UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND FIELD EVALUATION OF BLADES WITH DIFFERENT LIFTING ANGLES FOR MULCHING OIL PALM FRONDS PRIOR TO SEEDLING PLANTING

BALA GAMBO JAHUN

FK 2018 138

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By

BALA GAMBO JAHUN

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

February 2018

DEDICATION

I dedicate my dissertation work to my family and friends. A special feeling of gratitude to my loving parents, Malam Musa and Hajia Ladi whose words of encouragement drive me to the logical conclusion of my work. My sisters Dada Binta and Zuwaira have never left me for their prayers.

I also dedicate this dissertation to my wives Aisha, Fatima, and Khadijah who have supported me throughout the process. I will always appreciate all they have done, especially my children for their patience while I am away.

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

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In the oil palm industry, only 10% palm oil is produced and the other 90% is in the form of wastes which generates the largest amount of biomass, estimated at 80 million dry tonnes annually. The conventional technique of clearing old oil palm residues during pruning and subsequent field upkeep in Malaysia was the "chip and burn method". With the ban on open burning, the chipped palm biomass was not burnt but windrowed and this caused very high propagation of rhinoceros beetles, the most severe pest in immature and young mature palms, and severe crop loss in the first year of harvest due to beetle damage incidence. Nutrients in windrowed oil palm fronds are not readily accessible to replanted palms until the palm roots reached the windrows. The zero burning technique requires specialized machines. Heavy machinery caused damage to plantation roads and compaction of the soil which reduces its fertility to newly planted seedlings. A tractor mounted mulcher was designed and produced by Howard Company which is cheaper and more convenient than the heavy mulchers but farmers were complaining on the mulcher performance despite its evaluation.

This thesis focusses on the development and field performance of mulcher blades by cutting and incorporating the oil palm fronds/trunks into the soil during replanting period. Three different blades were developed with different geometries and lifting angles, both the modified and the original blade were tested and compared the performance. The effects of different blades with respect to noise, actual tractor PTO speed, vibration, degree of mulching, mulching depth, actual tractor forward speed, torque, power, and fuel consumption in mulching oil palm fronds were analyzed statistically. Mathematical equations were also developed to predict mulching power of the blades. The blades were drawn and developed using Solid Works software.

Tests were done at the Universiti Putra Malaysia oil palm plantation, under the same operating conditions using four blades with 0º, 60º, 120º, and 150º lifting angles, two tractor PTO speeds (540 and 1000 rpm) and three tractor forward speeds (1, 3, and 5 km/h). Bulk density and moisture content of the experimental plots were also measured at 20 cm from the surface level of the experimental plot before the experiment. Similarly, oil palm frond moisture contents prior to mulching were also determined. Tractor torque meter Kistler model was used to collect data on torque, power, and actual tractor PTO speed. The experimental plots were designed in a randomized complete block design (RCBD) at three factors. ANOVA was used to analyze significant and non-significant treatment effects and Tukey's Studentized Range (HSD) test was used to determine significance between the means ($P<0.05$) using statistical analysis systems (SAS 9.2) 2010 software.

The statistical analysis results also indicated that minimum noise effect on operator with level of 70.10 dB(A) was obtained at tractor forward speed of 5 km/h and tractor PTO speed of 1000 rpm using blade with 60º lifting angle. The minimum vibration was given by blade with 0º lifting angle at tractor forward speeds of 1 and 3 km/h and tractor PTO speeds of 540 and 1000 rpm with mean values of 0.47 and 0.50 Hz respectively. Degree of Mulching was best obtained by the blade with 120º lifting angle at tractor forward speeds of 1 and 5 km/h and tractor PTO speeds of 1000 and 540 rpm, with mean values of 63.15 and 89.67 % accordingly. The mean value for mulching depth was best recorded by the blade with 120º lifting angle at 14.20 cm with tractor forward speed of 3 km/h and at tractor PTO speed of 1000 rpm. Minimum torque requirement of 10.00 Nm was obtained for mulching oil palm fronds by blade with 0º lifting angle at tractor forward speed of 3 km/h and at tractor PTO speed of 1000 rpm. Power consumption of mulching blade with 0º lifting angle increased from 0.98 to 1.07 kW at tractor forward speed of 5 km/h when the PTO speed increased from 540 to 1000 rpm. Similarly, the power consumption of the mulching blade with 60º lifting angle increased from 2.04 to 2.47 kW at tractor forward speed of 3 km/h when the tractor PTO speed was increased from 540 to 1000 rpm. Optimum fuel consumption for mulching oil palm fronds was 1.52 l/ha best obtained at tractor PTO speed of 1000 rpm and tractor forward speed of 1 km/h. using blade with 0º lifting angle.

