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Influential parameters for designing and power consumption calculating of cumin mower

[1*]Esmail Mahmoodi, [2]Ali Jafari

[1*]Department of Mechanical Engineering in Agricultural Machinery, Agricultural Engineering and Technology Faculty, University of Tehran, Karaj, Iran
[2]Department of Mechanical Engineering in Agricultural Machinery, Agricultural Engineering and Technology Faculty, University of Tehran, Karaj, Iran

[*]Corresponding author: Esmahmoodi@ut.ac.ir

Abstract

Different tests were performed to measure parameters required for calculating power consumption and designing of cumin mowers. Hence, some engineering properties of cumin stems were measured. They included shearing and bending tests on cumin stem and specifying the coefficient of friction between mower knives and cumin stem. After that, relationships between static and dynamic friction forces being exerted on mower runners (soles) by soil with normal load on them and important factor of soil moisture content were found out. Harvest moisture content, maximum and average of cumin stem diameter, maximum bio-yield point of force and maximum ultimate point of force in the cutting, average needed energy to cut a stem, maximum elasticity module, maximum bending rupture force, average needed energy for bending a stem, friction coefficient between the stem and knife edge, relation between bio-yield force, failure force, elasticity and diameter in the cutting, relation between rupture forces and diameter in the bending and relations between soil friction draft forces and mower weight are some of the main measured and discussed parameters in this study that are important for calculating the power consumption and designing an optimized mower.

Key words: Design parameters; Cumin mower design; Cumin stem properties; Soil to runner friction; Power consumption.

Abbreviations: ACSD (mm)_Average of cumin stem diameter; D (mm)_Cumin stem diameter; E_c (kPa)_Cumin stem elasticity; F_b (N)_Rupture force in bending cumin stems; F_{Byp} (N)_Bio-yield point of force in cutting cumin stems; F_d (N)_Dynamically soil friction force; F_n (N)_Normal load (in relation with mower weight); F_p (N)_Failure point of force in cutting cumin stems; F_s (N)_Statically soil friction force; HMC (%, w. b.)_Harvest moisture content of cumin plant; L (mm)_Length of the cumin stem in the bending (distance from the support); MCSD (mm)_Maximum cumin stem diameter;

Introduction

The major goals of this study are to have engineering properties of cumin plant and soil to metal friction parameters in cumin farms that are most important parameters for calculating power consumption and consequently having an optimized design and construction in cumin mowers. Mowing forage is a highly energy consuming process compared to the other field activities after primary tillage (Srivastava et al., 2006). Chen et al. (2004) performed a research about power requirements of stem cutting and conditioning. They found that the maximum hemp cutting force requirement is 243 N and its energy requirement is 2.1 J. Some studies of cutting energy requirements have been conducted on soybean stalks (Mesquita and Hanna, 1995) and pyrethrum flowers (Khazaei et al., 2002). These researches showed that cutting energy is related to the maximum cutting force, stem shear strength, stem diameter, dry matter density and moisture content. Tavakoli et al. (2009) found that an increase in moisture content of straw lead to a decrease in the bending strength and Young's modulus and an increase in the shear strength and specific shearing energy in weight straw. Also, similar works have been conducted by Skubisz (2001) on rape stem and Skubisz (2002) on pea stem. Most studies on the engineering properties of plants have been carried out during their growth using failure criteria (force, stress and energy) or their Young's modulus and the modulus of rigidity. Studies have focused on plant anatomy, lodging processes, harvest optimization, animal nutrition, industrial applications and the decomposition of wheat straw in soil (Annoussamy et al., 2000; Skubisz et al., 2007). Types of both cutting knife and blade edge affect the cutting energy requirement. A serrated blade edge gives a higher cutting

Table 1. Equations representing relationships between the normal load and static and dynamic forces in four moisture content levels

