RESPONSE OF WW-517 OLD WORLD BLUESTEM TO FERTILIZATION, WATERING, AND CLIPPING

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ABSTRACT

An experiment (TUBE) was conducted to evaluate the effect of two levels of fertilizer, two levels of watering, and clipping on dry matter (DM) and crude protein yield, water use efficiency (WUE), and end of season root weights of WW-517 Old World Bluestem (OWB) (Bothriochloa intermedia var. indica) established in plastic tubes buried in the soil. A second experiment (MICROPLOT) evaluated dry matter and crude protein yield of OWB, in 2.7 ft² plots within a two year old grass stand, at two levels of fertilizer and five clipping regimes. In the TUBE experiment, fertilization had no effect on leaf yields, but the wet-clipped treatment increased leaf yields 40% compared to dry-unclipped plants. Level of fertilizer applied did influence OWB stem, top-growth (aboveground portion less stubble), and aboveground yields. The wet-fertilized-clipped treatment increased top-growth and above ground yields by 54 and 49% when compared to dry-unfertilized-unclipped plants. Frequency of watering, unlike fertilization or clipping, did not significantly influence OWB WUE. Water use efficiency of OWB, averaged across watering regimes, was 1.2 and 0.7 g DM/L water for fertilized-clipped and unfertilized-unclipped plants, respectively. Leaf crude protein yield of wet-fertilized plants was at least 35% greater than other treatments. End of season root weights increased with frequency of watering, but declined with fertilization and clipping. In the MICROPLOT experiment, leaf, top-growth, and crude protein yields were enhanced by fertilization and clipping. Results from this study indicate fertilization coupled with clipping at proper intervals increased aboveground plant yield and nutritive value. Response to these treatments was further enhanced with addition of water. In contrast, root weights were reduced following fertilization and clipping. Reduction in root weights, likely decreased the volume of soil from which plants could extract water and nutrients and may ultimately have an adverse affect on plant vigor.

INTRODUCTION

As a group, Old World bluestems are endemic to mid eastern countries. They possess the C_4 carbon assimilation pathway (Downton 1975) and most reproduce apomictically (Harlan et al. 1964). These grasses were first introduced into the United States in 1917 for use as improved forage plants and for soil stabilization purposes. Old World bluestems have significantly contributed to beef production in the Southern Great Plains because they are superior to native North American bluestems in production, persistence under grazing, and response to fertilization (Sims and Dewald 1982).

WW-517 Old World bluestem (**Bothriochloa intermedia** var. **indica**) is a selection from blends of genetically diverse bluestems with morphological similarities from Pakistan and Afghanistan (Sims and Dewald 1982). Sims et al. (1983) found animal performance on WW-517 comparable to WW-Spar, a released variety of Old World bluestem.

Forage yield, crude protein content, and water use efficiency can be enhanced by fertilization, irrigation, and defoliation (Wight and Black 1979; McMurphy et al. 1975; Smika et al. 1965; Jameson 1963). In Oklahoma, Caucasian bluestem (**Bothriochloa caucasia**) production increased 2000 and 1350 lb/ac during a wet and dry year following fertilization with 55 lb N/ac (Berg and Coyne 1983). The response of WW-517 Old World bluestem to fertilization, watering, and clipping must be understood to properly manage the species. With proper coordination of these treatments, plant yield, crude protein content, and water use efficiency can be enhanced. The objective of this study was to evaluate the effect of fertilization, watering, and clipping on aboveground, root, and crude protein yield, and water use efficiency of WW-517 Old World bluestem.

METHODS

To accomplish the objective of this study, TUBE and MICROPLOT experiments were conducted. In the TUBE experiment, WW-517 Old World bluestem plants were grown in plastic tubes buried in a field environment. As a result, response of aboveground and root portions of plants to fertilization, watering, and clipping could be evaluated. The MICROPLOT experiment was undertaken to determine the response of OWB; top-growth (aboveground plant portion less the stubble) to fertilization and clipping in a field environment.

