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## EFFECT OF FREQUENT CLIPPING ON THE DEVELOPMENT OF ROOTS AND TOPS OF GRASSES IN PRAIRIE SOD<sup>1</sup>

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A study has been made of the regeneration of bluestem grasses in enclosures in continuously grazed native pastures. The persistence of remnants of the bunches or mats of sod in old pastures for a long period of years is of interest, as is also their gradual but slow rate of recovery under protection when they are greatly weakened. Even in low, fertile, well watered soil, a period of three or four years must elapse before such species as *Andropogon furcatus* and *Sorghastrum nutans* produce the usual abundance of flower stalks and large quantities of viable seed. The first summer only a poor growth of scattered foliage outlines in a fragmentary manner the location of the underground parts that have been thoroughly weakened by continuous depletion of their food supplies. A second growing season shows a marked filling in of the sodded areas or clumps and about half the normal production of foliage. During the third summer the area is further extended and at least a few flower stalks and some seed are usually produced.

During this process of recovery it was repeatedly noticed that these grasses were much more subject to wilting than were similar species in adjacent areas that had not been grazed. The leaves would roll or fold and many of the lower ones dry and lose their green color. The evidence pointed clearly to a meager or inefficient root system.

The quantitative development of roots or their degree of deterioration is difficult to study under field conditions because of the labor involved in separating the living rhizomes and fibrous roots from those that are dead and from partially decomposed fragments of leaves, etc., intermixed with them. Earlier experiments where blocks of sod were transplanted showed that new roots were rapidly developed (Clements and Weaver, '24). Hence it was decided to select representative samples of the several most important native grasses, cut out blocks of soil containing them, and transplant these into large containers filled with soil free from roots and debris. One lot of each was to be clipped at 14-day intervals and the duplicates were to be grown as controls.

Grazing is a more or less destructive process since it periodically removes much of the photosynthetic area of the plants and an abrupt decrease in the photosynthetic activity causes a corresponding decrease in the growth of the

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roots. Continued defoliation will cause destruction of the root system and result in death. Hence, unless reasonable precautions are taken, the effects of grazing are likely to become cumulative and cause serious deterioration of the range.

The effect of the removal of the photosynthetic area upon the growth of the tops has received considerable study. Many data have been obtained from clipping vegetation in the western two-thirds of the United States. They show that the yield and vigor of the vegetation varies inversely with the frequency of clipping.

Crozier ('97) in Michigan, found that frequent mowing of various cultivated grasses reduced the yield to one-fourth normal and that the yields were highest on the plots clipped least frequently.

Sampson ('14), working in the Wallowa National Forest in Oregon, found that when *Festuca viridula*, one of the chief forage species, was clipped three times each season during a period of three consecutive years, the vegetative growth decreased in abundance each successive season.

Sarvis ('23), working in the mixed prairie of North Dakota, found that *Stipa comata* disappeared entirely under frequent harvesting and that various other grasses showed lowered vitality. The highest yields were obtained from plots clipped at 40-day intervals and the lowest from those clipped every 10 days.

Sampson and Malmsten ('26), in a study of forage species in Utah, found that the removal of the herbage four or more times in a season resulted in a sharp decline in yield and in a marked shortage of the life of the vegetation. *Stipa lettermani* and *Agropyron violaceum*, clipped five times annually for three successive years, yielded in the third year only 12 and 9 per cent respectively, of the amount of herbage that was produced during the first year of clipping. A short-lived perennial, *Bromus polyanthus*, died under similar treatment.

McCarty ('27), working in Colorado, judged yields on a basis of their calculated values for the second year of treatment, thus attempting to eliminate seasonal variation from year to year. "Quadrats of *Agropyron smithii*, harvested four times during one year, yielded 84 per cent of their calculated value during the second year of treatment. Quadrats harvested seven and eight times in one year yielded, respectively, 50 per cent and 40 per cent of their estimated values during the succeeding year."

Graber *et al.* ('27), in Wisconsin, showed that the productivity of well established bluegrass sod, following two years of frequent cuttings, was reduced to less than one-fourth that of adjacent bluegrass, *Poa pratensis*, cut but once annually at maturity. Similar results were obtained with red top, *Agrostis alba*.

Aldous ('30) applying clipping treatments at two-week intervals in Kansas, found that the density of the vegetation decreased about 60 per cent in three seasons. Clipping at three-week intervals resulted in only a 13 per cent reduction.

Numerous other researches bear out the conclusions of these investigators. Ellett and Carrier ('15), Stapledon ('24), Stapledon and Beddows ('26), Sturkie ('30), and Hanson *et al.* ('31) are all in agreement that the total yield of forage is reduced by frequent removal of tops.

Much less work has been done to show the deleterious effects of clipping on root development. This has probably been due to the difficulty of observing closely the parts below ground.

Fitts ('25), working with fine turf grasses, found that the length of the roots increased in relative proportion to the height to which the tops had grown.

Stapledon and Beddows ('26) showed that the repeated cutting of orchard grass, *Dactylis glomerata*, during the growing season not only decreased the amount of hay and aftermath crop but it also reduced the root systems of the plants and retarded their growth early the following spring.

Sampson and Malmsten ('26) state that any cropping which results in the reduction of the aerial growth of grasses is reflected in the root development and in the quantity of food stored in the underground parts.

Graber *et al.* ('27) found that frequent and immature cutting of bluegrass reduced the amount of rhizome and root growth and increased the prevalence of weeds when compared with similar bluegrass cut at maturity.

Pierre and Bertram ('29) studied the storage of organic foods as they affect the tops and roots of kudzu, a leguminous vine. They found that the roots of plants cut six times per season decreased in weight during a period of two years, while those from plants receiving four cuttings increased about 150 per cent. The reserves of starch and nitrogen were less than one-half as great in the roots of plants receiving six cuttings as in those receiving four. Similar studies on organic food reserves have been made by Graber *et al.* on alfalfa ('27).

It has been shown by Parker and Sampson ('31) that a single harvesting of the tops of *Stipa pulchra* and *Bromus hordeaceus* resulted temporarily in the cessation of root growth. Robertson ('32) found that the rate of growth of the roots of *Bromus inermis* diminished gradually as a result of clipping. Growth then ceased for 12 days before the roots started to die back from the tips.

