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EFFECT OF HARVEST DATE AND STALK SECTION ON SELECTED STRENGTH CHARACTERISTICS OF TURKISH OREGANO (*Origanum onites* L)

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Abstract

Background: The time required to harvest plant crops is important to the plant properties. It is affected by design of the harvest equipment and the desire for high-quality products with low energy usage.

Materials and Methods: Strength characteristics of *Origanum onites* L., an important medicinal aromatic plant, harvested on 2, 9, 16 and 23 July, 2012–2014 (H1, H2, H3 and H4, respectively) were measured at the bottom and top sections of the stalk. Measurements included maximum force, bio-yield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation.

Results: The highest maximum force (35.17 N) was at H4 on the bottom section, and the lowest was at H1 on the top. Maximum values for bio-yield force, shearing force, and bending stress were at H4 on the bottom section, and corresponding minimum values were at H1 on the top section. Shearing stress decreased at successive harvest dates for both stalk sections. The minimum shearing energy was at H4, (0.13 J and 0.06 J for bottom and top, respectively). Strength measurements for bottom sections of the stalk were greater than those for top sections.

Conclusion: When reduced harvesting force is needed because of harvester design or harvest procedures, harvesting near the top of the stalk is recommended.

Key words: harvest date, *Origanum onites*, mechanization means, shearing stress, stalks strength.

Introduction

The genus *Origanum* is a member of this family and is represented in Turkey by 32 species or sub-species; 21 of these, or 60%, are endemic to Turkey. This suggests that Turkey is the gene centre for Origanum. Turkey leads the World in the oregano trade, and annual exports have reached over 8000 tonnes in recent years with a value of 15 million US $ (Ozkan et al., 2010).

Immediately after Turkish oregano (*Origanum onites* L.) is harvested, the moisture content of the plants is about 40–50% (w.b). Plants harvested by handpicking or by reaping machines are laid on a shaded surface to dry and then blend manually or by a machine. Many previous studies have reported that the harvesting time of *O. onites* affects the essential oil content, phenolic compounds, and antioxidant properties of the plant (Ozkan et al., 2010). However, the stalk strength of the plant at the time of harvest affects the harvest and reaping operations, and therefore, a machine to be used. Knowing the stalk strength can ensure easy harvesting of the plant by using minimal force. Many studies have investigated the stalk strength properties of various plants as, plant stems (Leblicq et al., 2015), straw and hay (Nona et al., 2014), litchi (Lui, 2012), napier grass stems (Lien and Liu,2015), biomass stems (Yu et al., 2014) rose (Rabbani et al., 2015), winter wheat and spring barley (Šarauskis et al., 2013), rice stem (Zhou et al., 2012), sugar cane stems (Taghijarah et al., 2011; Hemmatian et al., 2012), barley straw (Tavakoli et al., 2009) corn stalk (Igathinathane et al., 2010), canola stem (Esehaghbeygi et al., 2009), rice straw (Zareiforoush et al., 2010), alfalfa (Galedaret al., 2008), sunflower (Ince et al., 2005), safflower (Ozbek et al., 2009; Shahbazi et al., 2011; Shahbazi and Galedar, 2012), rose (Yilmaz and Ekinci, 2011), rosemary stalks (Arevalo et al., 2013).

O. onites has an important place among medicinal aromatic plants, but there are no studies that examine the effect of harvest date on its stalk strength.

In this study, the effects of the harvest date and stalk section of *O. onites* on stalk strength were determined. Measured stalk strength properties included maximum force, bio-yield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation.

Materials and Methods

For this study, Turkish oregano (*O. onites* L.) plants were harvested by hand from the experimental field in Suleyman Demirel University, Isparta, Turkey. *O. onites* was harvested on four different dates, i.e. July 2 (H1), July 9 (H2), July 16 (H3) and July 23 (H4), in 2012. The total height of the *O. onites* stalk was approximately 360 mm. The portion defined as the top section was where budding began, i.e., the uppermost section from approximately 100 mm below the apex of the plant. The portion designated as the bottom section was defined as the portion of the plant from the soil surface up to a height of 150 mm (Fig. 1).

