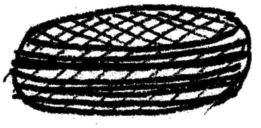
Step by step

1. Location grana in chloroplasts in leaf calls



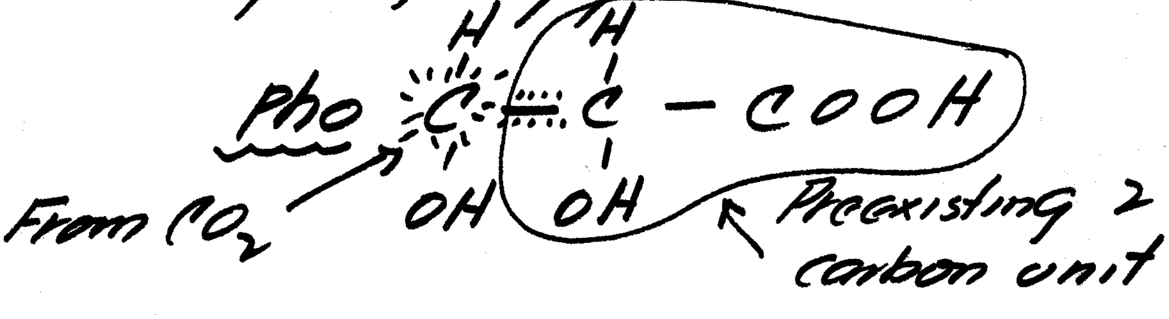
Chlorophyll
Carotenoid pigments
Xanthophyll, minerals, fat

2. Chlorophyll formed from proto-chlorophyll presence sunlight, essential minerals fatty substance etc; two H atoms added to protochlorophyll

3. Light energy trapped by chlorophyll used to split H_2O, produce H atoms and O atoms O_2 gas liberated is from H_2O End need light

Chlorophyll absorbs blue and red light (short and long wave lengths) and reflects green light.

4. First step formation glucose phosphoglyceric acid



5. Two molecules phosphoglyceric acid united to form glucose

Phosphoric acid liberated

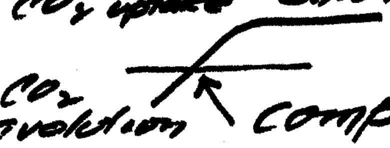
The process (Photosynthesis) Not continuous

1. Only in presence
   light
   chlorophyll

2. Production glucose proportional to

   a) Amount chlorophyll - size of green plant number green cells

   b) Light intensity - spring, summer fall



compensation pt $\frac{\text{photosyn}}{\text{respiration}}$

   c) Temperature - metabolic rate

3. Energy storing - energy for life processes.

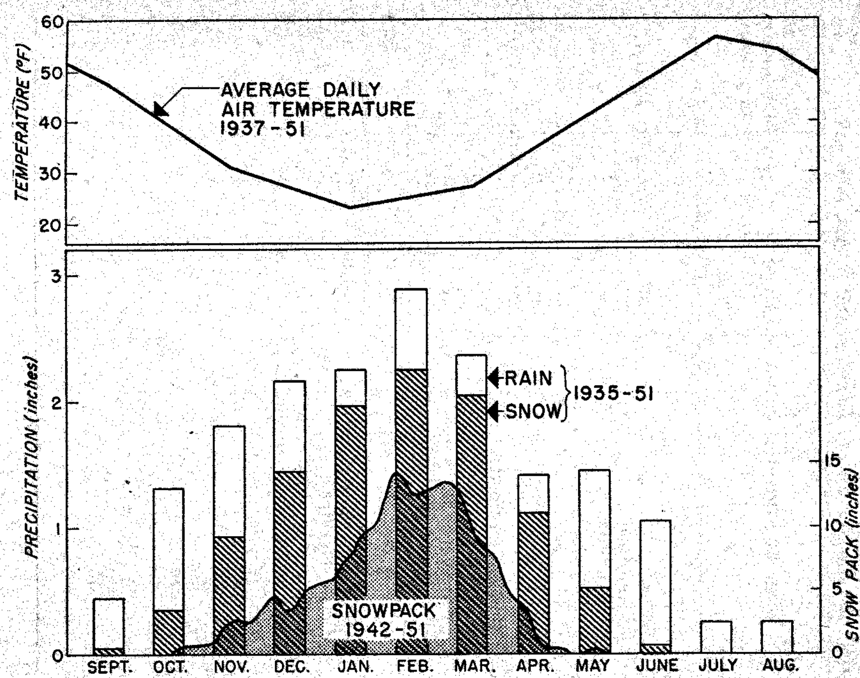


FIGURE 8.—Precipitation and temperature at the Blacks Mountain Experimental Forest headquarters.

TABLE 10.—*Basal area of Idaho fescue plants when clipped, and one year afterward the Burgess Spring Experimental Range*

Average date and growth stage at time of clipping [1]	Basal area—					
	When clipped in 1948	1949	Reduction	When chipped in 1951	1952	Reduction
	Sq. in.	*Sq. in.*	*Pct.*	*Sq. in.*	*Sq. in.*	*Pct.*
April 25. Leaves about 3 inches tall	4. 30	1. 23	71	5. 60	2. 00	64
May 13. Stems low in boot	4. 71	. 76	84	6. 10	1. 50	75
May 27. Stems emerging from boot	4. 79	. 45	90	5. 21	. 95	82
June 17. Stems two-thirds grown	4. 87	. 08	98	4. 20	. 30	93
July 6. Peak of flowering	4. 42	. 57	87	4. 20	. 47	89
July 21. Seed in milk	4. 88	1. 45	70	4. 20	. 57	86
August 8. Seed ripe	5. 05	1. 94	62	4. 71	1. 28	73
August 19. Plant 80 percent dry	4. 20	1. 65	61	4. 82	1. 45	70
September 1. Plant 90 percent dry	4. 30	2. 16	50	5. 10	1. 80	65
September 29. Plant 95 percent dry	4. 38	2. 51	43	3. 20	1. 20	62
Average	4. 59	1. 28	72	4. 73	1. 16	75

[1] 10 plants clipped at each growth stage in each series.

TABLE 11.—*Change in basal area or number of fascicles of forage species clipped 4 years at the seed-in-milk stage,[1] the Burgess Spring Experimental Range, 1946–49*

Year	Basal area				Fascicles			
	Idaho fescue		Bottlebrush squirreltail		Longspur lupine		Woolly wyethia	
	Sq. in.	*Pct.*	*Sq. in.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1946	4. 16	100	1. 88	100	15. 4	100	8. 2	100
1947	2. 16	52	2. 22	118	5. 0	32	7. 7	94
1948	1. 67	40	2. 25	120	6. 5	42	8. 8	107
1949	1. 39	33	. 69	37	2. 4	16	7. 9	96
1950	. 83	20	. 71	38	1. 4	9	6. 9	84

[1] Clipping was started in 1946 and ended in 1949 in all 4 species. The effect of a particular clipping is reflected in growth the year after clipping. Thus the effect of clipping in 1946 is reflected in the figures for 1947; the effect of clipping in the fourth year, 1949, is reflected in 1950.

Average date and growth stage at time of clipping:	*Flower stalks in regrowth* [1]	
	Per square inch of basal area (number)	*Height (inches)*
May 1. Leaves about 3 inches tall	2. 62	14. 50
May 13. Flower stalks low in boot	. 79	10. 82
May 27. Flower stalks surpassing basal leaves	. 30	6. 82
June 17. Flower stalks two-thirds grown	. 04	. 65
July 6. Peak of flowering	(2)	(2)
July 9. Flower stalks full grown	0	0
Check plants, unclipped	13. 09	23. 62

[1] Average 1946, 1947, 1948, and 1951.
[2] Trace.

The stunted flower stalks that were produced in the regrowth had little or no seed. Flower stalk production 1 year after clipping was severely reduced. Average reductions for 4 years ranged from 94 to 100 percent:

Average number of flower stalks per square inch of basal area one year after clipping

Average date and growth stage at time of clipping: [1]	
April 25. Leaves about 3 inches tall	0. 35
May 13. Flower stalks low in boot	0
May 27. Flower stalks surpassing basal leaves	. 33
June 17. Flower stalks two-thirds grown	. 20
July 6. Peak of flowering	. 28
Check plants, unclipped	5. 67

[1] Clipped in 1946, 1947, 1948, and 1951.

