ROOT-GROWTH STOPPAGE

Resulting From Defoliation of Grass

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Root-Growth Stoppage

Resulting From Defoliation of Grass

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SUMMARY

Removals during the growing season of half or more of the foliage of grasses—cool- and warm-season species including bunch, rhizomatous, and stolonifierous types—caused root growth to stop for a time after each removal, with one exception. The exception was orchardgrass (*Dactylis glomerata*) after the first clipping.

Aside from orchardgrass, a single clipping that removed most of the foliage caused root growth to stop for periods ranging from 6 to 18 days. Stoppage occurred usually within 24 hours and continued until recovery of the top growth was well advanced. When these clippings were repeated periodically, as in a system of rotation grazing, root growth of all the grasses stopped for periods that ranged from 25 to 45 days during the growing season.

The percentage of roots that stopped growth varied in proportion to the percentage of the foliage that was removed.

A single clipping of 90 percent of the foliage resulted in complete root-growth stoppage for 17 days, and removal of 80 percent of the foliage caused complete stoppage for 12 days. At the end of the 33-day test, 40 and 4 percent, respectively, of the roots still were not growing. Partial stoppage occurred after single clippings at the 70-, 60-, and 50-percent levels.

Effects of such clippings repeated frequently—similar to continuous grazing—were much more severe. All root growth stopped after the first clipping of 90 percent of the foliage, and the 3-times-a-week clippings that followed prevented root growth during the whole test. Root-growth stoppage was somewhat less as lesser amounts of foliage were removed, but where 70 percent or more of the foliage had been taken repeatedly, no roots were growing at the end of the 33-day test. Stoppage was also severe with repeated clippings at the 60- and 50-percent levels, showing maximum stoppage of 100 and 63 percent, respectively, at the close of the test.

Stoppage of root growth failed to take place in both the single and repeated percentage-clipping tests only when 40 percent or less of the foliage was removed. The balance point in the relation of top reduction and root-growth stoppage was found to lie between the 40- and 50-percent clipping levels.

Parts of bunchgrass plants were found to function independently so far as the effects of foliage removal on root growth were concerned.

[1] Submitted for publication May 6, 1954.

Clipping of the foliage of halves and individual culms of plants stopped root growth for only those parts. The habit of cattle grazing only part of a plant at a time seems desirable.

Reduction of the foliage of the grasses affected root production adversely. In the single-clipping series, the number of growing roots at the end of the 33-day test ranged from only 32 when 90 percent of the foliage was clipped to 132 when 10 percent was clipped. In the repeated-clipping series, the range was strikingly greater—from 0 at the 90-, 80-, and 70-percent clipping levels to 156 at the 10-percent level. Among the 7 types of grasses that were clipped periodically—2 to 4 times during the growing season—the ovendry roots of the unclipped plants weighed 8 times as much as those of the clipped plants.

The drastic effects of the higher percentages of foliage removal in causing complete and prolonged root-growth stoppage, and correspondingly reduced root production, was reflected in poor development of the grass plants.

These data have particular application to soil conservation and pasture-management practices. They emphasize that the growing top cannot be reduced more than half without adversely affecting the functioning of the root system and the plant as a whole. They are striking evidence that close grazing or mowing during the growing season is at the expense of stand establishment and maintenance.

The complete stoppage of root growth is of particular significance in conservation farming. Because of the continuous suppression of aboveground growth and the inability of the plant to replenish food reserves, the effects of root inactivity are lasting. Thus weakened, the plant is less able to resist grazing, erosion, drought, cold, and disease.

The conclusion is, therefore, that the successful use of grass for soil conservation and pasturage is contingent in large measure on the employment of practices that preserve the closest possible balance between top and root development.

INTRODUCTION

This investigation included studies of the extent to which removal of the foliage of grass causes root growth to stop, and the influence of this reaction upon root production. As early as 1927, the writer observed a strikingly close interrelation between the opposite growth terminals of citrus seedlings growing in glass-front boxes. The main roots ceased to elongate and remained inactive for periods of 4 to 6 weeks during the yearly growth cycle of the plant, and the growth and rest periods of the roots alternated with growth and rest periods of the top.

Studies with glass-front boxes also disclosed that the root growth of peach, plum, privet, and pine seedlings stopped for a time after the tops of the plants were cut back severely. The roots of herbaceous plants likewise ceased to elongate when the foliage was shortened. Tobacco, tomato, and cabbage were among the soft-bodied plants tested and found to be so affected.

Grass was particularly sensitive to the removal of top growth, as indicated by the promptness with which root growth stopped. Because of the major role of grass in holding and building soils, as well as in pasturage, knowledge about the behavior of the roots in relation to top reduction is of fundamental importance to conservation farming.

REVIEW OF LITERATURE

Many investigators have reported on the adverse effects of close and frequent clipping or grazing upon subsequent forage yields. Among them were Aldous (*1*),[2] Canfield (*3*); Crozier (*6*); Elliot and Carrier (*7*); Hanson, Love, and Morris (*11*); Sampson and Malmsten (*17*); Sarvis (*18*); and Tinker (*22*).

Other investigators have shown that reduction of the top growth likewise affects adversely the underground parts of the plant. Biswell and Weaver (*2*), working in Nebraska with transplanted sods of 7 grasses, found that clipping at 14-day intervals caused a relatively greater decrease in the production of roots than of tops. Gernert (*9*), in clipping tests with native prairie grasses, and Harrison and Hodgson (*13*), with leading introduced species of grasses, noted that the yields of both the underground and aboveground parts decreased with the severity of cutting. Stapledon and Beddows (*19*) found that repeated cutting of cocksfoot (*Dactylis glomerata*) during the growing season decreased the amount of both the hay and aftermath crops. It also reduced the root system of the plant and retarded its growth the following spring.

Fitts (*8*) reported that the length of the roots of turf grasses increased in direct proportion to the height to which the tops had grown. Harrison (*12*) clipped Kentucky bluegrass (*Poa pratensis*) and red fescue (*Festuca rubra*) to ½, 1½, and 3 inches, at intervals of 1 week, for a period of approximately 24 weeks. He found that "the shorter the grass was cut and the more the leaf area was reduced, the smaller was the quantity of roots produced." Any cutting of *Sorghum halepense*, says Sturckie (*21*), reduces the rootstock development, and the more frequent the cutting the greater is the reduction. Likewise, Stapledon and Milton (*20*) state that the more drastic the cutting of cocksfoot, as measured by the frequency and amount of defoliation, the less was the yield of roots, rhizomes, and tops.

