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Development and Testing of a Portable Palm Tree Pruning Machine

[1]K.M. Ismail and [2]K.A. Al-Gaadi
[1]Department of Agricultural Engineering, University of Alexandria,
Shatby Alexandria, Egypt
[2]Department of Agricultural Engineering, King Saud University,
Riyadh, Kingdom of Saudi Arabia

Abstract: An AC-operated portable machine was developed to mechanize the pruning operation conducted on the petioles of palm trees. The performance of the machine was tested in the laboratory on petioles at different petiole Moisture Contents (MC). Power, energy and time required for cutting were the three criteria considered to evaluate and test the machine's performance. Results of the test revealed that the relationships between petiole MC and power, energy and time required for cutting were all significant, where the values of the determination factors (R^2) were 0.86, 0.71 and 0.81, respectively. The results also showed that both energy and time required for cutting were proportional to the petiole MC. The average time and energy required at a petiole MC range of 60 to 75% were 3 sec cm^{-2} and 32 W sec cm^{-2}, respectively. However, the values of the two variables were 0.9 sec cm^{-2} and 12 W sec cm^{-2}, respectively, at lower petiole MC range (7 to 20%). Results also demonstrated that the power required for cutting was inversely proportional to the petiole MC. An average power values of 12 and 30 W cm^{-2} were required at high levels of petiole MC (60 to 75%) and low levels of petiole MC (7 to 20%), respectively.

Key words: Palm tree, pruning, cutting, energy, power, time, performance, moisture content

Introduction

Palm trees have an exceptional importance in the body of agriculture in the Kingdom of Saudi Arabia. The importance comes from the fact that the trees are widely planted all over the kingdom for their yield of dates and for decoration purposes. Palm dates are considered to be the main and the most popular fruit in Saudi Arabia supplied by 12 million palm trees spread over an area of 106,460 ha, where the total production reaches 648,000 tons/year (Bakry, 2000). On the other hand, palm trees, due to their durability, are commonly planted in houses, main streets and public parks throughout the kingdom for decoration and landscaping.

Sial and Khalid (1983) reported that most of palm tree farms in Saudi Arabia did not follow a specific engineering regime, where palm trees are randomly planted and often inter-cropped with forage and vegetable crops and, sometimes, even permanently inter-cropped with other fruit trees. They added that irrigation channels in these farms were not well organized causing difficulty in machine maneuvering around palm trees. The authors also stated that the traditional practice of climbing up a date palm tree was time consuming and hazardous requiring a skilled labor. Al-Kiady (2000) reported that trained and specialized labors that could professionally deal with date palm trees were becoming

Corresonding Author: K.A. Al-Gaadi, Department of Agricultural Engineering, King Saud University, Riyadh, Kingdom of Saudi Arabia

rare and expensive causing a serious depression in the production of dates. Ahmad *et al*. (1986) added that a new technology was not readily transferable to palm tree fields unless major changes in the functional machine design or agricultural practices took place. That was attributed to the fact that there were major mismatches between palm tree field conditions and agricultural mobilized machine specifications. Therefore, most of the field operations required for date production were reported to be currently manually performed, thus, inefficiently conducted, costly, tedious and time consuming (Bakry, 2000). Due to the scarcity and high cost of skilled labor, mechanization of field operations pertaining to palm trees is crucial to ensure a continuous and sufficient date production at an economically justified and reasonable farming cost (Brown, 1982).

Attempts have been made to mechanize, on different scales, some farming operations related to date palm trees. A hydraulic lifter was developed by Brown (1982) to reach the top of the palm tree for easier harvesting. The lifter was reported to reduce the required labor by 80% and the related cost by 50%. Al-Suhaibani *et al*. (1990) designed a date palm tree service machine based on a survey conducted on 19 palm tree farms in the Kingdom of Saudi Arabia that were thought to be representative of the range of typical farms and soil conditions likely to exist in the kingdom. The service machine implemented a hydraulic system powered by a 52 kW Perkins 4-cylinder diesel engine. The hydraulic system was utilized to extend a boom that ended with a basket carrying a worker up to a height of 10 m, which was enough to reach 98% of all the trees included in the survey. Machine field test revealed that the machine was slower in positioning itself at the palm tree crown level than the hand labor; however, date harvesting was generally found to be faster when the machine was utilized (Al-Suhaibani *et al*., 1991). Abdalla *et al*. (1986) developed a simple and inexpensive walk-up elevator to ease the climbing of palm trees for different farming operations. The elevator was composed of a single beam with two walking up feet pedals and a seat. The elevator was designed where a worker could lift himself up by pedaling and then sit when reaching the crown zone to perform required operations. Omar *et al*. (1986) modified two lifts to be utilized in palm tree crown-related operations, such as pollination, pruning and harvesting. One lift was one man operated called ‘Ben-10’, while the other was an aerial lift platform called ‘Palmates’. Modifications were necessary for the improvement of traction capability, working height and machine maneuverability. The modified two lifts were found to perform satisfactorily under palm tree field conditions. Ahmad (1997) developed a mechanical elevator that could easily move through palm trees and safely deliver laborer up to the tree crown level to perform desired operations. A saw-based pilot design of a palm tree pruning machine was conducted by Bahdal (2002). No performance tests for this machine were reported.

