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Determination of Cutting Properties, Protein and Mineral Content of Silage Corn Stalk

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The present research determined maximum shearing force, shearing stress, shearing energy and specific shearing energy for silage corn stalks. The mechanics of shearing on rigid surfaces was investigated *via* cutting tests. Shearing forces were measured using a cutting experiment setup and dynamometer. The specific shearing energy was calculated by using the area under the cutting force curve *versus* displacement curve. The shearing properties of corn stalks were evaluated at three moisture content levels of 66.5, 53.6 and 45.8 % d.b. The shearing properties were also evaluated at four sections of the corn stalks, from the bottom to the top (0-10, 10-20, 20-30 and 30-40 cm). At the end of the research, maximum shearing force, shearing stress, total shearing energy and specific shearing energy increased from 63.36 to 97.28 N, from 93.16 to 143.38 MPa, from 216.36 to 284.93 J and from 35.18 to 57.21 J cm^2, respectively in the moisture range from 66.5 to 45.8 % db. The results showed that the shearing values increased as the moisture content increased from the lower to the upper stalk sections. The protein content of silage corn stalk was 2.49 %. Macro nutrient values in the silage corn stalk such as Ca, P and S were determined as 0.346, 0.156 and 0.140 %, respectively. Micro nutrient values in the silage corn stalk such as Fe, Cu, Zn and Mn values were 10.32, 2.92, 13.12 and 16.44 mg kg^{-1}, respectively.

Key Words: Silage corn stalk, Physical-mechanical properties, Shearing force, Protein and Mineral content.

INTRODUCTION

Because of its high water content and sweet taste, silage corn is a particularly important cattle fodder crop. It increases the quality and amount of milk while fattening the feed value of silage corn changes upon harvest time. Corns cultivated for feed production are 'horse tooth' and 'hard corn' types.

The timing of the harvest is very important in silage plants, as there is a close relationship between moisture content, protein and carbohydrate ratios of the plants. The first step in obtaining qualified silage is obtaining a green plant having a moisture

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content of 65-70 %. In other words, the best time for harvesting is when the dry matter ratio is in the range 27-32 %. In order to employ all these, it is necessary to harvest plants at an appropriate time. In practical terms, the ideal time to harvest silage corn is during the period when it is pulpy hard pulpy. That is, in the period when the upper parts of the kernels on the stem start to collapse inwards, the dry matter content of the plant is about 30 %. Earlier harvests result in fodder material with a high moisture content and low carbohydrate level and the maturation of the silage in the grain elevator is delayed. If the harvest is too late, air will be trapped inside, since there will not be sufficient compression in the grain elevator and the silage will go off. Thus, timely harvesting of the silage material is important. Harvesting is achieved by means of a silage track which can farm in a single line or in two lines and the green material is sliced into 2.5-5 cm pieces. The sliced material is loaded onto a trailer and moved to the grain elevator[1].

After the harvesting of silage corn, the stalks, which are 10-20 cm in length, remain in the field. It is necessary that this waste material is appropriately broken down and mixed into the soil. Many researchers have noted that the process of mixing of plant wastes into the soil reduces the risk of soil erosion. The more surface waste left on the soil surface, the greater the protection against erosion by wind or surface flows. Plant wastes on the soil surface are the most significant components of many erosion control methods and the amount of surface waste necessary for erosion control differs depending on the amount of waste remaining after the harvest, on grazing, soil cultivation and the methods used in planting[2]. Retaining 20 % of corn waste on the field surface reduces soil erosion by 50 %; similarly, retaining 80 % of crop waste on the field surface reduces soil erosion by up to 90 %[3]. Particularly in areas where there is high risk of water erosion, plant wastes should be cleared away from the field[4]. Previous research has found that the incorporation of plant wastes to the soil improves some physical and microbiological properties of the soil. The incorporation of plant wastes into soil produces greater surface area for microbial activity and thus decomposition and thereby increases the rate of humus formation[5].

The cutting process of the stalk can be analyzed in two stages, (i) the applied pressure squeezes the material until the cutting edge gains shearing characteristics and (ii) the movement of the cutting edge inside the material being cut. The thickness of the cutting edge affects shear resistance. In knives with 70-80 μm shearing thickness, the shearing force remains constant, while in values above that it increases significantly. As a result, although they are easily deformed and quickly corroded, it is suggested that thin knife edges which have low energy consumption be used[6,7].