TUBE Experiment

During the fall of 1981, 342 Visten plastic tubes (12 inches diameter X 24 inches length), sealed at one end, containing 90 lb of Amarillo fine sandy loam soil (fine, loamy, mixed, thermic Aridic Paleustalf), were placed in holes. Tubes were secured in the soil with the open ends exposed. On 4 June 1982, approximately 25 caryopses of WW-517 Old World bluestem (OWB) were planted in each of 342 tubes. At the four leaf growth stage, seedlings were thinned to four per tube. Plants were uniformily watered every 14 days throughout the summer and early fall of 1982.

On 28 April 1983 OWB plants within the tubes were clipped to a 3-inch stubble height. At this time 20 tubes containing OWB were excavated and soil washed from the plant roots. This preliminary harvest provided information on aboveground and root portions prior to treatment application.

On 29 April 1983, 168 randomly selected tubes were fertilized each with 3.8 g NH_4NO_3 and 3.0 g KH_2PO_4 (comparable to broadcast fertilizer application rate of 65-30-40 lb N-P-K/ac). Watering started on 12 May and ended 1 November 1983. Ninety-eight of the fertilized tubes (F) and 84 unfertilized tubes (UF) were watered to field capacity once every seven days (WET) while remaining tubes were watered to field capacity at 14 day intervals (DRY). As a result of the limited volume of soil within the plastic tubes all plants were watered during the experiment.

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Soil samples were collected from four tubes per treatment combination 24 hours prior to watering, oven dried at 220°F, and weighed. An average water content of the four samples was obtained and amount of water applied to each tube was determined by comparing the average water content of the soil within the tubes with a water retention curve delineated for the soil. A pressure plate apparatus as described by Richards (1947) was used to determine water retention values for the soil. To lessen impact of soil removal during the study only two cores (10 inches length × 0.75 inch diameter were taken from any tube. In addition, oven dried loamy sand soil, passed through a 0.5 mm mesh screen, replaced soil removed during sampling.

Clipping treatments took place between 17 May and 15 September 1983. Half the OWB within each fertilization by watering treatment combination were clipped to a 3-inch stubble height when regrowth height reached 12 inches. To obtain an estimate of cumulative yield all plants were clipped to a 3-inch stubble height on 15 March 1984. At each clipping date aboveground plant portions were oven dried at 140°F for 48 hours. After drying, top-growth samples were separated into leaves (leaf sheath and blade) and stems then weighed. Leaf and stem tissue were then ground in a Wiley Mill. Crude protein content (CP) of these tissues was determined using the microkjeldahl procedure for nitrogen determination (N) (CP = % N × 6.25) (A.O.A.C. 1960).

At each top-growth harvest 14 plants per fertilization and watering treatment were excavated from the field. Seven of the excavated plants had been clipped according to previously specified clipping criteria. Remaining plants were not clipped until the date of excavation. Thus, a comparison between periodically clipped (C) and unclipped (UC) plants was possible. Soil was washed from plant roots within the excavated tubes. To reduce root loss, soil was washed through two, 0.5 mm mesh screens. Washed plants were oven dried, separated into aboveground and root portions, and weighed.

Immediately before excavation, gravimetric soil samples were taken from each tube. Soil water content of excavated tubes were used to estimate plant water use from the beginning of the growing season to time of excavation. Water use efficiency was calculated by dividing top-growth dry matter weight by amount of water added to tubes during the growing season minus amount of water present in the soil at time of harvest. When precipitation occurred on the study site it was assumed that it fell uniformly on all plants, regardless of treatment. Precipitation amounts were added to amount of water added during watering events and this combined total was used in calculating WUE. Precipitation data are presented in Figure 1A.

To obtain estimates of cumulative plant dry matter, crude protein yield, and top-growth water use efficiency for the growing season, seven plants (plants were the experimental units) per fertilization, watering, and clipping treatment combination were randomly selected and were not excavated until the final harvest date, 15 March 1984. Remaining plants were relegated to excavation following top-growth harvest.