TABLE 13.—*Flower-stalk production per square inch of basal area in Idaho fescue when rested one to four seasons after clipping, the Burgess Spring Experimental Range*

Seasons rest after clipping (number)	Flower stalks from plants clipped—			Unclipped check plants
	4 years 1946–49	3 years 1947–49	2 years 1948–49	
	No.	*No.*	*No.*	*No.*
1	0	----------	0	1. 12
2	6. 29	16. 39	17. 03	23. 57
3	1. 97	1. 17	. 31	. 61
4	5	3. 07	. 86	3. 91

TABLE 2.—*Average date of flowering and seed ripening of some abundant plant species, pine type, the Burgess Spring Experimental Range, 1936–54*

Species	Flowering		Seed ripening	
	Date	Basis, years	Date	Basis, years
		No.		*No.*
Ross sedge	May 15	5	June 24	7
Slender phlox	June 1	3	July 2	2
Littleflower collinsia	June 2	2	July 2	2
Lambstongue groundsel	June 6	4	July 10	4
Antelope bitterbrush	June 10	12	Aug. 5	5
Woolly wyethia	June 18	13	Aug. 1	6
Cheatgrass brome	June 19	10	July 24	8
Lemmon needlegrass	June 19	9	July 23	8
Sandberg bluegrass	June 21	10	July 24	7
Longspur lupine	June 25	14	July 29	6
Mountain brome	July 3	5	Aug. 7	5
Bottlebrush squirreltail	July 4	12	Aug. 6	6
Idaho fescue	July 9	13	Aug. 5	11
Flatpod groundsmoke	July 11	3	Aug. 27	2
Rabbitbrush goldenweed	Sept. 5	12	Oct. 5	6
Big sagebrush	Sept. 8	8	Oct. 6	4

Year	Forage production per acre [1] (pounds)	Percent of average
1936	343	104
1937	290	88
1938	472	143
1939	162	49
1940	399	121
1941	472	143
1942	399	121
1943	218	66
1944	327	99
1945	343	104
1946	182	55
1947	290	88
1948	452	137
1949	198	60
1950	290	88
1951	436	132
Average	330	100

[1] Measured by clipping in 1936, 1947, and 1948. Estimated in other years from field observations.

TABLE 15.—*Weight gains of yearling Hereford heifers in timber and grassland types, the Burgess Spring Experimental Range, 1944–48*

Year	Heifers	Grazing season		Beginning weight	End weight	Gain per head	Gain per head per day
		Dates	Days				
	Number			*Pounds*	*Pounds*	*Pounds*	*Pounds*
TIMBER TYPE—MAXIMUM SEASONAL GAINS [1]							
1944	10	June 2–Oct. 20	140	443	656	213	1.53
1945	14	May 23–Oct. 7	137	450	670	220	1.62
1946	12	May 12–Sept. 21	132	390	609	219	1.66
1947	9	May 7–Oct. 1	147	380	608	228	1.55
1948	9	June 9–Oct. 10	123	444	651	207	1.68
Av.	11	May 23–Oct. 6	136	421	639	217	1.61
TIMBER TYPE—TOTAL SEASONAL GAINS [2]							
1944	10	June 2–Oct. 31	151	443	649	206	1.36
1945	14	May 23–Oct. 26	156	450	645	195	1.25
1946	12	May 12–Oct. 17	158	390	593	203	1.28
1947	9	May 7–Oct. 20	166	380	603	223	1.34
1948	9	June 9–Oct. 10	123	444	651	207	1.68
Av.	11	May 23–Oct. 21	151	421	628	207	1.38
GRASSLAND TYPE [3]—MAXIMUM SEASONAL GAINS [1]							
1944	9	June 2–Oct. 6	126	443	656	213	1.70
1945	15	May 23–Oct. 2	132	446	670	224	1.70
1946	12	May 12–Sept. 25	136	385	616	231	1.70
1947	9	May 7–Sept. 21	138	380	619	239	1.73
1948	9	June 9–Oct. 10	123	448	678	230	1.87
Av.	11	May 23–Oct. 1	131	420	648	227	1.74
GRASSLAND TYPE [3]—TOTAL SEASONAL GAINS [2]							
1944	9	June 2–Oct. 31	151	443	629	186	1.23
1945	15	May 23–Oct. 26	156	446	636	190	1.22
1946	12	May 12–Oct. 17	158	385	603	218	1.38
1947	9	May 7–Oct. 20	166	380	608	228	1.37
1948	9	June 9–Oct. 10	123	448	678	230	1.87
Av.	11	May 23–Oct. 21	151	420	631	210	1.41

[1] Gains made from the beginning of the grazing season to the time the animals started to lose weight.
[2] Gains made between the beginning and end of the grazing season.
[3] See table 1, p. 11, for unit grazed each year.

TABLE 14.—*Estimated utilization by cattle of herbage of Idaho fescue and all forage species in openings in the pine type, by specified year, the Burgess Spring Experimental Range*

Year [1]	Grazing season	Utilization		
		Days	Idaho fescue	All forage species
		No.	*Pct.*	*Pct.*
1936	June 19–Sept. 25	98	7	18
1937	June 14–Oct. 3	111	17	22
1938	June 24–Sept. 23	91	45	39
1939	Aug. 10–Sept. 21	42	11	7
1943	July 9–Sept. 28	81	23	19
1944	June 2–Oct. 31	151	11	22
1945	May 23–Oct. 26	156	65	56
1946	May 12–Oct. 17	158	80	56
	Average, June 18–Oct. 7	111	32	30

[1] No grazing in 1940, 1941, and 1942.

TABLE 12.—*Basal area and fascicles of plant species after 4 years of clipping at the seed-in-milk stage and 4 years of rest, the Burgess Spring Experimental Range*

Date and treatment	Basal area		Fascicles	
	Idaho fescue	Bottlebrush squirreltail	Longspur lupine	Woolly wyethia
	Sq. in.	*Sq. in.*	*No.*	*No.*
1946. Start of clipping	4.16	1.88	15.4	8.2
1949. End of clipping	1.39	.69	2.4	7.9
1950. End of 1 year of rest	.83	.71	1.4	6.9
1951. End of 2 years of rest	.68	1.42	2.1	6.7
1952. End of 3 years of rest	.71	.92	2	6.7
1953. End of 4 years of rest	1.04	.61	2.4	6.9

STORED CARBOHYDRATES

Nutritive substances are of particular importance in the life of perennial grasses, especially carbohydrates such as mono- and disaccharides, starch, and, to some extent, hemicellulose. The carbohydrates are stored in all parts of the plant in considerable quantities. However, the most important role in plant nutrition is played by the roots, rhizomes, and the lower shoots, which do not die in winter; all these plant parts are important organs for the storage of nutritive substances.

During their first days, commencing from the beginning of spring, the green shoots of perennial grasses develop at the expense of the nourishment accumulated in the storage organs. Twelve to 20 days after the appearance of green shoots, when they reach a height of not less than

10 cm, the assimilatory activity of the leaves begins and accelerates, so that the storage of nutritive substances starts to take place and the vital activity of the roots and rhizomes is resumed. As shown by numerous investigations (Smelov and Morozov, 1954; Nikitina, 1940; Evseev, 1954; Nekrasova, 1948), throughout the further development of the plant, the percentage of nutritive substances increases until the flowering-seedbearing phases; later, toward winter, it either remains unchanged or registers insignificant losses (Tables 8, 9, and 12).

If, after the ear-formation phase, a drastic increase of the mass of the tops takes place, or if a new formation of shoots begins after the fall decline, the quantity of stored nutritive substance may decrease. This has been observed by S.P. Smelov and A.S. Morozov (Table 8).