Parker and Sampson (*14*) studied the anatomical structure of the roots of *Stipa pulchra* and *Bromus hordeaceus*. They found that frequent removal of aerial growth resulted in a poorly developed root structure. The diameter of the whole root, the diameter of the stele, and the number of ducts in clipped plants were invariably smaller than in roots of unclipped plants of the same age. As shown by Graber (*10*), unclipped plants of Kentucky bluegrass developed abundant rhizomes while those clipped seven times produced none.

Little investigation into the cessation of the root growth of plants, as influenced by removal of the top growth, has been reported. While working with citrus seedlings growing in glass-front boxes, Crider (*4*) discovered in 1927 that the roots stopped elongating and remained inactive for indefinite periods, and rest and growth periods of the roots alternated with the rest and growth periods of the top. Later, in studying weeping lovegrass (*Eragrostis curvula*) by the same method, Crider (*5*) found that the roots of 54-day-old plants which were cut back to within 1 inch of the ground stopped growth and

[2] Numbers in parentheses indicate literature cited.

remained inactive for 16 days. The writer also found that the roots of plants clipped to 3 inches every other day for 40 days stopped growth and remained quiescent for the entire period.

Parker and Sampson (*15*) worked with grasses grown in a nutrient solution in fruit jars. They found that a single harvesting of the leafage of 15-day-old *Bromus hordeaceus* plants "resulted in an immediate cessation of root growth, a function which did not resume activity for 8 days." Robertson (*16*) grew seedlings of *Bromus inermis* in 2-foot glass jars and noted the effect of top removal on root growth. The rate of growth of the roots down the sides of the jars diminished gradually when 28-day-old seedlings were cut to a height of 1.5 cm., and the clipping was repeated at intervals of a little more than 2 weeks. Growth then ceased for 12 days before the roots started to die back at the tips.

METHODS OF OBSERVATION

Investigation of the underground parts of plants, without undue interference with the normal functioning of the roots, presents unusual difficulties. It was essential to observe the roots in their growing state under as nearly natural conditions as possible. Three methods of examintion were employed, designated as (1) glass-box method, (2) field-excavation method, and (3) root-blacking method.

Glass-Box Method

Except for slight modification, the techniques used in the glass-box method of study were the same as those the writer employed previously (*4*, *5*). The grasses were grown in wooden containers 2½ inches wide, 24 inches long, and 24 inches deep, inside dimensions. The boxes had heavy glass fronts which, between examinations of the roots, were protected from the light by sheets of tar paper. Small holes in the bottoms of the boxes and 1-inch layers of pebbles provided drainage. The boxes were filled firmly to within 1 inch of the top with screened, uniformly mixed, fine sandy loam soil. They were kept in a forward-tilted position of approximately 30°, which caused a higher percentage of the roots to remain visible on the face of the glass. The day-to-day recordings of root elongation were made directly on the glass by use of red grease pencils (see fig. 1, p. 8).

Field-Excavation Method

The field-excavation method of study exposed representative new main roots for observation in their natural state, without disturbing the rest of the root system. The work was done in the field during midsummer. The soil was carefully washed away from one side of the plants, so as to reveal the freshly starting roots. Without undue exposure, small apical sections of the roots were blackened with moistened carbon black and surrounded immediately with wet sphagnum. Moist burlap was then placed over the sphagnum and the whole covered with soil to the ground level. Subsequent examinations to determine the growth status of the roots following clipping were made by lifting the burlap and gently removing the sphagnum (see fig. 6, p. 12).

Root-Blacking Method

The root-blacking method of study exposed all the growing roots of the plant for observation. Thus, it provided a means of determining the relation of top reduction to the root-growth stoppage and to root production. It consisted of growing the plants in small, movable, clay pots and blacking the roots so that the white apical root growth made between examinations could be seen. Moistened carbon black, which is not injurious to the roots and dissipates slowly in watering, was applied to the roots with a small, soft brush. The white, growing roots, which characteristically follow the inside perimeter of the pot, were easily seen and counted. To facilitate removing and handling the plants, shredded sphagnum was mixed with the potting soil. The pots also were lined with a thin layer of sphagnum so as to overlap lightly on top. Alternate blacking and examination of the roots at definite intervals revealed progressively their growth status following clipping (see figs. 11 and 12, p. 19).

TESTS AND RESULTS

Three specific tests were used in attaining the overall purpose of this investigation. Following is a description of these tests, together with an outline of results and tables which present the pertinent data in summary form.

Clipping at Different Intervals

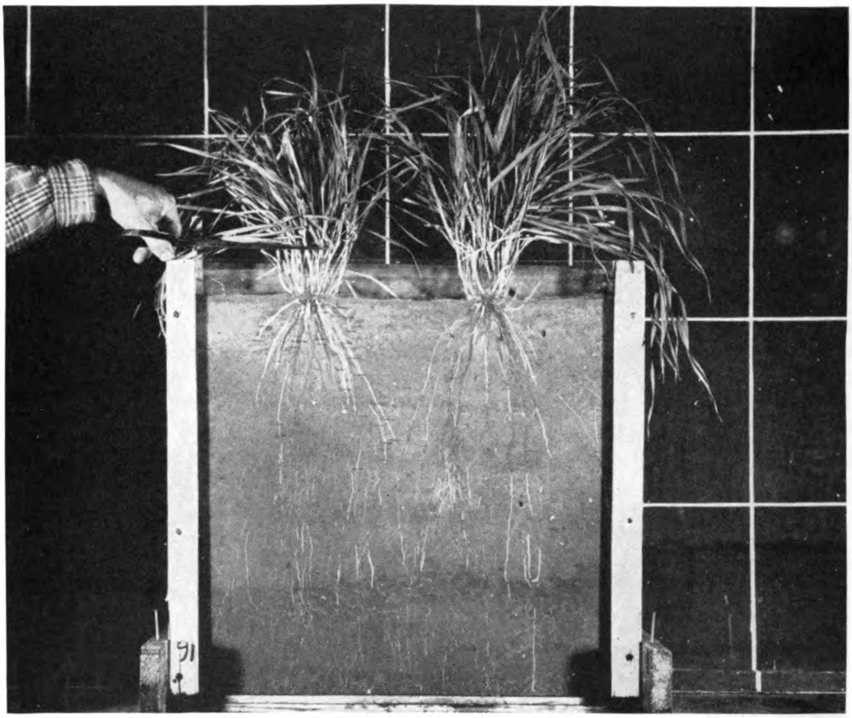
The periodic-clipping test served a twofold purpose: It confirmed the writer's previous observations that grass roots stop growth when the tops of the plants are cut back, and it determined the applicability of the phenomenon of root-growth stoppage to grasses of different growth habits. It served also as a measure of the effect of root-growth stoppage on root and top production.

