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Mechanization Status in Sweet Corn Cultivation in Malaysia

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ABSTRACT

This paper described the overall mechanisation status in the cultivation of sweet corn in Malaysia and the machinery energy, worker's energy expenditure and heart rate for the various flied operations that were involved in cultivation. The field operations include tillage, planting, fertilising, spraying, harvesting, and cutting. Field capacity and machinery energy for each of the operations were calculated. The calculated mechanization index was used in the study to describe the mechanization status in sweet corn cultivation. A mean overall mechanisation index of 38.62 % and an aggregate machinery energy of 281.00 ± 34.51 MJ/ha were registered for the crop. Highest mechanisation index and machinery energy were acquired in the tillage operation (94.09% and 105.35 ± 9.37 MJ/ha) while the lowest mechanisation index and machinery energy were in the fertilising operation (5.15 % and 2.504 ± 0.30MJ/ha). These calculated mechanization indexes were useful for ranking the field operations based on their priority for mechanization.

KEYWORDS

Mechanisation status, Machinery energy, Production capacity, Sweet corn.

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INTRODUCTION

The importance of corn and its various uses is evident through the human consumption of grains and corn syrup as well as animal consumption as green fodder in addition to the entry of this crop in industrial uses. Sweet corn species has now becoming more and more important because its taste and nutritional value has made it a valued crop in all countries while its production scope is constantly increasing (Szymanek. et. al, 2006). Yadav et. al (2013) studied the energy used in the production of the corn crop in Sikkim, India and found that human energy was highest followed by machinery, animal, seed and farm yard manure energies (i.e 38%, 20%, 26%, 14% and 2% of the total energy, respectively). In the crop cultivation operation, the highest energy consumed was 50% of total energy (1772.2 MJ/ha) that was in land preparation, while 25.6% or about 909.2 MJ/ha of total energy or the second highest consumed was in weeding operations and followed by 17.4% or about 615.6 MJ/ha for planting operations and 7.1% or about 250.3 MJ/ha for harvesting and transportation operations. In addition, the machinery energy appeared to exceed that of animal energy, possibly attributable to the use of inefficient traditional tools that required higher manual input in the overall production process. This suggest a need to enhance mechanisation for better yields and to reduce the level of needed manual labour. The mechanisation index of corn cultivation has been reported to be 0.26 which could be considered very low in the region.

In Nigeria, most agricultural field operations are highly ineffective and involves the use of hand tools which is heavily dependent on human muscle power. In cassava cultivation for example, it was reported that manual labour energy utilisation for the same end product was approximately 83 times higher than that of energy required when using a tractor. The resulting low productivities were due to poverty, ignorance, and lack of incentive to use of machinery in agricultural practices while the traditional tools being cheap, simple and readily available to the poor farmer. The total energy utilisations for the manual and machine operations per hectare for achieving the same outcome were 2738.9MJ and 33.5MJ. The use of high human energy using manual methods had a negative impact on reducing the living standards of farmers to subsistence levels. The cultivations of yam and cassava crops require more energy expenditure per hectare of land for manual than mechanical operations in Nigeria (Nkakini. et al, 2006).

In garlic cultivation, human labour energy was mainly used for harvesting, irrigating, planting and fertilizing operations. The harvesting and planting operations are the most expensive operations with 70 % for labour expenses (Samavatean et al, 2011). Mechanisation would minimise the demand of animals and humans with related increases in the demand of fuel and machinery in rice cultivation in Assam. As the level of mechanisation progresses, the demand for human workers reduced up to 86% in comparison to a non-mechanised scenario. Such a decrease in the demand for muscle power is associated with an increase in the requirements of fuel by up to 231% compared to the non-mechanised scenario (Baruah and Bora, 2008). Human labour energy had a big contribution in total energy inputs led to low mechanisation level in some operations such as fertilising operation, making water pits, irrigation and harvesting. To reduce the labour these involved field operations must be mechanized (Gezer et al, 1992)

Displacement of manual labour has been usually viewed as a negative aspect of mechanisation, especially in developing countries. Mechanisation index and deployment of manual labour and draught animals in the cultivation of wheat have been analysed for the period 1971 to 1997. It is evident that manual labour and animal draught use ared negatively correlated with mechanisation index. Manual labour deployment has declined marginally from 490 down to 468 h/ha, recording a negative growth rate of 0.18%, annually. In other words, mechanisation in India has not produced a significant impact in reducing manual labour deployment (Singh, 2006 and Marrit Van den Berg et. al, 2007).

Hence, this study was conducted to assess the mechanisation status in sweet cultivation Malaysia. Both total energy use and mechanisation index were being used as parameters to assess the mechanisation status and besides both duration time and production capacity were used as parameters to assess for the field operation effectiveness in the cultivation sweet corn. This analysis is important to carry out the necessary improvements that will lead to a more efficient and productive system.