The amount of required force and the work done in order to shear a stalk which is drawn by bending is 50 % less when compared to the required force and work done shearing the stalk without drawing. It was observed that the shearing process occurs in the direction of drawn stalks[7,8].

Some previous studies have been carried out on the shear resistance of different plant stalks. The shear resistance of sunflowers is 2.8-8.7 N/mm^2, with a shearing force of 0.455 J/mm^2 required at 81 % moisture content[9]. The shearing force of cotton stalk with 22.25 % moisture content was found to be 46.35 N and the shear tension was found[10] to be 0.74 N/mm^2. Kayisoglu *et al.*[11] determined the mechanical properties of sunflower stalks with regard to mechanization of sunflower harvesting. They reported shearing force ranging between 23.9 N and 33.6 N, which increased with the moisture content of the stalk. It was also shown that the shearing forces increased from table to root regions.

The present study aimed to determine the shearing properties of silage corn stalks which are to be broken down in order to mix into the soil in SEAP region where silage corn production increases day by day. The shearing force, shear stress, total shearing energy and specific shearing energy were analyzed for the stalks of plant waste material remaining in the field during and after the harvest of silage corn. The effects of stalk region and moisture content on the shearing properties were investigated.

Some minerals such as Fe, Zn, Cu and Mn are important for the health of animals and humans. Cu and Fe are required for the activity of enzymes; zinc is an essential element for all living organisms. Iron deficiency can cause anemia, while zinc deficiency has been shown to be the cause of dwarfism and hypogonadism. On the other hand, toxic heavy metal contamination such as zinc, iron and copper has a negative effect on animal and human health[12]. Protein is also necessary for animals and humans, especially for children. Corn silage is an excellent source of some minerals and protein. The protein content and mineral compositions of silage corn stalk are also important for biochemical functions in animals. The present study therefore aimed to determine some macro and micro nutrient composition and the protein content of silage corn stalks.

EXPERIMENTAL

Pioneer 3394 hybrid silage corn was used in the present study. This variety is widely grown since the irrigation of Sanliurfa-Harran plain, which is a part of GAP. Some of the physical properties of the stalks of this plant are given in Table-1. Experiments to determine the physical properties of the silage corn stalks were carried out in laboratory of the Mechanics Department at the Harran University Higher Vocational School and the workshops of the Faculty of Agriculture, Department of Agricultural Machines. The sample stalks were harvested by hand in two periods during September and October 2007. Trials were conducted immediately after completing the harvest by hand.

The silage corn stalk samples collected from the trial field at different times were separated into different section as shown in Fig. 1 and regional mechanical properties such as maximum shearing force, shearing stress, shearing energy and specific shearing energy were determined[13]. In order to determine the moisture content of the stalks, the samples were kept at 103 ºC until they reach a stable weight[14].

TABLE-1
SOME PHYSICAL PROPERTIES OF THE SILAGE CORN STALK

	Height of silage corn stalk (cm)	Density of silage corn stalk (number/m^2)	Diameter of silage corn stalk (mm)			
			A (0-10 cm)	B (10-20 cm)	C (20-30 cm)	D (30-40 cm)
Minimum	210.0	13.20	20.35	19.34	17.96	17.26
Maximum	295.0	16.00	22.40	21.07	20.97	20.96
Mean	273.2	14.80	21.34	20.22	19.42	19.11
SD	23.82	0.89	0.55	0.56	0.79	0.66

Fig. 1. Regions of the silage corn stalk at which measurements were made (A: 0-10 cm, B:10-20 cm, C:20-30 cm, D: 30-40 cm)

In order to determine the physical-mechanical properties of the silage corn stalks that remain on the field after harvesting, a cutting experiment was used (Fig. 2). The experimental cutting setup has two cutting edges.

In order to make measurements using the cutting setup in shear tests, a Hounsfield type pull machine dynamometer was used. The cutting experiment setup was placed between the two edges of the dynamometer. It was prepared[7,15] so that the vertical speed of the cutting edges during the shear process was 1.5 mm/s.