Table 8

Stored carbohydrate content of underground organs of plants during different phases of growth (as percentage of dry weight)

Plants	Emergence from snow	Tillering	Ear formation	Flowering	Seed-bearing	Dying off
Experiment by S.P. Smelov and A.S. Morozov (Fodder Institute, 1959)						
Awnless brome grass	19.1	34.6	20.5	27.4	31.3	15.4
Orchard grass	12.8	18.3	11.8	15.1	13.8	9.2
Meadow foxtail.	9.5	15.3	12.1	15.3	16.9	11.5
Meadow fescue.	12.6	24.9	14.1	13.7	15.7	8.4
Pasture rye grass	9.7	21.6	18.5	19.3	19.6	6.3
Average	12.6	23.0	15.4	18.1	19.4	10.2
Experiment by E.V. Nikitina (Kirgiz SSR, 1940)						
Orchard grass	31.9	27.4	38.2	39.4	42.2	46.5
Ganeshin's *Festuca sulcata* .	17.8	26.2	27.6	28.5	24.6	28.2
Couch grass	43.6	39.6	33.4	46.9	46.9	53.4
Alchemilla	16.3	17.1	-	36.0	45.6	43.2
Regel's geranium	19.3	-	31.9	25.2	30.1	32.3
Subalpine cereal-motley grass (*Phleum*) meadow . .	8.5	5.7	-	-	10.2	14.1
Alpine motley grass meadow	-	26.1	28.2	29.7	29.0	30.3
Low *Cobresia*	-	-	-	24.3	32.0	24.3
Experiment by Graber (USA)(Smelov, 1947)						
Alfalfa	31.3	19.3	40.8	49.4	41.2	42.4
Experiment by S.P. Smelov (Fodder Institute, 1947)						
Timothy (single culture). . .	-	47.4	52.8	65.5	65.0	61.1

15.2%. On the hay meadow, over a radius of 10 to 20 cm, the figure was 4.6%, and on the pasture, 5.9%. In the latter case the negative influence of frequent exploitation was less pronounced because the flood basin was fertilized each year by silt.

The diminished root weight is due to the fact that frequent cutting and grazing result in a smaller supply of nutritive substances. This is because the plant is frequently deprived of its assimilation organs (leaves).

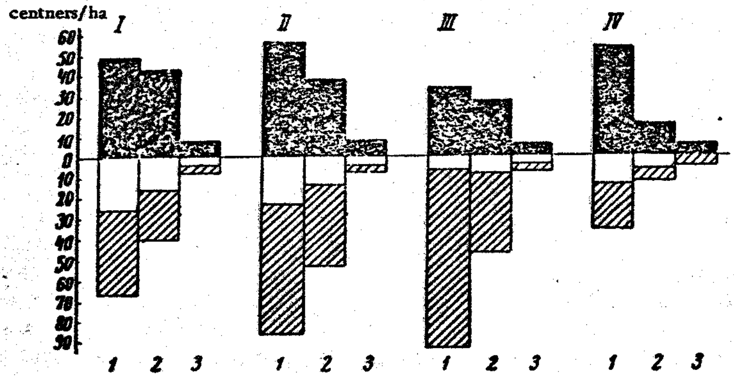


Figure 4. Yield of tops (black), stubble (white), and roots (striped) after repeated cutting of plants during the various phases of growth (experiment by E. Klapp, FRG, 1956)

I—orchard grass; II—pasture rye grass; III—Kentucky bluegrass; IV—fowl meadow grass; yearly cutting: 1—during the full flowering phase, 2—during ear formation, 3—before ear formation.

The root weight not only decreases as a consequence of frequent cuttings; it also decreases as the result of yearly cuttings, if carried out systematically during the early phases of growth over several consecutive years. The experiments of E. Klapp in FRG (Figure 4) testify to this. All of the plants he experimented with showed a decrease in root weight as a consequence of regular early cuttings (before the ear-formation phase) over a long period; the decrease appeared not only in the root weight but also in the weight of the tops. Both the yields of root weight and tops were several times lower than the yields obtained during the full flowering phase.

The reduction in the quantity of roots and in their content of nutritive substances, caused by frequent or early cuttings, also leads to reduced shoot formation, the nondevelopment of some of the plant parts, and to an overall reduction in yield. For instance, according to experiments by P.A. Voshchinin (Fodder Institute), timothy grass gave yields of 95 % when cuttings were made every 30 days, and, when cuttings were made every 20 days, the yield was 44 % more than when cuttings were made every 10 days. The yields after cuttings were made every 30 days were 218 % higher than when cuttings were made every 20 days and 112 % higher than when cuttings were made every 10 days. According to the experiments of S.I. Yuvenskaya

(Fodder Institute) made on rich flood meadows of the Oka River (yielding 87.2 centners/ha of cereal grasses and cereal-motley grasses), when three cuttings were made per year, the summer of the first year yielded a harvest which was 31 % higher than when seven cuttings were made yearly, while the yield of the second year was 64 % greater.

In a trial made by G.A. Tuzhikhin in 1939 at the Fodder Institute, the yield of mixed grasses (an average of two varieties), cut three times a year during the flowering phase over a period of several years, exceeded the yield of the same grass mixtures cut three to five times per summer by 33 %.

In a trial made by S.P. Smelov (Fodder Institute, 1947), the yield of a meadow foxtail, cut once a year in the course of four years during the flowering phase, was 76 % more than the yield of similar plants cut four to five times each summer over a period of four years. Under the same conditions, the yield of awnless brome grass was 162 % greater.

A drastic yield decrease (by 25 % and more) was registered as early as after one year when four to five cuttings were made of sown grasses, as compared with two to three cuttings. This was observed in numerous experiments made under our supervision in the forest-steppe and steppe zones. These experiments were conducted by the Department of Pasture and Meadow Economy in Barnaul and in Leningrad by T.R. Godlevskaya, M.F. Shirina, A.P. Kretova, and others, and by N.B. Bolodon at the Fodder Institute.

In the experiment of V.G. Tanfil'ev carried out in Omsk over two years with an average of six plant associations on solonetzes, solonchaks, and solonetzous forest-steppe complex soils, the yield during the third year, as compared with that of the yield from plots which remained uncut during the previous two years, was as follows: after two cuttings per year over the last two years, 82 % to 94 %; after four yearly cuttings, 81 %; and after five yearly cuttings, 79 %. After two years of experiments on a hill steppe in the Kirgiz SSR, E.V. Nikitina obtained on the third year a decrease in the yields of <u>Stipa</u> and <u>Avenastrum</u> by a factor of 1.5. This was obtained three times after four cuttings; on alpine motley grass with <u>Coleresia</u>, this was obtained after three cuttings. This represents a yield which is 1.5 times smaller than that obtained on plots which had not been cut during the previous years. Considerable yield decreases were also observed by V.I. Evseev and A.F. Slugina (Orenburg district) on steppe-type pastures and on single plants (Table 16).

In experiments made by V.G. Tanfil'ev on chernozem steppes in Stavropol' region, on an average of five grass varieties, <u>Festuca pratensis</u>, <u>Festuca sulcata</u>, <u>Stipa capillata</u>, <u>Agropyron repens</u>, and <u>Medicago sativa</u>, the following yields were obtained: after four cuttings during the previous year, 45 %, after five cuttings, 30 %, as compared to the yield which was obtained after two cuttings.

A yield decrease caused by frequent cuttings was also registered in the semidesert regions of the USSR. In experiments by L.P. Davydova (Emben Horse-Breeding Ranch, Aktyubinsk district) the yield during the first year [of the trial] was higher after one to two cuttings than after two to three cuttings per summer in eight out of the 15 grass stands on which the trial was made. On the following year the yield was higher in 10 plant associations (out of 15).

Yield of pasture grasses in relation to the number of yearly grazings (or cuttings) (according to experiments by V.I. Evseev and A.F. Slugina. Brody, Orenburg district)

Name of plant under experiment	Years of experimenting	Grass yield (centners/ha) after cutting or grazing			
		once a year	twice yearly	three times yearly	five times yearly
Agropyron pectiniforme, Festuca sulcata, Bromus inermis, Bromus erectus (average of 4 grasses)	First	12.8	17.3	24.0	31.1
	Second.	9.6	13.6	11.6	6.4
	Second year yield as compared with yield of 1st year (in %). . . .	75	64	48	21
Grasses of Euagropyron, Agropyron-brome grass and Festuca sulcata–Stipa on natural pastures (average of 3 types)	Second	14.9	-	7.6	-
	Second (in %) . . .	100	-	51	-

On the third year of a trial made by I.V. Larin, I.V. Kamenetskaya, and T.K. Gordeeva on three steppe associations in the semidesert, in the region between the Volga and Ural Rivers (Dzhanybek, West Kazakhstan district), there was a yield decrease of 41% after two to three cuttings. After a single cutting the yield remained practically unchanged.