MATERIALS AND METHODS

The data used in this study were collected during the months of October 2016 to February 2017 for the sweet corn cultivation from 8 farm lands which is located at 3°33'03.2"N 101°07'57.3"E that is near to Jalan Parit 7, Sekinchan, Sungai Besar in Sabah Bernam district of Selangor, Malaysia. The data collection includes the complete field operations namely tillage, planting, fertilising, harvesting, cutting plants and spraying in the cultivation of sweet corn. Details on equipment and manpower requirements for the field operations are listed in Table 1 and field operations of sweet corn cultivation are shown in Figure 1.

Table 1: Current technology use and worker involvement in field operations

Field operation		Equipment	Number of workers
Tillage		Tractor Kubota M9540 70.84 kW@2600 rpm with fully mounted Howard rotary plow	One worker
Planting	Seeds	Hoe 1.5 kg	Two workers
	Seedling	Rod digging 1.4 kg	Two workers
Fertilising		Plastic pail 0.425 kg	One worker
Spraying	Knapsack	Pabool Knapsack Sprayer 5.5kg	One worker
	Blower	Cifarelli Blower sprayer 31 kg	One worker
Harvesting	Wheelbarrow	Wheelbarrow 13.3 kg with basket 4 kg	One worker
	Bags	Bags made of HDPE material 0.065 kg	One worker
Cutting plants		Knife 0.615 kg	One worker

Tillage operation

Planting operation with seeds

Planting operation with seedlings

Fertilising operation

Spraying operation using knapsack

Spraying operation using blower

Harvesting operation with bags

Harvesting operation with wheelbarrow

Cutting plants operation

Figure1: Field operations in sweet corn cultivations

At the onset of the data collection phase field measurements were made to establish the net land area of individual farms. The measurements were made in order to facilitate precise computation of the respective field capacities for each of the machinery used in various field operations. The effective field capacity or Fc for each of the machinery used in the sweet corn cultivation operations was computed as follows:

$$Fc = A/T \quad (1)$$

where:

Fc =effective production capacity, ha h^{-1}
A = net farm land area, ha
T = net field time, h

The field time for every operation in all the farms was recorded with a digital stopwatch. The field time was separated into a number of time periods according to the involve tasks that were carried out to complete the field operation. In all the operations, the total field time covers the time spent in performing all the sequence of task starting from the beginning until the end of the field operation.

The machinery energy is an indirect energy assumed to be embodied in a piece of equipment resulting from its manufacture. It is a function of machinery weight amortised over its economic life. The general formula for computing machinery energy expenditure or ME on per area basis is expressed as follows:

$$ME = Cf * W/ Fc * L \quad (2)$$

where:

ME = machinery energy, MJ. ha^{-1}
Cf = conversion factor, MJ. kg^{-1}
W = weight of machinery, kg
L = useful life of machinery, h

The economic life of farm machinery employed by the farmers was derived from the farm machinery management standard as shown in Table 2

Table 2: Economic life of farm machinery used by farmers in the study area

Machine	Economic life/ h	source
Tractor 2WD	12000	ASABE standard D497.5 (2006)
Rotary tiller	1500	ASABE standard D497.5 (2006)
Hand tools	250	Pathak (1986)

In computing the machinery energy for tillage operation which involves the use of a tractor and rotary tiller having different weight, energy conversion coefficient and economic life. The total machinery energy or ME was obtained as the summation of machinery energies due to the tractor and rotary tiller used in performing the operation is given as:

$$ME=1/Fc*[(Cf_t * W_t /L_t) + (Cf_r * W_r /L_r)] \quad (3)$$

where:

ME = machinery energy, MJ. ha^{-1}
Cft = energy conversion factor for tractor, 93.61 MJ/kg
Wt = weight of tractor, 2311 kg
Lt = economic life of tractor, 12000 h
Cfr = energy conversion factor for rotary tiller, 62.70 MJ/kg
Wr = weight of rotary tiller, 315 kg
Lr = economic life of rotary tiller, 1500 h
Fc = effective field capacity for the tillage operation, ha/h

In computing the machinery energy for other operations which involve the use of hand tools that have different weight, energy conversion coefficient and economic life, the total machinery energy was

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obtained as the summation of machinery energies of the hand tools used in performing the operation is as used by (Yadav et al., 2013).

The general formula for computing machinery energy expenditure or ME on per area basis is expressed as follows:

$$ME = Cf_h * W_h / F_c * L_h \quad (4)$$

where:

ME = machinery energy, MJ. ha^{-1}
Cf_h = energy conversion factor for the hand tools used, MJ/kg
W_h = weight of the hand tools, kg
Fc = effective field capacity, ha/h
Lh = economic life of the hand tools, h

In this regard, the mechanisation index or MI of the operations involved in sweet corn cultivation system, in each of the farms investigated was evaluated as follows:

$$MI = ME / ME+HE * 100 \quad (5)$$

Where:

MI = mechanization index, proportion
ME = machinery energy, Mj/ha
HE = human energy, MJ/ha

The total farm machinery energy expenditure in MJ/ha was determined in each farm lot as the ratio of the summation of machinery energy expenditures for all the operations and the net land area of the respective farm lots. The average farm machinery energy expenditure for the block was obtained as the ratio of the summation of the machinery energy accrued to all the farms/hectare and number of farms in the block.

