UNIVERSITI PUTRA MALAYSIA

MODELLING THE OPTIMAL SIZE OF SILT PITS FOR SOIL WATER CONSERVATION

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By

HUSAM HASAN ABDULAALI AL-SHAHEEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

October 2018

DEDICATION

My precious father and mother whose have taken great pains to raise me up.

My dear brothers and sister.

My beloved wife and daughters.

My teachers who provided me with the best education

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

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Chairman : Christopher Teh Boon Sung, PhD
Faculty : Agriculture

Malaysia experiences high total rainfall intensity, which increases soil erosion on steep slopes and causes a reduction in soil fertility, pollution of fresh and groundwater, and the degradation of adjacent lands. Although Malaysia has high rainfall, oil palm may still experience water stress due to high rainfall intensity which results in fast downslope water movement and little time for water to infiltrate into the soil. One of the most effective measures of soil and water conservation in Malaysia is the use of silt pits. The function of a silt pit is to control the runoff, trap and settle down the sediments, increase soil moisture or recharge the groundwater, reduce the effect of slope length and further reduce soil erosion and fertiliser losses. However, what is the optimal size and dimensions of a silt pit to enable the water to reach the farthest roots and empty slowly to release the water over the most extended period? What is the effect of the slope, runoff (volume of water), the volume of the pit, and type of soil of the spatial silt pit size? The study aimed to use the HYDRUS 2D/3D models and to formulate the simulation results as equations to select the optimal size and dimensions of a silt pit depending on the rainfall and soil properties. The treatments used in this study included the following four factors: seven type of soils (sand, sandy loam, loam, silt, sandy clay, silty clay, clay), six surface slopes (0˚, 5˚, 10˚, 15˚, 20˚, and 25˚), three silt pits sizes (3, 4, and 5 m^3), each size having three depth levels (50, 75, and 100 cm), and several levels to cater for the volume of water available in the silt pit. Three stages were adopted in this study. The first stage utilised the software HYDRUS 2D/3D models to simulate the soil water content, wetting front, and time-to-empty from a silt pit of various sizes on different soils and slopes. The second stage distinguished the trend and determined the best fit by using statistical methods (Multiple linear regression (MLR) and Artificial neural network (ANN)) to estimate the optimal silt pit size. The last stage applied the fitted model to find the optimum silt pits in some areas of Peninsula Malaysia. From the simulation results, all parameters (distance of wetting front, water content, and time-to-empty) were affected by nearly all the factors (water head in the pits (H), pit width (W), amount of water applied (Vw), pit volume (Vp), and surface slope (Slope)). For instance, increasing the slope will slightly increase the wetting front distance (from 130.54 to 136.45 cm) and soil water content (from 0.374 to 0.375 m^3/m^3) with downslope, but decrease significantly the upslope wetting front and soil water content (130.53 to 101.26 cm and 0.373 to 0.333 m^3/m^3, respectively). However, there was no effect on the time-to-empty. The reduction of unfavourable results of the increasing slope was compensated by manipulating the values of H and Vp. The MLR models did not perform adequately especially for time-to-empty (Mean Squared Error (MSE) = 85.83; R^2 = 0.632) compared with the ANN models (MSE = 10.33; R^2 = 0.977), mostly due to the non-linear relations between the factors. The results demonstrated that despite requiring the same input data, the ANN models could favourably be used for all parameter predictions. However, process-based numerical models are undoubtedly a better choice for predicting the results with lower uncertainties when the required data are available. The fitted problem was then used to select the optimum sizes of the silt pit in Peninsula Malaysia, based on the soil texture and rainfall intensity. The results show that some types of the soils (sand, loam sand, and sandy loam) which have high values of hydraulic conductivity make the rainwater infiltrate into the soil. So, for these land, there is no need to construct the silt pits. While in the case of soils (sandy clay loam, clay loam, silt clay loam, sandy clay, silty clay, and clay) which have low values of hydraulic conductivity, a large volume of runoff water will be caught in those land compared to the sizes of silt pit used in the experiment. Therefore, length of the pit during construction must be extended to avoid flooding of water.

