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THE CHANGE OF SHEAR FORCE AND ENERGY OF COTTON STALK DEPEND ON KNIFE TYPE AND SHEAR ANGLE

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Abstract

The shear force and energy values of biological materials are very important data for suitable design of a cutting and pruning machines and related equipment. The objective of this study was to determine shearing force and shearing energy of cotton (Gossypium hirsutum L.) stalk at different shoots diameter as a function of knife type and knife edge angle. Dependent variables were maximum cutting force and cutting energy. The samples were obtained from the cotton experimental field at vegetation season for each plot. A universal test machine was used to measure the cutting force and the energy. The cutting energy was calculated by measuring the surface area under the cutting force-deformation curve. As a result, the main effect of the knife edge angle on the cutting force and energy were found significant. The best and minimal results were determined at serrated 2 knife types to be 69.61 N and 25.61 N cm, respectively, followed by the serrated 1 and flat knife. The highest values were observed at flat knife type. Nevertheless, the cutting force and cutting energy increased with an increase in the knife edge angle from 50° to 90°. The maximum values were obtained at 90° both cutting force and cutting energy. At this angle, while the maximum cutting force and cutting energy were determined to be 93.18 N and 31.60 N cm, respectively. The main minimum values were obtained at 50° angle. Cutting force and energy values of cotton stalk were found highly correlated with the stalk diameter. Cutting force and energy increased with increase diameter of stalk. The maximum cutting force and cutting energy were obtained at 29.20 mm^2 cross-sectional area as 102.30 N and 41.97 Ncm, respectively, while the minimum values of cutting force and cutting energy were obtained at 13.84 mm^2 cross-sectional area as 47.28 N and 16.76 N cm, respectively.

Key words: *cotton, stalk, shearing force, cutting properties, design.*

INTRODUCTION

Cotton is a major raw material for textile sector in worldwide and produced several countries. One of the important countries in terms of the magnitude of total cotton production is Turkeys and it is Europe's largest textile manufacturer and ranks seventh in the world cotton production. In Turkey, Cotton is cultivated primarily in the Aegean Region, Çukurova Basin and Southeast Anatolia Region. With GAP (Southeastern Anatolian Project) irrigation project in Turkey, the irrigated farmland and cotton production in Southeast Anatolia region has developed rapidly since 2000 year. That is, cotton production area was shift Aegean and Çukurova region to Southeastern Anatolia region and two decades and nowadays, more than half of the national cotton production is produces in Southeastern Anatolia region (Sessiz et al. 2009). The increase in cotton production has increased provided the development of the cotton industry (Sessiz, Esgici, 2015a). Therefore, this has a strategic importance for the region. GAP covered in Diyarbakır, Şanlıurfa, Mardin and Batman as agricultural areas with more as well as the producers of the region opportunities for irrigation on the GAP in the provinces of through boreholes have opened their own facilities, irrigated farmland has increased significantly. With water, a significant increase in the area of cotton production has occurred. This increase, today more than half of Turkey's cotton production is covered by the South-Eastern Anatolia. GAP region produces 61.5 % of Turkey's total cotton production area in the 2015 (TUIK, 2015). This has led to the development of industries based on cotton in the region. This production ratio in region is important for region's development, human resources development and rural development. Therefore, increasing cotton production and yield, reducing of cotton losses and protection of fiber quality are very important for sustainability of the production in Diyarbakır province.

Cotton production requires large-scale mechanization, from the operation of soil tillage to harvesting stage. In addition to conventional operations, cotton topping is another cultural practice that should be done during the vegetation period (Aydin, Arslan, 2018). Therefore, the production cost is quite high depending on cultural application during the production season. Especially, the cotton production costs are considerably high in harvesting and cutting of plant topping section. It has been reported by cotton producers that the cutting of cotton plant topping operation is directly related to the yield and reduces bollworm infestations without negatively affecting cotton yields. The similar results were reported by Obasi and Msaakpa (2005), Yang et al. (2008), Renou et al. (2011) and Aydin and Arslan (2018). According to these researchers, the cutting of top section of cotton plants increases the yield and quality of cotton and improves the earliness, limiting the vegetative growth of the plant and improving the development of generative organs of the cotton plants. To reduce of input operation costs, we need use of mechanical equipment.

