UNIVERSITI PUTRA MALAYSIA

SUITABILITY OF MECHANIZED SWEET CORN CULTIVATION IN SEKINCHAN, MALAYSIA

MOMTAZ ISAAK HOMMOOD

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By

MOMTAZ ISAAK HOMMOOD

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

February 2018

DEDICATION

To my compassionate parents;

My brothers and sisters;

My wife and my children, Sohaib, Mohammed, Elaf, Afnan, and Razan, and

To all who gave me a helping hand in my times of need,

I gratefully dedicate this humble effort to you all.

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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February 2018

Chairman : Professor Azmi Yahya, PhD
Faculty : Engineering

Corn (*Zea mays L.*) is grown for human consumption, animal feed and also for industrial applications. Its acreage has been increasing in Malaysia over the years and this trend is expected to continue as advances are made in its cultivation, harvesting, and processing concurrently with producing corn accompanied by the disbursements of energy. However, all reported physical and mechanical properties of sweet corn cobs and biomass materials depend on their moisture content. The following conclusions are drawn from the inquiry on physical and mechanical properties of sweet corn cobs and biomass materials. The average physical properties for weight 0.420 ± 0.0315 kg, length 21.68 ± 0.853 cm, diameter 4.94 ± 0.134 cm, volume 431.8 ± 9.83 cm^3, porosity 46.74 ± 2.13 %, repose angle 26.76 ± 1.142, and angle of friction 32.90 ± 0.82 of sweet corn cobs and some of their components were measured. Moreover, the average mechanical properties for pulling force at 0° 319.03± 11.15 N; at 45° 116.21± 2.53 N; at 90° 51.14± 1.97 N, compression force at vertical 497.56± 63.14 N; at horizontal 2801.26± 346.10 N, shearing force at 0º 503.76± 29.75 N; at 45º 448.27± 34.03 N and penetration 1.633± 0.144 N of sweet corn cobs and some of their components were measured. In addition, the physical properties of sweet corn plant for height of plant 211.7 ± 3.62 cm, width of plant 96.0 ± 2.17 cm, diameter of stalk at 20 cm from ground 2.21 ± 0.089 cm, weight of complete plant with root 0.833 ± 0.0491 kg, leaves 0.077 ± 0.0018 kg, stalk 0.318 ± 0.0094 kg, corncobs 0.420 ± 0.0315 kg and roots 0.068 ± 0.0017 kg, moisture content of leaves 56.22 ± 5.10 %, stalk 79.54 ± 2.14 % and roots 62.33 ± 3.85 %, and the average mechanical properties for pulling force at 0° 549.32± 6.27 N; at 45° 400.19± 3.05 N; 90° 334.00± 3.09 N, and shearing force at 0º 205.45± 20.59 N; at 45º 167.15± 25.10 N of the plant were conducted. Furthermore, a study on the biomass potentials of corn plant give an overview of the biomass situation of the sweet corn plant and their components. The calorie content of the corn cob was found to be the highest with an average of 18293 J/g (18.29 MJ/kg) followed by that of stalk with 17727 J/g (MJ/kg). The sugar content

was shown to be the highest in the kernel with 13.8 °Brix, as kernel sucrose concentration is regulated by endosperm carbohydrate metabolism during kernel development. The enhancement of kernels is made successful by; reduction of starch synthesis activities, increase in sucrose accumulation and productivity of yield in biomass material and its consumption annually as animal feed and in industrial applications. Cultivation of sweet corn in a standard plot size of 1.214 ha under a standard seed spacing of 29 cm and standard row spacing of 78 cm had the potential of producing 71,144 sweet corn ears/hectare or 26,742 kg sweet corn ears/hectare. The yield potential for sweet corn kernel is 8,558 kg sweet corn kernels/hectare whereas for plant residues it is 34,181 kg sweet corn plant residues/hectare. Besides, a study on machines and human performances in all agricultural operations of sweet corn in Malaysia has been successfully conducted to identify the crucial and critical field operations for the mechanisation index and their relationship with energy. The mechanisation index of 36.49 % was recorded for the cultivation system and is a reflection of the level of machinery inclusion in sweet corn production in Malaysia. The most critical operation requiring mechanisation is, therefore harvesting operation with bags. It has an index of 0.83 % representing human labour input of about 99.17 % of the operation's energy expenditure. Economy in energy systems is becoming increasingly essential for researchers both directly and indirectly, especially in the cultivation of sweet corn. Some of the advantages of reduced energy are a saving in energy input, reduced time and manpower costs, and improved yields. From the results of the study at mean yield of corn cobs 9991.02 kg/ha, the energy expenditure was 58714.81 MJ/ha with energy intensity value of 5.88 MJ/kg. The average effective field capacity for the harvesting operation was found to be 0.47 ha/hr. The average machine output of the harvesting operation for sweet corn cobs yield was 4695.78 t/hr, while, the average machine output of the harvesting operation for biomass material was 5275.96 t/hr. The results were used to develop yield predictive models for performance by using Artificial Neural Networks Modelling (ANN) and optimisation of the results of this estimate by using Particle Swarm Optimisation (PSO). A method of reference frequency was used to determine best sweet corn cultivation practices for enhanced productivity, a motion study was conducted to evaluate the mechanisation indices of operations.