RESULTS AND DISCUSSIONS

Time and motion analysis of field operations

Farmers in the study area used medium size two-wheel drive (2WD) tractors of different makes and models with engine power ratings ranging from 75 to 95 hp as prime movers in performing the tillage operations using rotary tillers of different working width of 1.8 m attached to the tractors. In planting and fertilising operations, all the farmers used manual labour. The planting operation was done using two methods a direct seeding using hoe for digging and seedling using rod for digging, while none of the farmers used a transplanting machine on their farms. The blowers were carried by farm workers on their backs during the spraying operation and they had an average weight of 13 kg with engine power rating of 3.6 kW. The knapsack sprayer was used by the farmers for their spraying applications. The harvesting operation was done using two methods: (a) using wheelbarrow with an average weight of 13 kg with 4 kg basket to collect corncobs; (b) using bags made of HDPE material to collect the corncobs. The cutting operation with workers using knives to cut the plants. Most of their sweet corn farmers who are low scale producers, still perform most operations manually, leading to huge human energy expenditures in terms of total field time.

Table 3 shows that there is diversity in the performance of production capacity and field time in the various operations for cultivating sweet corn in this study. The spraying operation using blower showed the highest production capacity of 0.81 ± 0.15 ha/h while, the field time of spraying operation using blower offered the lowest value 1.35 ± 0.18 h/ha among all the operations due to working width of spraying which covered around 7.2 m. In harvesting using wheelbarrow, the least production capacity was 0.04 ± 0.01 ha/h on account of the speed of the worker at about 1.96 ± 0.27 km/h whereas, the field time of this operation presented the highest amount of approximately 29.41 ± 3.89 h/ha. A cumulative field time of 137.64 ± 21.56 h/ha was used by the farmers.

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Table 3: Production capacity and total field time-based operations

Field operation		Production capacity, ha/h	Total field time, h/ha
Tillage		0.30 ± 0.03	3.38 ± 0.30
Planting	Seeds	0.06 ± 0.02	18.76 ± 2.71
	Seedling	0.05 ± 0.01	21.51 ± 3.72
Fertilising		0.19 ± 0.02	5.87 ± 0.69
Spraying	Knapsack	0.18 ± 0.03	6.13 ± 0.73
	Blower	0.81 ± 0.15	1.35 ± 0.18
Harvesting	Wheelbarrow	0.04 ± 0.01	29.41 ± 3.89
	Bags	0.05 ± 0.01	25.74 ± 5.48
Cutting plants		0.05 ± 0.006	25.49 ± 3.86
Total		1.73 ± 0.29	137.64 ± 21.56
Average		0.19 ± 0.03	15.29 ± 2.40

Table 4 presents the actual performance and turnaround time for the distribution of field time based on the three task operations. The spraying operation using blower had the lowest percentage of task operation at around 59 % ± 4.66 (1.35 ± 0.18 h/ha) due to the high percentage of turnaround time of 5.50 % ± 1.87 as a result of the length of rotation needed by the worker to move to the next line. In addition, the high percentage of the time for filling tank of blower was around 35.51 % ±4.72% compared to the other manual operations. However, the planting operation using seedling showed the highest percentage of task operation at about 98.14 % ± 0.33 (21.51 ± 3.72 h/ha) because of the low percentage of turnaround time by worker 1.86 % ± 0.33. Furthermore, tillage operation had the highest percentage of turnaround time of 27.84% (3.38 ± 0.30 h/ha) using machinery operation. Besides, the time for loading and unloading effected on the percentage of task operation which showed a difference in the loading and unloading time. In spraying operation using knapsack sprayer and blower sprayer the percentages of time for filling were 25.11 ± 2.42 % and 35.51 ±4.72 % respectively. Moreover, in harvesting operation using wheelbarrow and bags to collect the corncobs the percentages of unloading time of corncobs were 26.31 % ± 3.79 and 24.21 % ± 2.92, respectively. In comparison, the fertilising and cutting plants operations showed the lowest percentage of loading and unloading time of 10.85 % ± 3.25 and 10.25 % ± 3.59 respectively.

