2006. Field evaluation of urea as nitrogen fertiliser for oil palm and factors affecting their efficiency. In *procciding of Urea 2006, Urea the Fertiliser of Choice,* December 2006, Kuala Lumpur.

BIODATA OF STUDENT

The student, Mohsen Bohluli was born on 9 July 1981 in a city in west of Iran. He finished his high school in same city. After his secoundry education, he enrolled for Diploma of Associate's Degree in University of Ilam in 1999 and graduated in Technology of Range and Watershed Management in 2001. In 2004, he completed his bachelor degree in Natural Resources (Watershed Management) Engineering in University of Yazed and owned second place in Comprehensive Government Master Examination in whole country and continued his master degree in University of Tehran. He became graduated from University of Tehran in Natural Resources Engineering in 2006. Bohluli became a lecturer at Azad University of Iran from 2006 to 2008. He also cooperated with Tagh Saz Road & Construction Co. as a hydrologist from 2004 to 2007. His interest in learning encouraged him to continue his PhD in Universiti Putra Malaysia.

LIST OF PUBLICATIONS

1) MORADIDALINI, A., BOHLULI, M., TEH, C.B.S. & GOH, K.J. 2011. Effectiveness of silt pits as a soil nutrient and water conservation method for non-terraced slopes. In: Hamdan J. & Shamshudin, J. (Eds.). Advances in tropical soil science. Vol. 1. Universiti Putra Malaysia, Serdang, pp. 71-91.

2) BOHLULI, M., TEH, C.B.S., HUSNI, M.H.A. & ZAHARAH, A.R. 2012. The effectiveness of silt pit as a soil, nutrient and water conservation method in non-

terraced oil palm plantations. In: Rasidah, W.K., Rosazlin, A., Osumanu, A.H., Fakhri, M.I., Malik, Z., Hamzah, A., Ahmad, R. & Vijayanathan, J. (Eds.). Proceedings of the Soil Science Conference of Malaysia 2012. Soil quality towards sustainable agriculture production. Malaysian Soil Science Society, Sg. Buloh.

3) MOHSEN, B., TEH, C.B.S., HUSNI, M.H.A. & ZAHARAH, A.R. 2012. Simulation by HYDRUS 2D model on silt pit efficiency on conserving soil water. In: International Agriculture Congress 2012. Transforming Agriculture for Future Harvest. 4-6 September 2012, Putrajaya. (Proceedings in CD)

4) BOHLULI, M., TEH, C.B.S., HUSNI, M.H.A., ZAHARAH, A.R. 2014. Silt pit efficiency in conserving soil water as simulated by HYDRUS 2D model. Pertanika Journal of Tropical Agriculture. Vol 37(3) Agu 2014. (In press).

5) BOHLULI, M., TEH, C.B.S., HUSNI, M.H.A. & ZAHARAH, A.R. 2014. Review on the use of silt Pits (contour trenches) as a soil and water conservation. In: Hamdan J. & Shamshudin, J. (Eds.). Advances in tropical soil science. Vol. 3. Universiti Putra Malaysia, Serdang. (In press).