Harrison ('31) clipped grasses at different heights and concluded that the amount of roots increased with the height to which the grasses were clipped.

Robertson ('32) observed that in general root penetration of seedling grasses was retarded from 35 to 62 per cent as a result of frequent clipping, and that the dry weight of the roots was reduced from 66 to 98 per cent.

Investigators are in agreement that the more frequent and drastic the cutting treatment the less is the yield of tops, rhizomes, and roots (*cf.*, Nelson, '25; Albert, '27; and others). An exceptional finding is that of Laird ('30) who worked in the sandy soils of Florida. He states that "the largest and deepest root system of sod-forming grasses is not necessarily associated with

the best and most vigorous top growth. . . . mowing of centipede and Bermuda grasses increased the root growth. . . ."

#### METHODS

Representative bunches or clumps of several species of native grasses were selected in duplicate and removed from the unbroken prairie sod. This was done between June 28 and July 24. The species included were big bluestem, *Andropogon furcatus*, tall panic grass, *Panicum virgatum*, little bluestem, *A. scoparius*, slender grama, *Bouteloua curtipendula*, and a prairie drop-seed, *Sporobolus heterolepis*. The first two were taken in duplicate sets and will be designated as series 1 and 2. The prairie from which the preceding dominant grasses were taken has never been disturbed except by mowing. In addition, Kentucky bluegrass, *Poa pratensis*, blue grama grass, *Bouteloua gracilis*, buffalo grass, *Bulbilis dactyloides*, and western wheat grass, *Agropyron smithii*, were secured from a native pasture. Here the usual tall-grass prairie species had practically disappeared before these invaders. The pasture had not been grazed, however, since the previous summer and the grasses were all in excellent condition.

The sods of *Andropogon furcatus* were cut so that they each had a surface area of 25 square inches and a depth of 4 inches. Those of the other species had a similar surface area but a depth of 5 inches. Since all of these species renew activity about April 15, except *Poa pratensis* and *Agropyron smithii* which break their winter dormancy nearly a month earlier, they had already made a good growth. The height of the foliage at the time each species was transplanted and the height to which it was clipped are shown in table I.

TABLE I. Condition of the grasses at the time of transplanting. The figure in parentheses indicates the series.

Species	Date of transplanting	Height tops, in.	Height clipped, in.
<i>Andropogon furcatus</i> (1)	June 28	14	1.5
<i>Andropogon furcatus</i> (2)	June 28	20	1.5
<i>Bulbilis dactyloides</i>	June 28	6	0.5
<i>Panicum virgatum</i> (1)	June 28	15	1.5
<i>Poa pratensis</i>	July 10	4	0.5
<i>Sporobolus heterolepis</i>	July 10	14	1.0
<i>Agropyron smithii</i>	July 10	16	1.0
<i>Bouteloua gracilis</i>	July 11	8	0.5
<i>Andropogon scoparius</i>	July 11	10	1.0
<i>Panicum virgatum</i> (2)	July 24	34	1.5
<i>Bouteloua curtipendula</i>	July 24	14	1.0

The sods were transplanted into galvanized iron containers which were filled with a rich loam soil mixed with one-fifth of its volume of sand. The containers had a cross-sectional area of one square foot and varied from 2 to 2.5 feet in depth. Each sod was placed with its surface 0.5 inch below the top of the container, thus permitting watering without run-off, and the soil

was firmly compacted about it. An opening made in the side near the bottom of each container insured proper drainage and aeration. The containers were placed in a trench 14 inches wide which was excavated in a bluegrass lawn and soil was packed around them. The trench was just deep enough so that the level of the tops of the containers was 2 inches above the general soil surface. Thus, surface water following heavy showers was prevented from running into them and a drain made in the trench prevented any accumulation of water. Thus the grasses were grown with the same variations in sunshine and temperature that they would have had in the prairie.

The soil was kept at an approximate optimum water-content for growth by frequent watering, the sods that were producing an abundance of foliage requiring water in larger amounts than the clipped ones, as was shown by soil sampling.

After the plants had become well established, one lot of each species was clipped every 14 days. The foliage produced at each clipping was placed in a drying oven at a temperature of 85° C. for 48 hours and the dry weight determined.

The grasses were permitted to grow until October 5 to 10, when the containers were removed from the trench and placed in a large trough. They were cut open on one side and a gentle stream of water was used to wash away the soil. Such care was taken that the roots were secured almost if not quite in their entirety. The muddy water drained through a screen of fine mesh which was used to catch any broken fragments, but in any case there were but very few small pieces found. The process of washing away the soil required much care, and a whole day to lay bare the root system of a single species.

The tops were removed and their dry weight determined. The flower stalks and foliage of the unclipped grasses were, with a single exception, obtained separately. The roots were also cut away from the base of the original block of soil. The volume of the roots was obtained after all surface water had been removed by pressing the roots repeatedly for a few minutes between blotting papers.

A simple but accurate apparatus was devised for determining the volume. A glass jar 10 inches high and 3 inches in diameter had attached to it a small glass U-tube which served as a siphon. The jar was filled with water which was then allowed to run out to the level of the short end of the tube outside the jar. When the roots were then submerged the overflow water was caught directly in a small graduate. In measuring the volume of small root masses, the roots were placed in a 25-cc. graduate and water was allowed to drop slowly from a burette until it reached a certain mark above the level of the roots. Care was taken to exclude bubbles of air. The volume of roots was the difference between the number of cubic centimeters of water added and the total volume of water plus the submerged roots in the graduate.

Parts of typical roots of both the clipped and unclipped *Panicum virgatum*

and *Poa pratensis* were selected for study. They were the portions of the roots between the fifth and tenth centimeters from the tip. These were killed in formalin-acetic-alcohol and embedded in paraffin. Slides were prepared from this material.

RELATIVE DEVELOPMENT OF TOPS AND ROOTS

Growth of tops began almost immediately after the sods were transplanted, except in *Agropyron smithii* which was more mature. Here there was a delay of two weeks. Measurements made on alternate days (June 30-July 16) showed that the rate of growth, while varying considerably for the different species, was remarkably uniform within the species. The average daily rate of elongation during the first 16 days, for example, varied from 1.7 cm. for *Panicum virgatum* to 2.3 cm. for *Andropogon furcatus*.