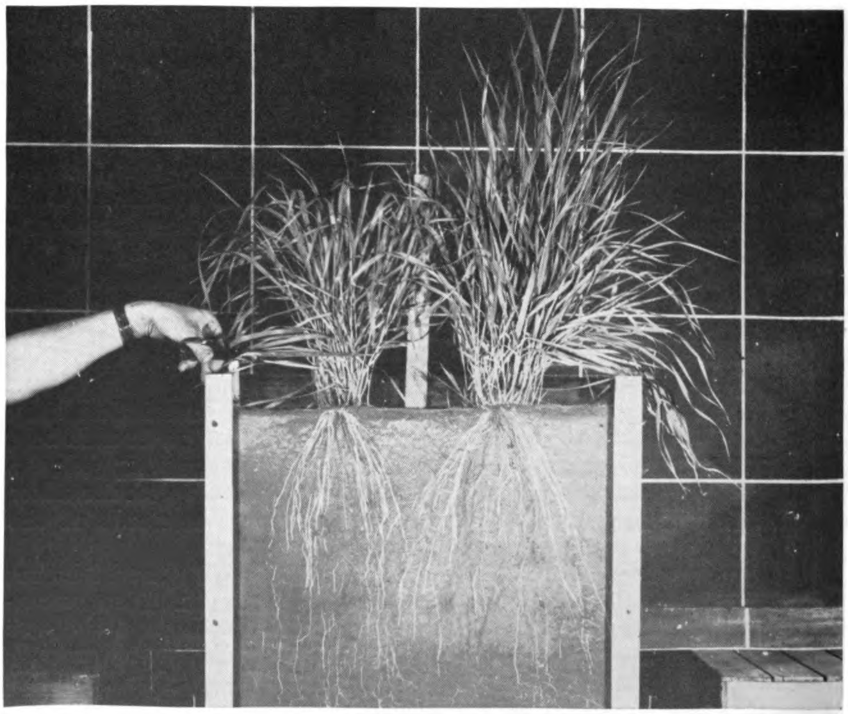
This work was done in a greenhouse, using the glass-box method. Eight grasses were studied. Three are cool-season species—smooth brome (*Bromus inermis*), tall fescue (*Festuca arundinacea*) and orchardgrass (*Dactylis glomerata*). Five are warm-season species—Florida paspalum (*Paspalum floridanum*), King Ranch bluestem (*Andropogon ischaemum*), switchgrass (*Panicum virgatum*), blue grama (*Bouteloua gracilis*), and bermudagrass (*Cynodon dactylon*).

One glass-front box was used for each species. All the grasses but bermudagrass, which was started from sprigs of newly rooted stolons, were grown from seed sown thinly next to the glass.

When the young plants were old enough for differentiation, they were thinned to 2 strong, uniformly developed specimens in each box, spaced about 1 foot apart. Only 1 plant in each box was clipped; the other was left as the control (fig. 1). Water and a complete fertilizer in solution were applied uniformly according to the needs of the plants.

The cool-season grasses were clipped 3 times to 2½, 2¾, and 3 inches at the first, second, and third clippings, respectively. The warm-season species were clipped as follows: Florida paspalum, 4 times to 2 inches; King Ranch bluestem, 3 times to 2 inches; switchgrass, 2 times to 2 inches; and bermudagrass 3 times to 1 inch. The first clip-





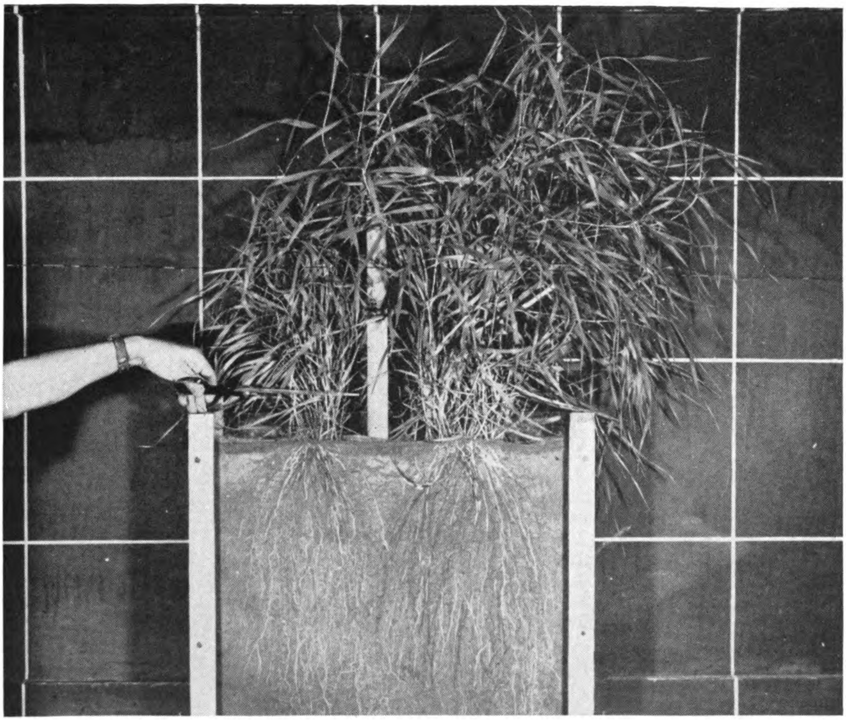


FIGURE 1.—(Top, opposite page), smooth bromegrass (cool-season grass) at the time of the first clipping (to 2½ inches). All visible roots of clipped plant stopped growing within 2 days and remained inactive for 12 days. Those of the unclipped plant continued to grow. (Backdrop is in 12-inch squares.)