Model development for mulching power prediction revealed that quadratic regression analysis indicates a highly significant and the intercept, was also highly significant. The quadratic effect of power on mulching oil palm fronds indicates that approximately 97.4 % of the variance in power is obtainable by blade lifting angles.

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

PEMBANGUNAN DAN PENILAIAN BILAH PELBAGAI SUDUT ANGKAT UNTUK MENGHANCUR PELEPAH KELAPA SAWIT SEBELUM PENANAMAN ANAK BENIH

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Dalam industri kelapa sawit, hanya 10 % minyak sawit dihasilkan manakala 90% adalah sisa biomass yang dianggarkan 80 juta tan setiap tahun.Teknik lazim dalam pelupusan sisa pelepah sawit tua yang telah di tebang dan pembersihan ladang di Malaysia adalah menggunakan kaedah "ricih dan bakar". Dengan pengharaman pembakaran secara terbuka, bahan sawit yang diricih tidak lagi dibakar tetapi dihancur dan digembur kedalam tanah. Cara ini mewujudkan kesekitaran yang subur bagi pembiakan kumbang tanduk yang menjejaskan pertumbuhan pohon sawit muda disamping menjejas pengeluaran buah sawit pada tahun pertama penuaian. Nutrien dalam tanah hasil gemburan sisa sawit juga sukar diperolehi. Teknik pembakaran sifar memerlukan peralatan khas untuk tujuan pembersihan kawasan dan pelupusan batang sawit yang telah ditebang. Jentera berat akan memadatkan tanah di permukaan jalan-jalan ladang serta mengurangkan kesuburan tanah untuk percambahan benih sawit yang baru ditanam. Sebuah alat pelupus pelepah yang dipasang pada traktor telah dihasilkan oleh Syarikat Howard. Ianya lebih murah dan mudah digunakan berbanding jentera pelupus pelepah jenis berat, namun terdapat rungutan di kalangan peladang mengenai prestasi alat berkenaan walaupun telah dibuat penilaian.

Tesis ini memfokus pada pembangunan dan penilaian bilah penghancur sisa kelapa sawit dengan cara memotong dan menggemburkan sisa pelepah dan batang sawit tersebut kedalam tanah ketika tempoh penanaman semula. Tiga bentuk bilah yang berbeza telah direka dan dioptimumkan dengan geometri tertentu dan sudut angkut serta dibandingkan dengan bilah asal. Kesan bilah berbeza dari aspek kebisingan, kelajuan sebenar PTO, gegaran, tahap penghancuran, kedalam gemburan, kelajuan traktor, tork, kuasa dan penggunaan bahanapi dalam proses penghancuran pelepah kelapa sawit dianalisis secara statistik. Persamaan matematik telah juga dihasilkan untuk menentukan kuasa penggemburan bilah. Bilah bilah tersebut direka dan dibangunkan menggunakan perisian SolidWorks.

