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LENGTH OF LIFE OF ROOTS OF TEN SPECIES OF PERENNIAL RANGE AND PASTURE GRASSES[1, 2]

J. E. WEAVER AND ELLEN ZINK

(WITH SIX FIGURES)

Introduction

It is well known that death of the tops of practically all prairie grasses occurs each fall in temperate grasslands where the soil is regularly frozen. Year after year new shoots replace the old ones in this vegetation of long-lived perennials. But as to what portion of the root system is retained and over what period of time, we are almost without information. This maintains despite the fact that much work has been done to increase our knowledge of the root systems of prairie grasses. Since the early studies of WEAVER (**6, 7**) on their depth and lateral extent, detailed investigations have been made by PAVLYCHENKO (**1**) upon their rate of growth, total root length, and quantity and quality of root material. The quantity of root material under different grassland climates has been ascertained by SHIVELY and WEAVER (**2**), and the quantity under different degrees of utilization of these grasses in the same climate by WEAVER and HARMON (**8**). WEAVER, HOUGEN, and WELDON (**9**) studied the amount of root material at different soil depths; but the length of life of the roots of prairie grasses, except for brief study by STODDART (**4**), seems to have been entirely neglected. However, an investigation on the longevity of the seminal roots of certain grasses has recently been made by WEAVER and ZINK (**10**).

This lack of information is general for other grasses as well. Notable exceptions are the studies of SPRAGUE (**3**) on Kentucky bluegrass and Colonial bent, and of STUCKEY (**5**) on twelve species of cultivated grasses. Sprague concluded that at least one-half of the root system is newly generated each spring; Stuckey states that for some species the whole root system is regenerated annually.

Methods

CONTAINERS

Plants were grown from seed in large containers. Nine cylindrical cans made of heavy galvanized iron, 24 inches tall and 18 inches in diameter, were filled with loam potting soil. This had been screened, brought to an approximately uniform water content favorable for rapid growth, and thoroughly mixed. The soil had a hygroscopic coefficient of about 10 per cent. Openings in the bottom of the cans, covered with woven wire and an inch

[1] Contribution from the Department of Botany, University of Nebraska, no. 148.

[2] This investigation was aided by a grant to the senior author from The Graduate Council of The University of Nebraska, and grants to the junior author from the Nebraska Academy of Sciences.

depth of gravel, afforded adequate drainage. In filling the containers to near the top, the soil was tamped firmly in place. A removable extension consisting of a heavy galvanized iron band, 6 inches wide, riveted and soldered, and just large enough to fit within the container, was inserted to a depth of 2 inches. Here it rested on a number of rivet-heads just inside the metal rim. This removable extension, which was filled with soil consisting of well-mixed half sand and half loam, increased the depth of the container 4 inches. In addition, 26 heavy galvanized iron containers, 9 by 9 inches in diameter and 29.5 inches deep, were used. Each was fitted with a removable extension, which increased the depth to 33.5 inches, and permitted by its removal and the washing away of the sand-loam mixture easy access to the roots.

Seeds were planted early in March. Those of two species of grasses were planted on opposite sides of each of the large containers and about 4 inches from the side of the extension. Thus, seed of each of 9 species was planted in duplicate but in different large containers. A third planting of each was made in one of the smaller containers. Three groups of each species were required, since the plan was to examine one lot at the end of each of three growing seasons, and it was necessary to destroy the plants in order to examine the individual roots. Also three other smaller containers were planted with seed of the tenth species. In addition, 5 more of the smaller containers were used since it was desired to grow additional plants of certain species. Proper watering and mulching promoted prompt germination and good establishment. Once established, the seedlings were thinned to 5 or fewer in each planting.

Banding

In order to ascertain with certainty the longevity of the roots, a method of banding them individually was devised. Preliminary banding was done in 1929 and methods of procedure outlined. These were successfully used by Stoddart (4) in 1932. An opportunity to band roots on a large scale was afforded in the spring of 1943. Bands 8 to 10 millimeters long and 2 to 3 millimeters wide were cut from tin obtained from new, unpainted tubes such as are used for tooth pastes, ointments, etc. The thickness of the sheet of tin was only 0.12 of a millimeter, and hence it was very pliable yet durable. Bands remained bright and unrusted even after 3 years in the soil.

The first banding of the roots was done between April 26 and May 14, 1943, when the seedling grasses were 53 to 67 days old. The roots were exposed by removing the extension and washing away the soil by means of a gentle spray of water. It was usually necessary to support the tops of the plants by fastening them to a wire thrust deeply into the soil. Banding was done on damp or rainy days in much subdued light (5 to 10 per cent.), and over a wet floor. Care was taken to keep the roots moist by frequent spraying with a bulb type of hand spray. The grasses were uninjured by this root exposure. At the initial banding all roots 2 inches or more in length (excluding the seminal root or roots) were banded. Usually 2 to 6

roots, varying with the species, were too short to band. The number banded varied from 5 to 74 depending upon the species and the number of seedlings employed. The banding required two persons, one to separate the individual roots one by one from the others. This was done with a hand ice pick. The other person placed a band, which had previously been formed by rolling the tin into an open cylinder around the small end of a pipette, about the root by means of tweezers. It was then gently but tightly rolled between thumb and forefinger until it fit closely around the root (figs. 1, 2). The band partly unrolled if the root grew in diameter. When all the roots were banded, the extension was replaced and the roots covered with a mixture of