Table 4: Time and motion analysis for sweet corn operations

Field operation		Percent field time, %		
		Task, %	Turning, %	Load/unload, %
Tillage		72.16 ± 6.91	27.84 ± 6.91	-
Planting	Seeding	97.95 ± 0.31	2.05 ± 0.31	-
	Seedling	98.14 ± 0.33	1.86 ± 0.33	-
Fertilising		87.00 ± 3.44	2.16 ± 0.55	10.85 ± 3.25
Spraying	Knapsack	73.63 ± 2.91	2.52 ± 0.87	25.11 ± 2.42
	Blower	59.00 ± 4.66	5.50 ± 1.87	35.51 ±4.72
Harvesting	Wheelbarrow	72.33 ± 3.64	1.36 ± 0.29	26.31 ± 3.79
	Bag	74.00 ± 2.74	1.79 ± 0.35	24.21 ± 2.92
Cutting plants		94.21 ± 1.62	2.87 ± 0.61	10.25 ± 3.59
Average		80.94 ± 2.95	5.33 ± 1.34	22.04 ± 3.45

Human energy expenditure in sweet corn cultivation

The human energy expenditure in crop production was evaluated using a special instrument known as Polar S810M Heart Rate Monitor and its transmitter. These instruments measures the actual physical human energy expended in performing a specific operation. Figure 2 appear a farm worker manually applying spraying operation using knapsack on the field wore a Polar S810M Heart Rate Monitor which comprised a heart rate transmitter placed on his or her chest and a receiver at the wrist for the measurement of physical human energy expenditures.

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(a) Wrist receiver (b) Heart rate transmitter

Figure 2: The Polar S810M Heart Rate Monitor to Measured Human Energy Expenditure

Distribution of polar measured physical human energy expenditure according to operations

Table 5 shows the distribution of physical human energy expenditure obtained through direct measurement with Polar S810M Heart for all the involved field operations in sweet corn cultivation. The lowest and highest physical human energy expenditure for the entire cultivation system occurred in the tillage operation (382.55 kcal/ha) and harvesting operation using wheelbarrow (15195.24 kcal/ha) operations respectively. The difference in physical human energy expenditure between the two opposing operations (i.e. harvesting using wheelbarrow and tillage operation) on a cumulative basis was about 14812.69 kcal/ha. This difference was more than 39 times the physical human energy expenditure for tillage operation. The harvesting operation using wheelbarrow also had a higher total physical human energy expenditure (15195.24 kcal/ha) compared to spraying operation using blower (3494.67 kcal/ha) by about 11700.57 kcal/ha, even though higher application frequency was recorded in spraying operation (4 times) than in harvesting operation using wheelbarrow (1 time). The fertilising operation used about 3.38 times the physical human energy expenditure used in chemical application with spraying operation using blowers. Cumulatively, the difference between physical human energy expenditure in fertilising operation and spraying operation using blower is about 8303.93 kcal/ha. The higher total physical human energy expenditure in harvesting operation using wheelbarrow highlighted its severity compared to the other operations.

Table 5: Distribution of human energy expenditure according to the involved field operations

Operations		Production Capacity ha/h	Human energy expenditure kcal/ha	Operation Frequency	Total human energy expenditure kcal/ha
Tillage		0.30	382.55	1	382.55
Planting	Seeds	0.06	9882.36	1	9882.36
	Seedling	0.05	12647.50	1	12647.50
Fertilising		0.19	2949.65	4	11798.60
Spraying	Knapsack	0.18	2444.47	4	9777.90
	Blower	0.81	873.67	4	3494.67
Harvesting	Wheelbarrow	0.04	15195.24	1	15195.24
	Bags	0.05	12926.33	1	12926.33
Cutting plants		0.05	10206.26	1	10206.26

Table 6 shows that fertilising operations had the highest annual human energy input of about 223701.45 kcal ha/yr/man (category 4, 29.26 % of the total input) due to the depletion of high energy per unit area increased proportion of energy spent during this operation where the effort was required of the worker for distributing, loading and applying fertiliser four times to the growing sweet corn plants. While, tillage operation had the least among the eight listed operations about 765.10 kcal ha/yr/ man (category 1, 0.10 % of the total input) due to the decrease of use of this operation compared with other operations where the average of the use of tillage was twice a year and with low physical effort and human energy during the operation.

Table 6: Estimated total annual human energy expenditure for the field operations in the sweet corn cultivation

Operations		Number of operations per year	Human energy expenditure per operation, kcal /ha/man	Human energy expenditure per year, kcal ha/yr/man	Energy proportion %	Operation Frequency
Tillage		2	382.55	765.10	0.10	1
Planting	Seeds	4.74	9882.36	46842.39	6.13	1
	Seedling	4.74	12647.50	59949.15	7.84	1
Fertilising		18.96	11798.60	223701.45	29.26	4
Spraying	Knapsack	18.96	9777.90	185388.98	24.25	4
	Blower	18.96	3494.67	66258.94	8.67	4
Harvesting	Wheelbarrow	4.74	15195.24	72025.44	9.42	1
	Bags	4.74	12926.33	61270.80	8.01	1
Cutting plants		4.74	10206.26	48377.67	6.33	1
Total				764579.92	100	