MICROPLOT Experiment

On 21 May 1982, a 2.5 ac field near Brownfield, Texas was seeded with WW-517 Old World bluestem at a rate of 2 lb PLS/ac. The soil on the Brownfield study site was an Amarillo loamy fine sand (fine, loamy, mixed, thermic Aridic Paleustalf). On 17 March 1984 the site was burned to remove standing dead plant material. On 20 April 1984 ten, 30 × 30 ft plots were established in the grass stand at the study site. Five plots were randomly selected and fertilized at a rate of 55-27-36 lb N-P-K/ac.

Five clipping treatments were conducted between 1 June and 15 September 1984 and on 9 March 1985. In May 1984 25, 2.7 ft² plots (microplots) were located within fertilized and unfertilized plots within the grass stand. The five clipping treatments were randomly assigned to five microplots located in each fertilized or unfertilized plot. The first treatment (D1) involved clipping five previously unclipped microplots on 9 March 1985. The second treatment (D2) consisted of clipping five microplots at 45 day intervals from 1 June to 30 August 1984 and on 9 March 1985. WW-517 Old World bluestem undergoing clipping treatments D1 and D2 were harvested to 3-inch stubble heights. The final three clipping treatments involved clipping OWB within five microplots each to either a 3-inch (D3) (same clipping criteria used in the TUBE experiment), 2-inch (D4), or 4-inch (D5) stubble height when regrowth height reached 12 inches. Plants undergoing clipping treatments D3, D4, and D5 were clipped from 1 June 1984 to 15 September 1984 and on 9 March 1985. Harvested top-growth from microplots was oven dried, separated into leaf and stem portions, and weighed. Crude protein content of plant tissues was determined as mentioned previously. Precipitation data are presented in Figure 1B.

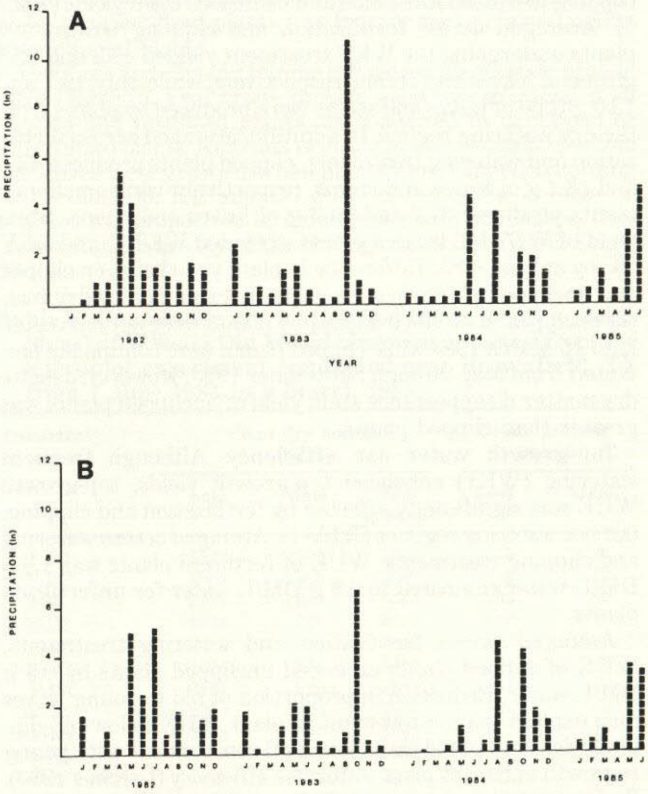

Figure 1. Monthly precipitation (in) occurring on the Lubbock (A) and Brownfield study sites (B) from 1982 through 1985.