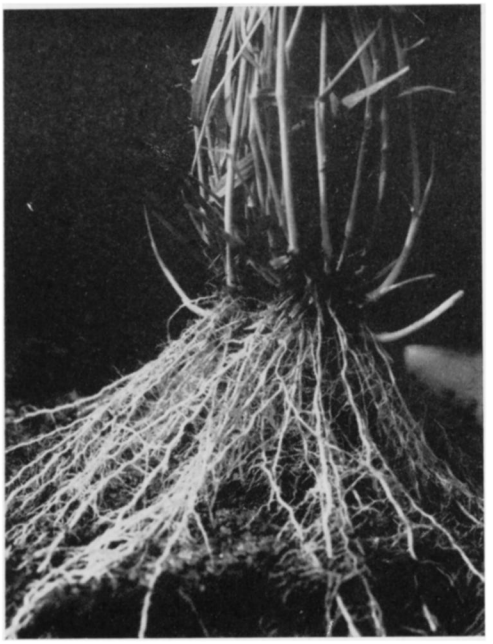

FIG. 1. Roots of switch grass (*Panicum virgatum*) about 3 months old, exposed for banding on June 11, 1943.

dry sand and soil. This readily filled all the spaces about them. It was added gradually and immediately watered by means of a bulb spray. This was repeated until the extension was filled.

A second banding, involving new roots of the same plants that developed later, was made between June 7 and 15, 1943. This was for the purpose of increasing the number of roots under observation. The plants had grown rapidly, tillered abundantly, and some had produced rhizomes. They were 12 to 21 inches tall. A few of the early bloomers had produced flower stalks, and some were flowering. After the extension was removed, a fine, gentle spray of water was used to slowly wash away the soil from the root-mass. Usually all of the new roots were banded, but in some species they were so numerous that only a part of them was used. The total number banded

per species varied between 100 and 419. In plants of most species the new roots formed a peripheral cover which obscured those banded earlier. After banding was completed, a process which required from 30 to 60 minutes or more, dry soil mixed with sand was placed about the roots and immediately watered. Even these larger plants showed no wilting or other signs of injury as a result of the root exposure. It was observed that with several species nothing was gained by banding before the new roots had enlarged considerably and that the same purpose could be accomplished by one banding at a date intermediate to those previously used. Hence, a single

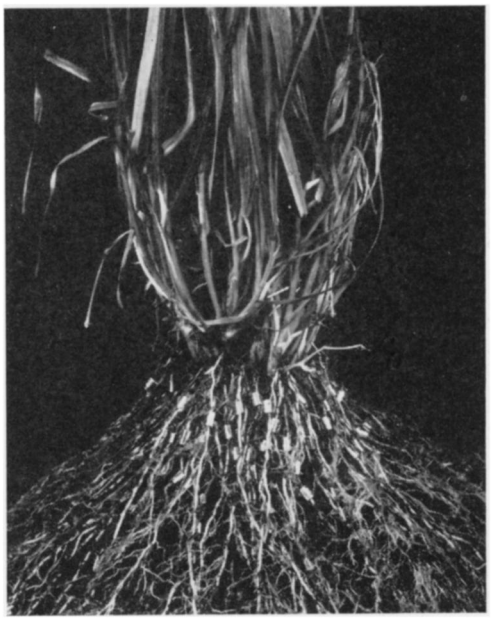

FIG. 2. Roots of crested wheat grass (*Agropyron cristatum*) with numerous bands attached but not yet tightly rolled. It produces an abundance of roots early in life.

banding was made thereafter for plants that were grown to supplement the group employed at the beginning of the experiment.

In 1943, 2,551 roots of 107 plants were banded. The next year roots of several species of grasses were banded where they were growing in the prairie. The following year other lots were banded to ascertain the effect of frequent removal of tops on the longevity of roots.

CONDITIONS FOR GROWTH

During the growing season the plants were placed in a greenhouse with panels of glass removed from the sides and with windows and ventilators open. The cement floor was well insulated with a thick layer of dried grass, tubs of water were placed on side benches, and humidity was approximately the same as out-of-doors. The sides of the containers were also well insulated against direct sunlight. Although the light was only 50 to 60 per cent.,

the plants were widely spaced, and all made an excellent growth. All but two species, whose normal time for blossoming is in June, flowered the first season, and all flowered profusely each of the following summers. In autumn, the plants were clipped at a height of 2 inches (as is a mowed prairie), and the containers were placed out-of-doors in a large trench. The bottom of the trench was filled with gravel to furnish good drainage, and moist soil was firmly packed about the containers. The tops, now level with the soil, were lightly mulched with grass as is commonly furnished by the growth following fall mowing in prairie. The soil froze solidly to a depth of several inches each winter and in spring thawed and froze repeatedly. Each spring when growth began the containers were removed to the greenhouse until fall. This was done in order to protect the plants from injury by hail or by grasshoppers or other animals. Here proper care could best be given and especially insurance against waterlogging of the soil during periods of heavy rainfall. Moreover, injury by insects and competition by invading grasses could be more readily detected and prevented. Finally, the roots were much more easily recovered for final examination where each container could be moved about.

