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CONTENTS

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GROWTH AND YIELD OF CERTAIN GRAMINEAE AS INFLUENCED BY REDUCTION OF PHOTOSYNTHETIC TISSUE

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A few investigations have shown the influence of the reduction of chlorophyll-bearing tissue on the carbohydrate concentration, and on the yield of fruit, grain, or herbage following removal of the aerial growth. Because of the difficulty of observing closely the parts below ground, however, few detailed studies have been reported which show the effect of the removal of top growth on the development of the plant as a whole, including the roots. The extent to which root development may be correlated with yield, also, is little understood. Further knowledge of such correlations appears to afford both scientific and practical possibilities.

Grasses were used in the studies here reported. The experiment was designed to obtain information on the following points: (1) the effect of removal of tops on root growth; (2) the effect of removal of tops on the yield and on the regeneration of the aerial growth; (3) the growth rate and the yield of non-harvested (undisturbed) plants. Study on the last mentioned phase was essential as a means of comparison.

The difficulty of observing and measuring roots was overcome by growing the plants in a nutrient solution. Although it is realized that

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roots grown in water cultures may be somewhat different from those produced in soil, it may be concluded from similar studies in soil cultures that root development in these media show in general a very similar trend.

In these studies growth is considered as composed essentially of the activities of the meristems in the production of new cells, and in cell enlargement.

RESUMÉ OF PERTINENT LITERATURE

Growth Measurement.—Thompson[18] pointed out that growth curves are characterized by a slow rise, followed by a rapid increase in rate to the point of inflection, and then by a slow decline. These observations are substantiated by Sampson and McCarty[15] who constructed under field conditions a growth curve for one of the species used in this investigation. West, Briggs, and Kidd[21] concluded that dry weight forms the most reliable measure of the growth rate of plants. Reed and Holland,[12] on the other hand, determined the growth rate of sunflower plants by measuring the elongation of the apical region of the shoot. Sampson,[13] in his studies with wheat and brome grass, employed the use of measurements of leaf and stem lengths taken at regular intervals. He also measured growth of peas by obtaining an index of leaf area by recording the number of leaflets and securing their average size.

Root Growth.—The supply of organic materials elaborated in the aerial parts influences profoundly the effect of factors potent in root development. Loeb[8] and Janse[6] have shown that the meristematic regions exert a profound attraction for food materials as well as for water and nutrient salts. A continuous supply of such foods enables the meristematic tissues to produce new cells, including meristematic cells, which in turn increase the demand for food materials. Accordingly, in a plant having primary and secondary meristems there is continuous competition between the various meristems for materials carried in the conducting tissues. Any factor which favors one growth center evidently curtails the supply of material available to the others, resulting in retardation in the development of the latter.

Root and Shoot Growth.—Alternation of root and shoot growth has been indicated by investigators as typical of some species. In other species alternation in growth does not occur simultaneously. Barker[1] working with young apple trees, which were so arranged that the exposed roots were sprayed at intervals of from three to five minutes with a nutrient solution, showed a short period of rapid root growth prior to the growth of shoots. This activity continued for only a short period after aerial growth began. Little root growth took place during the period of shoot elongation, and at the cessation of aerial growth, as in the autumn, root growth again became more vigorous and continued until late autumn. MacDougal,[9] studying in central Illinois the root growth of forest trees—*Carya, Querqus, Acer,* and *Tilia*—observed that root growth took place at a much earlier date than the opening of the buds.

Rest Period.—The rest period as influenced by cessation of activity in the growth centers, even when external conditions are favorable to that condition, does not take place in roots. Chandler[2] found that not only was there no rest period for roots but that even resting twigs may send out roots. Curtis[4] observed that cuttings may produce roots at any time in the year when external conditions are favorable to growth. Accordingly, it would appear that roots do not have a distinct rest period but grow whenever conditions are favorable and especially when shoot growth is not vigorous. Howard[5] concluded that roots do not appear to be influenced by treatments which bring about dormancy in the twigs.

Root Penetration.—Depth of penetration of roots has been studied by Weaver[20] in his investigations of root habits of grasses and crop plants in the Great Plains area. He concluded that differences in lateral spread or in output of branches may be correlated with changes in the water content of the soil. His observations show that a close correlation exists between depth of root penetration and amount of rainfall. Von Seelhorst[19] concluded that there were relatively more roots in soils of low average moisture than in soils of very high moisture content. When moisture was in excess roots deteriorated, whereas the tops were luxuriant. In this instance cessation of root growth was doubtless due to insufficient aeration. Chandler[3] found that in clay soils with an abundant water and nutrient supply, the root systems of nursery trees are small when compared with those grown in a sandy, gravelly soil where the moisture content was low, but where aeration was apparently better. Likewise, Singh[16] showed that the root system of wheat was better developed in pure sand underlain with barnyard manure than when grown in a heavy soil also supplied with manure.

Temperature.—For the best root growth in general the temperature must be lower than that required for maximum growth of the aerial parts. Mevius,[10] observing roots of *Pinus pinaster* found that growth ceased at 30° C although other conditions were favorable, but top growth continued normally. When the temperature was lower, root growth was resumed and continued vigorously even at a temperature below 15° C. Although studies in this field are limited, it would appear that relatively high temperatures are unfavorable to root growth. For the reason that investigations as to temperature influences have mostly been taken for short periods—usually only a few hours—such as the studies of Lehenbauer,[7] there is little reliable data to show the effect of temperature on the development of roots and on the top to root ratio.