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

KESESUAIAN PENANAMAN JAGUNG MANIS SECARA MEKANISASI DI SEKINCHAN, MALAYSIA

Oleh

MOMTAZ ISAAK HOMMOOD

Februari 2018

Pengerusi : Profesor Azmi Yahya, PhD
Fakulti : Kejuruteraan

Jagung (*Zea mays L.)* ditanam untuk makanan manusia makanan ternak dan penggunaan perindustrian. Kawasannya telah meningkat di Malaysia sejak kebelakangan dan trendnya dijangka berterusan memandangkan pendahuluan dibuat dalam penanaman, penuaian, dan pemprosesannya. serentak dengan menghasilkan jagung disertai tenaga pengeluaran. Walau bagaimanapun, semua sifat fizikal dan mekanikal yang dikaji daripada bahan gebu manis dan bahan biomas bergantung kepada kandungan lembapannya. Kesimpulan berikut diambil daripada penyelidikan mengenai sifat fizikal dan mekanik jagung manis dan bahan biomas. Sifat fizikal purata untuk berat 0.420 ± 0.0315 kg, panjang 21.68 ± 0.853 cm, diameter 4.94 ± 0.134 cm, kelantangan 431.8 ± 9.83) 1.142, dan sudut geseran 32.90 ± 0.82 daripada pokok jagung manis dan beberapa komponennya diukur. Selain itu, sifat mekanikal purata daya tarik di 0º 319.03 ± 11.15 N; di 45º 116.21 ± 2.53 N; di 90º 51.14 ± 1.97 N, daya mampatan di menegak 497.56 ± 63.14 N, di kekuatan ricih di 0º 503.76 ± 29.75 N; di 45º 448.27 ± 34.03 N dan penembusan 1.633 ± 0.144 N daripada pokok manis dan beberapa komponennya diukur 211.7 ± 3.62 cm, lebar tanaman 96.0 ± 2.17 cm, diameter batang 20 cm dari tanah 2.21 ± 0.089 cm, berat tumbuhan lengkap dengan akar 0.833 ± 0.0491, daun 0.077 ± 0.0018 kg, tangkai 0.420 ± 0.0094 kg, corncobs 0.420 ± 0.0315) kg dan akar 0.068 ± 0.0017 kg, kandungan lembapan daun 56.22 ± 5.10%, tangkai 79.54± 2.14% dan akar 62.33 ± 3.85 % dan sifat mekanikal purata untuk tarik daya di 0º 549.32 ± 6.27 N, di 45º 400.19 ± 3.05, di 90º 334.00 ± 3.09 N dan kekuatan ricih di 0º 205.45 ± 20.59 ; di 45º 167.15 ± 25.10 N kilang telah dijalankan. Tambahan pula, mengkaji potensi biojisim kilang jagung memberi gambaran keseluruhan keadaan biomas jagung jagung manis dan komponennya serta kandungan kalori yang didapati bahawa cob mempunyai kandungan kalori tertinggi dengan purata 18293 J /g (18.29 MJ / kg) diikuti dengan tangkai dengan 17727 J / g (MJ / kg), kandungan gula ditunjukkan bahawa kernel mempunyai kandungan gula tertinggi iaitu 13.8 ° Brix, kerana kepekatan sukrosa kernel dikawal oleh metabolisme