Ujian prestasi bilah telah dilakukan di ladang kelapa sawit Universiti Putra Malaysia, pada keadaaan operasi yang sama dengan empat jenis bilah berbeza sudut angkat (0^{o}, 60^{o}, 120^{o}, dan 150^{o}), dua kelajuan PTO traktor (540 dan 1000 psm) dan tiga kelajuan pergerakan traktor (1, 3 dan 5 km/jam). Ketumpatan pukal dan kandungan kelembapan plot experimen juga diukur pada kedalaman penggemburan 20 sm sebelum ujian dilakukan. Kelembapan pelepah sawit juga turut di tentukan. Meter tork traktor model Kistler telah digunakan untuk mengukur tork, kuasa dan kelajuan PTO sebenar. Plot eksperimen direka dalam Rekabentuk Blok Lengkap Rawak (RCBD). ANOVA telah digunakan untuk menganalisis kesan bererti dan tidak bererti manakala kaedah Tukey's Studentized Range (HSD) telah digunakan untuk menentukan perbezaan signifikan antara min faktor kajian ($P< 0.5$) menerusi sistem analisis statistik perisian (SAS 9.2) 2010.

Analisis statistik juga menunjukkan bahawa nilai purata kebisingan minimum setinggi 70.10 dBA dicapai pada kelajuan traktor 5 km/jam dan kelajuan PTO 1000 psm dengan menggunakan bilah bersudut angkat 60^{o}. Gegaran minimum dihasilkan oleh bilah bersudut angkat 0^{o} pada kelajuan traktor 1 dan 3 km/jam dan kelajuan PTO 540 dan 1000 psm dengan nilai purata 0.47 dan 0.50 Hz masing-masing. Tahap penghancuran terbaik diperolehi dari bilah bersudut angkat 120^{o} pada kelajuan traktor 1 dan 5 km/jam dan kelajuan PTO 1000 dan 540 psm dengan nilai purata masing-masing 63.15% and 89.67 % . Nilai purata kedalaman gemburan terbaik pada 14.20 cm dicapai oleh bilah bersudut angkat 120^{o} pada kelajuan traktor 3 km/jam dan kelajuan PTO 1000 psm. Nilai tork minimum 10.00 Nm dihasilkan oleh bilah bersudut angkat 0^{o} juga pada kelajuan traktor 3 km/jam dan kelajuan PTO 1000 psm. Kuasa penghancuran dan penggeburan bilah bersudut angkat 0^{o} meningkat dari 0.98 to 1.07 kW pada kelajuan traktor 5 km/jam apabila kelajuan PTO bertukar dari 540 kepada 1000 psm. Manakala kuasa penghancuran dan penggemburan bilah bersudut angkat 60^{o} berubah dari 2.04 kepada 2.47 kW pada kelajuan traktor 3 km/jam apabila kelajuan PTO bertukar dari 540 kepada 1000 psm. Penggunaan bahanapi optimum untuk menghancur dan menggembur sisa pelepah kelapa sawit adalah 1.52 l/ha pada kelajuan traktor 1 km/jam dan kelajuan PTO 1000 psm menggunakan bilah bersudut angkat 0^{o}.

Penghasilan model ramalan kuasa penggemburan menunjukkan analisis regresi kuadratik mempunyai nilai bererti yang tinggi, manakala intercept juga menunjukkan nilai bererti yang tinggi. Kesan kuadratik kuasa penghancuran dan penggemburan pelepah kelapa sawit menunjukkan hampir 97.4 % varian kuasa dihasilkan oleh sudut angkat.

ACKNOWLEDGEMENTS

In the Name of Allah, Most Gracious, Most Merciful, all praise and thanks are due to Allah, and peace and blessings be upon His Messenger. I wish to thank my committee members who were more than generous with their expertise and precious time. A special thanks to Prof. Ir. Dr. Desa Bin Ahmad, my committee chairman for his countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. Thank you, Prof. Dr. Shamsuddin Sulaiman and Dr. Razif Muhammad @ Othman for agreeing to serve in my committee.

I would like to acknowledge the Nigerian Government for sponsoring my study under FGN/TetFund Scholarship Grant. I would also like to acknowledge and thank Howard Company for providing the mulcher implement and production of blades for my field performance evaluation. Also the University Farm for allowing me to conduct my research and providing assistance requested. Special thanks go to the department for acquiring instruments and members of staff for their continued support.

