Reprinted from *Journal of Range Management*
Vol. 35, No. 5, September 1982, p. 623-627

Switchgrasses: Forage Yield, Forage Quality and Water-use Efficiency

P.T. KOSHI, J. STUBBENDIECK, H.V. ECK, AND W.G. MCCULLY

Abstract

The purpose of the study was to evaluate 3 strains of switchgrass (*Panicum virgatum* L.) under 3 water and 3 harvest regimes. Dry matter yields, under natural rainfall and full irrigation, averaged 2.0 and 6.7 metric tons/ha, respectively. Productivity of the 3 strains ranked G 300>HV-341>Blackwell. Yields of HV-341 and Blackwell were similar under 1, 2, or 3 harvests per year but those of G-300 were reduced by 2 or 3 harvests. Switchgrass forage contained about 10.8% crude protein (CP) and 0.23% P in late June. In November, previously unclipped forage contained 4.3% CP and 0.12% P, while that clipped twice contained 5.5% CP and 0.15% P. Maximum production was obtained with 116.5 cm of water use but maximum water use efficiency was obtained with about 85.5 cm of water use (rainfall + irrigation + soil water). The switchgrasses are adapted for use both without irrigation and when varying amounts of irrigation water are availble. G-300 yielded more and produced earlier and later than the other two strains thus it may be the best choice for use for range improvement or for irrigated pastures. However, it requires careful management because it is more susceptible to overuse than the other two strains.

Switchgrass (*Panicum virgatum* L.) is a perennial tallgrass adapted to the diverse climate and soils of the mid-continent and is widely distributed throughout the United States (Hitchcock 1951). It is a productive warm-season forage-grass used primarily for summer grazing, and is most abundant on sandylands of the remaining natural grasslands of the Great Plains. Adapted strains and varieties are used in pure stands or in mixtures with other warm-season prairie grasses for range, pasture, and conservation plantings.

In the Southern High Plains, yields of upland native rangeland were estimated to be from 730 to 1,120 kg/ha on deep sand sites (Wilhite 1965), and from 2,240 to 2,575 kg/ha on sandhill sites with more favorable plant-soil-water relations (Wilhite 1959). Most of these sites are now producing much less than their potential because of deteriorated range condition.

Forage quality is an essential criterion in the selection and management of forage for livestock consumption. Phosphorus and protein are the most deficient components in livestock nutrition in the southwest.

Crude protein in Texas range grasses decreases during the growing season and is not closely related to soil nitrogen content (Fudge and Fraps 1945). In Northwest Texas the phosphorus content of forage was sufficient for range cattle in 66% of the grasses early in the growing season but deficient in 91% of the grasses at maturity (Fudge and Fraps 1945). Average protein content of short and mid-grasses of the southern mixed prairie in Texas seldom meet the protein requirements of beef cows (Rogers and Box 1967).

Performance with limited moisture is of primary concern in evaluating and selecting superior forage plants. Water-use efficiency (forage production/unit of water) is of prime importance in selecting material for seeding deteriorated rangelands and submarginal croplands in semiarid areas.

Water-use efficiency varies among native grasses (Weaver 1941). Dobrenz et al. (1969) working with eight clones of blue panic (*Panicum antidotale* Retz) showed no significant difference in transpired water between the highest and lowest water-use efficiency clones. In Nebraska, southern switchgrass yielded more forage than either local or northern strains (Newell 1968). A late-maturing southern strain, however, was adversely affected by close and frequent clippings.

This study was designed to compare the effects of three water regimes and three harvesting regimes on forage yield, water-use efficiencies, and forage quality of three switchgrasses from Texas and Oklahoma. Knowledge of the performance of these grasses under different water inputs and availability would be valuable in plant selection and breeding. This knowledge would also be very useful in developing management practices to maximize forage yields.

Methods and Materials

The study was conducted at the U.S. Big Spring Field Station, Big Spring, Texas, on Amarillo fine sandy loam, an Ardic Paleustalf of the fine-loamy, mixed, thermic family. The soil has been described in detail by Burnett et al. (1962). The 74-year average preseasonal precipitation (November–March) and seasonal precipitation (April–October) are 9.7 and 37.1 cm, respectively. The average growing season is 222 days.

