ASH CONTENT OF THE AWN, RACHIS PALEA, AND KERNEL OF BARLEY DURING GROWTH AND MATURATION

By HARRY V. HARLAN, *Agronomist in Charge of Barley Investigations*, and MERRITT N. POPE, *Assistant Agronomist in Barley Investigations, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

The ash determinations here assembled were made with two primary objects in view. Earlier studies had shown that in the varieties under observation the awns possessed a physiological function. When they were removed the kernel development was retarded and the spike became brittle through the greater ash deposit in the rachis. In order to see if usable variations existed in the amount of ash deposited in the rachises and awns, a considerable number of varieties were studied.

The previous experiments were not as complete as was desired. Mechanical difficulties had prevented the taking of samples to the point of absolute maturity. There thus existed a possible doubt as to the nature of the changes in the days immediately following the date when kernel sampling became impossible. The determination of ash in the awns and rachises was, therefore, continued for some time after maturity in one series of varieties at Chico, Calif.

The results point a possible way to the securing of desirable non-shattering awnless and hooded varieties. They also throw some light on the ash content of the kernel during growth.

MATERIAL USED

Material for the study of ash in the barley spike was collected from several sources. Two series of samples originated at Aberdeen, Idaho. The awns, rachises, and paleas were obtained from the irrigation plots, the kernel studies of which were previously reported. In this series and the one from Minnesota the glumes were forcibly removed from the kernels. To eliminate the possible effect of imperfect separation when the glumes were thus removed, the kernels from a naked barley grown at Aberdeen were included for comparison.

Two lots of samples were grown at Chico, Calif. The first of these consisted of a collection of varieties embracing a wide range of botanical characters. The second consisted of a lesser number of varieties, which were allowed to stand in the field for a time after ripening. Frequent samples were taken, and the change of ash after maturity was determined.

Further use also was made of the data from an experiment carried on at St. Paul, Minn. Ash determinations were made on a number of varieties grown at Arlington, Va., the detailed results of which are not included.

Journal of Agricultural Research, Washington, D. C. aao

(433)

Vol. XXII, No. 8 Nov. 19, 1921 Key No. G-255

ASH OF THE AWNS

The awns of barley contain a very high proportion of ash. One of the most finely divided carbons known has been secured from barley awns. This extremely fine division is probably caused by the high percentage of ash. The ash is deposited during the time the kernel is developing. At the time of their emergence the awns contain little ash and are very flexible.

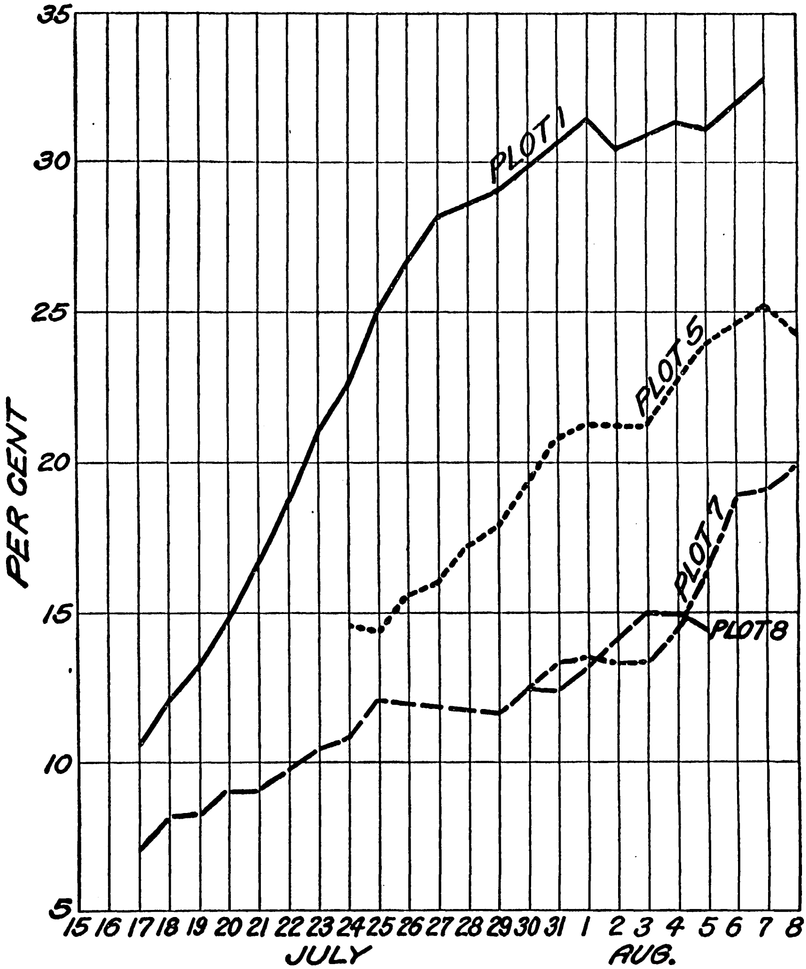

FIG. 1.—Percentage of ash, by progressive three-day averages, in the awns of Hannchen barley grown on plots variously irrigated at Aberdeen, Idaho, in 1917.

The ash at flowering time and for a few days immediately following usually runs from 4 to 8 per cent of the dry matter. As may be seen in Table I, the awns of the Hannchen variety may sometimes contain a slightly higher percentage at flowering time. Varieties of this type, however, contain more ash than do those of most other types of barley. The increase in the ash content after flowering is very regular. The daily increment is quite uniform. In figure 1 it will be seen that within the variety the rate of deposit has a direct relationship with the amount of moisture in the soil and probably with the amount of water transpired. On plot 8, which was not irrigated after flowering, the plants were suffering from lack of water during most of the time the kernels were developing. This lack of water is reflected in the percentage of ash in the awns. The awns on this plot never contained as high as 16 per cent of ash. The uniformity of the deposit was in no wise affected. The daily increment, however, was less than on plot 1, which received ample irrigation. The normal ash content of the awn of Hannchen barley when grown in the western United States is over 30 per cent at maturity. As will be seen, the awns on the spikes from plot 1 reached this percentage several days before maturity. Plots 2 to 7 received the same treatment as plot 8 until the time of their final irrigation. Only one irrigation after flowering was given to any plot except plot 1. The irrigation occurred on the day the first ash determination was reported. Following the application of water there was an acceleration in the rate of deposit of ash in plots 2 to 6, inclusive. The barley on plot 7 was maturing when the water was applied. The leaves had begun to wither and the awns were almost color-free at the time of the irrigation. The rate of deposit was not materially increased over the rate on plot 8. The maturation was, however, delayed, and the final ash content of the awns was decidedly greater than in plot 8.