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

PERMODELANL SAIZ OPTIMUM PERANGKAP KELODAK UNTUK PEMULIHARAAN AIR DAN TANAH

Oleh

HUSAM HASAN ABDULAALI AL-SHAHEEN

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Malaysia mengalami intensiti hujan yang tinggi, ini meningkatkan hakisan tanah di cerun yang curam dan menyebabkan pengurangan kesuburan tanah, pencemaran air tawar dan air bawah tanah, serta pencuraian sifat tanah. Walaupun Malaysia mempunyai jumlah taburan hujan yang tinggi, pokok kelapa sawit boleh mengalami kekurangan air disebabkan pengaliran air yang pantas dan air tidak sempat untuk meresap ke dalam tanah. Salah satu langkah pemuliharaan tanah dan air yang paling berkesan di Malaysia adalah menggunakan perangkap kelodak. Fungsi perangkap kelodak adalah untuk mengawal air larian permukaan, memerangkap dan memendapkan sedimen, meningkatkan kelembapan tanah atau memperbaiki air bawah tanah, mengurangkan pengaruh panjang cerun dan seterusnya mengurangkan hakisan tanah dan kehilangan baja. Walau bagaimanapun, apakah saiz dan dimensi optimum parit kelodak untuk membolehkan air mencapai akar dan secara perlahan melepaskan air untuk jangka masa yang panjang Apakah kesan cerun, aliran air (isipadu air), isipadu lubang, dan jenis tanah dalam perangkap kelodak tersebut Kajian ini bertujuan untuk menggunakan model HYDRUS 2D/3D untuk merumuskan hasil model simulasi sebagai persamaan untuk memilih saiz optimum dan dimensi perangkap kelodak bergantung kepada hujan dan sifat tanah. Rawatan yang digunakan dalam kajian ini termasuk empat faktor berikut: tujuh jenis tanah (pasir, lom berpasir, lom, kelodak, lempung berpasir, kelodak berlempung dan lempung), enam kecerunan tanah (0˚, 5˚, 10˚, 15˚, 20˚, dan 25˚), tiga ukuran parit kelodak (3, 4, dan 5 m^3) setiap lubang mempunyai tiga tahap kedalaman (50, 75, dan 100 cm), dan beberapa peringkat untuk memenuhi jumlah air yang ada dalam lubang tersebut. Tiga peringkat digunakan dalam kajian ini. Peringkat pertama menggunakan perisian HYDRUS 2D / 3D model untuk mensimulasikan kandungan air tanah, barisan depan pembasahan, dan masa-mengosong dari pelbagai saiz di tanah dan cerun yang berlainan. Tahap kedua membezakan trend dan menentukan yang terbaik dengan menggunakan kaedah statistik (Regresi Linear Berganda (MLR) dan Rangkaian Neural Buatan (ANN))

untuk menganggarkan saiz parit kelodak yang optimum. Peringkat terakhir menggunakan kaedah statistik untuk menentukan lubang perangkap kelodak yang optimum di Semenanjung Malaysia. Dari hasil simulasi, semua parameter (jarak barisan depan pembasahan, kandungan air, dan masa pelepasan air) dipengaruhi oleh faktor-faktor dalam eksperimen (permukaan air dalam lubang (H), lebar lubang (W), jumlah air digunakan (Vw), isipadu lubang (Vp), dan permukaan cerun (*Slope*). Sebagai contoh, peningkatan cerun akan sedikit meningkatkan jarak barisan depan pembasahan (dari 130.54 hingga 136.45 cm) dan kandungan aliran air (dari 0.374 hingga 0.375) ke bawah cerun, tetapi mengurangkan kandungan air ke atas cerun (130.53 hingga 101.26 cm dan 0.373 hingga 0.333). Walau bagaimanapun, tidak ada kesan kepada masa pengaliran air. Model-model MLR adalah kurang tepat, terutamanya untuk masa pengaliran air (*Mean Squared Error* (MSE) = 85.83; R^2 = 0.632) berbanding dengan model ANN (MSE = 10.33; R^2 = 0.977), terutamanya disebabkan oleh hubungan bukan linear antara faktor-faktor. Keputusan menunjukkan walaupun model ANN memerlukan data input yang sama, ianya dapat digunakan dengan tepat untuk semua ramalan parameter. Walau bagaimanapun, model berasaskan proses merupakan pilihan yang lebih baik untuk meramalkan keputusan dengan ralat yang lebih rendah jika ada data yang diperlukan. Keputusan dari model tersebut telah digunakan untuk memilih saiz optimum lubang perangkap kelodak di Semenanjung Malaysia, berdasarkan tektur tanah, topografi dan taburan hujan tahunan. Keputusan menunjukkan bahawa beberapa jenis tanah yang mempunyai nilai kekonduksian hidraulik yang tinggi menyebabkan air hujan menyusup ke dalam tanah. Oleh itu, bagi tanah-tanah ini, perangkap kelodak tidak perlu dibina. Walau bagaimanapun, dalam keadaan tanah yang mempunyai nilai kekonduksian hidraulik yang rendah, sejumlah besar isipadu aliran air akan menjadi kawasan tadahan di kawasan tersebut berbanding dengan saiz lubang perangkap kelodak yang digunakan dalam eksperimen ini. Oleh itu, dimensi panjang perangkap kelodak perlu dibesarkan untuk mengelakkan limpahan air keluar.