The above literature shows the importance of putting more efforts into the mechanization of date palm tree farming operations. Thus, the objectives of this study include the design and the development of a portable palm tree pruning machine and testing its performance.

Machine Description

The developed portable pruning machine shown in Fig. 1 with its dimensions illustrated in Fig. 2 was designed so it could be carried by one person. Thus, the total weight and size of the machine were carefully considered in its design, where the weight and length were maintained at 7 kg and 130 cm, respectively. The machine was designed utilizing an AC-operated drill motor with a power of 1200 W at 2400 rpm which was readily available in the local market. The motor was implemented to provide the mechanical energy from the electrical energy. Connected to the motor was a one meter long rotating shaft with a diameter of 0.9 cm. The shaft was used to transfer the motor's rotational

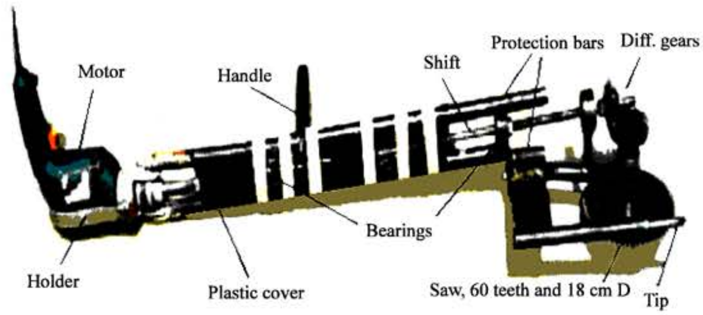

Fig. 1: The developed portable palm tree pruning machine

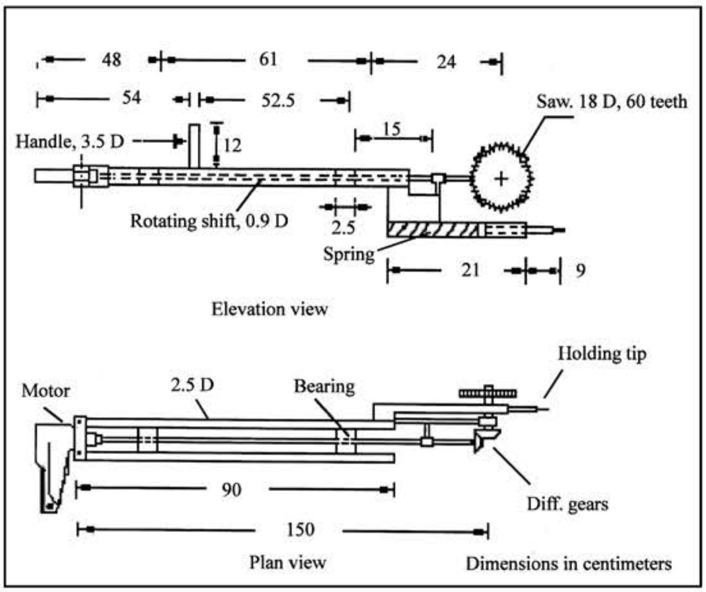

Fig. 2: Elevation and plan views of the developed pruning machine

motion at one end to a couple of differential gears, pinion connected to the shaft and crown connected to a cutting saw, at the other end. The functions of the gears were to convert the horizontal shaft motion into a vertical motion and reduce its rotational speed before it was supplied to the saw. Reduction of the speed was performed to increase the cutting torque on the saw and was obtained by employing a 10 teeth, 3 cm radius pinion gear engaged with a 16 teeth, 4 cm crown gear. Thereby, the speed of the shaft was reduced by a ratio of 1.6 resulting in a saw no-load rotational speed of 1500 rpm. A circular saw of 60 teeth and 18 cm diameter was employed as the cutting component driven by the gears. Mounting bearings and the cutting saw axis were carried by a frame composed of two parallel protection bars. In order to reduce machine vibration and increase its stability during cutting operation, a 9 cm long tip was mounted on the frame to function as a side supporter. A spring inside a metal tube was utilized to place a force sufficient to inject part of the tip into the petiole required to be cut. Thereby, big portion of the machine's weight would be carried by the tip and stability of the machine would be increased due to the fact that the machine would be held by the tree through the tip. For safety purposes, a plastic wrap was used to cover the moving parts close to the operator.

