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Measuring Some Mechanical Properties of Boxwood and Privet Plants by an Izod Impact Tester

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INFO

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ABSTRACT

The information of the impact cutting behavior of plants stalk, play an important role in the design and fabrication of plants cutting equipment. It is difficult to investigate a theoretical method to define cutting properties of plants stalks because the cutting process is complex. Thus, it is necessary to set up an experimental approach to determine cutting parameters for a single stalk. To measure the shear force, shear energy and shear strength of plant stalk, a special impact cutting tester was fabricated. The apparatus included four strain gages and a digital indicator to show the real-time cutting force and requirement cutting energy of plant stalk. To test the apparatus, a series of laboratory tests were conducted to measure the shear force, shear consumption energy and shear strength of stem internodes of two plants stalk like boxwood or box with a scientific name of Buxus (Buxus Sp) and privet with a scientific name of Ligustrum Ovalifolium (Oleaceae Sp) under impact cutting at four loading rates (1, 2, 3 and 4 m/s) and three internodes of stalk (fifth, tenth and fifteenth). At boxwood cutting analysis: the minimum and maximum values of shear consumption energy were obtained as 3.19 J at fifth internode and loading rate: 4 m/s and 19.6 J at fifteenth internode and loading rate: 1 m/s, respectively. The minimum and maximum values of shear strength were obtained as 0.06 MPa at fifth internode and loading rate: 4 m/s and 1.55 MPa at fifteenth internode and loading rate: 1 m/s, respectively. At privet cutting analysis: the minimum and maximum values of shear consumption energy were obtained as 3.95 J at fifth internode and loading rate: 4 m/s and 28.56 J at fifteenth internode and loading rate: 1 m/s, respectively. The minimum and maximum values of shear strength were obtained as 0.2 MPa at fifth internode and loading rate: 4 m/s and 2.50 MPa at fifteenth internode and loading rate: 1 m/s, respectively.

INTRODUCTION

The information of the impact cutting properties of plants stalk, like shear force, shear consumption energy, and resistance to stem cutting, are necessary to design and fabrication of proper trimmer equipment. In recent years, several researches have been conducted to determine the quasi-static cutting properties of some plants stem like barley, wheat, alfalfa, forge crops, safflower, sunflower etc. Unfortunately, it seems that there is not any published work relating to the determination of impact cutting properties of plants stem. In practice and real cutting, the cutting of plants stalk is not a quasi-static cutting but it is a dynamic process.

The impact cutting process by a rapidly moving cutting blade, is similar to dynamic process and in impact cutting, with increasing loading rate, the primary compression of outer layer was decreased as a result's inertia and plastic behavior of plant stalk material and the shear consumption energy decreased (Sitkei, 1986). The stem cutting like some of agricultural applications is very slowly, repetitive and occasionally dangerous for labors and current trimmer machines are not suitable and accountable. Nowadays, most operators are exposed to the unpleasant and dangerous arms and body vibration and sound of the plant stem trimmer machines. To reduction of dangerous effects of vibration on operator's arms and for increasing the speed and quality of plant cutting, the design and fabricate of proper trimmer equipment is necessary. Thus, by determining the mechanical properties of plants stalk such as shear force, shear consumption energy and stem resistance to cutting, a suitable cutting machine can be designed. Therefore, the objective of this study was to introduce the new method to measurement of impact cutting behavior of plants stalk.