To design a new harvester, the first step is to measure the cutting force and cutting energy. Several studies have been carried out to determine these parameters for cotton stems considering various cutting knife edge angles. In general, the cutting knife of a harvesting machine cuts the plant material and separates it into different parts by external force. Knife edge angle, knife approach angle, shear angle, and knife rake angle are the most important knife angles that can directly influence the cutting force and energy (Ghahraei et al., 2011). Why we conducted this study, because the cotton is one of important product for both our country and several countries in the world. However, cotton topping is done by worker during the vegetation period. To reduce production cost and increase yield, we have to use suitable cutting machine. So, firstly, we must determine cutting properties of cotton stalk.

The objectives of this study were to determine the optimum the knife type and knife edge angles that use the lowest cutting force and energy to be used in the design and to fabricate of the cotton stalk cutting machine and then the test it in the field conditions. For this purpose, cutting tests were carried out at 5 cm intervals from the top of the plant and cutting force and cutting energy were determined during the vegetation period.

MATERIALS AND METHODS

The field experiment was conducted at a commercial farm in 2017 during the growing season at the Bismil district, Diyarbakır province (latitude 37°53′N and longitude 40°16′E, 680 m altitude), Southeast part of Turkey, where cotton production is intensively done. The BA-440 cotton cultivar was planted on 12 April in 2017 by a pneumatic planter. A randomized complete block design with five replications was used in this study. Experimental field consisted of 18 plots with each measuring 15 m x 5 m with an inter row spacing of 0.7 m distance. The same agricultural practices were applied in all the plots during the growing season. The some mean values of these measurements are given in Table 1.

Table 1. The some properties of cotton plant

Properties	Mean values
Plant height, cm	92.00
Boll number on the plant, number	16.70
Number of branch on one the plant	14.00
Average yield (kg/da)	596.80

To determine the cutting tests of cotton stalks, the cotton plants were, randomly selected five different locations on the experimental field, uprooted in December 2017 from soil surface and then transported to the laboratory for cutting tests. Then, the leaves were removed from the plants in the laboratory (Figure 1). Prior to the tests, the stalks were cutted into four different groups according to diameters (Figure 1) and heights, namely at 0-10 cm (first internode, IN1), 11-15 cm (second internode, IN2), 16-20 cm (third internode, IN3) and 21-20 cm (fourth internode, IN4) from the top of cotton plants toward bottom. The cutting properties include the cutting force and cutting energy was determined along the stem from first internode to fourth internode.

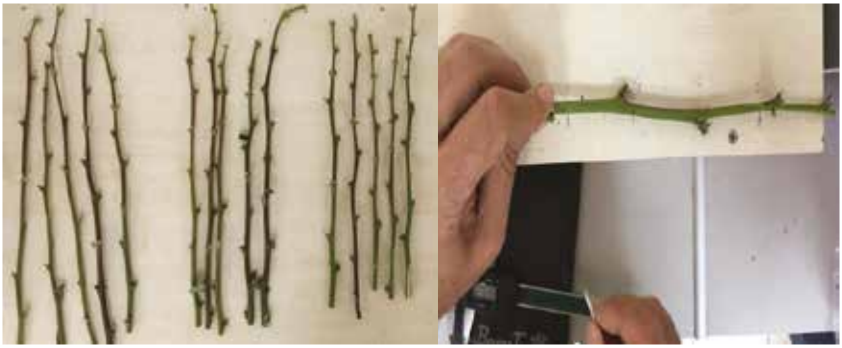

Figure 1. The cotton stalk and samples

The diameter of the cotton stalk (stem) decreases from the roots toward the shoots at the top of plants. Therefore, the average diameter of the stalk has changed between 4.00 mm-8.00 mm. According to height, the average diameters were considered as 4.2, 4.8, 5.4 and 6.10 mm in this study. The ranges of diameter of the stem were converted to cross-section area in mm^2 (13.84, 18.06, 22.89 and 29.20 mm^2). The stem diameters were measured before the test using a caliper with five replications at about the cutting point near the node section of an each test specimen. Testing was completed as rapidly as possible in order to reduce the effects of drying. The moisture content of each sample was determined according to ASABE standard method (ASABE Standards, 2008) by oven-drying 50 g of each sample at 105°C for 24 h before the cutting tests. The average moisture content was determined as 50.20% during the cutting tests.