Machine's Performance Evaluation

A laboratory machine's performance test was conducted in 2003 in the laboratories of the college of Agriculture and Veterinary Medicine that belonged to King Saud University, Kingdom of Saudi Arabia. The test was designed to reveal the behavior of the machine in terms of its consumption of electrical power and time required to cut one unit of a petiole's cross section area (cm^2) at different levels of petiole's Moisture Content (MC). The time and power measurements were utilized to compute the energy required for cutting. Power, time and energy were determined to be the dependent variables and were functions of the petiole sample MC. Different petiole's MC levels were obtained by subjecting fresh green samples of petioles to four different periods of natural drying (sun drying). After each period, 20 cuts were performed to form 20 replicates of one drying period (specific MC levels). During cutting operations, petiole samples were safely fixed horizontally on a special arrangement designed for this purpose. The arrangement carrying the sample was connected to a spring that was utilized to ensure that the sample was steadily held against and constantly fed to the cutting edge (Fig. 3).

Determination of Petiole Moisture Content (Mc)

The determination of petiole moisture contents was conducted on the wet basis using the standard methods reported by Rygg (1948) and Ismail (2003). After each natural drying period, samples were weighed using an electrical scale (LIBROR EB-4000H; model: 1410D) with an accuracy of 0.01 g. For complete drying, the samples were placed for 48 h in a vacuum oven (Sheldon Manufacturing Inc., USA) at a temperature of 65°C and a vacuum of 762 mm Hg. The samples were again weighed after they were completely dried and MC% was calculated using the following formula:

$$MC, \% = \frac{W_W}{W_T} * 100 \tag{1}$$

where: W_W = Weight of removed water
W_T = Total weight of sample before oven drying

The four natural drying periods produced several levels of petiole MC that ranged between 7 and 76%.

Power Measurement

A power measuring device (WSE, LVM210) shown in Fig. 3 was used to measure the electrical power required by the machine to perform cutting of different petiole samples (different moisture contents). The device was specified to have a capacity of 4000 W with an accuracy of ±0.5%. A stop watch was used to determine the time, in seconds, consumed in cutting. Energy required for cutting was calculated by multiplying the power measurement by the time consumed in petiole cutting.

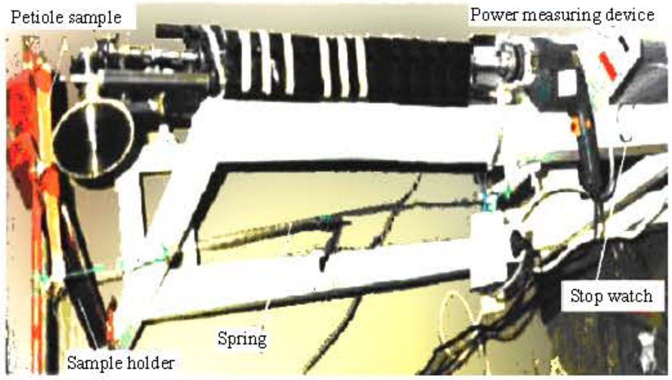

Fig. 3: The experiment setup used for testing the developed machine

Calculation of Petiole Cross-section Area

For each cut (each replicate), the cross section area resulting from cutting was depicted on a paper to obtain the actual exact shape and boundaries of the cut area on a petiole sample. A computer program was designed to calculate the area of the depicted shapes utilizing MATHCAD software. The program used scanned images of the depicted shapes and computed the number of pixels contained in the areas of the different shapes. By knowing the number of pixels in a calibration known area of, for example, 1 cm^2, the program conducted a comparison and calculated the areas of the different scanned irregular shapes based on the number of pixels they contained.

Results and Discussion

Results of the performance tests revealed that the power required for cutting was inversely proportional to the petiole MC (Fig. 4). The regression model for these two factors is shown in Eq. 2, where the determination factor (R^2) was found to be 0.86 suggesting a linear relationship between the two variables.

$$P = 32.17 - 0.3145\,MC, \quad R^2 = 0.86 \tag{2}$$

where: MC = Petiole moisture content (%)
P = Power required to cut 1 cm^2 of petiole cross section area (W)

On the average, the power required to cut petioles with high levels of moisture content (60-75%) was found to be 12 W cm^{-2}, while it was 30 W cm^{-2} for dry petioles with low levels of moisture content (7-20%).

The performance test has also revealed that the required time for petiole cutting was proportional to the petiole MC (Fig. 5). The R^2 of this relationship was found to be 0.81 suggesting a linear relationship between time required for cutting and petiole MC. The regression model is indicated in Eq. 3. On the average, the time required to cut through petioles with high levels of moisture content (60-75%) was 3 sec cm^{-2}. However, petioles with low moisture content levels (7-20%) needed lower average cutting time of 0.9 sec cm^{-2}. This was attributed to the fact that moisture strengthened petiole fibers and their internal tissue bonds making them more resistant to cutting.