Yiljep and Mohammed reported the high correlation between knife velocity, cutting energy requirement and cutting efficiency. Also they estimated the minimum cutting energy requirements for 20 and 120 mm stalk cutting height, 7.87 and 12.55 N.m respectively, at corresponding knife velocities of 2.91 and 3.54 m/s (Yiljep and Mohammed, 2005). Tabatabaee and Borgheie studied shear cutting of

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four rice variety and stated that the dynamic shearing strength decreased from 234.4 to 137.4 KPa with an increase in blade cutting angle speed from 0.6 to 1.5 m/s (Tabatabaee Koloor and Borgheie, 2006). Taghijarah et al. found that loading rate had a significant effect on the shear strength and specific shearing energy of the stalk and reported with increasing loading rate, the shear strength and specific shearing energy was increased (Taghijarah *et al.*, 2011). Dange et al. studied on the cutting energy and force required for the pigeon pea crops, and they observed that the cutting energy and cutting force were directly proportional to cross-sectional area and moisture content at the time of harvesting of pigeon pea crop (Dange *et al.*, 2011). Taghijarah et al. investigated that the ultimate stress and specific cutting energy decreased with an increase in size of cutting section in sugarcane stalks (Taghinezhad *et al.*, 2013). Mathanker et al. investigated that specific cutting energy increased with an increase in sugarcane stalks shear velocity (Mathanker *et al.*, 2015). Azadbakht et al. studied impact cutting of canola and reported that at blade velocity 2.64 m/s, the maximum and minimum cutting energy was measured 1.1 kJ in 25.5 % w.b. moisture content at 10 cm cutting height and 0.76 KJ in 11.6% w.b. moisture content and 30 cm cutting height respectively at the time of cutting (Azadbakht *et al.*, 2015).

Kaewwinud et al. studied investigation of physical and mechanical properties of cassava stalks under the effects of moisture content and region of cut. They showed that the relationship between stalk region and shearing stress was much stronger than that between moisture content and shearing stress (Kaewwinud *et al.*, 2017). Boydas et al. determined effects of moisture content, internode region, and oblique angle on several mechanical properties of sainfoin stem and reported that the maximum shearing stress and specific shearing energy were 5.76 MPa and 16.65 $mJ.mm^{-2}$ with a moisture content of 71.76% and an oblique angle of 0° at the first internode, respectively (Boydas *et al.*, 2019). Konuralp Elicin et al. studied, cutting properties of canes of local grapes varieties Okuzgozu and found that the effect of knife loading speed on the cutting forces, cutting strength, cutting energy and specific cutting energy were significant. Also they determined the lowest cutting force, cutting strength, cutting energy and specific cutting energy were obtained at the 1 m/s as 246.1 N, 8.705 MPa, 1.273 J and 0.04502 $J.mm^{-1}$, respectively (Konuralp Eliçin *et al.*, 2019).

MATERIALS AND METHODS

It is difficult to investigate a theoretical method for define impact cutting properties of plant stalks because the impact cutting process is complex. Thus, it is necessary to set up an experimental approach to determine impact cutting parameters for a single stalk (Prasad and Gupta, 1975). To determine the shear force of plants stalk, an impact cutting tester designed, fabricated and calibrated. It was similar to an Izod impact cut tester for metals. A cutting blade with sharpened angel of 23 degree and oblique angle of 60 degree was attached to the end of pendulum's arm (Yiljep and Mohammed, 2005).

A data acquisition system was attached to pendulum arm and it included four strain gages and a digital indicator to show the real-time shear force. Four strain gages were contacted to each other by Wheatstone bridge circuit and were mounted on two sides of pendulum**.**

By the principle of conservation of potential energy to kinetic energy, the pendulum when released from φ_1 is expected to swing to the other side of equilibrium line and deflection through an angle φ_2 and due to frictional losses in the parts and air resistance, φ_2 is normally less than φ_1. To delete the parts friction and air resistance effects, the losses energy was computed by pendulum oscillation at loading rates without any cutting and was detracted of main energy values.

For calibration of data acquisition system, pendulum was released from predetermined distance and the blade was contacted to strong sample. After contact, the pendulum has been stopped and kinetic energy is converted to heat energy. The pendulum momentum is equal to multiplication of pendulum weight and contact speed or area under output volt of strain gage versus time curve. Finally, the output volts of strain gages were converted to impact force by the usage of conversion ratio (*Cr*) which was calculated as in Equation 1 (Farahat and Brooghani, 2016).

$$\int F\,dt = mV \text{ and } F = Cr \rightarrow \int CrVdt = mV \rightarrow Cr = \frac{mV}{\int vdt} \qquad (1)$$

Where, F is contact force (N), m is pendulum weight (N), v is output volt (V), V *is b*lade velocity of pendulum at contact time (m/s), Cr *is c*onversion ratio.