FIGURE 2.—(Bottom, opposite page), Smooth bromegrass (the same specimen as fig. 1) at the time of the second clipping (to 2¾ inches), 23 days after the first. All visible roots stopped growth within the first day and remained inactive for 17 days. Those of the unclipped plant continued to grow.

FIGURE 3.—(Top, this page), Smooth bromegrass (the same specimen as figs. 1 and 2) at the time of the third clipping (to 3 inches), 46 days after the second. All visible roots of the clipped plant stopped growth within the first day and remained inactive for 8 days. Those of unclipped plant continued to grow.

ping was made after the plants were well established. The initial nodal or main roots had reached the bottoms of the boxes, and the second sets of main roots were 4 to 10 inches long (fig. 1). At the time of clipping, the position of each new root was marked on the glass. Day-to-day observations and markings thereafter revealed the growth status of the roots. Succeeding clippings were delayed until the plants were well recovered, with a number of new, normally active main roots present (figs. 2 and 3).

The observations covered a normal growing season of 247 days for the cool-season and 146 days for the warm-season grasses. At the end of the growing season, the roots were washed free of soil, photographed, and ovendried, and all but the bermudagrass roots were weighed.

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TABLE 1.—*Effect during an entire growing season of severe top reduction on root-growth stoppage and root production*

Species	Clipping		Root-growth stoppage			Root production (ovendry weight)	
	Date cut	Height cut	Start	Duration	Total	Clipped plant	Unclipped plant
		Inches	*Day*	*Days*	*Days*	*Grams*	*Grams*
Smooth brome [1]	Apr. 28	2½	2d	12			
Do	May 20	2¾	1st	17			
Do	July 7	3	1st	8	37	4.3	61
Tall fescue [1]	Apr. 28	2½	1st	13			
Do	May 20	2¾	1st	12			
Do	July 7	3	1st	7	32	6.2	20.8
Orchardgrass [1]	Apr. 28	2½	none	none			
Do	May 20	2¾	3d	18			
Do	July 7	3	4th	7	25	4.6	26.2
Florida paspalum [2]	July 15	2	2d	11			
Do	July 29	2	1st	6			
Do	Aug. 4	2	1st	10			
Do	Sept. 9	2	2d	18	45	1	9.6
King Ranch bluestem [2]	July 22	2	1st	8			
Do	Aug. 12	2	2d	7			
Do	Sept. 9	2	1st	18	33	1.5	17.6
Switchgrass [2]	July 22	2	1st	18			
Do	Aug. 30	2	1st	11	29	1.4	17.4
Blue grama [2]	July 29	2	1st	17			
Do	Aug. 23	2	2d	13	30	.6	3.8
Bermudagrass [2]	May 20	1	1st	9			
Do	June 21	1	1st	6			
Do	Sept. 28	1	2d	16	31		

[1] Cool season.
[2] Warm season.

RESULTS

The roots of all the grasses, except orchardgrass, stopped growth when the foliage was first cut back (table 1). The visible roots of all the grasses ceased to elongate after each succeeding clipping. Roots of orchardgrass were inactive for an unusually long period after the second clipping, compensating for their failure to stop growth after the first clipping.

Six days was the shortest period of complete root-growth stoppage after clipping. This followed the second clipping of Florida paspalum and bermudagrass. The longest periods of complete stoppage were 18 days, which followed the first cutting of switchgrass, the second cutting of orchardgrass, the third cutting of King Ranch bluestem, and the fourth cutting of Florida paspalum. Total complete root-growth stoppage during the test ranged from 25 days for orchardgrass (clipped 3 times) to 45 days for Florida paspalum (clipped 4 times).

No root growth for so great a part of the growing season resulted in a tremendous reduction in root production (figs. 4 and 5). The

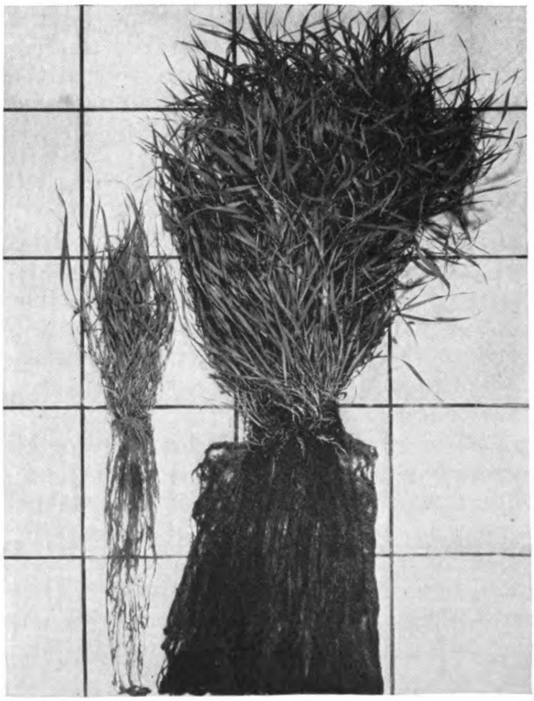

FIGURE 4.—Smooth bromegrass (the same specimen as figs. 1, 2, and 3)—the washed roots of the clipped plant (left) and unclipped plant (right) 46 days after the third clipping.

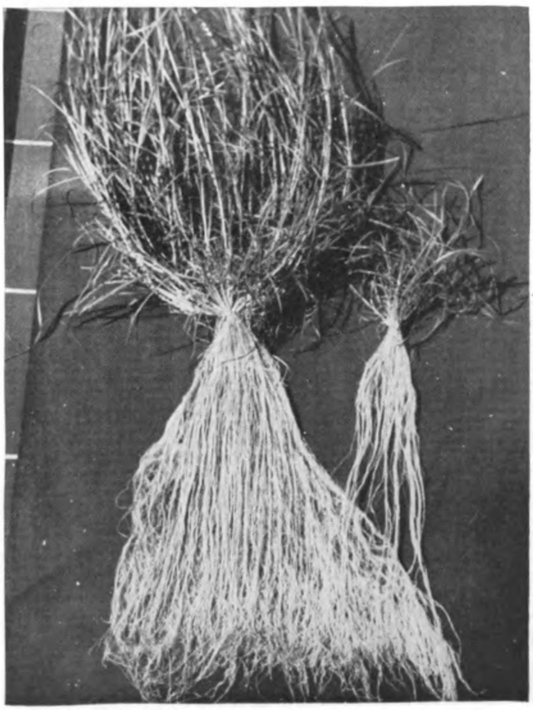

FIGURE 5.—King Ranch bluestem (warm-season grass)—the washed roots of clipped plant (right) and unclipped plant (left), 41 days after the third clipping to 2 inches.

roots of the clipped plants weighed only one-eighth as much as the roots of the unclipped ones. This striking difference in root production by clipped and unclipped plants was manifest as well in the development of the plants as a whole. Compared with unmolested plants, the mature, clipped specimens were greatly lacking in size and vigor.