karbohidrat endosperma semasa penjanaan kernel. Peningkatan biji dibuat dengan berjaya dengan pengurangan aktiviti sintesis kanji dan peningkatan dalam pengumpulan sukrosa dan produktiviti bahan biomas hasil dan penggunaannya setiap tahun untuk digunakan sebagai makanan haiwan dan industri. Penanaman jagung manis dalam saiz plot 1.214 ha di bawah jarak benih standard 29 cm dan jarak baris standard 78 cm berpotensi menghasilkan 71,144 tongkol manis / hektar atau 26,742 kg tongkol manis / hektar. Potensi hasil untuk kernel jagung manis adalah 8,558 kg biji jagung manis / hektar sedangkan untuk sisa tanaman adalah 34.181 kg residu tanaman jagung manis / hektar. Selain itu, kajian mengenai mesin dan persembahan manusia dalam semua operasi pertanian jagung manis di Malaysia telah berjaya dijalankan untuk mengenal pasti operasi lapangan kritikal dan kritikal untuk mengenal pasti indeks mekanisasi dan hubungan mereka dengan tenaga. Indeks mekanisasi sebesar 36.49 % direkam untuk sistem penanaman dan merupakan cerminan dari tingkat inklusi mesin dalam produksi jagung manis di Malaysia. Oleh itu, operasi yang paling penting yang memerlukan mekanisasi adalah. operasi penuaian menggunakan beg. Ia mempunyai indeks 0.83% mewakili pembabitan tenaga manusia kira-kira 99.17% daripada perbelanjaan tenaga operasi. Mengurangkan sistem tenaga menjadi semakin penting bagi penyelidik baik secara langsung atau tidak langsung, terutamanya dalam penanaman jagung manis. Beberapa kelebihan tenaga berkurangan ialah penjimatan tenaga input, mengurangkan masa dan kos tenaga kerja, hasil yang lebih baik. Dari hasil kajian pada hasil purata jagung 9991.02 kg / ha, perbelanjaan tenaga sebesar 58714.81 MJ / ha dengan nilai intensitas energi 5,88 MJ / kg. Keupayaan ladang purata untuk operasi penuaian didapati 0,47 ha / jam. Pengeluaran mesin purata operasi penuaian untuk hasil jagung jagung manis adalah 4695.78 t / jam. Walaupun, purata pengeluaran mesin bagi operasi penuaian bagi bahan biomas ialah 5275.96 t / jam. Hasilnya digunakan untuk menghasilkan model ramalan hasil untuk prestasi dengan menggunakan Pemodelan Rangkaian Neural Buatan (ANN) dan pengoptimuman keputusan anggaran ini dengan menggunakan Pengoptimuman Swarm Partikel (PSO). Satu kaedah frekuensi rujukan digunakan untuk menentukan amalan penanaman jagung manis yang terbaik untuk meningkatkan produktiviti mereka, Satu kajian pergerakan dijalankan untuk menilai indeks mekanisasi operasi.

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To my family, especially my father, my mother, my wife and my children for giving me much needed support during all the years of my study.

To the many others too numerous to mention by name, I thank them for their moral and spiritual support and would like to let them know that they will always have a place in my heart.

I certify that a Thesis Examination Committee has met on 21 February 2018 to conduct the final examination of Momtaz Isaak Hommood on his thesis entitled "Suitability of Mechanized Sweet Corn Cultivation in Sekinchan, Malaysia" 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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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Signature: ______________________________
Name of Member of Supervisory Committee: Dr. Nazmi Mat Nawi

Signature: ______________________________
Name of Member of Supervisory Committee: Dr. Muhammad Razif bin Mahadi

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LIST OF ABBREVIATIONS

A	Area
ANN	Artificial Neural Networks
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
BCR	Benefit-Cost Ratio
CE	Chemical Energy
CF	Conversion Factor
CI	Coefficient Interval
DMRT	Duncan's Multiple Range Test
EGL	Energy Level
El	Energy intensity
EP	Energy Productivity
FAO	Food and Agricultural Organization
FE	Fuel Energy
FTE	Fertiliser Energy
IADA	Integrated Agricultural Development Authority
IUTM	Instron Universal Test Machine
GHG	Greenhouse Gas
GM	Gross margin
h	Hour
ha	Hectare
HE	human energy

hp	Horsepower
HRL	Heart Rate Level
K	Potassium
Kcal	Kilocalorie
Kg	Kilogram
l	Liter
L	economic life
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
ME	Machinery Energy
MI	Mechanisation index
MJ	Mega Joule
MLR	Multiple linear regression
MPa	Mega Pascal
MPP	Marginal Physical Productivity
MSE	Mean square error
MSW	Municipal Solid Waste
Mt	Million tons
MOA	Ministry of Agriculture
N	Nitrogen
NA	Not Available
NEG	Net Energy Gain
REBA	Rapid Entire Body Assessment
RM (MYR)	Ringgit Malaysian