When the pendulum is normally released from one side of the equilibrium position by an angular deflection (φ_1), it is swung to the other side of equilibrium line and deflected through an angle (φ_2). Fig. 1 shows schematic diagram of pendulum arm position before and after cutting.

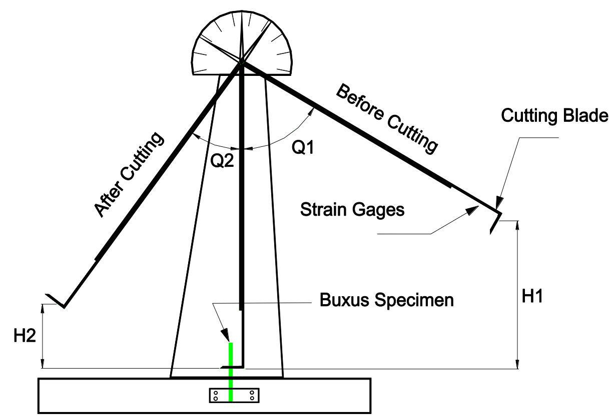

Fig 1. Schematic diagram of pendulum arm position before and after stalk cutting

To obtain the different velocities, the pendulum arm was released from different positions in the vertical plane on the upswing. Equations 2 and 3, respectively calculated the blade velocity and cutting energy in contact position to specimen.

$$E = W_t R(\cos\varphi_2 - \cos\varphi_1) \qquad (2)$$

$$V = \sqrt{[\frac{2w_t R(1-\cos\varphi_1)}{I}] \times L} \qquad (3)$$

Where, E is Shear consumption energy (J), φ_2 is maximum angular displacement of pendulum from vertical line after cutting (deg), φ_1 is maximum angular displacement of pendulum from vertical line before cutting (deg), w_t is total weight of the pendulum including arm, load cell and cutting blade weight (N), R is distance of the center of gravity of the pendulum from the axis of rotation (m), V is blade velocity in the lowest position of pendulum (m/s), I is mass moment of inertia of the pendulum about the axis of rotation (kg. m^2) and L is distance of the blade from the axis of rotation (m).

The release angels (φ_1) selected for this case are: 85, 60, 40 and 20 degrees and cutting velocities (4, 3, 2 and 1 m/s) were calculated related to these angles. After calibration, the impact shear force was applied to the boxwood samples by releasing the pendulum arm in the testing machine up to the sample failure. The real-time applied force and cutting time were measured by data acquisition system.

To test the apparatus, a series of experimental tests were conducted to measure the shear force, shear strength, shear energy consumption of boxwood and privet stem at impact cutting process as a function of a shear velocity, and stalk region. The boxwood and privet stalks used for the present study was obtained from green space of College of Abouraihan, Pakdasht, Tehran, Iran. The boxwood and privet stalk samples were collected at the last month of the spring season in 2016 and the ASAE (2005) was used to measure the average moisture content of the stalks (ASAE, 2005b). The initial moisture content of the boxwood and privet samples were measured to be 72% and 58% on wet base respectively (Fig. 2 and Fig. 3).

