Conversion of Solar Energy into Digestible Energy: a Basis for Evaluating Range Forages?

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Abstract

Identification of forage species that have high solar energy/digestible energy conversion ratios could lead to the development of forage varieties which produce more digestible energy per unit area of land. This concept was tested by first determining if certain forage species differed in their physiological capability of converting solar energy into a digestible form. The digestible energy conversion efficiency (DECE) of *Agropyron cristatum* (L.) Gaertn., *Agropyron smithii* Rydb., *Bouteloua gracilis* (A.B.K.) Lag., *Carex filifolia* Nutt., *Koeleria pyramidata* (Lam.) Beauv. and *Stipa comata* Trin. & Rupr. was calculated from 1977 field data. Initial results indicated *Agropyron cristatum* was more efficient ($P < 0.05$) than any of the natives. But correction of digestible energy content for unequal aboveground biomass production reduced species differences to a nonsignificant level.

With respect to the plant community, there are 4 general ways to improve forage production: increasing the vertical strata of useful vegetation, increasing plant population density, improving species productivity, and improving species quality (Baumer 1982). Development of higher producing or better quality forage varieties would augment results from other forage management practices. Because primary production can be measured as plant energy content (Singh et al. 1981) which is also an important constituent of forage quality (Kothmann 1980), the physiological capability of a plant to convert solar energy into a digestible form could be used to express forage productivity in terms directly related to livestock requirements. Identification of species that have high solar energy/digestible energy conversion ratios could lead to the development and use of forage varieties which produce more digestible energy per unit area of land. Consequently, livestock production levels could be increased if protein, calcium, phosphorus and carotene levels were not limiting. However, it must first be determined if differences in energy conversion capabilities exist among forage species. Therefore, this study was initiated to quantify the capability of certain forages to convert solar energy into digestible energy.

Materials and Methods

Study Area

The study was conducted in northeastern Wyoming near the community of Gillette. Native plant communities sampled during the course of the study had a Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* Beetle and Young) overstory. The understory was dominated by either blue grama (*Bouteloua gracilis* (A.B.K.) Lag.) and western wheatgrass (*Agropyron smithii* Rydb.) or needleandthread (*Stipa comata* Trin. & Rupr.) and threadleaf sedge (*Carex filifolia* Nutt.). A vigorous stand of crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) composed 95-98% of the ground cover in the introduced pastures sampled. However, reliable information on management of the introduced pastures was unavailable. Rolling topography crossed by deep, intermittent drainages characterized much of the area. Soils of the haplargid,

palaeargid, or torriorthent associations predominated (Wyoming General Soil Map, 1977).

Meteorological Measurements

Accumulated precipitation and daily maximum and minimum air temperatures were recorded at each site. Rainfall was measured with a rain gauge mounted 1.0 m above the ground surface. The gauge was 7 cm (2.8 in.) by 28 cm (11 in.). Air temperatures were taken from a standard maximum-minimum thermometer contained in a ventilated shelter placed approximately 15 cm off the ground.

Determination of Digestible Energy Content

A paired plot design was the basis for the vegetation sampling. This was accomplished by establishing a 50 × 100 m macroplot at an arbitrary point along each side of a native-introduced pasture boundary. To reduce "edge-effect" and yet minimize edaphic variability, each macroplot was located 20 m from the pasture boundary and directly parallel to its counterpart in the other pasture type. Three separate native-introduced pastures within 1.6 km (1 mi.) of each other were chosen as replicates. One set of paired plots was established at each pasture. Species selected for evaluation are listed in Table 1.

Table 1. Species selected for evaluation of solar energy conversion efficiency.

Introduced pasture:		
<i>Agropyron cristatum</i> (L.) Gaertn.	(Agcr)	crested wheatgrass
Native Range:		
<i>Agropyron smithii</i> Rydb.	(Agsm)	western wheatgrass
<i>Bouteloua gracilis</i> (A.B.K.) Lag.	(Bogr)	blue grama
<i>Carex filifolia</i> Nutt.	(Cafi)	threadleaf sedge
<i>Koeleria pyramidata</i> (Lam.) Beauv.	(Kopy)	prairie junegrass
<i>Stipa comata</i> Trin. & Rupr.	(Stco)	needleandthread

Three 100-m transects were located parallel to and 20 m from each other within each macroplot pair. Ten 20 × 50 -cm quadrats per transect were harvested at 10-m intervals for a total of 30 quadrats per macroplot.