The three strains of switchgrass were: Blackwell (originally collected near Blackwell, Okla.); G-300 (collected from South Texas near Raymondville); and HV-341 (collected from North-Central Texas near Breckenridge).

Three water regimes and 3 harvest regimes were applied in a 4-year study. Water variables occupied main plots (9 × 12 m); switchgrass strains occupied subplots (3 × 12 m); and harvest variables occupied sub-subplots (3 × 4 m) in a split-split-plot design with 3 replications. Main plots were leveled and bordered to contain all precipitation and irrigation water. In 1968, greenhouse-grown seedlings were transplanted into 4-row plots at 50- by 50-cm spacings. Water regimes and harvesting treatments were started in 1970. Data were collected from the center 2 rows.

Water regimes were: W_1 (precipitation only); W_2 (10 cm of water applied when W_3 required irrigation); and W_3 (20 cm of water applied when 20 cm of water had been depleted from the upper 180 cm of the soil profile. Soil water was measured each month, using the neutron scattering technique. Measurements were made at 20-cm increments to a depth of 360 cm. Growing season precipitation, irrigation water applied, soil water depletion, and total water use are presented in Table 1. Growing season precipitation was only 59% of average in 1970, near average in 1973, and above the long-time average in the other seasons.

Harvesting intensities to remove half the current production were (H_1) 1 clipping to 35-cm stubble height at the end of the growing season; (H_2) 2 clippings to 35-cm stubble height, one at mid-season, and the other at the end of the growing season; and

Authors are soil scientist, U.S. Dep. Agr., Big Spring, Texas, (retired); associate professor of agronomy, University of Nebraska, Lincoln; soil scientist, U.S. Dep. Agr. Bushland, Texas; professor of range science, Texas Agr. Exp. Sta., College Station.

This report is a contribution from U.S. Dep. Agr., Agr. Res. Serv., in cooperation with the Texas Agr. Exp. Sta., Texas A&M Univ., College Station 77843.
Manuscript received July 10, 1980.

(H_3) clippings at 6 or 10-week intervals during the growing season. Clipping began in 1970 when 50% of the above-ground production yielded stubble 10 cm high and then at 6-week intervals for a total of 5 clippings. This level of harvesting seemed too severe and the 1971–1973 H_3 clippings were started when 50% forage removal yielded stubble 30 cm high. Succeeding clippings were at 10-week intervals for a total of 3 clippings. Representative forage samples (approximately 1000g) were oven-dried at 65° C. Forage yields are reported on the oven-dried basis. Oven-dried samples were ground with a Wiley mill to pass a 40-mesh screen.

Total nitrogen ws determined by the Kjeldahl method (as modified to include nitrates) and multiplied by 6.25 to obtain percent crude protein (CP). Forage was wet-ashed by the method of Wolf (1944) and total phosphorus was determined colorimetrically (Watanabe and Olsen 1965). The data were statistically evaluated by analysis of variance and significances were tested by the Student-Newman-Keuls method (Federer 1955).

Soil tests were made each year and fertilizer was applied to obtain vigorous plants and good grass growth. In 1969, 1970, and 1971, 16-20-0 fertilizer was used. Rates of nitrogen and P_2O_5 were, respectively, 100 and 125 kg/ha in 1969, and 200 and 250 kg/ha in 1970 and 1971. In 1972 and 1973, the soil tests indicated that only nitrogen was required. In those years, ammonium nitrate was applied at 200 kg N/ha.

Fertilizer was applied in a single spring application in 1969. In later years, a split application was used with half of the fertilizer applied in April or May, and the other applied in July.

Results and Discussion

The southernmost strain, G-300, began growing 1 to 3 weeks earlier than HV-341 or Blackwell. Blackwell headed in early June, HV-341 in mid-June, and G-300 in late June to early July. In 1971, the representative plant heights after heading were 120, 125, and 150 cm for Blackwell, HV-341, and G-300, respectively.