Soil moisture content (%, w. b.)	Condition	Equation	R^2
2.48	Static	$F_s = 0.54F_n + 36.754$	0.970
	Dynamic	$F_d = 0.43F_n + 39.694$	0.912
5.13	Static	$F_s = 0.45F_n + 44.521$	0.948
	Dynamic	$F_d = 0.46F_n + 14.603$	0.961
12.67	Static	$F_s = 0.59F_n + 12.766$	0.981
	Dynamic	$F_d = 0.58F_n - 7.155$	0.899
17.02	Static	$F_s = 0.60F_n + 29.575$	0.966
	Dynamic	$F_d = 0.54F_n + 23.130$	0.933

force and requires more cutting energy than a smooth edge (Persson, 1987). Persson (1987) carried out some researches on the cutting speed and concluded that cutting power is only slightly affected by cutting speed, although an increase in cutting speed will often increase the power losses caused by material acceleration. Tensile strength of alfalfa stem was measured by Nazari et al. (2009) at different moisture content. They found which tensile strength increase exponentially with decrease in the moisture content and towards the lower regions of alfalfa stem. The physical properties of cellular material that are important in cutting are compression, tension, bending, density and friction. These properties depend on the species, variety, stalk diameter, maturity, moisture content and cellular structure (Bright and Kleis, 1964; Persson, 1987). These physical properties also vary along the plant stalk. It is also necessary to determine the physico-mechanical properties, such as the bending and shearing stress, and energy requirements for suitable knife designs to be developed and for operational parameters to be optimized (Ince et al., 2005). A lot of the researchers have focused on energy consumption during the cutting process of different crop plants and have collected invaluable information related to which help the mower manufactures remarkably. Stanfford and Tanner in 1977, 1983a and 1983b focused on internal soil and soil to metal frictions. They in 1977 confirmed the linear proportionality between frictional, τ, and normal stress, σ, when soil slides on mild steel. The angle of soil to metal friction, δ, derived from the Coulomb-type equation ($\tau = c_a + \sigma.\tan\delta$) where c□ is the soil adhesion, was shown to decrease with increasing speed that cased to decrease power consumption (Stanfford and Tanner, 1983b). Their studying results had important bearing on efficiency of soil working operations such as cultivation, earth moving and traction.

Materials and methods

For doing the cutting, bending and friction tests, some samples of the plant were collected at the beginning of June in 2005, because of suitable time to harvest in Iran farms. Having there specimen of 31 g and using an oven in 103 ºC for 24 h (ASAE, 2006) enabled us to calculate its harvest moisture content (HMC) 31.23 (%, w. b.). Plants must be mowed in suitable moisture content, namely HMC, to reach minimum harvesting wastes and cutting power consumption (Persson, 1987; Mansourirad, 2005). For this reason, the HMC was only used in fresh stem shearing, bending and friction tests of the cumin stems. Cutting and bending tests were done by an Instron Universal Testing Machine (Instron UTM/SMT-5, SANTAM Company, Tehran, Iran) showed in Fig.1. A 25 kgf strain gage Load cell (S shape) was installed on the device to have a suitable range in the cutting and bending of stems. Friction force between sand-clay soils plus cumin plant residues on the surface (common soil condition in cumin farms during harvest (Kouchaki, 2004)) and mower runners were measured by use of a 100 kgf dynamometer and a data acquisition system. Cutting test results is necessary to calculate the useful power consumption, bending test results is necessary to calculate a part of the draft force and consequently a part of the wasted power, stem friction test results is necessary to calculate ratio of mower knife speed to forward speed of mowers and obtain optimum oblique angle of the knives and runner friction test results is necessary to calculate the other part of the draft force and wasted power. Also, all of these parameters are needed to determine loads applied on mower parts and subsequently have mechanical analyses (Srivastava et al., 2006; Mahmoodi, 2008).

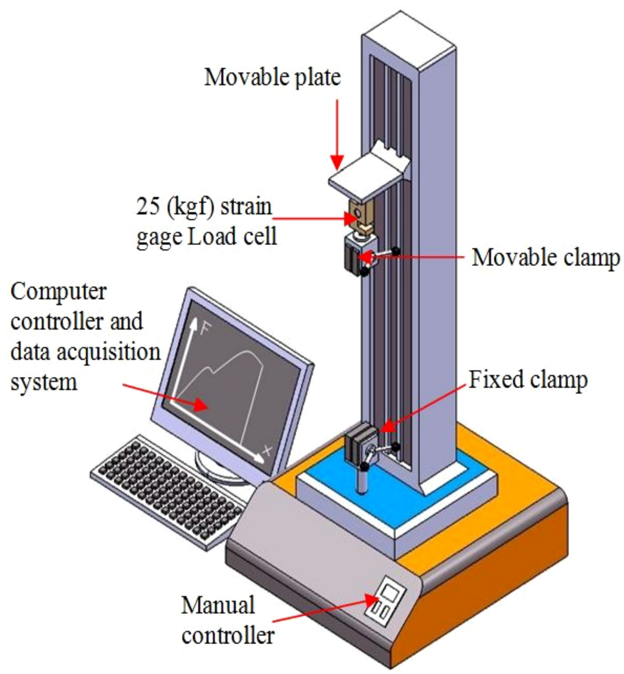

Fig1. Instron Universal Testing Machine (Instron UTM/ SMT-5, SANTAM Company, Tehran, Iran)