The Universal Testing Machine (Lloyd LRX Plus) was used to determine the cutting force and the cutting energy of cotton stalks (Figure 2). Cutting experiments were carried out with three various knife types (Figure 2), two of them are serrated type, Serrated 1 (knife-edge thick), Serrated 2 (knife-edge thin), and Flat (knife-edge flat) with five knife edge angles (50°, 60°, 70°, 80° and 90°) and four different stalk diameters (4.20 mm, 4.8 mm, 5.40 mm and 6.10 mm). To determine the cutting force, cutting energy, and displacement, the knife was held and fixed to the crosshead of an universal testing machine (Figure 2). The maximum cutting speed of the machine, 3 mm s^{-1}, was used for all tests.

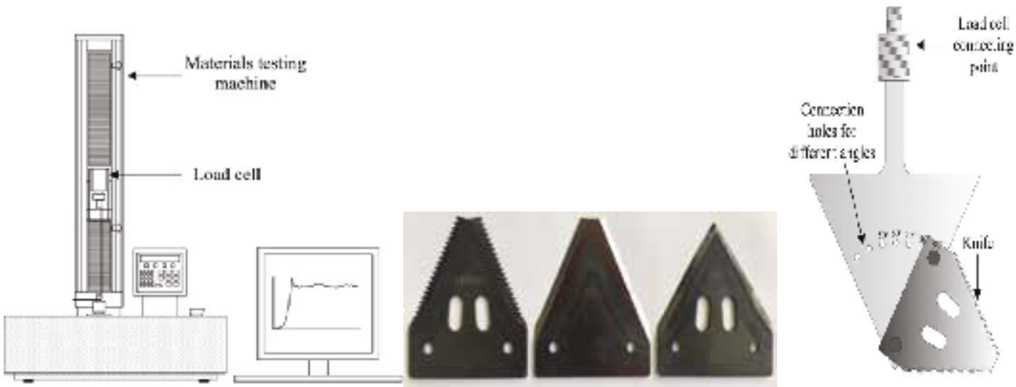

Figure 2. Materials testing machine and different cutting knives with edge angles.

The cutting force and cutting energy were determined as the maximum force and the maximum energy depend on type of knife, angle of knife-edge and stalk diameters. The cutting energy was calculated by measuring the surface area under the cutting force-deformation curve (Mohsenin., 1986; Persson, 1987; Yore et al., 2002; Kocabiyik, Kayisoglu, 2004; Chen et al., 2004; Taghijarah et al.,2011; Ghahraei et al., 2011; Sessiz et al., 2013; Sessiz et al., 2015b; Ozdemir et al., 2015; Nowakowski, 2016; Öztürk et al., 2017) with the force and displacement data by using a NEXYGEN computer program. A computer data acquisition system recorded all the force-displacement curves during the cutting process by testing machine. A typical force-deformation is given in Figure 3. As you seen in Figure 3, the first peak corresponds to the yield point (offset yield) at which stalk damage was initiated. The second peak (upper yield) corresponds to maximum force (Figure 3).

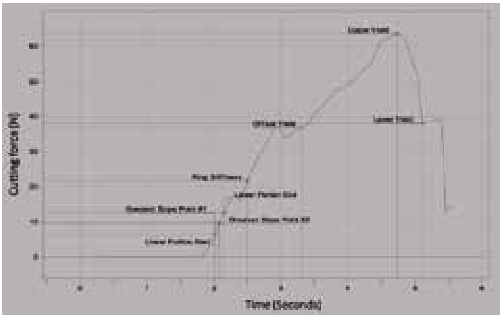

Figure 3. Typical force-deformation curve for cutting of cotton stalk

An analysis of variance (ANOVA) of the three factor randomized complete block design with five replications was performed to detect significant differences in the observations due to the effect of knife type, knife edge angle and stalk diameter of each factor using the MSTATC software. Means were compared at the 1% level of significance using Duncan's multiple range tests to identify the specific differences among treatments means.

