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Determination of minimal cutting speed by flailing potato vines

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ABSTRACT

Mathematic model was developed to determine minimal cutting speed of flail knives at potato vine killing using special flail mower. Model bases on bending moment equilibrium and depends on mechanical properties of material to be cut, and height of cut level, as well as height of stalk. Mechanical properties of potato stalk were measured and through the model calculated values were compared with experimental results. Average shear strength of potato stalk was 2.07 N/mm^2 and Young's modulus 51.23 N/mm^2. Calculated minimal cutting speeds were from 4.01 to 11.8 m/s, depended upon different height of cutting level and centre of stalk mass. By flailing the potato vines with cutting speeds 6.2, 11.6 and 17.6 m/s, the average percentages of cut off stalks were 35%, 68% and 88% and lengths of rest part of stalks were 23, 20 and 10 cm respectively. The experimental results refected, that the predicted values of cutting speed showed good agreement with experimental values, therefore such mathematical model should be used to estimate the minimal required cutting speed at flailing potato vines.

Key words: potato, vine killing, shear strength, Young's modulus, cutting speed, impact cut

IZVLEČEK

DOLOČANJE NAJMANJŠE REZALNE HITROSTI PRI REZANJU KROMPIRJEVKE

V prispevku je predstavljen matematični model za določitev najmanjše rezalne hitrosti pri prosti rezi stebel krompirja. Temelj modela je ravnotežje upogibnih momentov, ki delujejo na steblo pri naletu rezila. Najmanjša rezalna hitrost je odvisna od mehanskih lastnosti stebla, od višine rezanja in višine težišča stebla. Povprečna izmerjena strižna trdnost stebla krompirja je bila 2,07 N/mm^2 in Young-ov modul elastičnosti 51,23 N/mm^2. Izračunane najmanjše rezalne hitrosti so znašale od 4,01 do 11,8 m/s, v odvisnosti od različne višine rezanja in višine težišča stebla. Pri rezanju krompirjevke z rezalnimi hitrostmi 6,2, 11,6 in 17,6 m/s je znašal povprečni delež odrezanih stebel s posameznih rastlin 35%, 68% in 88% in so bila stebla v povprečju odrezana na višinah 23 cm, 20 cm in 10 cm. Rezultati poskusa so pokazali dobro ujemanje dejanskih najmanjših rezalnih hitrosti z izračunanimi iz modela.

Ključne besede: krompir, rezanje krompirjevke, strižna trdnost, modul elastičnosti, rezalna hitrost, prosta rez

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1 INTRODUCTION

Potato vine killing before harvest is a common practice in potato production. Killing vines about three weeks before harvest allows stolons to loosen from the tuber, develops tuber maturity, sets skin and decreases vine quantity. Vine killing has also been used to limit seed tuber size and to decrease the spread of disease. Although vine killing aids potato harvest and tuber maturation, it reduces tuber yield and specific gravity compared to no vine killing (Hutchinson and Stall 2003, Davies and Milne 2000). Different vine killing or desiccation methods as chemical and mechanical methods can be used. The most common mechanical method is flailing the potato vines, while pulling or rolling vines are more pretentious procedure and so used less times in spite of some good attributes. Unless care by flailing is taken, tubers near the soil surface can be damaged, particularly if the hill shape is not similar to the flail blade contour. Flailing too high will also leave long vine stems and increase regrowth. Flailing has a sizeable power requirement and a relatively low area efficiency compared to spraying and for flailing is usually required specially mechanisation (Hutchinson and Stall, 2003). All this facts avert producers to implement mechanical vine killing in potato production. With intention to reduce number of machines involved into potato production, an especially machine – PTO driven cultivator was developed and constructed, which base use is cultivation and hilling up the ridge. For wine killing use, only rigid tines on rotor must be substituted with flail knives and gearbox ratio must be changed. So, the same machine can be used for cultivation with ridge hilling and for vine killing too. The range of cutting speed by flailing is very important while cutting principle is impact cut, which mean without countershear. The velocity of the flail knife must be high enough to cut the stem. The common range of cutting speed at impact cut for most plant materials is between 20 and 60 m/s (Chattopadhyay and Pandey 2001). Also lower values of at least 10 m/s are required for effective impact cut if the height of cut is reduced and the diameter and mass of stalk is larger (Chancellor, 1987). At cutting speed 5 to 10 m/s the most grass stems remained uncut (O'Dogherty and Gale, 1986).