Examination of banded roots

In examining the banded roots, the container was placed on a small stout table about 18 inches high, so that it was accessible from all sides. The extension was removed after tapping it repeatedly to free it from the soil. It was sometimes necessary to insert a long-bladed knife between it and the soil. The tops of the plants were then removed at the soil surface. With a gentle stream of water, the mixture of sand and loam was slowly washed away, except for that portion close to the plants. A sharp, long-bladed knife was then used to cut through the soil mass and sever the roots at the level of the top of the container. It was completely loosened from the loam soil below. The top 4 inches of the root system with soil intact about it was then inverted and placed in a white enameled tray 18 by 15 inches in length and width and 2.25 inches deep. The tray was tilted, and the soil below the depth of banding was carefully washed away with a bulb spray or a very gentle stream from a hose.

As the tangled root-ends were exposed, they were removed with a scissors and saved for inspection. Muddy water and loose soil were caught in a tub as they left the tray. Soon the small glistening bands became visible (fig. 3). As soon as one was found the root within it was examined to ascertain whether or not it was still alive. While no completely satisfactory test has been devised to determine whether roots of grasses are living or dead, long experience with the roots of many individuals of each species adds greatly to the accuracy of determination. Living roots often had a yellowish-white or brownish color which was usually very different from the color of the dead ones. They had good tensile strength and were not brittle. The dead roots were easily broken, and tensile strength was low. They were often

smaller, and sometimes they had decayed, and the band lay free in the mass of roots. Once familiar with the roots of these grasses, dead roots could be distinguished with certainty where, as here, several inches of the roots were exposed.

After all the bands were removed from the more distal parts of the roots, two or more inches of the root-ends were again clipped. These were retained with the other clippings. Gentle spraying of the inverted roots revealed the bands near their proximal ends. They too were removed one by one. It was often necessary in older roots to carefully pry the crown apart to regain the last few bands. A record was kept of the total number of bands,

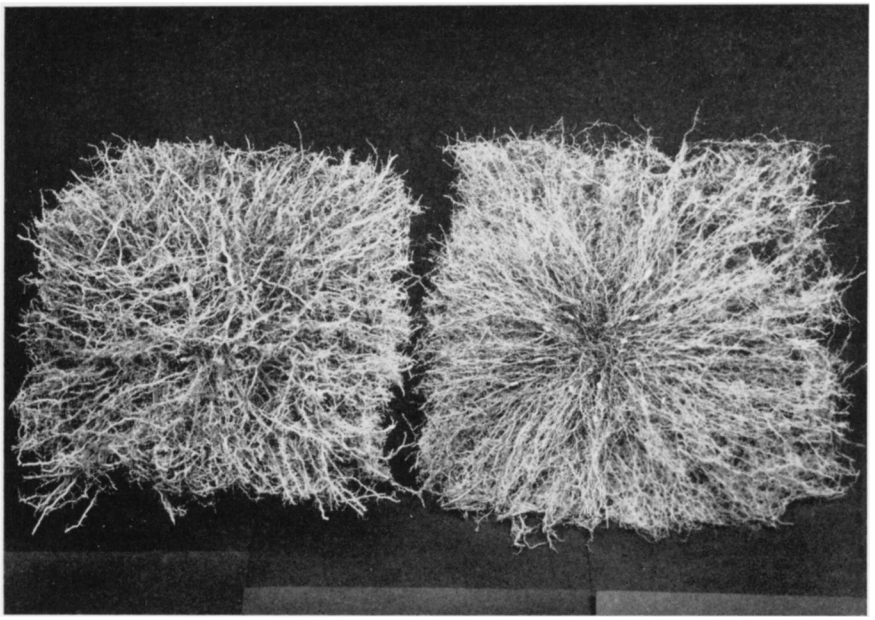

FIG. 3. (Left) Inverted mass of roots of 3 plants of *Panicum virgatum* that were cut from the top of a container after the extension had been removed. The soil has been partly washed from the roots, but they have not been cut back far enough to reveal the bands. (Right) Roots of *Andropogon scoparius*. The finer and more flexible roots of the 3 plants of this species have been pressed back and reveal some of the numerous bands. Both grasses were examined at the end of the second growing season. Each mass of roots is about 9 × 9 inches in diameter.

the number from living roots, and the number from dead ones as well as unattached bands. Since all of the washing was done in the white enameled tray and all soil was plainly visible in a very thin layer, it was only rarely that a band was washed out of the tray. Wash water and all soil were retained, however, until the total number of bands was accounted for.

Results

RESULTS OF FIRST GROWING SEASON AND FIRST YEAR

The number of banded roots of each species and the percentage that died either by the end of the first growing season or by the end of the first year

after banding are shown in table I. Each entry represents a separate group of plants, and where there is only one banding it indicates that new lots of plants were grown during a later season in order to increase the total number of banded roots.