Clipping in the Field

Conducted with grasses growing naturally in the field, the field-clipping test dealt with the effects on root growth of overall top reduction and top reduction of parts of plants. The first served further to confirm the fact that root-growth stoppage is actuated by top reduction. The second served to show the functional relationship of one part of a bunchgrass plant to another, insofar as top reduction and root-growth stoppage are concerned.

Weeping lovegrass (*Eragrostis curvula*) and breadgrass (*Brachiaria brizantha*), summer-growing bunchgrasses, were used in the overall top-reduction phase. Single specimens of each grass were started in 3-inch pots in the greenhouse, and at the beginning of the growing season were transplanted to the field 18 inches apart in the row. A 12-foot section of row was planted to each grass. In midsummer, after the plants were well developed, the soil was washed away from one side. The exposed, freshly growing roots then were blackened and

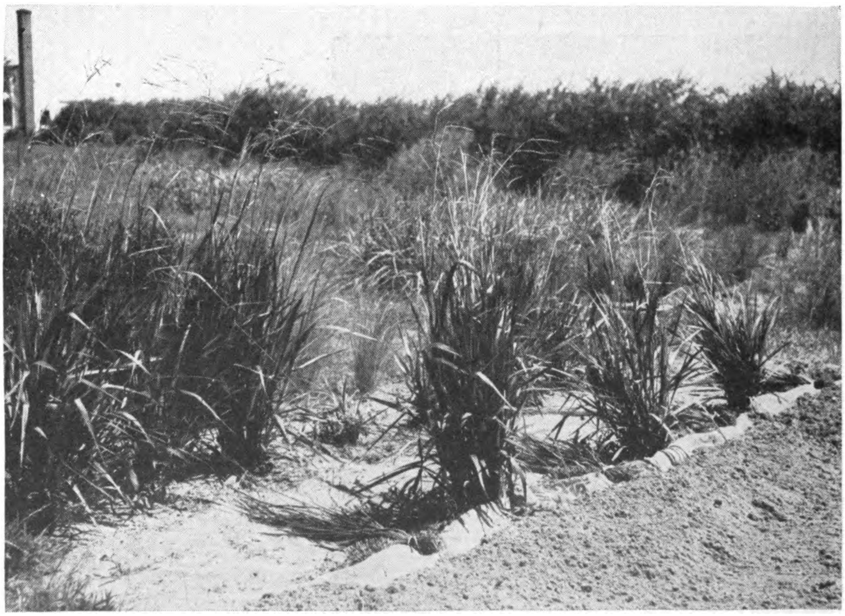

Figure 6.—Field-excavation method of observing root-growth stoppage. Breadgrass, growing naturally in the field, just after the tops of every other plant in the row had been cut back, the soil washed from one side, and the freshly growing roots treated and covered.

TABLE 2.—*Root-growth of weeping lovegrass and breadgrass, growing naturally in the field, 6 days after clipping to 2½ inches*

Plant and No.	Treatment	Active main roots at time of clipping	Average root elongation 6 days after clipping	New main roots 6 days after clipping
Weeping lovegrass:		*Number*	*Inches*	*Number*
1	Clipped	8	0.50	0
2	Unclipped	6	5.25	13
3	Clipped	8	.25	0
4	Unclipped	2	6.00	3
5	Clipped	4	.25	0
6	Unclipped	4	4.75	7
7	Clipped	5	.19	0
Breadgrass:				
1	Clipped	4	.37	0
2	Unclipped	3	9.00	5
3	Clipped	6	.62	0
4	Unclipped	4	8.00	7
5	Clipped	4	.62	0
6	Unclipped	5	9.50	9
7	Clipped	5	.55	0

otherwise treated as described under the field-excavation method. Alternate plants in the row were then cut back to within 1½ inches of the ground. This left an equal number of plants as controls (fig. 6). The tip-blackened and the control roots were examined 6 days later. Earlier observation was avoided, so as not to disturb or expose the roots unduly. A longer test than 6 days was found impractical, because of the tendency of the roots of the unclipped plants to grow out of bounds.

Summer-growing bunchgrasses, weeping lovegrass (*Eragrostis curvula*), and corngrass (*Tripsacum dactyloides*), likewise were used in the fractional top-reduction phase. Halves and individual culms of well-established plants growing singly in the field were clipped to 2½ inches, without cutting back the rest of the tops. At the same time, freshly growing roots of the clipped and unclipped parts were washed free of soil, blackened, and otherwise treated as in overall top reduction. Examination 6 days later revealed the relative growth status of the roots.

RESULTS

Except for negligible "momentum" elongation, the roots of the clipped plants in the overall top-reduction phase made no growth in the 6-day test (table 2). On the other hand, roots of the unclipped weeping lovegrass plants made a combined average growth of 5.33 inches and those of breadgrass, 8.83 inches. None of the clipped plants showed new main roots, but the unclipped weeping lovegrass plants showed an average of 7.7, and breadgrass, 7. Figure 7 shows the exposed roots of clipped and unclipped weeping lovegrass plants at the end of the 6-day test.

