Bending characteristics of birdsfoot trefoil stems

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Bilanski, W. K., Maw-Rong Lin, and Graham, W. D. 1989. **Bending characteristics of birdsfoot trefoil stems.** Can. Agric. Eng. **31**: 163–166. Birdsfoot trefoil (*Lotus corniculatus* L.) is a valuable forage crop, as it is highly palatable and does not tend to become woody if not harvested until early fall. However, the leaves dry very quickly compared to the stems and are quite brittle and break off when the stems are still at 30% or more moisture (WB). The ultimate stem bending strength was found to vary according to linear density, moisture content and maturity. The critical moisture content was found to be about 20% (WB). Above this level, moisture content had no effect on strength, while below it stem strength increased rapidly with decreasing moisture content. For a given level of moisture content, there was a linear relationship between the ultimate bending strength and the linear density of the stem. The maturity of the plant had a definite effect upon its ultimate bending strength as mature plants registered a greater resistance to bending force than young plants. The modulus of elasticity increased as the moisture content decreased.

INTRODUCTION

Birdsfoot trefoil has proven itself to be a valuable forage crop. Once established, it is very tolerant of poorly drained soil and yet is as drought-resistant as alfalfa. It is highly palatable and does not cause bloating of livestock. Furthermore, it does not become woody or unpalatable if harvest is delayed until early fall.

However, there are some serious difficulties involved in harvesting birdsfoot trefoil for hay or seed. Trefoil has proven to be a crop which is difficult to field dry (Fulkerson 1983; Papadopoulos and McKersie 1983). The stems dry more slowly than the leaves (MacAulay and Bilanski 1968). Once the moisture content of the leaves drops below 15% (WB) they become quite brittle and are easily broken off. At the same time, the moisture in the stems is usually 30% (WB) or more. Thus, considerable leaf losses can occur with baling. Pederson and Buchele (1960) showed that for alfalfa, 90% of the transpired moisture leaves the plant through the stomata and only 10% passes through the waxy cuticle of the stems and leaves. It is reasonable to assume that this is also the case with trefoil. Therefore, mechanical conditioning is needed to increase the drying rate of the stems without shattering the leaves. Harvesting is complicated by the presence of trefoil plants at all stages of maturity at harvest. Usually, the crop is windrowed to allow the plant material to dry more slowly and evenly (Macdonald and Clark 1987).

Any harvesting operation, be it baling, combining, conditioning, or raking, involves mechanical action on the plant. Only a limited supply of data on physical properties is available to designers of harvesting machines, particularly for forage crops such as birdsfoot trefoil. The portion of the plant with the greatest strength and which is able to offer the greatest resistive force to breaking is the stem. Therefore, a logical starting point is the bending characteristics of the stem since much of the action in conditioning, baling and combining involves bending and breaking stems at various moistures and maturities.

OBJECTIVE

The objective of this study was to determine the ultimate bending strength and the modulus of elasticity of birdsfoot trefoil stems in terms of linear density, maturity, and moisture content.

REVIEW OF LITERATURE

There have been several studies of the physical properties of forage stems; however, birdsfoot trefoil has received only limited attention. MacClelland and Spielrein (1957) tested the ultimate bending strength of ryegrass, alfalfa, and oats as simply supported beams. They established that a precise relationship exists between the ultimate bending strength and the linear density for each species. This relationship was also found by Prince (1961) who tested alfalfa, timothy, and oats as cantilever beams.

Prince et al. (1964) tested alfalfa, timothy, alsike clover, and red clover stems as centrally-loaded simply-supported beams. A quadratic relationship was found to exist between the ultimate bending strength and the moisture content. The minimum fiber strength for bending of alfalfa stems was observed between 50 and 60% moisture (WB).