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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:

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LIST OF ABBREVIATIONS

J_{wi}	Darcy's flux [LT^{-1}] in the i^{th} direction
K_{ij}^{A}	Components of dimensionless anisotropy tensors for the hydraulic conductivity K^A [-]
K_r	Denoted the relative hydraulic conductivity [-]
L_{ex}	Extending length (m)
W_{ij}	Connection weight between the nodes i of the previous layer
X_i	Output of the node i in the previous layer
b_j	Represents the threshold (bias).
x_1 and x_n	Independent variables
α_0 and α_n	MLR parameters
$\vert h \vert$	Pressure
1D, 2D,and 3D	One, two, and three dimensions
AMC	Antecedent Moisture condition
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
ANN	Artificial neural network
D	Pit depths
DLL	Dynamically Linked Library
DTC	Decision Tree Classification
DWFD	Distance wetting front with downslope
DWFU	Distance wetting front with upslope
EWDrz	Equivalent Water Depth of the root zone
FACHIG	Farmers Association of Community self-help Investment Groups
FEFLOW	Finite Element subsurface FLOW
FI	Full irrigation
GIS	Geographic Information System
H	Water head in the pits
h	Matrix potential
HSG	Hydrologic Soil Group
HYDROGEOCHEM	Hydrologic transport and Geochemical
ho	Depth of ponding water over the soil surface
hs	Represents the capillary suction head at the wetting front
IFA	Interfacial Area
L	Length
LEACHM	Leaching estimation & chemistry
MLR	Multiple linear regression
MOPIC	Ministry of Planning and International Cooperation
MSE	Mean Squared Error
MWBUS model	Model of Water Budget of Unsaturated Soil
P	Precipitation
PASTIS	Predicting Agricultural Solute Transport in Soils
Q	Cumulative Boundary water fluxes (Cum.Flux)
Q_r	Residual water content
Q_s	Saturated water content

R^2	Correlation coefficient
RMSE	Root mean square error
RNN	Recurrent neural network
SCS-CN	Soil Conservation Service-Carve Number
SMR	Stepwise multiple regression
SVM	Support Vector Machine
SWAP	Soil Water Atmosphere Plant
SWC	Soil water content
SWCD	Soil water content with downslope
SWCU	Soil water content with upslope
TDR	Time-domain reflectometer
TTE	Time-to-empty
UZF1	Unsaturated Zone Flow
Var.H	Variable head
Vp	Pit volume
VSF	Variably Saturated Flow
Vw	Amount of water applied
Vw/W	Volume of water over width of pit
W	Width of the silt pit.
WD	Groundwater table Depth
Wetted W:F reatio	Area of all the wetted wall over area of floor
K_s	Saturated hydraulic conductivity [LT^{-1}].
Y	Dependent variable
θ	Volumetric water content
$\theta(h)$	Water content
θ_r	Residual water content
θ_s	Saturated water content
H	Denotes the total hydraulic head [L]
$H0$	Initial water head with time 0
$H1$	New water head with time (t)
K	Unsaturated hydraulic conductivity
$K(h)$	Referred to the saturated/ unsaturated soil hydraulic conductivity function [LT^{-1}]
S	Sink (source) term [T^{-1}],
d	Depth of wetting front at the bottom of the pond
t	Time
x	Distance
z	Vertical coordinate which was directed upwards
α	Angle between the flow path and vertical axis

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

One of the earth's resources being cultivated and consumed is arable land. Without addressing the problem of land degradation, food security will not be achieved and thereby foregoing biodiversity, climate change, and the necessities of life. Given the rapid increase in global population, this has resulted in the necessity for usable land areas.

There has been a significant rise in the demand for palm oil due to its usage in the production of edible, non-edible, and biodiesel products (Thoenes, 2006). It is estimated that the need for vegetable oils will grow significantly to about 240 million tons in 2050. One advantage of palm oil is that its production cost is low, besides high productivity compared to other oil crops (Corley, 2009). For that reason, it is advisable to increase plantation areas as well as employing the necessary technologies to prevent the shortage of oils in the future. This is especially relevant for planting palm oil trees in Malaysia to grow on sloping land.