Harvest dates were at 2-week intervals beginning May 25, 1977, and ending August 22, 1977. To eliminate the effects of regrowth on digestibility estimates, the starting point for each successive harvest plot was moved back 1 m from the previous location. This allowed sampling of an unclipped area approximately 1 m from the quadrat harvested 2 weeks earlier. Aboveground biomass for each species selected was collected separately for each transect line. Samples were oven-dried at 80°C. for 24 hours, cooled, and weighed to the nearest 0.1 g.

Dried forage samples from each collection date were ground through a 1-mm screen (40 mesh) and digested with a modified two-stage in vitro technique (Harris 1970) to determine percent dry matter digestibility. Percent dry matter digestibility was averaged

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then multiplied by the grams of oven-dried material for each species to obtain an estimate of total digestible nutrients (TDN). Waggoner (1977) reported that values developed in this manner vary from actual TDN by $\pm 3\%$. Digestible energy (DE) was calculated from the formula $DE = 4400 \text{ cal per g TDN}$ (Maynard and Loosli 1969) and converted to joules by multiplying by 4.19 joules per cal (Merck 1968).

Calculation of Digestible Energy Conversion Efficiency

To measure photosynthetically active radiation at the top of the plant canopy, a silicon cell pyranometer and automatic recorder were placed midway between the sample sites. The pyranometer was placed 30 cm above the ground surface and readings were made weekly, from April 25 to August 22, 1981.

Etherington (1974) and Hinds (1975) suggested that energy conversion efficiency (ECE) be calculated from

$$ECE = \frac{\text{Plant energy content m}^{-2}}{\text{intercepted radiation m}^{-2}} \quad (1)$$

Consequently, species digestible energy content must be expressed on a square meter basis.

However, differences in stand architecture and species productivity could bias results from equation (1). Therefore, equation (2) (Campbell 1977) was used to reduce the bias from such differences.

$$PAR = PAR_0 (1 - e^{-KL_A}) \quad (2)$$

In this formula, PAR_0 is the photosynthetically active radiation received at the top of the canopy from April 25, 1977, until the period of most active growth. K is the extinction coefficient for sunlight in the canopy and L_t is the total leaf area. In this study, percent composition by weight for each species was substituted for L_t while a constant value of 0.30 (Singh et al. 1981) was used for K . This allowed a modification of intercepted radiation on an individual species basis. Consequently, species with high production per square meter, such as crested wheatgrass, had much higher PAR values than those with less production.

Selection of the DE content used in calculation of digestible

energy conversion efficiency was based on the period of most rapid plant growth. Because environmental conditions are not limiting during this time, the species' physiological capacity to convert solar energy into a digestible form should be optimal. Growth rate was determined by calculating the net increase (or decrease) in above-ground biomass for each harvest date. The DE content corresponding to the period of most rapid growth was then used in equation (3) to calculate digestible energy conversion efficiency (DECE).

$$DECE = \frac{\text{Digestible energy content (KJ m}^{-2}\text{)}}{\text{PAR (KJ M}^{-2}\text{)}} \quad (3)$$

Data Analysis

Differences in digestible energy content among species were tested for statistical significance with a standard analysis of variance. Means from significantly different sources of variation were compared with the Student-Newman-Keul's test at the 95% confidence level.

Results and Discussion

Environmental Conditions

Based on information from the nearest reporting station, Gillette, Wyo., (2 km), total annual precipitation for 1977 was 121 mm (5 in.) above normal but precipitation for April, May, and June of 1977 was 61 mm (2.5 in.) below normal (U.S. Weather Bureau 1977). The long-term averages for the same station indicated June air temperatures were 5°C . above normal, while July and August temperatures were near normal or below.