Top and bottom sections of stalks were combined with other portions of the plants for some evaluations. Stalks damaged during cutting were discarded. Diameter and cross-sectional area of the experimental samples were measured before the bending and shearing tests. Moisture content of the plants was determined at harvest time. Specimens were weighed and dried in an oven at 102°C for 24 h and then reweighed (ASABE, 2006). It was provided concisely but complete information about the materials and the analytical and statistical procedures used. This part should be as clear as possible to enable other scientists to repeat the research presented. Brand names and company locations should be supplied for all mentioned equipment, instruments, chemicals, etc.

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A universal testing machine (LF Plus, UK) with a 500 N load cell and a computer-aided cutting and bending apparatus (Fig. 2) was used to measure the strength characteristics of the Turkish oregano (*Origanum onites* L) stalks. All the tests were carried out at a speed 0.8 mm s^{-1}, and data were recorded at 10 Hz. All data were analysed by nexgen software program.

The bending force was determined with load cell that produced force × time data up to failure of the Turkish oregano (*Origanum onites* L) stalk (Fig. 2B). Force-deformation curves were calculated from the test data by the software.

The shearing forces on the load cell with respect to knife penetration were recorded by computer (Ozbek, 2009). The shearing stress in $N.mm^2$ was calculated using the equation of Shahbazi (2012):

$$\tau = \frac{F_{s\max}}{A},$$

Where F_{smax} is the maximum shearing force of the curve in N, and A is the area of the stalk at the deformation cross-section in mm 2.

An example is shown in Figure 3. The shearing tests were conducted with 0.8 $mm.s^{-1}$ knife speed progress (Simonton, 1992). Bio-yield force, shearing force, bending stress, shearing stress, and shearing deformation were calculated from the force-deformation curves at the inflection point as defined by ASAE Standard (1985). S368.1 (ASAE Standards, 1985) was obtained from all curves. The energy of shearing was determined as the area under these curves (Chen et al., 2004; Srivastava, 2006). All measured characteristics were analysed against three years and four harvesting times and two stalk sections Comparisons between treatments of means were used in Duncan's multiple range test ($p < 0.05$).

Results and Discussion

The average stalk diameter, stalk length, and moisture content at the four harvest dates are shown in Table 1. The strength measurements of Turkish oregano (*Origanum onites* L) stalks are given in Table 2. The diameter of Turkish oregano (*Origanum onites* L) stalks decreased from the bottom to the top of plant, suggesting that the strength characteristics may vary due to cross-sectional area.

Maximum force was evaluated as a function of harvest date (H1, H2, H3 and H4) and stalk sections. Maximum force increased with increasing harvest date and was lower at the top section of the stalks than at the bottoms (Fig. 4). The relationship was expressed by linear equations with R^2 values of 0.96 and 0.94 for the bottom and top sections, respectively. The effect of harvest date on the maximum force applied to the stalk Turkish oregano (*Origanum onites* L.) plants was statistically significant ($P < 0.05$). Leblicq et al., 2015 and Ince et al. (2005) were reported similar results for different. The highest maximum force (35.17 N) was observed at the H4 harvest date on the bottom stalk section, and the lowest maximum force was observed at the H1 harvest date on the top section. The higher moisture level of the plants at the H1 harvest date may be responsible for the low observed force (Table 1). The smaller size of the top section compared with the bottom section may also have contributed to the lower maximum force.

The bioyield force increased at successive harvest dates. This may be attributable to decreased moisture level in the stalk with increased harvest date, causing the texture of the stalk tissue to become more rigid. This result is similar reports on other plant species (Chen et al., 2004; Ince et al., 2005). For both stalk sections, the harvest date had a significant effect on the bioyield force ($P < 0.05$). The maximum bioyield force of 28.13 N was observed at H4, and the minimum bioyield force of 11.23 N was at H1. The bioyield force is the force that is reached at the bioyield limit of the plant. It was observed to be approximately 80% of the maximum force (Fig. 5).

Shearing force is one of the most important plant characteristics affecting plant harvesting. If the weight of the plant is known, the shearing force and the shearing height can be used to determine the speed of the blade to be used in harvesting (Igathinathane et al., 2010; Taghijarah et al., 2011). The shearing force increased with time as the harvest dates passed (Fig. 6).