A great number of experiments have been made abroad on the influence of frequent grazings. We shall quote some of them. In England, after four years of experimenting, Springfield concluded that 20% more sheep had been fed and their added weight was 32% higher when the sheep were grazed on a four-week pasture rotation plan than when they were grazed on pastures rotated every two weeks, and their weight increment was 15% greater than when the grass was cut every third week.

Frank, in 1934, after five years of experiments on a lowland meadow, found that the maximum quantity of grass was obtained by cutting for hay and by subsequent grazing on the aftergrowth. This amounted to 73% more than that obtained by weekly grazings, but the albumin content was lower by 24%. The maximum albumin content was obtained by the method of biweekly grazings, which yielded 34% more than with the combination of hay cutting with grazing, although the grass bulk was 41% less than when the grass was cut for hay and the cattle subsequently grazed on the aftergrowth.

Sampson (experiments carried out in the state of Utah in the USA in 1933) notes that, as the result of monthly cuttings, bushy cereal grasses perished during the fourth year of their life, and that after four cuttings per summer in previous years, toward the end of the third year the yield was four times less than after one to two cuttings per summer.

Experiments made by Hudson in New Zealand showed that after monthly grazings the pastures yielded 34 % more grass during the following year than after years in which the pasture had been grazed every fourth day.

Experiments made in Germany by Klapp in 1956 showed that young pastures (with one and two-year-old grass), even when properly taken care of, have a considerably lower yield even after only three grazings. Older pastures show such a decrease after only four to five grazings. When the initial grazing is not carried out too early, the pastures can easily withstand even more than five grazings per year (Table 17).

Table 17

Comparative yields of pastures at different grazing frequencies (Klapp, 1956)

Experimental subjects	Number of cuttings			
	2	3	4	5
Young meadows. Investigations by Klapp	100	88	64	-
Old meadows. Investigations by Klapp	100	96	90	-
First cutting, not made too early. Investigations by Kaut	100	97	97	100

Frequent cuttings and grazings also often cause the mortality of plants from freezing. Thus, according to the experiment by V.G. Tanfil'ev (1940), a fivefold cutting caused the death of 31 % of meadow fescue and 25 % of Festuca sulcata; twofold cuttings resulted in practically no mortality (0-4%). This phenomenon may be seen particularly clearly in alfalfa plants. In the experiment of M.F. Shirnina (Leningrad), it was shown that a five to sixfold cutting of sown alfalfa caused a very high mortality rate (over 50 %) for the following year. Experiments in the USA showed that after three cuttings a year, the mortality of plants during the winter was 2.5 to 3 times higher than after twice-yearly cuttings.

From all the above it is clear that even normal methods of exploitation, such as two to three cuttings or grazings a year, lead to a lowering of yields as compared to those of grass stands that have never been exploited or have been exploited only once.

This is explained by the fact that after each cutting or grazing the development of new shoots necessitates an expenditure of certain amounts of nutritive substances, which inevitably affects the development of both the underground and overground parts of plants.

Therefore, it naturally follows that those plants which have the majority of their leaves concentrated on the upper parts of the stalks, or have their leaves distributed evenly along the stalks, are the ones most affected by frequent cuttings. Plants whose leaves are situated closer to the ground are least affected. To the first group belong almost all the plants with considerable top development: red clover [Trifolium pratense], Trifolium hibridum, sown alfalfa [Medicago sativa], Onobrychis, awnless brome grass [Bromus inermis], timothy [Phleum pratense], couch grass [Agropyron repens], and others. To the second group belong plants with considerable development on the ground: white bent grass [Agrostis alba], Kentucky bluegrass [Poa pratensis], red fescue [Festuca rubra], Festuca sulcata, white clover [Trifolium repens], Alchemilla, Sibbaldia, etc.

Experiments have shown that top-leafy plants, when untended and cut four to five times a year, begin to die out and disappear entirely from the pasture, and after three to four years begin to be replaced by low-leaved grasses. The latter can often withstand as many as eight to ten cuttings or grazings. One of the experiments showed that white bent grass, after 13 cuttings in the course of two years, gave a similar yield on the third year (during which it was cut only once) to that obtained after three years of a single annual cutting; it has also been shown that even after 22 cuttings the yield declined by only 50 per cent. Kentucky bluegrass was more strongly affected: six to 13 cuttings over two years reduced the yield to one third, while nine to 22 cuttings reduced it to one fifth (Graber and others, 1927).

Thus, it seems to be established that even two to three yearly cuttings or grazings are to be avoided. However, in order to obtain the greatest quantity of nutritive substances as possible per hectare after single annual cuttings, harvests should not be gathered earlier than the end of the earing-budding phase, at which time the plants contain 1.5 to two times less protein and 30% to 40% more cellulose than plants subjected to three yearly cuttings. Also, the yield of nutritive substances per unit of surface area is also not the same: after single grazings the cattle receive less protein (and albumin), as well as a great deal more poorly digestible cellulose (Table 18).

Table 18

Variation of protein and cellulose yield (in centners/ha) of pasture grasses as the result of different numbers of cuttings and grazings (experiment of V.I. Evseev, 1934-1955; Brody, Orenburg district)

Number of cuttings	Euagropyron-pasture		Agropyron-brome grass pasture	
	protein	cellulose	protein	cellulose
1	0.41	1.06	2.94	13.14
2	0.81	1.12	5.74	12.49
4	-	-	6.14	6.18

121.0 centners/ha, whereas the yield of the underground parts of annual grasses was only 34.0 centners/ha.

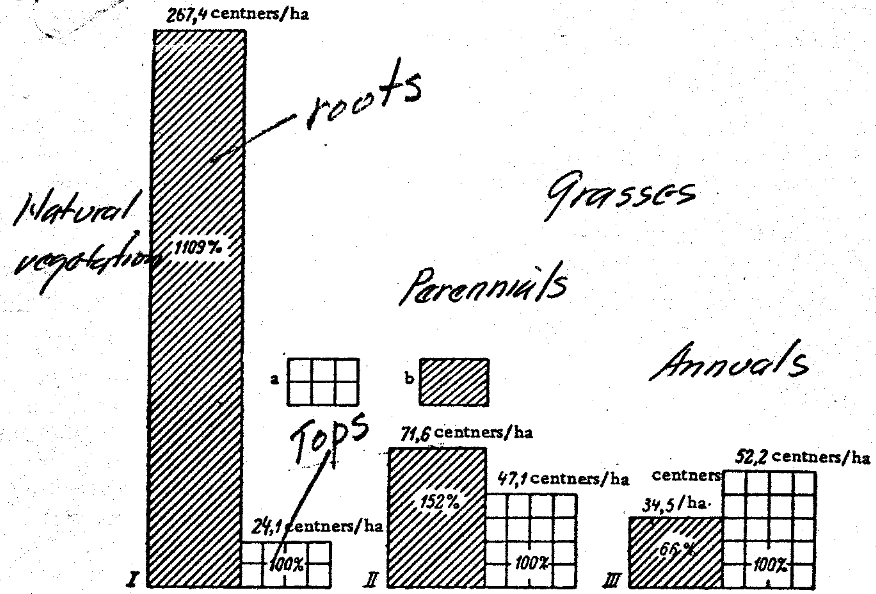


Figure 3. Yield of (a) roots and of (b) tops of perennial and annual grasses

I–natural vegetation (results of 73 experiments); II–perennial grasses (74 experiments); III–annual grasses (27 experiments)

Enormous quantities of root mass accumulate in virgin soil under the natural vegetation; this mass is many times that of the tops. Thus, according to calculation (Figure 3), the weight of the tops was 24.1 centners/ha, while that of the underground parts was 267.4 centners/ha, which is 11.1 times greater (Manokhina, Larin, Akimtseva, 1956; Orlovskii and Afanas'eva, 1929; Shalyt, 1950; Kachinskii, 1925; and others; compiled by I. V. Larin). The weight of the underground parts and its correlation to the weight of the tops can reach enormous proportions in different associations. Thus, according to calculations made at the Dzhanybek Station of the Academy of Sciences of the USSR in the Trans-Volga semidesert region, the weight of the tops of plants of the Stipa–Agropyron pectiniforme association was 11.3 centners/ha, while that of the underground parts was 660.0 centners/ha, which is 58.4 times greater (Kamenetskaya, Gordeeva, Larin, 1955). According to calculations made at the Limann Station, the weight of the tops of the motley grass–Agropyron association was 32.3 centners/ha, while the weight of the underground parts was 703.8 centners/ha (21 times more); the sedge [Carex melanostachya M. B.] association offered a proportion of 16.3 to 663.0, which is 41 times greater; the motley grass–cereal associations, when grown in containers, gave a ratio of 8.9 to 645.0, or 71.8 times greater (Manokhina, Larin, Akimtseva, 1956). When virgin

340 cm. The roots of plants in a three-grass mixture, in their third year, penetrated meadow-chestnut soil to a depth of 300 cm, and were exposed to the sun [sic] to a depth of 120 cm.