Removal of Photosynthetic Tissue.—Decreased leaf surface appears to be clearly correlated with root development. An abrupt decrease in the synthetic activity of leaves causes a corresponding slowing down in root growth. Continued defoliation will cause destruction of the root system and, finally, death of the plant. Stirrup,[17] working with mangolds and sugar beets, found that in semi-defoliated mangolds the yield was 89 per cent of that of the undisturbed plant, and that from the semi-defoliated sugar beet it was 81 per cent. Sampson and Malmsten[14] in the study of forage species, found that the removal of herbage, four to five times in a season, resulted in a sharp decline in yield and a marked shortage of life of the vegetation. On the other hand, harvesting or grazing vigorous bunch grasses—two times, or in a very good soil and a favorable climate, three times in a season, leaving between each harvesting interval considerable time for the development of aerial growth—did not appear to decrease appreciably the forage yield. It was found that such cropping as would result in the reduction of the aerial growth was also reflected in root development and in the quantity of food stored in the underground parts. Poor development of the root system resulted in the production of an increasingly small quantity of herbage the following season.

METHODS AND PROCEDURE

The Plants.—One of the plants used was *Stipa pulchra* of the tribe Agrostideae, a native perennial bunch grass occurring commonly throughout the coast ranges and some interior areas of California between sea level and an elevation of 5,500 feet. Stands of this species generally indicate that the range is in a subclimax or in a climax stage of development. The other species was *Bromus hordeaceus* of the tribe *Festuceae,* an annual species native of southern Europe. It occurs throughout the state from sea level to an elevation of about 4,000 feet. The presence of this species may indicate that plant development is in a comparatively low successional stage, as it grows in soils unfavorable to the more exacting perennial grasses.

The seed of both species was collected in the foothills near Berkeley, California. At the time of selecting the seed for germination only the seeds of normal appearance, as judged from size and weight, were used. The seed was germinated on wire screens held closely over a free water surface. This was done in such a manner as to keep the air above the seed practically saturated with moisture. Highly satisfactory germination results were obtained. Seedlings were selected so as to obtain individuals as nearly alike as possible. This was done by measuring the shoots with a millimeter rule, assuming an average, and selecting individual plants which measured within three millimeters of the average.

The containers used in the experiment were ordinary half-gallon (approximately 2 liters) fruit jars wrapped in two layers of heavy manila paper and one layer of opaque tar paper, which served to exclude light (fig. 1). The position of the containers on the table was

Fig. 1. Cultures of grasses showing exposure in the greenhouse.

changed each day so that all plants would be subjected to approximately the same light conditions.

The Culture.—A nutrient solution devised by Professor D. R. Hoagland of the College of Agriculture was used. The culture solution, in addition to the regular constituents, contained in the formula a small quantity of so-called "A–Z" solution which served to correct any deficiency due to the need of certain other elements. The culture also required 2 cubic centimeters of a 5/10 per cent solution of ferric tartrate per liter of solution, to supply iron. The constitution of the solution was as follows:

Salts used	Concentration of solution	Molar solution per liter, cc	Ions, parts per million
Ca $(NO_3)_2$ $4H_2O$	1. Mol.	3.9	Ca—157
KNO_3	1. Mol.	3.6	NO_3—709
			K—181
Mg SO_4 $7H_2O$	1. Mol.	2.2	Mg.—55 SO_4—217
KH_2 PO_4	1. Mol.	1.1	PO_4—105

The seedlings were placed in the containers filled with solution and were held in place by means of a loose wad of cotton inserted in the hole of the cork. Two plants were placed in a jar. The number of plants in each series is indicated in table 1.

The measurement of growth was procured by recording the total leaf length of each leaf with a millimeter rule at the time of harvesting, which was at 15-day intervals. Since the tops (but not the stem bases and roots) of 10 plants were harvested at each interval, and simultaneously 6 plants were completely harvested, that is, the tops, stem bases, and roots were removed, it was possible to procure measurements directly on the detached leaf blades of 16 plants. The fresh weight and the dry weight of tops and roots were obtained from the 6 plants completely harvested. The growth of adventitious roots for the first 30 days that the plants were in solution was measured with a millimeter rule.

Volumetric Root Measurement.—Priestly and Pearsall[11] devised an elaborate apparatus for measuring the volume of roots by the displacement of water. This plan, however, was not applicable to this experiment. A rather simple instrument was devised instead, which would give direct quantitative readings (fig. 2). The results procured through the use of this apparatus were finally abandoned in this study because of the small root growth of some of the plants, and consequent little displacement of water in the instrument. The data for root growth given in this study were obtained by recording the dry weight of the roots.

Order and Time of Harvesting.—Table 1 shows the order and time of harvesting, and the number of plants in each series.