*Big Bluestem.* The unclipped *Andropogon furcatus* made a luxuriant growth throughout the period of the experiment. Flower stalks began to appear on August 19 and when the grass was harvested on October 5, 45 had developed. They had an average height of 69 inches. Large, well developed fruits were produced in abundance. At this time the grass was taking on the reddish autumnal color similar to that in the prairie. The dry matter produced weighed 216.34 grams.

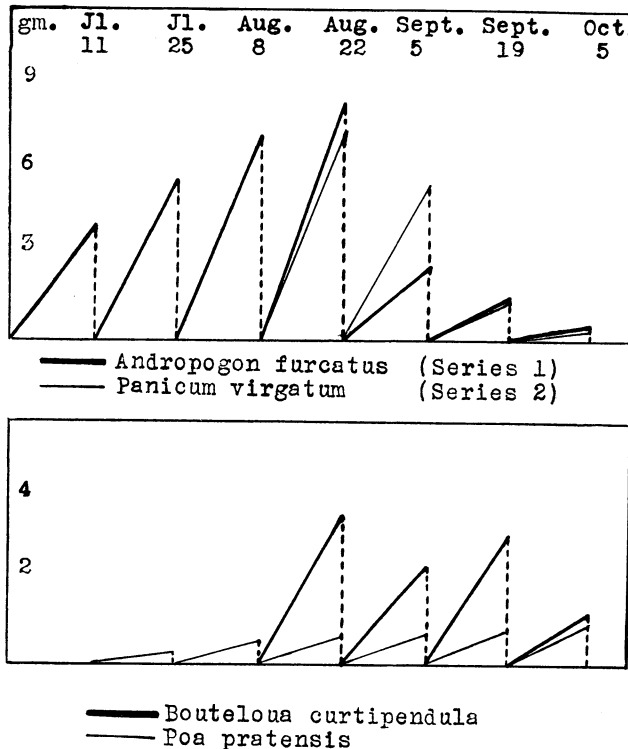


FIG. 1. Amount of dry matter produced by the several grasses at each clipping.

The amount of growth of the clipped grass increased gradually for the first four clippings. After the fourth clipping, however, both rate of growth and amount of dry matter decreased considerably (fig. 1). The stand of grass was thinner after the fourth clipping since some stems did not recover and others made a growth of only 1 to 3 inches. Other stems grew well even after the fifth and sixth clippings, but the growth was not as great as that following the earlier ones. The total amount of dry matter produced by the clipped sod was 31.32 grams, which was only 14.5 per cent as much as that of the control.

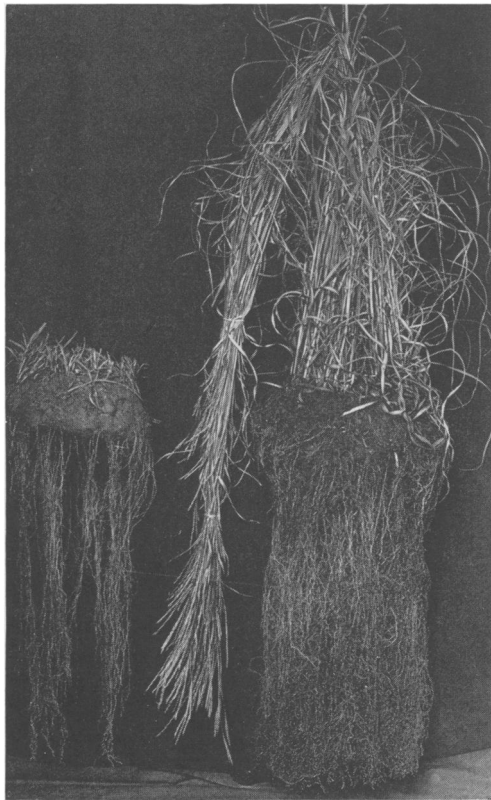


FIG. 2. *Andropogon furcatus* about 3 months after transplanting. Plants on the left have been repeatedly clipped.

The roots of the control formed a dense mat throughout the whole volume of soil. Those of the clipped sod were not nearly so abundant (fig. 2). Practically all of those of the control and about 30 per cent of the others extended to the bottom of the container, which was 2 feet deep. While the photograph shows the length and width of the mass of roots, it does not show the thickness of the mat, which was more than an inch when the roots were



TABLE II. Amount of dry matter in grams produced at each clipping; also total amount for clipped and control plants, and percentage of dry weight of clipped compared to unclipped plants.

Date of clipping	July 11	July 25	Aug. 8	Aug. 22	Sept. 5	Sept. 19	Oct. 5-10	Total dry weight of tops		Per cent
								Clipped	Control	
<i>Andropogon furcatus</i> (1) . . . . .	4.12	5.91	7.41	8.52	2.88	1.86	.62	31.32	Lvs. 53.54 Stems 162.80	14.5
<i>Andropogon furcatus</i> (2) . . . . .	4.14	5.83	7.33	6.26	2.92	1.39	.28	28.15	Lvs. 41.83 Stems 111.26	18.4
<i>Bulbilis dactyloides</i> . . . . .	1.12	3.52	4.51	3.91	3.44	3.22	.45	20.17	Lvs. 31.95 Stems .00	63.1
<i>Panicum virgatum</i> (1) . . . . .	.57	1.75	2.73	4.12	2.37	.38	.08	12.00	Lvs. 38.16 Stems 53.69	13.1
<i>Poa pratensis</i> . . . . .		.23	.52	.64	.73	.88	1.20	4.20	Lvs. 16.93 Stems .00	24.8
<i>Andropogon scoparius</i> . . . . .		.95	2.05	2.79	3.31	3.47	1.50	14.07	Lvs. 47.12 Stems .00	29.8
<i>Bouteloua gracilis</i> . . . . .		1.14	2.99	3.70	2.65	1.07	.47	12.02	Lvs. 19.93 Stems 44.00	18.8
<i>Panicum virgatum</i> (2) . . . . .			7.64	7.64	5.54	1.48	.60	15.26	Lvs. 39.89 Stems 14.09	28.2
<i>Bouteloua curtipendula</i> . . . . .			3.79	3.79	2.44	3.09	1.16	10.48	Lvs. 16.88 Stems 5.15	47.5

closely compacted. The volumes of the roots of the control and clipped plants were 166 and 9.2 cc. respectively, and the dry matter 41.15 and 2.22 grams (tables II and III). Thus the volume of the roots of the clipped plants was only 5.5 per cent of that of the controls and the amount of dry matter produced was only 5.3 per cent as great.