RMSE	Root Mean Square Error
RULA	Rapid Upper Limb Assessment
P	Phosphorus
PCL	Production Capacity Level
PER	Percent Energy Use
PSO	Particle Swarm Optimisation
SE	Seed Energy
SSC	Soluble Solid Content
TC	Total Cost
TEI	Total Energy Input
TOE	Total Energy Output
USA	United States America
W	Weight
yr	year

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Corn (*Zea mays L.*) ranks as the third most important cereals in the world. Asian countries are significant producers of sweet corn and more than 62% of their corn production is consumed in the form of animal feed, while the balance is for human consumption. While sweet corn has been traditionally a popular vegetable in the USA, China and Brazil, it has in recently gained popularity in many other Asian countries including Malaysia. Corn is the staple food of a large population of the world's communities and one of the most economically principal food crops in the world. According to FAOSTAT (2017), total world production of corn in the year 2014 was at 1,037,791,518 tons, grown over 184,800,969 ha of farmlands. The world average corn yield for the year was estimated at 6.08 t/ha. By 2025, corn is expected to be the world's most cultivated cereal crop and between now and 2050, the demand for corn in the developing world is expected to be doubled (Rosegrant et al., 2009).

This is a realistic estimate as the total population of the world during the period from 2000-2014, increased 18.77 %, which was about 7,298,450,000 people in 2014. According to FAOSTAT (2017) human consumption of corn was about 1,037,791,518 tons in 2014, indicating a 75.16 % increase during the same 2000-2014 period. Corn production has increased progressively with the high increase of the world's human population as shown in Figure 1.1.

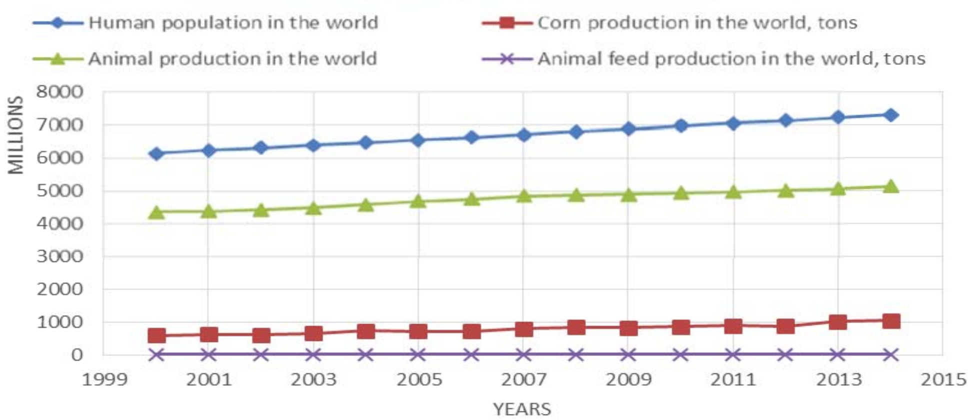

Figure 1.1 : Growth of human population, animal production, corn production, animal feed production trends in the world during 2000 - 2014
(Source : FAOSTAT 2017, animal production includes asses, beehives, buffaloes, camelids, camels, cattle, chickens, ducks, geese, goats, horses, mules, pigs, rabbits, rodents, sheep and turkeys)

In light of the above, more attention needs to be given to corn crop and to increase corn production in order to provide food security to people as the third crop in the world. While, the total animal production in the world was about 5,117,487,369 in 2014 it has increased year by year with 17.37 % during the 2000-2014 period but, this increase has been offset by the growth of feed production at a negligible 4.06 % during 2000-2014. Thus, this gap between the large increase in animal production and the feed production is noteworthy because they threaten food security.

Human population increase, animal production, and corn production in Malaysia are shown in Figure 1.2. From the figure, it can be seen that the world's human population showed an increasing trend during 2000-2014 with a 30.37 % increase or an addition of 30,228,000 people in 2014. Corn production however stayed basically constant and in fact dipped slightly by 9.82 % during the 2000-2014 period to 59,188 tons in 2014. It is therefore imperative that the Ministry of Agriculture and Agro-based Industry in Malaysia take care of this vital crop and encourage its cultivation on a large scale to increase production to address the gap between human population increase and the less than corresponding increase in corn production. (See Figure 1.2.)

On the other hand, livestock production showed a marked increase of 12.07 % during the 2000 to 2014 period in Malaysia, indicating the interest of the government in the livestock production sector in the early decades of the new millennium. Animal production touched a peak of 3,856,917 animals in 2008 as shown in Figure 1.2, which included buffaloes, cattle, chickens, ducks, goats, horses, pigs, and sheep. Animal feed takes up 60 to 70% of livestock production cost and four to seven million tons of feeds are required annually, with chicken consuming 4%, pig 27%, ruminants 21% and others 8%.