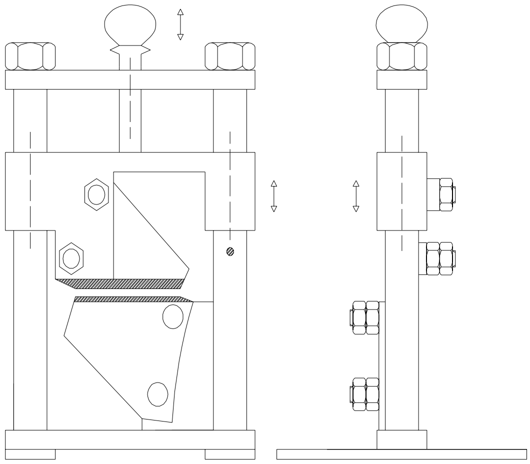

Fig. 2. Cutting experiment setup

Some macro and micro nutrient composition of silage corn stalk such as Fe, Cu, Zn, Mn, Ca, P and S were determined using an atomic absorption spectrometer[16]. Stalk protein content was determined by the micro Kjeldahl method[17].

Shearing stress: Each measurement was repeated for three different moisture content levels of the silage corn stalks and cutting was done at three different points for every cutting region along the stalk. The silage stalk was placed on the cutting edges and the highest cutting force value was read from the memory of the dynamometer. By dividing the largest shear force value from the dynamometer by the cross section area of the stalk at the cutting point, shear stress was calculated[11,18,19].

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

where τ = Shear stress (N/mm^2), F = Maximum shear force (N), A = Cross sectional area of the material at the cutting point (mm^2).

Total shearing energy: In order to determine the total shearing energy during shearing of corn stalks, the shear resistance was recorded after each mm. The total shearing energy of the stalk, related to the forces recorded during shearing and the distance traveled by the cutting edge, was calculated from the following equation[11,18,20].

$$E = \int_a^b F(x)dx$$

where E = Total shearing energy (J), F = Shearing force (N), dx = Instant displacement of the knife (m) a = The point where shearing force is zero and where the knife starts movement (m), b = The last point where the knife reaches and where the shearing ends (m).

In the shear experiment, the point where the knife first starts movement (a) should be equal to zero and the last point the knife reaches (b) should be equal to the handle diameter (Fig. 3).

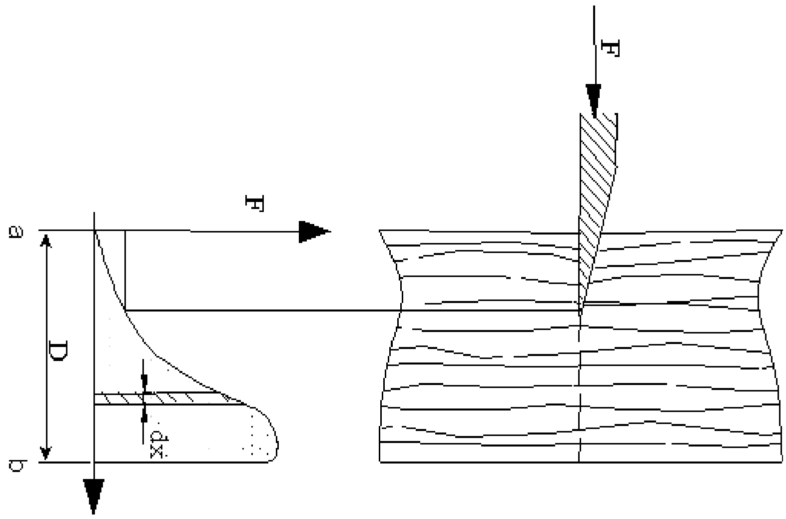

Fig. 3. Movement of cutting edge and strength diagram for the shear experiment [Ref. 8]

Specific shearing energy: The total shearing energy, calculated according to the above equations, was used to calculate the specific shearing energy by means of the following equation[11,19,21].

$$E_o = \frac{E}{A}$$

where; E_o = The specific shearing energy (J/cm^2), E = Total shearing energy (J), A = The cross sectional area of the material at the cutting point (cm^2).

RESULTS AND DISCUSSION

Maximum shearing force: Maximum shearing force of silage corn stalk at 66.5, 53.6 and 45.8 % moisture contents is given in Fig. 4. The highest value for the maximum average shearing force was 97.28 N. This result was produced in samples with 45.8 % moisture content and was obtained in the "A region" of the stalk, where the stalks are nearer to the soil. The lowest shearing value was obtained from samples with 66.5 % moisture content, which recorded a shear force value of 44.21 N in the uppermost section of the stalk (region D). It was observed that the maximum shearing force decreased with increasing moisture content of the stalks. The maximum shearing force also decreased when moving upward in the stalk region. The highest "maximum shearing force" was determined in the middle parts of the stalk section.