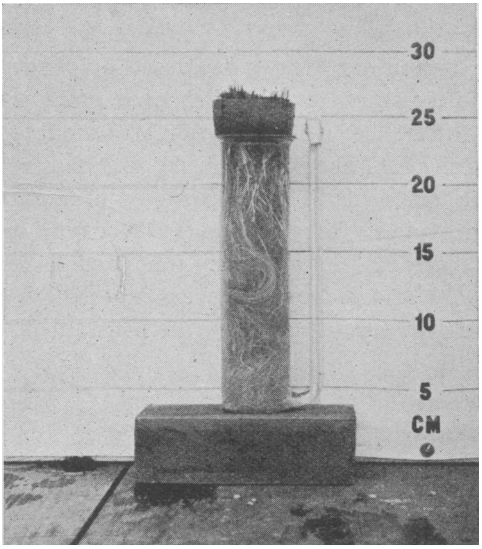

Fig. 2. Apparatus for measuring volumetrically the area of the roots of grasses subjected to different treatments.

TABLE 1

DATES OF HERBAGE REMOVAL FROM STIPA PULCHRA

Number of plants*	Number of days							
	15 Dec. 7	30 Dec. 22	45 Jan. 6	60 Jan. 21	75 Feb. 5	90 Feb. 20	105 Mar. 7	120 Mar. 22
10	X							XX
10		X						XX
10			X					XX
10				X				XX
10					X			XX
10						X		XX
10							X	XX
40								XX
20	X	X	X	X	X	X	X	X
42†	XX	XX	XX	XX	XX	XX	XX	

* Seedlings were set in jars on November 23, 1928.

Explanation of table 1: Single X—tops harvested; double XX—tops and roots harvested.

† Complete harvest (tops and roots) of 6 plants every 15 days. The plan for herbage removal on *Bromus hordeaceus* was identical with the above plan for *Stipa pulchra*.

Experimental Error.—It is generally known that plants of the same species when grown in the same habitat possess an inherent tendency to vary in size in different individuals. In this study these variations may, to a minor degree, be caused by very slight differences in the amount of solar radiation which each plant received. Serious effort to avoid difference in illumination was made by systematically changing the position of the plants on the greenhouse tables each day.

The probable error of the measurements of plants not harvested, as compared with plants harvested every 15 days during a period of 120 days, was determined by using the following formula: the summation of all the deviations from the mean regardless of sign, divided by the number of cases, multiplied by the constant 0.845. The results are set forth in table 2.

TABLE 2

PROBABLE ERROR OF PLANT MEASUREMENTS, BASED ON DRY WEIGHTS

Plant	Number of plants	Mean weight of tops, grams	Probable error	Mean weight of roots, grams	Probable error
Bromus hordeaceus control	42	5.38	.41	1.46	.26
Bromus hordeaceus harvested	20	.40	.11	.14	.04
Stipa pulchra control	42	2.07	.22	.506	.055
Stipa pulchra harvested	20	.08	.02	.02	.005

Since the probable errors of the dry weights of the plants not harvested and of those harvested frequently do not overlap when combined with their respective means, it is evident that comparisons between these two sets of differently treated plants are reliable.

RESULTS AND DISCUSSION

Growth Rate of Plants.—The data on the growth of the two species studied are given in table 3, and summarized in figure 3.

Bromus hordeaceus grew much more rapidly than *Stipa pulchra* and produced a much larger amount of leafage (table 3, fig. 3). At the end of 120 days, for example, *Bromus hordeaceus* had produced an average of 6.368 grams of air-dry herbage and 1.464 grams of air-dry roots; whereas, for the corresponding period *Stipa pulchra* produced only 2.617 grams of herbage and 0.506 grams of roots. Growth of each species appeared normal and healthy. In *Bromus hordeaceus* the growth rate of the tops and the stem bases began to

TABLE 3

GROWTH RATE OF BROMUS HORDEACEUS AND STIPA PULCHRA; BASED ON DRY WEIGHT

Number of days	*Stipa pulchra*, weight in grams		*Bromos hordeaceus*, weight in grams	
	Tops and stem bases	Roots	Tops and stem bases	Roots
1	.002	X	.001	X
15	.005	.002	.006	.002
30	.026	.019	.042	.015
45	.128	.048	.264	.071
60	.244	.074	.824	.176
75	.511	.150	1.669	.328
90	1.134	.251	3.702	.652
105	1.908	.356	5.257	.854
120	2.617	.506	6.368	1.464

