FURTHER STUDIES ON THE PERMANENCE OF DIFFERENCES IN THE PLOTS OF AN EXPERIMENTAL FIELD [1]

By J. Arthur Harris, *Head, Department of Botany, University of Minnesota, and Collaborator, Bureau of Plant Industry,* and C. S. Scofield, *Senior Agriculturist in Charge, Office of Western Irrigation Agriculture, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

The fruitfulness of the biometric method of attack on the problem of field heterogeneity—one of the greatest sources of difficulty in the interpretation of the results of all experiments involving plot tests—has been shown by a series of papers cited in publications readily accessible to agriculturists (*2, 3, 4, 5, 6*).[2]

In an earlier investigation (*7*) the writers considered the permanence of the differences in the plots of one experimental tract, comprising 46 plots, at the Huntley (Mont.) Field Station.

By applying the method of interannual correlation (*3*) the writers demonstrated that during the period from 1911 to 1919, inclusive, plots which showed a higher yield in one year were generally characterized by a measurably higher yield in subsequent years, whereas those which fell below the average yield in a given year generally proved measurably inferior in other years.

The crops grown during the nine years covered by the first investigation comprised sugar beets, alfalfa, ear corn, oats, silage corn, and barley. Altogether, 19 crop records (including the various cuttings of alfalfa and the separate and combined yields of grain and straw, in the cereals) were available. Since the report of these investigations appeared, 6 crops, giving 10 measures of yield, have been grown on this land. These were silage corn, barley, alfalfa (three years), and silage corn.

The purposes of the present investigation are: (1) To consider the relationship between the yield of these various crops and the other crops grown on these plots during the whole period that the uniform-cropping experiments were under way—that is, from 1911 to 1925, inclusive; (2) to suggest physical explanations for certain of the biological results; and (3) to indicate the bearing of these results on the problem of the technic of agricultural experimentation.

MATERIALS

While the experimental tract was briefly described in an earlier paper (*7*), certain of the features must be noted in somewhat greater detail to make possible a full understanding of the results here presented.

---

[1] Received for publication Sept. 17, 1927; issued February, 1928.

[2] Reference is made by number (italic) to "Literature cited," p. 40.

This consideration of materials may fall logically into two parts: (1) A description of features of the experimental area, and (2) a discussion of the agronomic details of the crop yields.

The Huntley Field Station is located in the Yellowstone Valley on land having a very slight and uniform slope to the north.

The plots involved in this experiment occupy a rectangular block of land known as Series II and III of field B. Field B is triangular and lies between the main canal of the Huntley Reclamation Project and an open drain ditch known as Custer Coulee. Series II and III occupy the center of the north side of this triangle.

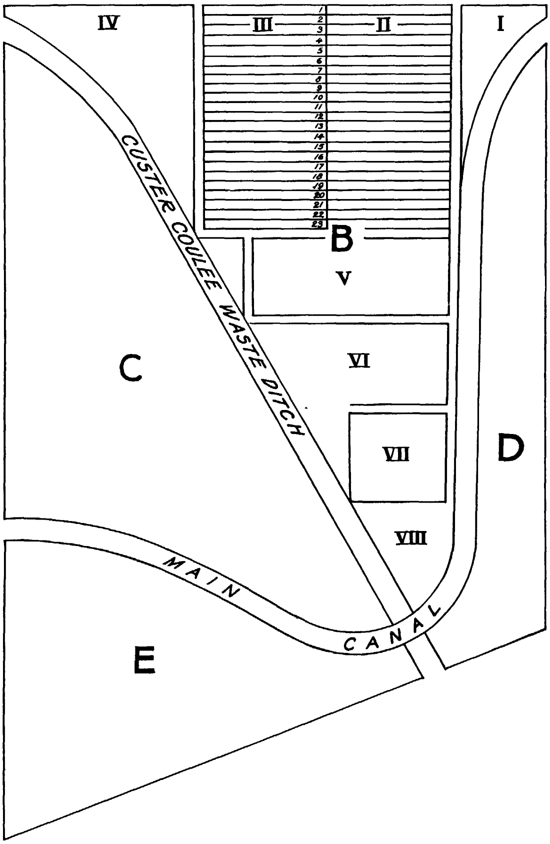

FIG. 1.—Diagram of fields B, C, D, and E of the Huntley (Mont.) Field Station, showing the locations of the plots of Series II and III of field B as related to the irrigation and drainage canals

The map (fig. 1) shows the form and relative position of the 46 plots which constitute Series II and III. Each plot measures 23.3 by 317 feet and contains approximately 0.17 acre. The two series are separated by a narrow alleyway 5 feet wide; the entire block of ground is 639 feet (east and west) by 536 feet (north and south). The slope to the north is 1 foot in 536 feet, while the slope to the west is 2.5 feet in 639 feet. The northeast corner is therefore 3.5 feet lower than the southeast corner. This slope is adequate for the distribution of irrigation water by flooding, as for alfalfa and grain, or by furrows, as for sugar beets and corn. Irrigation water is distributed from a shallow ditch running along the east side of Series II from south to north. When the ground is occupied by a cultivated crop, such as corn, the irrigation water runs between the rows across both series. When the land is planted with grain or alfalfa, another shallow ditch is made in the alleyway between the two series, and each series is flooded from the ditch along its east side.

Some slope of the land is necessary for the distribution of water, but it is found to be difficult to establish and maintain a uniform surface slope over the entire field. An effort is made to smooth the surface each time the land is prepared for a new crop, but slight inequalities of slope may persist. Furthermore, some soil movement may take place through wind action between the time the field is leveled for planting and the time the crop is grown to a size that affords protection for the soil. Even when the land is well stabilized by a crop such as alfalfa, wind may carry soil from adjacent fields or roads, thus making the surface to some extent uneven. Any such irregularities may have a direct influence on the distribution of irrigation water and consequently on the depth of penetration even where the physical conditions of the soil of the root zone are substantially uniform. These irregularities in the soil surface must have some influence upon the character of the crop growth. Growth conditions may be affected adversely either where the surface is slightly high, so that too little water enters the root zone, or where the surface is slightly low, so that water collects and keeps the surface soil saturated too long. The indications are that, with the quantities of irrigation water that have been used on this field, more injury has resulted from local deficiencies of water than from local surpluses. These differences of surface level do not occur in the same spots from year to year, because they are the result of accidental conditions. Consequently, differences of yield from year to year may be due in part to these slight surface irregularities.

The question of the relation of the field to water supply and drainage—factors which are believed to be of importance in determining some of the results reported here—will now be considered.

The southeast corner of Series II, the east series, is about 80 feet from the main canal, and the southwest corner of Series III is about 50 feet from Custer Coulee. The main project canal carries normally during the irrigation season about 400 second-feet of water. The water surface in the canal is about 4 feet above the high corner of the field. It is evident from surface conditions, as well as from borings made between the canal and the field, that there is extensive seepage from the canal into the subsoil of the field. The volume of this seepage has been larger in recent years than it was in the earlier years of the cropping experiments, probably because the canal bank has been worn away by internal erosion, exposing a stratum of sandy subsoil that underlies the canal and part of the field.