Table 2. Important parameters for designing and power consumption calculating of cumin mowers

	Parameter	Value	Unit	First condition	Second condition
1.	Harvest moisture content (HMC) of cumin plant	31.23	(%, w. b.)	---	---
2.	Maximum cumin stem diameter (MCSD)	2.1	(mm)	HMC	---
3.	Average of cumin stem diameter (ACSD)	1.48	(mm)	HMC	---
4.	Maximum bio-yield force in cutting of cumin stem	50.91	(N)	MCSD	HMC
5.	Maximum ultimate force in cutting of cumin stem	53.07	(N)	MCSD	HMC
6.	Maximum elasticity module of cumin stem	2323.03	(kPa)	MCSD	HMC
7.	Average energy required for cutting cumin stem	80.02	(mJ)	ACSD	HMC
8.	Maximum bending rupture force of cumin stem	3.24	(N)	Stem diameter: 2.1 (mm) & Distance from the support: 10 (mm)	HMC
9.	Average energy required for bending cumin stem	29.39	(mJ)	ACSD	HMC
10.	Friction coefficient between cumin stem and knife edge	0.19	---	HMC	---
11.	Relation between failure force and diameter in cutting cumin stem	$F_p = 47.90D - 46.232$ ($R^2 = 0.972$)	F: (N) D: (mm)	HMC	---
12.	Relation between bio-yield force and diameter in cutting cumin stem	$F_{Byp} = 49.18D - 50.873$ ($R^2 = 0.962$)	F: (N) D: (mm)	HMC	---
13.	Relation between elasticity and diameter in cutting cumin stem	$E_c = 2333.10D - 2178.2$ ($R^2 = 0.758$)	E: (kPa) D: (mm)	HMC	---
14.	Relation between rupture forces and diameter in bending cumin stem	$F_b = 0.3425e^{1.041D}$ ($R^2 = 0.954$)	F: (N) D: (mm)	L= 10 (mm)	HMC
15.		$F_b = 0.4933e^{0.725D}$ ($R^2 = 0.917$)	F: (N) D: (mm)	L= 20 (mm)	HMC
16.	Relation between soil friction draft forces and mower weight	$F_s = 0.54F_n + 36.75$ ($R^2 = 0.970$)	(N)	Statically on sand-clay soil plus cumin plant residues	MC: 2.48 (%, w. b.)
		$F_d = 0.43F_n + 39.69$ ($R^2 = 0.912$)	(N)	Dynamically on sand-clay soil plus cumin plant residues	MC: 2.48 (%, w. b.)

Cutting test

Schematic of the cutting test is shown in Fig.2a. The cumin stems were cut by two cutting knives made of case hardening steel (St37) and the results of force versus blade movements were recorded by Instron Universal Testing Machine at HMC, namely 31.2 (%, w. b.), and different stem diameter. The cutting speed was 50 mm/min to have a suitable data acquisition. During the cutting, because of oblique angle of the blades, the knife material and edge roughness, no slip was observed. Each stem level was described by measuring its mass (to the nearest 0.3-0.7 mg with 0.01 mg accuracy balance), its length (between 20-30 mm) and its diameter. Length and diameter of the stems were measured by a digital vernier caliper with 0.02 mm accuracy (Taka, Iran).

Bending test

Schematic of the bending test is shown in Fig.2b. Each of stems was constrained on one end as a cantilever and on the other end of stem, vertical force was exerted by a thin blade. Force-displacement diagrams were recorded by Instron Universal Testing Machine at HMC, different stem diameter and two distances of 10 and 20 mm (L in Fig.2b) from the support. The bending speed was 50 mm/min to have a suitable data acquisition.

Stem friction test

Two smooth blades having the same sharpness as the ones used in the tractor sidemounted reciprocating mowers were constructed and placed parallel to each other and perpendicular to the sloped plate as showed in Fig.3. Stems at HMC had been cut in the same lengths. In order to prevent the stems from rolling, their ends were clipped with aluminum foils. These foils were stretched and placed parallel to the blades to enable us to repeat the test again if the parallelism is disturbed. Eventually, the test got finished by five replications at HMC and the results were recorded.