TABLE I.—*Percentage of ash in the awns of Hannchen barley grown on eight different plots variously irrigated, at Aberdeen, Idaho, in 1917*

Date.	Plot. 1	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
July 16	9.4	16.2	....	....	....	....	....	6.0
17	10.8	12.5	....	....	....	....	....	7.8
18	11.6	14.2	8.7	....	....	....	....	7.3
19	13.9	16.1	14.0	....	....	....	....	9.3
20	14.0	14.7	15.7	7.8	....	....	....	8.2
21	16.5	16.5	18.4	7.9	....	....	....	9.5
22	19.6	17.7	18.8	9.7	....	....	....	....
23	20.0	19.3	19.8	15.1	13.8	....	....	9.4
24	23.8	20.2	21.9	16.3	13.4	....	....	12.2
25	23.9	19.8	18.1	15.0	16.5	....	....	10.7
26	27.5	20.6	19.9	18.7	13.4	10.3	....	13.2
27	28.6	21.6	21.9	....	17.2	13.2	....	11.8
28	25.4	20.4	21.9	....	17.7	16.0	....	10.5
29	28.4	20.4	....	....	17.0	12.2	11.1	13.0
30	30.0	21.5	....	....	18.9	15.4	12.6	11.7
31	31.2	21.1	....	20.5	22.1	18.4	13.9	12.4
Aug. 1	30.7	22.4	26.5	23.1	21.7	18.3	13.5	13.1
2	32.7	21.2	24.2	23.9	19.9	21.5	13.1	13.9
3	....	....	26.2	22.6	21.5	23.2	13.2	15.4
4	28.2	....	26.3	20.2	22.1	18.0	13.8	15.6
5	33.1	29.1	32.9	20.4	24.5	21.7	16.6	13.7
6	....	....	30.1	19.7	25.4	22.5	19.0	13.8
7	29.1	....	27.8	20.0	24.0	26.2	21.2	....
8	33.1	28.2	23.2	....	26.2	22.7	17.2	....
9	....	....	32.3	25.7	22.7	32.1	21.5	....

TABLE II.—*Percentage of ash in awns, rachises, and kernels of eight varieties of barley grown at Chico, Calif., and sampled on 10 different dates*

C. I. No.	Variety.	June 6.	June 9.	June 13.	June 16.	June 20.	June 25.	June 27.	June 30.	July 7.	July 14.
	PERCENTAGE OF ASH IN AWNS										
531	Hannchen	36.7	36.1	34.4	31.8	35.5	34.6	31.5	33.2	32.8	35.8
234	Nepal[1]	16.6	......	......	......	......	......	16.4	13.8	15.5	16.3
257	Tennessee Winter	29.1	......	32.1	33.2	34.4	34.1	34.1	35.3	34.3	30.7
916	Odessa	34.3	35.8	35.6	34.6	33.1	35.3	36.1	37.4	37.2	35.5
261	Mariout	34.1	34.3	34.5	36.7	35.2	37.2	33.5	32.6	34.0	33.7
195	Smyrna	32.0	30.1	35.5	29.5	35.0	29.0	32.7	29.5	31.2	35.2
690	Coast	31.9	31.8	26.6	32.8	33.0	30.8	32.5	32.2	31.7	32.4
652	Poda	27.3	30.0	28.4	31.0	33.6	32.1	32.4	33.4	32.5	33.5
	PERCENTAGE OF ASH IN RACHISES										
531	Hannchen	12.1	11.1	11.7	10.7	10.2	......	9.5	10.0	11.4	11.5
234	Nepal	9.5	......	......	......	......	......	9.5	9.9	10.5	9.8
257	Tennessee Winter	7.4	10.0	9.6	8.1	7.9	9.8	9.8	8.9	8.3	8.8
916	Odessa	8.1	......	8.5	6.6	7.7	7.5	......	8.7	9.6	8.0
261	Mariout	7.7	7.8	7.6	8.9	8.6	9.1	8.5	7.8	8.6	8.4
195	Smyrna	7.7	7.7	8.2	7.2	8.4	6.8	7.1	7.7	6.8	7.8
690	Coast	6.0	5.4	5.0	6.3	6.8	6.2	6.8	6.4	6.9	6.0
652	Poda	5.1	5.4	5.4	5.5	5.1	5.7	5.8	6.0	6.0	6.1
	PERCENTAGE OF ASH IN KERNELS										
531	Hannchen	3.3	3.2	3.6	3.4	3.4	3.5	3.3	3.6	3.3	3.4
234	Nepal[2]	1.8	......	......	......	......	......	1.9	1.8	2.1	2.0
257	Tennessee Winter	3.2	3.4	3.5	3.1	3.2	3.2	3.3	3.2	......	3.0
916	Odessa	3.6	3.6	3.4	3.4	3.4	3.6	3.4	3.6	3.6	3.6
261	Mariout	3.0	3.1	2.9	3.2	3.1	3.2	3.1	3.1	3.1	3.1
195	Smyrna	2.7	2.7	3.1	2.8	3.1	3.8	2.8	3.3	2.8	3.1
690	Coast	3.0	3.2	3.0	......	3.1	2.9	......	3.1	3.5	......
652	Poda	2.8	2.9	2.8	2.9	3.0	2.9	3.1	3.0	2.8	2.9

[1] Hoods. [2] Naked kernels.

Since the studies on irrigation were not carried beyond the stage of actual maturity, there was some question as to whether the awn had ceased to accumulate ash when the studies were terminated. It was impossible to carry these particular samples further, as this was a study of kernel growth and the paleas could not be stripped from the kernels after mechanical loss of water had commenced. In order to determine whether there was a later transfer of ash a series of varieties was allowed to stand in the field for six weeks after maturity, at Chico, Calif. Samples were taken, commencing at about the stage where they were discontinued at Aberdeen. These results are reported in Table II. It will be seen that there was very little change of ash content after the growth of the kernels had been completed. The changes indicated in the table are probable variations of individual samples, inasmuch as the average of all the samples showed no consistant change.

