



UNIVERSITI PUTRA MALAYSIA

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

MOHSEN BOHLULI

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**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

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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

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November 2014

Chairman: Christopher Teh Boon Sung, PhD.

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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

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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 ($1 \times 3 \times 1$ m), H2 ($1.5 \times 3 \times 1$ m), H3 ($2 \times 3 \times 1$ m) dan H4 ($2 \times 3 \times 0.5$ 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 pengecalan 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.



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I certify that a Thesis Examination Committee has met on 24 November 2014 to conduct the final examination of Mohsen Bohluli on his thesis entitled "Effectiveness of Silt Pit as a Soil, Water and Nutrient Conservation Method in Non-Terraced Oil Palm Plantation" 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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TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vi
DECLARATION	viii
LIST OF TABLES	xii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xix
CHAPTER	
1 INTRODUCTION	1
1.1 Problem Statement	1
1.2 Objectives of Study	5
2 LITERATURE REVIEW	6
2.1 Oil Palm in Malaysia	6
2.2 Oil Palm and Soil Erosion	8
2.3 Oil Palm Water Requirement and Water Stress	13
2.4 Contour Trenches and Silt Pits	16
2.4.1 Dimension and Distances Between Trenches	17
2.4.2 Continuous Vs Staggered Contour Trenches	19
2.5 Pit and Silt Pit	24
2.5.1 Pits	24
2.5.2 Silt Pit	26
2.6 Summary of the Literature Review	29
3 MATERIALS AND METHODS	31
3.1 Site Description	31
3.2. Sampling	38
3.3. Soil Chemical and Physical Analyses	39
3.4 Measurement of Soil Water Content	40
3.5. Amount of Sediments Trapped	41
3.6. Statistical Analysis	41
3.7. HYDRUS 2D Model	42
3.8. KINEROS2 Model	45
4 RESULTS AND DISCUSSION	46
4.1 Rain in Experimental Sites	46
4.2. Initial soil characteristics in experimental sites	47
4.3. Effect of Silt Pits on Soil Water Content	47
4.4. Run-off Simulation by KINEROS 2 Model	57
4.5. Simulation by HYDRUS 2D Model	60
4.6. Effect of Silt Pits on Amount of Sediment Trapped	71
4.7. Effect of Silt Pits on Soil Chemical Properties	76

4.7.1. Effect of Silt Pits on Soil Carbon	80
4.7.2. Effect of Silt Pits on Soil Total Nitrogen	85
4.7.3. Effect of Silt Pits on Soil Base Cations	89
4.7.4. Effect of Silt Pits on Soil Phosphorous Content	98
4.7.5 Effects of Silt Pits on Soil Cation Exchange Capacity and pH	102
4.8. Effects of Silt Pits on Soil Physical Properties	104
4.9. Cost and Benefit Analysis	109
5 CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH	111
5.1. Conclusion	111
5.2. Recommendations for future research	113
REFERENCES	114
BIODATA OF STUDENT	131
LIST OF PUBLICATIONS	132

LIST OF TABLES

Table		Page
2.1	Run-off, soil erosion, dissolved solutes and sediment losses via run-off in Southeast Asia rainforest	9
2.2	soil erosion and nutrient losses in surface water from spatial components of an oil palm plantation on a Typic Hapludult in Malaysia	11
2.3	Soil erosion losses under oil palm in Malaysia	13
2.4	Yield of oil palm with different irrigation methods	15
2.5	interval trench spacing by hillslope	18
2.6	Effect of continues contour trenches on surface run-off and soil loss	18
2.7	The treatments by Pradhan and Rajbans	23
2.8	Surface run-off losses under different conservation practices	27
2.9	Totl mean soil losses under different treatments	28
2.10	Effectiveness of bund terraces and silt pits on overland flow and sediment load	28
2.11	Effectiveness of ridge terrace and silt pit on soil water content	30
3.1	Treatments including different sizes, opening area and wall-to-floor area ratio	34
3.2	Soil hydraulic parameters for the analytical functions of HYDRUS 2D for 12 textural classes of the USDA soil textural triangle.	44
4.1	Soil characteristics of Tuan Mee and Tekam experimental sites	48
4.2	Average daily and percentage increase in soil water content for the 0.90 m soil profile due to different silt pit treatments in Tuan Mee	49
4.3	Simulated run-off over 3 different slopes by Kinerose 2 model in Tuan Mee and Tekam experimental sites	58
4.4	Releasing time (hr) of total trapped water in H1 into the different soils for different amounts of run-off	65
4.5	Releasing time (hr) of total trapped water in H2 into the different soils for different amounts of run-off	65