To determine the minimal cutting speed by flailing the potato vine, the mathematical model is used and compared with experimental results.

2 MATERIAL AND METHODS

The field trial was set up at the beginning of year 2003 on field of Mr. Cajhen′s farm in Pšata near Ljubljana. There is middle heavy soil with 19.7 % of clay, 17.0 % of coarse silt, 31.2 %, of fine silt and 32.0 % of sand hence texture class of loam. The trial was designed as blocs with five repetitions. In trial potato cultivar Carlingford was included, seeded on row spacing of 75 cm. Seed density was 45000 plants per hectare so, distances between plants in row were 29.6 cm. Width of each trial plot was four rows and length 10 m. Stalk samples for mechanical analysis were taken and were analysed in the same day as vine killing was carried out.

- Shear strength
  The shear strength of potato stalk was measured in shear apparatus displayed on fig 1. The specimen was putted between fixed and movable knife which was driven by hydraulic cylinder with adjustable moving speed. Cutting force was measured by strain gauge load cell and shear deformation by measuring potentiometer. Both signals were leaded via measuring amplifier and signal conditioner to PC computer, which recorded and stored measured data. Ultimate shear strength τ of the specimen was calculated from the expression

$$\tau = \frac{F_s}{A}$$

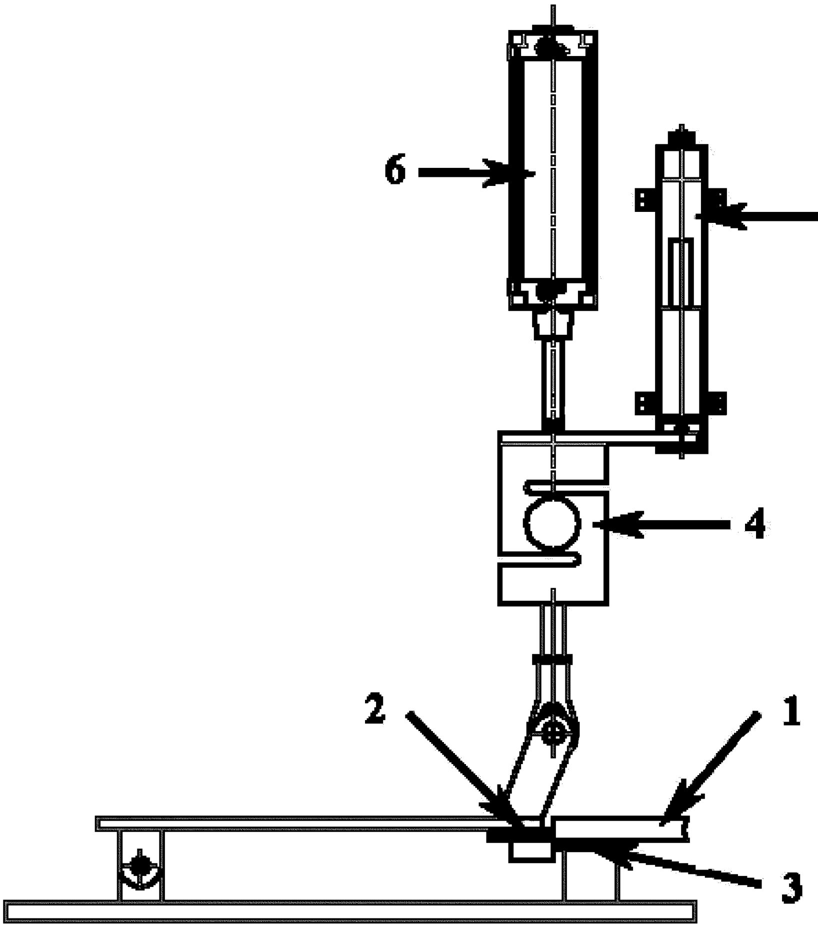

Figure 1: Shear apparatus (1, specimen; 2, movable knife; 3, countershear; 4, strain-gauged load cell, 5, displacement sensor; 6, loading cylinder)

where F_s is maximal shear force and A is the cross sectional area of stalk at failure position.