TABLE III.—*Percentage of ash in the rachises, awns, and kernels of 39 varieties of barley grown at Chico, Calif., 1917*

C. I. No.	Variety.	Description.	Percentage of ash.			
			Rachis.	Awn.	Grain.	Hoods.
1079A	Chinerne	Black awnless 6-rowed	13.6	......	3.5	......
1289	Horsford	Hooded 6-rowed	13.1	......	3.2	17.4
678	Hanna	Lax 2-rowed	13.0	35.3	3.2	......
1045	Envoy	Dense 6-rowed	11.4	20.9	3.7	......
1097	Black Hull-less	Naked 6-rowed	10.2	21.2	2.7	......
1449	Hadaka	Short-awned naked 6-rowed	10.1	28.9	2.3	......
1041	Thomas	Naked 6-rowed	10.1	23.5	2.4	......
1094	Crocket	Shattering 6-rowed	9.5	27.6	3.8	......
1284	Feline	Smooth-awned 6-rowed	9.4	27.9	3.0	......
679	Franconian	Lax 2-rowed	9.3	28.7	2.6	......
1046A	Temple	Dense naked 6-rowed	9.2	22.5	2.2	......
1236	Abyssinian	Dense deficient 2-rowed	9.1	24.7	3.5	......
1061	Consul	Lax 6-rowed	8.7	24.2	3.5	......
914	Italian	Lax 2-rowed	8.4	23.9	3.3	......
1072	Squiers	Lax purple 6-rowed	8.4	18.9	3.4	......
1451	Carrol	....do	8.1	20.4	3.4	......
187	Svanhals	Dense 2-rowed	8.1	20.1	2.3	......
927	Odessa	Dense 6-rowed	8.1	23.9	2.3	......
1060	Coolie	....do	8.1	20.1	3.4	......
1450	Mochi	Long-awned naked 6-rowed	8.0	20.4	2.4	......
1281	Welch	Smooth-awned 6-rowed	7.8	31.5	3.5	......
1296	Kitchin	....do	7.7	31.1	2.9	......
1059A	Filer	Dense 6-rowed	7.6	17.2	3.4	......
1038	Judith	Lax 6-rowed	7.2	19.3	3.2	......
1121	Hanchamont	Lax 2-rowed	7.2	23.2	2.7	......
1121	....do	....do	7.2	20.4	2.5	......
669B	Abyssinian	Purple deficient	7.1	23.1	2.9	......
957	Oderbrucker	Lax 6-rowed	7.0	26.3	2.4	......
973	Red River	....do	6.9	19.5	2.4	......
972	Luth	....do	6.8	20.8	2.5	......
1076B	Venezuela	....do	6.8	25.2	2.8	......
190	Beldi	....do	6.5	33.9	3.0	......
1074B	Algeria	....do	6.1	26.7	2.8	......
996	Rasput	....do	6.1	28.7	3.4	......
1058	Gobi	....do	5.7	17.2	2.7	......
1098B	Kurof	Lax 2-rowed	5.6	13.4	3.5	......
1297	Claudia	Smooth-awned 6-rowed	5.5	30.2	2.8	......
1283	Catto	....do	5.2	34.0	3.1	......
1307	Cheddar	....do	4.8	30.1	3.3	......

Single samples from a larger number of varieties were taken at Chico the same year. These samples were not taken until it was evident that all growth in the plant had ceased. The results are reported in Table III. The list of varieties included almost all the major botanical variations of barley. The table is arranged in order of the ash content of the rachis, the ash of the awns being given in the second column. It will be noticed that the greater number of varieties have an ash content very much lower than the Hannchen at Aberdeen. It is not thought that much of this is due to environment, although part of it probably is. The water available for the plants at Chico was less than at Aberdeen, since the plots at Chico were not irrigated. Although the Hannchen variety was not included in this nursery series, C. I. 679, Franconian, is of the same general type as Hannchen, and Hanna 678 probably is even more closely related. In Table II samples of Hannchen from a neighboring plot are reported, and these do not differ materially from those grown at Aberdeen. The agreement between the results at Chico and Aberdeen is close when it is realized that varieties do vary a great deal according to their environment, as was evident in the results from the irrigation experiments. Varieties grown in the East, under humid conditions where the ash content of the soil is very low, have a much lower percentage of ash than do those from the West. The determinations from Arlington, Va., are not reported, but they show far less ash than those from either Chico or Aberdeen. Despite the variation in the ash content, the awns of different varieties seem to maintain the same relationship. The varieties which are high in ash under the arid conditions of the West are also the ones which are highest in ash at Arlington, even though the ash content at Arlington may be only half that of the western-grown samples.

Varieties which have a low ash content in the rachis do not necessarily have a low ash content in the awns. The awn itself does not have the same ash content throughout its length. Variation in individual samples can easily come about through the loss of the tips of the awns in the field. In Table IV are given the results of determinations made on the basal, middle, and apical portions of the awns of three barleys from Chico, Calif. The ash content of the tip is much greater than that of the base. In the Hannchen and Tennessee Winter varieties, the ash reaches 40 per cent of the dry weight in the tips of the awns. The bases of the awns in the Coast variety were low in ash as compared with those of the Hannchen and Tennessee Winter varieties. This may have some connection with the fact that the awns of the Coast variety do not break cleanly from the grain in thrashing.

TABLE IV.—*Percentage of ash in the tip, middle, and basal portions of awns in three varieties of barley grown at Chico, Calif., in 1917*

C. I. No.	Variety.	Date taken.	Percentage of ash.		
			Tip.	Middle.	Base.
257	Tennessee Winter	June 6	34.3	35.7	29.7
		July 14	37.8	36.5	31.3
690	Coast	June 6	29.6	28.4	23.8
		July 14	34.5	32.2	26.4
531	Hannchen	June 6	41.4	39.6	33.2
		July 14	40.3	37.9	32.5

ASH IN THE RACHIS

The deposit of ash in the rachis of the barley spike is less easily interpreted than is the ash in the awns. The awns serve as a place of deposit, probably for ash excluded from the cell sap. The rachis, on the other hand, is a conductive organ through which passes the nourishment of the various kernels and the water which is transpired from the awns. The daily deposit of ash in the rachis is confusing. Although a large number of analyses were made they are not reported, as no plausible explanation could be offered for the fluctuations. The general trend of the results is indicated in figure 2.