Soil to runner friction test

Stanfford and Tanner in 1983b found which interaction of cultivation implements, rollers, tracks and earth moving equipment with soil inevitably involves a soil to metal

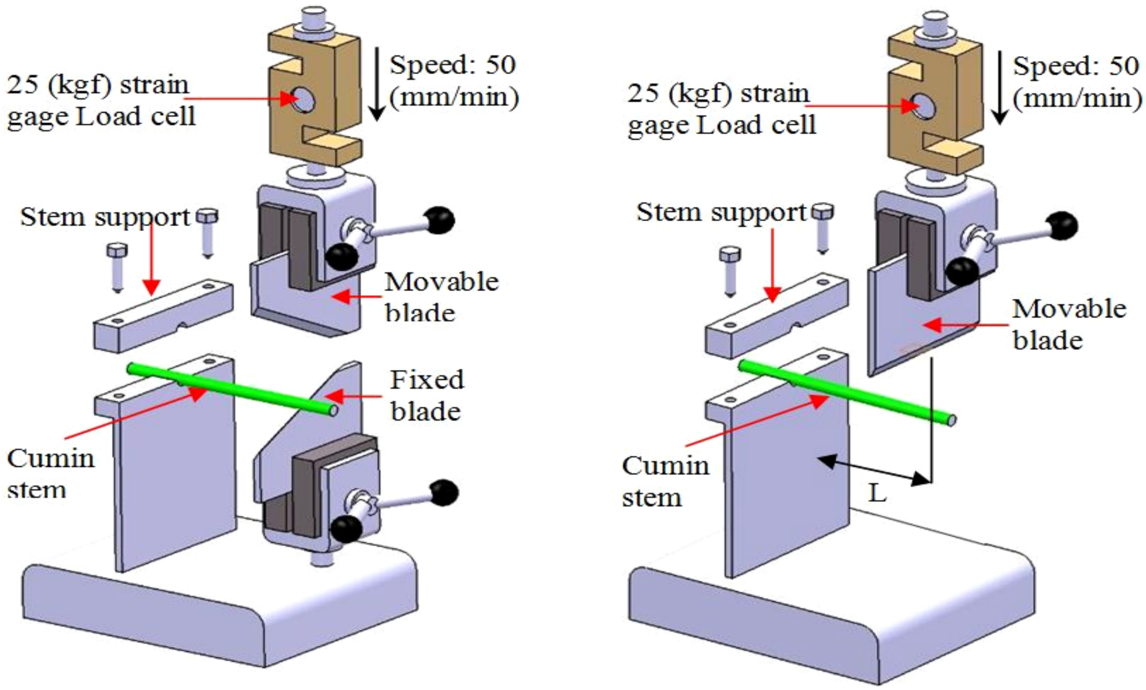

Fig 2. Schematic of cutting (a) and bending (b) tests of cumin stem.

friction component. Most of agricultural mowers also have this component because of soil to metal contact during harvest. It is clear that during the crop harvesting, whenever the floating spring is adjusted well, the mower runners will be in good (minimum) contact with soil. As a result, the friction is appeared which brings about tension in mower parts and resists its forward movement. Hence, the friction test was performed. For this aim, four plots of sand-clay soil plus cumin plant residues on the surface with different moisture contents were prepared. The first plot got prepared in a way similar to the real conditions of the cumin farms during harvest (2.48 (%, w. b.)), the second, third and fourth plots had 5.13, 12.67 and 17.02 (%, w. b.) moisture contents respectively. To specify the friction forces between soil and runner surface, the proposed method of Srivastava et al. (2006) was followed. In each plot, different normal loads (F_n) were applied onto the metallic surface, runners in Fig.4, force needed to initiate the movement of the runner was determined as the static friction force (F_s), and in a similar manner, the force while runner kept moving was recorded as the dynamic friction force (F_d). Two runners were constructed as the ones used in the tractor sidemounted reciprocating mowers and were connected to each other. For measuring the forces, a dynamometer having a 100 kgf measuring range was used as showed in Fig.4. Replication for each normal load was three and average of them was recorded for static and dynamic friction forces in all plots, namely 2.48, 5.13, 12.67 and 17.02 (%, w. b.) soil moisture contents.