As early as 1921 it was observed that in some parts of the field the subsoil was saturated late in the season not far below the surface. In the spring of 1922 an observation well was established near the center of the south line of the field, at the end of the alleyway that separates the two series. In April, when the well was put down, the saturated zone was 7 feet below the surface. During the irrigation season the underground water rose until in October it stood at 2.1 feet below the ground surface. Each year since 1922 a similar condition has been observed. The underground water rises during the irrigation season and falls again during the following winter. Other observation wells were sunk in 1923 along the east and north sides of the field. From these it has been learned that the zone of subsoil saturation extends under the whole field. The slope of this saturated zone is rather greater than that of the surface soil, so that while it rises nearly to the soil surface along the east side of the field (Series II) it remains 4 to 5 feet below the surface along the west side. It seems obvious that this zone of saturated subsoil as it approaches the surface must restrict the roots of the plants and to some extent influence crop growth. At some stages this influence may be beneficial, since the plants may be able to utilize this subsoil water. At higher stages or with such a deep-rooted crop as alfalfa the influence may be injurious.

It is believed that in the earlier years of these uniform-cropping experiments the subsoil water did not rise so close to the surface as it has recently, although no detailed observations were made prior to 1922. It is also believed that the effects of the subsoil saturation have been more pronounced on the plots of Series II than on those of Series III. It seems probable that the negative correlations reported in this paper between the alfalfa yields of 1912–1914 and those of 1922–1924 may be associated with the unequal effect on the two series of plots of the rising zone of subsoil saturation.

The following notes with respect to the field conditions and crops grown each year may contribute to a better understanding of the yields reported and analyzed in this paper.

The detailed history of the field prior to 1910 is not definitely known. Probably it was first broken from the original prairie sod in the spring of 1908. In 1909 it was planted to sugar beets, but the crop was destroyed by hail in the late summer. In 1910 the field came under experimental control. At that time the major portion was sown to oats, which produced a yield of 66 bushels per acre. That year a small tract in the southeast corner of the field was used as an implement park and stack yard and was not put into crops. This area occupied about two-thirds of the length of the first five plots of Series II. Possibly this difference in treatment in 1910 may have influenced the crop yields of 1911, but it seems probable that such influence was not great.

Year by year the crops were as follows:

1911. Sugar beets. (See above.)

1912. Montana common alfalfa was seeded on May 18 without a nurse crop. The first crop was cut July 18, but the plots were not harvested separately. The total yield from the two series was 6,840 pounds. The second cutting (reported in Table 2 as "1912, alfalfa total") was made September 10.

1913. Alfalfa I was cut June 20; Alfalfa II was cut August 2; the third cutting was made September 21. While this crop was curing in the field a severe windstorm occurred, and the hay was so badly mixed that the plot yields could not be determined. It was not possible even to obtain the total yield, as part of the hay was blown completely off the field.

1914. Alfalfa I was cut June 15; Alfalfa II was cut July 7; Alfalfa III was cut September 20. The land was subsequently plowed.

1915. Ear corn, variety Northwestern Dent, was planted May 20. Harvest was begun September 20, but was delayed for several weeks by stormy weather. The stover weights were not taken, because of storm injury during harvest.

1916. Ear corn, variety Northwestern Dent, was planted May 26. The soil was very dry at planting time and the crop was slow in starting. Harvesting was delayed by wet weather until December 1, and again the injury to the stover was so great that it seemed inadvisable to weigh it by plots.

1917. Oats, variety Banner, were sown May 28 and harvested August 17. No exceptional conditions were noted. The crop yield was very good.

1918. Silage corn, variety Northwestern Dent, was planted May 20 and cut September 18. No exceptional conditions were noted.

1919. Barley, variety Trebi, was sown May 10 and harvested September 12. Because of drought, an irrigation was necessary to germinate the seed. Only a fair stand was obtained.

1920. Silage corn, variety Northwestern Dent. On July 4 water from Custer Coulee caused an overflow of the main canal and flooded the experimental field. This set back the growth of the corn crop and probably reduced the yield, but so far as could be observed the injury was fairly uniform on the two series. The crop was harvested September 16.

1921. Barley, variety Trebi. A good yield was obtained and approximately a normal grain-straw ratio for this variety.

1922. Alfalfa, variety Grimm, was seeded with the barley in May, 1921, but owing to severe grasshopper injury it was necessary to reseed in August, 1921. In 1922 the first and second cuttings of alfalfa were not harvested by separate plots because of the prevalence and irregular distribution of weeds and grasshopper injury. The alfalfa reported for 1922 in Table 2 is the third crop, cut September 27. The yields for the first cutting, June 23, were: Series II, 8,090 pounds, or 1.03 tons per acre; Series III, 7,000 pounds, or 0.90 ton per acre. The yields for the second cutting, August 4, were: Series II, 8,050 pounds, or 1.03 tons per acre; Series III, 7,950 pounds, or 1.02 tons per acre.

1923. Alfalfa. The first cutting was made June 15. The second cutting, made August 3, was so badly lodged by wind and rain that it was not practicable to weigh the plot yields separately. The yield of Series II was 15,730 pounds, or 2.01 tons per acre; the yield of Series III was 16,911 pounds, or 2.16 tons per acre. The third cutting was not made until November 20, about six weeks after it was ready to cut. This delay was due to continuously unfavorable weather, and although there was appreciable loss of weight because of the delay it was not apparent that any lack of uniformity in yield resulted.

1924. Alfalfa. The first crop was cut June 25. It was so badly lodged by wind and rain that the plots could not be weighed separately. Series II yielded 18,660 pounds, or 2.39 tons per acre, and Series III yielded 19,500 pounds, or 2.50 tons per acre. The second cutting was made August 5. The third cutting was made September 26. The hay from plots B–II, 1 to 14, inclusive, was weighed on October 2. The hay from the remaining plots of B–II and all the other plots was weighed October 16. The delay was due to a heavy rain, which may have caused some loss of leaves occasioned by the necessary turning and drying.

1925. Silage corn, variety Northwestern Dent, harvested September 12. Apparently a normal crop and good yield.

The yields of the various crops grown during the period 1911–1919 are set forth in Table 3 of a previous paper (7). Those for the period 1920–1925 are shown in Table 1 of the present paper. This table gives the yields in terms of pounds per plot. For the convenience of agriculturists the average yields in pounds per plot and the equivalent yields per acre in conventional units are shown in Table 2.