In 1917, in plot 8, which received no irrigation after flowering, the ash gradually increased from about 2 per cent at flowering time to about 7 per cent at maturity. In this case there were no large fluctuations. Where irrigation water was applied, the ash content was considerably increased. Although this increase was exhibited on all plots, in many cases the increases were irregular, fluctuating and not easily explained. The results in 1916 were more uniform and showed a gradual increase from flowering to maturity, the content reaching 11 to 14 per cent at that time. In 1917, on the irrigated plots, the content at maturity ranged from 12 to 18 per cent.

While the drop in ash in plot 1 is doubtless exaggerated by the accident of sampling, most of the large fluctuations in the daily samples of 1917 are not thought to be errors of determination. On the plots where the water content was low the fluctuations either did not occur or were small. The analyses of the awns and rachises were made from the same samples at the same time and in the same way. Those of the awns were satisfactory. It is probable that the variations in the ash of the rachises were due to some relationship of soil water and the rate of transpiration.

In a previous paper[1] it was shown that the removal of the awns resulted in an increase of the ash content in the rachis of an awned barley. From this it was inferred that the rachises of awnless barleys were likely to be high in ash. It was known that awnless and hooded varieties shattered badly in the field. It was to discover varietal differences, if such existed, that the samples were taken which are reported in Table III. As previously stated, the experiment included not only varieties which differed in the character of the awns but in many other taxonomic characters as well. It was found that the ash content varied greatly with the variety. As these samples were grown in California, the percentage of ash is higher than if the samples had been grown in the more humid districts. In all determinations made on barleys grown in Minnesota and at Arlington, Va., under humid conditions and where

[1] HARLAN, Harry V., and ANTHONY, Stephen. DEVELOPMENT OF BARLEY KERNELS IN NORMAL AND CLIPPED SPIKES AND THE LIMITATIONS OF AWNLESS AND HOODED VARIETIES. *In* Jour. Agr. Research, v. 19, no. 9, p. 431-472, 13 fig. 1920.

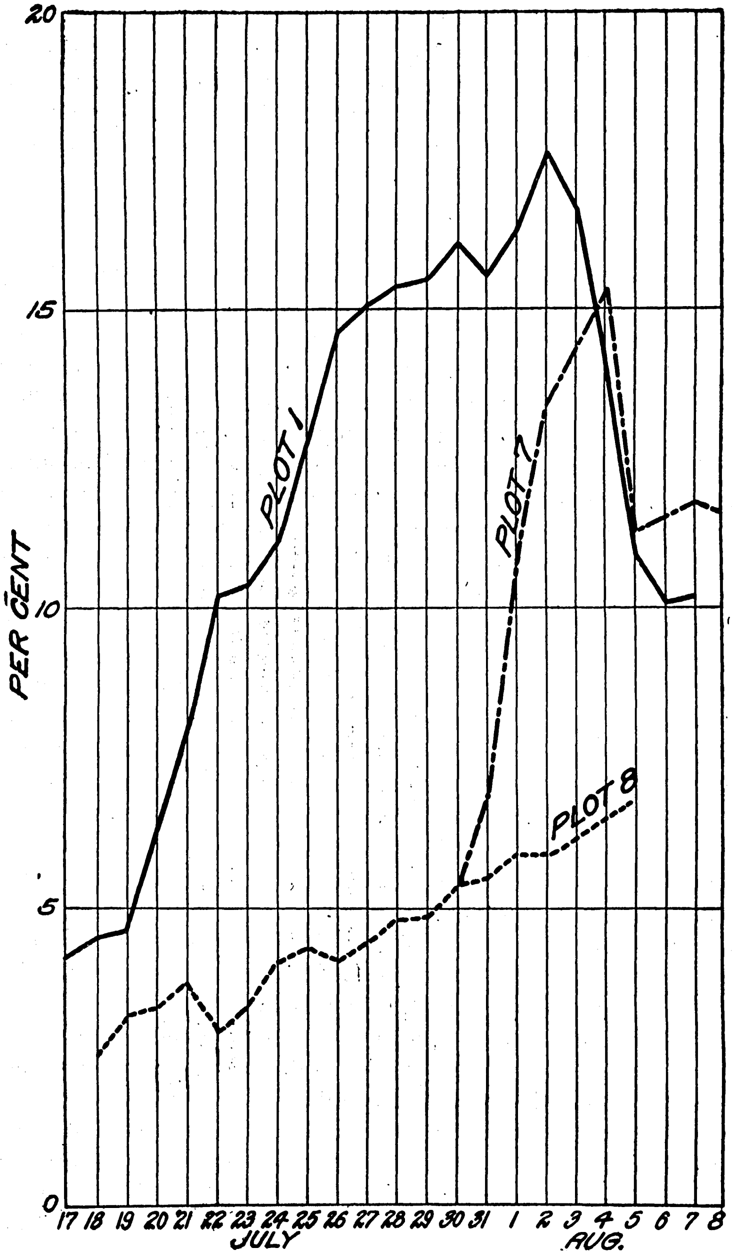

FIG. 2.—Percentage of ash, by progressive three-day averages, in the rachis of Hannchen barley grown on plots variously irrigated at Aberdeen, Idaho, in 1917.

the ash content of the soil is low, there was a much lower percentage of ash than in the western-grown samples. The analyses from the West, are, however, more significant in this connection, as shattering occurs much more commonly in the arid regions than in the humid regions.

In Table III it will be seen that the variety containing the highest percentage of ash in the rachis was an awnless variety. The second highest was a hooded sort. Among those varieties having an ash content over 9 per cent in the rachis were the awnless and hooded varieties referred to above, a variety from north Europe which was known to shatter badly, and C. I. No. 1449, a short-awned variety from Japan. In the original importation from which this last variety was obtained, there were two types of barley, differing only in the length of awn. C. I. 1449, which was short-awned, contained 10.1 per cent of ash in the rachis, while C. I. 1450, the long-awned strain, contained only 8 per cent.

The rachises of most of the common 2-rowed varieties are rather high in ash, many of them containing from 7 to 9 per cent when grown at Chico. The two samples of C. I. 1121 were taken from different parts of the nursery. The analyses show that there was very little variation due to location. C. I. No. 957, 973, and 972 are all of the Manchuria type. They contain less ash in their rachises than do most of the 2-rowed, but distinctly more than do the Coast types, C. I. No. 1076, 190, and 1074, which follow them in the table.