Analysis of machinery energy expenditure

An overall machinery energy expenditure of 281.00 ± 34.51 MJ/ha was used by the farmers in performing all the operations in this study, which was given in Table 7. The highest machinery energy expenditure of 127.62 ± 16.89 MJ/ha (2.04 ± 0.27 kg/ha) representing 45.42% of the total machinery energy was accounted by harvesting operation using wheelbarrow. In tillage operation was given high machinery energy expenditure of 105.35 ± 9.37 MJ/ha (1.36 ± 0.12 kg/ha) appeared 37.49 % of the total machinery energy. Followed by planting operation using seedling which gave machinery energy expenditure of 13.39 ± 3.55 MJ/ha (0.21 ± 0.057 kg/ha) symbolising 4.77 % of the total machinery energy. The least machinery energy was recorded in harvesting operation using bags to collect corncobs with share of 0.42 ± 0.09 MJ/ha (0.007 ± 0.001 kg/ha) accounting for 0.15 % of the total machinery energy used by the farmers, reflecting the high level of human labour interventions in conducting the operation. Compared to machinery energy used by corn farmers in developed agriculture.

Table 7: Distribution of machinery energy expenditure according to the involved field operations

Field operation		Energy expenditures	
		(kg/ha)	(MJ/ha)
Tillage		1.36 ± 0.12	105.35 ± 9.37
Planting	Seeds	0.17 ± 0.025	10.72 ± 1.55
	Seedling	0.21 ± 0.057	13.39 ± 3.55
Fertilising		0.040 ± 0.005	2.504 ± 0.30
Spraying	Knapsack	0.56 ± 0.068	34.96 ± 4.25
	Blower	0.67 ± 0.088	41.97 ± 5.50
Harvesting	Wheelbarrow	2.04 ± 0.27	127.62 ± 16.89
	Bags	0.007 ± 0.001	0.42 ± 0.09
Cutting plants		0.06 ± 0.01	3.93 ± 0.60
Total		5.12 ± 0.64	340.67± 41.99

Mechanisation Level of Sweet Corn Field Operation Based on PHE Cartesian Plot

Table 8 shows the production capacity, mean increase in heart rate and energy expenditure of the workers for all the involved field operations. On the basis of the energy expenditure, planting using seeds is classified as the operation incurring the highest energy demand which was 911.8 ± 146.2 kcal /h/worker because the worker had to use a hoe to dig and prepare the seed bed in this operation, which was more labourious, followed by planting using seedling and this is considered as the operation with the highest energy demand which was 810.8 ± 152.8 kcal /h/worker. Fertilising operation, spraying

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operation using blower sprayer, harvesting operation using wheelbarrow and harvesting operation using bags are classified as of upper intermediate energy demand, while, tillage is the operation with lowest energy demand.

Based on the basis of the measured mean increase in heart rate, planting using seedling and spraying operation using blower sprayer had the highest heart rate level but there was no significant difference with the following operations. Harvesting operation using wheelbarrow and cutting plants operation which incurred upper intermediate energy demand, while, planting using seeds and harvesting operation using bags showed lower intermediate heart rate level. However, tillage operation showed the lowest heart rate level due to reduced worker's fatigue in this operation.

On the basis of the measured production capacity, spraying operation using blower sprayer had the highest level of production capacity, followed by tillage operation which showed upper intermediate level of production capacity. Planting using seeds, planting using seedling, harvesting operation using wheelbarrow, harvesting operation using bags and cutting plants operation showed the lowest level of production capacity.

Using graphics to represent the combination of measured production capacity, measured mean increase in heart rate and estimated human energy expenditure for the individual operations it was possible to plot in an X, Y, Z coordinate system. The coordinates used the three measured values (i.e., production capacity level, heart rate, and energy demand) in Table 8. As previously clarified, the energy demand, heart rate and production capacity were separated into four levels i.e., highest, upper intermediate, lower intermediate, lowest, which were numbered 1,2,3 and 4. The 3D plots were employed to determine the priorities of the operations for formulating a mechanisation programme for sweet corn cultivation. The operation represented by X, Y, Z coordinates close to the origin is the highest priority operation for mechanisation, i.e., the operation that had the highest energy demand, highest heart rate and highest production capacity. Additionally, the operation represented by X, Y, Z coordinates farthest from the origin is the lowest priority operation for mechanisation i.e., the operation with the lowest energy demand, lowest heart rate and lowest production capacity. Planting operation using seedling with X, Y, Z coordinates (1,1,1) in Figure 3 is takes high level for mechanisation, while, tillage operation is of the lowest level for mechanisation with X, Y, Z coordinates of (3,4,4).