Forage Yields

Average annual yields of the 3 strains were G-300:5.9; HV-341:4.6; and Blackwell:4.1 metric tons per hectare (Fig. 1). Without irrigation, the 3 strains produced similar yields, on the W-2 treatment, Blackwell and HV-341 produced similar yields and G-300 outyielded both of them; and on the W_3 treatment, yields were highest from G-300, intermediate from HV-341 and lowest from Blackwell. Average annual forage yields on the lower irrigation level were almost triple those on the nonirrigated treatment and were 87% of those on the higher irrigation level. The switchgrasses showed more response to irrigation than cane bluestems. In a similar experiment (Koshi et al. 1977) cane bluestem responded to the lower irrigation level but additional water did not further increase yields.

The average data show that similar total yields were produced under all 3 harvest regimes (Fig. 1). However, harvest regimes had some effect on when the forage was produced and the 3 selections performed differently under different harvest regimes (Fig. 2). With end of season harvest only (H_1), the grasses produced about 37% of their growth by mid-June, about 22% between mid-June and mid-July, and 41% after mid-July. When harvested in July and November (H_2), they produced 72% of their growth by mid-July and 28% after mid-July. When harvested in mid-June, late August, and November (H_3), they produced 41% of their growth by mid-June, 50% between mid-June and mid-August and 9% after mid-August.

Two factors made major contributions to the higher forage yields of G-300. They were (1) its ability to produce high yields with end of season harvest only (H_1) and (2) its higher production after mid-July (Fig. 2, H_2. Under H_1, it outyielded the other 2 selections and with 2 harvests per season (H_2) it outyielded Blackwell. With 3 harvests per season (H_3) the 3 selections produced similar yields. The trend of decreasing relative yield with increasing harvest pressure, plus yield data and observations in 1970 when the grasses were harvested 5 times (Fig. 2), indicate that G-300 was more adversely affected by frequent harvesting than the other 2 grasses.

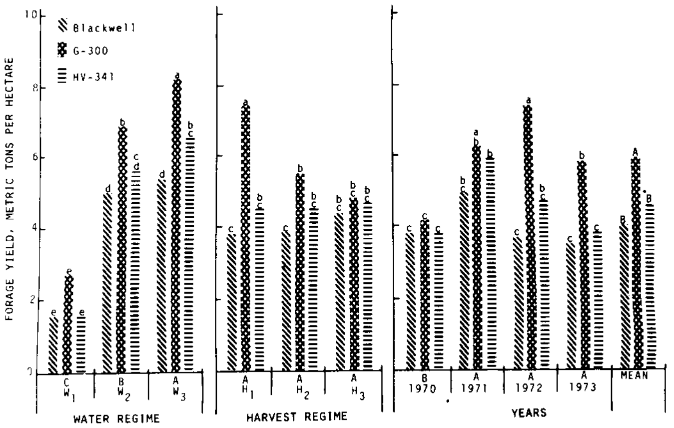

Fig. 1. *Mean forage yields of three switchgrass strains. Bars with the same letter are not significantly different at the 0.05 level of probability.*

Forage Quality

The crude protein (CP) data (Table 2) show that strains and water levels had relatively minor effects on CP concentrations while harvest regimes had major effects. Average CP was highest in G-300, intermediate in HV-341 and lowest in Blackwell. Average CP was highest in the nonirrigated treatment while levels were