METHODS

Trefoil plants at two stages of maturity were tested: young plants between 15 and 25 cm in height and plants in full bloom. Plants were cut at the height that would simulate typical harvest conditions, and all leaves were removed carefully from the stalks. A 90-mm segment was cut from the bottom end of each stalk, straightened, taped to a sheet of stiff paper, and put into a forced-air oven for air drying at 57°C to the required moisture content. The dried segments were removed from the oven and a specimen was cut from the center of each segment, leaving the taped ends behind. The length and weight of each specimen were determined immediately before each test was run. Moisture contents were computed on the wet basis, using the following formula:

$$\text{moisture content} = \frac{\text{moisture mass}}{\text{dry matter} + \text{moisture mass}} \times 100 \quad (1)$$

The linear density at a given moisture level was defined as the total dry matter weight of the specimen divided by its length.

The trefoil stem, while being processed, would best be modeled as a simply supported beam rather than a cantilevered beam. Hence, the specimen was placed on two knife-edged supports 38.1 mm apart. A knife edge applied a concentrated downward force on the center of the span between the two supports.

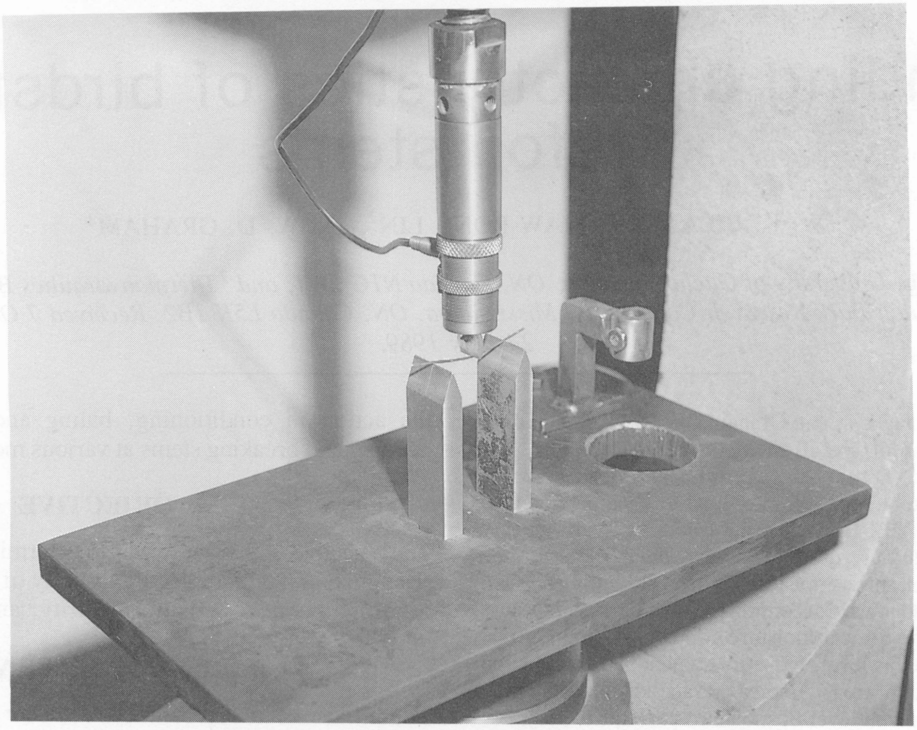

Fig. 1. Testing apparatus used to find the ultimate bending strength of birdsfoot trefoil stems.

The knife, attached to a differential transformer-type force transducer fixed to the ram of a loading machine (Fig. 1), was lowered at a constant rate of 2.54 mm/min. The output of the force transducer was amplified and recorded on the *Y* axis of an *X-Y* recorder; the *X* axis was set at a suitable time scale calibrated to display the stem deflection. Thus, force-deflection curves were generated for each specimen.

It was assumed that the trefoil stem is homogeneous, isotropic and circular in cross-section, and that the flexural formula applies.

RESULTS AND DISCUSSION

Ultimate bending strength

Using moisture content as a parameter, the experimental data of the ultimate bending strength for mature plants were plotted against the linear density in Fig. 2. A regression analysis shows that there is a linear relationship between the ultimate bending strength and the linear density of the stem of a mature plant (Table I and Fig. 2). Moreover, as can be seen from Fig. 2, a minimum ultimate bending strength, which occurs at a moisture content of about 40% (WB), exists for a given stem. Since all the data with moisture content above 20% (WB) are scattered along a straight line, it is clear that above a moisture content of about 20% (WB), the change of moisture content of a given stem does not appreciably affect the change in its ultimate bending strength. Below 20% (WB) moisture content, the strength of the stem increases rapidly as the moisture content decreases.