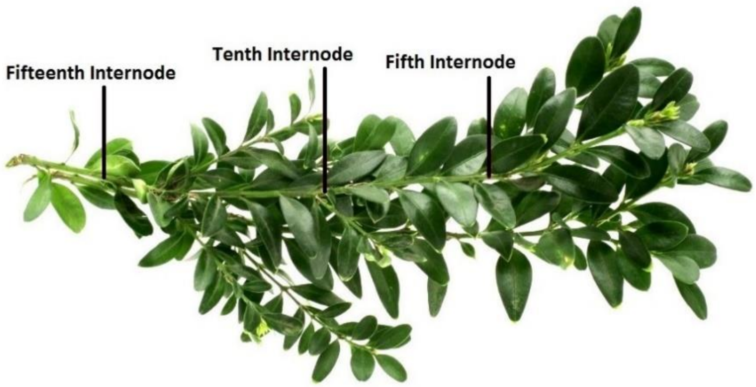

Fig 2. Diagram of boxwood stalk and three selected internode positions

Fig 3. Diagram of privet stalk and three selected internode positions

The boxwood and privet stalks diameter decrease towards to the top of the plant stalks, which means it shows different physico-mechanical properties at different heights of stalks due to the variable cross section area (O' degherty *et al.*, 1995; Shahbazi and Nazari Galedar, 2012). The cross section area of boxwood stalk is similar to oval, it was equally divided into three regions downward from the stem terminal bud: (a) fifth internode position with small diameter ranges from 3.17 to 3.96 mm and large diameter ranges from 4.15 to 4.85 mm, (b) tenth internode position with small diameter ranges from 4.05 to 4.72 mm and large diameter ranges from 5.12 to 5.88 mm and (c) fifteenth internode position with small diameter ranges from 4.45 to 5.05 mm and large diameter ranges from 5.35 to 5.88 mm. Also, the cross section area of privet stalk is similar to oval and divided into three regions downward from the top of stalk: (a) fifth internode position with small diameter range of 3.44 to 4.56 mm and large diameter range of 4.38 to 5.11 mm, (b) tenth internode position with small diameter range of 3.90 to 5.11 mm and large diameter range of 4.87 to 5.98 mm and (c) fifteenth internode position with small diameter range of 4.72 to 5.85 mm and large diameter range of 5.44 to 6.88 mm.

The design of experiment was completely randomized block design. The experimental tests were conducted with eight replications in each treatment and finally the collected data were analyzed using analysis of variances (ANOVA) and the means were separated by 5% and 1% probability levels by using Duncan's multiple range test in SPSS (version 17, SPSS Inc., USA) software.

RESULTS AND DISCUSSION

This study was undertaken to design and fabricate a new apparatus to measurement the impact cutting properties of plants stalk. Some information as shear force, shear consumption energy and shear strength regarding to impact cutting of plants stalk is needed to design of proper trimmer machines. To testing the apparatus, a series of laboratory tests were conducted to measure the shear force, shear consumption energy and shear strength of stem internodes of two plants stalk like boxwood and privet under impact cutting at four loading rates (1, 2, 3 and 4 m/s) and three internodes of stalk (fifth, tenth and fifteenth). The results of two analysis are presented in the following sections**:**

Test analysis of boxwood stalk

The variance analysis of the effects of loading rate, internode position and interaction effect of loading rate and internode position on shear consumption energy and shear strength was shown in Table 1. The variance analysis of the data revealed that the loading rate, internode position and their interaction loading rate and internode position created significant effects in probability level of 1% on shear consumption energy and shear strength.

Table 1. Variance analyses of cutting boxwood stalk under different loading rates and internode positions

Source of variation	Degree of freedom	Shear energy (J)	Shear strength (MPa)
Loading rate (A)	3	130.27**	0.56**
Internode position (B)	2	6.65**	0.21**
Interaction A×B	6	0.23**	0.046**
Error	11		

**. Significant in statistic level of 1%

Fig. 4 shows the interaction effects of loading rate and internode position on energy requirement of boxwood shear. In all regions in this figure, the shear energy decreased poly-nominally with the increase of loading rate and its value varied from 3.19 to 16.4 J, 3.3 to 18.3 J and 5.9 to 19.6 J for the fifth, tenth and fifteenth internode respectively at different loading rate. As demonstrated in Fig. 4, the cutting energy increased with the increase of loading rate for all the region of boxwood stalk**.**