4.6	Releasing time (hr) of total trapped water in H3 into the different soils for different amounts of run-off	66
4.7	Releasing time (hr) of total trapped water in H4 into the different soils for different amounts of run-off	67
4.8	The percentage of occupied initiate volume of silt pit treatments by sediment over one year in Tuan Mee	72
4.9	Analysis of variance for the soil chemical properties outside of silt pits (Tuan Mee)	76
4.10	Soil chemical changes outside of the silt pits, across time and depth (Tuan Mee).	77
4.11	Analysis of variance for the soil chemical properties inside of silt pits (Tuan Mee)	77
4.12	Soil chemical parameters inside of the silt pits, across time and depth (Tuan Mee)	78
4.13	Analysis of variance for the soil chemical properties of trapped sediments inside of silt pits (Tuan Mee)	78
4.14	Soil chemical parameters in trapped sediments inside of the silt pits, across time (Tuan Mee).	79
4.15	Average nutrients of five times random samplings in run-off and collected water inside the silt pit	79
4.16	Average of soil organic C during experiment period in different sampling areas (Tekam)	85
4.17	Average of soil total N (%) during experiment period in different sampling areas (Tekam).	89
4.18	Average of soil total K (cmol/kg) during experiment period in different sampling areas (Tekam)	97
4.19	Average of soil total Ca (cmol/kg) during experiment period in different sampling areas (Tekam)	97
4.20	Average of soil total Mg (cmol/kg) during experiment period in different sampling areas (Tekam)	98
4.21	Average of soil phosphorous (mg Kg ⁻¹) during experiment period in different sampling areas (Tekam)	100
4.22	Analysis of variance for soil physical properties outside of silt pits in Tuan Mee	105

4.23	Soil physical properties outside of silt pits, across time and depths (Tuan Mee)	105
4.24	Analysis of variance for soil physical properties outside of silt pits in Tekam.	108
4.25	Soil physical properties outside of silt pits, across time and depths (Tekam)	108
4.26	Required fertilizer for production of 30 t ha ⁻¹ yr ⁻¹ of EFB in Malaysia	109
4.27	Effects of silt pits on increasing soil nutrients	110
4.28	Cost and benefit analysis table	110



LIST OF FIGURES

Figure		Page
1.1	Silt pits collect the run-off and sediments flowing over the slope and redistribute collected water and nutrients into the root zone of oil palms in non-terraced slopes of oil palm plantations	4
2.1	Worldwide trend of oil palm's fruit yield, plantation area and oil production from 1961 to 2006	7
2.2	Output of Malaysian palm oil	7
2.3	Effect of irrigation and fertilizer application on bunch weight in the fifth year of harvest in Ecuador	16
2.4	Continuous Vs. staggered trenches	20
2.5	Straggled contour trenches with trapezoid cross section combined with tree and grass plantation on embankment	21
2.6	Application of staggered contour trenches for water harvesting in order to revive dying springs in Himalaya	22
2.7	Ground cover changes and collected water after application of mentioned trenches in figure 2.6	22
2.8	Planting pits along contour lines in arid steeply slopes	25
2.9	Basic design of planting pits in arid and semi-arid areas	26
3.1	Illustration of Tuan Mee experimental site	32
3.2	Illustration of Tekam experimental site	33
3.3	Field layout of the experiment	34
3.4	Silt pit across section and 3D illustration of dimensions	35
3.5	H1 (1×3×1 m) had the smallest volume and floor area and the biggest wall-to-floor area ratio.	36
3.6	H2 (1.5×3×1 m)	37
3.7	H3 (2×3×1 m)	37
3.8	H4 (2×3×0.5 m) was the shallowest silt pit treatment with a 0.5 m depth and the smallest wall-to-floor area ratio and the biggest opening area.	38

3.9	Cross section of a silt pit. Sampling areas were outside (OS) and inside (IS) of the silt pit as well as trapped sediments of the silt pit (Sed)	39
3.10	Calibration of moisture probe through linear relationship of actual volumetric soil water content and readings of moisture probe	41
3.11	S_p as the slope of the soil water retention curve at a point halfway between θ_r and θ_s	44
4.1	Total rainfall during the experiment in Tuan Mee (Jan-Dec 2010)	46
4.2	Total rainfall during the experiment in Tekam (Jul-Dec 2010 to Jan-Jun 2011)	47
4.3	Monthly average of total soil water content up to 0.90 m soil depth (Tuan Mee, from Jan to Dec 2010)	49
4.4	Trend of average daily soil water content around silt pit treatments up to 0.90 m soil profile (Tuan Mee)	51
4.5	Monthly average of total soil water content up to 0.90 m soil depth (Tekam)	52
4.6	Changes of the soil water from the soil surface up to 0.90 m depth (Tekam)	53
4.7	Comparison of measured cumulative infiltration in both experimental sites	54
4.8	Comparing the soil structure between Tekam and Tuan Mee	55
4.9	Ground cover at experimental sites	56
4.10	Hydrograph of 10 mm simulated rain in 30 min for Tuan Mee and Tekam	57
4.11	Measured runoff and sediments for a high intensity simulated rain of 36 cm hr ⁻¹ in Tuan Mee and Tekam.	59
4.12	Simulated temporal changes to water head (height of stored water from the bottom of silt pit) in the silt pit	61
4.13	Simulated volumetric soil water content at the various distances from the silt pit walls. Soil water content shown here is for 0.50 m soil depth and at 72 hours of simulation time	62
4.14	Simulated amount of water output from walls and floors of the silt pit treatments. Value in parenthesis indicates total wall-to-floor area ratio (W:F) of a silt pit treatment	63
4.15	Initial water head inside of simulated silt pits for different run-off	64
4.16	Water holding ability of silt pits for 10 m ³ ha ⁻¹ of simulated run-off	68