TABLE 1.—*Crop yields in the uniform-cropping experiments at Huntley, Mont., 1920–1925*

Series and plot No.	Yield per plot (pounds)									
	Silage corn, 1920	Barley, 1921			Alfalfa					Silage corn, 1925
		Grain	Straw	Total	III, 1922	I, 1923	III, 1923	II, 1924	III, 1924	
Series II:										
1	2,230	506	344	850	420	530	270	450	250	4,940
2	2,405	571	389	960	520	450	220	460	290	3,820
3	2,800	554	376	930	390	640	280	550	280	3,570
4	2,720	559	361	920	340	510	260	500	330	3,600
5	2,470	569	381	950	390	620	290	650	290	4,150
6	2,290	512	388	900	390	540	250	540	340	4,490
7	2,320	552	348	900	400	600	310	680	280	4,280
8	2,335	514	326	840	390	510	250	530	310	4,120
9	2,380	499	341	840	410	540	290	670	330	4,400
10	2,655	548	372	920	490	545	280	590	370	4,110
11	2,410	559	341	900	480	730	360	700	310	4,760
12	2,560	598	312	910	500	610	280	610	400	4,510
13	2,490	547	303	850	450	670	330	740	400	4,600
14	2,560	550	280	830	440	570	290	630	450	4,140
15	2,300	509	261	770	400	660	410	800	380	4,150
16	2,590	566	334	900	430	560	300	640	430	4,720
17	2,490	634	416	1,050	420	630	310	700	350	4,550
18	2,550	616	374	990	430	550	250	550	370	4,340
19	2,610	568	342	910	340	640	310	600	280	4,390
20	2,430	571	379	950	360	630	260	560	230	4,420
21	2,180	546	344	890	320	640	290	650	290	4,520
22	2,360	521	239	760	230	550	210	530	310	4,320
23	1,790	452	288	740	200	540	240	530	260	4,180
Series III:										
1	2,240	466	304	770	260	645	350	720	360	4,690
2	2,110	485	325	810	330	540	360	660	410	3,590
3	2,535	519	351	870	340	750	370	720	380	3,070
4	2,480	493	307	800	350	490	320	590	410	3,140
5	2,300	498	342	840	395	670	340	790	400	3,940
6	2,215	436	334	770	350	590	340	640	350	3,960
7	2,150	502	338	840	420	720	330	800	400	4,170
8	2,220	497	303	800	390	500	360	660	420	3,880
9	2,400	476	304	780	395	760	320	820	390	3,970
10	2,460	489	311	800	305	590	290	620	420	3,270
11	2,245	465	305	770	290	620	360	780	380	4,105
12	2,330	492	298	790	410	550	340	550	390	4,495
13	2,400	506	304	810	380	600	280	750	330	4,825
14	2,430	526	314	840	370	550	270	590	360	4,390
15	2,300	523	297	820	340	630	290	690	340	4,380
16	2,530	501	289	790	305	500	280	530	380	4,580
17	2,540	515	305	820	380	640	300	670	360	4,520
18	2,480	537	273	810	365	600	240	570	390	4,290
19	2,610	505	285	790	375	740	290	720	380	4,620
20	2,610	531	309	840	370	650	310	600	420	4,510
21	2,480	542	288	830	440	640	340	790	400	4,770
22	1,940	523	317	840	345	680	270	620	420	4,850
23	2,200	530	300	830	410	670	320	810	420	5,230

TABLE 2.—*Average yields of crops grown in the uniform-cropping experiments at Huntley, Mont., 1911–1925*

[Yields per acre (last column) are stated in tons except for ear corn, barley grain, and oats grain, which are in bushels]

Year	Crop	Per plot (pounds)	Per acre
1911	Sugar beets	4,179.00	12.29
1912	Alfalfa (total)	356.54	1.04
1913	Alfalfa I	541.41	1.59
	Alfalfa II	483.26	1.42
	Alfalfa I and II	1,024.67	3.01
1914	Alfalfa I	489.13	1.44
	Alfalfa II	499.34	1.47
	Alfalfa I and II	988.47	2.91
	Alfalfa III	471.95	1.38
	Alfalfa I to III	1,460.43	4.29
1915	Ear corn	522.58	42.70
1916	do	396.15	32.40
1917	Oats: Grain	555.80	102.10
	Oats: Straw	521.54	1.53
	Oats: Total	1,077.34	3.16
1918	Silage corn	3,175.43	9.34
1919	Barley: Grain	358.19	43.80
	Barley: Straw	230.50	.67
	Barley: Total	588.69	1.73
1920	Silage corn	2,394.13	7.04
1921	Barley: Grain	525.60	64.20
	Barley: Straw	324.82	.95
	Barley: Total	850.43	2.50
1922	Alfalfa III	379.67	1.12
1923	Alfalfa I	603.91	1.77
	Alfalfa III	300.22	.88
	Alfalfa I and III	904.13	2.66
1924	Alfalfa II	642.39	1.89
	Alfalfa III	357.39	1.05
	Alfalfa II and III	999.78	2.94
1925	Silage corn	4,267.93	12.55

PRESENTATION OF RESULTS

The correlations between the crops grown from 1911 to 1919, inclusive, have been set forth in Tables 4 to 6 of an earlier publication (*7*).

With the new materials at hand it is worth while to review all of the correlations available for the entire period of 15 years over which these uniform-cropping experiments have been continued.

The correlations between each crop yield of the period 1920 to 1925 and the yields of each of the crops grown from 1911 to 1925, both inclusive, are shown in Table 3.

The publication of one of the present tables in condensed form and the appearance of these tables in two different places renders the examination of the results extremely difficult. A graphic method of representation, therefore, has been adopted.

TABLE 3.—*Correlation between the yields of various crops in the uniform-cropping experiments at Huntley, Mont.*

Year	Crop	Item	Sugar beets, 1911	Alfalfa: Total, 1912	Alfalfa: I, 1913	Alfalfa: II, 1913	Alfalfa: I and II, 1913	Alfalfa: I, 1914	Alfalfa: II, 1914	Alfalfa: I and II, 1914
1920	Silage corn	Correlation	−0.237	+0.074	+0.117	+0.189	+0.179	+0.164	+0.164	+0.177
			±.093	±.098	±.098	±.095	±.096	±.096	±.096	±.096
		r/Er	2.52	.75	1.20	1.97	1.86	1.70	1.69	1.84
1921	Barley: Grain	Correlation	+.081	+.001	+.473	+.219	+.408	+.529	+.286	+.432
			±.098	±.099	±.077	±.094	±.082	±.071	±.091	±.080
		r/Er	.82	.01	6.13	2.31	4.93	7.39	3.13	5.35
	Barley: Straw	Correlation	−.350	+.219	+.415	+.189	+.356	+.492	+.408	+.484
			±.087	±.094	±.082	±.095	±.086	+.075	±.082	±.076
		r/Er	4.02	2.31	5.04	1.97	4.10	6.54	4.93	6.36
	Barley: Total	Correlation	−.144	+.121	+.515	+.237	+.443	+.591	+.398	+.528
			±.097	±.097	±.073	±.093	±.079	±.064	±.083	±.071
		r/Er	1.48	1.24	7.05	2.52	5.55	9.15	4.76	7.38
1922	Alfalfa III	Correlation	−.197	+.195	+.056	+.203	+.151	+.292	+.115	+.214
			±.095	±.095	±.099	±.095	±.097	±.090	±.098	±.094
		r/Er	2.06	2.04	.57	2.13	1.55	3.21	1.18	2.26
1923	Alfalfa I	Correlation	+.082	−.011	−.066	−.207	−.159	−.224	−.264	−.265
			±.098	±.099	±.099	±.095	±.096	±.094	±.092	±.092
		r/Er	.83	.11	.67	2.17	1.64	2.38	2.86	2.87
	Alfalfa III	Correlation	−.081	+.150	−.224	−.333	−.326	−.396	−.438	−.452
			±.098	±.097	±.094	±.088	±.088	±.083	±.080	±.079
		r/Er	.82	1.54	2.37	3.77	3.67	4.73	5.45	5.72
	Alfalfa I and III	Correlation	+.025	+.055	−.143	−.292	−.254	−.332	−.379	−.386
			±.099	±.099	±.097	±.090	±.092	±.088	±.085	±.084
		r/Er	.26	.55	1.47	3.22	2.73	3.75	4.45	4.56
1924	Alfalfa II	Correlation	+0	+.099	−.272	−.362	−.371	−.394	−.369	−.412
			±.099	±.098	±.092	±.08	±.085	±.083	±.085	±.082
		r/Er	0	1.00	2.95	4.19	4.33	4.69	4.30	4.99
	Alfalfa III	Correlation	−.026	−.047	−.556	−.279	−.492	−.540	−.544	−.586
			±.099	±.099	±.068	±.091	±.075	±.070	±.069	±.065
		r/Er	.26	.48	8.09	3.04	6.53	7.67	7.77	8.98
	Alfalfa II and III	Correlation	−.010	+.054	−.435	−.388	−.483	−.520	−.503	−.553
			±.099	±.099	±.080	±.084	±.076	±.072	±.074	±.069
		r/Er	.10	.54	5.41	4.59	6.34	7.18	6.79	8.01
1925	Silage corn	Correlation	+.512	−.572	+.131	+.096	+.134	+.074	+.022	+.051
			±.073	±.066	±.097	±.098	±.097	±.098	±.099	±.099
		r/Er	6.99	8.57	1.34	.98	1.37	.75	.20	.51