The 1977 growing season was characterized by spring drought, intensified by higher than normal air temperatures. However, July and August precipitation was above normal. So, the overall effect appeared to be minor.

Digestible Energy Conversion Efficiency

The date of the most rapid growth and the corresponding digestible energy content for the selected species is shown in Table 2. It is interesting to note that the growth rate of blue grama was greatest in early June rather than late July or August as expected. This may

Table 2. Digestible energy conversion efficiency for six species near Gillette, Wyoming in 1977.

Date	Species	DE KJ m ⁻²	PAR KJ M ⁻²	DECE (%)**	Average
June	AGCR	9501.96	242272.37	.0392	3.16 ^a
		8614.72	278360.13	.0309	
		7909.04	321680.71	.0246	
July 6	AGSM	1401.69	108505.48	.0129	1.43 ^b
		2119.22	140281.70	.0151	
		528.93	35428.68	.0149	
June 8	BOGR	399.32	37323.22	.0106	1.61 ^b
		2190.16	108693.16	.0201	
		1294.74	73008.11	.0177	
June 22	CAFI	394.25	26397.77	.0149	1.56 ^b
		133.84	7085.93	.0189	
		115.04	8852.10	.0130	
June 22	KOPY	1595.00	98662.00	.0162	1.71 ^b
		2133.54	95247.51	.0224	
		112.53	8791.32	.0128	
June 22	STCO	636.23	54464.20	.0116	1.58 ^b
		1421.40	67658.20	.0200	
		5129.89	346072.55	.0148	

**Values with the same superscript are not significantly different at $P < 0.05$.

Table 3. Comparison of mean digestible energy content per gram dry matter.

Species	DE g ⁻¹	Average
AGCR	10.45	8.60***
	7.24	
	8.11	
AGCM	7.61	7.50 ^a
	7.87	
	7.01	
BOGR	7.01	6.89 ^a
	6.77	
	6.89	
CAFI	8.66	7.19 ^a
	8.11	
	4.79	
KOPY	9.46	7.49 ^a
	5.53	
	7.49	
STCO	6.47	6.64 ^a
	8.72	
	4.74	

***Means followed by the same superscript are not significantly different at the 0.50 level.

have been due in part to the lower air temperatures and increased cloud cover in July and August 1977.

Although the initial results (Table 2) indicate that crested wheatgrass is significantly more efficient ($P<0.05$) than the native species, there was a definite bias in the calculation. The level of digestible energy used in estimation of DECE was based in part on aboveground biomass production per square meter. Consequently, crested wheatgrass, which produced more biomass ($P<0.05$) than any of the natives, had the highest level of digestible energy per square meter (Table 2). But comparison of DE per gram of dry matter (Table 3) indicated there were no significant differences ($P>0.05$) between any of the species tested.

Apparently, if the natives had been as productive as crested wheatgrass, there would have been no difference in DECE.

This idea was tested by assuming 1,000 g m⁻² of biomass production for all species. When this was done, there was no significant difference ($P<0.05$) between species in their physiological capability to convert solar energy into a digestible form.

Conclusions

Crested wheatgrass, western wheatgrass, blue grama, threadleaf sedge, prairie junegrass, and needleandthread all appear equally capable of converting solar energy into a digestible form. The

overriding cause for differences between the species in this study was aboveground production. Crested wheatgrass grown in a monoculture produced more dry matter per square meter than did the natives and since digestible energy content was based in part on ry matter production, crested wheatgrass also produced the most digestible energy per square meter. The magnitude of this difference was great enough to limit the effectiveness of equation (2) in reducing the bias from stand architecture. Thus, it appears that little improvement in forage quality could be gained by screening varieties or species on the basis of digestible energy conversion efficiency calculated in the manner of this study. But before the concept of digestible energy conversion efficiency is entirely dismissed, it may be worthwhile to conduct the experiment again using digestible energy produced on an individual plant or unit leaf area basis. This approach coupled with the refinements in intercepted energy gained from equation (2) might provide a better comparison of species' physiological capacity to convert solar energy into a digestible form.

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