Data Analyses

The TUBE experiment was arranged as a 2^3 factorial in a completely random design with seven replications per treatment combination. The MICROPLOT experiment was a randomized complete block arranged as a split plot with fertilization as the main plot effect and clipping treatment as the subplot effect with five replications per treatment combination. Since plants were clipped according to morphological criteria and not at specific time intervals-standard statistical procedures could not be used to compare plant responses during the growing season. However, because final harvests for all plants, regardless of clipping treatment, occurred on 15 March 1984 in the TUBE experiment and 9 March1985 in the MICROPLOT experiment cumulative dry matter yield and crude protein content of the grasses in both experiments and cumulative water use efficiency and end of season root weights of plants in the TUBE experiment were evaluated using analysis of variance procedures appropriate for the respective experimental designs. Treatment means were compared at the 0.05 level of probability using Tukey's w-procedure (Ott 1977).

RESULTS AND DISCUSSION

TUBE Experiment

Top-growth yield. Fertilization, unlike watering and clipping regimes, had no significant effect on cumulative leaf dry matter yields (Table 1). In contrast, cumulative stem and top-growth dry matter yields were significantly affected by fertilization, watering, and clipping. Averaged across watering and clipping treatments, fertilized plant stem yield was 19.0 g/tube compared to 13.7 g/tube for unfertilized plants.

The WET treatment increased leaf and stem yields while clipping increased leaf yields and decreased stem yields (Table 1). Averaged across fertilization and clipping treatments, plants undergoing the WET treatment yielded 43.3 and 29.1 g/tube of leaves and stems, respectively, while only 19.7 and 13.0 g/tube of leaves and stems were produced by plants from the dry watering regime. In addition, averaged across fertilization and watering treatments, clipped plants produced 44.6 and 13.4 g of leaves and stems, respectively, while unclipped plants produced 27.7 and 19.3 g of leaves and stems. Stem yield of WET-UC treated plants exceeded WET-C, and DRY-UC by at least 40%. Difference in plant yield between clipped and unclipped plants may be partially explained by dry matter disappearance since unclipped plants were not harvested until 15 March 1984 while clipped plants were continually harvested from May through September 1983. However, despite dry matter disappearance stem yield of unclipped plants was greater than clipped plants.

Top-growth water use efficiency. Although frequent watering (WET) enhanced top-growth yields, top-growth WUE was significantly affected by fertilization and clipping, but not watering regimes (Table 1). Averaged across watering and clipping treatments, WUE of fertilized plants was 1.0 g DM/L water compared to 0.8 g DM/L water for unfertilized plants.

Averaged across fertilization and watering treatments, WUE of clipped plants exceeded unclipped plants by 0.3 g DM/L water. Reduction in proportion of old to young leaves may explain the improvement in plant WUE following clipping. Removal of old leaf tissue and replacement with young regrowth enhances plant water use efficiency (Larcher 1980). Svejcar and Christiansen (1987) found reduction in transpiring surface of Caucasian Old World bluestem by heavy grazing reduced water loss and enhanced plant water potential. Moreover, adequate water was available for a longer period of time on heavily grazed areas.

Crude protein yield. Leaf and stem crude protein yield was greatest for WET-F-C-treated plants (Table 1). Fertilized and clipped plants, watered at seven-day intervals, contained 30, 34, and 53% greater amounts of crude protein than WET-UF-C, DRY-F-C, and DRY-UF-C, respectively. Regardless of fertilization or watering regime, unclipped plants yielded less crude protein than clipped plants.

Contribution of stems to crude protein pool within the plant was minor. Averaged across all treatments, leaves accounted for 88% of the crude protein yielded by the combined leaf and stem fractions. Typically, nutritive value of leaves far exceeds that of stems, regardless of stage of plant maturity (Kalmbalcher 1983; Beaty and Engel 1980).

Aboveground plant and root weights. By March, 11 months after treatment initiation, WET-treated plants had produced 30% more aboveground plant dry matter than plants watered at 14-day intervals, regardless of fertilization or clipping treatment (Table 2). Clipping fertilized plants, regardless of watering regime, increased yield by more than 20% as compared to unclipped fertilized plants. In contrast, clipping had no effect on yield of unfertilized OWB, within a watering regime.