Year	Crop	Item	Alfalfa—Continued: III, 1914	Alfalfa—Continued: I to III, 1914	Ear corn: 1915	Ear corn: 1916	Oats: Grain, 1917	Oats: Straw, 1917	Oats: Total, 1917	Silage corn, 1918
1920	Silage corn	Correlation	+0.111	+0.171	−0.478	+0.105	+0.251	+0.983	+0.185	−0.152
			±.098	±.096	±.076	±.098	±.093	±.098	±.096	±.097
		r/Er	1.13	1.77	6.24	1.07	2.69	.84	1.93	1.56
1921	Barley: Grain	Correlation	+.248	+.411	−.131	+.401	+.268	+.143	+.238	+.011
			±.093	±.082	±.097	±.083	±.092	±.097	±.093	±.099
		r/Er	2.65	4.97	1.34	4.81	2.90	1.47	2.54	.11
	Barley: Straw	Correlation	+.343	+.048	−.035	+.400	+.331	+.278	+.370	+.036
			±.087	±.099	±.099	±.083	±.088	±.091	±.085	±.099
		r/Er	3.91	.48	.35	4.79	3.74	3.03	4.31	.36
	Barley: Total	Correlation	+.339	+.573	−.098	+.463	+.345	+.240	+.348	+.027
			±.087	±.073	±.098	±.078	±.087	±.093	±.087	± 099
		r/Er	3.85	7.00	1.00	5.93	3.93	2.56	3.99	.27
1922	Alfalfa III	Correlation	+.057	+.184	−.058	+.192	+.148	+.397	+.369	−.126
			±.099	±.096	±.099	±.095	±.097	±.083	±.085	±.097
		r/Er	.57	1.91	.59	2.01	1.53	4.74	4.30	1.29
1923	Alfalfa I	Correlation	−.125	−.244	−.127	−.260	−.187	+.095	−.020	+.101
			±.097	±.093	±.097	±.092	±.095	±.098	±.099	±.098
		r/Er	1.28	2.61	1.30	2.80	1.95	.97	.20	1.03
	Alfalfa III	Correlation	−.142	−.394	−.101	−.439	−.405	+.141	−.092	−.127
			±.097	±.083	±.098	±.080	±.083	±.097	±.098	±.097
		r/Er	1.45	4.70	1.02	5.47	4.87	1.45	.94	1.29
	Alfalfa I and III	Correlation	−.152	−.346	−.136	−.376	−.308	+.130	−.054	+.021
			±.097	±.087	±.097	±.085	±.089	±.097	±.099	±.099
		r/Er	1.56	3.95	1.39	4.40	3.43	1.33	.54	.21
1924	Alfalfa II	Correlation	−.214	−.385	−.021	−.459	−.381	−.025	−.206	−.130
			±.094	±.084	±.099	±.078	±.085	±.099	±.095	±.097
		r/Er	2.26	4.54	.22	5.85	4.48	.26	2.16	1.33
	Alfalfa III	Correlation	−.363	−.565	+0.42	−.561	−.430	+.040	−.181	−.154
			±.086	±.067	±.099	±.068	±.081	±.099	±.096	±.097
		r/Er	4.21	8.35	.42	8.25	5.30	.40	1.88	1.58
	Alfalfa II and III	Correlation	−.312	−.524	+.001	−.578	−.465	−.002	−.230	−.162
			±.089	±.072	±.099	±.066	±.077	±.099	±.094	±.096
		r/Er	3.48	7.26	.01	8.73	5.96	.02	2.44	1.67
1925	Silage corn	Correlation	−.027	+.031	+.107	+.192	+.176	−.030	+.064	+.093
			±.099	±.099	±.098	±.095	±.096	±.099	±.099	±.098
		r/Er	.28	.31	1.09	2.01	1.83	.30	.65	.95

TABLE 3.—*Correlation between the yields of various crops in the uniform-cropping experiments at Huntley, Mont.*—Continued

Year	Crop	Item	Barley: Grain, 1919	Barley: Straw, 1919	Barley: Total, 1919	Silage corn, 1920	Barley: Grain, 1921	Barley: Straw, 1921	Barley: Total, 1921
1920	Silage corn	Correlation	−0.092 ±.098	−0.274 ±.091	−0.195 ±.095	------	+0.532 ±.071	+0.206 ±.095	+0.435 ±.080
		r/*Er*	.93	2.98	2.04	------	7.46	2.16	5.39
1921	Barley: Grain	Correlation	−.184 ±.096	−.282 ±.091	−.253 ±.093	+.532 ±.071	------	+.495 ±.075	+.877 ±.022
		r/*Er*	1.92	3.08	2.72	7.46	------	6.60	38.3
	Barley: Straw	Correlation	+.348 ±.087	+.203 ±.095	+.308 ±.090	+.206 ±.095	+.495 ±.075	------	+.851 ±.027
		r/*Er*	3.99	2.13	3.42	2.16	6.60	------	31.2
	Barley: Total	Correlation	+.081 ±.098	−.057 ±.099	+.017 ±.099	+.435 ±.080	+.877 ±.022	+.851 ±.027	------
		r/*Er*	.82	.58	.17	5.39	38.3	31.2	------
1922	Alfalfa III	Correlation	+.282 ±.091	+.184 ±.096	+.259 ±.092	+.376 ±.085	+.534 ±.071	+.372 ±.085	+.528 ±.071
		r/*Er*	3.08	1.92	2.80	4.41	7.51	4.35	7.36
1923	Alfalfa I	Correlation	−.021 ±.099	−.001 ±.099	−.012 ±.099	+.018 ±.099	+.005 ±.099	−.091 ±.098	−.047 ±.099
		r/*Er*	.21	.01	.12	.18	.05	.93	.47
	Alfalfa III	Correlation	+.232 ±.094	+.078 ±.098	+.175 ±.096	−.109 ±.098	−.296 ±.090	−.196 ±.096	−.265 ±.092
		r/*Er*	2.47	.79	1.82	1.11	3.26	2.05	2.87
	Alfalfa I and III	Correlation	+.082 ±.098	+.032 ±.099	+.064 ±.099	−.032 ±.099	−.120 ±.097	−.133 ±.097	−.146 ±.097
		r/*Er*	.83	.33	.65	.32	1.23	1.37	1.50
1924	Alfalfa II	Correlation	+.130 ±.097	+.065 ±.099	+.109 ±.098	−.144 ±.097	−.193 ±.095	−.239 ±.093	−.249 ±.093
		r/*Er*	1.33	.65	1.11	1.47	2.02	2.55	2.67
	Alfalfa III	Correlation	+.024 ±.099	−.058 ±.099	−.547 ±.069	+.073 ±.098	−.155 ±.097	−.411 ±.082	−.321 ±.089
		r/*Er*	.24	.58	7.85	.74	1.60	4.97	3.60
	Alfalfa II and III	Correlation	+.108 ±.098	+.024 ±.099	−.146 ±.097	−.077 ±.098	−.209 ±.095	−.351 ±.087	−.320 ±.089
		r/*Er*	1.10	.24	1.50	.78	2.20	4.02	3.59
1925	Silage corn	Correlation	−.283 ±.091	−.191 ±.095	−.535 ±.070	−.167 ±.096	+.194 ±.095	−.152 ±.097	+.033 ±.099
		r/*Er*	3.10	1.99	7.54	1.73	2.02	1.57	.33