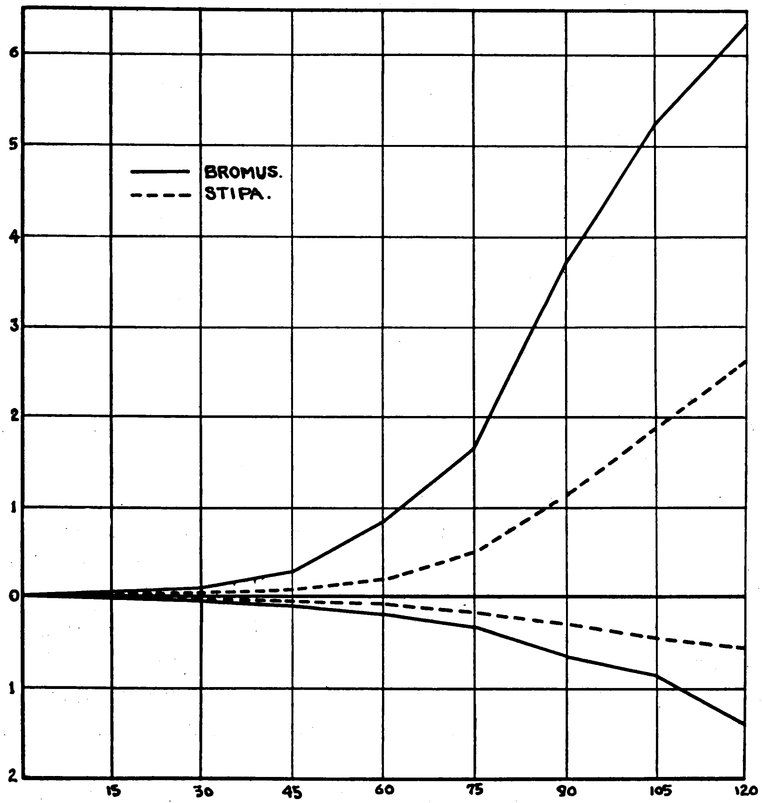

Fig. 3. Rate of growth of tops and roots of undisturbed (untreated) plants of *Stipa pulchra* and of *Bromus hordeaceus* based on dry weight.

rise abruptly after 45 days of growth and was most precipitous between 75 days and 90 days. After that there was a slight slowing down in growth, but throughout the period the rate was more rapid than in the other species. In *Stipa pulchra* the growth rate increased rather gradually through the entire period and was at its maximum between 75 days and 120 days of growth. There was no evidence of a declining growth rate at the time of harvesting. The ratio of the two species was as 2.4 to 1.

TABLE 4

REGENERATION OF TOPS AND GROWTH OF ROOTS OF STIPA PULCHRA AFTER A SINGLE HARVESTING

Date of measurement	Length of shoot, centimeters		Length of adventitious roots, centimeters	
	Harvested plant	Control plant	Harvested plant	Control plant
Dec. 7	....	20.3	0.9	1.0
Dec. 8	1.0	21.3	1.0	3.1
Dec. 9	1.4	22.6	1.0	4.8
Dec. 10	2.3	24.7	1.0	5.4
Dec. 11	2.9	27.2	1.0	6.6
Dec. 12	3.6	28.5	1.0	7.5
Dec. 13	4.0	29.7	1.0	8.8
Dec. 14	4.8	31.4	1.0	9.7
Dec. 15	5.6	32.8	1.0	10.7
Dec. 16	6.4	34.4	1.0	11.9
Dec. 17	7.1	36.7	1.1	13.0
Dec. 18	7.9	38.8	1.1	14.2
Dec. 19	8.9	42.9	1.2	15.3
Dec. 20	10.1	48.1	1.2	16.4
Dec. 21	11.4	53.9	1.3	18.1

The root growth was likewise appreciably more rapid and larger in *Bromus hordeaceus,* the weight as compared with *Stipa pulchra* being 2.8 to 1 at the end of 120 days. In both species root growth was sustained and gradual, but there was a tendency towards retardation during the period of most rapid aerial growth. In *Bromus hordeaceus,* for example, the most rapid root growth took place between the 105- and 120-day periods, a time which corresponded with the post inflection period of the top growth. In *Stipa pulchra* there appeared to be a similar periodicity in root and top growth, notably between the 105- and 120-day period. This behavior of slow root growth during its time of rapid top growth had previously been recorded for *Stipa pulchra* under field conditions.[15]

It is well known that growth is greatly influenced by the prevailing meteorological conditions during the growing season. In this experiment conditions for growth were at an optimum except during periods of low light intensity as in foggy or rainy weather. No alternation in shoot and root growth was apparent, but the intervals between measurements were such that if there was such alternation it was not discernible. The greater growth activity of *Bromus hor-*

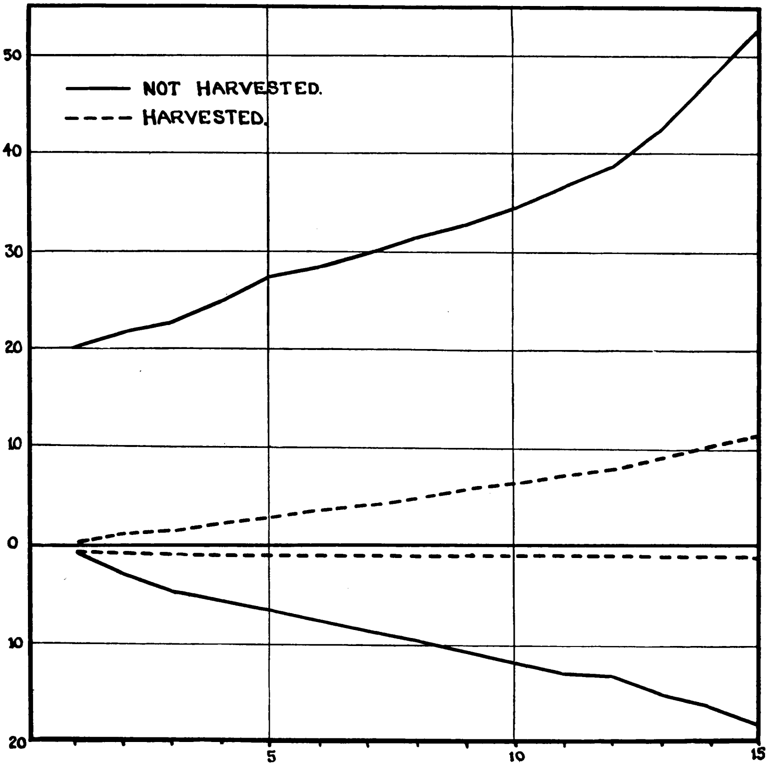

Fig. 4. *Stipa pulchra,* showing effect of harvesting on growth of adventitious roots, and on rate of regeneration of tops.

deaceus is explained by the fact that it is an annual. To complete the cycle of growth in the habitat typically occupied, rapid development is essential. *Stipa pulchra,* on the other hand, growing as it does in habitats where the upper soil horizon is comparatively rich in organic materials and well supplied with moisture, develops relatively slowly.