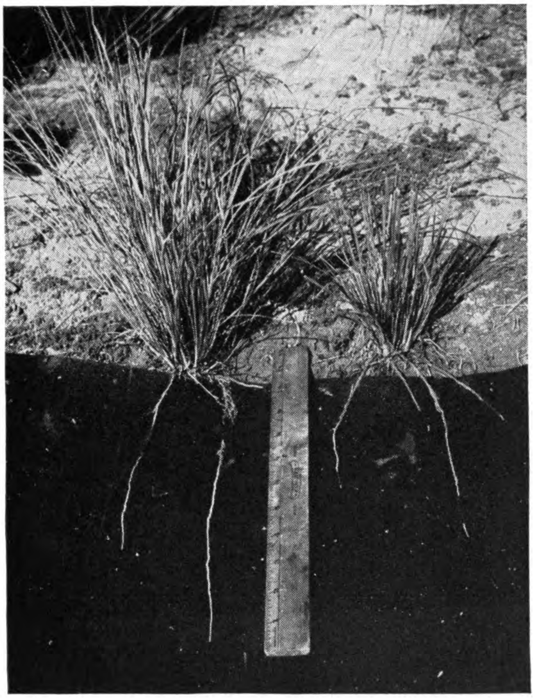

FIGURE 7.—Two plants of weeping lovegrass subjected to the field-excavation method of root observation, with tar-paper backdrop to show root-growth stoppage 6 days after plant at right was clipped to 2½ inches. The black markings show the length of the roots at the time of clipping; the white extensions the amount of growth afterward. The 4 marked roots of the clipped plant stopped growth except for the negligible "momentum" elongation indicated by the white tips, and remained inactive. In contrast, the 2 marked roots of the unclipped plant continued to grow, reaching lengths of about 7 and 4 inches, and there are 2 new basal roots.

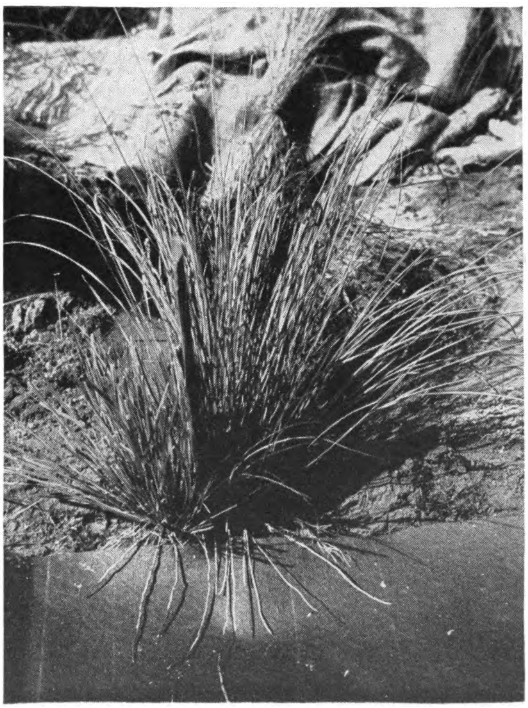

FIGURE 8.—Individual plant of weeping lovegrass subjected to the field-excavation method of root observation, with tar-paper backdrop to show root-growth status 6 days after the left half was clipped to 2½ inches. As in figure 7, the black markings show the length of the roots at the time of clipping, and the white extensions the amount of growth afterward. The 4 marked roots of the clipped half of the plant stopped growth and remained inactive without any new basal roots having formed. On the other hand, the 1 marked root (cut by picture) of the unclipped half of the plant continued to grow, and there are 7 new roots.

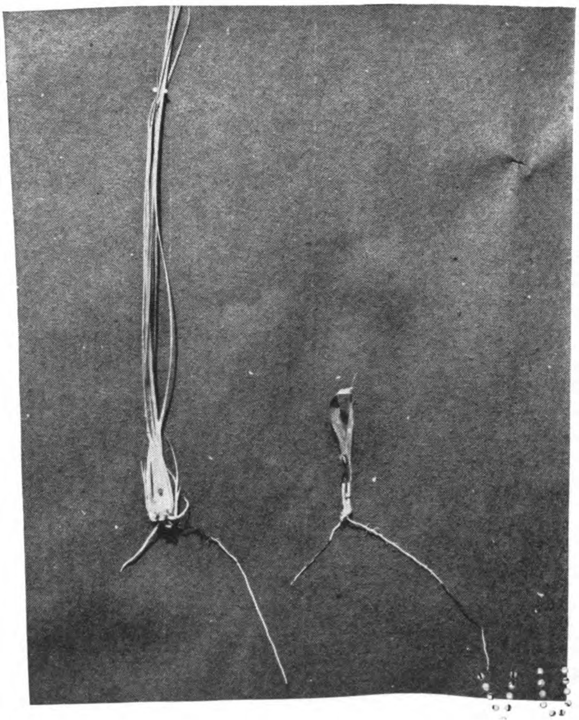

FIGURE 9.—Single culms of corngrass (detached from the same plant) 6 days after culm at right was clipped to 2½ inches. Like the clipped half of the plant in figure 8, individual culms were found to function independently of the mother plant insofar as top reduction and root-growth stoppage are concerned. The 2 marked roots of the clipped culm (right) show no growth, except negligible "momentum" elongation indicated by the white tips; the 1 marked root of the unclipped culm (left) shows extensive growth, and there is 1 new basal root.

The fractional top-reduction phase revealed that in each instance the individual parts functioned independently of the rest of the plant, insofar as the effects of top-growth removal on root-growth stoppage were concerned. The roots of the clipped parts of the plants—both halves and culms—stopped growth at the time of clipping and were still inactive at the end of the 6-day test (figs. 8 and 9). In contrast, the roots of the unclipped portions continued normal growth.

Clipping to Different Percentage Levels

The percentage-clipping test included 9 levels of top reduction, ranging by tens from 90 to 10 percent. To determine the relative effect of single clippings and repeated clippings, the test was conducted in two series, simultaneously.

These tests covered a 33-day period—no longer because of the probability that the plants would become pot-bound and function abnormally. The work was done in the greenhouse using the root-blacking method. The grasses in the repeated-clipping series were reclipped to the point of initial severance each time the root systems were examined.

Fourteen examinations of the root systems were made at intervals of 2 and 3 days to determine progressively the growth status of the roots. The 3-day intervals include Sundays.