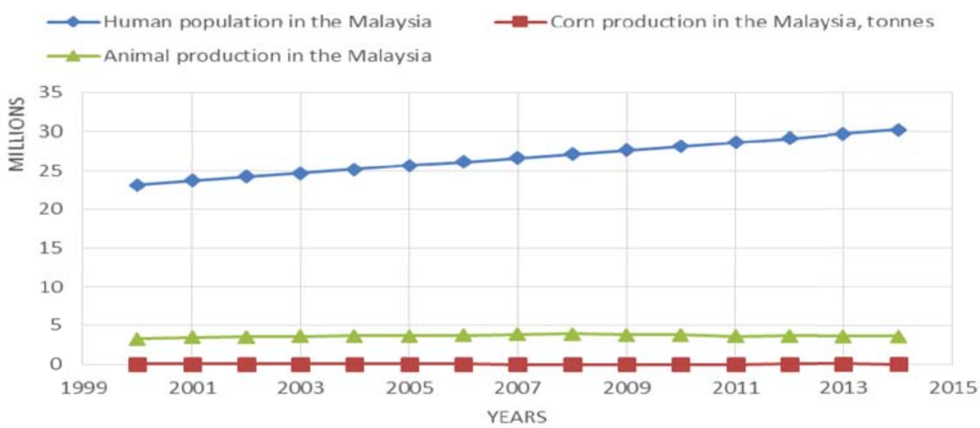

Figure 1.2 : Growth of human population, corn production and animal production trends in Malaysia during 2000 - 2014
(Source : FAOSTAT 2017), animal production includes (buffaloes, cattle, chickens, ducks, goats, horses, pigs, and sheep)

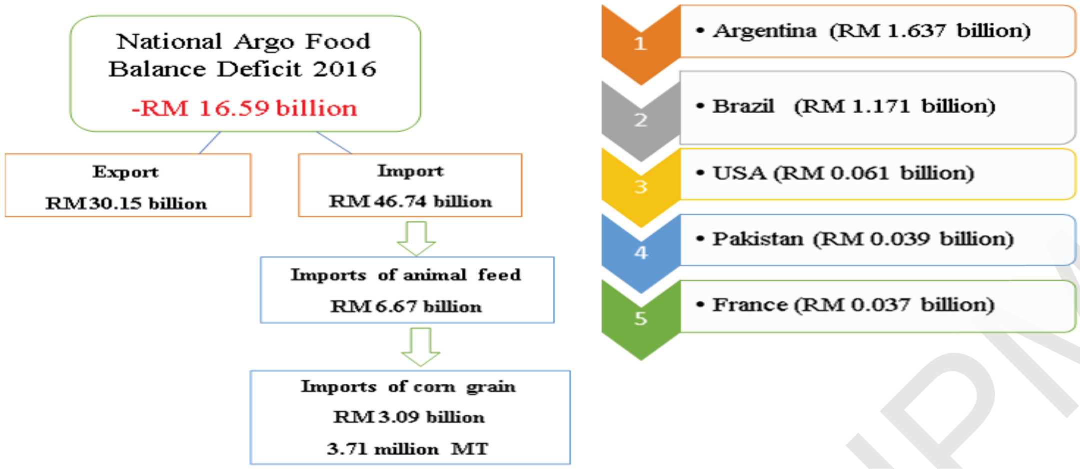

Figure 1.3 : Malaysian corn imports
(Source : MOA, 2017)

However, there are no official statistics on the production of animal feed in Malaysia, especially the corn feed production but it has been admitted that there is a deficit which has required the import of animal feed from various countries. The MOA (2017) admits that national agro-food balance deficit in 2016 was RM -16.59 billion which comes from an import bill of RM46.74 billion and export RM30.15 billion). Malaysia imports for corn were 3.71 million tons in 2016, up by 22.44 % from 3.03 million tons in 2012. The import of animal feed was RM6.67 billion while the import of corn grain was RM 3.09 billion for 3.71 million tons. Argentina is one of the main sources of Malaysia's corn imports whereas the total imports to Malaysia were RM1.637 billion. Other sources were Brazil, USA, Pakistan and France (RM 1.171billion, RM 0.061 billion, RM 0.039 billion and RM 0.037 billion respectively) as shown in Figure 1.3.