Finally, I would like to thank Mr. Azlan, Alh Kamal Aliyu Babando, Engr. Nuhu Danraka, Engr Salihu Abdulkadir, Engr Ismail Mukthar, Engr Ola Akangbe, Engr. Habib Gololo, Engr. Habeeb Ismail, Abdulmumini Alabi, Muhammad Shahid Dodo and Mal. Usman Magaji for their kind assistance during field data collections and analysis. Their excitement and willingness to provide feedback made the completion of this research an enjoyable experience.

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

4WD	Four Wheel's Drive
ANOVA	Analysis of Variance
ASAE	American Society of Agricultural Engineers
BDX	Initial Bulk Density
BSR	Basal Stem Rot
CPO	Crude Palm Oil
CRBD	Complete Randomized Block Design
DF	Degree of Freedom
DOE	Malaysian Department of Environment
EAV	Exposure Action Value
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
HICs	High-Income Countries
ILO	International Labour Organisation
MOE	Modulus of Elasticity
MOR	Modulus of Rigidity
NIOSH	National Institute for Safety and Health
OSHA	Occupational Health and Safety Administration
PKO	Palm Kernel Oil
POF	Palm Oil Fronds
PSD	Particle Size Distribution
PTO	Power Take Off
RMS	Root Mean Square
SAS	Statistical Analysis System
WBV	Whole Body Vibration
WI	Total Weight of Soil
WPT	Waste Palm Oil Trees

LIST OF SYMBOLS

β	Angle of forward failure plane
δ	Tool lift angle
Ø	Angle of internal friction of the soil
ℓ	Soil density, Kg/m^3
r	weight density of soil, N/m^3
μ	Coefficient of soil metal friction, dimensionless
μ^1	Coefficient of soil metal friction, dimensionless
A	Shear Plane, m^2
b	Cutting Width or Tool Thickness, m
B	Acceleration force for the Blade Cut Soil, N
C	Soil Cohesion, Pa
d	Pool depth, m
$\hat{d}$	Height of Trapezoidal Section at Soil Segment, m
F_o	Soil Normal Reaction, N
F_1	Normal Force on the Forward Failure Plane, N
μF_1	Soil Frictional Reaction, N
μF_0	Soil Metal Friction, N
K	Soil Cutting Resistance, N/m
K_b	Soil Cutting Resistance, N
L_o	Tool Length or Base of Trapezoidal Soil Segment, m
L_1, L_2	Segmental Length of the Opposite Side of the Trapezoidal Soil Segment, m
V_0	Tool Velocity (directed horizontally), m/s
Z	Tool draft parameter which is a function of the tool lifting angle, f, the angle at the soil failure plane, B and coefficient of soil- soil friction M, and coefficient of soil metal friction, M_1

CHAPTER 1

INTRODUCTION

1.1 Overview of Oil Palm Fronds

Mulching is a sequence of operations that cut and mixed the soil and dry oil palm fronds during the replanting operations. Ideally, the oil palm fronds and oil palm trunks are scattered or windrowed for the vertically operated steel mulcher blade to penetrate 20 cm below skid/tyre level cut and mulch the fronds and trunks. It is generally recommended 2-3 months waiting period to dry after felling or pruning of oil palm fronds before mulching (Pandey, 2004). A mulching tool, particularly the blade system, cut the oil palm fronds and trunks to the desired degree and mixes them well with the soil and manipulate the soil sufficiently during replanting. They are important parameters for assessing implement performance energy requirements (Godwin, 2007). The force required to drag the mulcher blades into the soil for soil mulching are criteria used to measure the suitability of blades (Arvidsson et al., 2004; Olatunji and Davies, 2009). The primary concern is the relationship between mulching implement and soil in design and practice of blades for soil mulching (Shen and Kushwaha, 1998). The soil conditions and geometry of mulching blades affects the force required for a given implement. Hence, the soil-tool-mulching combination should be studied and blade geometry to evaluate the blade performance. The energy applied to the soil by the mulching blades must be exploited efficiently in incorporating the oil palm fronds into the soil. The power requirement per unit of soil mulched with the oil palm fronds must be low. The capacity of the mulching blade system must be high as reported by Yovel et al., (2008). The soil parameters used to determine the performance of mulching blades are depth of penetration of the blades and soil condition.