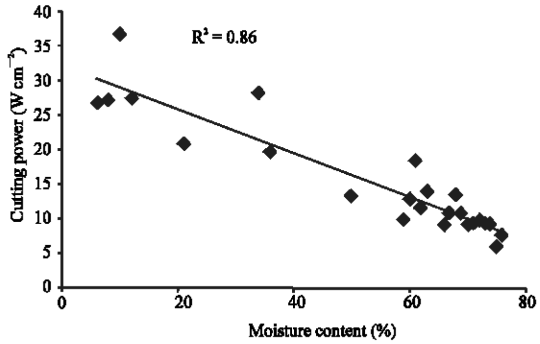

Fig. 4: Relationship between petiole moisture content and power required for cutting.

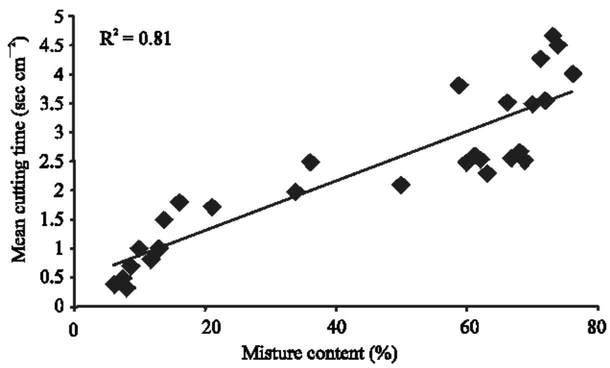

Fig. 5: Relationship between petiole moisture content and time required for cutting

$$T = 0.4187 + 0.0432\ MC, \quad R^2 = 0.81 \tag{3}$$

where: T = Time required for cutting (sec cm^{-2})
MC = Petiole moisture content (%).

Measurements of cutting power and cutting time were utilized to calculate the energy required for cutting at different petiole moisture content levels (Fig. 6). As the time required for cutting was proportional to the petiole MC, the energy required for cutting was expected and found to be proportional to the petiole MC. Obviously; increasing petiole moisture content increased the cutting energy due to increasing cutting time. The R^2 value of the relationship, shown in Eq. 4, between petiole moisture content and cutting energy was 0.71 suggesting a linear relationship between the two variables. On the average, the energy required to cut petioles with MC of 60 to 75% was 32 W sec cm^{-2}, however, the required average energy was 12 W sec cm^{-2} at lower moisture content levels of 7 to 20%.

$$E = 7.13 + 0.399\ MC, \ R^2 = 0.71 \tag{4}$$

where: E = Energy required for cutting (W sec cm^{-2})
MC = Petiole moisture content (%).

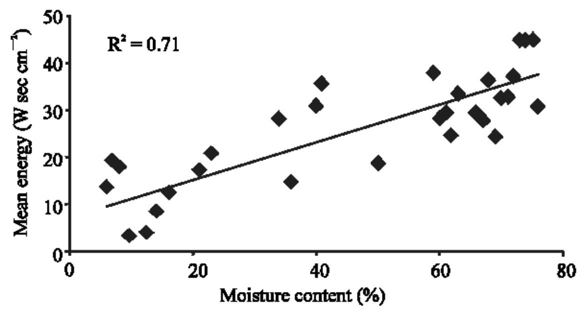

Fig. 6: Relationship between petiole moisture content and energy required for cutting

Conclusions

An AC-operated portable pruning machine was developed as a participation in the efforts put into the mechanization of field operations conducted on date palm trees. The performance of the machine was lab tested using petioles with different Moisture Contents (MC). The following conclusions can be inferred from the study:

- Linear relationships were found to exist between petiole MC and power, time and energy required for cutting.
- The power required from the pruning machine to cut petioles was found to be inversely proportional to the petiole MC. An average power of 12 W cm^{-2} was required at petiole MC ranging from 60 to 75%. However, an average power of 30 W cm^{-2} was required for petioles with low MC levels (7 to 20%).
- The time and energy required for cutting were found to be proportional to the petiole MC. The average time and energy required at 60 to 75% petiole MC range were 3 sec cm^{-2} and 32 W sec cm^{-2}, respectively. However, the values of the two variables were 0.9 sec cm^{-2} and 12 W sec cm^{-2}, respectively, at lower petiole MC range (7 to 20%).
- The developed machine was found to be portable and durable as this was considered in its design in terms of weight and dimensions. Moreover, the machine performed the pruning operation satisfactorily in the lab at different petiole MC levels. However, the need for an AC power source was thought to impose a limit to the use of this machine in agricultural fields.

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