Despite the government's efforts to be self-sufficient in the supply of animal feed, Malaysia still relies on substantial imports to meet domestic demand. More than half (66%) of the imported food materials were from corn and about 7% of the imported food materials were for feed as shown in Figure 1.4. All of these imported food materials were used either for the human food production or the animal feed production industries in the country.

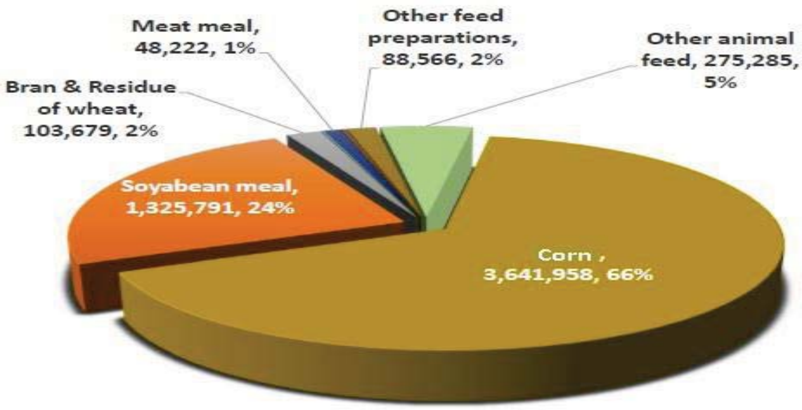

Figure 1.4 : Malaysian imports of food material (mt and %)
(Source : MOA, 2017)

The Malaysian government had now formulated a corn crop production development plan for the country. A roadmap was set to cultivate a total of 20,000 hectares for corn grain production in Malaysia by 2020. This is being done through the development of a realistic and sustainable business model for various categories of industry players in the production and supply chain of corn in Malaysia. The Malaysian government seeks to modernise the agriculture sector with the objective of increasing food production. This is important for stabilising the economy. In general, agriculture has been identified as the third engine of economic growth in Malaysia, resulting in large-scale farming projects being implemented throughout the country (Mahmood 2006). According to FAOSTAT (2017), Malaysia with a total corn production of 59,188 tons in 2014 was ranked 117th among the world's producers, led by the United States of America with a total production of over 360 million tons. Malaysia's contribution to the world corn production in 2015 was 61,473.44 tons cultivated on 9,480 ha of land and the country's mean yield for the year was 6.49 t/ha. Major states producing corn in Malaysia are Johor, Kelantan, and Pahang. To better understand why corn is such an important crop, the following paragraphs describe the nutrition vales of the cereal and its impressive versatility in many applications.

Capper et. al, (2013) and Orhun (2013) concluded that the corn grain gives the highest nutritional value compared to other grains as livestock feed. This is due to its high starch and low fibre content which makes it a very concentrated source of energy for livestock production. This was confirmed by Kataria (2014) who reported that the nutritional content of corn was 1.49% ash, 6.8 % moisture, 8.9% crude protein, 4.47% crude fat, 1.38% crude fibre while the nutritional content of rice was 0.67% ash, 11.8% moisture, 7.2% crude protein, 0.9% crude fat, and 0.5% crude fibre. Furthermore, corn has a number of advantages as a feed grain such as relatively high digestibility, high energy source, and high palatability (Olaniyan 2015; Senti & Schaefer 1972). In addition, corn is used as a main feed source by many livestock producers. The grain or the whole plant is harvested to feed the animals; sometimes it is made into silage to become another source of feed for dairy and beef production (Nieuwenhof, 2003).

On the industrial front, corn is the most important raw material for industrial starch. Corn starch is a corn product much used in manufacturing ceramics, dyes, plastics, oil, paper, textiles, cosmetics, and pharmaceutical products (Orhun 2013; Senti & Schaefer, 1972).

1.2 Problem Statement

There is no commercial corn production for animal feed in Malaysia during the period from 2000-2014. Most corn produced in this country is sweet corn for human consumption. For animal consumption, Malaysia needs to import the corn grains from other producing countries such as the Argentina, Brazil, United States, Pakistan and France (FAOSTAT, 2017). Roth and Heinrichs (2001) reported that silage corn is an important animal feed in most of the world's livestock farms. The silage offers livestock farmers a high-quality product, a comparatively stable and palatable material of animal feed which is also readily digestible. Corn silage produces more energy per hectare than any other feed crops and its high energy as an animal feed is particularly beneficial for dairy cows. This is most critical for herds of cattle with a high yield and for companies that have problems in producing or purchasing a high-value silage crop. Corn silage with elevated energy content is also suitable for use in low-cost rations for fattening livestock. Production wise, it requires the involvement of fewer workers per ton compared to many other crops. It can extend the harvest time for the whole corn area and give the chance to save corn fields from damage. According to FAOSTAT (2017), corn is the highest component of Malaysia's corn imports compared to other goods and the importance of corn as a source of animal feed ingredient has been increasing year by year.