Results and discussions

After accomplishing the cutting, bending and stem friction on cumin plant and also friction between mower's runners and soil tests, the results were brought in statistical analyses. The analyses were focused on data collection needed for power consumption calculating and designing in cumin mowers.

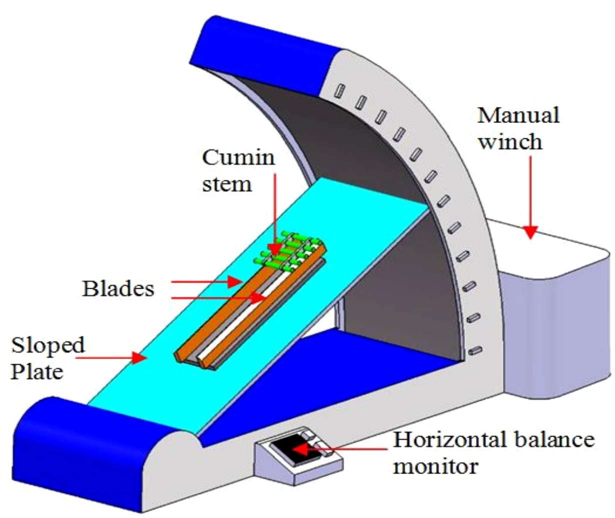

Fig 3. Instrument to determine the friction between blade and cumin stem at harvest moisture content with 1° degree accuracy

Analysis of cutting test

Fig.5 shows shape of the force-displacement curve when cumin stem is cut by the knife and counter shear. In section A, only compression occurs as the knife edge force is not

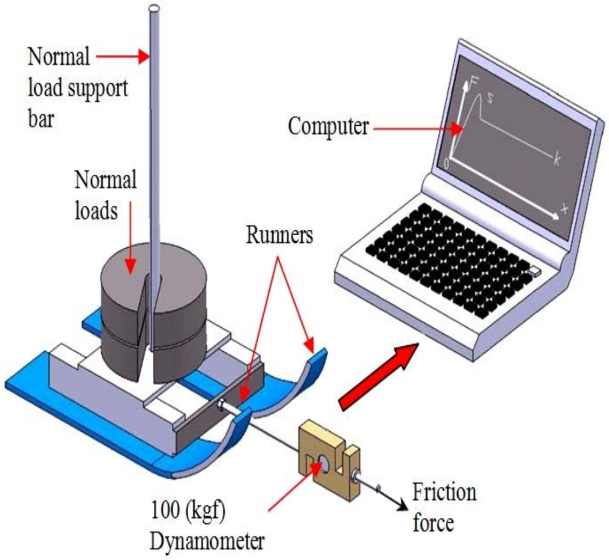

Fig 4. Data acquisition system for determining friction forces between mower runner and sand-clay soils plus cumin plant residues on the surface.

yet high enough to cause shearing. After initial stem failure, namely bio-yield point, some compression continues in section B along with shearing. In section C, the material is fully compressed, shearing continues and then the force drops rapidly as the knife edge crosses the edge of the counter shear.

Energy consumption in sections A, B, C and total energy require to cut a cumin stem were calculated 29.33, 37.60, 13.27 and 80.20 mJ at HMC and average cumin stem diameter (ACSD) respectively. Chen et al. (2004) found that required energy for hemp cutting was 2.1 J that is remarkably more amount than 80.20 mJ for cumin stem cutting, here. Nazari et al. (2008) found that maximum cutting energy for lower section of alfalfa stem is 345.80 mJ that is 4.3 times cumin stem cutting energy in the same section. Also energy consumption in section B (Fig.5) has the most value, namely 46.88 percent of total, due to have both shear and compression simultaneously. And also, energy consumption in section C has the least value, namely 16.55 percent of total, due to have only shear. With comparing energy consumption in sections A and C, it was found that if cutting the cumin stems occurs by shear solely, the energy consumption in the harvesting will decrease significantly. This will be achieved by using the most sharpen knives and counter shears, decreasing clearance between them and increasing the cutting speed (Persson, 1987; Mahmoodi, 2008). Fig.6 shows bio-yield and failure points of force in cutting of cumin stem having different diameters at HMC. As shown, increase of diameter leads to increased bio-yield point of force (Byp: first peak in Fig.5) and failure (ultimate) point of force (Fp: second peak in Fig.5) with slopes 49.18 and 47.90 respectively. This is for increasing lignin tissues in the ones stems which have higher diameter (Bright and Kleis, 1964; Persson, 1987; Srivastava et al., 2006). Thus, the larger stem diameter, the higher cutting forces and the more power consumption in cumin mowers. Also, as shown in Fig.7, increase of stem diameter leads to increase modulus of elasticity with slope 2333.1 and $R^2 = 0.76$. This represents that stem fragility has an increasing trend as a result of diameter addition. This claim is also approved by the results of stem tissue mechanical properties (Persson, 1987; Srivastava et al., 2006). But some studies have shown that, on the contrary, when alfalfa stem diameter is increased the elastic modulus is reduced (Nazari et al., 2008). It is probably for difference between biological properties of alfalfa tissue and the others plant as cumin stem.