Year	Crop	Item	Alfalfa: III, 1922	Alfalfa: I, 1923	Alfalfa: III, 1923	Alfalfa: I and III, 1923	Alfalfa: II, 1924	Alfalfa: III, 1924	Alfalfa: II and III, 1924	Silage corn, 1925
1920	Silage corn	Correlation	+0.376 ±.085	+0.018 ±.099	−0.109 ±.098	−0.032 ±.099	−0.144 ±.097	+0.073 ±.098	−0.077 ±.098	−0.167 ±.096
		r/*Er*	4.41	.18	1.11	.32	1.47	.74	.78	1.73
1921	Barley: Grain	Correlation	+.534 ±.071	+.005 ±.099	−.296 ±.090	−.120 ±.097	−.193 ±.095	−.155 ±.097	−.209 ±.095	+.194 ±.095
		r/*Er*	7.51	.05	3.26	1.23	2.02	1.60	2.20	2.02
	Barley: Straw	Correlation	+.372 ±.085	−.091 ±.098	−.157 ±.096	−.133 ±.097	−.239 ±.093	−.411 ±.082	−.351 ±.087	−.152 ±.097
		r/*Er*	4.35	.93	1.62	1.37	2.55	4.97	4.02	1.57
	Barley: Total	Correlation	+.528 ±.071	−.047 ±.099	−.265 ±.092	−.146 ±.097	−.249 ±.093	−.321 ±.089	−.320 ±.089	+.033 ±.099
		r/*Er*	7.36	.47	2.87	1.50	2.67	3.60	3.59	.33
1922	Alfalfa III	Correlation	------	+.027 ±.099	+.069 ±.098	+.049 ±.099	+.074 ±.098	+.147 ±.097	+.117 ±.098	+.185 ±.096
		r/*Er*	------	.28	.69	.50	.75	1.51	1.19	1.92
1923	Alfalfa I	Correlation	+.027 ±.099	------	+.457 ±.078	+.926 ±.014	+.717 ±.048	+.155 ±.097	+.601 ±.063	+.175 ±.096
		r/*Er*	.28	------	5.81	66.2	14.9	1.60	9.49	1.81
	Alfalfa III	Correlation	+.069 ±.098	+.457 ±.078	------	+.757 ±.042	+.710 ±.049	+.410 ±.082	+.703 ±.050	−.119 ±.098
		r/*Er*	.69	5.81	------	17.9	14.4	4.97	14.0	1.21
	Alfalfa I and III	Correlation	+.049 ±.099	+.926 ±.014	+.757 ±.042	------	+.826 ±.031	+.287 ±.091	+.738 ±.045	+.078 ±.098
		r/*Er*	.50	66.2	17.9	------	26.2	3.15	16.4	.79
1924	Alfalfa II	Correlation	+.074 ±.098	+.717 ±.048	+.710 ±.049	+.826 ±.031	------	+.424 ±.081	+.925 ±.014	+.129 ±.097
		r/*Er*	.75	14.9	14.4	26.2	------	5.20	65.2	1.31
	Alfalfa III	Correlation	+.147 ±.097	+.155 ±.097	+.410 ±.082	+.287 ±.091	+.424 ±.081	------	+.735 ±.045	−.073 ±.098
		r/*Er*	1.51	1.60	4.97	3.15	5.20	------	16.1	.74
	Alfalfa II and III	Correlation	+.117 ±.098	+.601 ±.063	+.703 ±.050	+.738 ±.045	+.925 ±.014	+.735 ±.045	------	+.065 ±.099
		r/*Er*	1.19	9.49	14.0	16.4	65.2	16.1	------	.66
1925	Silage corn	Correlation	+.185 ±.096	+.175 ±.096	−.119 ±.098	+.078 ±.098	+.129 ±.097	−.073 ±.098	+.065 ±.099	------
		r/*Er*	1.92	1.81	1.21	.79	1.31	.74	.66	------

In Figures 2 to 4 the correlation between each of the crop yields and all of the other crop yields [3] is indicated in one of the panels. The crop considered as the primary variable is shown on each panel. The crop yields considered as the secondary variables are shown at the bottom of each figure. In each panel a heavy bar represents

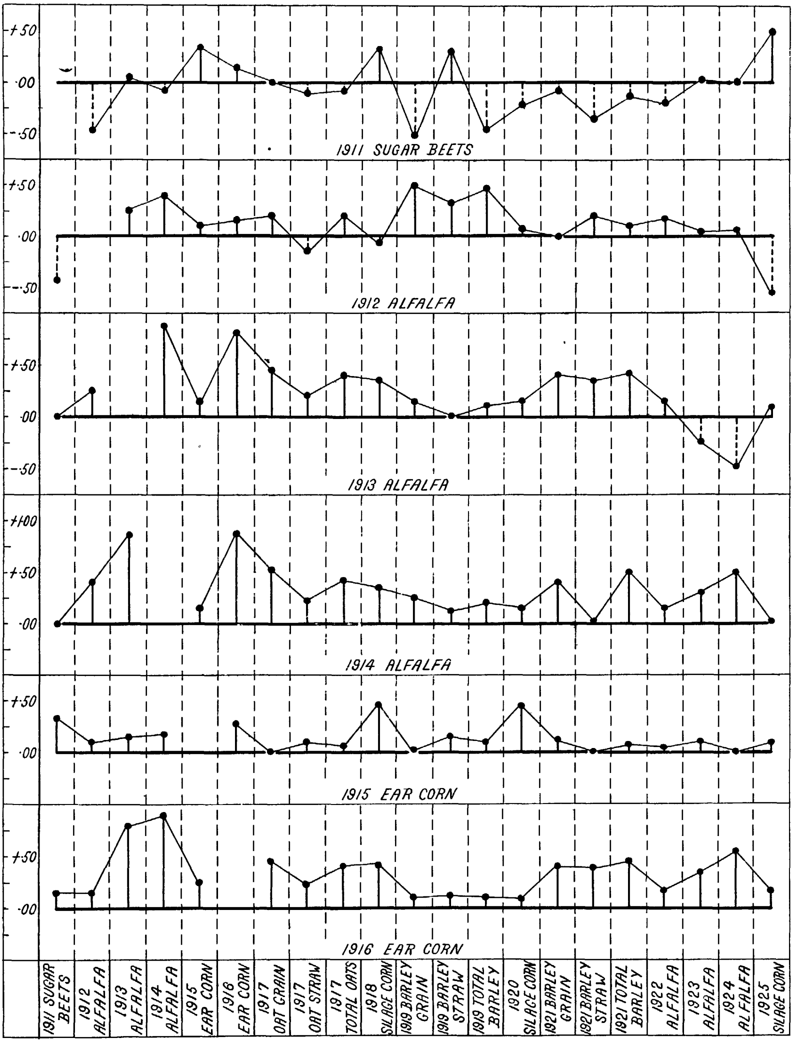

FIG. 2.—Magnitudes of correlations between the yields of various crops as grown in the uniform-cropping experiments at the Huntley Field Station, 1911-1916