TABLE III. Dry weight and volume of roots of control and clipped plants and the per cent of dry weight and volume of the clipped compared to the control plants.

Species	Dry weight of roots			Volume of roots		
	Clipped grams	Control grams	Per cent	Clipped cc.	Control cc.	Per cent
<i>Andropogon furcatus</i> (1)	2.22	41.15	5.3	9.2	166.0	5.5
<i>Andropogon furcatus</i> (2)	1.95	50.00	3.9	10.1	214.5	4.7
<i>Bulbilis dactyloides</i>	3.11	11.37	27.3	17.2	47.2	36.4
<i>Panicum virgatum</i> (1)	1.55	58.11	2.6	9.5	268.0	3.6
<i>Poa pratensis</i>	.41	1.99	20.6	1.9	10.2	18.6
<i>Andropogon scoparius</i>	.79	9.94	7.9	5.8	46.8	12.4
<i>Bouteloua gracilis</i>	.41	9.75	4.2	1.9	54.0	3.5
<i>Panicum virgatum</i> (2)	.92	25.59	3.6	7.2	161.5	4.4
<i>Bouteloua curtipendula</i>	1.46	9.32	15.6	5.0	30.0	16.6

The second series of *A. furcatus* corresponded closely to the first. When harvested, there were 41 flower stalks with an average height of 60 inches. The total amount of dry matter was 153.09 grams.

The amount of growth of the clipped sod increased after each of the first three clippings and then decreased rapidly. The total dry matter obtained from all the clippings was 28.15 grams, or 18.4 per cent as much as that of the control.

The roots of the control formed a larger mat in the bottom of the container than did those of the first series. The volume of roots of the undisturbed sod was 214.5 cc., that of the clipped sod 10.1 cc. Dry weights were 50 and 1.95 grams for the unclipped and clipped plants respectively. The amount of roots produced in the second series was greater than in the first although the amount of tops was less.

*Tall Panic Grass.* *Panicum virgatum*, also transplanted on June 28, grew more slowly than that transplanted later in the season. On August 19 the flower stalks were 16 inches tall and the panicles were beginning to open. When harvested on October 8, the foliage was 18 inches high and 40 flower stalks had developed. These averaged 30 inches in height, but some were 10 inches taller. Large, well matured fruits were produced. The total amount of dry matter was 91.85 grams.

The production of foliage by the clipped plants increased for each of the first four clippings after which there was a decrease for each of the following ones (table II). This grass seemed to be affected more by the repeated clipping than did *Andropogon*. After the fifth clipping there were only a few short stems produced. The total amount of dry matter was 12 grams, or 13.1 per cent as much as that of the control.

The root system of the panic grass was composed of many coarse, glistening white roots. All of the roots of the control extended to the bottom of the container but only a few of those of the clipped grass were so deep (fig. 3).

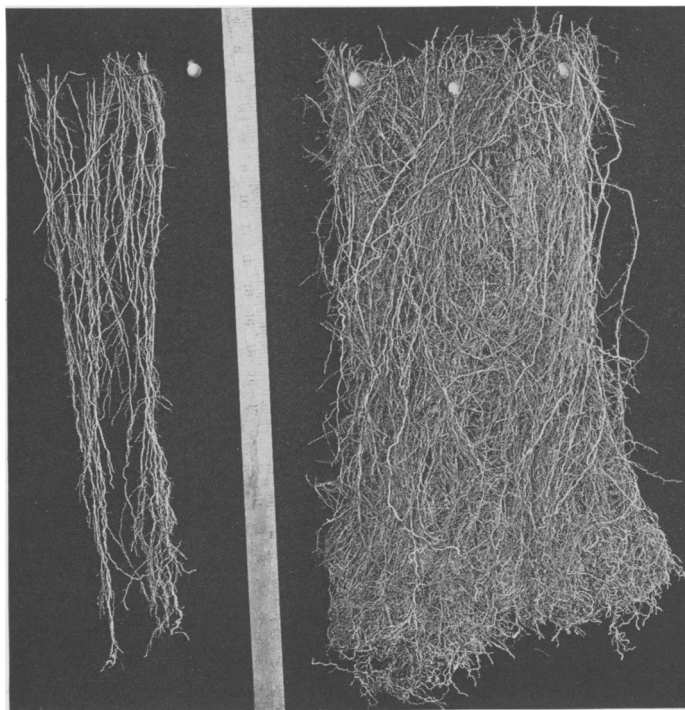


FIG. 3. Root systems of clipped (left) and unclipped *Panicum virgatum* nearly two feet long.

The differences in volume and dry matter produced by the two lots of sod were great. The volumes were 268.0 cc. and 9.5 cc., and the dry matter 58.11 grams and 1.55 grams respectively (table III).

*Panicum virgatum* (series 2) was transplanted on July 24. It made a very rapid growth averaging approximately 2 cm. increase in height per day for the first 12 days. This rapid development was probably due to the reserve food that had accumulated in the roots and rhizomes. At the time of harvest (October 8), 23 flower stalks were present. These averaged 23 inches in height, with a maximum of 32 inches. The total dry matter produced by the control grass was 53.98 grams. The amount of dry matter from the clipped sod was 7.64 grams for the first two-week period, while that of series 1 was only 0.57 gram. The amount of forage produced at each clipping decreased, however, after the first one (fig. 1). The grass was not clipped as many times (4 instead of 7) as the first lot and the percentage of dry matter produced by the clipped as compared to the unclipped sod was correspondingly

greater, *viz.*, 28.2 as against 13.1. Neither the volume nor the dry weight of the roots was as great as that of the first lot, but the percentage between the clipped and unclipped plants was about the same. The roots of the clipped plants had only 4.4 per cent of the volume and 3.6 per cent of the dry weight of the controls (table III).