Effect of a Single Harvesting on Growth.—The data on the effect of a single harvesting of the top growth of *Stipa pulchra* are summarized in table 4 and figure 4.

The harvesting of *Stipa pulchra* when the plants were 15 days old resulted in a retardation of the growth rate, both of the tops and of the adventitious roots. Removal of herbage resulted in an immediate cessation of root growth which recovered only slightly towards the end of the 15-day interval. Regeneration of the tops, however, took place immediately following the harvesting and resulted in a sharp acceleration of the growth rate for a period of about 24 hours. Following this active growth period the rate of leaf blade elongation

TABLE 5

REGENERATION OF TOPS AND GROWTH OF ROOTS OF BROMUS HORDEACEUS AFTER HARVESTING

Date of measurement	Length of shoot, centimeters		Length of adventitious roots, centimeters	
	Harvested plant	Control plant	Harvested plant	Control plant
Dec. 7	....	17.8	1.3	1.3
Dec. 8	1.4	19.1	1.4	2.2
Dec. 9	2.0	20.8	1.4	3.7
Dec. 10	2.8	21.6	1.4	5.3
Dec. 11	4.0	23.9	1.4	7.2
Dec. 12	5.0	26.0	1.4	8.7
Dec. 13	5.8	28.5	1.7	9.2
Dec. 14	6.7	32.1	1.8	10.6
Dec. 15	8.2	36.3	2.4	12.3
Dec. 16	9.1	39.8	2.8	14.2
Dec. 17	10.2	44.3	3.8	17.7
Dec. 18	11.6	48.0	4.7	19.2
Dec. 19	13.6	53.2	5.8	21.3
Dec. 20	16.7	60.2	6.5	23.2
Dec. 21	19.7	68.6	9.2	25.7

declined and did not increase in activity until a considerable photosynthetic area was produced. Root growth practically ceased for a period of 15 days, presumably because of the cutting off of the photosynthetic nutrients following herbage removal. At the same time a sharp demand for nutrients in the highly active growth centers of the aerial parts followed the harvesting stimulus.

In *Bromus hordeaceus* the effects of herbage removal were similar to those of *Stipa pulchra,* although less pronounced, as may be deduced from the data summarized in table 5 and in figure 5.

Harvesting of the leafage of the *Bromus* plants when 15 days old resulted in an immediate cessation of root growth, a function which did not resume activity until after eight days. Regeneration of tops, as in *Stipa pulchra,* also took place immediately and for a period of 24 hours the growth rate was rapid, appreciably more so than in the non-harvested specimens of the same age.

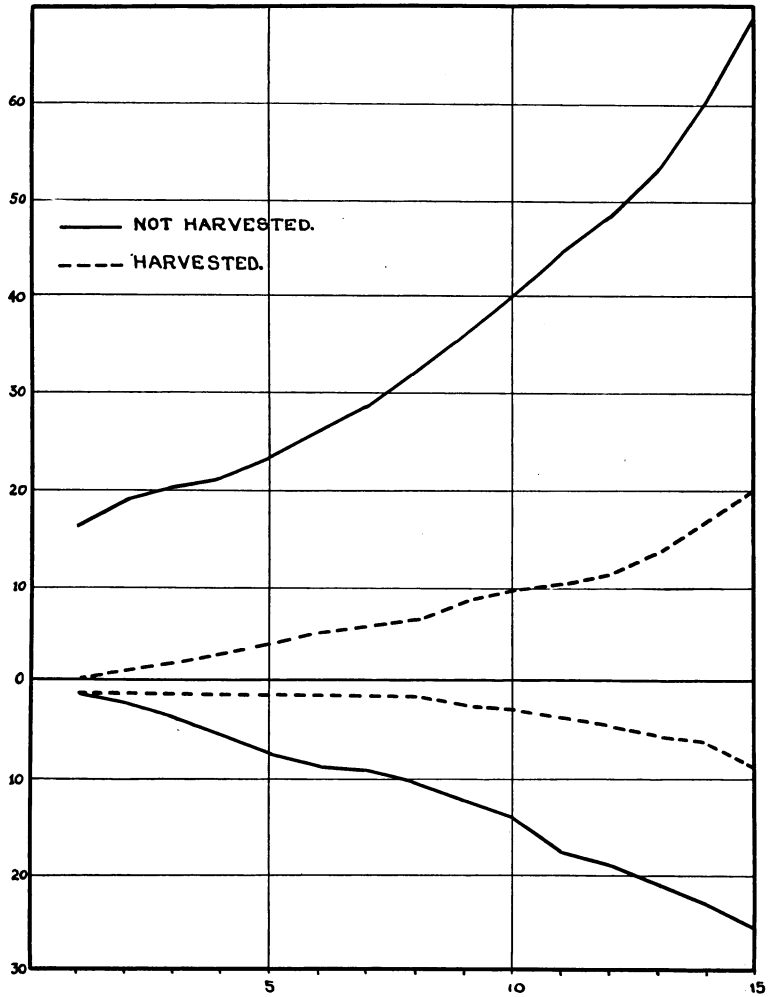

Fig. 5. *Bromus hordeaceus,* showing effect of harvesting on growth of adventitious roots, and on rate of regeneration of tops.