Above the maximum shearing force, the difference between stalk regions and moisture levels ($p > 0.1$) were found to be statistically significant. Kocabiyik and Kayisoglu[7], Janusz *et al.*[22] and Cakir[19] found similar results in previous studies carried out on the shearing forces of different plant wastes.

Shearing stress: The shearing stress of silage corn stalk at 66.5, 53.6 and 45.8 % moisture contents is given in Fig. 5. The highest shearing stress was obtained in the sample group with 45.8 % moisture content. This group recorded an average shearing stress of 180.38 MPa in the A region. The lowest shearing stress was obtained in the sample group with 66.5 % moisture content, which recorded an average shearing stress of 77.01 MPa in region D of the stalk length. It was observed that shearing stress decreased when moving up the stalk. Also, when the moisture level of the stalks increased, the shearing stress decreased. Above the maximum shearing force, the difference between stalk regions and moisture levels ($p > 0.1$) were found to be statistically significant. The shearing stress results are compatible with the findings of Ince *et al.*[22] in shear experiments on sunflowers and the results obtained by Annoussamy *et al.*[23] in the shear resistance of wheat stalks.

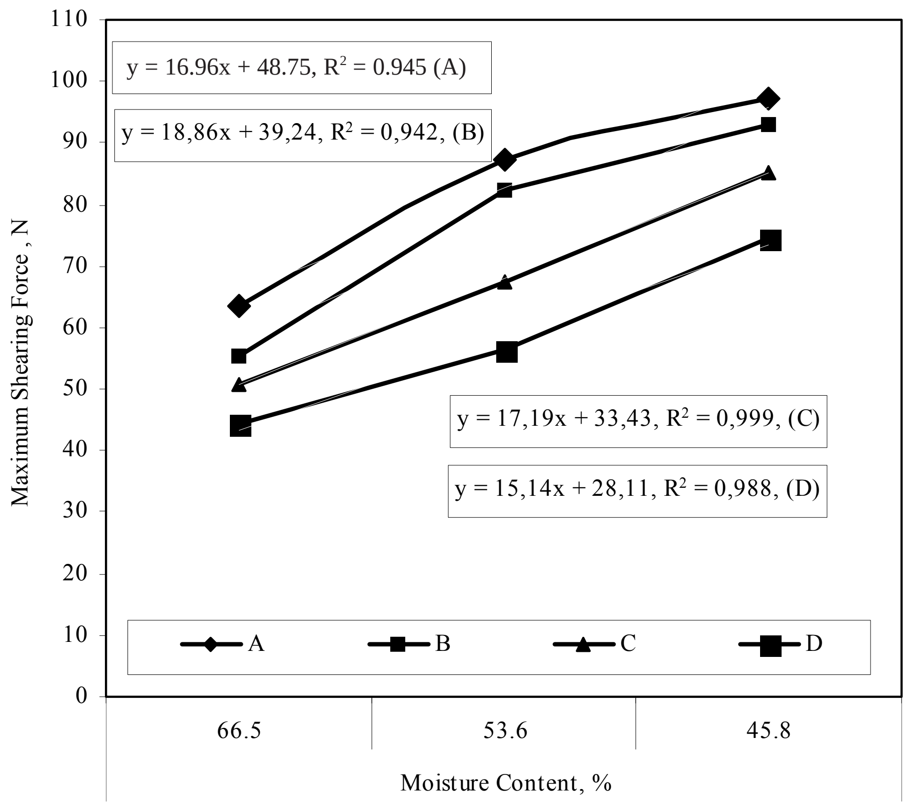

Fig. 4. Maximum shearing force

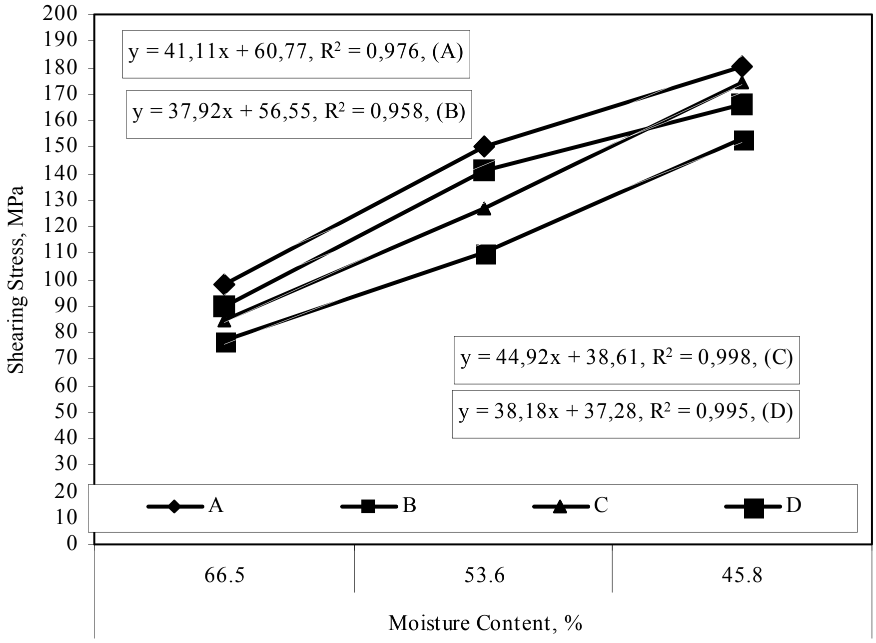

Fig. 5. Shearing stress