Rhodes grass (*Chloris gayana*) was used in the single-clipping series mainly because its roots are large, grow rapidly, and are easily

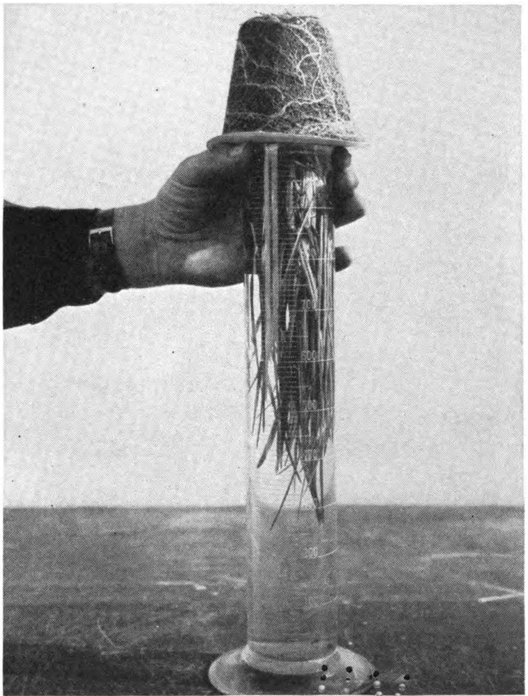

FIGURE 10.—Top of grass plants inserted full length into water-filled 1,000-cc. graduate—the first step in determining by volumetric displacement the point of severance in percentage-clipping tests. The thin paper disk prevents debris from falling into graduate and lessening accuracy.

observed. Three grasses were used in the repeated-clipping series: Rhodes grass, a warm-season species; and Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), cool-season species.

The seeds were planted in 4-inch clay pots filled with sphagnum-treated soil, as previously described. In their early growth the plants were thinned to 3 individuals per pot.

A total of 15 plants—the number in 5 pots—were clipped at each level of top reduction. Duplicate groups of unclipped plants were used for controls.

To insure uniform moisture content, the pots were placed in firmly packed peatmoss. They were turned around in place frequently enough to prevent the roots from growing through the drainage holes. Occasional, uniform applications of a complete fertilizer in solution kept the plants in good growing condition.

Clipping was deferred until 64 days after seeding, when the plants had strongly developed tops and root systems.

The point to which the plants were to be cut back was determined by volumetric displacement of water. A 1,000-cc. graduate, with the lip removed so that the foliage of the plants could be immersed completely, was filled to the brim with water (fig. 10).

A disk of thin, stiff paper, with a slit in one side and a hole in the center, was placed around the base of the plants. This prevented any debris from falling into the graduate to lessen the accuracy of the displacement measurement.

The 3 plants in each pot were lifted as a unit and inverted. The tops were then immersed full length into the graduate, and the displaced water flowed over the side. Next, the plants were withdrawn and their displacement noted. From this displacement, the displacement measures of the desired percentages of top reduction were calculated for each level.

Water was then added to the graduate until the unfilled space equaled the displacement measure of the percentage of top to be removed. The tops then were reinserted in the graduate until the column of water was raised to the brim. The tops were clipped with scissors at their point of contact with the waterline at the brim of the graduate.

To measure root growth at the start of the test, the plants were lifted from the pots 2 days before the first clipping and the entire root mass was blackened with moistened carbon black. Just preceding the actual clipping, they were lifted again and the white, growing root terminals of the plants were counted, recorded, and blackened. This procedure was repeated during each succeeding examination.

Using the initial root count as a basis, the percentages of roots that had stopped growth and the percentages of growing roots were calculated. Thus was shown, from one examination to the next, the growth status of the roots at each of the 9 clipping levels.

The growth status of the roots following each clipping and the averages for the full 33-day test showed the relative effects of the 9 different percentage levels of top reduction on root-growth stoppage. Likewise, the number of active main roots showed the relative effect of the 9 percentages of top reduction on root production.

RESULTS OF SINGLE-CLIPPING SERIES

Root-growth stoppage occurred to some extent in the single-clipping series after every reduction of the top by 50 percent or more (table 3).

Root growth stopped completely for 17 days after removal of 90 percent of the top and for 12 days after removal of 80 percent of the top. Thereafter, stoppage continued to the end of the test but with less intensity (fig. 11). After reduction of the top at the 70-, 60-, and 50-percent levels, 78, 50, and 2 percent of the roots stopped growth. Stoppage at these levels decreased proportionately as recovery growth increased but continued for 28, 17, and 14 days, respectively.

No stoppage resulted from a top reduction of 40 percent or less.

The number of active main roots of plants clipped at the 90- and 80-percent levels was 22 and 2 less, respectively, at the end than at the beginning of the test. With smaller percentages of top reduction, the number of roots was greater than the initial count—showing 26, 36, 52, 61, 69, 91, 93, and 95 more roots, respectively, at the 70-, 60-, 50-, 40-, 30-, 20-, and 10-percent clipping and the control levels. Total root production, as expressed by the final counts of the 9 clipping levels, graduated upward from 32 at the 90-percent level to 132 at the 10-percent level and 135 at the control level.

TABLE 3.—*Effect on Rhodes grass of single clippings to 9 different percentage levels*

Top reduction (percent)	Root-growth stoppage[1]														Root production (main roots)	
	3d day	5th day	7th day	10th day	12th day	14th day	17th day	19th day	21st day	24th day	26th day	28th day	31st day	33d day		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
90	−100	−100	−100	−100	−100	−100	−100	−85	−81	−80	−83	−67	−61	−40	−22	32
80	−100	−100	−100	−100	−100	−83	−72	−65	−52	−47	−48	−47	−29	−4	−2	44
70	−78	−70	−50	−52	−50	−50	−52	−40	−36	−27	−25	−5	+24	+59	+26	70
60	−50	−45	−15	−12	−16	−11	−12	+7	+17	+19	+33	+75	+87	+92	+36	75
50	−2	−3	−3	−3	−4	−2	+4	+7	+40	+42	+107	+122	+114	+123	+52	94
40	+10	+21	+28	+40	+41	+46	+50	+54	+62	+67	+76	+108	+118	+133	+61	107
30	+17	+27	+35	+47	+51	+57	+61	+69	+78	+86	+97	+115	+135	+150	+69	115
20	+23	+30	+41	+55	+79	+100	+111	+134	+148	+167	+190	+204	+225	+224	+91	132
10	+28	+61	+76	+92	+105	+105	+128	+151	+179	+200	+215	+225	+230	+238	+93	132
(check)	+29	+57	+71	+95	+117	+119	+137	+156	+181	+190	+211	+227	+231	+238	+95	135

[1] Minus sign indicates proportion of roots not growing (−100 indicates no growth). Plus sign shows the percent increase in growing roots over the active roots at the beginning of test.