the zero correlation which should be found if there were no permanency of the differences in the crop-producing capacity of the several plots of the field. Positive correlations are represented by the magnitudes of the deviations above this line, and negative correlations

[3] In the case of the alfalfa crops the correlations for total yield only are represented, not those for individual cuttings.

are represented by the deviations below this line, as shown on the scale of ordinates.

The results obtained with respect to individual crops merit detailed consideration. The correlations for the yield of sugar beets in 1911 with the 20 subsequent crop yields show large irregularities. Prac-

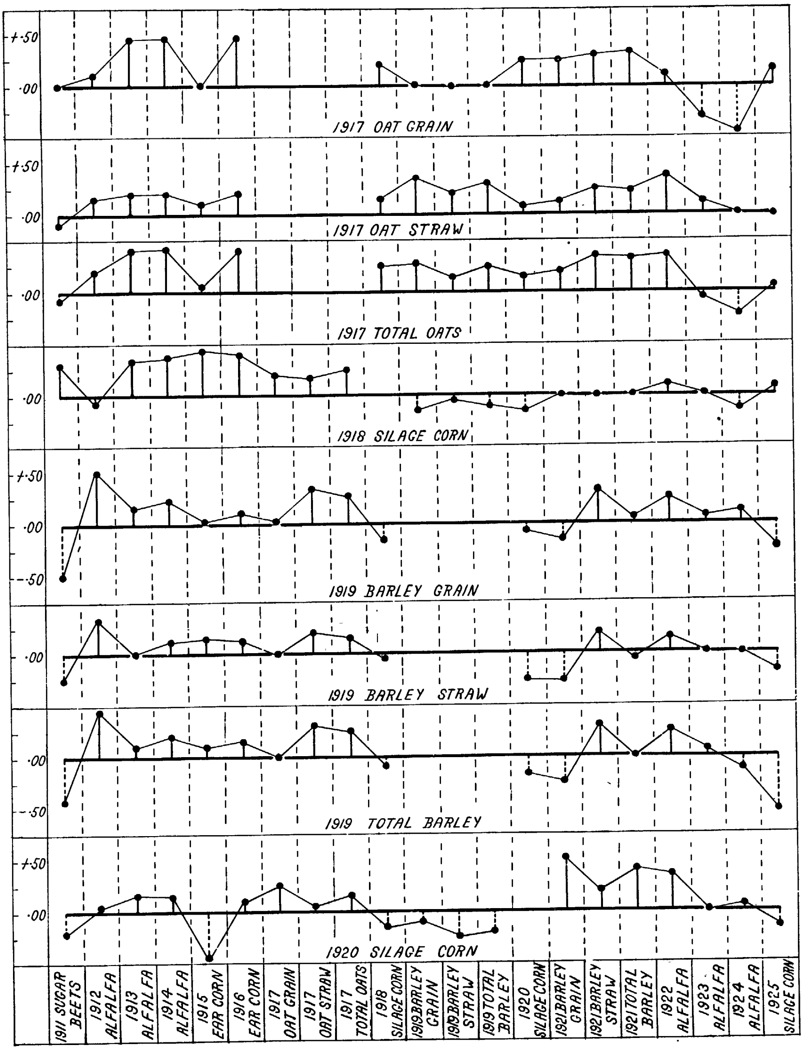

FIG. 3.—Magnitudes of correlations between the yields of various crops as grown in the uniform-cropping experiments at the Huntley Field Station, 1917–1920

tically as many negative as positive correlations are seen. Taking the series as a whole, it appears that variations in the factors influencing the yield of sugar beets on these plots had no relationship to the yields of subsequent crops.

In 1912 the first of the crops of the first stand of alfalfa was harvested. For all of these crops (1912, 1913, 1914) the correlations with antecedent crops and with practically all subsequent crops are positive in sign. Thus the original heterogeneity factors of the fields, or those introduced by differences in stand of alfalfa, persisted practically throughout the period of cultivation of this field. An exception is noted in the case of the correlation with the 1911 crop

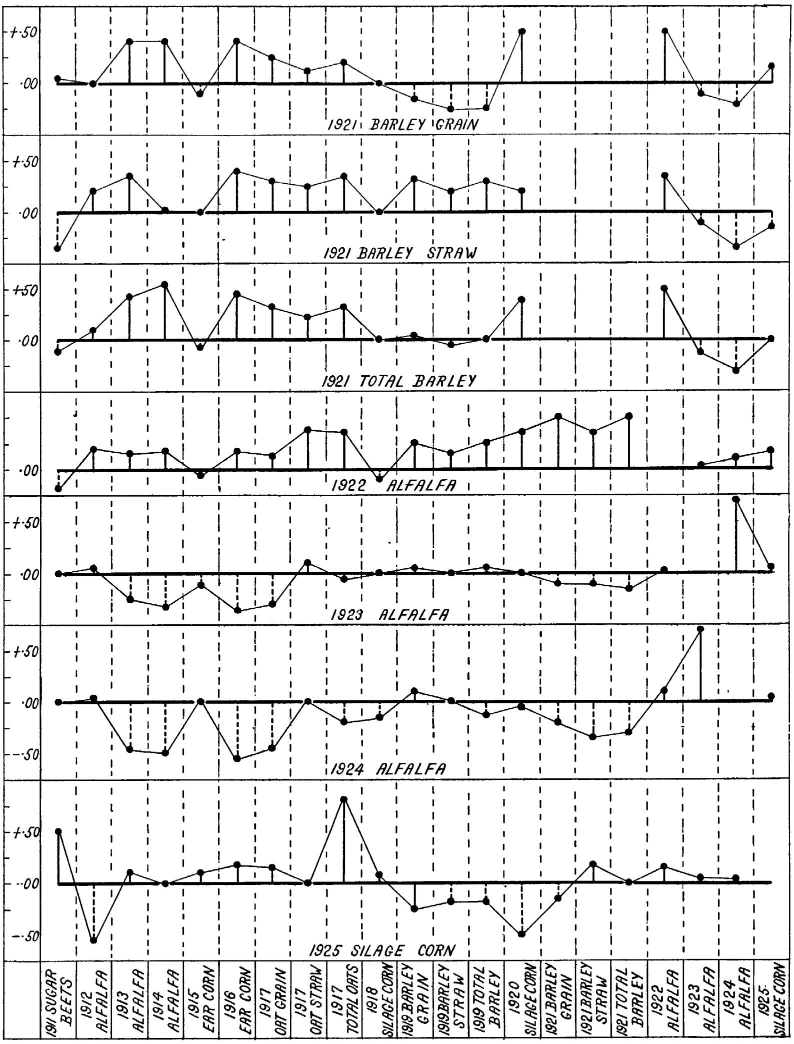

FIG. 4.—Magnitudes of correlations between the yields of various crops as grown in the uniform-cropping experiments at the Huntley Field Station, 1921–1925

of sugar beets and with the 1923 and 1924 crops of alfalfa and the 1925 crop of silage corn. The sensibly zero or even negative correlation with the crops of alfalfa grown 10 years later indicates that plots which were particularly suited for alfalfa at one period were not necessarily especially adapted to this crop at a subsequent period.