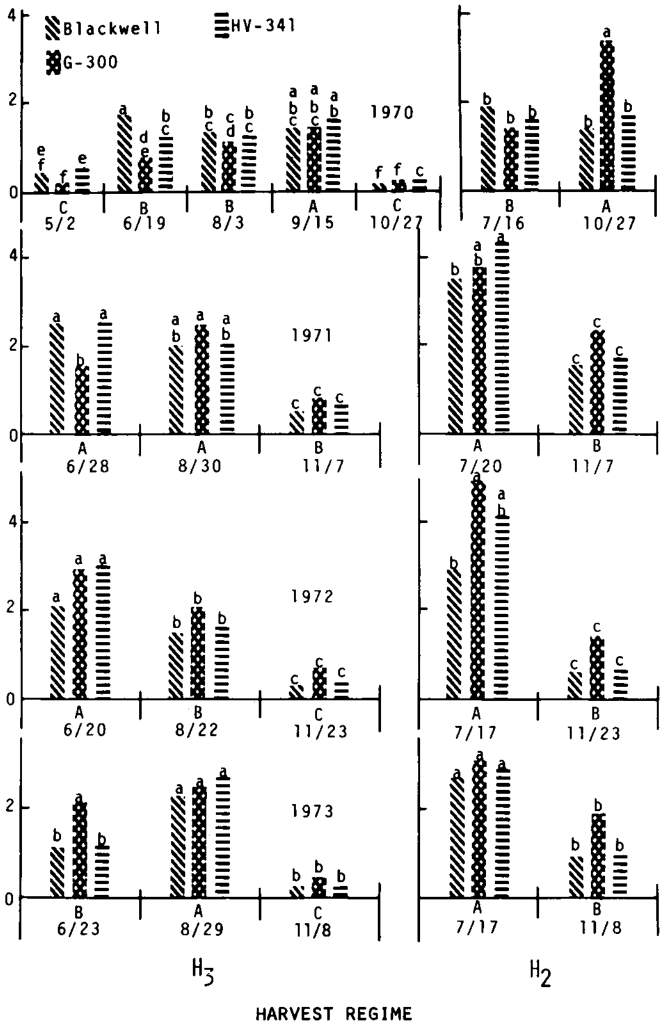

Fig. 2. *Per-clipping yields of three switchgrass strains from H_3 and H_2 harvest regimes. Bars with the same letter are not significantly different at the 0.05 level of probability.*

Table 1. Growing season precipitation, irrigation, soil water depletion, and seasonal water use by switchgrasses.

Year	Water input	Water regime (cm) W_1	W_2	W_3
1970	Precipitation	22.0	22.0	22.0
	Irrigation	0.0	35.0	70.0
	Soil water depletion[1]	37.9	38.1	21.9
	Total water use	59.9	95.1	113.9
1971	Precipitation	43.7	43.7	43.7
	Irrigation	0.0	40.0	80.0
	Soil water depletion	7.5	-17.4	-13.2
	Total water use	51.2	66.3	110.5
1972	Precipitation	44.2	44.2	44.2
	Irrigation	0.0	46.0	81.0
	Soil water use	-7.8	3.1	3.9
	Total water use	36.4	93.3	129.1
1973	Precipitation	37.7	37.7	37.7
	Irrigation	0.0	20.0	43.3
	Soil water use	22.9	30.8	31.3
	Total water use	60.6	88.5	112.3
Average annual water use		52.0	85.5	116.5

[1]Total soil water to 360 cm in March less that present in November.

similar on the W_2 and W_3 treatments. The 1971-73 data show that CP was high early in the season and it declined as the season advanced. In previously unharvested grass it averaged 10.82% in late June, 8.98% in mid-July, and 4.29% in mid-November. However, when the grass was harvested in June and again in August, CP contents remained higher throughout the season. The average had declined to 9.92% by late August and to 6.06% by mid-November. The effect of harvest regime on forage yield, CP yield, and CP content of the harvested forage is illustrated in Figure 3. Data are combined averages for 3 switchgrass strains for W_3 for 1971, 1972, and 1973. In the A section, data are plotted for the first dates of sampling from H_3, H_2, and H_1. The resulting curves are assumed to describe cumulative growth for H_1. In the B section, all data are from H_3 and describe cumulative growth for that harvest regime. Utilization during the growing season increases both CP yields and average CP content of the total forage produced. When plants were not harvested until the end of the season (H_1), they proceeded through the reproduction stage with much of the forage matured at the time of removal, resulting in sharply decreased protein contents. However, when they were harvested before they reached maturity, forage at the first harvest was high in protein and later growth remained vegetative and protein contents were maintained at higher levels. Data from the H_2 harvest regime (Table 2) show that delaying the first harvest until mid-July resulted in decreases in protein contents but those decreases were not nearly so drastic as those encountered when harvest was delayed until the end of the growing season.

The CP data obtained in 1970 (Table 2) were not consistent with those obtained during the 1971-73 period. Inconsistency in data from the H_3 harvest regime may be partially attributable to the frequency of harvests in 1970. Also, timing of irrigation and of fertilizer application may have caused inconsistencies in H_3 as well as in the other harvest regimes.

The CP requirements specified by the National Academy of Sciences (6) for beef cattle are: 9.2% for 450 kg cows nursing calves; 8.9% for growing steers with 0.5 kg/day gain; and 5.9% for dry pregnant cows. A grazing schedule similar to the H_3 harvest could supply nursing cows with adequate CP for at least 3 months. The forage of the first clipping of all strains and second clipping of the G-300 from the H_2 harvest could supply the CP needs of growing steers. Mature forage from the H_1 harvest was inadequate and would require CP supplementation regardless of the class of beef cattle used.