FIGURE 11.—Root masses of Rhodes grass removed from 4-inch pots 33 days after single clippings to different levels. Left to right, none (control), 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent of the top of the plant has been clipped off. Two days before clipping the roots had been blackened. The white roots are new growth.

FIGURE 12.—Root masses of Kentucky bluegrass removed from 4-inch pots after repeated clippings to different levels during a 33-day test. Left to right, none (control), 10, 20, 30, 40, 50, 60, 70, 80, and 90 percent of the top of the plant had been clipped off at the first clipping and the plants were cut back to those levels 14 times. Two days before clipping, the roots had been blackened. The white roots are new growth.

RESULTS OF REPEATED-CLIPPING SERIES

The roots of all 3 grasses clipped to the 90-percent level in the repeated-clipping series (fig. 12) stopped growing completely when first clipped and continued inactive for the remainder of the 33-day test (table 4).

Likewise, complete and permanent cessation of root growth took place at other clipping levels, as follows: At the 80-percent level—Rhodes grass after the 1st clipping, and Kentucky bluegrass and smooth brome after the 4th clipping; at the 70-percent level—Rhodes grass after the 3d clipping, Kentucky bluegrass after the 8th clipping,

TABLE 4.—*Effect on 3 grasses of repeated clippings to 9 different percentage levels. (Tops were cut back to original clipping level 3 times a week.)*

RHODES GRASS

Top reduction (percent)	Root-growth stoppage [1]														Root production (main roots)	
	3d day	5th day	7th day	10th day	12th day	14th day	17th day	19th day	21st day	24th day	26th day	28th day	31st day	33d day		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
90	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
80	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
70	−97	−93	−90	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
60	−80	−83	−75	−75	−91	−91	−85	−83	−83	−83	−91	−97	−97	−100	−100	0
50	−8	−11	−17	−17	−15	−25	−62	−78	−78	−79	−69	−65	−65	−52	−25	23
40	+10	+12	+5	+11	+12	+13	+13	+13	+17	+13	+20	+19	+21	+25	+10	50
30	+9	+10	+13	+13	+9	+12	+16	+14	+14	+16	+12	+25	+39	+53	+26	75
20	+15	+9	+6	+8	+8	+11	+11	+14	+11	+27	+65	+65	+66	+86	+30	65
10	+19	+10	+28	+28	+20	+13	+10	+13	+9	+10	+30	+40	+64	+90	+36	76
(check)	+18	+13	+19	+29	+28	+29	+35	+49	+61	+55	+76	+87	+101	+123	+48	86

KENTUCKY BLUEGRASS

Top reduction (percent)	3d day	5th day	7th day	10th day	12th day	14th day	17th day	19th day	21st day	24th day	26th day	28th day	31st day	33d day	Root production, percent	Root production, number
90	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
80	−91	−93	−93	−98	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
70	−77	−82	−81	−89	−91	−86	−94	−93	−100	−100	−100	−100	−100	−100	−100	0
60	−54	−39	−18	−52	−65	−73	−75	−70	−63	−88	−94	−100	−100	−100	−100	0
50	−38	−40	−26	−34	−29	−25	−24	−27	−38	−45	−53	−62	−65	−63	−73	42
40	+30	+51	+65	+73	+73	+77	+78	+81	+86	+101	+87	+90	+92	+92	+78	163
30	+33	+60	+93	+119	+126	+129	+133	+137	+135	+139	+137	+138	+144	+148	+102	171
20	+50	+79	+111	+119	+126	+129	+129	+131	+137	+145	+149	+147	+154	+154	+111	180
10	+61	+101	+133	+147	+155	+167	+170	+181	+179	+179	+183	+197	+221	+224	+157	227
(check)	+40	+65	+81	+96	+155	+187	+221	+227	+223	+201	+211	+219	+229	+231	+206	295

SMOOTH BROMEGRASS

90	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
80	−81	−79	−82	−97	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	0
70	−76	−57	−64	−72	−87	−85	−89	−90	−90	−92	−94	−94	−94	−100	−100	0
60	−36	−2	−2	−8	−25	−19	−11	−11	−8	−11	−9	−14	−59	−59	−37	26
50	−13	−9	−2	−10	−7	−11	−13	−7	−18	−32	−30	−32	−36	−35	−23	42
40	+8	+10	+18	+20	+13	+10	+8	+9	+8	+19	+32	+67	+66	+67	+57	141
30	+8	+13	+13	+15	+17	+15	+27	+31	+35	+37	+39	+43	+57	+68	+65	160
20	+9	+6	+5	+11	+21	+31	+40	+35	+41	+41	+50	+53	+59	+71	+68	163
10	+12	+16	+23	+26	+29	+21	+34	+26	+43	+44	+53	+70	+80	+87	+77	165
Check	+17	+21	+33	+35	+47	+47	+58	+63	+77	+81	+95	+104	+111	+111	+89	167

[1] Minus sign indicates proportion of roots not growing (−100 indicates no growth). Plus sign shows the percent increase in growing roots over the active roots at beginning of test.

and smooth brome after the 13th clipping; and at the 60-percent level—Kentucky bluegrass after the 11th clipping, and Rhodes grass after the 13th clipping.

As in the single-clipping series, the root-growth stoppage was generally less when less of the top was removed, and no stoppage occurred when 40 percent or less of the top was removed. In contrast to the single-clipping series, however, the root-growth stoppage increased with repeated clippings.

Neither Rhodes grass, Kentucky bluegrass, nor smooth brome clipped at the 90-, 80-, and 70-percent levels had any growing roots at the end of the 33-day test. These 3 grasses, clipped at the 60- and 50-percent levels had an average of 57 and 35 fewer growing roots, respectively, after the last clipping than before the first.

Occurring first at the 40-percent clipping level, the number of growing roots in excess of the original count increased with lowered percentages of top reduction. The average increase in the number of active main roots of the 3 grasses was 42 at the 40-percent level, 64 at the 30-percent level, 70 at the 20-percent level, 90 at the 10-percent level, and 114 for the control plants.

In total root production, the averages of the 3 grasses at the 9 clipping levels gradated upward from 0 at the 90-, 80-, and 70-percent levels to 156 at the 10-percent level, and to 183 at the control level.

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