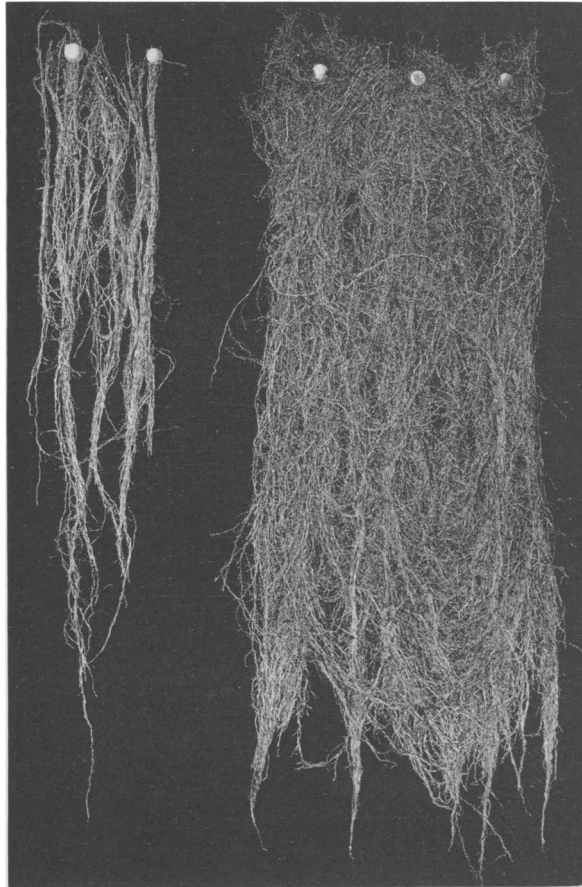


FIG. 4. Root systems of clipped (left) and unclipped *Andropogon scoparius*.

*Little Bluestem.* The control of *Andropogon scoparius* formed a very thick, heavy tuft of grass. A few flower stalks were developing but no fruits had been produced at the time of harvest on October 10. The dry weight of tops was 47.12 grams. The yield of tops of the treated grass increased for the first five clippings and then decreased suddenly (table II). The total dry weight of tops was 14.07 grams. An abundance of roots were produced by the control plants; they averaged 21 inches in length. Those of the clipped sod were few and had an average length of about 13 inches (fig. 4). The

volume of roots was 46.8 cc. and 5.8 cc., and the dry weight 9.94 grams and 0.79 gram for the control and clipped sods respectively.

*Slender Grama Grass.* *Bouteloua curtipendula* was another species transplanted late in the season. It made a very rapid growth. When it was harvested, the 26 flower stalks averaged 21 inches in height (fig. 5). The fruits



FIG. 5. Sodds of *Bouteloua curtipendula* at the end of the experiment. The meter stick indicates the relative length of roots and tops. Unclipped sod at right.

were large and well developed but were not yet mature. The total amount of dry matter of the unclipped grass was 22.03 grams (table II). The sod from which the grass was cut every two weeks did not have its growth retarded as much as did the preceding grasses. As with *Panicum virgatum* (series 2), the yield was greatest at the first clipping. At the second clipping it decreased, but again increased at the third cutting (fig. 1). The dry matter weighed 10.48 grams which was 47.5 per cent as great as that of the control.

The difference in amount of roots produced by the unclipped and clipped sods was not so great as for the preceding species (table III). Most of the roots of the control grass, however, extended to the bottom of the container, but only two of those of the clipped sod penetrated so deeply.

*Bluegrass.* *Poa pratensis* makes its greatest growth in the prairie during the spring and early summer. In this experiment it developed poorly throughout the hottest part of the year. The flower stalks that were produced were few and short. The total amount of dry matter of the control was 16.93 grams while that of the clipped plant was only about one-fourth as great. There was a gradual increase in amount, however, after each of the six clippings, as shown in figure 1. The percentage of dry matter produced by the clipped plants as compared to the control (24.8) was not greatly different from that of several other species. The volume of roots was 18.6 per cent and their dry weight 20.6 per cent as great as those of the control sod.

*Blue Grama Grass.* *Bouteloua gracilis* made a very fine growth which, because of a more constant water supply, was even somewhat better than that in the prairie. Very numerous flower stalks were produced which had an average height of 28 inches and yielded an abundant crop of seed (fig. 6). The total yield of tops was 63.93 grams. The amount of grass produced increased after each of the first three cuttings and then decreased after each of the three following (table II). After the clipping on August 22, flower stalks 6 inches long and flowers were produced by September 1. After another clipping on September 5, flowers were developed on stalks 3 inches long by September 12. The total amount of dry matter was 12.02 grams, which was 18.8 per cent as much as the control.

The roots of the clipped grass made a very poor growth. The average length below the sod was 9 inches, but below the unclipped sod 23 inches. The volume of the roots of the clipped plants was only 3.5 per cent as great as that of the unclipped ones, and the dry weight was 4.2 per cent as great.

*Buffalo Grass.* *Bulbilis dactyloides* differs from the other grasses in that it produces stolons. These were near the soil surface and were not removed from either the clipped or control sods until the time of the fifth clipping. There was a marked increase in dry weight of tops until the third clipping after which there was a slight but consistent decrease. The total dry matter, exclusive of the stolons, was 31.95 grams for the control and 20.17 grams for the clipped plants. The weight of stolons from the two sods differed by only 0.41 gram, those from the clipped plants (56.24 grams) being slightly lighter.

The percentage differences in volume and dry matter of roots were not so great in this grass as in the preceding since the stolons with their numerous short leaves were not removed from the clipped sod until late in the season (table III). The volume and dry weight of the clipped plants were 36.4 and 27.3 per cent respectively of the controls.

*Sporobolus heterolepis* and *Agropyron smithii* were not harvested. Observations were made, however, which showed that the controls had the same

abundant foliage and comparatively large amount of roots as did the other control grasses, while the roots of the clipped plants were sparse.



FIG. 6. Roots and tops of *Bouteloua gracilis* on October 9 which was 21 days after the fifth clipping.