RESULTS AND DISCUSSIONS

The effect of Knife type

The effect of knife type on cutting force and cutting energy are given in Table 2. Duncan test showed that there were significant differences among the three knife types ($p<0.01$) on cutting force and cutting energy. The results of the analysis of variance and Duncan's test also showed that the main effect of knife type, blade angle and cross-section area (stem diameter), and their interactions were found significant ($p<0.01$). The lowest and best results were determined at serrated 2 knife type as 69.61 N and 25.61 N cm, respectively, followed by the serrated 1 and flat knife. The highest cutting force values were observed at flat knife type as 78.31 N. However, there were not found significant differences between serrated 1 knife type and flat knife according to cutting energy. According these results, flat-edge knife type is not suitable, when compared to serrated knife types and we can recommend that the serrated type knife for a new design of cutting machine and pruning for cotton shoots topping.

Table 2. Analysis of variance of the cutting force and cutting energy with respect to knife type*

Knife type	Cutting force (N)	Energy (N cm)
Serrated type 1 (knife-edge thick)	73.30^{b}	29.03^{a}
Serrated type 2 (knife-edge thin)	69.61^{c}	25.61^{b}
Flat type (knife-edge flat)	78.31^{a}	29.51^{a}
Mean	73.74	28.05
LSD	2.326	1.485

*Means followed by the same letter in each column are not significantly different by Duncan's multiple range tests at the 1% level.

The Effect of Knife Edge Angle

The results of the analysis of variance of the cutting force and energy depending on different knife edge angle are shown in table 3. The main effect of the knife edge angle on the cutting force and energy were found significant. Moreover, reducing the knife edge angle led to a decrease in the cutting force and cutting energy (Ghahraei et al., 2011). The cutting force and cutting energy increased with an increase in the knife edge angle from 50° to 90°. Table 3 shows the results of the comparison among means of the cutting force and cutting energy. Also, according to results of variance analysis, the effect of interactions were found significant ($p<0.01$) on cutting force and cutting energy. There were found significant differences among from 50° to 70°. However, there was no significant difference among means for 70°, 80°, and 90° at the probability level of 1% and 5%. Nevertheless, cutting force and cutting energy gradually increased with increase knife-edge angle. A maximum cutting force and cutting energy of 93.8 N and 31.60 N cm were obtained with 90° edge angles, respectively. The main values were obtained at 50° angle as 59.38 N and 26.32 N cm, respectively. The similar results were observed by Kronbergs et al. (2011), they were noticed that the significant material deformation for the cutting knives with bevel angle 90º during the experiments. They argued that cutting energy depends on the material deformation process and friction forces. This situation is causes significant cutting energy increasing. According they results, the suitable knives bevel angle is change between 25° and 45°.The decrease of cutting force and cutting energy depend on knife edge angle allows proper design of the cutting unit and cutting machine for cotton stalk of top section and predicting the power requirements (Nowakowski, 2016; Ozdemir et al., 2015; Esgici et al., 2017). Prasad and Gupta (1975) reported that the optimum knife bevel angle value for cutting of corn stalk was 23°. According to Suryanto et al. (2009), the knife edge angle has an significant effect on the cutting force and energy. Dowgiallo (2005) also reported that besides the cutting edge, knife edge sharpness and knife speed are effect on cutting properties. Based on our results, a preferred knife edge angle of 50° for cutting the top of cotton stalk is recommended. We will consider these results for a new design and construct a prototype cutting machine for cotton stalk of topping in future.

Table 3. Analysis of variance of the cutting force and cutting energy with respect to knife edge angle*

Knife cutting angle (°)	**Cutting force (N)**	**Energy (N cm)**
90	93.18^{a}	31.60^{a}
80	78.05^{b}	28.65^{b}
70	72.78^{c}	26.72^{c}
60	65.30^{d}	26.92^{c}
50	59.38^{e}	26.32^{c}
Mean	73.73	28.04
LSD	3.003	1.329

*Means followed by the same letter in each column are not significantly different by Duncan's multiple range tests at the 1% level.