In adopting a zero-waste concept in sweet corn fields in Malaysia, the country's annual animal feed import bill of more than RM6.67 billion could be dramatically reduced (MOA, 2017). By exploiting the potential use of crop residues, especially those of animal feed crops, the post-harvest practice of burning the crop residues can also be avoided. It has been found that the plant biomass in the field after harvesting the corn cobs with the husk together and the cobs from the kernel shelling operation could be used as animal feed. The reason why corn can be categorised as a high-value crop is simply that the corn biomass can be profitably used for animal feed while the corn cob can be for human consumption as reported by (Olaniyan 2015; Nieuwenhof, 2003; Senti & Schaefer 1972).

To fully exploit the many potential derivative uses if corn, there is a need to create a database on the crop, particularly the physical and mechanical properties of sweet corn plant as such knowledge would be required to facilitate design engineers to create machines and equipment that are operationally more efficient and effective. Knowledge of all the mechanical properties of biological materials is necessary for the design of technological processes as mentioned by Szymanek. et. al. (2006). At the same time, there is a need to analyse the current status because corn has been planted in Malaysia for quite some time, but not on a large scale. Therefore, if

Malaysia is to embark on the cultivation of corn on a large scale, there is a need to consider the methods to be used, the terms of energy use in order to focus correctly on critical operations and the necessary tasks to ensure success. There is also the need to study options for mechanisation, which would be required for large scale cultivation of the corn crop.

Currently, there are no documented studies on the mechanisation index in typical sweet corn cultivation systems in Malaysia. Agriculture policy makers can use information on the level of machinery used at each level of sweet corn cultivation cycle in their task. Developing a comprehensive agricultural mechanisation plan for the country would be in line with the rapid modernisation and industrialisation of the country. These developments will be crucial for the success of large scale cultivation of corn in Malaysia. Most of the available harvesting machinery available in Malaysia from abroad for corn cobs are quite standard but the ones that are more critical is for both corn cobs and the animal feed at the same time. There is need a combine harvester that can collect the corn cobs and at the same time take biomass and then separate that during harvesting.

On the other hand, many energy expenditures will be involved, including selection, seed purchase, preparation of soil, planting, fertilisation, control, and removal of weeds, pest control, harvesting, irrigation, and post-harvest operations such as cutting and removing the remnants of the previous crop, transport, and marketing. These operations are managed using energy from various sources including human labour, machinery, fuel, fertiliser, chemical applications, and seeds. Essentially, the production capacity of crops is directly consumed in the operation of machinery and equipment, and indirectly through the application of fertilisers and chemicals used in agriculture. The timely availability of adequate energy is a prerequisite for timely completion of sweet corn production, which is essential to ensure maximum yield (Beckingham, 2007; Muazu et al., (2015). In order to maximise benefits, farmers must have the right mix of energy sources in time. Much of the energy inputs indicate non-economic production and thus waste, which may lead to a reduction or loss of utility, an increase in global warming and some stress on the environment. In reality, very little energy (i.e fertiliser, and chemical applications) is required to reach the maximum level of productivity and ensure the required level of food sufficiency (Muazu et al., 2015).

Abadi et al., (2015), Ajabshirchi (2013), Abdi et al., (2012a,b), Banaeian and Zangeneh (2011), and Canakci et al., (2005) studied on energy in crop production are available that link energy flows to crop yields. However, the models currently available do not predict the maximum yield the farmer should expect from a given level of energy inputs. It is therefore desirable that the farmer has a user-friendly model that can predict the maximum expected yield from a given level of primary energy inputs (human labour, machinery, fuel, fertilisers, chemical applications, and seeds). This model can serve as a tool to assess the performance of previous corn cultivation and assess the level of underperformance so that appropriate remedial action can be taken to improve corn productivity in the future. To the best knowledge of this research, to date, there has not been any study of energy that has achieved optimal energy input in the sweet corn cultivation system and is correlated to crop yields. As such, there should be particular application of intelligent models with high resolution such as Artificial Neural Network (ANN) model and Particle Swarm Optimisation (PSO).