Analysis of bending test

With respect to Fig.8, that has been recorded from the bending test, contrary to cutting curve that was smooth, some fluctuations are observed. They are probably for tearing the stem fiber strings as the stem is bent. Also total consumption energy in bending a stem was calculated 29.39 mJ at HMC and ACSD that is one third of total consumption energy in cutting. Therefore, it can be said that energy consumption in the cutting is three times more than the bending of stems in cumin mowers. In Fig.9, the other results of bending test for cumin stems at HMC, different diameters and two lengths of specimen of 10 and 20 mm from the support are displayed. As it is observed, the rupture force (showed in Fig.9) has an exponentially increasing trend in both 10 and 20 mm of length. Also, Nazari et al. (2008) in their study found that increasing of alfalfa stem diameter case to increase the bending force and decrease the bending strength. Therefore, because the rupture force is also used to calculate the draft force and power consumption, harvesting from lower height leads to increase both the power consumption and draft force.
Therefore, the lower harvesting height, the larger stem diameter, the higher draft force of stem bending resistance and the more power consumption.

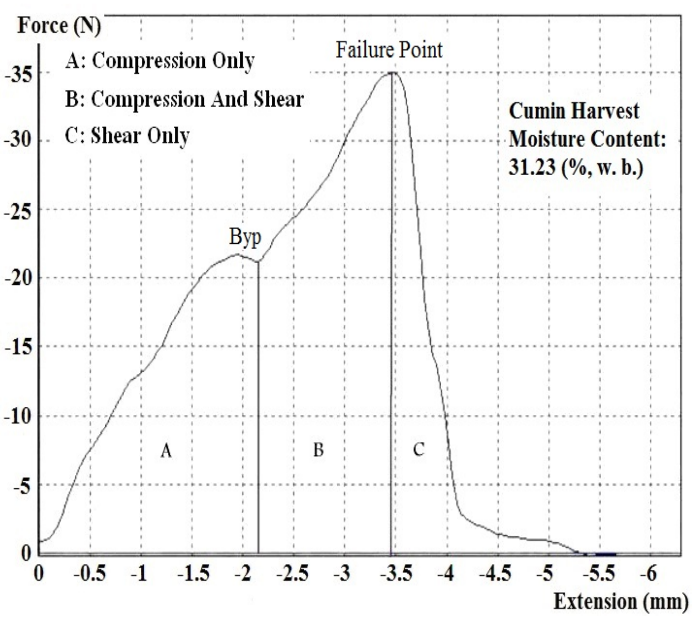

Fig 5. A curve of cumin stem shearing test recorded by Instron Universal Testing Machine at HMC

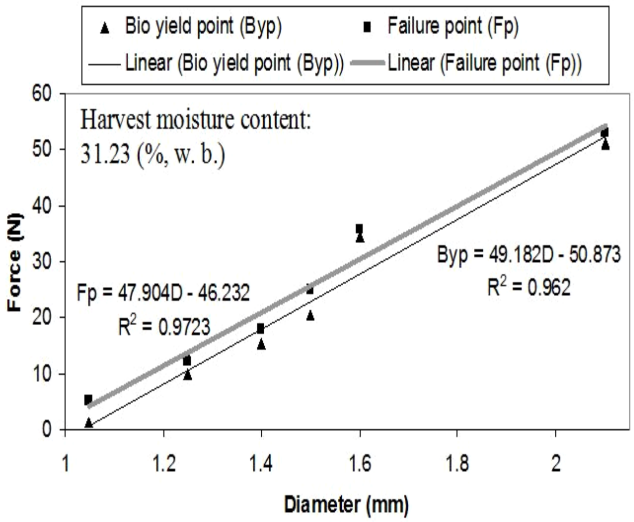

Fig 6. Relation between bio-yield and failure points of force with diameter of cumin stem at HMC