Consideration of the underlying causes of these differences in correlation is reserved until the present review of the results for the several crops is completed.

The correlations between the two crops of ear corn (1915 and 1916) and the other yields considered are generally positive. Those for 1916 are sensibly higher than those for the earlier year. This point has been considered in some detail in the former paper (7). Differences in the conditions of the soil, original or induced by agricultural technic and expressed in variations in the yield of ear corn, are therefore reflected in the yields of the other crops throughout the period of the investigation.

The three measures of oat yield in the crop grown in 1917 show a generally positive correlation with other yields except for the sugar-beet crop of 1911 and the alfalfa crops of 1923 and 1924 and the silage-corn yield of 1925. These will be considered later.

Correlations for the silage-corn yields (1918) with preceding crops are generally positive, the only exception being that for the 1912 crop of alfalfa. The relationship between the yields of this crop of silage corn and the yields of subsequent crops are, however, sensibly zero.

The three measures of the yield of barley as grown in 1919 are in general positively correlated with the yields of other crops. It is, however, interesting to note that they show a slightly negative correlation with the yield of silage corn of the preceding year (1918), of the year immediately following (1920), and of the sixth subsequent year (1925).

The 1920 crop of silage corn shows positive correlations with 12 of the other crops and negative correlations with 8 of the other crops. It shows a positive correlation with the three barley yields of the following year. This indicates that there is no necessary inverse relationship between the capacity of these plots for producing barley and corn. Turning to the three yields which furnish a measure of the capacity of these plots for barley production as grown in 1921, it is noted that in general the correlations are positive. The conspicuous exceptions are seen in the constants for alfalfa as grown in 1923 and 1924. These will be considered presently.

It should be noted that the correlations between barley as grown in 1921 and the first available test of silage corn, 1918, are sensibly zero. The correlations for the 1925 crop of silage corn are also sensibly zero. Those for the 1920 crop of silage corn, however, are more substantial positive magnitudes. The correlations with the 1915 crop of ear corn are sensibly zero, but those with the 1916 crop of ear corn are more substantial positive values. Taking these results as a whole, they indicate that there is no definitely demonstrated evidence for a negative correlation between the capacities of the plots for the production of barley and corn.

Beginning with 1922, the area was again put into alfalfa. The alfalfa yield of 1922 shows in general a positive correlation with the yields of preceding crops, but practically no correlation with the following two years' records of alfalfa or with the third subsequent year's yield of silage corn.

In the preceding investigation (7) the yields of alfalfa were found to be highly correlated with the yields of other crops. Since alfalfa occurred early in the rotation adopted in these experiments, it is possible that differences in the yields of alfalfa influenced subsequent crops by the introduction of differences in the nitrogen content or tilth of the soil of the various plots. The present results for alfalfa are more irregular. The cutting of 1922 shows in general a positive correlation with other yields. The record for 1923 shows a sensibly zero correlation with the harvest of oat straw of 1917 to alfalfa yield of 1922. The correlation with the 1924 crop of alfalfa is high, as might be expected from the fact that both of them are influenced by the stand obtained. The correlation with the 1925 crop of silage corn is sensibly zero. The correlations with the preceding crops from the 1913 yields of alfalfa to the 1917 yields of oat grain are actually negative. Similar results are found for the 1924 crop of alfalfa. It is important to note, however, that these correlations are based on the total yields of alfalfa for these years. In both of these years one cutting (the second cutting in 1923 and the first cutting in 1924) of alfalfa was not weighed by plots. Thus, it might be suggested that because of the incompleteness of the data these yields may be inaccurate as a measure of the actual annual producing capacity of the fields. If one deals with only the first cutting in 1923, however, it is noted that only 12 of the 28 correlations are positive. If one deals with the third cutting in 1923, it is found that only 11 of the 28 correlations are positive. Similarly, if one considers only the second cutting of 1924, it appears that only 10 of the 28 correlations are positive. For the third cutting of 1924 only 8 of the 28 correlations are positive. Thus, there is clear evidence that for the individual cuttings of alfalfa there is a sensibly zero or even a negative correlation between the yields of 1923 and 1924 and those of other crops grown previously on these areas.

Turning to the final crop, silage corn as grown in 1925, it is clear that the correlations are about evenly distributed between positive and negative values.

DISCUSSION OF RESULTS

In an earlier investigation (*7*), based on the results of cultures grown from 1911 to 1919, inclusive, a high preponderance of positive correlations (many of which were clearly significant in comparison with their individual probable errors) was found between the yields of a series of plots in one year and the yields of these plots in another year. These relationships between yields were found to hold whether the crop grown was the same or different in the two years. Such results indicate clearly a relatively high permanence of the differences in the plots of the experimental field.

These findings have been confirmed by many of the constants deduced for the first time in the present investigation involving crops grown for the years 1920 to 1925. In a number of cases, however, negative correlations between the yields of crops grown on the same plots in different years have been demonstrated. This is conspicuous in the case of the correlations for alfalfa grown near the end of the experimental period.

To provide a general survey of the whole series of constants, Table 4 has been prepared. This shows the distribution of the magnitudes of the correlations between each of the crops grown and all of the other crops with the exception of crops which have a direct organic relation to the several crops listed. These have been omitted. For example, in dealing with alfalfa the correlations between the different cuttings in one and the same year have been omitted. Similarly, the correlation between grain and straw and between either grain or straw and total yield have been omitted in the case of the cereals.