Of the 7 species examined at the end of the first summer, only three showed root losses. These were *Bromus inermis* with 25 per cent. loss in one lot only. Losses in *Agropyron cristatum* were very low, 2 and 5 per cent., but *Stipa spartea* lost 18 per cent. Of roots examined at the end of the first year those of *Bouteloua curtipendula* alone suffered no fatalities; losses in four other species ranged from 16 to 36 per cent. (table I).

TABLE I

RESULTS OF FIRST GROWING SEASON AND FIRST YEAR

SPECIES*	NUMBER OF ROOTS BANDED		PERCENTAGE OF DEAD BANDED ROOTS	
	FIRST BANDING	SECOND BANDING	FALL, 1943	SPRING, 1944
Andropogon furcatus Muhl. (Big bluestem)	5	13	0	.....
	.....	60	0	.....
Elymus canadensis L. (Nodding wild rye)	26	43	.....	23
Panicum virgatum L. (Switch grass)	23	77	0	.....
Agropyron smithii Rydb. (Western wheat grass)	22	78	.....	36
Andropogon scoparius Michx. (Little bluestem)	11	45	0	.....
	.....	55	0	.....
Bouteloua curtipendula (Michx.) Torr. (Side-oats grama)	29	78	.....	0
Stipa spartea Trin. (Needle grass)	.....	33	18	.....
Bouteloua gracilis (H.B.K.) Lag. (Blue grama)	37	68	0	.....
Agropyron cristatum (L.) Beauv. (Crested wheat grass)	.....	56	2	.....
	.....	60	5	.....
	19	56	.....	25
Bromus inermis Leyss. (Hugarian brome grass)	33	69	25	.....
	.....	80	0	.....
	.....	60	0	.....
	34	66	.....	16

* The first three are tall grasses, the next four are mid grasses, blue grama is a short grass, and the last two are important cultivated species.

The excellent development of both roots and tops of grasses is shown in figure 4. *Bromus inermis* and *Andropogon scoparius*, both of which produced abundant flower stalks, had developed root systems nearly 3 feet long. There were 57 and 93 roots per plant, respectively. Thus, the mass of roots of the several seedlings in the clump was very large. This reflected the good conditions for growth.

RESULTS OF SECOND GROWING SEASON AND SECOND YEAR

The number of banded roots and the percentage of those that died by

fall, or by the following spring of the second year, are shown in table II. The plants were reduced to 9 species, since one lot of *Agropyron cristatum* grew very poorly. By the end of the second summer banded roots of *Andro-*

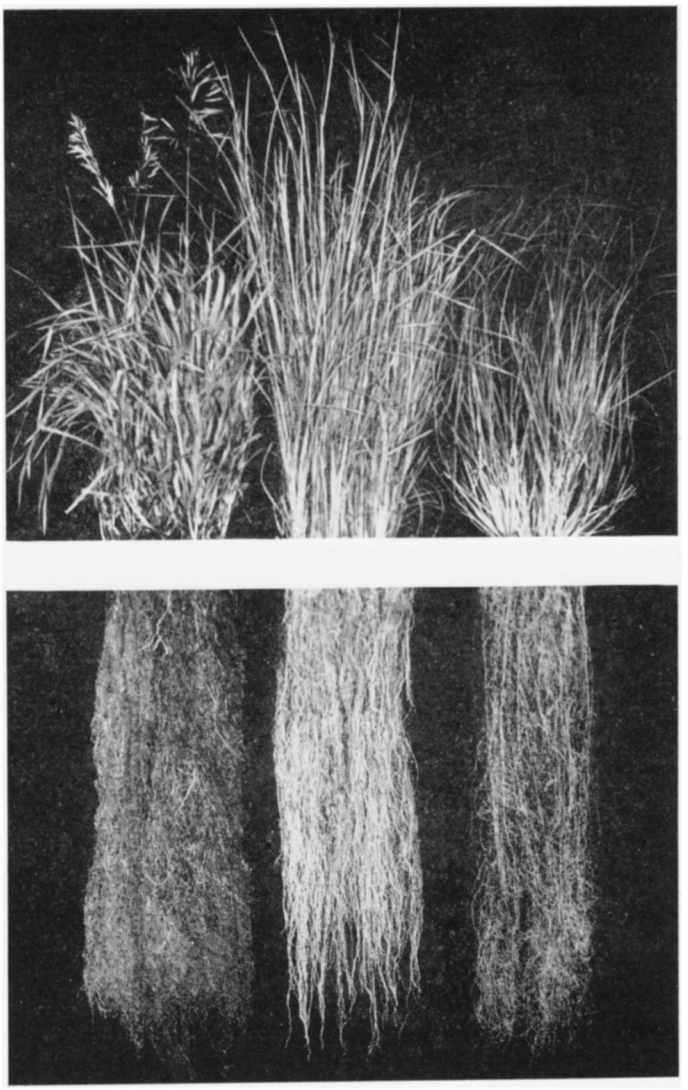

FIG. 4. Tops and deeper roots of one season's growth of *Bromus inermis* (left), *Andropogon scoparius*, and *Stipa spartea* (right). The top 4 inches of the root systems was destroyed in recovering the bands. Depth of root penetration was 32 inches.