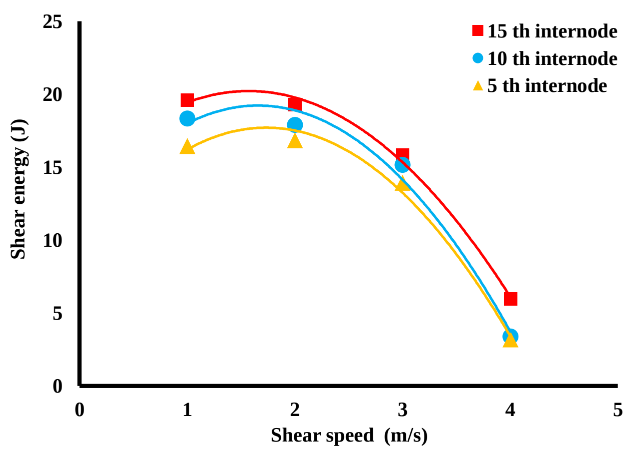

Fig 4. Relationship between shear energy and shear speed at different internode positions

Fig. 5 shows the interaction effect of loading rate and internode position on boxwood shear strength. In all regions and internode positions of Fig. 5, the shear strength decreased polynomial with the increase of loading rate. The highest strength shear was obtained as 1.03 MPa for fifteenth internode of stalk at the speed rate of 2 m/s and the lowest value was obtained as 0.14 MPa for fifth internode at the speed rate of 4 m/s.

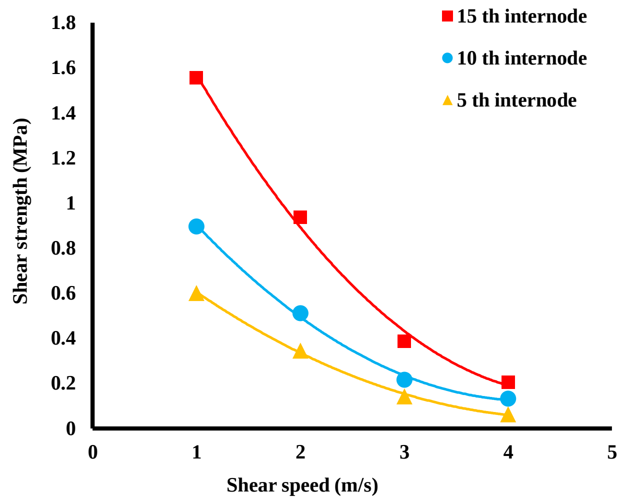

Fig 5. Relationship between shear strength and shear speed at different internode positions

The reduction proportion of energy consumption at blade velocity of 1 to 4 m/s was about 3.3. It showed the shear consumption energy in low speed level of impact cutting was 3.3 times higher than that in high-speed level cutting. Additionally, results showed that the shear consumption energy decreased upward from fifteenth to fifth internode position. Meanwhile, the increment proportion of shear consumption energy at internode position 15th to 5th was about 25%.

By considering to shearing results, shear strength strongly decreased with an increase of loading rate and was upward from fifteenth to fifth internode position. The reduction proportion of shear strength at blade velocity of 1 to 4 m/s is about 40 and the increment proportion of shear strength at internode position 15th to 5th is about 2.5.

Test analysis of privet stalk

The variance analysis of the effect of loading rate, internode position and the interaction effect of loading rate and internode position on the shear force, shear energy and shear strength in impact shear test as shown in Table 2.