A number of smooth-awned varieties of hybrid origin are found in the table. These were included because of the potential economic importance of smooth-awned strains. The awn of the common barley is extremely harsh and is very objectionable to farmers and feeders. The annual acreage of barley is undoubtedly reduced because of the discomfort in handling the crop. On the other hand, it is known that the awn possesses a physiological function and it is improbable that maximum yields can be obtained from awnless and hooded varieties. In order to retain the functional value of the awn and at the same time to remove its objectionable features, the smooth-awned strains have been produced.

From the analyses given it appears that the smoothness of the awn has in no wise limited its function. One smooth-awned strain is included which has an ash content in the rachis of over 9 per cent. There are two strains with ash contents of nearly 8 per cent. Three others are found at the very bottom of the table with an ash content in the rachis of about 5 per cent. It is evident that in the latter varieties the low ash content is not due to any inactivity of the awn, as the awns themselves contain over 30 per cent of ash, indicating that they have been very active in transpiration. As can be seen in Table II, the Hannchen variety would come in the upper part of the list given in Table III.

ASH OF THE PALEAS

Ash determinations were made on the paleas of the samples reported in Table I. These determinations are found in Table V. The ash content of the paleas is quite comparable with that of the awn as far as the nature of the daily deposits are concerned. While the total percentage at maturity is much less, there is the same uniform increment from flowering until maturity. As with the awns, the daily increase on plot 8, which received no irrigation after flowering, was less than on the other plots which received one or more irrigations. Unlike the case of the awn, however, the maximum percentage of ash was reached on plots which suffered to a considerable degree from lack of water. The ash content showed a response to irrigation even on plot 7.

TABLE V.—*Percentage of ash in the paleas of Hannchen barley from variously irrigated plots at Aberdeen, Idaho, in 1917*

Date.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
July 16	4.9	10.7	....	....	....	....	....	4.0
17	8.0	7.3	....	....	....	....	....	4.4
18	5.3	....	7.1	....	....	....	....	4.3
19	6.5	5.7	8.2	....	....	....	....	5.3
20	6.4	6.4	8.2	8.6	....	....	....	5.1
21	9.9	7.3	10.1	8.3	....	....	....	5.6
22	9.4	7.2	9.9	8.3	....	....	....	6.0
23	9.5	8.0	10.7	6.4	10.1	....	....	6.3
24	10.4	8.2	11.5	7.2	9.9	....	....	7.0
25	12.6	8.4	7.5	7.1	10.2	....	....	7.0
26	12.7	8.7	8.5	11.0	10.6	6.9	....	7.5
27	12.6	9.0	8.5	....	10.7	7.6	....	7.2
28	12.6	8.2	9.2	....	12.0	10.9	....	7.1
29	13.9	10.7	8.4	....	7.7	10.9	7.9	7.7
30	13.2	9.7	9.4	11.6	8.7	11.2	8.1	7.6
31	13.4	....	11.1	12.3	9.3	12.5	9.0	8.1
Aug. 1	13.8	10.2	12.3	11.7	8.0	11.9	8.2	7.9
2	13.9	13.7	13.3	9.8	10.1	12.7	8.2	8.3
3	14.6	13.5	12.1	11.7	8.8	9.5	8.2	8.4
4	11.4	13.9	12.5	8.9	12.2	12.7	11.8	9.1
5	12.5	....	13.3	9.5	13.8	10.7	11.6	9.2
6	12.1	11.6	14.0	9.7	13.0	13.0	12.7	8.8
7	12.9	10.8	10.0	9.4	13.4	10.3	9.7	....
8	13.3	10.7	14.0	9.1	13.3	8.5	9.9	....
9	16.2	10.7	15.3	15.4	12.7	11.7	9.6	....

No determinations were made which would show the variations in the ash content of the paleas of different varieties. With mature samples, such as those discussed in Table III, it is impossible to strip the paleas from the kernels. For the same reason the analyses of the kernels in Table III are not particularly valuable. The ash content of the caryopsis is much lower than that of the inclosing glumes, so that any variations in the ash of the glumes, or in the proportion of caryopsis to glumes, appear in the table as a difference of the ash content of the kernels.

ASH IN THE KERNELS

In the previous papers published on kernel development,[1] the ash in the kernel was computed as a percentage of the dry matter. In the case

[1] HARLAN, Harry V. DAILY DEVELOPMENT OF KERNELS OF HANNCHEN BARLEY FROM FLOWERING TO MATURITY AT ABERDEEN, IDAHO. *In* Jour. Agr. Research, v. 19, no. 9, p. 393-430, 17 fig., pl. 83-91. 1920. Literature cited, p. 429.

HARLAN, Harry V., and ANTHONY, Stephen. OP. CIT.

of the awns, paleas, and rachises, this is probably the best method of comparison. These organs do not increase perceptibly in size during the time the deposit of ash is taking place. In the awns the deposit probably consists of ash eliminated from the cell sap. In consequence of this very heavy deposit, the ash in the awn reaches a percentage of the