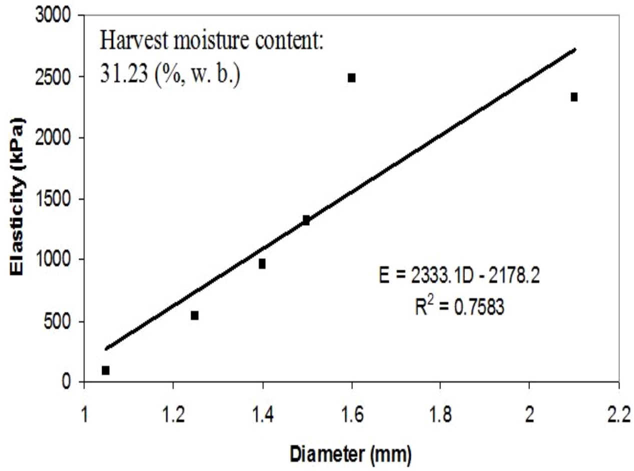

Fig 7. Relation between elasticity module and diameter of cumin stem at HMC

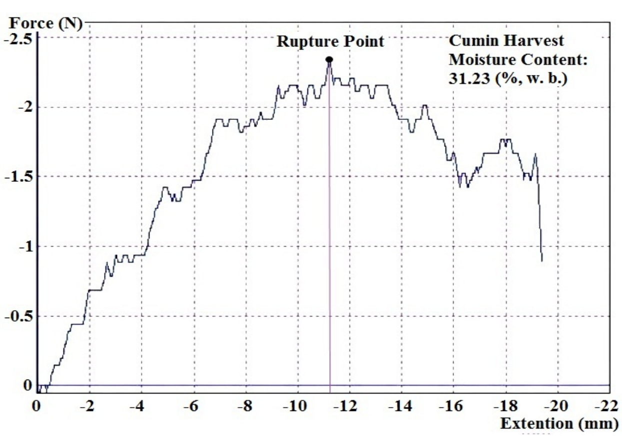

Fig 8. A curve of cumin stem bending test recorded by Instron Universal Testing Machine at HMC

Stem friction coefficient

Result of friction test showed which cumin stems at HMC starts to slip on the edge surface when it is inclined with angle of 23.7 degree, regarding the standard variation of 0.97, which brings 0.19 for the coefficient of friction. By use of this, Mahmoodi (2008) found that if range of knife speed to forward speed ratio in cumin mowers is between 0.879 and 44.053 $m.s^{-1}$, the stem will be cut with no slipping on the edge.

Runner friction force

Table.1 shows equations representing relationship between the normal load on the runners and static and dynamic friction force in four soil moisture content levels plus cumin plant residues on the surface. If they are plotted in each soil moisture contents separately (static and dynamic force equations in each treatment together as a chart), it can be seen that the regression line of static friction force will always place upper than that dynamic friction force in all of soil moisture content levels. It shows that the maximum soil resistance draft force and consequently its power consumption are in the beginning of movement. The regression lines represented acceptable correlations between normal load and friction force ($0.899 < R^2 < 0.970$). It suffices to specify the moisture condition of sand-clay soil farm plus plant residues on the surface and machine weight (normal load) and consequently determine the one part of the draft force of the mower using the achieved formula.
Fig.10 and Fig.11 represents the relationship between friction force and soil moisture content plus cumin plant residues on the surface for static and dynamic modes respectively. As can be seen in both Figures, with increasing vertical load, the amount of the friction force has also been increased. Also with more carefully in Fig.10 and 11, it can be seen that increasing the vertical force in both static and dynamic modes case to more friction force dependence on soil moisture variation. It is also observed that increasing the soil moisture leads to an ascending trend of friction force that is more possibly attributed to the contact area and adhesiveness increases between soil and runner sole in higher normal loads. Thus, the lower mower weight and soil moisture content, the lower soil resistance draft force and the lower wasted power. Stanfford and Tanner in 1983a found which the soil internal friction angle was independent of deformation rate and the residual shear strength did not vary in a consistent manner with deformation rate. In their research in 1983b, they also found which Soil to metal friction angle affects the direction and magnitude of vertical forces as well as the magnitude of draft forces.. But they didn't present application formulas and discussion about them focused on implement consuming power calculation and designation.