Conventional methods of land clearing for replanting and subsequent upkeep of oil palms involve the “chip and burn method” (Ooi et al., 2004). Cut down of long-standing oil palm trees and breaking into pieces and allow it to dry are methods involved, after which the crop residues are set ablaze. However, burning was usually incomplete and leftover oil palm fronds and trunks became a breeding ground for *Oryctes rhinoceros* (L) beetles. Kamarudin et al. (2007) reported that up to 500/ha of beetle larvae and pupae were found in the unburnt palm biomass at 12 months after burning.

With the ban on open burning, the chipped oil palm fronds and trunks were not burnt but windrowed, usually, two oil palm fronds rows to one windrow, and left to decompose in the palm inter-rows or mulched when the oil palm fronds have dried and decomposed (Ooi and Heriansyah, 2005).

The windrowed oil palm fronds and trunks took two years to decompose completely and this resulted in very high breeding of *O. Rhinoceros* beetles. Gitau et al. (2009) reported that when oil palm fronds and trunks from two palm rows were stacked into a windrow in the inter-row, a total of 1258/ha of larvae, pupae, and adult beetles were found in the windrowed oil palm biomass at the twelfth month after felling of old oil palms trees.

The number increased to 1870/ha at the twenty-fourth month. Breeding of beetles continued into the third year even in the smaller windrows comprising a single row of oil palm fronds and trunks and 1920/ha of larvae, pupae, and adult beetles were found in such windrows at the thirtieth month after the palms were felled (Ooi et al., 2010).

The zero-burning technique of replanting oil palm was the underplanting method whereby the new young plant was planted under thinned old palms, which were gradually poisoned as the young plant grew (Manjeri et al., 2014). This method of replanting resulted in even higher level of beetle breeding. Ramle, Wahid, Norman, Glare, and Jackson, (2010) reported beetle larvae amounted to 2100/ha in the poisoned standing oil palms twelve months after the palms were poisoned and the population increased to 18,000/ha six months later. It took 24 months for the poisoned standing palms to decompose completely. The beetle-caused varying degree of damage to 84% of the under-planted palms as reported by Ooi et al., (2004).

Currently, the *rhinoceros* beetle is the most serious pest in immature and young mature palms in Malaysia. Ahmad and Suan, (1993) and Chung et al., (1999) reported that beetle damage caused crop losses of 40% and 92% in the first year of harvesting respectively. Although the pest could be controlled by a combination of cultural and chemical methods (Chung, 2015), the most effective way of controlling the pest is through the destruction of the pest breeding sites during mulching.

Oil palm fronds and trunks if not properly treated would serve as the source of rats and *Ganoderma boninense* disease problem. Severe infestations of the later caused yield loss of 45% (Darus and Basri, 2000). The presence of large amount of big chunks of windrowed oil palm fronds and trunks about 85t/ha dry matter (Haron et al., 1996) impeded field access and hindered replanting and the subsequent field upkeep work. Similarly, the nutrient released by the windrowed decomposing oil palm biomass were beyond the root zone of the young replanted palms as the major drawback.

Annual production of oil palm fronds globally is projected at 3.440 million tonnes and the vast amounts were not utilized properly. The increase in demand for palm oil yearly keeps the oil palm fronds waste figures rising and based on that, 10 percent of oil palm wastes were utilized with leftover 90 percent causing plantation problems as current techniques of discarding are hazardous (Gupta et al., 2010).

Mulching of oil palm trunk chips and fronds encouraged accelerated decomposition of oil palm fronds and trunks, thus eradicating *Oryctes rhinoceros* (L) beetles breeding locations. Similarly destroyed *Oryctes rhinoceros* (L) beetles larvae during the operation, field upkeep work were speeded up, improved access to oil palm field and enhanced supervision. The legumes and oil palms benefited well from distributed mulched oil palm fronds as added advantage (Sung et al., 2017).