The cross sectional area A of stalk, which is not circular shaped, was calculated from measured dimension d and experimentally determined coefficient k_π .

$$A = \frac{k_\pi \cdot d^2}{4}$$

From fifteen, random sampled potato stalks, cross sectional area and characteristic dimension d (like diameter) were measured (Fig. 2). From this data coefficient k_π was determined through equation

$$k_\pi = \frac{4 \cdot A}{d^2}$$

Figure 2: Cross-sectional area of potato stalk with marked dimension d

To determinate shear properties, fifteen random sampled potato stalks were cut, seven times each. Before single cut, the dimension d was measured at cutting point.

- Young's modulus of elasticity
  Young's modulus E was determined by applying force transversely to length of stalk which was simply supported (Fig. 3). Three-point loading was used to apply uniform bending moment on specimen. The distance between supports was 80 mm and load was applied in the middle between supports at a rate of 4.5 mm/s. Bending force, which was produced by hydraulic cylinder, was measured together with bending deformation. On the basis of slope of linear part of curve on force – deflection diagram the modulus E was calculated as follows.

Maximal deflection of beam on two supports caused by the load in the middle is presented by following equation

$$f = F \cdot \frac{l^3}{48 \cdot E \cdot I},$$

where f is the deflection of the beam under the load, F is applied force, l is distance between supports, E is Young's modulus and I is the moment of area in bending and is defined for circular area as

$$I = \frac{\pi d^4}{64},$$

where d is diameter of circular area. From first equation E can be expressed

$$E = \frac{F}{f} \cdot \frac{l^3}{48 \cdot I}$$

and by insertion of expression for I, the final equation become

$$E = \frac{F}{f} \cdot \frac{4 \cdot l^3}{3 \cdot \pi \cdot d^4}$$

where $\frac{F}{f}$ represent the slope of linear part of curve on force – deflection diagram.

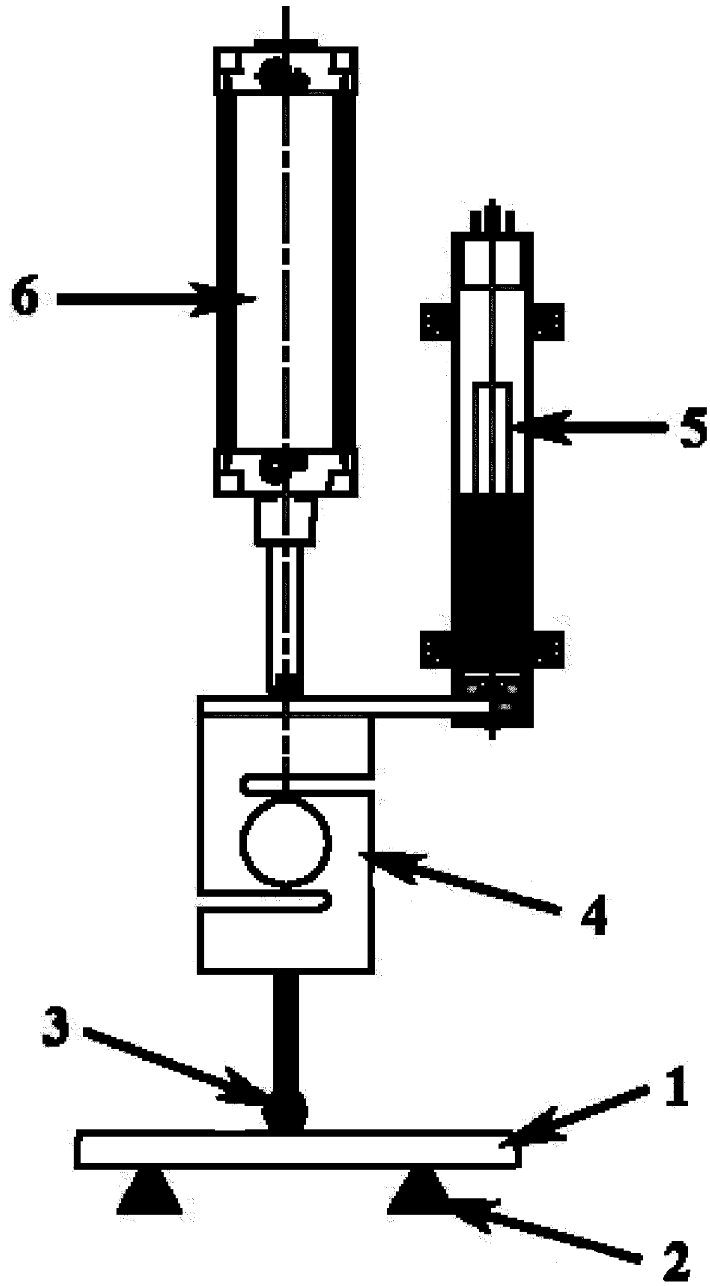

Figure 3: Bending device used for the measurement of Young's modulus (1, specimen; 2, supports; 3, loading rod; 4, strain-gauged load cell, 5, displacement sensor; 6, loading cylinder)