The roots of wild plants of the Trans-Volga regions penetrate the soil as follows (according to observations made at the Dzhanybek and Limann Stations of the Academy of Sciences of the USSR by Kamenetskaya, Gordeeva, and Larin in 1955; Manokhina, Larin, and Akimtseva in 1956):

1) On saline soils and on light-chestnut semisaline soils:

annuals and perennial ephermerals	10 to 12 cm
Artemisia pauciflora Web.	50 to 85 cm
Kochia prostrata (L.) Schrad.	over 200 cm
Pyrethrum achilleifolium M.B.	120 to 140 cm
Agropyron desertorum (Fisch.) Schult.	150 cm
Agropyron ramosum (Trin.) Richt.	100 to 120 cm

2) On meadow-chestnut soils of low-lying areas:

Agropyron pectiniforme Roem. et Schult.	180 to 200 cm
Festuca sulcata Hack.	150 cm
Stipa capillata L.	200 to 210 cm
Artemisia austriaca Jack.	150 to 200 cm
Medicago romanica Prod.	200 to 220 cm

3) In flood basins during the periodic spring floodings:

Agropyron repens (L.) P.B.	160 to 220 cm
Agropyron pectiniforme	140 to 200 cm
Puccinellia Fomini Bilyk.	120 to 140 cm
Glycyrrhiza glabra L.	200 cm
Artemisia monogyna W. et K.	120 cm
Artemisia pontica L.	150 to 170 cm
Carex melanostachya M.B.	200 cm

In cereal grasses, the majority of overground shoots form their own roots. The roots of non-seedbearing shoots usually hibernate and develop during the following year. A part of the roots of seed-bearing shoots die off in the spring of the following year, while some live for several years. Most of the legumes and representatives of other families extend their roots deeper than the cereals. They often live for many years, and only a small part of them die off every year.

It has been found that the roots of cultivated perennial cereals and legumes increase during at least the first four to five years of their life. According to experiments by A.R. Kozhevnikov and E.I. Popova in Omsk (1946), made on six varieties of grasses, the weight of roots, according to age, was (in centners/ha): first year, 47.0; second year, 102; third year, 161; and fourth year, 166.

Under conditions of irrigation the weight of the roots of Agropyron pectiniforme (Sakharina, 1940, Valui Experimental Station) and of Medicago sativa (Golodkovskii and Golodkovskii, 1937) began to drop toward the sixth year of life. In the experiments of F.I. Filatov (1951) soil is first cultivated, the yields of the first two to four years are known to be higher than the yields of plants grown on soil which has been cultivated for a long time. This is because virgin soils have a better structure and also, in all probability, it is due to the presence of the still undecomposed underground parts of plants.

The root length of plants per square meter has been calculated as reaching many kilometers; it is especially great in herbaceous plants. According to the investigations of N.I. Savvinov and N.A. Pankova (1942), root length under the virgin soil of the Trans-Volga region varied from 21.7 to 51.7 km. According to the investigations of V.M. Ponyatovskaya (1956), the root length of sown grasses (per m^2) on sodpodzol soils of the Kaliningrad district was from 4.9 km for awnless brome grass—in the association Bromus inermis, Festuca pratensis, Phleum pratense, and Festuca rubra—to 58 km for orchard grass in the association Dactylis glomerata and Herbae diversae. According to the investigation of B. Ya. Metelev and Khuan Ven'-ui (1938) made on the dark colored soil of a depression in the Trans-Volga region, the root length of plants in a high yield season attained 9.4 km for wheat, 11.7 for corn, 12.0 for Sudan grass, and 12.3 for sorghum. In the third year of growth the figures were 20.3 km for alfalfa, 19.9 for Euagropyron, and 27.3 km for awnless brome grass. The latter experiments show that the root length of annual grasses is less than that of perennial grasses.

It often happens that the root system of perennial grasses continues to develop until late into the fall within one single growth period. Thus, the experiments of S.P. Smelov (1947), based on an average of three grass varieties (meadow fescue, awnless brome grass, and meadow foxtail) showed that 5,000 cm^3 of soil from a surface area of 100 cm^2, taken at a depth of from 0 to 50 cm, contained the following quantities of roots: during spring tillering, 4.4 g; during ear formation, 5.6 g; during flowering, 8.1 g; and during seed-bearing, 9.9 g. According to experiments made by E.V. Nikitina (1940) on a hill meadow in which orchard grass predominated, the weight of a unit area of the roots of orchard grass alone was: 8 May, 11 g; 5 July, 12.0 g; 5 August, 14.6 g; 19 September, 16.0 g; and 11 October, 12.0 g.

In annual plants the root system completes its development with the onset of flowering; in the fall, it dies off.

It follows that the productivity of cattle fed on grass of single grazings or cuttings is lower than that of cattle fed on grass cut a number of times. This has been established by a series of experiments by V.I. Evseev in the Orenburg steppe region, as well as by experiments made abroad. Thus, according to the experiments of Veiske (Klapp, 1956), after 14 cuttings during the course of a summer, a yield of 42.7 centners per hectare of hay was obtained, containing 27.1 % of albumin and 9.0 centners per hectare of digestible albumin; after three cuttings a yield of 69.2 centners per hectare of hay was obtained, containing 13.4 % albumin and 6.2 centners per hectare of digestible albumin.

It therefore frequently happens that even without any care, the total yields of the first two to three years of exploitation contain the maximum quantity of nutritive units—especially of digestible protein and albumin—as the result of frequent cuttings, and not at all, as one would suppose, after single annual cuttings.

Taking all the above into consideration, we conclude that it is desirable to make use of the grass several times a year in order to raise the productivity of the cattle. The ability of the grasses to grow back should, of course, be taken into account. It is recommended that the grass be grazed (or cut) as follows: in the forest zone, three to four (and even up to five to seven) times per year; in the forest-steppe zone, two to four times; in the steppe and in the semidesert zones, two to three times; and in the desert, one to two times.

Turf grasses (meadow grass, Agrostis, pasture rye grass, red fescue, sheep's fescue, etc can withstand frequent and very low cutting (eight and more per year). This is explained by the fact that, as a consequence of selection, turf grasses have large quantities of leaves close to the ground, and also by the fact that turfs are usually systematically and generously fertilized; turfs are also usually rolled and irrigated. A.G. Golovach (1955) recommends the mowing of lawns (in Leningrad) to a height of three to four cm from the ground; this should be done for the first time in spring, when the grass has reached a height of 10 to 15 cm; the aftergrowth should be mowed every 10 to 15 days after the first mowing to a height of 10 cm.

plants -- or remains bare and subject to erosion. The main problems of grazing management on western ranges center on perennial plants particularly those that reproduce from seed. Management that maintains these plants invariably maintains plants that reproduce vegetatively. An understanding of why plants are killed by grazing is essential for development of satisfactory grazing methods and maintenance of the range resource.

Plants, like animals, require food for growth and sustenance. The food materials used for these purposes are carbohydrates, proteins, and fats. Animals obtain these substances by eating plants or other animals. Plants manufacture these substances; in other words, plants make their own food.

The plant first produces the sugar glucose in the process of photosynthesis. Using this sugar as a building block, it then makes all the other food materials. Glucose is formed only in green cells and principally in leaves. The other compounds can be made anywhere in the plant, in the top or roots, or in green or non-green cells. But because glucose is the basis of all food materials, the plant may be said to make its food in its green leaves.