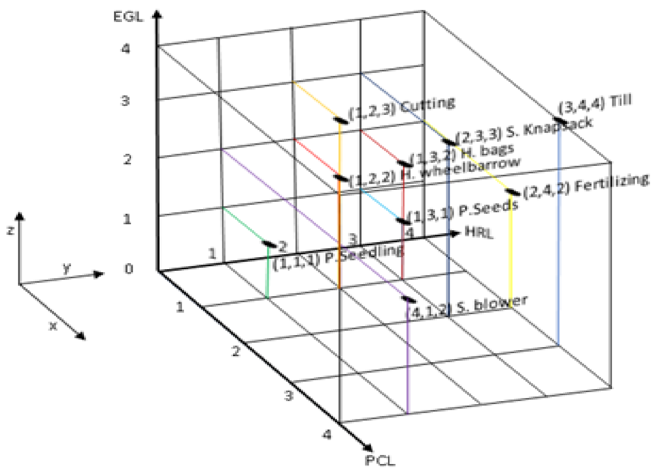
Table 8: Production capacity, mean increase in heart rate and energy expenditure for individual field operations in the sweet corn cultivation

Operations		Production Capacity		Mean Increase in Heart Rate		Energy expenditure	
		(ha/h)	Level (1-4)	beats/min	Level (1-4)	Kcal/h/ worker	Level (1-4)
Tillage		0.30	3 b	98.33 ± 0.65	4 c	112.8 ± 35.4	4 d
Planting	Seeds	0.06	1 d	106.45 ± 4.00	3 b	911.8 ± 146.2	1 a
	Seedling	0.05	1 d	117.44 ± 5.90	1 a	810.8 ± 152.8	1 a
Fertilising		0.19	2 c	103.23 ± 3.02	4 c	575.9 ± 92.0	2 b
Spraying	Knapsack	0.18	2 c	108.15 ± 3.86	3 b	407.1 ± 31.9	3 c
	Blower	0.81	4 a	116.20 ± 1.81	1 a	653.8 ± 98.4	2 b
Harvesting	Wheelbarrow	0.04	1 d	113.95 ± 2.83	2 a	571.5± 103.1	2 b
	Bags	0.05	1 d	107.24 ± 3.35	3 b	599.3 ± 117.6	2 b
Cutting plants		0.05	1 d	113.89 ± 3.05	2 a	459.3 ± 71.0	3 c

Mechanisation Level of Sweet Corn Field Operation Based on Mechanisation Index

A mechanisation index for all the nine-basic sweet corn production activities, namely, tillage, planting using seeds, planting using seedling, fertilising, spraying using knapsack sprayer, spraying using blower sprayer, harvesting using wheelbarrow, harvesting using bags and cutting plants operations in all the farm lots of the study area was determined. The summary statistics for the average mechanisation index for the nine operations is given in Table 9. As indicated in Table 9, the highest and lowest human energy expenditures were in planting using seedling and tillage operations at 74.51 MJ/ha and 6.62 MJ/ha respectively. The Duncan's multiple range test (DMRT) reveals significant differences exist between the human energy expenditure for planting using seedling and other operations. Whereas, no significant differences were recorded among the human energy expenditures for planting using seeds, fertilising, spraying using knapsack sprayer, harvesting using wheelbarrow, harvesting using bags and cutting plants operations, while, in tillage and spraying using blower sprayer there were no significant differences between them.

Total machinery energy used for sweet corn cultivation in the study area was 340.67 MJ/ha in performing the nine operations covered by the study. The highest machinery energy expenditure of 127.62 MJ/ha representing 37.46 % of the total machinery energy expended per hectare was accounted for by harvesting operation using wheelbarrow. The difference in machinery energy for harvesting operation using wheelbarrow compared with the other operations indicated use of machinery in harvesting operation compared with the machinery used by the farmers in performing the other operations. The DMRT test conducted on the machinery energy among the nine operations shows significant differences between the mechanised operations of harvesting and tillage operations. However, the machinery energy for planting using seeds, fertilising, and cutting plants operations was not significantly different from one another. The tillage operation 105.35 MJ/ha in combination accounted for about 30.92 % and spraying operation using blower, with 41.97 MJ/ha represented about 12.32 % of the total average machinery energy expended by the farmers. The lowest machinery energy was recorded in harvesting operation using bags with a value of 0.42 MJ/ha of the total machinery energy used by the farmers as presented in Table 9.