The maximum shearing force was observed at H4 at the bottom section of the stalks. The minimum shearing force was at H1 on the top section. For both stalk sections, the harvest date had a significant effect on the shearing force ($P < 0.05$). The bending stress value is also used to determine the speed of the cutting unit of the harvesting machine. The effect of harvest date on bending stress is shown in Figure 7. As time increased, the bending stress increased as a result of the decreased moisture content of the stalks. This was in agreement with the findings of (Ince et al., 2005; Galedar et al., 2008; Shahbazi et al., 2012). The effect of harvest date on bending stress was significant ($p < 0.05$), and varied between 5.47 and 14.68 MPa. The maximum bending stress was observed at H4 in the top section of the stalk.

The shearing stress values decreased at successive harvest dates (Fig. 8). The maximum shearing stress value (5.23 MPa) was observed at H1 on the bottom section of the stalk. The minimum shearing stress (2.72 MPa) was observed at H4 on the top section of the stalk. The effect of harvesting time on shearing stress was significant ($P < 0.05$). These results were similar to those of Ozbek et al (2009).

The shearing stress decreased in both sections at successive harvest dates (Fig. 9). The shearing stress varied between 0.07 and 0.19 J. These results were similar to Šarauskis et al. (2013), Yu et al. (2014) and Lien et al. (2015). The shearing energy values observed for the bottom section of the stalks were greater than the values observed for the top section (Table 2), and the effect of harvest date on shearing energy was significant ($P < 0.05$).

Deformation has an important place among the strength characteristics of the plant. The effect of harvest date on shearing deformation is presented in Figure 10. The maximum shearing deformation (25.30 mm) was observed at H1 on the bottom, and the minimum (8.04 mm) was observed at H4 on the top section of the stalk. The high moisture level in the plants at the H1 harvest date may be responsible for the higher shearing deformation observed at that time (Fig. 10). The effect of harvest date on shearing deformation was significant ($P < 0.05$). The decreased shearing deformation at successive harvest dates is similar to the results of Ozbek et al. (2009).

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Table 1: Physical characteristics of Turkishoregano (*Origanum onites* L) at four harvest dates

Average length (mm)	Harvest date[a]	Moisture content (%, dry weight basis)	Diameter (mm)			
			bottom	standard deviation[b]	top	standard deviation[b]
360	H1	42.40	2.60[a]	0.50	1.63[a]	0.31
	H2	25.70	2.48[b]	0.42	1.53[b]	0.36
	H3	14.30	2.34[c]	0.38	1.51[c]	0.31
	H4	9.70	2.22[d]	0.41	1.45[d]	0.33

Note. H1 – 2 July, H2 – 9 July, H3 – 16 July, H4 – 23 July; [b] – the number of samples was 45 and the number of replications was 3.

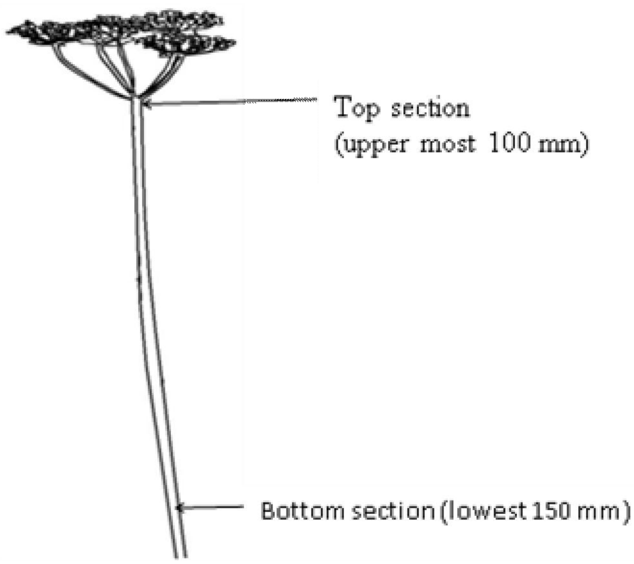
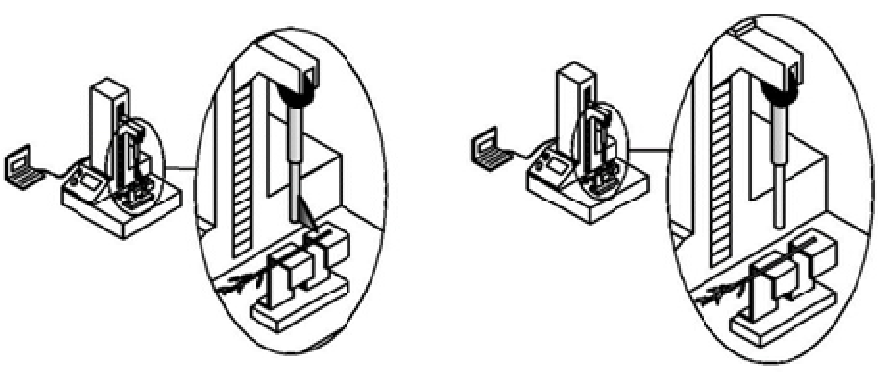