Trends in the phosphorus (P) data were similar to those in the CP data, even to the extent that the 1970 data were not consistent with those from 1971, 1972, and 1973. Phosphorus content, like CP, was more affected by harvest regime than by water levels or switchgrass strains (Table 3). G-300 was highest in P, Blackwell was intermediate, and HV-341 was lowest. However, P contents in Blackwell and HV-341 were not significantly different. Average P level was highest on the nonirrigated treatment while levels were similar on the W_2 and W_3 treatments. Also, like CP, P content was high early in the season and declined as the season advanced. The 1971-73 data show that in previously unharvested grass, it averaged 0.232% in late June, 0.223% in mid-July, and 0.116% in mid-November. However, when the grasses were harvested in June and again in August, P contents remained higher throughout the season. The average had declined to 0.211% by late August and to

Table 2. Crude protein concentrations (%) in switchgrass forage at various clipping dates.

Harvest regime	Clipping dates	Water Regime W_1	W_2	W_3	Strains Blackwell	G-300	HV-341	s Means
					1970			
	5/2	6.56	6.60	7.07	7.78	6.13	6.32	6.74E[1]
	6/19	5.12	5.56	5.24	4.89	5.44	5.59	5.30F
H_3	8/3	5.92	10.24	10.79	8.64	9.67	8.64	8.94D
	9/15	14.32	15.49	14.84	14.38	15.26	15.00	14.88A
	10/27	15.44	13.43	12.88	13.67	14.76	13.33	13.92B
H_2	7/16	3.48	6.45	5.88	4.71	5.62	5.49	5.27F
	10/27	13.20	9.85	8.60	9.49	12.37	9.78	10.55C
H_1	10/27	6.58	8.24	7.66	5.71	8.02	8.76	7.49E
	Means	8.83B	9.48A	9.12AB	8.66B	9.66A	9.11AB	9.14
					1971-73			
	6/25	12.51a[2]	10.20b	9.74b	10.64ab	11.30a	10.51b	10.82A
H_3	8/27	10.36b	9.84b	9.54bc	9.79bc	10.11b	9.85bc	9.92B
	11/13	6.18e	5.62ef	6.40e	5.09gh	7.56e	5.54g	6.06D
H_2	7/18	9.55bc	8.62d	8.76d	8.75d	9.10cd	9.08cd	8.98C
	11/13	5.50ef	5.50ef	5.91ef	4.78ghi	6.67f	5.36gh	5.60E
H_1	11/13	5.04f	3.72g	4.10g	3.96i	4.40hi	4.50hi	4.29F
	Means	8.19A	7.23B	7.41B	7.17C	8.19A	7.47B	7.61

[1]Means with different upper-case letters are significantly different at the 0.05 level of probability.
[2]Averages with different lower-case letters are significantly different at the 0.05% level of probability.

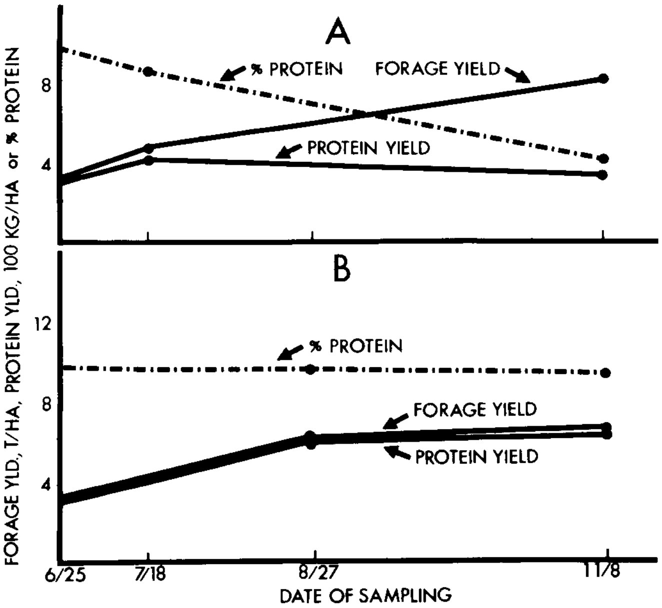

Fig. 3. *Forage yield, protein yield and percent crude protein in forage at various harvest dates, W_3, average 1971-73; (A) H_1 harvest regime; (B) H_3 harvest regime.*