Conclusions

In this study, in order to calculate consuming power and design of cumin mowers, some tests have been accomplished. In some cases, manufacturers fabricate sim

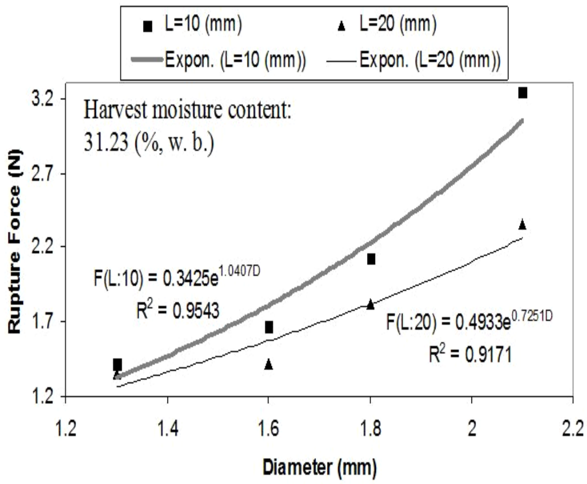

Fig 9. Relations between bending rupture force and diameter of cumin stem at HMC

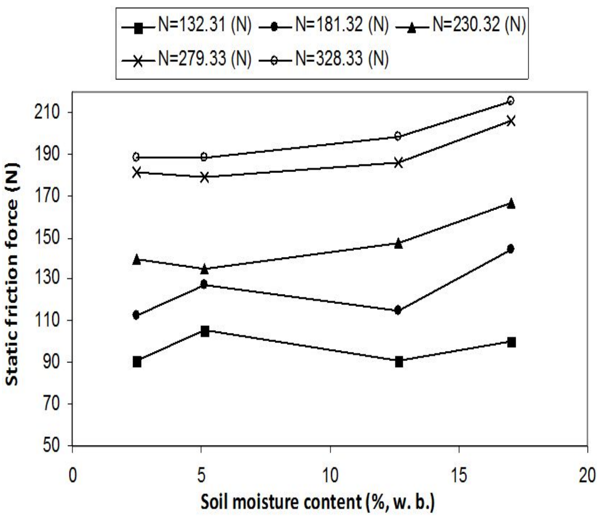

Fig 10. Relations between static friction force and soil moisture content (with plant residues on the soil surface) in five normal loads

ilar machine without doing enough related basic research which lead to increase manufacturing, maintenance etcetera costs. We should pay attention that cumin mower is under study and it is not marketable yet. Then results of present research can be useful for this purpose. Table.2 is a summary of main measured parameters for designing and power consumption calculating of cumin mowers.

2. The lower harvesting height, the larger diameter of cumin stems, the higher cutting forces, the higher bending forces, the higher modulus of elasticity and the more power consumption.
3. It is found that as the normal load on mower's runner increases, the friction force in result is more dependent to moisture variation.
4. It is also observed that soil moisture content increase leads to an ascending trend of friction forces. Hence, the lower soil moisture contents, the lower soil to metal friction forces, the lower mower draft force, and the lower power consumption.

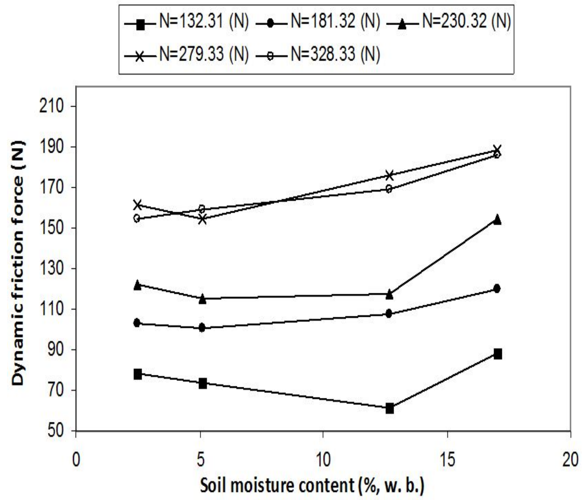

Fig 11. Relations between dynamic friction force and soil moisture content (with plant residues on the soil surface) in five normal loads

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