The HM50 tractor mounted mulcher had the potential of mulching 340 oil palm trunks or 2.5 hectares per day as indicated from the initial results obtained in 1998. However, because of machine outage duration and worn out of mulching blades, actual yield was less (Hoak et al., 2001).

The use of mulcher in oil palm plantation is increasing for mulching oil palm fronds and trunks during replanting operations. However, there is lack of information about the performance evaluation of the implement based on relationship between blade lifting angles, tractor forward speed and tractor PTO speed on the effects of noise, actual tractor PTO speed, vibration, degree of mulching, mulching depth, actual tractor forward speed, torque, power and fuel consumption on mulching oil palm fronds and trunks during replanting operation which is the aim of the research. Similarly, an equation to predict power requirement of mulcher blades for mulching oil palm fronds is lacking.

1.2 Statement of the Problem

The conventional method of establishing new oil palm plantations or replanting is the clearing and burnt technique. Forest or old palm trees are felled, stacked and burnt, thereby polluting the environment and particles cause a haze problem. Burning is aimed at disposing of waste material, eliminating pests and diseases by destroying their breeding ground. In addition, burning of unwanted biomass and other waste material is the cheapest and fastest method of waste disposal. This activity causes excessive release of CO_2 to the atmosphere and contribute to climate change and global warming. Besides, the zero-burning technique in oil palm plantation was financially and economically expensive compared to the burn method.

Machine acquisition and maintenance usually involves a high cost to the plantation. Only large plantations are able to afford these new heavy mulchers and not readily available to smaller plantation owners.Though the tractor mounted mulcher implement is cheaper and more convenient than the heavy mulchers but farmers were still complaining on its low performance in degree of mulching. Hence there is a need to improve the blade.

1.3 Research Objectives

The general objective of the project was to develop and evaluate blades with different lifting angles for mulching oil palm fronds prior to seedling planting and the specific objectives were:

1. To modify the original blade and fabricate three different tractor mounted mulcher blades.
2. To determine the effects of different blades lifting angles with respect to noise, actual tractor PTO speeds, vibration, degree of mulching, mulching depth, actual tractor forward speeds, torque, power, and fuel consumption.
3. To derive an equation to predict power requirement of mulcher blades for mulching oil palm fronds

1.4 Significance of the Study

The main contribution of this research is on the development and evaluation of blades based on geometry and lifting angles and the performance in terms of noise, actual tractor PTO speeds, vibration, degree of mulching, mulching depth, actual tractor forward speeds, torque, power, and fuel consumption. This research will also provide to literature in related works on development and field evaluations of different lifting angles blades on mulching oil palm fronds. Conference papers and peer-reviewed journal articles published in research learned community will be made available to researchers and students for the contribution as the background knowledge. It is expected that the selected mulcher blade will reduce oil palm fronds and trunks wastes, disease inoculums of *Ganoderma boninense,* reduces idle period, facilitate cultivation and successive plantation maintenance and encouraging utilization of minerals released by decaying oil palm crop residues by freshly planted oil palm. Hence, it contributes to sustainable palm oil production in Malaysia.

1.5 Research Scope

The scope of this research was limited to the development and performance evaluation of a new blade for tractor mounted mulcher with particular interest on mulching oil palm fronds and trunks during replanting period. Field evaluation of the mulcher blades was focussed on the performance in terms of good degree of mulching with less torque, low fuel consumption and less noise and vibration during the field operations. Furthermore, an equation was derived to predict power requirements of mulcher blades for mulching oil palm fronds.

1.6 Thesis Organisation

The thesis is outlined as follows; Chapter one describes the background of the study on mulching oil palm fronds and how the development and field evaluation of blades would aid in mulching the oil palm fronds to ease decomposition and destroy insects and diseases during replanting. Chapter two begins by laying out the theoretical dimensions of the research and looks at how the effect of blade geometry and lifting angles influence rate of fuel consumption, degree of mulching, torque, noise, and vibration. Chapter three describes the design, synthesis, characterization, and evaluation of the methodology in developing and evaluating of blades and data collections. Chapter four presents results and detailed discussions based on the analysis and inferred with other researchers. Summary, Conclusions, and Recommendations are drawn for future work in Chapter five.