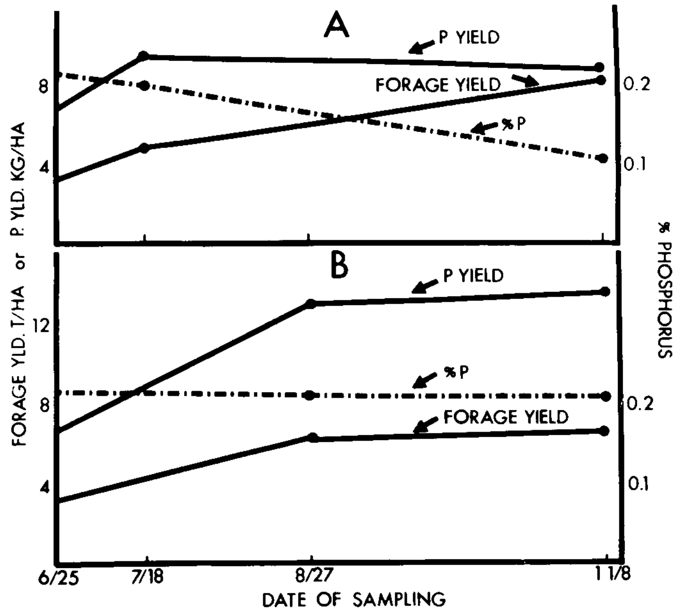

Fig. 4. *Forage yield, phosphorus yield and percent phosphorus in forage at various harvest dates, W_3, average 1971-73; (A) H_1 harvest regime, (B) H_3 harvest regime.*

0.154% by mid-November. Data from the H_2 harvest regime (Table 3) show that delaying the first harvest until mid-July did not result in significant decreases in P content of the forage. The effect of harvest regime on forage yield, P yield and P content of the harvested forage is illustrated in Figure 4. Data were selected from the same treatments as those used for CP in Figure 3. Results and reasons for them are similar to those given for CP.

The National Academy of Sciences (1970) P requirements of beef cattle are: 450 kg cows nursing calves, 0.22%; for growing steers with 0.5 kg/day gain, 0.18%; and for dry pregnant cows, 0.16%. Forages of the three switchgrass strains could supply the required dietary P for nursing cows at least through mid-July. Also there is adequate P for growing steers to late August. With two or more clippings, forages at the end of the growing season are almost adequate for dry pregnant cows, especially with the G-300 strain. The mature forage of the H_1 requires phosphorus supplementation for all classes of beef cattle.

Water Use and Water-use Efficiency

Water use data are given in Table 1. The W_2 and W_3 treatments were irrigated 4 times yearly from 1970 through 1972. Only 2 irrigations were necessary in 1973 because of substantial soil water storage from above-average, early-season precipitation which was followed by well distributed growing season precipitation. Average annual water use on the W_1, W_2, and W_3 treatments was 52.0, 85.8, and 116.5 cm, respectively. Stored soil water was very important under the W_1 and W_2 treatments.

Water-use efficiency data are presented in Figure 5. Since the 3 switchgrass strains exhibited similar total water use, water use efficiencies were proportional to forage yields. Thus, the 3 strains

Table 3. Phosphorus concentrations (%) in switchgrass forage at various clipping dates.