Malaysia experiences high total annual rainfall (2000-3000 mm) and high rainfall intensity. Sloping farmland under heavy rains will experience overland flow and cumulative water runoff (Mu et al., 2015) that leads to the increase of accelerated soil erosion, reduced soil water storage, reduced soil fertility, fresh and groundwater pollution, and degradation of adjacent lands.

Oil palm trees grow in warm and wet conditions. Corley & Tinker (2008) stated that this type of tree needs 2000-2500 mm of annual rainfall and a minimum of 100 mm monthly. However, when the annual precipitation of 4000 mm is exceeded, the spreading of diseases will result. A rainfall value of 5000 mm and above is considered as the upper limit of palm oil tree planting (Nachtergaele et al., 2009).

Water management is an important aspect of growing oil palm trees, as water shortage presses palm oil trees and destroys crop productivity significantly. Water management objectives help to reduce the effects of drought by improving the use of rainwater by adding it to irrigation water and applying soil water conservation practices (Comte et al., 2012). Accordingly, annual oil palm yield could increase by 13 – 23 % when additional water for irrigation between 120 and 240 L palm^{-1} day^{-1} is provided, compared with no irrigation (rain-fed) (Palat et al., 2000). However, irrigation is expensive and often impractical. So, water needs to be carefully conserved in oil palm plantations. Hence, using steep land is not encouraged for oil palm plantations unless there are improvements in soil productivity and in conserving soil and water.

The primary goal of soil conservation is to benefit the maximum sustained production capacity from a farm and consequently prevent soil loss below its threshold. Therefore, by applying sound practices based on a scientific assessment of both the soil and vegetation, this will help to reduce soil erosion by up to 99 % (Labrière et al., 2015).

There are many methods to conserve water and soil on steep lands, one of which is through constructing terraces. Terraces may be defined as ground embankments built across the slope to lower surface runoff and guide it to a stable outlet at the velocity to prevent soil erosion, through the shortest path (Morgan, 2005).

In some cases, the construction of terraces has many limitations. For instance, on steep hill slopes, the mere reduction of slope length by contour bonding may not be able to reduce the intensity of the scouring action of runoff water (Afandi et al., 2017). In this case, it is essential to modify the degree of the slope (Haridas, 2005). Notwithstanding the important effect of terracing to reduce runoff and erosion for slopes between 6-20 degrees (Hammad et al., 2006), terracing loses its efficiency on gentle slopes and should instead, be replaced by others soil conservation practices (Corley & Tinker, 2003a). In Malaysia, tree crops are grown (usually rubber or oil palm) with the terraces widely spaced, and the shelves likewise are widely spaced for one row of plants (Morgan, 2005), that will lead to soil compaction and removal of the fertile layer of topsoil during construction that thereby reducing soil productivity (Hamdan et al., 2000).

The compaction and removal of the layers of soil across terraces result in harmful consequences on the physical attributes of soil like: decrease in hydraulic conductivity and overall stability as well as capacity of water retention (Ramos et al., 2007). Hill levelling is not recommended on granular, thin layer of soil or soil containing a large number of stones (Troeh et al., 2004). Bench terraces are inapt for thin layer of soils since their composition can uncover infertile subsoil (Morgan, 2005).

Another approach for soil and water conservation is through building trenches or silt pits. Contour trenches are constructed by trenching using a uniform level across the slope of the land in the upper reaches of the catchment area. The soil excavated from the trenches may be used to construct bunds that are required to be made in the lower reaches and transitions.

The primary function of slit pits is to reduce soil erosion by dividing the length of the sloped farm into many sections for retarding the runoff rate as well as the erosion of soil. Water trapped in these pits helps in increasing moisture content and vegetation growth. Further, contour trenches help to reduce the runoff velocity which leads the water to penetrate slowly in the soil. Notably, this will protect and enhance soil fertility by reducing the loss of nutrients, returning lost nutrients, and redistributing eroded nutrients. Furthermore, contour trenches help in the protection of land contour bunds from upper catchments runoff (Figure 1.1). Contour trenches are not only used in hill slopes and degraded and wasted lands but also on all slopes regardless of rainfall conditions, soil types, and depth (Haridas, 2005; Bohluli et al., 2014). However, over time, these trenches become filled with soil. So promotion of grass beds in the intermittent spaces among the trenches and plantation of soil stabilising trees on the upper edges of the trenches is beneficial (Haridas, 2005).