Although vigorous growth of both tops and roots took place beginning after the 15th day, the yield of both species was less, as will be shown later, than in the unharvested plants.

Effect of Frequent Herbage Removal on Total Yield.—The effect of frequent herbage removal on the total yield for the 120-day period is summarized in table 6 and in Figures 6, 7, and 8.

TABLE 6

REGENERATION OF TOPS OF PLANTS HARVESTED AT 15-DAY INTERVALS OVER A PERIOD OF 120 DAYS, NOVEMBER 22, 1928, TO MARCH 22, 1929; AND GROWTH OF PLANTS NOT HARVESTED

Number of days	Plants harvested every 15 days*		Plants not harvested		Per cent difference, dry weight, harvested and non-harvested plants
	Total length of leaf blades, centimeters	Dry weight of tops, grams	Total length of leaf blades, centimeters	Dry weight of tops, grams	
			Stipa pulchra		
1	5.6	0.002	5.6	0.002	0.0
15	26.3	0.004	20.3	0.004	0.0
30	41.7	0.013	53.9	0.022	41.0
45	64.6	0.021	140.9	0.088	76.2
60	85.8	0.028	323.2	0.183	84.8
75	102.5	0.035	535.0	0.397	91.2
90	135.9	0.049	817.6	0.812	94.0
105	177.0	0.069	1595.6	1.524	95.5
120	201.9	0.081	2023.3	2.070	96.1
			Bromus hordeaceus		
1	5.1	0.001	5.1	0.001	0.0
15	22.3	0.005	20.3	0.005	0.0
30	50.6	0.014	68.6	0.038	63.2
45	102.7	0.034	276.2	0.184	81.6
60	179.1	0.062	646.4	0.643	90.4
75	265.0	0.095	1321.8	1.342	93.5
90	486.7	0.185	2605.8	2.917	93.7
105	845.5	0.345	3679.2	4.272	91.3
120	1017.6	0.407	4057.0	5.386	92.5

* Cumulative results.

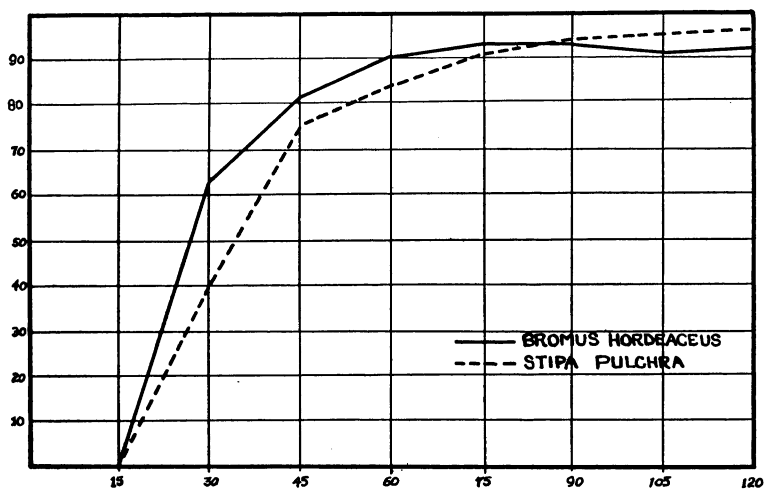

Fig. 6. Decrease in growth, expressed in per cent difference in dry weights of plants harvested every 15 days compared with those not harvested.

Stipa pulchra harvested every 15 days over the period of 120 days produced .081 gram of dry herbage as compared with a yield of 2.070 grams from plants not harvested, a difference of 96.1 per cent. The difference in yield between non-harvested *Stipa* plants and those frequenty harvested increased sharply with each subsequent removal

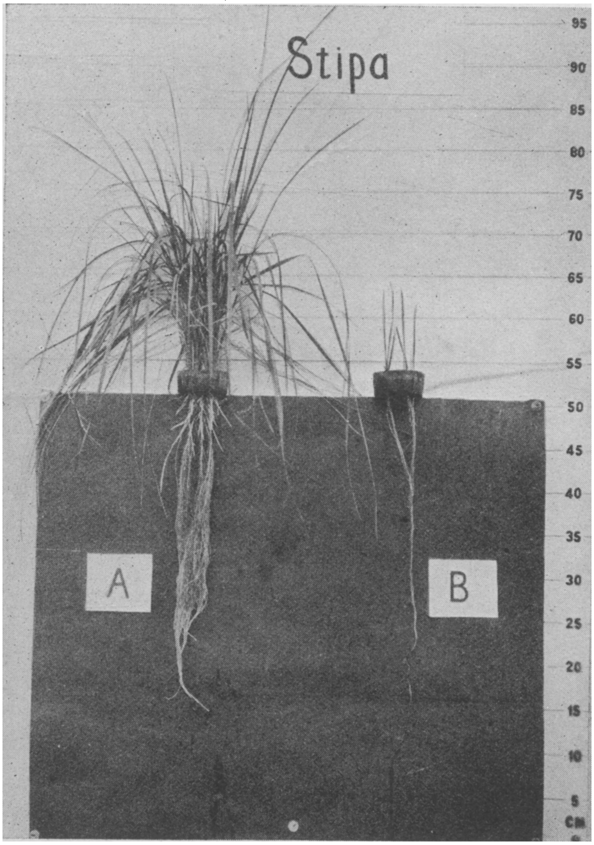

Fig. 7. *Stipa pulchra,* 120 days old. *A,* not harvested; *B,* harvested every 15 days.