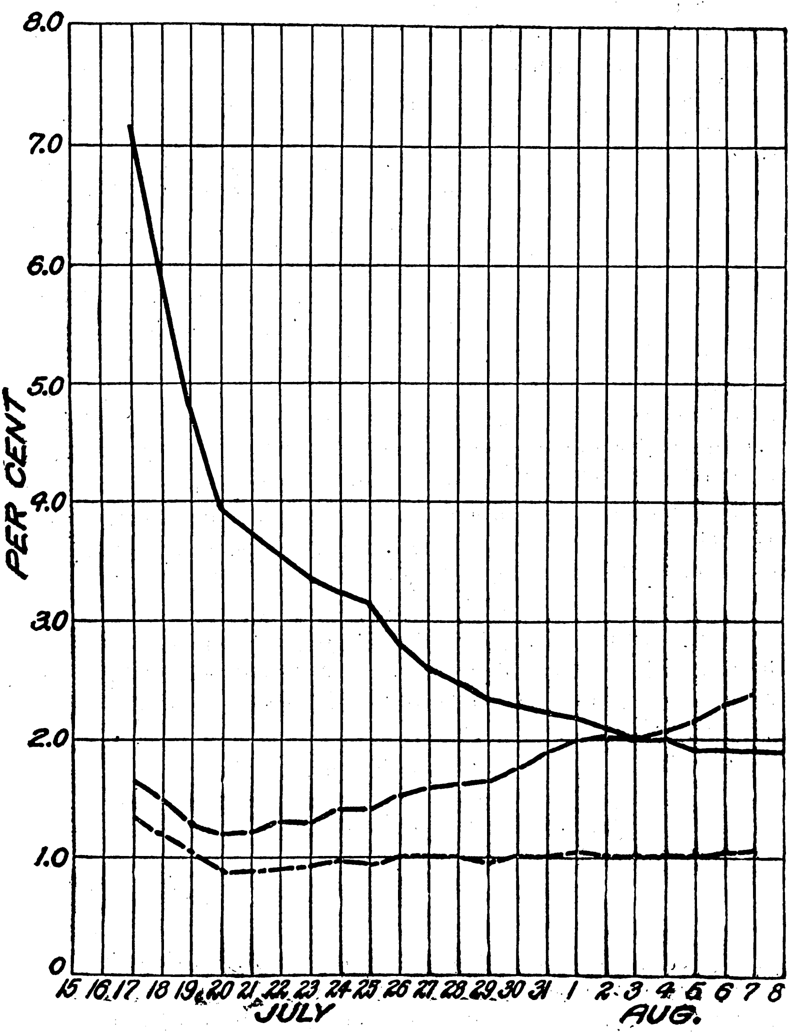

FIG. 3.—Percentage of ash in barley kernels, computed on the basis of dry matter (solid line), water (broken line), and wet weight (dots and dashes), from flowering to maturity, at Aberdeen, Idaho, 1917.

total weight which overshadows any variation of sample or defect of method in calculation. In the case of the kernel it is not thought that the dry matter is a desirable basis of computing ash. When computed on this basis, as will be seen in figure 3, the ash content at flowering time is very high. In most determinations it has been around 8 per cent at this period of growth.

Shortly after fertilization the percentage of ash commences to drop, falling very rapidly for a few days and then more gradually until complete maturity. This is obviously not a clear statement of what occurs. The percentage of ash on the dry-matter basis is a perfectly accurate statement, but the plotted curve of such percentage does not give a graphic idea of what is taking place in the kernel. There is a daily increase in total ash. This increase is almost uniform. The total ash content of the kernel when plotted is an ascending nearly straight line. Whether more of this ash is contained in one part of the kernel than another is not apparent. The ash at flowering time must be in solution and in the protoplasm. There has not been time for any deposit in the newly formed cell walls. Until several days after flowering the ash content must be in the cell sap, the proteids, and such penetration of cell walls as probably would occur if the tissue were not living.

As about 80 per cent of the content of a newly formed kernel is water, it was thought at first that calculating the percentage of ash on the basis of water would be the best method of comparison. In the very early stages, before any deposit could occur in the cell walls, this might be true. However, as the development of the kernel proceeds, the water occupies a smaller and smaller percentage of the kernel. Not only does the proportion of cell walls increase, but the proportion of the proteid matter in the active tissue probably is increased by the growth of starch grains. These starch grains, being formed in the cells, must occupy space previously largely occupied by cell sap.

If the ash is to be accounted for entirely on the basis of cell sap, the concentration of the cell sap must show a progressive increase to account for the total ash. This is highly improbable. The curve of percentage of ash based on water content is, however, more regular than the one based on dry matter and is in the direction of the actual ash deposit.

The ash was finally computed on the basis of the wet weight of the growing kernel. By computing it on this basis, allowance was made for both the ash in the cell sap and that in the organized components of the cell. The use of such a method assumes that the ash in the dry matter would be a mechanical infiltration from the cell sap which would eventually show the same percentage throughout the cell. When computed in this way a striking uniformity is revealed (fig. 3). Although the proportion of water and dry matter varies over a range of 40 per cent during the growing period, the percentage of ash on the basis of wet weight is almost constant. In Table VI are given the analyses of kernels from various plots. These plots differ in irrigation, in the years grown, and in the variety used. The awns from the same samples from which the kernels were taken show a variation of 15 per cent under the radical changes of conditions of growth. The variation in the percentage of ash on the basis of wet weight of kernel is a matter of tenths of a per cent. Many of the apparent fluctuations have plausible explanations. At

Minnesota, for instance, the grain was badly lodged and ripened very unevenly. There was also considerable rain at ripening time which delayed the ripening of part of the spikes. That many of these irregularities were due to the stage of ripening was apparent in a table published in a previous paper.[1] In this table the kernels with high ash content are the kernels which weighed less than 50 mgm. In other words, they were kernels in which maturation had been carried to the point where the mechanical loss of water had reduced the wet weight below 50 mgm.

TABLE VI.—*Percentage of ash in kernels of barley from flowering to maturity, compile on the basis of the wet weight*

Days from flowering.	Plot 1, 1917.	Plot 3, 1917.	Plot 4, 1917.	Plot 5, 1917.	Plot 6, 1917.	Plot 7, 1917.	Plot 8, 1917.	Hannchen, 1916.	Hannchen, clipped, 1916.	Manchuria, 1915.	Manchuria, clipped, 1915.
0	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.95	1.16
1	1.41	.....	.....	.....	.....	.....	2.23	0.62	1.18	1.02	1.07
2	1.39	1.31	.....	.....	.....	.....	.99	.81	.79	.90	.95
3	1.17	.88	.....	.....	.....	.....	1.61	1.04	.....	.84	.81
4	.90	.87	.....	.....	.....	.....	1.07	.93	.92	.96	.96
5	.91	.76	0.96	.....	.....	.....	.96	.85	.96	.81	.95
6	.82	1.14	1.18	.....	.....	.....	.80	.88	.93	.89	.93
7	.90	.85	.94	.....	.....	.....	.94	.....	.....	.77	.98
8	1.03	1.00	.94	1.11	.....	.....	.91	.87	.98	.91	.95
9	.90	1.14	.97	.87	.....	.....	.73	1.00	.96	1.02	1.04
10	.94	1.21	1.27	.79	.....	.....	1.03	1.14	.94	1.08	1.07
11	.97	1.55	1.12	.78	0.81	.....	.97	1.04	1.06	.....	.....
12	1.01	.82	1.00	1.12	.86	.....	.91	1.04	1.15	1.12	1.03
13	.97	.95	1.07	.....	.81	.....	1.06	1.02	1.15	1.13	1.22
14	1.01	.92	1.25	.95	.76	0.85	1.00	.....	.....	1.13	1.01
15	1.01	.....	.95	1.08	.78	.96	1.14	1.06	1.17	1.13	1.14
16	1.06	1.04	1.00	.96	1.08	.86	1.04	1.22	1.20	1.12	1.15
17	1.10	.96	.94	1.04	.90	1.01	1.00	1.08	1.32	1.17	1.26
18	.99	.98	1.10	1.06	.92	.94	1.06	1.34	1.26	.....	.....
19	1.02	1.06	.99	1.04	.82	.85	.91	1.19	1.26	1.16	1.25
20	1.01	1.04	1.11	1.03	1.49	.84	.89	1.19	1.31	1.11	1.28
21	1.02	1.02	.97	1.12	1.15	.88	1.17	.....	.....	1.29	1.44
22	1.04	1.08	1.36	.91	1.32	1.18	1.23	1.35	1.21	1.26	1.44
23	1.08	1.08	1.14	1.40	.90	1.15	.....	1.34	1.42	1.20	1.28
24	1.08	1.00	1.00	1.06	.93	.86	.....	1.51	1.57	1.25	1.44
25	1.07	.....	.....	1.04	.....	.....	.....	1.62	1.75	.....	.....
										1.25	1.20
										1.02	1.37
										1.08	1.30
										1.41	1.26
										1.79	1.71