A regression analysis shows that there is also a linear relationship between the ultimate bending strength and the linear density (Table II and Fig. 3). Since there was a considerable variation in the stiffness and moisture distribution of the specimens, the experimental data for young plants are more scattered. Although the existence of a critical moisture content at which the ultimate bending strength is minimum, it is not as well defined as for mature plants. Figure 3 indicates that above a moisture content of about 25% (WB) (20% in mature plants), the change of moisture content in a young stem does not appreciably affect its ultimate bending strength. Below this 20-25% (WB) range, the strength of the stem increases rapidly as the moisture content decreases.

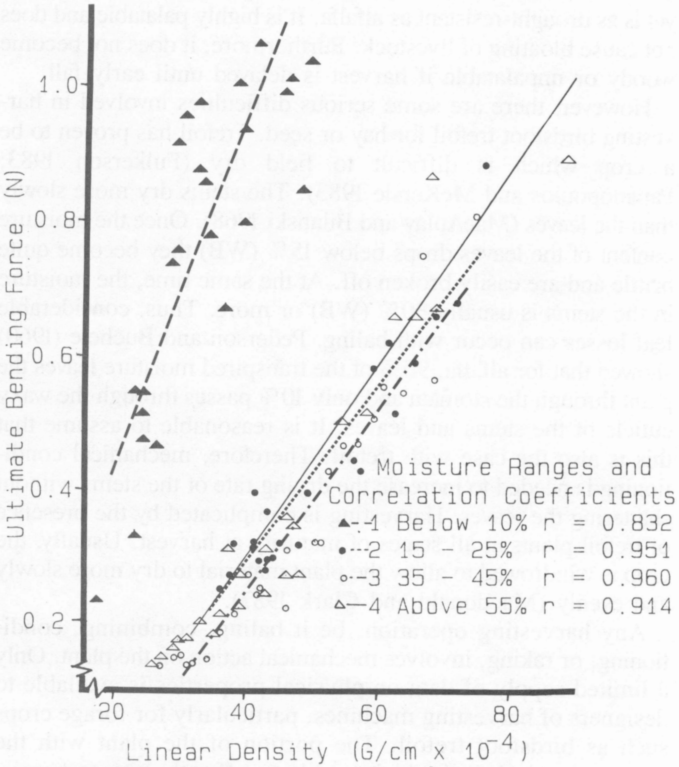

Fig. 2. Ultimate bending strength of the stem vs. linear density for a mature plant.

Table I. Regression equations relating ultimate bending strength of the stems to linear density for a mature plant

Regression equation	Validity range	Corr. Coeff. *r*
(1) Below 10% moisture content $F = [-6.4+26700(LD)]\ (0.00981)$	$16.9\times10^{-4}<=(LD)<=52.5\times10^{-4}$	0.832
(2) 15-25% moisture content $F = [-25.6+13800(LD)](0.00981)$	$35.6\times10^{-4}<=(LD)<=74.5\times10^{-4}$	0.951
(3) 35-55% moisture content $F = [-31.0+14100(LD)]\ (0.00981)$	$27.2\times10^{-4}<=(LD)<=74.4\times10^{-4}$	0.960
(4) Above 55% moisture content $F = [-31.9+15500(LD)]\ (0.00981)$	$26.0\times10^{-4}<=(LD)<=88.1\times10^{-4}$	0.914

LD = linear density (g/cm), F = ultimate bending force (N).