of herbage. The percentage difference, for example, increased from zero per cent, for the first 15 days of growth, to 41 per cent at 30 days, the time of the second harvesting. It decreased 76.2 per cent at the 60-day interval, representing the fourth harvesting; and 91.2 per cent at the end of 75 days, which was the fifth harvesting. From this time on the difference increased more slowly, reaching 94 per cent in favor of the non-harvested plants at 90 days, representing the sixth harvesting; 95.5 per cent at 105 days for the seventh harvesting; and 96.1 per cent at 120 days, which was the final harvesting.

In *Bromus hordeaceus* the results of the frequent harvesting were similar to those of *Stipa pulchra*, but in the final harvestings the differences were somewhat less pronounced (table 6, figure 8). For

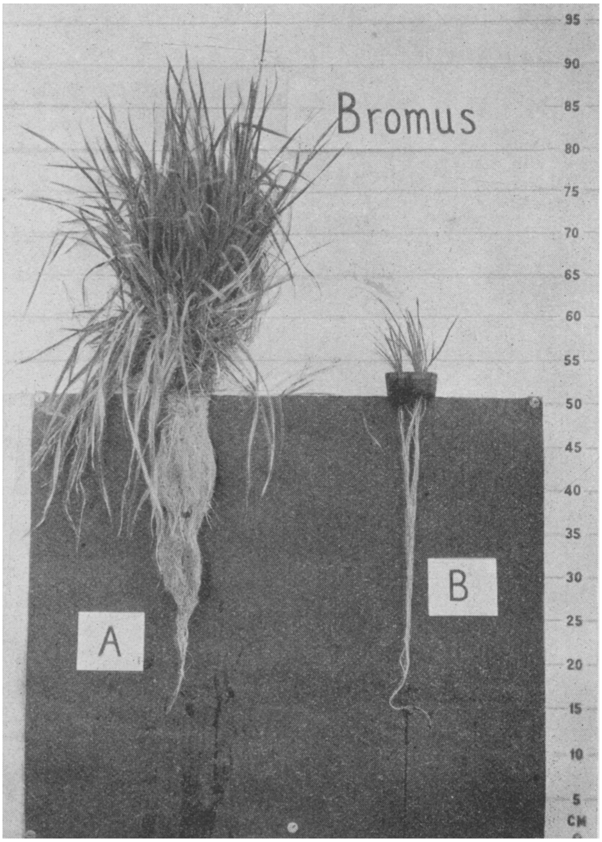

Fig. 8. *Bromus hordeaceus,* 120 days old. *A,* not harvested; *B,* harvested every 15 days.

example, plants harvested at 15-day intervals for the period of 120 days yielded 0.407 gram of dry material as compared with 5.386 grams of plants not harvested. The percentage difference between the non-harvested and the frequently harvested plants of this species increased rapidly in the early intervals and was less pronounced as the growth cycle declined. The percentage of difference increased from zero per cent for the first 15-day interval, representing the first harvesting, to 63.2 per cent at the second harvesting; and 81.6, 90.4, 93.5, 93.7, 91.3, and 92.5 per cent, respectively, at the six 15-day interval harvestings which followed.

That the frequent harvesting should give so pronounced a decline in yield in *Stipa pulchra* is in accord with the comparatively rapid disappearance of this species on overgrazed areas. The results of early frequent harvesting may also be interpreted to indicate that

TABLE 7

AVERAGE DRY WEIGHT OF PLANTS HARVESTED ONCE DURING 120-DAY PERIOD

Age at time of first harvest, days	Weight of tops at first harvest, grams	Weight of tops at last harvest, grams	Weight of stem bases at first harvest, grams	Combined weight of tops and stem bases, grams	Weight of roots at final harvest, grams	Total weight of entire plant, grams	Root volume on 120th day, cubic centimeters
			Stipa pulchra				
15	negligible	1.37	0.35	1.72	0.36	2.08	6.3
30	0.02	1.58	0.36	1.96	0.35	2.31	6.2
45	0.08	1.47	0.39	1.94	0.36	2.30	6.4
60	0.18	1.23	0.39	1.80	0.39	2.19	7.0
75	0.39	1.04	0.29	1.72	0.31	2.03	5.7
90	0.81	0.57	0.30	1.68	0.32	2.00	5.8
105	1.52	0.04	0.33	1.89	0.34	2.23	6.0
120	0.00	2.07	0.54	2.61	0.50	3.11	9.1
			Bromus hordeaceus				
15	negligible	4.17	0.69	4.86	1.17	6.03	11.5
30	0.04	4.65	0.73	5.42	1.03	6.45	10.6
45	0.18	3.96	0.74	4.61	1.24	5.85	13.2
60	0.64	3.49	0.71	4.74	1.19	5.93	12.1
75	1.34	2.80	0.71	4.85	0.97	5.82	10.1
90	2.91	0.62	0.59	4.12	0.59	4.71	9.3
105	4.27	0.20	0.60	5.07	0.65	5.72	9.7
120	0.00	5.38	0.98	6.36	1.46	7.82	16 3