pogon furcatus and *Panicum virgatum* had suffered no loss and those of *Andropogon scoparius* only 5 per cent. loss. But half or more than half of the banded roots of four other species died. The following spring loss in *Andropogon scoparius* was 31 per cent., which was nearly the same as

TABLE II

RESULTS OF SECOND GROWING SEASON AND SECOND YEAR

SPECIES	NUMBER OF ROOTS BANDED		PERCENTAGE OF DEAD BANDED ROOTS	
	FIRST BANDING	SECOND BANDING	FALL, 1944	SPRING, 1945
Andropogon furcatus	13	10	0	.....
Elymus canadensis	35	67	.....	73
Panicum virgatum	20	31	0	.....
Agropyron smithii	20	47	55	.....
	26	59	60	.....
Andropogon scoparius	15	53	5	.....
	31	69	.....	31
Bouteloua curtipendula	33	68	.....	64
Stipa spartea	17	23	50	.....
Bouteloua gracilis	27	89	.....	34
Bromus inermis	21	56	64	.....

that of *Bouteloua gracilis*. In *Elymus canadensis* and *Bouteloua curtipendula* the loss was two-thirds or more of the roots banded.

RESULTS OF THE THIRD GROWING SEASON

Six species of grasses continued growth during the third summer. Plants of *Panicum virgatum* and *Agropyron cristatum* were accidentally destroyed. Work on *Bromus inermis* was terminated in the fall of 1944, and *Agropyron smithii* spread so widely in the container that it was necessary to remove it in the fall of 1944 in order to save *Stipa spartea* with which it was planted. The losses of banded roots among the six remaining species are shown in table III. They were lowest in *Andropogon furcatus* (19 per cent.), 55 per cent. in *Bouteloua gracilis*, and in four species they varied between 86 and 100 per cent.

SUMMARY OF SURVIVAL

The average percentage of survival of each of the 10 species at each period they were examined is shown in table IV. Losses in all species, except

TABLE III

RESULTS OF THIRD GROWING SEASON

SPECIES	NUMBER OF ROOTS BANDED		PERCENTAGE DEAD BANDED ROOTS
	FIRST BANDING	SECOND BANDING	FALL, 1945
Andropogon furcatus	20	60	19
Elymus canadensis	17	43	100
Andropogon scoparius	43	57	90
Bouteloua curtipendula	74	56	86
Stipa spartea	12	15	90
Bouteloua gracilis	45	45	55

TABLE IV

PERCENTAGE SURVIVAL AT EACH EXAMINATION

SPECIES	FALL, 1943	SPRING, 1944	FALL, 1944	SPRING, 1945	FALL, 1945
Andropogon furcatus	100	.....	100	.....	81
Elymus canadensis	.....	77	.....	27	0
Panicum virgatum	100	.....	100	.....	.....
Agropyron smithii	.....	64	42	.....	.....
Andropogon scoparius	100	.....	95	69	10
Bouteloua curtipendula	.....	100	.....	36	14
Stipa spartea	82	.....	50	.....	10
Bouteloua gracilis	100	.....	.....	66	45
Agropyron cristatum	97	75	.....	.....	.....
Bromus inermis	92	84	36	.....	.....

Agropyron cristatum, were gradual. *Agropyron smithii* had a survival at the end of the second summer of 42 per cent., and *Bromus inermis* of 36, but all banded roots were alive on *Panicum virgatum*. Percentage survival at the end of the third growing season was: *Andropogon furcatus* 81, *Bouteloua gracilis* 45, *B. curtipendula* 14, *Andropogon scoparius* 10, *Stipa spartea* 10, but on *Elymus canadensis* none survived.

NUMBER OF ROOTS PRODUCED

It is common knowledge that each spring new roots are produced, often in abundance, by perennial grasses, at least in temperate climates. It is important to consider the total number of roots in relation to the death of those produced early in life and the significance of the loss of the latter to the general welfare of the plant. Consequently, when the plants were examined a count of the total number of roots was made, and the average number per plant at different ages was thus ascertained (table V). All counts were of living roots; very few dead ones were found. In general, there was a steady increase in numbers with age. The number per plant was quite large and especially so in *Bromus inermis* (841). The very fine roots of *Bouteloua gracilis* likewise became very numerous (567), but the large, coarse ones of

TABLE V

AVERAGE NUMBER OF ROOTS PER PLANT AT DIFFERENT AGES

SPECIES	FALL, 1943	SPRING, 1944	FALL, 1944	SPRING, 1945	FALL, 1945
Andropogon furcatus	40	.....	228	.....	882
Elymus canadensis	307	.....	.....	319	438
Panicum virgatum	60	.....	269	.....	.....
Agropyron smithii	.....	249	.....	.....	.....
Andropogon scoparius	69	.....	248	323	177
Bouteloua curtipendula	.....	170	.....	423	378
Stipa spartea	24	.....	.....	.....	175
Bouteloua gracilis	37	.....	.....	167	567
Agropyron cristatum	.....	329	.....	.....	.....
Bromus inermis	.....	841	794	.....	.....