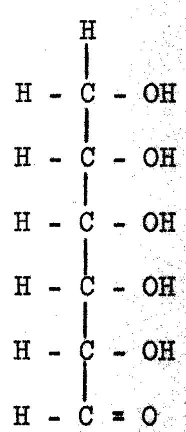
In perennials, some of the food materials made by the plant each year is stored for future use. Carbohydrates, proteins, and fats are all stored, but the bulk of the material is starch. In herbaceous perennials, the materials are stored in roots and other underground parts and stem bases. In woody plants, they are stored above ground in stems, branches, twigs and leaves as well as in underground parts.

Some of these reserves are used to start growth in spring and to nourish the plant when it is not making food -- in winter, for example, when the plant is dormant. Reserves are replenished regularly in normal growth.

Perennials store enough food to last for several years. So even if the plant is defoliated, as by grazing, for a year or two, it does not die. Under continuous close grazing year after year during the green period, however, the plant cannot make and replenish reserves. Consequently, reserves are ultimately depleted, and the plant dies. As in the case of an animal, the plant becomes progressively weaker and smaller as it runs out of food. It can, in fact, starve to death.

PHOTOSYNTHESIS

Glucose, $C_6H_{12}O_6$ (see structural formula below) is formed in the living cell from carbon dioxide gas CO_2 and water H_2O in the presence of the green pigment chlorophyll ($C_{55}H_{72}O_5N_4M_g$) and sunlight in the process of photosynthesis. Oxygen gas O_2 and water are generated as glucose is formed.



Glucose

The chemical reaction of photosynthesis may be written as follows:

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll (green)}]{\text{Sunlight}} \underset{\text{(stored energy)}}{C_6H_{12}O_6} + 6O_2 + 6H_2O$$

Photosynthesis

Photosynthesis takes place in the chloroplasts of the cell. Chloroplasts are green because of the presence of chlorophyll. The carbon dioxide used in photosynthesis is obtained from the atmosphere. The water is obtained from the soil. And the energy used to drive the process is obtained from sunlight.

Chlorophyll traps and converts sunlight energy into work energy in the cell. A portion of this energy is then used to disintegrate carbon dioxide and water into essentially atom units and to reassemble these units in the form of glucose,oxygen gas, and water. Another portion is stored in glucose as it is produced. And a further portion is stored temporarily in special phosphorus-containing compounds. This latter energy is ultimately incorporated in other organic compounds as they are formed or is expended in work.

Thus, photosynthesis is an energy-storing process. The energy derived from sunlight is stored in the bonds connecting atoms in molecules. This energy is released when the molecules are disintegrated adn the bonds broken. The energy contained in all food materials is derived through photosynthesis and is released when the materials are utilized.

Essentially then, the plant can make food only when it is green. The amount produced is controlled by such factors as light intensity, temperature, availability of water and soil minerals, and amount of chlorophyll in the plant, which is related to the size of the green plant. Some of these factors, such as availability of water and minerals and size of the green plant, are affected by grazing, and can be controlled by the range manager.

COMPOSITION OF FOOD MATERIALS

Carbohydrates

The more important carbohydrates in the plant from the standpoint of growth are the three sugars -- glucose, fructose, and sucrose -- and starch, inulin, and cellulose. All these compounds except cellulose are prime sources of energy and growth materials for the plant. Cellulose is a structural material and is not usually broken down once it is formed.

Fructose (fruit sugar) is a 6-carbon sugar like glucose and is formed from it. These sugars have the same chemical formula, but the molecules differ structurally. Phosphorus is essential for conversion of glucose to fructose, in fact, for the formation of glucose and all carbohydrates.

Sucrose (beet or cane sugar) $C_{12}H_{22}O_{11}$ is formed by the union of one molecule of glucose with one molecule of fructose.

Starch makes up the bulk of the food reserves in plants. It occurs in cells in the form of starch grains. It consists of long, often branched, spiral, chains of glucose molecules linked together.

A molecule of water is eliminated from between each two adjoining glucose units as starch forms. It is a partially dehydrated compound and because it is relatively insoluble, it makes a good storage material.

Inulin is like starch and is used in the same way. It consists of chains of fructose units rather than glucose units.

Cellulose is the main component of the cell wall. It consists of long straight chains of glucose molecules. The chains are bound together in cable-like strands of varied size which are interwoven in the cell wall to form a porous framework. In mature cell walls, the spaces between cellulose strands are characteristically filled with lignin and relatively insoluble carbohydrates. These materials strengthen the wall and make it largely impervious to water. Cellulose forms the bulk of the roughage in forage plants and feedstuffs.

Proteins

Proteins make up most of the living material in cells. A yellowish viscid substance, protein looks like raw egg white. Most of the protein in the plant is enzymatic, but some is inert and comprises food reserves. ~~Reserve~~ proteins are concentrated in buds, root tips and other meristematic tissues, terminal portions of twigs, and seeds.

Proteins oontain nitrogen and sulfur in addition to carbon, hydrogen, and oxygen. The molecules consist of long chains of amino acids and are large and tremendously complex.

Amino acids are characterized by the presence of an amino radical (NH_2), and an acid radical (COOH), in the molecule. The general formula for an amino acid may be written as follows:

$$\begin{array}{ccccc} & & (R) & & \\ & & | & & \\ (NH_2) & - & C & - & (COOH) \\ & & | & & \\ & & H & & \end{array}$$

Twenty-two amino acids are known to occur in plant proteins. They differ from each other by the arrangement of chemical elements in the (R) group. The simplest amino acid is glycine in which the (R) group is a hydrogen atom.

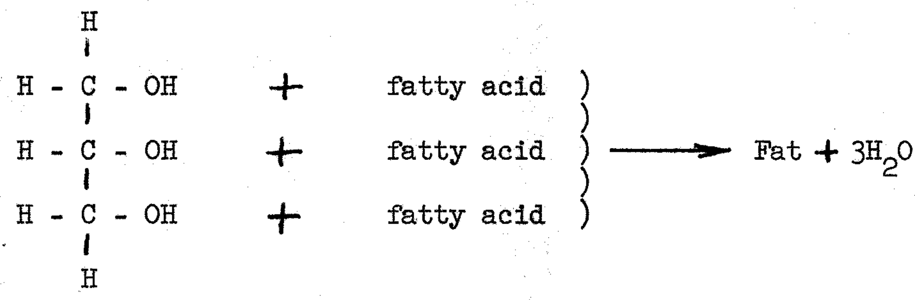
Proteins differ from each other mainly in the number, kind, and arrangement of amino acids in the molecule. Some proteins contain all 22 amino acids, some less. Proteins, like all organic compounds, contain energy -- but somewhat less than carbohydrates and fats.

Fats

Fats (or oils) occur in small amounts in all plant cells. They play vital roles in the cell. Fats occur in large amounts in the stems and twigs of some shrubs and trees, especially in winter, and also in some seeds. Fats contain large amounts of energy.

Fats and oils are the same chemically but differ physically. In general, fats are solid at room temperature, oils are liquid.

Fats are formed by the union of glycerol and certain organic acids, known as fatty acids, as shown below:



(glycerol)

Some of the more abundant fatty acids are oleic, lauric, myristic, palmitic, stearic, linoleic, and linolenic. Fats differ from each other in the kinds of fatty acids in the molecule. The acids in the three positions may be the same or different.

RESPIRATION

Respiration is an oxidation or burning process that requires gaseous oxygen. It is essentially the reverse of photosynthesis. The energy stored in organic compounds during photsynthesis is liberated in respiration. The initial breakdown of organic materials is accomplished by enzymes. Starch may be reduced to glucose units, sucrose to glucose and fructose, proteins to amino acids, and fats to glycerol and fatty acids. These units may be reduced even further and then reassembled into new compounds. Carbohydrates, proteins, and fats can all be interconverted this way. Or the ultimate units may be degraded to carbon dioxide and water with the liberation of large amounts of energy. Gaseous oxygen is required in this final step. The chemical formula for respiration, using glucose as an example of an organic compound, may be written as follows:

$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{Energy}$$

Respiration is continuous. Food materials are burned and energy liberated continuously even when the plant is dormant. Reserves can, therefore, be depleted by respiration alone.

To grow normally, the plant must contain adequate food materials to burn and adequate gaseous oxygen to effect burning. Vigorous growth depends on a high level of reserves in roots and a well aerated soil.