#### EFFECT OF CLIPPING ON THE SIZE AND STRUCTURE OF ROOTS

An effect of frequent removal of the aerial parts is well shown in the relative size of the roots. The average diameter of the roots of *Panicum virgatum* was 1.5 and .96 mm. for the control and clipped sods respectively. In figure 7 the roots of the unclipped plants measured 1.6 mm., the clipped .96 mm. The width of the stele was slightly greater than that of the cortex. The average diameter of the stele was about .52 mm. for the control plants and .36 mm. for the clipped ones. The root had a pith which was surrounded by large metaxylem strands. The number of strands varied for different roots. Those from the unclipped sod ranged from 7 to 11; 8, 9, and 10 occurring most often. These averaged .062 mm. in diameter. The number of strands in roots from the clipped sod ranged from 5 to 8, 6 and 7 occurring

most often. They were .05 mm. in average diameter. The number of protoxylem groups varied greatly. In the panic grass they were 4.5 to 5.5 times as numerous as the metaxylem strands. The control had 48 protoxylem points; in most cases they were composed of one strand (fig. 7). The strands averaged .021 mm. in diameter. In the treated plants there were only 32 protoxylem points, the strands of which averaged .015 mm. in diameter. The

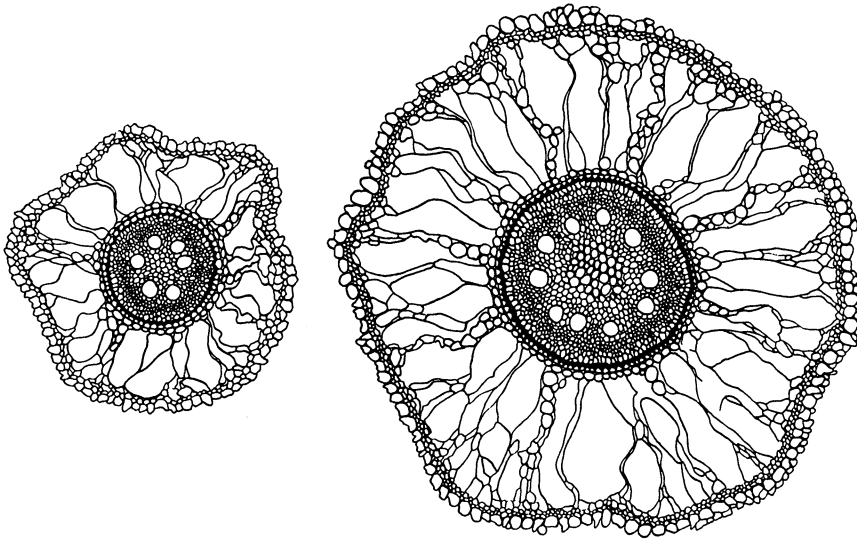


FIG. 7. Cross-sections of roots from clipped (left) and unclipped plants of *Panicum virgatum* drawn to same scale.

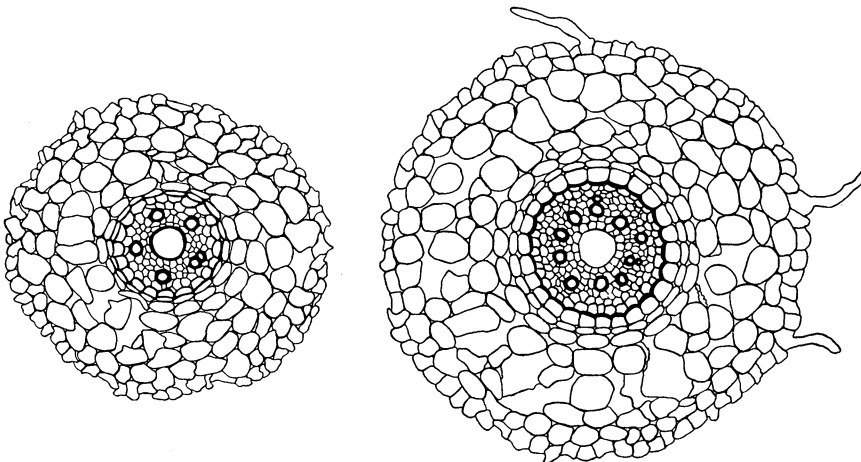


FIG. 8. Cross-sections of roots from clipped (left) and unclipped plants of *Poa pratensis* drawn to same scale.



inner tangential walls of the endodermal cells were conspicuously thickened. As the root became older the cortex began to disintegrate.

Very similar results were found for *Poa pratensis*. The differences, however, were more constant. The average diameter of the roots of the untreated grass was .38 mm., that of the treated one .29 mm. (fig. 8). Each root was characterized by a large central metaxylem vessel which had a lignified wall. The average diameter of the central vessel for the roots of the control grass was .036 mm., that of the clipped one .03. The number of protoxylem elements of the polyarch system varied from 8 to 11 for the controls, and from 4 to 6 for the roots of the clipped grass. The diameters of the protoxylem strands of the untreated and treated plants were very similar. The average diameter of the controls was .012 mm., that of the clipped plants .011 mm. The inner tangential wall of the endodermis was heavily thickened in the unclipped plants but less so where the tops had been repeatedly removed.

#### RESISTANCE TO FREEZING

During the process of recovering the root systems from the soil in which they had grown, differences in the sods were observed. The control plants had apparently not only retained the network of living rhizomes but also had extended their area somewhat by the production of new ones. The clipped plants, on the contrary, had produced few or no new underground stems, and many of the old ones had died. Thus in the process of washing it was difficult to retain all of the original soil about the clipped plants. This accounts for the slightly smaller size of the blocks of sod, as shown in figures 2-6.

In order to determine the relation between the repeated removal of the tops and resistance to winterkilling, several of the sods were saved for further study. These included *Andropogon furcatus*, *A. scoparius*, *Panicum virgatum* (series 2), and *Bulbilis dactyloides*. They were placed in a box with moist soil packed firmly about them, covered with burlap, and transported to a dark room kept at a temperature of 5° C. A week later (October 19) duplicate sods of *Andropogon scoparius* and *Panicum virgatum* were obtained from the prairie and similarly treated. On November 2, all were placed in a refrigerator maintained at a temperature of -12° to -15° C. After freezing for one week they were kept at 5° C. for four days and then again frozen for a period of five days. After thawing for three days at 5° C. their temperature was gradually raised until on November 20 it reached that of the greenhouse.

Containers of the sizes already described were filled with screened loess soil of good water-content. The sods were placed in the several containers and the soil packed firmly about them. Water was added regularly as required to maintain the original weight of the container and contents. Greenhouse light was supplemented on cloudy days and between 5.30 and 8.00 P.M. each day by two 150 watt electric lights mounted in 15-inch, white, enameled

reflectors suspended three feet above the tops of the containers. Care was taken that each pair of sods was equally illuminated. On December 19, *Poa pratensis* and *Stipa spartea* were obtained from the prairie, where the soil had been frozen and thawed, and added to the group. They and the preceding group of untreated plants served as controls for the species employed during the summer.