Total shearing energy and specific shearing energy: The variation of total shearing energy and specific shearing energy of silage corn stalk, with respect to moisture and stalk region, is given in Figs. 6 and 7. The highest values for total shearing energy (284.93 J) and specific shearing energy (57.1 J/cm^2) were obtained in the sample group with 45.8 % moisture content within the 0-10 cm (A region) stalk region. The lowest values were found to be 150.64 J/cm^2 (total shearing energy) and 34.15 J/cm^2 (specific shearing energy). These results were obtained from the 30-40 cm (D region) stalk region of the sample group with 66.5 % moisture content. Total shearing energy and specific shearing energy decreased inversely proportional to the increasing moisture content of the stalk, moving upward from the root region. Total shearing energy values of the stalk regions in the sample group with 66.5 % moisture content were found to be statistically significant at the $p > 0.5$ level. However, in the groups with 53.6 and 45.8 % moisture content, they were found to be significant at the $p > 0.1$ level. No statistically significant difference was observed between specific shearing energy values of different stalk regions in the group with 66.5 % moisture content. However, in the groups with 53.6 and 45.8 % moisture contents, the difference between specific shearing energy values of different stalk regions was found to be statistically significant at the $p > 0.05$ level. Similar results were obtained in previous studies by Annoussamy *et al.*[23] on wheat stalk; Chen *et al.*[24] on bhang stalks and Ince *et al.*[22] on sunflower stalks.