At final maturity, where the base of calculation was reduced by the rapid mechanical loss of water, there was sudden rise in the percentage of ash. This increase is taken to indicate maturity. The taking of samples usually ceased just before the final rapid fall of water content. The glumes began to adhere to the caryopsis several days before maturity. After they commenced to adhere the separation of glumes and caryopsis

[1] HARLAN, Harry V., and ANTHONY, Stephen. OP. CIT.

was imperfect. Fragments of the inner tissues of the glumes frequently remained clinging to the caryopsis and pieces of the outer layers of the pericarp were as often removed with the glumes. It was thought that this small interchange of tissue did not affect the results, but to be certain a comparable series of kernels from a naked barley was studied. The results were added to figure 4. The curve of the percentage of ash based on wet weight is essentially the same as in the hulled varieties. In this figure it is apparent that neither the application of irrigation water nor the difference in the character of the barley influenced the percentage of ash when computed on the basis of wet weight. The analyses of a number of mature samples of commercial naked varieties were also available. When the ash was recalculated on a wet basis of 45 per cent water the ash content was about the same as that obtained in the field.

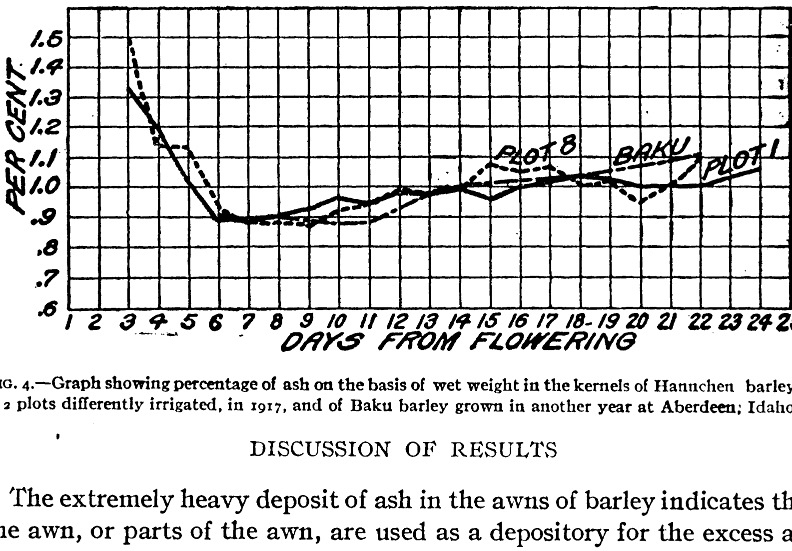

FIG. 4.—Graph showing percentage of ash on the basis of wet weight in the kernels of Hannchen barley on 2 plots differently irrigated, in 1917, and of Baku barley grown in another year at Aberdeen; Idaho.

DISCUSSION OF RESULTS

The extremely heavy deposit of ash in the awns of barley indicates that the awn, or parts of the awn, are used as a depository for the excess ash absorbed by the roots. The fact that some varieties contain much more ash in the awns and rachises than others is due probably to two causes. There most probably is a difference between varieties in the amount of water transpired. As was shown in the irrigation plots at Aberdeen, this results in a marked variation of ash deposit. There may also be a difference in the selective functions of the roots of different varieties. Some varieties may absorb more ash from the soil than do others. This is strongly indicated in the ash content of the rachises. It is also of greatest importance in this connection. Varieties of the Coast type are characterized by a low ash content of the rachis. In most of the shattering varieties the rachises are high in ash content. The hooded varieties have long been known to shatter badly. From results previously reported it would seem that much of this is due to the loss of the awn as an organ partially utilized for the elimination of ash. On the other hand,