Figure 1: Tested sections of the Origanumonites



A. Cutting system

B. Bending system

Figure 2: Computer-aided systems for measuring the cutting and bending strength of Turkishoregano (Origanumonites L) plant

Table 2: Average strength characteristics of Turkishoregano (Origanumonites L)

Harvest date[1]	Maximum force (N)	Bioyield force (N)	Shearing force (N)	Bending stress (MPa)	Shearing stress (MPa)	Shearing energy (J)	Shearing deformation (mm)
	Bottom section						
H1	26.43[d]	21.14[d]	7.57[d]	5.47[d]	5.23[a]	0.19[a]	25.30[a]
H2	29.60[c]	24.28[c]	10.87[c]	6.24[c]	3.87[b]	0.16[b]	22.34[b]
H3	34.25[b]	27.40[b]	12.19[b]	6.80[b]	2.98[c]	0.15[c]	22.68[c]
H4	35.17[a]	28.13[a]	13.81[a]	7.06[a]	2.53[d]	0.13[d]	17.23[d]
Mean	31.361	25.239	11.112	6.394	3.654	0.157	21.886

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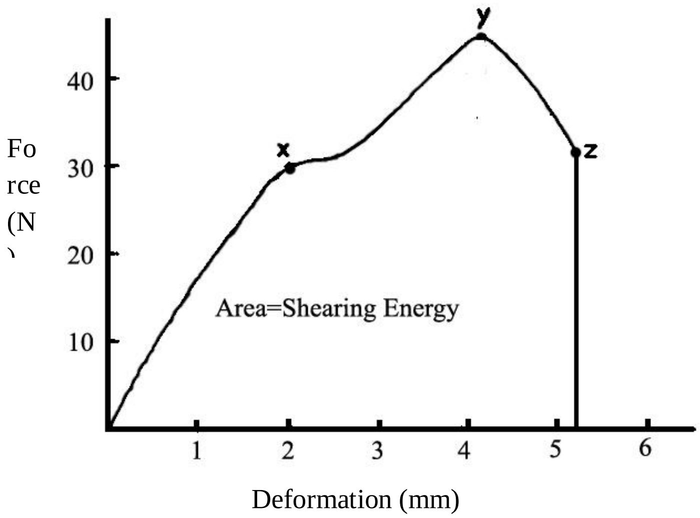
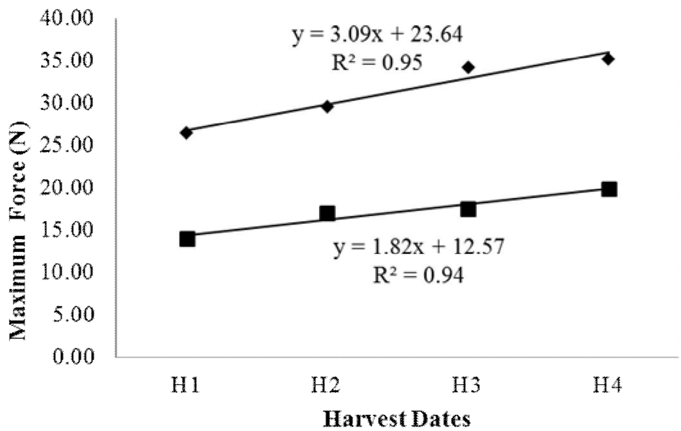
Standard deviation	2.80	2.41	2.10	1.32	1.02	0.08	1.95
	Top section						
H1	14.04	11.23 d	4.26 d	9.04 d	2.72 a	0.07 a	15.61 a
H2	16.98 c	13.59 c	6.02 c	11.72 c	2.69 b	0.07 a	12.86 b
H3	17.54 b	14.03 b	6.32 b	13.12 b	2.24 c	0.06 b	12.89 c
H4	19.92 a	14.33 a	8.05 a	14.68 a	2.11 d	0.06 b	8.04 d
Mean	17.119	13.295	6.165	12.141	2.441	0.066	12.348
Standard deviation	2.03	1.88	2.60	2.23	1.08	0.04	2.75