Harvest regime	Clipping dates	Water Regime			Strains			Means
		W_1	W_2	W_3	Blackwell	G-300	HV-341	
					1970			
H_3	5/2	0.271	0.264	0.244	0.254	0.270	0.256	0.260A[1]
	6/19	0.193	0.174	0.173	0.168	0.208	0.166	0.180C
	8/3	0.154	0.263	0.269	0.233	0.227	0.237	0.229B
	9/15	0.244	0.258	0.279	0.228	0.294	0.259	0.260A
	10/27	0.258	0.201	0.223	0.204	0.257	0.221	0.227B
H_2	7/16	0.108	0.188	0.200	0.146	0.171	0.179	0.165C
	10/27	0.233	0.253	0.231	0.221	0.270	0.227	0.239AB
H_1	10/27	0.127	0.119	0.120	0.108	0.131	0.127	0.122D
	Means	0.199B	0.215A	0.218A	0.194C	0.228A	0.209B	0.210
					1971-73			
H_3	6/25	0.252a[2]	0.227ab	0.218b	0.228ab	0.248a	0.221ab	0.232A
	8/27	0.219b	0.212b	0.202b	0.205bc	0.221ab	0.207bc	0.211B
	11/13	0.174c	0.135def	0.152cde	0.143e	0.177d	0.142e	0.154C
H_2	7/18	0.247a	0.213b	0.208b	0.226ab	0.231ab	0.211be	0.223AB
	11/13	0.165cd	0.140def	0.162cd	0.144e	0.183cd	0.141e	0.156C
H_1	11/13	0.125ef	0.110f	0.116f	0.129e	0.108f	0.112e	0.116D
	Means	0.197A	0.173B	0.176B	0.179B	0.195A	0.172B	0.182

[1]Means with different upper-case letters are significantly different at the 0.05 level of probability.
[2]Averages with different lower-case letters are significantly different at the 0.05% level of probability.

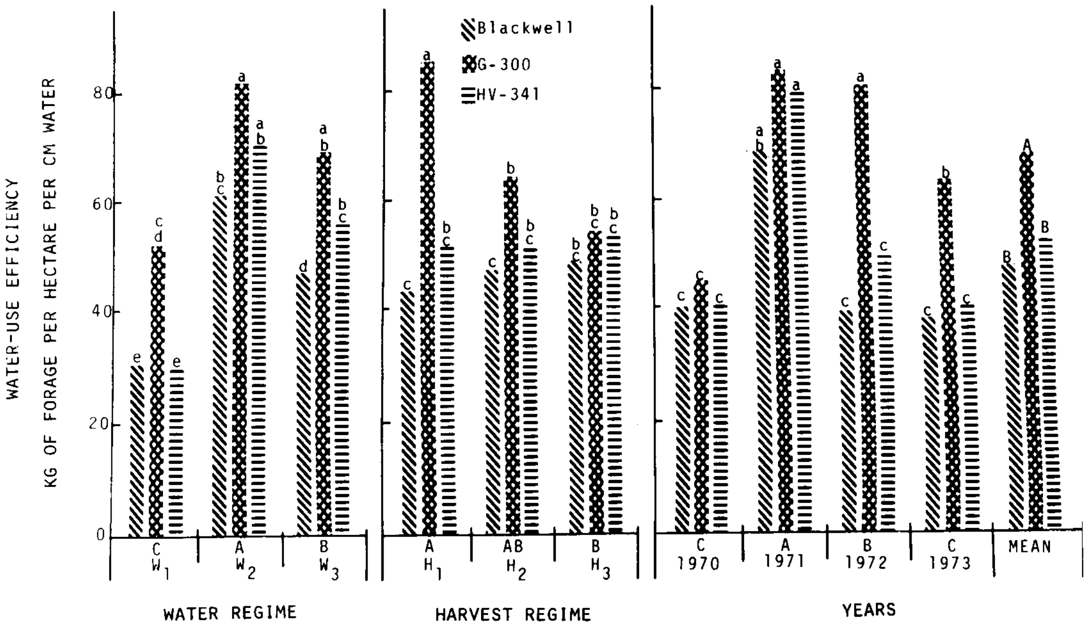

Fig. 5. *Water-use efficiencies of three switchgrass strains. Bars with the same letter are not significantly different at the 0.05 level of probability.*

had the same relative ranking in water-use efficiency as they had in yield. Highest water-use efficiencies were obtained under the intermediate water level. Those under the high water level were intermediate while those on the nonirrigated treatment were lowest. Since water use efficiency was higher on W_2 than on W_3 and yields on W_3 were only slightly higher than those on W_2, it appears that the average annual water use on W_2 (85.5 cm) was insufficient for maximum yields of switchgrass while that on W_3 (116.5 cm) was in excess of the needs of the plants. If the timing of irrigation was satisfactory to keep the plants growing rapidly, the average annual water use on W_3 (116.5 cm) was more than adequate for maximum yields of these switchgrasses under the uniform fertility imposed.