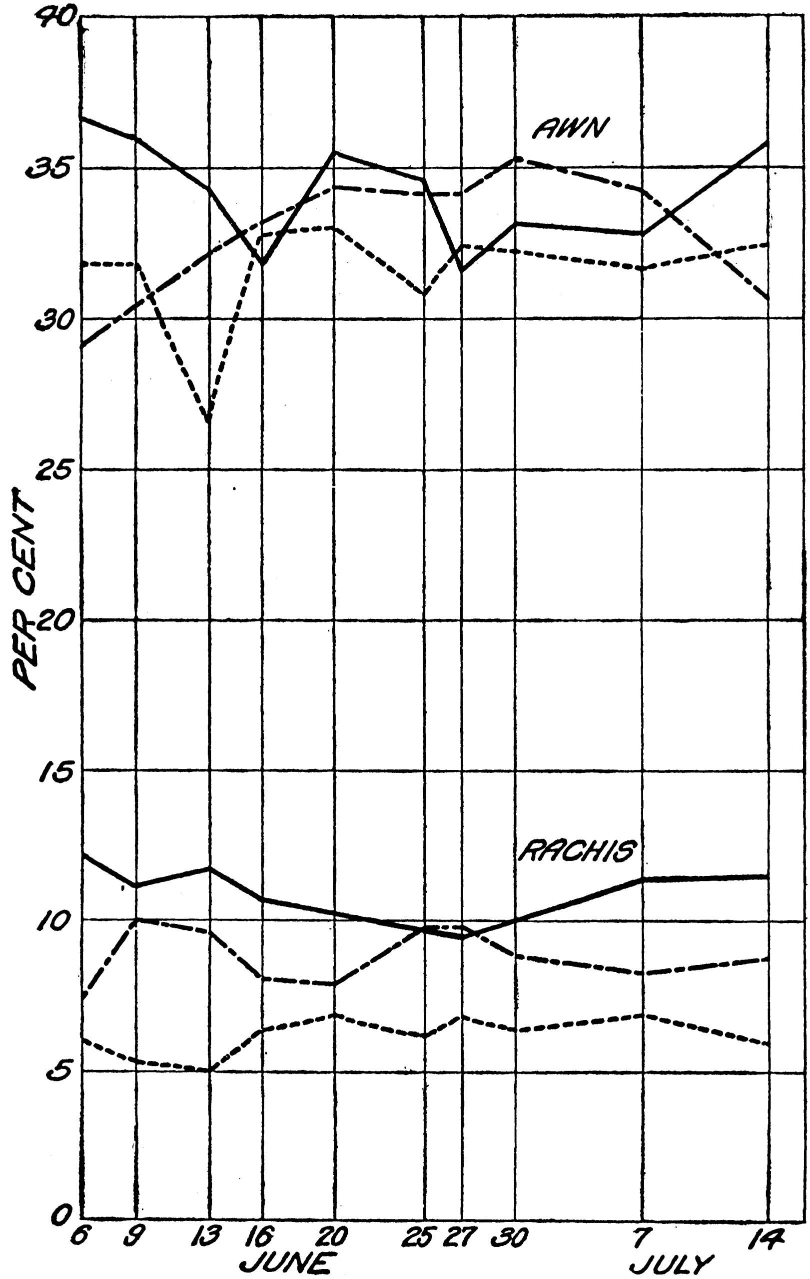

FIG. 5.—Percentage of ash in the awn and rachis of Hannchen (solid line), Tennessee Winter (dots and dashes), and Coast (broken line) barleys sampled on 10 different dates, at Chico, Calif., in 1917.

the hooded varieties most largely grown have come from hybrids whose parents were both from humid districts. The resulting hybrids might be less brittle if parents adapted to arid conditions were used.

On account of the low ash content of the rachis of the Coast barley (fig. 5), varieties of this type may be useful in the production of non-shattering awnless and hooded sorts. Barleys of the Coast group probably take less ash from the soil than do most others. There certainly is less deposited in the awns and rachises than in those of the other common varieties. Crosses of hooded varieties with varieties of the Coast type should give hooded segregates which are less brittle than the common hooded forms. Indeed the Meloy, one of the best hooded varieties under cultivation, is probably the result of such a cross. In a more complex cross it might be possible to use some of the characters of the Hanna variety. The Hanna is not classified as a shattering variety, yet its rachis contains a high percentage of ash. In this case the rachis is able to withstand a heavy deposit. It is possible that this resistance might also be of use, although hooded crosses of this sort, when not combined with the Coast, have not been very promising. In this connection it is desired not to overemphasize the relation of ash content to shattering. There is an obvious relation, but the ash content is only one of a number of factors. The tenacity of the vascular bundles, the character of the cell walls, and the size of the rachis, all have a bearing on shattering. There is also more than one type of shattering. In the Manchuria barley, for instance, when grown in Idaho under irrigation, the kernels become loosened from the spike without the rachis itself being affected. In this case the ash content of the paleas may have some bearing on deciduousness.

The ash of the kernel is of particular interest. In this case all of the ash is contained within cells which are engaged in highly active metabolism. The ash is either in the cell sap itself, the active proteid content, or the cell walls. When the ash is computed on total wet weight a very uniform percentage is maintained. It is obvious that at no time is any part of the kernel set aside as a repository for ash. There is very little difference between the kernels of plants which are dying from drouth and those which are growing under an ample supply of water. Why the ash content of the active kernel is maintained at a nearly constant precentage and whether a higher percentage of ash than that exhibited interferes with normal metabolism is not indicated from these analyses. That the uniform percentage of ash in some way is connected with the fundamental processes of growth is indicated further by the fact that the percentage coincides with that found in roots, tubers and fruits, all storage organs, and even with that of meat and eggs.

The percentage of ash based on the wet weight of kernel is not quite constant. There is a loss in percentage immediately following fertilization and then a gradual increase until full maturity. This behavior can not be adequately interpreted. It appears that at the time of fertilization the ash content of the ovary is very high. Immediately after fertilization there is a decided distention, partially due to the turgidity of a high water content. The tissues arising from the fertilized egg cell occupy a very small part of the growing kernel for several days after fertilization. The ovary wall increases very rapidly. A tissue develops at the end of the kernel arising from the ovary walls which persists for a considerable time and which grows very rapidly for the first few days after flowering. Histological sections of this tissue indicate that very little is concerned in its growth except the addition of cell walls, the enlarging of cells, and the increase of the watery cell content. A small starch deposit is found in the cells, but it is negligible. This high proportion of watery tissue might result in the drop of ash content immediately following fertilization. The gradual increase from then to maturity may be due to the fact that the proteids contain a greater percentage of ash than does the cell sap, or it may come about from a light deposit in some limited tissue of the caryopsis.

SUMMARY

The awn of barley receives a very large deposit of ash, comprising over 30 per cent of the dry weight in some varieties. Barleys differ in the amount of ash deposited in the awn and probably in the selective function of the absorbing roots. Within a variety the amount of ash in the awn is correlated with the supply of soil water and probably with the amount of water transpired.

There are varietal differences in the amount of ash deposited in the rachis. The rachises of hooded and awnless varieties are usually high in ash and usually brittle. The tendency to shatter may possibly be overcome in hooded varieties by crossing them with barleys of the Coast type, which have little ash in their rachises.

No part of the kernel proper is used as a repository for ash. The ash of the kernel is the ash of cell sap and of highly active protoplasm. When computed on the basis of the wet weight, the wet weight being a measure of the organ when active, there is almost no variation in the proportion of ash. During most of the period of growth the variation is only 0.3 of 1 per cent, the content increasing gradually from slightly less than 1 per cent in early growth to slightly more than 1 per cent at maturity.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
15 CENTS PER COPY
SUBSCRIPTION PRICE, $3.00 PER YEAR
▽