The specimens were obtained from fifteen, random sampled potato stalks. The roots were removed and first 15 cm long parts of stalks were used for measurement. The result of measurement was table with applied forces in the first and resulted deflection in the second column. Frequency of data acquisition was set at 100Hz and by load rate of 4.5 mm/s that means each measurement at 0.045 mm of deflection.

- Cutting speed

The minimum knife speed at impact cut was calculated according to Persson 1987 with some adaptations using the following simplifying assumptions.
At cutting level the stalk moves for distance of one diameter in cut direction.
The time for cut is the time for knife travel at distance equal to two stalk diameters.
The mass of the plant above the cut is accelerated uniformly up to knife velocity.
The cutting force is constant during the cut.

The average bending resistance of stalk is taken into consideration.

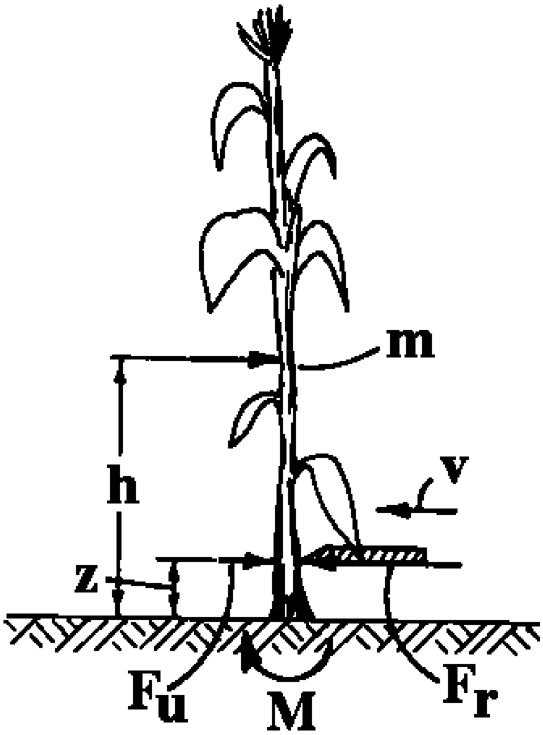

Figure 4: Forces on plant stalk in impact cut (according to Persson, 1987).

The moment equilibrium can be written, using variables in Fig. 4

$$\sum M = 0$$

$$F_r \cdot z - F_u \cdot z - m \cdot a \cdot h = 0$$

$$a = \frac{\Delta v}{t}$$

While initial velocity of stalk is 0

$$a = \frac{v}{t}; v = \frac{2 \cdot d}{t} \Rightarrow t = \frac{2 \cdot d}{v} \Rightarrow a = \frac{v^2}{2 \cdot d}$$

$$F_r \cdot z - F_u \cdot z - m \cdot \frac{v^2}{2 \cdot d} \cdot h = 0$$

$$v = \sqrt{(F_r - F_u) \cdot \frac{2 \cdot z \cdot d}{m \cdot h}}$$

Where: F_r is cutting force and is equal to maximal shear force F_s [N]
F_u is average bending force at deflection of stalk for value d [N]
z is height of the cutting level above ground [m]
h is height of stalk centre of gravity above ground [m]
d is the value of diameter of plant stalk [m]
m is the mass of stalk [kg]

Average bending force can be calculated at assumption that bending occurs as on two supports at distance of $2 \cdot z$ by d/2 deflection. Hence

$$F_u = \frac{3 \cdot E \cdot \pi \cdot d^5}{64 \cdot z^3}$$

Bending force has greater importance on reduce of minimal cutting velocity at lower cutting heights and by stalks with greater diameter and Young's modulus or higher stiffness.