Operations	Ranking Decrease order
Tillage (Till)	1
Planting (seeds)	6
Planting (seedling)	8
Fertilising	2
Spraying (knapsack)	3
Spraying (blower)	4
Harvesting (wheelbarrow)	7
Harvesting (bags)	5
Cutting plants	5

Figure 3: PCL-HRL-EGL cartesian plot for field operations in sweet corn cultivation: PCL= production capacity level, HRL= heart rate level, EGL= energy level, Till = tillage operation, P. seeds= planting operation using seeds, P. seedling = planting operation using seedling, Fertilising = Fertilising operation, S. Knapsack = Spraying operation using knapsack, S. blower = Spraying operation using blower, H. wheelbarrow = harvesting operation using wheelbarrow, H. bags = harvesting operation using bags, and Cutting = cutting plants operation

Table 9: Specific mechanisation index for individual field operations in the sweet corn cultivation

Operations		Human, MJ/ha	Machinery, MJ/ha	Mechanisation index, %	Ranking decrease order
Tillage		6.62 ^{c}	105.35 ^{b}	94.09 ^{a}	1
Planting	Seeds	55.85 ^{b}	10.72 ^{de}	16.10 ^{e}	5
	Seedling	74.51 ^{a}	13.39 ^{d}	15.23 ^{f}	6
Fertilising		46.07 ^{b}	2.50 ^{de}	5.15 ^{h}	8
Spraying	Knapsack	49.67 ^{b}	34.96 ^{c}	41.31 ^{d}	4
	Blower	10.58 ^{c}	41.97 ^{c}	79.87 ^{b}	2
Harvesting	Wheelbarrow	57.63 ^{b}	127.62 ^{a}	68.89 ^{c}	3
	Bags	50.45 ^{b}	0.42 ^{e}	0.83 ^{i}	9
Cutting plants		49.96 ^{b}	3.74 ^{de}	6.96 ^{g}	7
Average		44.59	37.85	36.49	-

Mechanisation index for all the nine-basic sweet corn production activities, namely, tillage, planting using seeds, planting using seedling, fertilising, spraying using knapsack sprayer, spraying using blower sprayer, harvesting using wheelbarrow, harvesting using bags and cutting plants operations in all the farm lots was determined, and the result is presented in Table 9. An overall mean 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. Tillage operation had the highest mechanisation index of 94.09 %, thus indicating the near exclusion of manual labour in carrying out the operation. The next operation with high mechanisation index is the spraying operation using blower, with a recorded value of 79.87 %. About 20.13 % of the energy expended in performing spraying operation using blower was accounted for by human labour. The higher contribution of human labour in conducting planting operation using seedling compared with the share contribution of human labour in other operations is indicated in Table 9. The harvesting operation using wheelbarrow is third on the mechanisation index with about 68.89%. Furthermore, the spraying operation using knapsack had a mechanisation index of 41.31 %. As for the remaining operations (i.e. planting using seeds, planting using seedling, fertilising, harvesting using bags and cutting plants operations), their mechanisation index was found to be below 16 % each, thereby suggesting more human labour involvement compared with machinery energy used in performing the operations. It is therefore important to note that the aforementioned operations were conducted mainly manually.

The most critical operation requiring mechanisation is, therefore. harvesting operation using bags. It has an index of 0.83 % representing human labour involvement of about 99.17 % of the operation's energy expenditure. This suggests that harvesting operation using bags as currently done by farmers in the study area is not only laborious and tiring, but also poses significant threat to speed of marketing and product supply. Hence, as a result of the major drawback to the sustainability of sweet corn production in Malaysia, there is an urgent need for mechanising harvesting operation in sweet corn farms in the country.

General Mechanisation Status in Sweet Corn Cultivation Based on Mechanisation Index

An overall general mechanisation index was developed for all the six-basic sweet corn production activities, namely, tillage, planting, fertilising, spraying, harvesting and cutting plants operations in all the farms where the study was determined. The summary of statistics for the average mechanisation index of the six operations is given in Table 10. As indicated in table 10, the highest and lowest human energy expenditures were in planting and tillage operations at 64.14 MJ/ha and 6.62 MJ/ha respectively. The Duncan's multiple range test (DMRT) reveals significant differences exist between the human energy expenditure for harvesting with tillage and spraying operations. whereas, no significant differences were recorded among the human energy expenditures for planting, fertilising and cutting plants operations.

Farmers practising sweet corn cultivation in the study area used total machinery energy of 230.63 MJ/ha in performing the six operations covered by the study. The highest machinery energy expenditure of 105.35 MJ/ha representing 45.68 % of the total machinery energy expended per hectare of farmland was for tillage operation. The difference in machinery energy for tillage compared with the other operations indicated use of heavy duty machinery in tillage operation compared with the machinery used by the farmers in performing the other operations. The DMRT test conducted on the machinery energy among the six operations showed significant differences between the three mechanised operations of harvesting, tillage, and spraying operations. However, the machinery energy for planting, fertilising, and cutting plants operations was not significantly different from one another. Farmers in the area harvested their sweet corn manually. The harvesting operation 69.17 MJ/ha in combination accounted for about 29.99 % and spraying operation, with 37.96 MJ/ha represented about 16.46 % of the total average machinery energy expended by the farmers. The lowest machinery energy was recorded in the fertilising operation with a value of 2.50 MJ/ha of the total machinery energy used by the farmers as presented in Table 10.