4.17	Water holding ability of silt pits for 20 m ³ ha ⁻¹ of simulated run-off	68
4.18	Water holding ability of silt pits for 50 m ³ ha ⁻¹ of simulated run-off	69
4.19	Water holding ability of silt pits for 75 m ³ ha ⁻¹ of simulated run-off	69
4.20	Water holding ability of silt pits for 100 m ³ ha ⁻¹ of simulated run-off	70
4.21	Water holding ability of silt pits for 150 m ³ ha ⁻¹ of simulated run-off	70
4.22	Water holding ability of H3 for 200 m ³ ha ⁻¹ of simulated run-off	71
4.23	Volume of collected sediments inside the silt pit treatments (Tuan Mee)	72
4.24	Exponential regression (3 rd month onwards) between occupied volume of silt pits and months after silt pit construction for estimating the time that silt pits would become full by sediments	74
4.25	Comparing a deep silt pit with a shallow silt pit 18 months after their construction	75
4.26	Changes of soil organic C in Tuan Mee due to different silt pit sizes over time outside of silt pits	81
4.27	Comparing ground cover around H1	82
4.28	Changes in soil organic C in Tuan Mee due to different silt pit sizes over time for trapped sediments inside pits	83
4.29	Changes of soil organic C in Tuan Mee due to different silt pit sizes over time inside of silt pits at depth	84
4.30	Changes in soil N in Tuan Mee over time and outside of silt pits	86
4.31	Changes in soil N in Tuan Mee over time inside of silt pits	88
4.32	Changes in soil K in Tuan Mee due to different silt pit treatments over time outside of pits	90
4.33	Changes in soil K in Tuan Mee due to different silt pit treatments over time inside of pits	91
4.34	Changes of Ca in Tuan Mee due to different silt pit treatments outside of the pits	93
4.35	Changes of Mg in Tuan Mee due to different silt pit treatments outside of the pits	94
4.36	Changes of Ca in Tuan Mee due to different silt pit treatments inside of the pits	95

4.37	Changes of Ca in Tuan Mee due to different silt pit treatments inside of the pits	96
4.38	Changes of phosphorous across all times outside of silt pits in Tuan Mee	99
4.39	Changes of phosphorous in trapped sediments inside of pits over time in Tuan Mee	100
4.40	Changes of phosphorous inside the pits in Tuan Mee	101
4.41	Changes of soil pH	103
4.42	Total Ca, Mg and K content inside of silt pits over time and across depths in Tuan Mee	104
4.43	Average of mean weight diameter (MWD) of soil aggregates for outside of different silt pits in Tuan Mee	106

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	Statistical 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
h	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 6-20° (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.

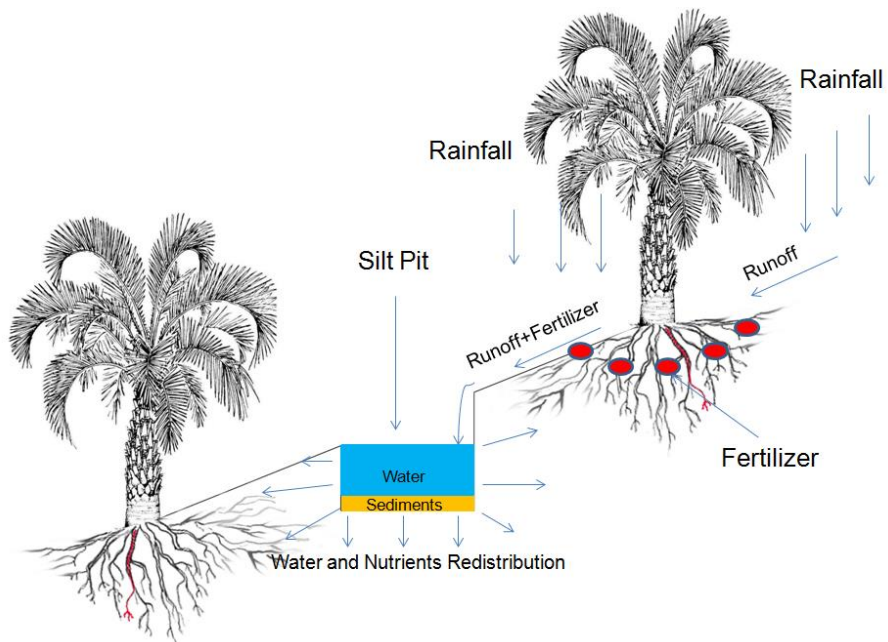


Figure 1.1. Silt pits collect the run-off and sediments flowing over the slope and redistribute the collected water and nutrients into the root zone of oil palms in non-terraced slopes of oil palm plantations.

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.

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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 secondary 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. & Shamsudin, J. (Eds.). Advances in tropical soil science. Vol. 1. Universiti Putra Malaysia, Serdang, pp. 71-91.

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- 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)
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