Table 1. Cumulative dry matter (DM) and crude protein yield and top-growth water use efficiency (WUE) of WW-517 Old World bluestem obtained from the tube experiment conducted near Lubbock, TX from 17 May 1983 to 15 March 1984.

Treatment[1]	Plant dry matter (g/tube)			WUE of top-growth (g DM/L) water)	Crude protein (g/tube)	
	Leaf	Stem	Top-growth[2]		Leaf	Stem
WET						
F-C	59.1	21.4	84.2	1.3	7.6	0.7
F-UC	28.9	25.9	55.5	0.8	1.9	0.7
UF-C	52.3	8.6	63.1	0.9	4.9	0.2
UF-UC	32.8	22.9	56.2	0.8	1.4	0.6
DRY						
F-C	37.0	13.8	52.8	1.1	3.5	0.4
F-UC	24.9	14.7	40.5	0.9	1.8	0.4
UF-C	30.0	9.6	42.7	1.0	4.3	0.3
UF-UC	24.4	13.7	38.7	0.7	1.6	0.4
Tukey (0.05)[3]	NS	NS	NS	0.2	1.2	0.2

Analyses of variance[4]

Source	df	Leaf	Stem	Top-growth	WUE	CP Leaf	CP Stem
Replication	6	NS	NS	NS	NS	NS	NS
(F)ertilize	1	NS	**	**	**	**	**
(W)ater	1	**	**	**	NS	**	**
(C)lip	1	**	**	**	**	**	**
F X W	1	NS	*	NS	NS	**	**
F X C	1	*	**	**	NS	NS	**
W X C	1	**	**	*	NS	**	*
F X W X C	1	NS	NS	NS	*	**	*
Error	42	55.8	15.8	76.7	0.02	0.5	0.01

[1]Treatments are, WET = watered every seven days, DRY = watered every 14 days, F = fertilized (equivalent to broadcast application of 65-30-40 lb N-P-K/ac, UF = unfertilized, C = clipped to a 3 inch stubble height when regrowth reached 12 inches, and UC = unclipped.

[2]Top-growth is aboveground plant portion less the stubble.

[3]Critical values for comparison of treatment means obtained using Tukey's w-Procedure where $\alpha = 0.05$ and df = 40. NS is not significant.

[4]** and * indicate significance at the 0.01 and 0.05 levels.

Based on main treatment effects, end of season root weights were increased by the WET watering regime and decreased by fertilization and clipping (Table 2). Average across treatments root weights of fertilized and unfertilized plants were 28.7 and 40.0 g/tube, WET and DRY treatments were 41.0 and 24.7 g/tube, and clipped and unclipped plants were 29.2 and 36.5 g/tube.

Adverse response of OWB roots to clipping in this study is similar to decline in Caucasian and WW-Spar Old World bluestem root biomass following severe defoliation and subsequent aboveground plant regrowth observed by Coyne and Bradford (1986). Crider (1955) found defoliation reduced root weight of selected grasses and degree of decrease was proportional to amount of foliage removed. Little bluestem roots harvested from an ungrazed portion of a pasture weighed 2.5 and 15.5 times more than root samples taken from moderately and heavily grazed areas within the pasture (Weaver 1950). Clipping-induced reduction in OWB root weight could have an adverse effect on plant productivity.

Extrapolation of these result to a defoliated plant in a pasture environment, unencumbered by a plastic tube as in this study, would equate to a decrease in soil volume exploited by the roots, reducing plant access to nutrients and water. Total quantity of water available to the plant increases with volume of soil occupied by its roots (Taylor and Klepper 1978). White and Brown (1972) found the ability of green needlegrass (**Stipa viridula**) to extract water from deeper than 35 inches in the soil profile was decreased because of reduced root penetration caused by clipping.