Table II. Regression equations relating ultimate bending strength of the stems to linear density for a young plant

Regression equation	Validity range	Corr. Coeff. *r*
(1) Below 10% moisture content $F = [-16.8+22900(LD)]\ (0.00981)$	$10.9\times10^{-4}<=(LD)<=25.7\times10^{-4}$	0.799
(2) 20-30% moisture content $F = [-9.0+7250(LD)]\ (0.00981)$	$12.7\times10^{-4}<=(LD)<=27.2\times10^{-4}$	0.896
(3) 40-50% moisture content $F =]-4.2+4850(LD)]\ (0.00981)$	$14.4\times10^{-4}<=(LD)<=35.5\times10^{-4}$	0.871
(4) Above 70% moisture content $F = [-4.0+5760(LD)]\ 0.00981)$	$10.3\times10^{-4}<=(LD)<=34.2\times10^{-4}$	0.840

LD = linear density (g/cm), F = ultimate bending force (N).

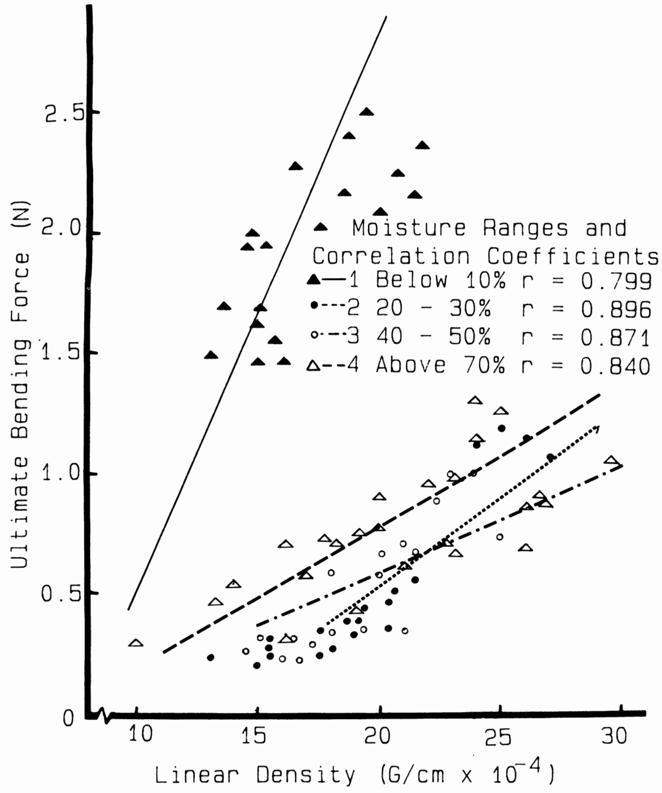

Fig. 3. Ultimate bending strength of the stem vs. linear density for a young plant.

Table III. Initial modulus of elasticity in bending (MPa)

Range of moisture in percent (WB)	Initial modulus of elasticity in bending in MPa mature plant	Standard deviation in MPa
Below 10	1190	177
15-25	447	54
35-45	272	46
Above 55	137	37
	Young plant	
Below 10	814	96
20-30	268	41
40-50	170	39
Above 70	54	12

A comparison of the experimental data for mature and young plants (Fig. 2 and 3) indicates that plant maturity has a definite effect upon its ultimate bending strength: the mature plants registered greater bending strength.

Modulus of elasticity

Assuming that the trefoil stem is homogeneous, isotropic and circular in cross-section, the modulus of elasticity in bending was calculated as the deflection formula for a concentrated load on a simply-supported solid circular beam with a fixed span length. In finding the modulus of elasticity, only the initial straight-line portions of the experimental load-deflection curves were used. This ensured that the calculations were done in the elastic region. The average values of the initial moduli of elasticity and their standard deviations are presented in Table III. As can be seen from this table, the modulus of elasticity increases as the moisture content decreases.

CONCLUSIONS

(1) The critical moisture content for a stem in bending was about 20% (WB). Above this moisture level, the change in moisture content did not appreciably affect the force required to break the stem. Below the critical moisture content, a decrease in moisture content was accompanied by a rapid increase in the ultimate bending strength of the stem.

(2) The ultimate bending strength of the stem was affected by the linear density in a linear relationship. Above the critical moisture content, the linear density could be considered as the only factor affecting the ultimate bending strength of the stem.

(3) Mature plants registered greater bending strength than young plants, indicating that the maturity of the plant had a definite effect upon its ultimate bending strength.

(4) The initial modulus of elasticity decreased as the moisture content increased.

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