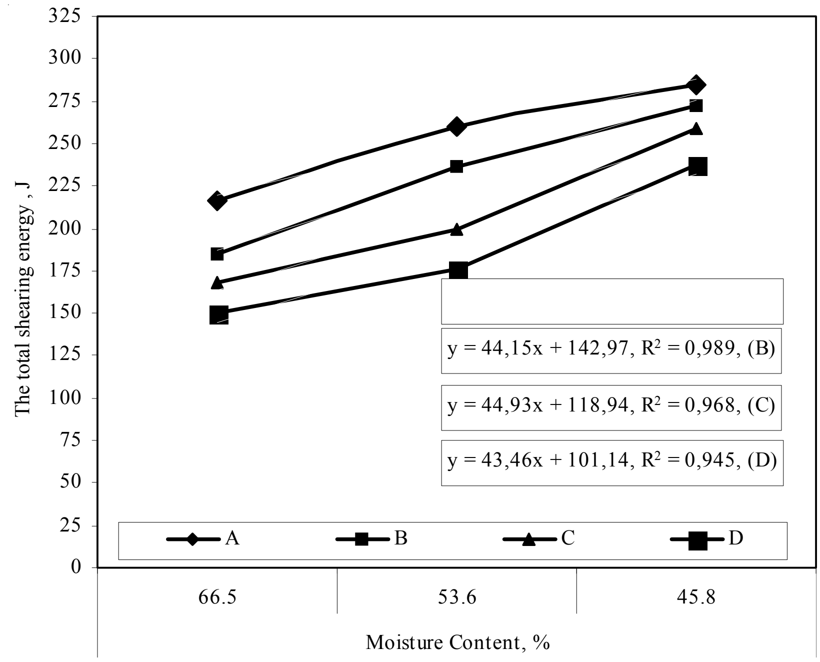

Fig. 6. Total shearing energy

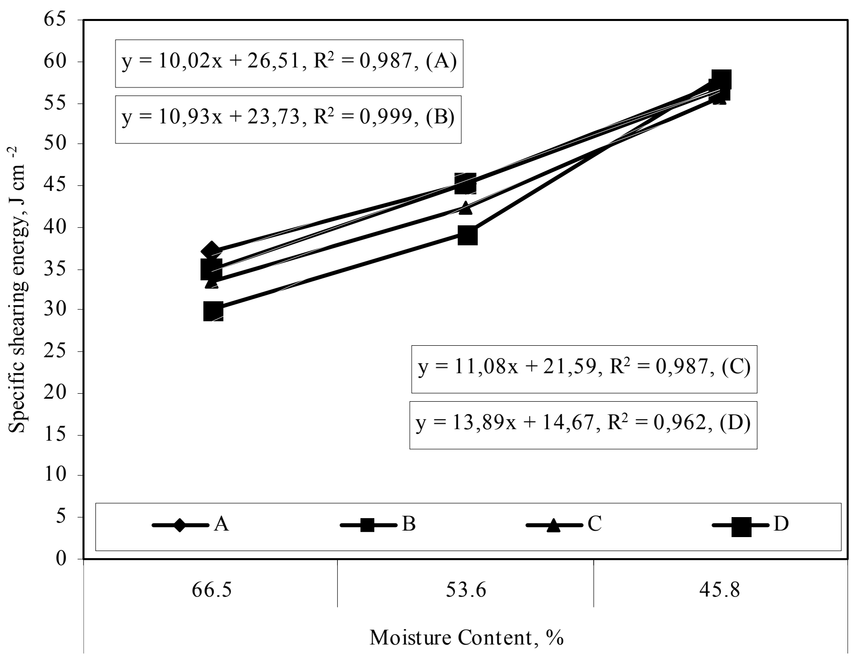

Fig. 7. Specific shearing energy

Protein and mineral concentration of silage corn stalk: Protein content was 2.49 % in the silage corn stalks. Similar findings were reported by Oktem and Oktem[25]. Macro nutrients values in the silage stalks were determined as 0.346 % (Ca), 0.156 % (P) and 0.140 % (S). Micro nutrients values in the silage stalks were 10.32 mg kg^{-1} (Fe), 2.92 mg kg^{-1} (Cu), 13.12 mg kg^{-1} (Zn) and 16.44 mg kg^{-1} (Mn) (Table-2).

TABLE-2
PROTEIN AND MINERAL CONCENTRATION OF THE SILAGE CORN STALK

	Protein (%)	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Ca (%)	P (%)	S (%)
Minimum	2.180	8.900	2.300	11.900	14.600	0.280	0.120	0.110
Maximum	2.860	11.800	3.500	14.200	18.300	0.410	0.180	0.170
Mean	2.490	10.320	2.920	13.120	16.440	0.346	0.156	0.140
SD	0.268	1.117	0.460	1.047	1.568	0.049	0.023	0.022

Conclusion

The effect of moisture content of silage corn stalk on shearing force, shearing stress, total shearing energy and specific shearing energy according to the different regions of stalk was determined. Protein and mineral concentration of silage corn stalk were determined. The following conclusions are drawn from this research into the properties of silage corn stalk: (**1**) All of the physical properties (shearing force, shearing stress, total shearing energy and specific shearing energy) of silage corn stalk were shown to be dependent on moisture content. (**2**) As the moisture content decreased from 66.5 to 45.8 % (d.b.), shearing force, shearing stress, total shearing energy and specific shearing energy of stalks was found to increase linearly. These results indicate that the shearing force and shearing energy requirements for harvesting and post-harvest cutting of the stalks can be minimized by harvesting at times when the corn has a high moisture content. (**3**) There were significant differences between stalk regions in shearing force, shearing stress, total shearing energy and specific shearing energy. In the A-region (0-10 cm) with 66.5 % (d.b.) moisture content, the shearing force and total shearing energy were 97.28 N and 284.93 J, respectively. However, in the D-region (30-40 cm) 66.5 % (d.b.) moisture content, the shearing force and total shearing energy were 74.49 N and 237.55 J, respectively. (**4**) The protein content of silage corn stalk was 2.49 %. Macro nutrient values in the silage corn stalk for Ca, P and S were determined as 0.346, 0.156 and 0.140 %, respectively. Micro nutrient values in the silage corn stalk for Fe, Cu, Zn and Mn were 10.32, 2.92, 13.12 and 16.44 mg kg^{-1}, respectively.

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