Table 2. Cumulative aboveground plant and end of season root weight and root:aboveground ratio of WW-517 Old World bluestem obtained from the tube experiment conducted near Lubbock, TX from 17 May 1983 to 15 March 1984.

Treatment[1]		Aboveground plant weight (g/tube)	Root weight (g/tube)	Root: aboveground ratio
WET				
F-C		132.4	29.8	0.22
F-UC		96.9	39.6	0.40
UF-C		107.7	38.2	0.35
UF-UC		101.7	56.4	0.56
Dry				
F-C		86.7	20.5	0.23
F-UC		68.5	25.1	0.37
UF-C		81.2	28.2	0.35
UF-UC		67.3	25.1	0.37
Tukey (0.05)[2]		18.1	10.5	0.11
		Analyses of variance[3]		
Source	df			
Replication	6	NS	NS	NS
(F)ertilize	1	*	**	**
(W)ater	1	**	**	**
(C)lip	1	**	**	**
F X W	1	NS	**	*
F X C	1	*	NS	NS
W X C	1	NS	**	**
F X W X C	1	*	*	*
Error	42	112.1	37.6	0.004

[1]Treatments are, WET = watered every seven days, DRY = watered every 14 days, F = fertilized (equivalent to broadcast application of 65-30-40 lb N-P-K/ac, UF = unfertilized, C = clipped to a 3 inch stubble height when regrowth reached 12 inches, and UC = unclipped.
[2]Critical values for comparison of treatment means obtained using Tukey's w-Procedure where $\alpha = 0.05$ and df = 40. NS is not significant.
[3]** and * indicate significance at the 0.01 and 0.05 levels.

Pattern of OWB root weight changes over time differed between clipping treatment (Fig. 2). OWB responded to clipping by producing aboveground growth at expense of root growth. Root weights of clipped OWB increased initially from mid-May to mid-June followed by a decline through mid- to late-July then increased through March. The period of root decline corresponded with growth of aboveground portions. In contrast, with the exception of fertilized and WET-treated plants, root weights of unclipped plants increased throughout the study period. Rate of increase of root and aboveground plant weight of clipped and WET-treated plants from early June to mid-July was -0.02 and 1.4 g/day/tube for fertilized plants and -0.3 and 0.9 g/day/tube for unfertilized plants. At the same time, root and aboveground plant weight of unclipped plants, watered every seven days, increased 0.3 and 1.3 g/day/tube for fertilized and 0.2 and 0.7 g/day/tube for unfertlized plants. Decrease in root weight and increase in aboveground weight following clipping may result from reallocation of carbon assimilates from roots to shoots. This assimilation reallocation enables the plant to reestablish predefoliation root:shoot ratios (Ryle and Powell 1975; Detling et al. 1979).

With the exception of DRY-UF-treated plants, the proportion of root to aboveground yield was consistently greater in unclipped than clipped plants. By March 1984, root: aboveground yield ratio of fertilized and clipped, WET- and DRY-treated plants was only 0.22 and 0.23, respectively, while ratio of fertilized and unclipped plants was 0.40 and 0.37 for WET- and DRY-treated plants, respectively (Table 2). This evidence indicated clipped OWB was unable to regain predefoliation root:shoot ratios, comparable to unclipped plants prior to dormancy.

MICROPLOT Experiment

Leaf and top-growth weight of fertilized OWB was greatest for plants that were clipped every 45 days to a 3-inch stubble height (Table 3). Stems comprised 50% of top-growth of unclipped plants and 34% of top-growth of plants clipped at 45 day intervals. In contrast, only about 10% of the harvested top-growth of plants clipped according to regrowth height criteria (D3, D4, and D5 treatments) were composed of stems.

Unfertilized OWB responded differently to clipping than fertilized plants (Table 3). Top-growth weight of unfertilized OWB did not differ, regardless of clipping treatment. Stem yield of unfertilized plants was greater for unclipped plants than clipped plants.