The sod of *Andropogon scoparius* that had not been clipped until the end of the summer, renewed growth 10 days after it was reset; the clipped one 10 days later. At the end of 24 days, the former had developed a thick stand of grass over 3 inches high, but the weakened sod had produced only five shoots. The control plants made a good growth and were 4.5 inches tall 5 weeks after transplanting. No further growth was made by the weakened plants, two of which were dying. Neither sod had extended roots into the new soil.

The control sod of *Bulbilis dactyloides* produced new shoots in about 10 days. At the end of five weeks a good sod 3-5 inches tall had developed but no roots extended into the soil below the sod. The grass that had been regularly clipped had been killed by freezing.

The control plants of *Andropogon furcatus* put forth many new shoots after a period of 20 days; the treated plants but two and only after 35 days. By January 31, 70 days after transplanting, the 88 stems of the control had reached a height of 15-26 inches. Growth of the clipped grass was very slow and irregular. Of the 14 stems produced, 3 were dying, and the others, which were undernourished, averaged only 4 inches in height. The control had produced a good growth of roots (4.96 g. dry weight), many of which were beginning to run along the bottom of the container at a depth of 2.5 feet. On the weakened plants there was a single root, about 2 inches long, extending below the sod.

Both sods of *Panicum virgatum*, used the previous summer, renewed growth 24 days after transplanting. At first no differences were noticeable between the two, but after a week the repeatedly clipped plants grew much more slowly. On January 18 the control grass had 64 vigorous stalks with an average height of 10 inches. The other lot had lost its deep green color, and some of the stems were dying. The 16 living shoots had a height less than one-third that of the control. These were clipped at this time. When the plants were examined two weeks later, only two stalks had made any perceptible growth, nor had any roots extended beyond the depth of the sod. The control plants, which were a foot high and thriving had developed 10 new roots, the longest being nearly 2 feet. Many new rhizomes also were starting.

Summarizing, one of the clipped sods failed to grow; two were delayed 10 to 15 days in renewing growth; and in all cases the grasses that had been repeatedly clipped produced only a very few weak shoots, some of which died. Two species had produced no roots five weeks after transplanting;

the controls of the other two had good absorbing organs but the treated plants had none.

The behavior of the sods of *Andropogon scoparius* and *Panicum virgatum* secured early in the fall and artificially frozen is of interest. They renewed growth in 14 and 25 days respectively. Both developed a fairly thick growth of shoots. After two fortnightly clippings many of the shoots failed to recover and marked deterioration of tops was evident. The dry weight of tops decreased rapidly; in *Panicum*, for example, it was 1.28, 0.78, and 0.37 g. respectively, for the several clippings. The unclipped plants had produced numerous flower stalks and a dry weight more than 4.5 times that of the several clippings. They had a great mass of roots that extended nearly 2.5 feet deep. The unclipped *Andropogon* had a good development of roots with an average depth of 13 inches; the clipped plants had produced none. *Panicum*, excavated 5 weeks after the third clipping and when the tops showed considerable recovery, had 8 roots 2 to 11 inches long.

Thus renewal of growth of these new sods was similar in time to that of the previous controls. The absence of roots in *Andropogon* was also similar. Root development, although poor on the clipped plants, was in contrast to their lack of growth on the *Panicum* weakened by clipping the preceding summer.

The two lots of *Poa pratensis* and *Stipa spartea*, both species that grow early in spring, resumed growth almost immediately, when transferred from the prairie to the greenhouse in December. Both also recovered rapidly from each of three fortnightly clippings although the yield gradually decreased. The one clipping of the control *Panicum*, for example, was 77 per cent greater than that of the several clippings. When examined after eight weeks of growth it was found that the clipped plants had developed only a few, poorly branched roots although those of the controls were quite extensive. The control and clipped plants of *Poa* weighed 0.04 and 0.64 g. respectively and those of *Panicum* 0.15 and 1.67 g. Thus the plants, although handicapped by clipping, were sufficiently vigorous to produce new roots and repeatedly regenerate the tops.

#### DISCUSSION

The grasses used in these experiments are all important grazing species, *Andropogon furcatus* and *A. scoparius* alone constituting fully 70 per cent of the tall grass prairie (Weaver and Fitzpatrick, '32).

The regeneration of tops immediately after the original cutting (except for a delay in *Agropyron*) is in accord with their behavior in the prairie, two and, on low ground, sometimes three crops of prairie hay being harvested. The regeneration of tops immediately after each cutting afforded some new photosynthetic area very soon after the disturbance. Nearly all of the species commonly produce flower stalks in late autumn when mowed not later than the middle of July. Unless the herbage is removed by mowing or grazing,

none save *Poa* produces much foliage after midsummer, although flower stalks may develop in abundance.

That the removal of the herbage at any time prior to the maturity of the plant was followed by more or less vigorous growth is in accord with grazing experience. Similar results were found by Parker and Sampson ('31) in their experiments with species of *Stipa* and *Bromus*.

The sods were transplanted at a time (June 28) when the growing tops had probably used considerable amounts of the root reserves, or at least before much storage for the current year had taken place. The more rapid growth of *Panicum virgatum* (series 2) and the other species transplanted later in the season (July 24) was probably due to a greater accumulation of reserve materials.

While some of the decrease in root production was to be expected, the amount of roots produced under clipping was surprisingly small. The extremely poor growth of the roots of the clipped *Bouteloua gracilis* was unexpected, since this species usually does well even under close grazing. Robertson ('32) states, however, that "In spite of clipping (of seedlings), penetration continued slowly in all species except *Bouteloua*, which responded by a gradual decrease in root length."

It seems probable that after transplanting, the production of new roots was delayed until the tops were well established. This was indicated by the delay in root growth of species transplanted in winter and verified by the experimental transplants the following summer. In one extreme case *Andropogon scoparius* produced, during a period of five weeks, an excellent growth of tops but no new roots.