Andropogon furcatus were even more abundant (882). A single clump of 4 seedlings of *Bouteloua gracilis* produced during three seasons of growth a total of 2,268 individual roots (fig. 5).

In the examination of three-year-old bunches of *Bouteloua curtipendula* it was observed that a few dead rhizomes occurred in the center of the clump.

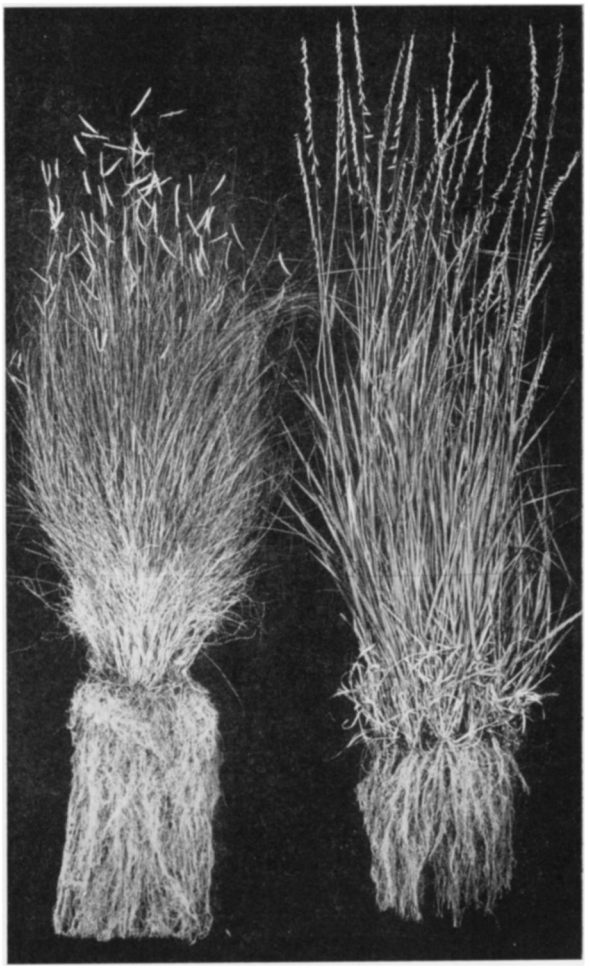

FIG. 5. Bunches of *Bouteloua gracilis* (left) and *B. curtipendula* at the end of the third growing season. In the root system of the first (cut off at a depth of 16 inches) roots occurred at the average rate of 28 per square inch. The four plants in the bunch on the right have a total of 1,512 roots.

This was only 1 to 3 per cent. of the total interwoven lot. Likewise a part of the central and older portion of the crown of *Andropogon scoparius* had died. This, while very small, was the part to which most of the older roots (mostly banded) had been attached. In prairie, degeneration of plants of these species and of many bunch grasses usually begins in the center

of the crown and proceeds outward. Such degeneration would be well advanced in the soil before it would be at all conspicuous above ground, due to the crowding of stem and leaves. This may have been the beginning of the process. Certainly the loss of a few score of roots among hundreds of others would have little effect upon the plant. The writers have determined experimentally that under usual conditions of growth the removal of half or even more of the root system had little harmful effect upon the growth of several species of grasses. Whether or not the roots that develop the second and third years are of longer life-span than those of the first remains to be ascertained.

Root banding in prairie

The roots of six species of grasses were banded where they grew in clay loam soil in prairie. This was accomplished with much more difficulty than when the plants were grown in containers. Early in June, 1944, the soil was removed by means of a continuous stream of water from a portable spray pump to a depth of 3 to 4 inches about the roots of four species of bunch-forming grasses. Trenches 18 inches deep were dug in the sod of *Andropogon furcatus* and *Sorghastrum nutans* (L.) Nash. By using the spray of water on a wall of the trench, numerous roots were exposed. A few, as in the bunches, were white and turgid and clearly of the current year's growth. Most of them were one or more years old. The exact age, of course, could not be determined. While the roots were kept moist by frequent sprinkling, the bands were attached to selected uninjured individuals. Moist soil was replaced about them and thoroughly watered. The exact location of the plants was carefully marked by stakes driven into the soil so that the roots could be recovered later by removing a block of sod of minimum size.

In April of the following spring bands were recovered by the washing process already described. This was far more difficult than with sand-loam soil even after the sods were thoroughly soaked in water. Four of the 20 banded roots of *Stipa spartea* were dead, but only 1 among 24 roots of *Adropogon scoparius*. On young bunches of June grass (*Koeleria cristata* (L.)) Pers., 6 of the 30 banded roots had died, but 5 among 14 on mature plants.