Water-use efficiency was significantly higher on the H_1 harvest regime than on the H_3 regime. This was caused by the comparatively high yield of G-300 on the H_1 regime (Fig. 1).

Summary and Conclusions

Three strains of switchgrass (*Panicum virgatum* L.) were evaluated under 3 water and 3 harvest regimes. Strain G-300 yielded more forage and had higher water-use efficiency, higher crude protein, and higher phosphorus content than Blackwell or HV-341. Yields were highest on the wettest water regime [(w_3) 20 cm of water applied when 20 cm of water had been depleted from the upper 180 cm of the soil profile] but water was used more efficiently under the intermediate water regime [(w_2) 10 cm of water applied when W_3 required irrigation]. Water use efficiency was lowest under natural rainfall conditions (W_1). The 3 strains produced similar yields when harvested 3 times per season but with 2 harvests, G-300 yielded significantly more than Blackwell and with a single harvest, it outyielded both Blackwell and HV-341. Frequent harvesting weakened G-300 more than the other 2 strains.

Forage crude protein and phosphorus levels were affected more by harvest regimes than by strains or water levels. They were highest with 3 harvests per season and lowest with a single harvest. With summer grazing, the switchgrasses would supply sufficient crude protein and phosphorus for all classes of beef cattle for most of the growing season. However, for winter utilization of the forage, both crude protein and phosphorus supplementation would be required.

The switchgrasses produced about 2 metric tons of good quality forage ha^{-1} yr^{-1} under nonirrigated conditions and 6.7 metric tons ha^{-1} under full irrigation. Since they tolerate dry conditions and respond to irrigation, they are adapted for use both without irrigation and when varying amounts of irrigation water are available. Since G-300 yielded more and produced earlier and later than the other 2 strains, it may be the best choice for use for range improvements or for irrigated pastures. However, if it is used, it should be managed carefully since it is more susceptible to overuse than the other 2 strains.

Literature Cited

Burnett, E., H. Oakes, and C.L. Godfrey. 1962. Soils of the Big Spring Field Station. Texas Agr. Exp. Sta. Misc. Pub. 559. 12 p.

Dobrenz, A.K., L.N. Wright, M.A. Massengale, and W.R. Kneebone. 1969. Water-use efficiency and its association with several characteristics of blue panic grass (*Panicum antidotale* Retz.) clones. Crop Sci. 9:213-216.

Federer, W.T. 1955. Experimental Design. The MacMillan Co., New York. 544 p.

Fudge, J.F., and G.S. Fraps. 1945. The chemical composition of grasses of Northwest Texas as related to soils and to requirements for range cattle. Texas Agr. Exp. Sta. Bull. 669.

Hitchcock, A. 1951. Manual of the grasses of the United States. USDA Misc. Pub. 200. 1051 p.

Koshi, P.T., H.V. Eck, J. Stubbendieck, and W.G. McCully. 1977. Cane bluestems: Forage yield, forage quality, and water-use efficiency. J. Range Manage. 30:190-193.

National Academy of Sciences. 1970. Nutrient requirements of domestic animals. No. 4. Nutrient requirements of beef cattle (4th revised edition). 55 p.

Newell, L.C. 1968. Effects of strain source and management practice on forage yields of two warm-season prairie grasses. Crop Sci. 8:205-210.

Rogers, J.D., and .T.W. Box. 1967. Seasonal protein content of four southern mixed prairie grasses. J. Range Manage. 20:177-178.

Watanabe, F.S., and S.R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Amer. Proc. 29:677-678.

Weaver, R.J. 1941. Water use of certain native grasses in prairie and pasture. Ecol. 22:175-192.

Wilhite, A.T. 1959. Use and management of rangeland. *In:* Soil Survey Terry County, Texas. USDA-SCS, Soil Surv. Ser. 1959. No. 6:30-33.

Wilhite, A.T. 1965. Use of soils for range. *In:* Soil Survey Gaines County, Texas. USDA-SCS Soil Surv. Ser. 1965, No. 34:28-33.

Wolf, B. 1944. Rapid photometric determination of total nitrogen, phosphorus, and potassium in plant material, Ind. and Eng. Chem. 16:121-123.