PLANT GROWTH

The seasonal growth and development of perennial plants is illustrated here with Idaho fescue (Fig. 1). The growth pattern of this bunchgrass applies to other grasses and similar plants and to forbs and woody plants as well. Shoot growth of herbaceous plants and twig growth of woody plants are comparable. Plant growth stage is best expressed in terms of percentage growth and greenness of the shoot.

The elapsed time from start of growth to dormancy in Idaho fescue is 6 or 7 months. Shoot growth is completed in about 4 months. The plant loses greenness over a comparable period. The moisture content of the plant starts declining about the time the plant is half grown and starts slowing in growth. The total weight of the shoot declines late in the season because seeds shatter and plant parts dry out and disintegrate.

(The period of growth and development of different species on different sites may differ appreciably from that for this species. Some plants dry completely or shed leaves as they become dormant.)

Roots start and complete growth before the shoot. Root growth is largely completed by the time the shoot is half grown. By then the plant is growing most rapidly and presumably has greatest need for a fully developed root system.

Approximately one third of the roots die each year. They start to die about the time root growth ends. A large amount of organic matter gets into the soil each year this way.

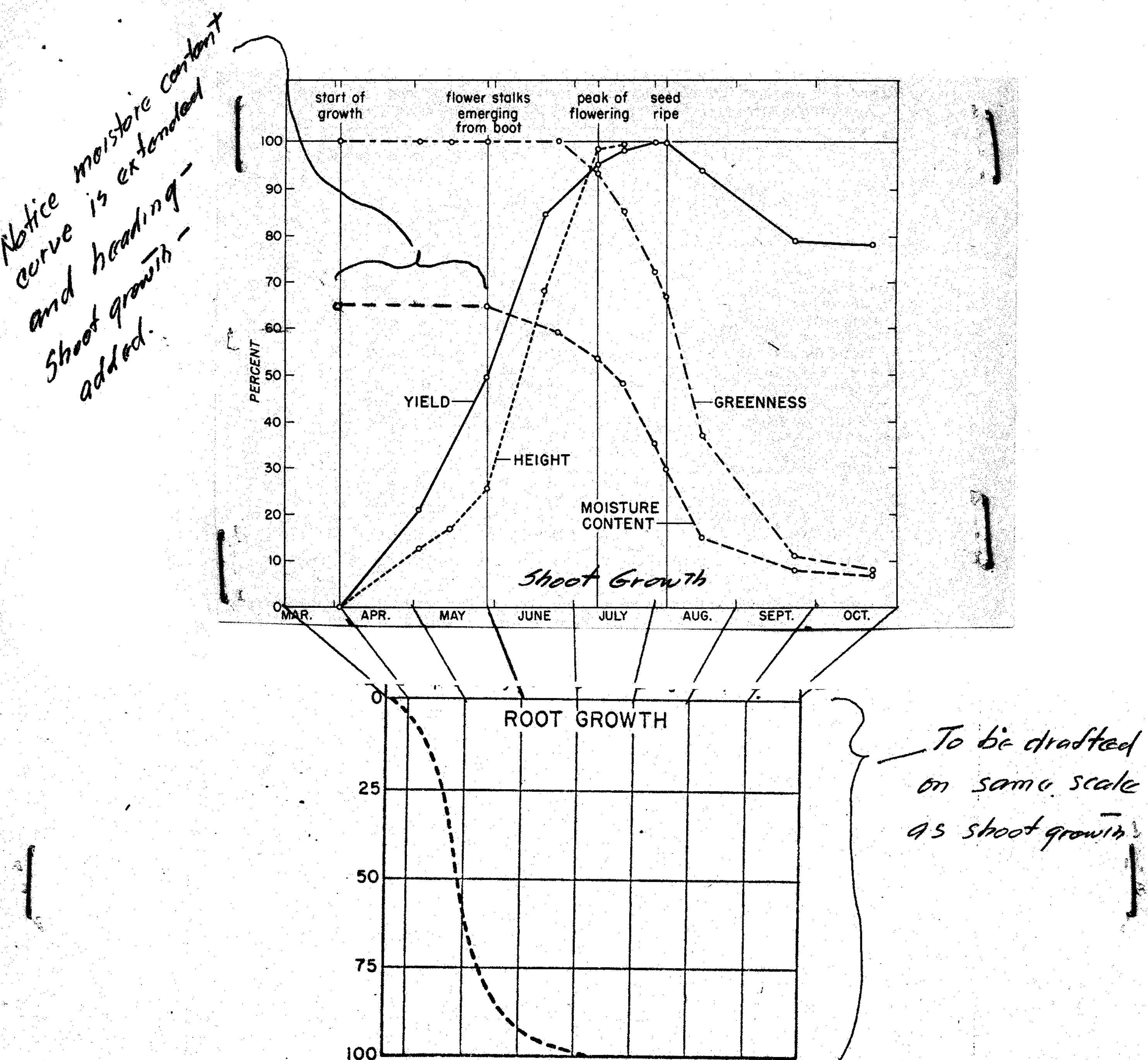


Figure 1.--Average seasonal growth and development of Idaho fescue. Shoot growth, based on data by Hormay and Talbot (1961), and general curve for root growth, based on information by Troughton (1957).

REGROWTH

Potential for the plant to regrow during the season is highest early in the season, and declines with advance of the season as soil moisture and the growth impetus of the plant decline (table 3). After the plant is half grown and starts slowing in growth rate, its regrowth is negligible. Grasses may regenerate practically a full size crown and produce appreciable viable seeds if defoliation or grazing is ended before the plant starts growing rapidly -- before flower stalks are tall enough to be removed. Several weeks of grazing may be provided up to this time.

The combined yield of initial growth and regrowth from plants clipped early in the growing season is less than the yield of growth from unclipped full grown plants (table 3). Therefore, herbage production and grazing capacity during the season are reduced by early grazing. The amount of reduction is discussed later in the section on season of grazing.

TREND IN FOOD RESERVES

The plant starts storing food reserves when it is about half grown and begins slowing in growth (Fig. 2). From there on it makes more food than it uses in growth and respiration. The excess is stored. The plant maintains vigor by maintaining a normal supply of food reserves.

Approximately half of the seasonal stores are deposited by the time the shoot is 90 percent grown. In grasses and plants of similar growth development, this is about flowering time. Most of the

Table 3.--Yield of initial growth and regrowth of Idaho fescue clipped one to a 1.5-inch stubble at different growth stages; regrowth harvested when full grown.

Average date and growth stage at time of initial clipping	Initial growth	Regrowth	Initial growth and regrowth combined	
	Grams	Grams	Grams	Percent
May 1: Leaves about 3 inches tall.	0.78	0.70	1.48	60
May 13: Flower stalks low in boot.	1.09	.29	1.38	56
May 27: Flower stalks surpassing basal leaves.	1.42	.20	1.62	66
June 17: Flower stalks two-thirds grown.	2.16	.05	2.21	90
July 6: Peak of flowering.	2.39	.01	2.40	98
July 9: Flower stalks full grown.	2.41	.01	2.42	99
July 18: Seed in milk.	2.45	0	2.45	100