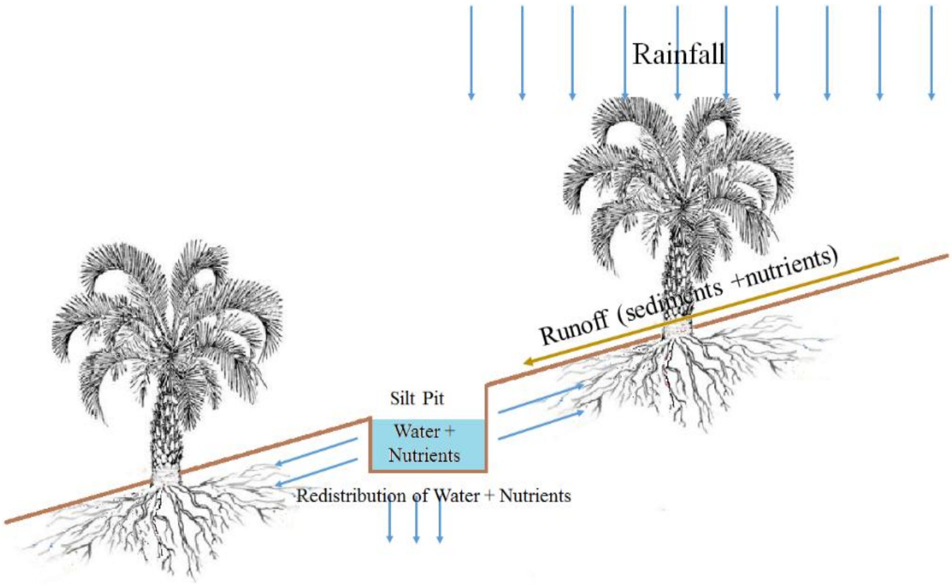

Figure 1.1 : Silt pits collect the runoff and sediments flowing overland and redistribute the water and nutrients through the root zone of the oil palms (Bohluli et al., 2014).

In Malaysia, the silt pit is considered as one of the most recommended soil and water conservation practices (Teh et al., 2011) and is one of the most marked procedures used in erosion control and increasing of yield. Indeed, the maximum production can be increased through yield intensification with the efficient management of land such as using a silt pit (Goh et al., 1994). Silt pits are narrow, long, close-ended, and deep trenches that are dug between palm rows (Roslan & Haniff, 2004).

Historically, silt pits have been implemented over many decades to coincide with oil palm planting, however, there are limited studies that have investigated the interaction of this method on the quality of soil and water especially when compared to other methods in the conservation of soil and water (Bohluli et al., 2015). The larger the silt pit, the greater volume of water it can store. However, a silt pit should be able to capture all runoff water that is generated from rainfall for the catchment area and then redistribute the collected water into the oil palm active root zone rather than the water being lost through deep percolation through the pit floor. Another point is that the water should possibly be stored for long periods so that the water can be used during dry periods where rainfall is less.

Therefore, this raises the following question: "What is the optimum dimension of a silt pit to increase the following factors; water content, distance of wetting, time to empty in different conditions, such as soil types, slope steepness, and rainfall intensity?". The answer will accordingly be solved using a numerical model using the HYDRUS software package. HYDRUS is a well-known software package used for modelling and simulation of two- and three-dimensional water movement in a dynamically saturated media in the presence of heat and solutes (Šimůnek et al., 2006; Sejna & Simunek, 2007). The software is used to simulate processes like irrigation, precipitation, evaporation, infiltration, soil water storage, root water uptake, deep drainage, groundwater recharge, capillary rise, and finally lateral flow in 2D/3D (Šimunek et al., 2012).

Over the years, many different software packages have originated from the HYDRUS family (e.g., HYDRUS (2D/3D), HYDRUS-2D, SWMS-2D, HYDRUS-1D, CHAIN-2D, UNSATCHEM, and CW2D, HP1). Moreover, these software packages have been widely deployed and used to assess water flow and dissolved movement in soil and groundwater (Šimunek et al., 2012). The official website of HYDRUS lists around one thousand references in which HYDRUS packages have been implemented (www.pc-progress.com).

1.2 Objectives of the Study

The objectives of this study were:

1. To determine the sensitivity of some selected parameters on the silt pit sizing using HYDRUS 2D/3D.
2. To distinguish the trend of all experimental elements and find the best-fit curves for the simulation results to select the optimal size of a silt pit by employing statistical models.
3. To develop a fitted statistical model for silt pit sizing in some areas of Peninsula Malaysia.

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LIST OF PUBLICATIONS

Husam, H. H., Teh, C. B. S., Ali, H. H., Rowshon, M. D. K., & Roslan, I. (2019). Using artificial neural network to estimate the optimal silt pit dimensions to maximize the water supply period for oil palm plantations. EnvironmentAsia. Vol. 12 No. 3 (In press).

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