In view of all these challenges, a comprehensive study on agricultural energy in the field of sweet corn cultivation to optimise the use of agricultural inputs would be beneficial for farmers as well as agricultural policy makers in the country. The results of the study when integrated into a computer programme will not only enhance our understanding of the potential impact of changes in the energy mix on sweet corn productivity but still, also give farmers the opportunity to make informed decisions in choosing the energy mix for maximum productivity of crops and ensure food security and poverty eradication among corn farmers. Sweet corn productivity should be significantly increased and costs lowered. Therefore, a user-friendly computing system is required to serve as a decision support system for farmers in their quest to achieve higher yield with less use of agricultural inputs.

1.3 Purpose and objectives of the Study

The goal of this research is about the development of an energy model for sweet corn cultivation system i.e. suitability of mechanized sweet corn cultivation in Malaysia. Therefore, the specific objectives of the current study are:

1. To determine the physical and mechanical properties of the whole sweet corn plant and its respective components.
2. To quantify the biomass potential of the cultivation and nutrition value of sweet corn in Malaysia
3. To determine the energy inputs and mechanisation status as well as production cost of sweet corn cultivation in Malaysia.
4. To develop model for predicting the product yield by using inputs energy consumption, and optimisation of results by using numerical methods.

1.4 Scope and limitation of the study

In Malaysia, there is no specific season for cultivating sweet corn look like rice but sweet corn cultivation takes place in cropping periods during the year. In addition, most of the researchers were collecting data on energy expenditures in fields using the questionnaire method (i.e. Pishgar Komleh et al., 2011a; Canakci, et al., 2005; Ozkan et al., 2004). While in this study, energy expenditures were collected based on direct measurement using Polar S810M Heart Rate Monitor which require great effort and high cost to measure energy expenditures. As a result, the data was collecting for three cropping periods during this study.

Sekinchan was selected as the place of commercial corn production in Malaysia. The selected farms in Sekinchan were based on a recommendation from the Integrated Agricultural Development Authority (IADA) North-West Selangor for being among the most productive areas in the irrigation scheme and having dedicated practicing in sweet corn cultivation.

In this study was quantified the performance of ANN-PSO models to estimate the potential sweet corn yield based on energy inputs in cultivating the crop due to a high accuracy in relation to prediction (Farjam et al., 2014; Lazzús, (2010); Lazzús,(2013). The best structures (5-15-15-1) and (5-10-8-1) of ANN-PSO model for predicted sweet corn cobs yield and biomass yield respectively were selected based on the highest coefficient of determination and the lowest value of the error (Farjam et al., 2014).

1.5 Contributions of research work

This study has succeeded in adding to the existing body of knowledge pertaining to the cultivation of sweet corn in Malaysia in particular and in other countries in general. The major contributions are as follows:

1. Highlight the importance of a holistic scientific approach in cultivating sweet corn for human food and animal feed production.
2. Provide detail and complete information and specifications on the plant physical and mechanical properties that are required in the design of agricultural field or processing machineries for sweet corn cultivation.
3. Provide detail and complete information on the potential feed value based on the caloric value and sugar content of the various components of a sweet corn plant.
4. Show holistically the extent of the use of energy in sweet corn cultivation and provide the possibility of optimising the energy usage in the respective field operation in order to maximise the cost benefit ratio.
5. Quantified the current mechanisation status in sweet corn cultivation in Malaysia and rank all the field operations according to their priorities for mechanisation based on Mechanisation Index and PCL-HRL-EGL Cartesian plot.
6. Development of models to predict sweet corn or biomass yields based on the use of farm inputs that will enable the farmers to predict potential yield they ought to achieve by using the inputs optimally.

1.6 Thesis layout

The thesis was divided into five chapters. Chapter one – Introduction, discusses the background of the corn crop, its production and importance. It discusses the problem statement and the gap in knowledge from previous works on the corn crop, why this research was important for Malaysia, purpose and objectives then, scope and limitation of the study. Chapter two presents literature reviewed on corn crop in terms of physical and mechanical properties, biomass material of sweet corn, energy analysis and cost, and yield modelling and energy inputs in sweet corn production. Chapter three discussed the experiments, materials and methods used in the conduct of the research from measure physical and mechanical properties, biomass material of sweet corn, energy analysis and cost, determination of mechanisation index for the cultivation, and development of sweet corn yield predictive model. Chapter four present results and discussions on experiments conducted from physical and mechanical properties, biomass material of sweet corn, energy analysis and cost, determination of mechanisation index for the cultivation, time and motion analysis of field operations, development of sweet corn yield predictive model, validation data, and sensitivity analysis of energy inputs on products yield. Chapter five presented conclusions and recommendations for further works on the sweet corn cultivation.

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