The higher contribution of machinery energy expenditure due to sprayer applications over planting operation highlighted the multiple application frequencies for spraying operations. On the other hand, the fertiliser application used multiple frequencies, but it does not get high value of machinery energy due to the manual nature of the application using plastic container in this operation. These effects of the low-level mechanisation of the operation resulting in a high level of human effort being required for the operation. Nevertheless, averagely, farmers in the study area carried out four rounds of fertiliser and chemical applications in comparison with one round of planting operation.

Mechanisation index for all the six-basic sweet corn production activities, such as, tillage, planting, fertilising, spraying, harvesting, and cutting plants operation in all the farm lots was established, and Table 10 presents the results. An overall mean mechanisation index of 38.62 % was noted for the cultivation system and this reflects the level of machinery inclusion in sweet corn production in Malaysia. In similar studies, Yadav et al. (2013) reported a mechanisation index of 0.26 for corn production in Sikkim, India, where extensive use of human and animal power was prevalent. Understandably, the estimated values of mechanisation and machinery energy indices are very poor in the region, while in Iran a mechanisation index of 0.77 was reported for garlic production (Samavatean et al., 2011). Operation-wise, tillage operation had the highest mechanisation index of 94.09 %, thus indicating the near exclusion of manual labour in carrying out the operation. Sweet corn farmers in Malaysia generally use a tractor with rotary plough in performing tillage operation. The next operation with high mechanisation index is the harvesting operation, with a recorded value of 56.01 %. About 43.99 % of the energy expended in performing harvesting operation was accounted for by human labour. The higher contribution of human labour in conducting harvesting operation compared to the share contribution of human labour in spraying operation reflected multiplicity in the conduct or spraying operation. Spraying operation, conducted by farmers using knapsack sprayer or blower sprayer in the study area, is another operation in sweet corn cultivation with medium mechanisation index of up to 53.56 %, denoting human labour involvement of about 46.44 %. There are no significant differences between the mechanisation index of planting, fertilising and cutting plants operations as indicated in Table 10. As for the remaining operations (i.e. planting, fertilising and cutting plants), their mechanisation index was found to be below 16 % each, thereby suggesting more human labour involvement compared to machinery energy used in performing the operations. It is therefore important to note that the three aforementioned operations were conducted manually. No significant differences exist between the mechanisation indices of planting, fertilising and cutting plants operations.

Table 10: Overall mechanisation index for individual field operations in the sweet corn cultivation

Operations	Human, MJ/ha	Machinery, MJ/ha	Mechanisation index, %	Ranking decrease order
Tillage	6.62 ^{c}	105.35 ^{a}	94.09 ^{a}	1
Planting	64.14 ^{a}	11.90 ^{d}	15.65 ^{d}	4
Fertilising	46.07 ^{ab}	2.504 ^{d}	5.16 ^{d}	6
Spraying	32.92 ^{b}	37.96 ^{c}	53.56 ^{c}	3
Harvesting	54.33 ^{a}	69.17 ^{b}	56.01 ^{b}	2
Cutting plants	49.96 ^{ab}	3.93 ^{d}	7.29 ^{d}	5
Average	42.34	38.47	38.62	-

The most critical operation requiring mechanisation generally is, therefore. fertilising operation. It has an index of 5.16 % representing human labour involvement of about 94.84 % of the operation's energy expenditure. This suggests that fertilising operation as currently done by farmers in the study area is not only laborious and tiring, but also poses significant threat to the health of the farmers/farm workers due to their prolonged exposure to the chemicals during application. Hence, as a result of the major drawback to the sustainability of sweet corn production in Malaysia, there is an urgent need for mechanising fertiliser application operation in the country.

CONCLUSIONS

Two methods were used to evaluate the mechanisation level of the respective field operations in sweet corn cultivation in Malaysia. The first method used was the PHE cartesian plot where the production capacity, mean increase in heart rate and energy expenditure of the workers were used as the basis in evaluating the mechanisation level of any field operation. With this method, planting operation with seedlings with coordinates of (1,1,1) has highest level of mechanisation while tillage operation with coordinates of (3,4,4) has lowest level of mechanization. The second method used was mechanisation index where machinery energy and total energy were used as the basis in evaluating the mechanization level of any field operation. With this method, tillage operation with an index of 94.09% has highest level of mechanization while harvesting operation with bags with an index of 0.83% has lowest level of mechanisation. However, the general mechanisation status on the basis of the computed overall mechanisation index in the sweet corn cultivation was 38.62%. Admittedly, the field operation that should be given the highest priority for mechanisation is fertilizing operation with an index of 5.15% while the lowest priority for mechanisation was tillage operation with an index of 94.09 %. This rule of thumb should be followed whenever any mechanisation plan is to be implemented for sweet corn cultivation in Malaysia.

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