1.7 Research Methodology Flow Chart

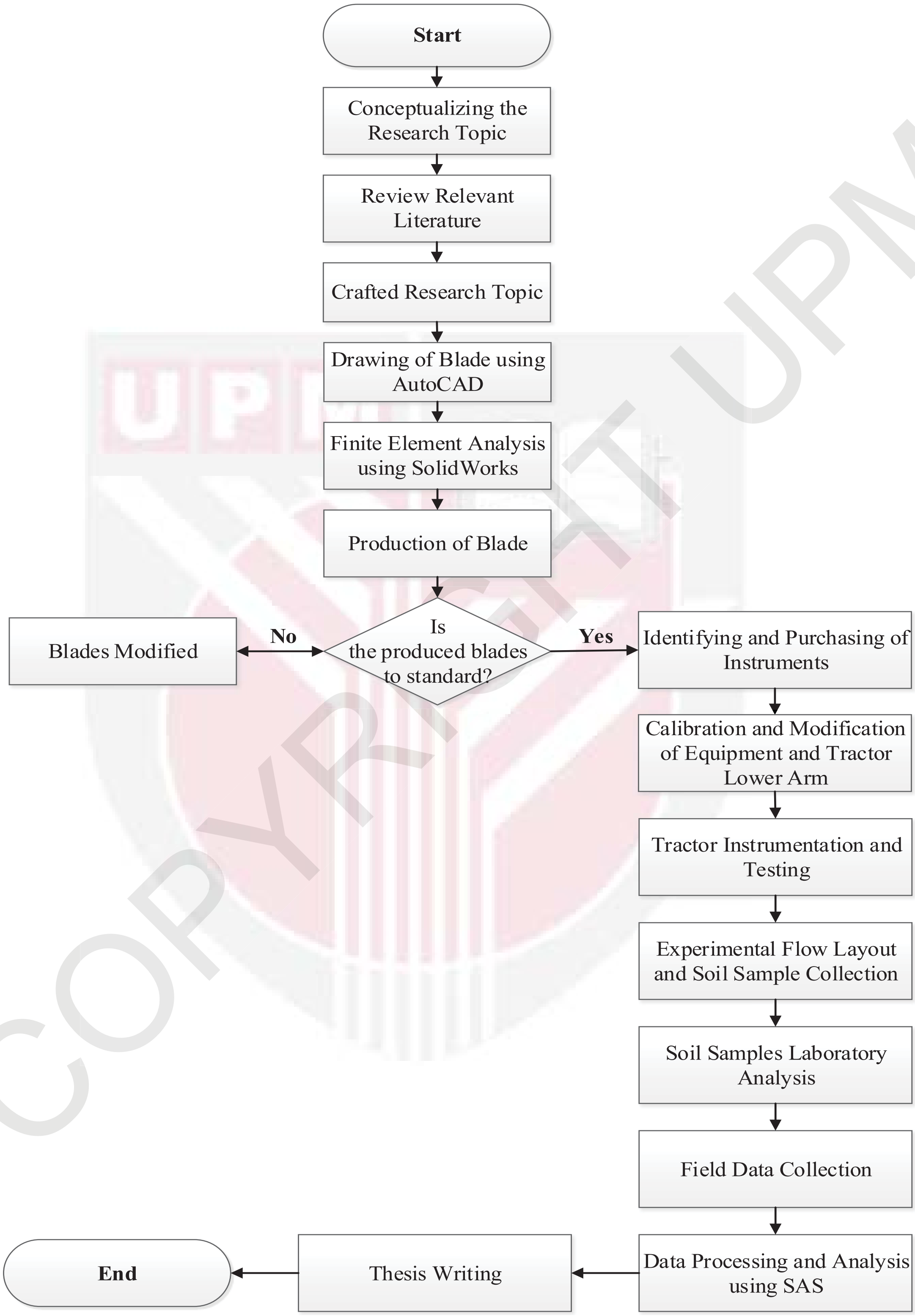

Figure 1.1 : Research Methodology Flowchart

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