premature grazing may be expected to bring about a declining yield of the perennial species for a single season, if not the actual thinning out of the cover of *Stipa pulchra*. *Bromus hordeaceus,* on the other hand, being less susceptible to injury as a result of herbage removal, and because of the fact that the root growth is apparently resumed sooner thereafter, would appear to account in part for the fact that this species withstands remarkably well both heavy grazing and premature grazing. The species occupies not only thin soils, which might be termed severe sites, but also the more favorable habitats where soil horizon A is well developed.

Effect of a Single Harvesting on the Final Yield During the 120-day Period.—The data on the effect of a single harvesting during the 120-day period for both species studied are given in table 7.

The harvesting of the plants once during the period of 120 days affected slightly the total yield of herbage, the weight of the roots, and the total weight of the plant (tops and roots). Moreover, there was no appreciable difference in the total yield of herbage resulting from harvesting once at different periods in the season. This holds in general for both species. The least amount of herbage following the first harvest was procured in the 90-day and 105-day periods, but these lesser yields were practically brought up to the average amount of herbage produced when the yield of the first harvest was taken into account. The smallest total (seasonal) weights of the plants (tops and roots) were obtained when the harvests were made during the period of most rapid growth. In field conditions, where, following the most rapid growth period the edaphic conditions are usually less favorable than earlier in the season, Sampson and McCarty[15] procured considerably smaller yields. In *Stipa pulchra* these workers also noted a much smaller accumulation of carbohydrates in the stem bases, and a correspondingly weaker growth the following spring.

Regardless of the period when the harvesting was made relative to the growth cycle, vegetative growth was vigorous and immediately followed the harvesting. In a few hours sufficient leafage was produced to elaborate some food materials.

SUMMARY AND CONCLUSIONS

During the period of 120 days the growth rate of *Bromus hordeaceus,* an annual exotic species, was more vigorous in water culture than *Stipa pulchra,* a perennial native species. This behavior is similar to that in the natural habitat. A single harvesting during the 120-day period resulted temporarily in cessation of root growth. This was more pronounced in *Stipa pulchra* than in *Bromus hordeaceus,* owing possibly to the more rapid and vigorous growth of both tops and roots of the latter, and the fact that it completes its cycle of development in a much shorter period. Following each harvesting, regardless of the stage of development, regeneration of the aerial portion took place immediately in both species. Frequent harvesting at 15-day intervals over the period of 120 days proved more detrimental to *Stipa pulchra* than to *Bromus hordeaceus.* Both species when harvested at 15-day intervals produced much less dry material than when not harvested. Moreover, a single harvesting prior to the final harvesting, which was made at the end of 120 days, affected slightly the total amount of herbage produced for the entire period. In both species the smallest yields were procured when the herbage was removed at the time when the growth rate was at its maximum.

These investigations, in so far as they may represent growth and response to stimuli under natural conditions, indicate the loss resulting from frequent herbage removal, as by grazing or cutting, as well as of heavy grazing during the period of the most rapid growth rate. Such practices result in an appreciable decrease in yield. They also indicate, as have similar studies, decreased longevity of perennial bunch grasses and the curtailment in the establishment of such desirable species leading to a succession towards the climax or subclimax community.

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The titles of the Technical Papers of the California Agricultural Experiment Station, Nos. 1 to 20, which HILGARDIA replaces, and copies of which may be had on application to the Publication Secretary, Agricultural Experiment Station, Berkeley, are as follows:

4. Effect of Sodium Chlorid and Calcium Chlorid upon the Growth and Composition of Young Orange Trees, by H. S. Reed and A. R. C. Haas. April, 1923.
5. Citrus Blast and Black Pit, by H. S. Fawcett, W. T. Horne, and A. F. Camp. May, 1923.
6. A Study of Deciduous Fruit Tree Rootstocks with Special Reference to Their Identification, by Myer J. Heppner. June, 1923.
7. A Study of the Darkening of Apple Tissue, by E. L. Overholser and W. V. Cruess. June, 1923.
8. Effect of Salts on the Intake of Inorganic Elements and on the Buffer System of the Plant, by D. R. Hoagland and J. C. Martin. July, 1923.
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10. The Seasonal Variation of the Soil Moisture in a Walnut Grove in Relation to Hygroscopic Coefficient, by L. D. Batchelor and H. S. Reed. September, 1923.
11. Studies on the Effects of Sodium, Potassium, and Calcium on Young Orange Trees, by H. S. Reed and A. R. C. Haas. October, 1923.
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16. The Moisture Equivalent as Influenced by the Amount of Soil Used in its Determination, by F. J. Veihmeyer, O. W. Israelsen and J. P. Conrad. September, 1924.
17. Nutrient and Toxic Effects of Certain Ions on Citrus and Walnut Trees with Especial Reference to the Concentration and Ph of the Medium, by H. S. Reed and A. R. C. Haas. October, 1924.
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