Table 2. Variance analyses of cutting privet stalk under different loading rates and internode positions

Source of variation	Degree of freedom	Shear energy (J)	Shear strength (MPa)
Loading rate (A)	3	80.42**	0.255**
Internod position (B)	2	15.01**	0.08^{ns}
Interaction A×B	6	1.53**	8.68**
Error	11		

**and *.significant in statistic level of 1% (P < 1%) and 5% (P < 5%), ^{ns}. not significant

The interaction effect of loading rate and internode position on the shear consumption energy is presented in Fig. 6. As demonstrated in Fig. 6, the cutting energy strongly decreased with increase in the loading rate for all regions of privet stalk. The highest cutting energy was obtained 28.60 J for the fifteenth internode of stalk at the speed rate of 1 m/s and the lowest value was obtained 3.19 J for the fifth internode at the speed rate of 4 m/s. In all regions of Fig. 6, the shear energy decreased polynomial shape with an increase of loading rate and its value varied from 3.19 to 19.22 J for fifth internode, 5.53 to 24.05 J for tenth internode and 11.07 to 28.60 J for fifteenth internode at different loading rate.

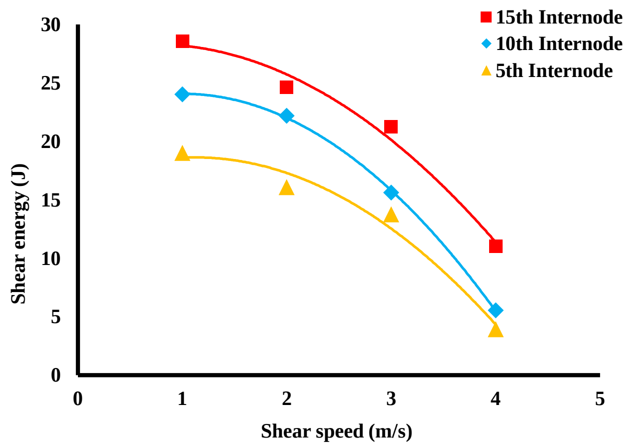

Fig 6. Relationship between shear energy and shear speed at different internode positions

Fig. 7 shows the interaction effect of loading rate and internode position on shear strength of privet stalk. The highest value of shear strength was obtained as 2.53 MPa for the fifteenth internode at the speed rate of 1 m/s and the lowest value was obtained as 0.21 MPa for the fifth internode at the speed rate of 4 m/s. This effect of loading rate and internode position on shear strength was also reported by (McRandal and McNulty, 1978) for forge crops, (Yiljep and Mohammed, 2005) for sorghum stalk, (Chattopadhyay and Pandey, 2001) for sorghum, (Tabatabaee Koloor and Borgheie, 2006) for rice stem, (Dange *et al.*, 2011) for pigeon pea stem, (Alizade *et al.*, 2011) for rice stem and (Azadbakht *et al.*, 2015) for canola stem.

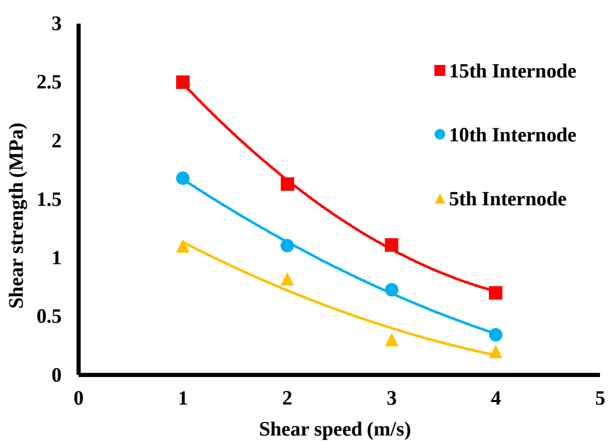

Fig 7. Relationship between shear strength and shear speed at different internode positions

The impact cutting results demonstrated that an increase in shearing loading rate led to a decrease in the shear strength and the shear consumption energy. The reduction proportion of privet stalk cutting consumption energy at shear velocity of 4 m/s to 1 m/s is about 2.5 at fifth internode, 2.4 at tenth internode and 3.4 at fifth internode of privet stalk. It shows the shear consumption energy in low speed level of impact cutting is around 2 to 3.5 times higher than high-speed level cutting. The reduction proportion of privet stalk resistance to cutting at shear velocity variation from 4 m/s to 1 m/s is about 1.2 at fifth internode, 1.3 at tenth internode and 1.5 at fifth internode of privet stalk. It shows the shear strength in low speed level of impact cutting is around 1 to 1.5 times higher than high-speed level cutting. In addition, results showed in impact cutting, the shear consumption energy and shear strength increased downward from fifth to fifteenth internode position. Meanwhile the mean increment proportion of shear consumption energy and shear strength at fifteenth internode position to fifth internode position are 1.76 and 2.27 respectively.