Fertilizer and clipping regime influenced plant crude protein yield (Table 3). Leaf crude protein yield was greatest in all clipped and fertilized plants, as compared to unclipped or unfertilized plants. Amounts of crude protein contained within the leaves were greatest when plants were clipped according to the D2, D3, D4, and D5 criteria. Generally, defoliation reduces the proportion of older, less nutritious leaves, thus increasing the quality of the herbage mass (Beaty and Engle 1980).

Table 3. Cumulative dry matter and crude protein yields (lb/ac) of WW-517 Old World bluestem obtained from the microplot experiment conducted near Brownfield, TX from 1 June 1984 to 9 March 1985.

Treatment[1]		Plant dry matter (lb/ac)			Crude protein (lb/ac)	
		Leaf	Stem	Top-growth[2]	Leaf	Stem
F-D1		2532	2363	5006	110	25
UF-UC		1963	1568	3547	55	12
F-C		3977	1892	5666	333	60
UF-D2		2052	728	3100	142	12
F-D3		3725	595	4617	427	18
UF-D3		1534	648	2319	94	8
F-D4		2801	503	3304	284	11
UF-D4		2318	630	2977	146	5
F-D5		2998	380	3549	372	16
UF-D5		1163	646	2052	72	9
Tukey (0.05)[3]		1210	732	2030	125	28
			Analyses of variance[4]			
Source	df					
Replication	4	NS	NS	NS	NS	NS
(F)ertilize	1	**	**	**	**	**
Error a	4	592615	112334	887547	7727	207
(C)lip	4	**	**	**	**	**
F X W	4	**	**	*	**	**
Error b	32	348265	127477	980671	3752	176

[1]Treatments are, F = fertilized (55-27-36 lb N-P-K/ac), UF = unfertilized, D1 = clipped 9 March 1985 to 3 inch stubble height, D2 = clipped at 45 day intervals from 1 June 1984 to 30 August 1984 and on 9 March 1985, D3 = clipped to 3-inch stubble height when regrowth height reached 12 inches, D4 = clipped to 2-inch stubble height when regrowth reached 12 inches, and D5 = clipped to 4-inch stubble height when regrowth reached 12 inches.
[2]Top-growth is aboveground plant portion less the stubble.
[3]Critical values for comparison of treatment means obtained using Tukey's w-Procedure where $\alpha = 0.05$ and df = 16. NS is not significant.
[4]** and * indicate significance at the 0.01 and 0.05 levels.