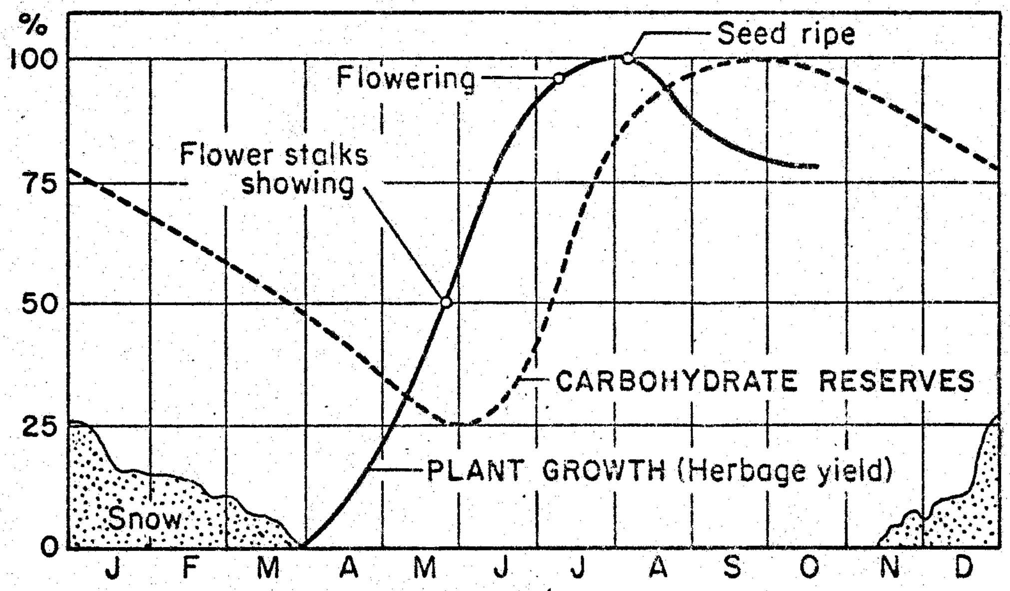


Figure 2.--Trend in carbohydrate reserves in relation to shoot growth. Shoot growth of Idaho fescue and based on data by Hormay and Talbot (1961). Carbohydrate curve, based on data by McCarty and Price (1951), is related to curve of Idaho fescue by plant growth stages.

reserves are deposited by the time the shoot is full grown, or at seed-ripe time in grasses. But reserves continue to accumulate for several days or weeks, while the plant still has greenness, until the amount of food made in photosynthesis just balances the amount used in respiration. Then reserves decline throughout the dormant period because of respiration, and continue to decline as growth resumes -- until the shoot is about half grown -- because of both growth and respiration. Reserves are lowest when the shoot is about half grown.

EFFECT OF DEFOLIATION

Removal of the leaves of the plant any time during the green period reduces the amount of food made and stored by the plant. As a result, the capacity of the plant to produce both shoot and root growth the next year is reduced. Defoliation is most harmful when reserves are lowest. This is about the time the plant is growing most rapidly.

However, defoliation of the plant anytime up to the time food storage is completed is harmful even at a relatively late growth stage (Table 4). Plants vary in their ability to withstand defoliation. Wyethia, for example, withstands clipping better than other species because of greater food storage capacity and perhaps other reasons. Generally, close defoliation of the plant year after year at almost any green growth stage ultimately results in depletion of food reserves and the death of the plant.

Table 4.--Change in size of four forage species clipped yearly to a 1.5 inch stubble at the seed-in-milk stage

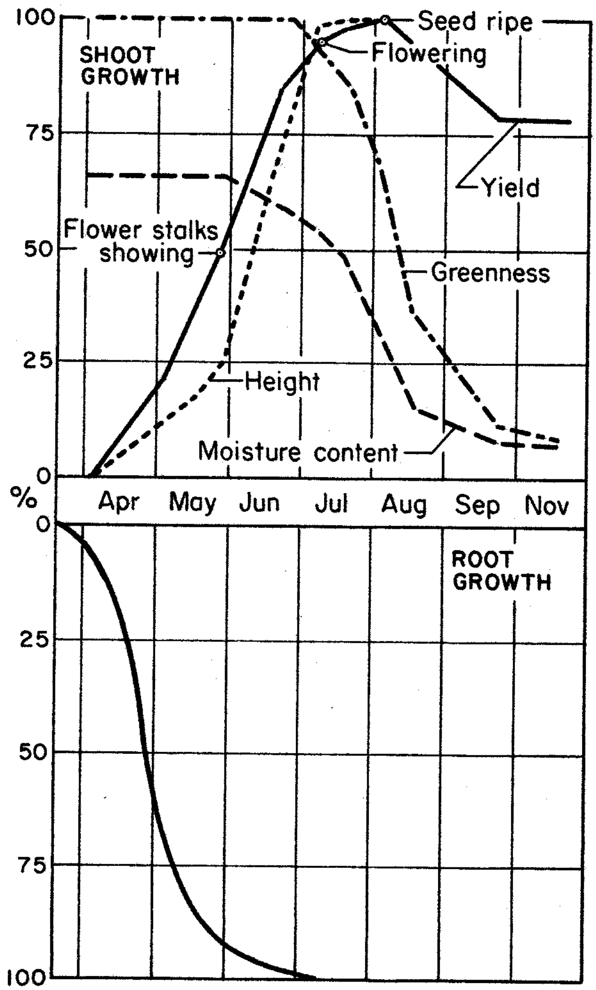
Year	Basal area				Fascicles 1/			
	Idaho fescue		Bottlebrush squirreltail		Longspur lupine		Woolly wyethia	
	Sq.in.	Pct.	Sq.in.	Pct.	No.	Pct.	No.	Pct.
1946	4.16	100	1.88	100	15.4	100	8.2	100
1947	2.16	52	2.22	118	5.0	32	7.7	94
1948	1.67	40	2.25	120	6.5	42	8.8	107
1949	1.39	33	.69	37	2.4	16	7.9	96
1950	.83	20	.71	38	1.4	9	6.9	84

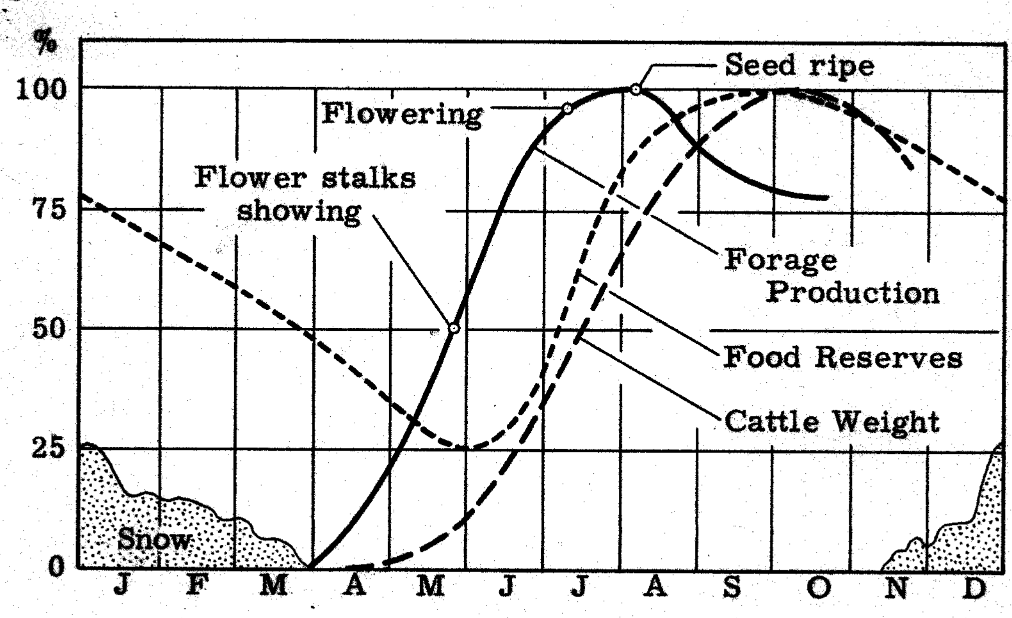
1/ A fascicle is a group of leaves or leaves and stems that originate from a single bud.

Rhizomatous plants generally stand grazing better than tufted plants. They are not grazed as completely because of their prostrate growth habit. They retain more greenness in the grazed-off stubble. And they usually have greater regrowth and food storage capacity.

The growth of herbaceous plants is not affected significantly by grazing after reserves are stored. The reserves and growing points on the plants are out of reach of animals. In woody plants, however, reserves and growing points are exposed, and grazing after reserves are stored and during the dormant period can harm these plants. Removal of growing points does the most damage.

The effect of defoliation is proportional to the amount of crown removed from the green plant. Studies show that 60 percent and more can be removed from some species without interfering with the future normal growth of the plant. Apparently, the plant can make adequate food in less than a normal size crown. The portion of the crown that can be removed safely is called the proper-use amount.


100
75
50
25
0
%
0
25
50
75
100
SHOOT GROWTH
Seed ripe
Flowering
Yield
Flower stalks showing
Greenness
Height
Moisture content
Apr
May
Jun
Jul
Aug
Sep
Nov
ROOT GROWTH


%
100
75
50
25
0
Seed ripe
Flowering
Flower stalks showing
Forage Production
Food Reserves
Cattle Weight
Snow
J
F
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