Although little experimental evidence is available, it appears that the roots of grasses grow whenever the conditions are favorable and especially when the growth of shoots is not vigorous. Loeb ('24) and Janse ('25) have shown that the meristematic regions exert a profound attraction for food, water, and nutrient salts. When these regions are continually supplied with food it enables them to produce new tissues, including more meristematic tissue, which in turn further increases the demand for food. Thus there appears to exist within the block of sod competition for the accumulated food for building new roots and new shoots. These experiments indicate that for several weeks at least all or nearly all of the accumulated storage materials is used by the growing shoots and only after these are fairly well established are new roots developed. If the new shoots are again removed the process is repeated and the development of the root system is greatly retarded.

The lack of production of new rhizomes in all of the clipped sods and the death of old rootstocks, especially by winterkilling, may be directly attributed to lack of reserve food supplies and the weakened condition of the plants. McCarty ('32) has shown that in *Avena fatua* food accumulation is a factor of low or declining growth rate. "Inverse proportion has been shown to obtain between the food march and meristem activity, both vegetative and

reproductive in character, and between the food march and increase in dry weight increment." Waters ('15), Aldous ('30), and other investigators have shown that cutting frequently or cutting at immaturity depletes the reserves in the roots of herbaceous plants. The bulbs of *Phleum pratense* are depleted by the rapid growth of the plants. If the plants are cut at such an interval they decrease both in vigor and yield and are more susceptible to winterkilling.

Analyses of *Agropyron smithii* showed that low yields were associated with diminished food accumulations in the subterranean organs (McCarty, '27). The lack of growth or poor growth of tops was a direct result of food depletion. Thus low capacity for survival is a concomitant of low organic food reserves. Graber ('31) found that unclipped potted plants of bluegrass produced abundant rhizomes while those that were clipped seven times produced none. Sturkie ('30) states that any cutting treatment of *Sorghum halepense* reduces the rootstock development, and the more frequently the cutting is made the greater is the reduction.

Robertson ('32) found that all but one of the six grasses with which he worked produced roots of greater diameter when the tops were uncut. Parker and Sampson ('30) showed that frequent removal of the aerial growth resulted in a poorly developed root structure, in that the diameter of the whole root, the diameter of the stele, and the number of ducts were smaller than in roots of untreated specimens of the same age.

The thinning of the cover of grass by frequent removal of the tops, as in close grazing, too frequent mowing of lawns and greens, etc., includes a similar or possibly greater decrease in the abundance of roots and other underground parts. Both of these phenomena are directly related to soil erosion. In a grass plat on a hillside in Kansas, repeated clipping had reduced the density of the vegetation to about one-third normal, including about 40 per cent weeds. A rainfall of 7.5 inches in four hours eroded away approximately two inches of surface soil, but the amounts removed from any of the other fully vegetated plats was not appreciable (Aldous, '30). Forsling ('31) states that "The increase in the density of the vegetation from 16 to 40 per cent of a complete cover and the replacement of certain plants by others with more extensive and more fibrous root systems reduced the rainfall surface run-off 64 per cent and rainfall erosion 54 per cent."

A direct relation also exists between too frequent removal of the tops, deficient root systems, and humus content of the soil. A decrease in humus results in a decreased bacterial activity since the soil population is dependent almost entirely upon the growing plant for energy material. Plants that are weakened by repeated clipping are less efficient in absorbing water and solutes. They are more subject to damage by drought, disease, and to extremes of heat or cold. They extend their area little or not at all and compete less vigorously with invaders. Invasion of weeds is an inevitable result. Not only is the annual yield of forage reduced, but the life of the plant itself is

probably lessened. Moreover, the effects of reduced vigor persist for a long time. As pointed out by Robertson ('32) the greatest reduction in yield is accompanied by the greatest reduction in root development.

The common practice of pasturing tall-grass prairie a year or more before breaking so that the sod will be less dense and more easily tilled is a practical demonstration of the harmful effects upon the underground parts resulting from the close removal of tops. Harrison ('31) states that "Field observations as well as greenhouse studies show that Kentucky bluegrass cannot maintain itself under ordinary field conditions if it is cut shorter than three-quarters of an inch more frequently than once each week." The deleterious effect of frequent cutting may, however, be offset partially by cutting the plants at a greater height above the soil. Early or frequent cutting of newly seeded lawns or newly laid sod is almost certain to result in poor establishment.

#### SUMMARY

This paper deals with the effects of the removal of tops on root growth in soil and on regeneration and yield of aerial parts. Blocks of well established sod of seven important native pasture grasses were transplanted into large containers, grown in the field, and clipped fortnightly.

Growth of tops, which were cut upon transplanting, was resumed immediately, as well as after each subsequent cutting from July to October. The dry weight of tops of *Andropogon furcatus*, *A. scoparius*, *Panicum virgatum*, *Bouteloua gracilis*, and *Bulbilis dactyloides* increased for the first three to five intervals following the initial clipping, after which it decreased rapidly. The yield of *Poa pratensis* increased after each of the clippings. *Panicum virgatum* and *Bouteloua curtipendula*, transplanted in midsummer, decreased in yield after the first clipping. The unclipped grasses grew normally and in all cases, except one, produced flower stalks and seeds.

The total dry weight of tops from the clipped sods ranged from 13.1 per cent (*Panicum virgatum*) to 47.5 per cent (*Bouteloua curtipendula*) of that of the same species unclipped after transplanting. In *Bulbilis dactyloides*, where the stolons were permitted to grow, it was 63.1 per cent. In all cases there was a considerable decrease in the ground cover as the stand of the weakened grasses became thinner.

The clipped plants failed to produce new rhizomes and many of the old ones died.

The length of roots was greatly decreased, and the relative production of roots was more greatly reduced than that of tops. By volume, it ranged from 3.5 per cent of the controls (*Bouteloua gracilis*) to 18.6 per cent (*Poa pratensis*), although that of *Bulbilis dactyloides* was 36.4 per cent. The dry weight varied from 2.6 per cent in *Panicum virgatum* to 20.6 in *Poa pratensis*. The average volume of roots of the clipped sods was 11.7 per cent of that of the controls; the average dry weight was 10.1 per cent.

The roots of the clipped grasses were smaller in diameter than were those of the controls. The diameter of those of *Poa pratensis* was 76 per cent as great and those of *Panicum virgatum* only 64 per cent.

Plants weakened by repeated clipping renewed growth slowly if at all after being frozen. No new roots were produced during the period of the experiment by those that survived.

The harmful effects of the frequent removal of the cover of grasses and the accompanying deterioration of the parts underground are discussed.

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