The remaining bands were recovered from the prairie at the end of the second summer. The number varied from 30 to 60 per species. Losses in one bunch of *Stipa spartea* were 54 per cent., in another 60. Other losses were: *Andropogon scoparius* 23 per cent., *A. furcatus* 45, *Bouteloua curtipendula* 36, and *Sorghastrum nutans* 37. This work was done primarily to ascertain whether or not the method was feasible under field conditions; the losses may or may not be representative of those over a long period of time.

Effect of clipping of tops on longevity of roots

The banding method was used in an experiment on the length of life of both seedlings and established plants of several species of grasses. Seeds of

Bromus inermis were planted in the large type of container previously described. When the seedlings were 6 inches tall and tillered abundantly (May 10) 130 roots were banded. A week later the plants were clipped at a height of 2 inches (to simulate grazing) and every 10 days thereafter until June 20. After each clipping recovery occurred rather promptly. When the roots were examined on August 2 the plants were 5 to 10 inches tall and in good condition. Only 20 of the banded roots had died, which was 15 per cent. of those originally marked. On the unclipped controls all of the 140 banded roots remained uninjured.

A similar experiment was performed at the same time with *Agropyron cristatum.* It recovered less promptly after clipping and grew poorly. Hence, next to the last clipping was omitted. On August 2 many of the tops below the clipping level were partially dead and dry, but all of the plants had made some new growth, which was 3 to 6 inches tall. Of the 110 roots banded 80 had died. Of the unclipped controls, only 3 per cent. of the 116 banded roots had succumbed. Thus, repeated clipping resulted in a mortality of 73 per cent. of the roots.

Four pieces of sod containing vigorous plants of *Andropogon furcatus,* and 4 with *A. scoparius,* were secured on April 15 from a prairie where the plants were just renewing growth. Each block of sod was 5 inches long, 3 inches wide, and 3.5 inches deep. Each was placed in a separate box on a layer of moist sand and loam 5 inches deep, and soil was compacted about it. The tops grew rapidly and by May 17 abundant new roots 4 to 8 inches long had developed. The soil was now washed from the roots extending below the blocks of sod, the roots banded, and the sods carefully transplanted in the large containers previously used. They contained a mixture of sand and loam which was placed about the roots and sods in a manner that did them no injury.

A total of 53 bands was placed on the new roots of the two lots of plants used as controls and 60 on those of the plants to be clipped. The experimental plants were clipped at a height of 2 inches and the controls at 4 inches immediately after this second transplanting. Clipping, except for the controls, was repeated at intervals of 10 to 14 days until July 8, a total of 5 clippings. The plants recovered promptly after each clipping except the last, *Andropogon furcatus* showing better growth than *A. scoparius.* When examined on August 1, only 3 per cent. of the roots of the controls of *Andropogon furcatus* had died but 45 per cent. of those of the clipped plants. In *A. scoparius* the percentages of death of control and clipped were 3 and 64, respectively. Thus, the injurious effects of the frequent removal of most of the tops is shown by the response of roots as well as by death in the crown, a loss that could be definitely ascertained by the banding method.

Discussion

The banding method was found unsatisfactory for some species of grasses with very fine roots. In *Poa pratensis, Eragrostis trichodes,* and a few other

species it was difficult to adjust the bands tightly enough to keep other roots from entering the same band. This difficulty was not encountered with most of the native prairie grasses. Also where the number of moderately fine roots was very great and the roots compact, as in *Bromus inermis* and *Agropyron cristatum,* banding was more difficult. That the process of banding or the presence of the bands did not harm the roots is apparent since in most plants all of the banded roots were alive at the end of the first summer and many after a year or more.

Bands were much more readily recovered from bunch grasses than from those producing sods, although certain sod-formers retained the bunch habit for a long time. *Agropyron smithii,* for example, had only a few fine roots

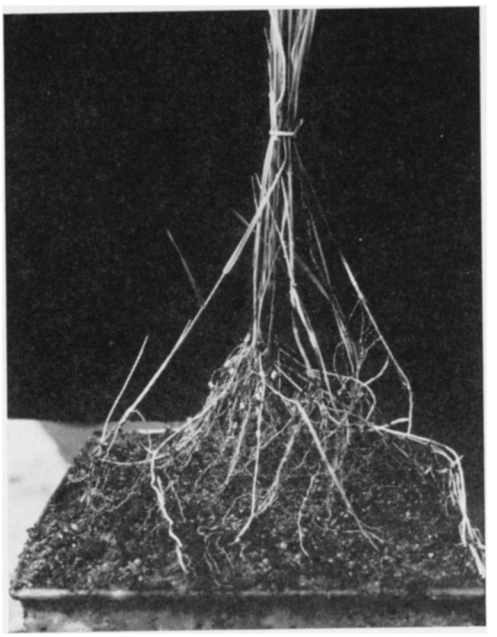

FIG. 6. The first four inches of underground parts of *Agropyron smithii.* The large, widely spreading, white rhizomes are more prominent than the rather small fine roots. This made banding difficult as well as the replacement of the soil without root injury. June 14, 1942.

that supported the seedling plants. Very early several slender rootstocks developed which produced whorls of a few roots each from the nodes, which were an inch or more apart. Hence, the area for banding soon equaled the area of the soil surface (fig. 6). Quite in contrast were the root habits of bunch formers, and even *Andropogon furcatus* and *Panicum virgatum* in early life. They took complete possession of the soil immediately below the crown. The roots of these two species became so large (often two or more millimeters in diameter), even after two or three months, that they were closely compacted at their points of origin from the lower nodes and abundant tillers.