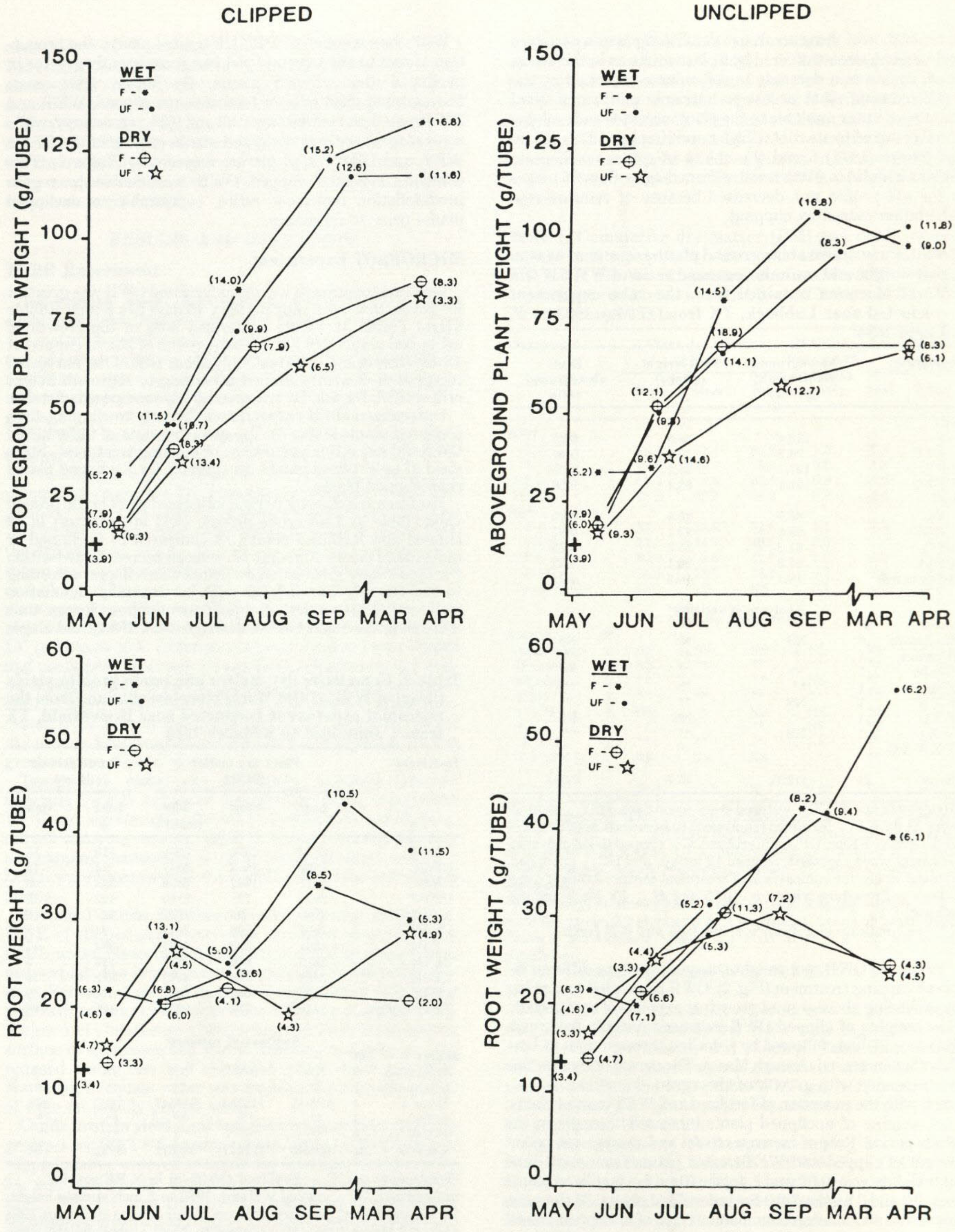

Figure 2. Aboveground and root weights (g/tube) of clipped (clipped to 3-inch stubble height when regrowth height reached 12 inches) and unclipped WW-517 Old World bluestem from the TUBE experiment conducted near Lubbock, Texas. WET = watered every seven days, DRY = watered every 14 days, F = fertilized (equivalent to broadcast application of 65-30-40 lb N-P-K/ac), and UF = unfertilized. The + denotes pretreatment means. Numbers within parenthesis represent standard deviation of associated treatment mean.

Stems produced by plants clipped according to D2 (clipped at 45-day intervals) criteria contained significantly greater amounts of crude protein than other fertilized plants. This greater amount was attributed to increased stem yield rather than a greater concentration of nitrogen within the stem tissue (data not shown).

CONCLUSION

Comparison between the TUBE and MICROPLOT experiments is difficult because of differences in plant environments. In the TUBE experiment plants were established in plastic tubes and therefore, did not compete with other plants for nutrients, water, or light, unlike plants in the MICROPLOT experiment. However, despite difference in magnitude of response, fertilizer and clipping increased yield of aboveground plant portion and crude protein of plant tissue in both experiments. Moreover, clipping reduced amount of stems in top-growth plant portions, thus maintaining plants in a vegetative condition of higher nutritive quality. Results from this study indicate fertilization coupled with clipping at proper intervals enhanced plant growth and nutritive value and magnitude of plant response to these treatments was further enhanced by water supplementation. In contrast, fertilization and clipping reduced root weights. Root biomass reduction could restrict plant access to soil water and nutrients and ultimately decrease plant productivity.

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