- Experimental flail mower

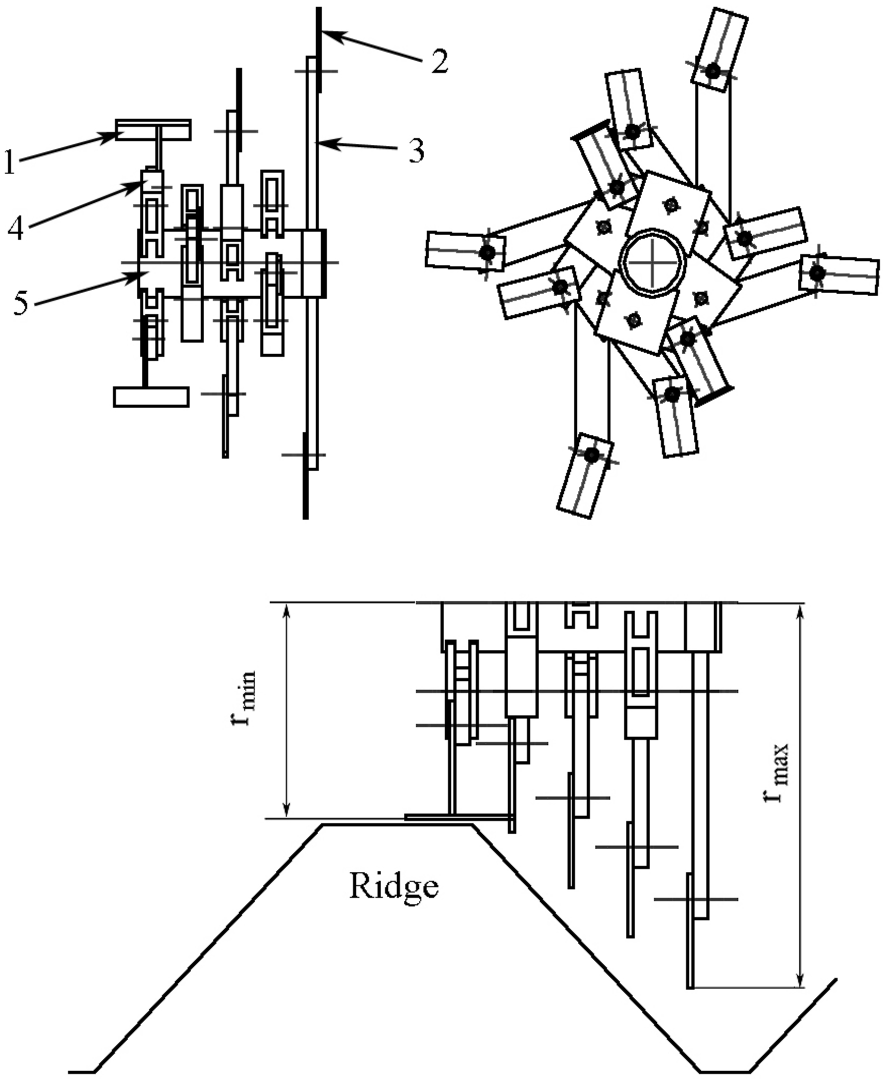

Figure 5: Rotor of flail mower (1, inner knife; 2, straight knife; 3, knife arm; 4, arm holder: 5, main shaft)

To obtain experimental data a special flail mover was used. The main working part of mower is specially constructed rotor to which 20 flail knives for each single ridge are fastened in such way that fit well the shape of ridge (Fig 5). While single pairs of knives are mounted at different radius, different cutting speeds are reached at same rotary frequency of the main shaft.

Inner knives, which are on smaller radius, have lower speed, but main importance for cutting because they operate at the top of the ridge from where the potato vines grow. So cutting speeds of that knives only were observed.

The radius r_{min} of inner knives was 220 mm. While rotational speed of knives had the same direction as driving speed of machine, cutting speed was the difference between rotational speed and driving speed.

Rotation frequency, forward driving speed of machine, used in field trial, and from that calculated cutting speeds are represented in Table 1.

Table 1: Cutting speed at different rotary frequency of main shaft and driving speed

Rotary frequency [1/min]	250.0	300.0	550.0	800.0
Driving speed [km/h]	1.3	2.7	3.7	3.1
Cutting speed [m/s]	5.4	6.2	11.6	17.6

The working effect at different cutting speeds was explained through percentage of cut off stalks from all stalks of single plant and average length of rest part of stalks.