The results of both boxwood and privet stalk cutting showed the plant cutting process has two stages: at the first stage, the cutting blade involves preliminary compaction of stalk outer layer and the second stage starts when the material under the cutting blade yields and the motion of the cutting blade in the stalk material cuts the stalk. The outer layer material of stalk is compressed up to a spatial amount until the cutting resistance of privet stalk is overcome. Therefore, the increase of deformation outer layer of plants stalk is the important reason for increase the shear consumption energy and shear strength. It seems the variation of the static cutting characteristics is a function of the layer deformation of plant stalk and with increasing preliminary compaction amount, the proportion of outer layer deformation work is increased and the shear consumption energy is increased (Mohsenin, 1963).

In practice, the cutting of plant stalk is not a quasi-static cutting but it is a dynamic process. The impact cutting process by a rapidly moving cutting blade, is similar to dynamic process and in impact cutting, with increasing loading rate, the primary compression of outer layer was decreased as a result's inertia and plastic behavior of plant stalk material and the shear consumption energy decreased. It is clear, in plant stalk impact cutting, with increasing the cutting velocity the shear energy requirements decreased considerably, and the proportion of useful cutting work increased (Sitkei, 1986).

At the other hand, the cutting consumption energy and cutting resistance of plant stalk at both cutting methods correspond to variations in the texture, primarily in the proportions of fibrous and ligneous of stalk material. The thickness and texture of stalks also vary as functions of height, and so the shear consumption energy and shear resistance to cutting depend on the location of the cut and internode position. So in quasi-static and impact cutting, the mentioned parameters are highest close to the lower region of stalk and decreases going upwards (Sitkei, 1986).

The models fitted to the data using the regression techniques showed that the cutting energy and shear strength increased polynomial shape with increasing the loading rate for all stalk regions. Based on figures 4, 5, 6 and 7, it is clear that the character of the changes in the shear consumption energy and shear strength properties was best expressed by a quadratic polynomial equation at impact cutting methods.

CONCLUSIONS

In this study, the effects of shear loading rate of boxwood and privet stem on shear strength and shear energy were investigated according to the internode positions of stem. Results indicated that an increase in shearing loading rate led to a decrease in the shear strength and the shear consumption energy. Additionally, results showed that the shear consumption energy decreased upward from fifteenth to fifth internode position. By considering to shearing results, shear strength strongly decreased with an increase of loading rate and was upward from fifteenth to fifth internode position.

The plant cutting process has two stages: at the first stage, the cutting blade involves preliminary compaction of stalk outer layer and the second stage starts when the material under the cutting blade yields and the motion of the cutting blade in the stalk material cuts the stalk. The outer layer material of stalk is compressed up to a spatial amount until the cutting resistance of privet stalk is overcome. Therefore, the increase of deformation outer layer of plants stalk is the important reason for increase the shear consumption energy and shear strength. It seems the variation of the static cutting characteristics is a function of the layer deformation of plant stalk and with increasing preliminary compaction amount, the proportion of outer layer deformation work is increased and the shear consumption energy is increased.

The models fitted to the data using the regression techniques showed that the cutting energy and shear strength increased polynomial shape with increasing the loading rate for all stalk regions. Based on figures, the shear consumption energy and shear strength at impact cutting were significantly affected by internode position and these values increased towards to lower region of privet and boxwood stalks because of more cross-section diameter and more accumulation mature fibers in the lower region of the stalks.

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