[1] – Harvest dates as H1 – 2 July, H2 – 9 July, H3 – 16 July, H4 – 23 July



Note. Labels on the graph indicate the following points: x – bioyield force, y – maximum force, z – shearing force (Liu, 2012).

Figure 3: Typical force-deformation curve of stalk during shearing loading



♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 4: The effect of harvest date on maximum force

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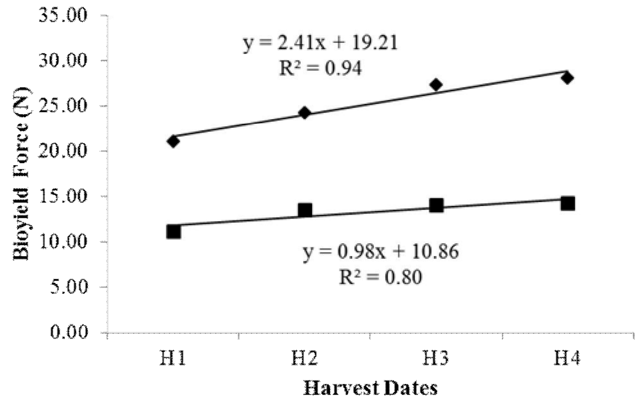
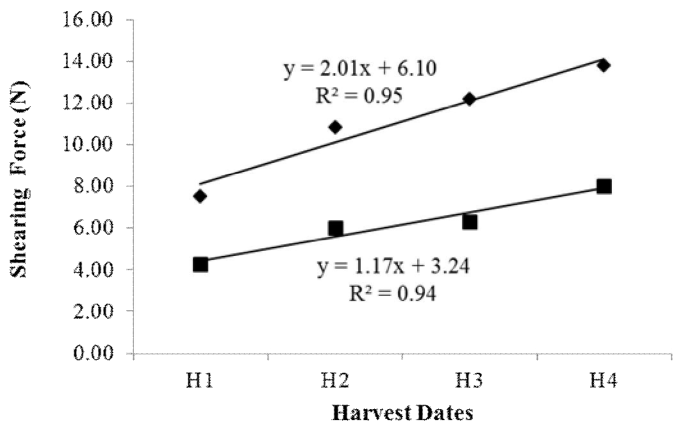


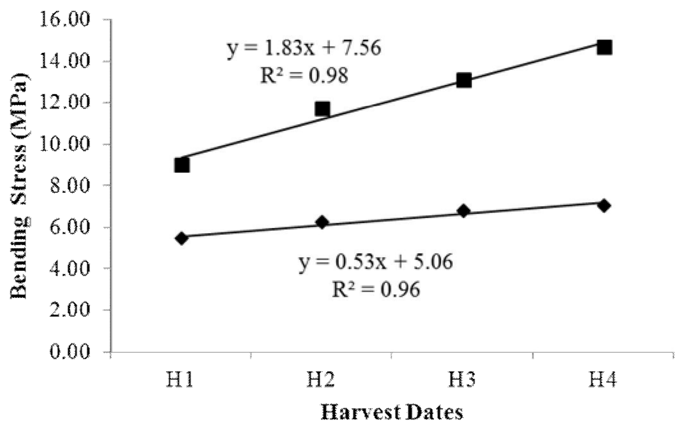
♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 5: The effect of harvest date on bioyield force



♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 6: The effect of harvest date on shearing force



♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 7: The effect of harvesting time on bending stress

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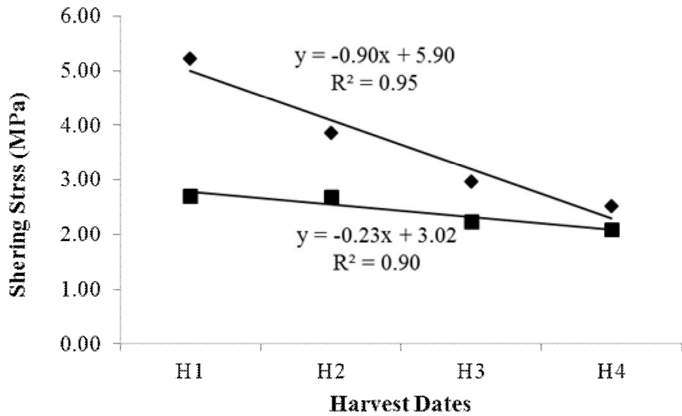
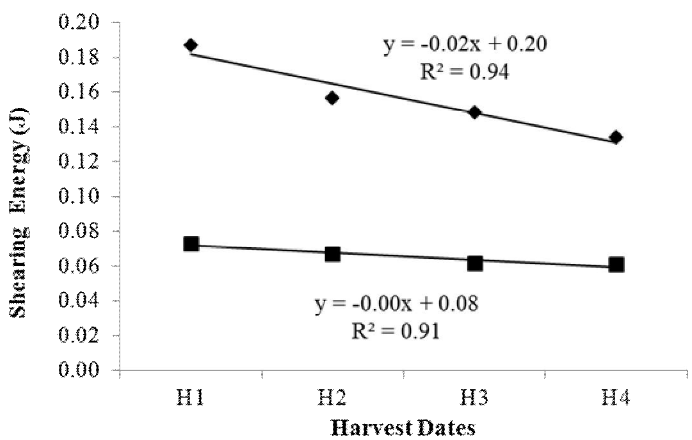


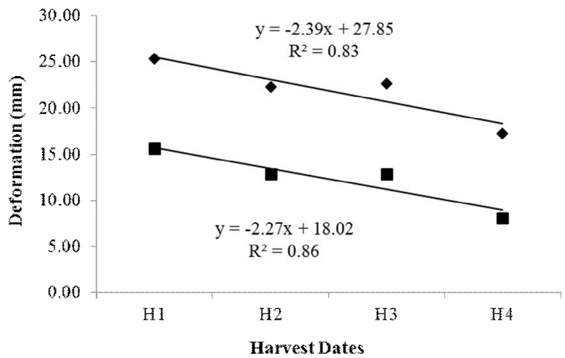
♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 8: The effect of harvest date on shearing stress



♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 9: The effect of harvest date on shearing energy



♦ – bottom section of stalk, ■ – top section of stalk; harvest dates

Figure 10: The effect of harvest date on shearing deformation

Conclusions

In this study, the effect of harvest date and stalk section on stalk strength properties of Turkish oregano (*Origanum onites* L) was determined. Maximum force, bioyield force, shearing force, bending stress, shearing stress, shearing energy, and shearing deformation were examined at four different harvest dates and on two different sections of the plant stalk.

The strength characteristics of the bottom section of the plant were greater than the corresponding values for the top section. With regard to bending stress, the top section of the stalk had higher values than the bottom section. This is due to the more elastic structure of the top section.

The maximum force, bioyield force, shearing force, and bending stress values all increased with increasing time, whereas the shearing stress, shearing energy, and deformation values decreased with later harvesting dates.

These experiments have demonstrated that harvest date and harvesting height of the plant were important factors in decreasing the shearing energy required to harvest *O. onites* plants. Therefore, when reduced force is necessary due to harvester design or harvest methodology, harvesting near the top of the plant is recommended.

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