3 RESULTS AND DISCUSSION

- Mechanical properties of potato stalk

In Table 2 are represented average measured mechanical properties of potato stalks. By comparison with other most common plant material (wheat straw, maize stalk) it is evidently that potato stalk shear strength is about two to four times lower than wheat's straw (5 – 8.5 N/mm^2; Kronbergs, 2000, O'Dogherty et al., 1995) and is in same range as for maize stalk (1.5 – 3.5 N/mm^2; Jekendra, 1999). The Young's modulus of potato stalk differs much more and is less than one hunderth of wheat's (5.2 – 13 kN/mm^2; Kronbergs, 1999, O'Dogherty, 1995).

Table 2: Average values of mechanical properties of potato stalk

Max. shear force F_s [N]	Dimension d [mm]	Coefficient k_π	Cross-sectional area A [mm^2]	Ultimate shear strength τ [N/mm^2]	Young's modulus E [N/mm^2]	Linear density ρ [g/m]
162.16	10.42	3.14	87.10	2.07	51.23	87.71

Very interesting result is also the value of the coefficient k_π, which represents ratio between cross-sectional area and diameter. At circular area, value of this ratio is π. Measured average value for stalk cross-sectional area, which has not circular shape (see Fig. 2) is also 3.14 therefore almost exactly π.

- Minimal cutting speed

To determine the minimal cutting speed from experimental evaluated mechanical properties of stalk, the height of cutting level above ground (z) and the height of stalk centre of gravity above ground (h) should be fixed.

Three values: 0.05, 0.1 and 0.15 m for cutting height z, and two: 0.15 and 0.25 m for height of stalk centre of gravity h were taken into calculation. Results are presented in Table 3.

Predicted values of minimal cutting speed were just about half of those, stated in references as minimal for grass stems and other forage plants. The explanation for such low values can be found in lower shear strength of potato stalk and it's relatively high linear density, regarding to diameter.

Predicted values are also in the same range as cutting speeds by flail mower at 300 and 550 rev. per minute of main shaft and therefore some working effect is expected at those rotary frequencies.

Table 3: Predicted values of minimal cutting speeds [m/s] at different height of stalk centre of gravity and cutting levels.

z [m]	h [m]	
	0.15	0.25
0.05	6.68	4.01
0.10	9.63	5.78
0.15	11.81	7.09

At rotary frequency 250 rev. per minute of main shaft, almost no through-cut stalks were found. The results for other cutting speeds are presented in Table 4.

Table 4: Working effect of flail mower at different cutting speeds.

	Cutting speed at flail mower work [m/s]		
	6.2	11.6	17.6
Average percentage of cutted stalks [%]	34.8	68.2	87.5
Average length of rest part of stalks [mm]	23.0	20.2	10.2

At cutting speeds of 6.2 and 11.6 m/s which are in range of predicted minimal cutting speed, significant part of stalks was cut. At higher cutting speed all stalks were cut except those which lay close on ridge and were inaccessible for knives. The experimental results reflected that the predicted values of cutting speed showed good agreement with experimental values therefore such mathematical model should be used to estimate the minimal required cutting speed at flailing potato vines.

4 REFERENCES

Chancellor, W. J. (1987): Cutting of biological materials. In Agr. Eng. Handbook, R. Brown (Ed.). CRC Press Inc. 1987.

Chattopadhyay, P. S., Pandey, K. P. (2001): Impact cutting behaviour of sorghum stalk using a flail-cutter – a mathematical model and its experimental verification. Journal of Agricultural Engineering Research, 78: 369 – 376

Davies, K., Milne, F. (2000): Potato haulm destruction in conventional and organic crops. Technical note T491, SAC Edinburgh, 4 p.

Hutchinson, C. M., Stall, W. M. (2003): Potato vine killing or desiccation. HS925 Document, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.

Jekendra, Y. (1999): Physical and rheological properties of forage crops with reference to cutting. Archivos de zootecnia 48: 75 – 78

Kronbergs, E. (2000): Mechanical strength testing of stalk materials and compacting energy evaluation. Industrial Crops and Products 11: 211 – 216

O'Dogherty, M. J., Gale, G. E. (1986): Laboratory studies of the cutting of grass stems. Journal of Agricultural Engineering Research, 35: 115 – 129

O'Dogherty, M. J., Huber, A. J., Dyson, J., Marshall, C. J. (1995): A study of the physical and mechanical properties of wheat straw. Journal of Agricultural Engineering Research, 62: 133 – 142

Persson, S. (1987): Mechanics of cutting plant material. American Society of Agricultural Engineers, St. Joseph, Michigan: 288 p.