The relationship between the cross-sectional area with the cutting force and cutting energy are shown in table 4. The results of variance analysis showed that the independent parameters and their interactions has significant effect on cutting force and cutting energy. The significant differences were found between all of cross-sectional areas at a 1% probability level. There is high correlation between cutting energy and diameter. The cutting force and cutting energy increased with increase cross-sectional area. The maximum cutting force and cutting energy were obtained at 29.20 mm^2 cross-sectional area as 102.30 N and 41.97 N cm, respectively, while the minimum values of cutting force and cutting energy were obtained at 13.84 mm^2 cross-sectional area as 47.28 N and 16.76 N cm, respectively (Table 4). This information is very valuable for selecting a suitable equipment design for reduces energy requirement and consumption. Because, the selection of suitable cutting apparatuses and equipment are plays an important role in economizing on cutting force and energy requirement (Sessiz et al., 2013). This effect is in agreement with a previous study on maize stalks, in which both the cutting energy and maximum cutting force were directly proportional to cross-sectional area (Prasad, Gupta, 1975; Sessiz, 2005). The effect of stem diameter on the maximum cutting force and cutting energy is consistent with Chen et al. (2004), who reported that both the cutting energy and maximum cutting force are directly proportional to the cross-sectional area of hemp stalk. The results have shown that the cutting strength and cutting energy related to plant physical and mechanical properties (Igathinathane et al., 2010). Similar results were reported by Yore et al. (2002) for rice straw, by Kronsberg et al. (2011) for hemp stalk, by Alizadeh et al. (2011) for rice stem, and by Ghahraei et al. (2011) for kenaf stems, by Sessiz et al. (2013) for olive sucker, by Ozdemir et al. (2015) for grape sucker, by Sessiz et al. (2015b) for cane of some different grape variety, Öztürk et al. (2017) for soybean stem. These results also are in agreement with Aydin and Arslan (2018) who determined shearing force and energy for shoot of cotton plant at different height of plant. Proper equipment design to accomplish the cutting will maintain the quality of the harvested product while minimizing the force and energy needed to accomplish the task (Srivastava et al., 2006). Based on the results from this study, for cutting of cotton stalk, lower cotton shoots diameter, lower knife edge angle and serrated knife type can be recommended to minimize the shearing force and shearing energy requirements.

Table 4. The relationship between cutting properties and cross-sectional area of cotton stalk*

Cross-sectional area (mm^2)	Cutting force (N)	Energy (N cm)
13.84	47.28[d]	16.76[d]
18.06	64.69[c]	23.15[c]
22.89	80.73[b]	30.32[b]
29.20	102.30[a]	41.97[a]
Mean	73.75	28.05
LSD	5.201	1.329

*Means followed by the same letter in each column are not significantly different by Duncan's multiple range test at the 1% level.

CONCLUSIONS

The results of the analysis of variance and Duncan's tests also showed that the main effect of knife type, blade angle and cross-section area (stem diameter), and their interactions were found significant on cutting force and cutting energy ($p<0.01$). The lowest and best results were determined at serrated 2 knife type as 69.61 N and 25.61 N cm, respectively, followed by the serrated 1 and flat knife. The highest values were observed at flat knife type. The cutting force and cutting energy increased with an increase in the knife edge angle from 50° to 90°. A maximum cutting force and cutting energy of 93.8 N and 31.60 N cm were obtained with 90° edge angles, respectively. The maximum cutting force and cutting energy were obtained at 29.20 mm^2 cross-sectional area as 102.30 N and 41.97 N cm, respectively, while the minimum values of cutting force and cutting energy were obtained at 13.84 mm^2 cross-sectional area as 47.28 N and 16.76 N cm, respectively. This information is very valuable for selecting a suitable equipment design for reduces energy requirement and consumption. Based on our results, a preferred knife edge angle of 50° for cutting the top of cotton stalk is recommended. We will consider these results for a new design and construct a prototype cutting machine for cotton stalk of topping.

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