A close check was had on root losses from the two species of Andropogon by the minute examination of the roots of about 50 plants of each species each fall. They were grown out-of-doors in large steel drums for experimental purposes. In preparing these washed roots for weighing, the crowns were separated, and from each portion of the crown the roots were cut individually or in such small groups that every root was distinctly visible. They were then finally washed in a white enameled tray where dead or discolored roots could be seen plainly. None was observed at the end of either the first or second growing season. They occurred occasionally the third year.

No losses and replacements of root systems similar to those reported by SPRAGUE (3) and STUCKEY (5) occurred. Sprague examined plants whose roots were almost confined to the first 9 inches of a gray-brown forest soil in New Jersey. He found that one-half of the root system, by weight, was newly generated each year. Stuckey states that for some of the species the whole root system was regenerated annually, with active production of new growth beginning in October. Most of the old roots degenerated shortly after the new ones developed. These species included *Phleum pratense* L., *Festuca elatior* L., *Poa trivialis* L., *Lolium perenne* L., and probably *Agrostis tenuis* Sibth. and *Agrostis alba* L. But on *Poa pratensis* L., *Poa compressa* L., *Agropyron cristatum* (L.) Beauv. and *Dactylis glomerata* L., only a small percentage of roots disintegrated the first year. Although data by STODDART (4) are meager the results with each of the four species of prairie grasses banded are in accord with those of the writers.

Field observations over a long period of years indicate that *Elymus canadensis,* a grass common in moist places, is a species that depends for its permanency of occupation more upon rapid reproduction from seed than upon length of life of the individual. The limited data on *Bromus inermis* and *Agropyron cristatum* indicate considerable permanence of the roots developed the first year. All of the other prairie grasses grown are species of great stability, some individuals probably enduring for a quarter-century or more. While there was a gradual loss of the older roots year by year, the loss is indeed small if not entirely negligible when the great abundance of new roots produced annually is considered. For example, the loss in *Bouteloua gracilis* of 90 per cent. of the roots it produced by June 10 of the first summer amounted after three growing seasons to only 8 per cent. of the total living roots. Similar losses in *Andropogon furcatus* were 2 per cent.

Long life and hence permanency of occupation are characteristics which aid greatly in the adaptation of a grass to semiarid and arid climates. They are likewise important characters of grasses well adapted to soil binding and prevention of erosion.

Summary

Seeds of 10 species of perennial range and pasture grasses were planted in triplicate lots in loam soil in containers large enough for ample root

development. A removable extension at the top of each container was filled with sandy loam soil easily washed away when the extension was removed, thus exposing the roots for examination.

Small bands of very thin, pliable sheet tin were placed around individual roots at each of two stages in the development of the plant. A total of 3,424 roots of 181 plants were banded to ascertain their longevity.

The roots were kept moist while exposed and then covered with dry soil which was immediately watered. Some were examined at the end of the first and second year, respectively, and the remainder at the end of each of three growing seasons.

Ninety-seven per cent. of the banded roots of *Agropyron cristatum* survived the first summer and 75 per cent. the first year. Survival on *Bromus inermis* was 92, 84, and 36 per cent. at three examinations. Survival on *Panicum virgatum* and *Agropyron smithii* was, after the second summer, 100 and 42 per cent., respectively. After three growing seasons 81 per cent. of the roots on *Andropogon furcatus* survived, but none on *Elymus canadensis*. Losses in all species were gradual, and after three growing seasons survival of roots was as follows: *Bouteloua gracilis* 45 per cent., *B. curtipendula* 14, and *Andropogon scoparius* and *Stipa spartea* each 10 per cent.

Average number of roots produced by individual plants varied from 175 to 882 at the end of the third summer. Compared with the total number of roots, losses among the banded roots were small to negligible. They often amounted to only 2 to 8 per cent. of the total number of living roots. Nearly all of the species studied have a long life and show great permanency of occupation, both important features in prevention of soil erosion.

Roots of 6 species of grasses of unknown age were banded in clay loam soil in prairie. At the end of a second growing season, losses ranged from 23 to 45 per cent. except in *Stipa spartea,* where they were 57.

Established seedlings of *Bromus inermis* and *Agropyron cristatum* with banded roots were clipped at 2 inches' height at 10-day intervals. There was no loss from unclipped control plants of the first species and only 3 per cent. from the second. But roots of clipped Bromus suffered a loss of 15 per cent. and those of Agropyron 73.

New roots from vigorous transplanted blocks of sod of *Andropogon furcatus* and *A. scoparius* were banded and the tops of one lot of each clipped at intervals of 10 to 14 days. After 5 clippings losses of roots were 45 and 64 per cent., respectively. The unclipped controls lost only 3 per cent. each.

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