TABLE 4.—*Magnitudes of correlation coefficients measuring the relationship of crop yields on plots at Huntley, Mont., in different years*

Year	Crop	−0.551 to −0.650	−0.451 to −0.550	−0.351 to −0.450	−0.251 to −0.350	−0.151 to −0.250	−0.051 to −0.150	−0.050 to +0.050	+0.051 to +0.150	+0.151 to +0.250	+0.251 to +0.350	+0.351 to +0.450	+0.451 to +0.550	+0.551 to +0.650	+0.651 to +0.750	+0.751 to +0.850	+0.851 to +0.950
1911	Sugar beets		2	2	1	3	6	9	3	1	2		1				
1912	Alfalfa	1	1				1	3	7	9	2	4	2				
1913	Alfalfa I	1		1	1	1	2	3	5	3	1	2	3	2		3	
	Alfalfa II			2	3	1		2	2	8	1	2	1	2	3	1	
	Alfalfa I and II		2	1	2	1		2	2	6	1	4	1		1	2	3
1914	Alfalfa I		2	2	1	1		1	2	4	3	3	2	2		2	1
	Alfalfa II		2	3	1	1		2	3	3	3	3	1	1	1	2	
	Alfalfa I and II	2	1	2	1		1		2	6	1	3	3		1	1	2
	Alfalfa III			1	1	2	3	2	4	1	5	2	1	2	2		
	Alfalfa I to III	1	1	2	1	1	1	2	1	6		4	2			2	2
1915	Ear corn		1				6	8	6	4	4		1				
1916	do	2	1	2	1				4	5	1	4	2	1	2	3	2
1917	Oats, Grain		1	3	1	1		5	1	3	4	4	5				
	Oats, Straw						1	4	7	10	4	2					
	Oats, Total					3	3	1	2	4	6	9					
1918	Silage corn					4	6	4	2	6	3	2	2	1			
1919	Barley, Grain		1		1	2	1	4	7	4	6	1	1				
	Barley, Straw				3	1	3	7	7	6	1						
	Barley, Total		2	1	1	1	2	4	7	5	4		1				
1920	Silage corn		1		1	4	4	2	6	8	1	2	1				
1921	Barley, Grain				3	4	2	3	2	4	2	4	4				
	Barley, Straw			2	1	3	2	3		4	5	6	2				
	Barley, Total				3	1	4	4	2	2	3	3	4	2			
1922	Alfalfa III					1	2	2	8	8	3	4	2				
1923	Alfalfa I				3	5	4	9	3	2				1	1		
	Alfalfa III		1	5	4	2	7		4	2		1			2		
	Alfalfa I and III			3	5	1	7	5	4		1				1	1	
1924	Alfalfa II		1	7	1	5	2	3	6						2	1	
	Alfalfa III	4	4	3	2	3	2	5	2	1	1	1					
	Alfalfa II and III	2	5	3	2	3	2	4	4					1	2		
1925	Silage corn	1	1		1	3	2	5	11	5			1				
	Total	14	30	45	45	58	76	108	126	130	68	70	43	15	18	18	10

The frequency distributions of correlation coefficients in this table show a rather wide range of both positive and negative values. These have been considered in detail on the basis of the three diagrams constituting Figures 2, 3, and 4, and nothing further need be said for the moment in regard to the relationships for the individual crops.

Taking the materials as a whole, it appears that 108 of the coefficients fall essentially in the class of zero correlations—i. e., of −0.05 to +0.05.[4] The distribution of positive and negative coefficients on the two sides of this arbitrarily limited (zero) value is very unlike. Thus 76 constants fall between −0.051 and −0.150, whereas 126 fall between the limits +0.051 and +0.150. Similarly, only 58 coefficients fall between the limits of −0.151 and −0.250, whereas more than twice this number (130) fall between +0.151 and +0.250. Again, only 45 coefficients fall between the limits of −0.251 and −0.350, whereas 68 fall between +0.251 and +0.350. Finally, only 89 fall below the limit −0.350, whereas 174 fall above +0.350.

Thus the results indicate clearly the great preponderance of positive correlations for the series as a whole. Notwithstanding this fact, the figures just given show that many fairly substantial negative

[4] This range is probably too narrow for the zero class of coefficients based on samples of only 46 plots, but it forms a convenient unit for present purposes

coefficients occur. It is now necessary to estimate the significance of these when considered in relation to their probable errors.

The ratios of these coefficients to their probable errors, as computed by the usual formula, appear in Table 5. These ratios are arranged in class intervals of 2.50. Of these values, 299 positive coefficients fall between +0 and +2.50, whereas 169 fall between the limits of −0 and −2.50. A total of 136 coefficients fall between +2.51 and +5.00, whereas 88 coefficients fall between −2.51 and −5.00. Finally, 128 positive coefficients are more than five times as large as their probable errors, whereas only 54 negative coefficients are more than five times as large as their probable errors.

These results indicate clearly that, while there is a preponderance of positive correlations in this series and while the positive coefficients taken as a class have a greater probability of significance, certain of the negative coefficients are statistically significant in comparison with their probable errors. It appears, therefore, that in general plots which yield better in certain individual years will give better results throughout a long period of time, but that under certain conditions they may actually give yields significantly below the average.

Having demonstrated that both positive and negative correlations occur as measures of interrelationship between the crop yields of the 15 years over which these experimental cultures have extended, it still remains to analyze the series of coefficients more minutely with a view to determining, if possible, what the reasons for the apparent inconsistencies may be.

TABLE 5.—*Ratios of correlation coefficients measuring the interrelationship of yields to their probable errors for crops grown in different years on plots at Huntley, Mont.*

Year	Crop	−7.51 to −10.00	−5.01 to −7.50	−2.51 to −5.00	−0 to −2.50	+0 to +2.50	+2.51 to +5.00	+5.01 to +7.50	+7.51 to +12.50	+12.51 to +17.50	+17.51 to +25.00	+25.01 to +37.50	+37.51 to +42.50
1911	Sugar beets	1	2	3	13	8	2	1					
1912	Alfalfa	1	1	0	3	15	6	4					
1913	Alfalfa I	1	1	1	4	9	3	4	2		2	1	
	Alfalfa II			5	1	11	3	2	2	4			
	Alfalfa I and II		2	3	1	9	5	2	1		2	1	2
1914	Alfalfa I	1	1	3	2	6	5	3	2		1	2	
	Alfalfa II	1	2	3	1	7	7	1	1	1	2		
	Alfalfa I and II	2	1	3	1	6	4	5		1	1	1	1
	Alfalfa III			2	6	5	6	3	3	1			
	Alfalfa I to III	1	1	4	1	7	4	3	1	1	1		2
1915	Ear corn		1		9	15	4	1					
1916	do	2	2	2		9	4	3	1	2	3	1	1
1917	Oats: Grain		2	3	4	6	5	7	1				
	Oats: Straw				4	16	8						
	Oats: Total				7	5	14	2					
1918	Silage corn				10	10	6	3	1				
1919	Barley: Grain	1		1	4	13	8	1					
	Barley: Straw			3	7	17	1						
	Barley: Total	2	1	1	4	14	5	1					
1920	Silage corn		1	2	8	15	2	2					
1921	Barley: Grain			3	6	7	7	4	1				
	Barley: Straw			4	5	6	10	3					
	Barley: Total			4	5	5	6	7	1				
1922	Alfalfa III				3	18	7	1	1				
1923	Alfalfa I			4	14	8			1	1			
	Alfalfa III		3	7	9	6	1			2			
	Alfalfa I and III			8	9	8	1			1		1	
1924	Alfalfa II		1	10	7	7				2		1	
	Alfalfa III	7	2	4	7	6	2						
	Alfalfa II and III	2	6	4	7	6			1	2			
1925	Silage corn	2		1	7	19		1					
	Total	24	30	88	169	299	136	64	20	18	12	8	6

The foregoing relationships as indicated by the average values of the correlations for each of the crops grown will be first considered. In computing these averages the constants may be divided into two groups. The first comprises correlations between each crop and every other crop grown for the period 1911 to 1919, inclusive, and is therefore identical with that for the period covered by the first investigation (7). The second comprises all correlations for the period 1920 to 1925, inclusive.

The averages and the number of correlations on which these are based are given in columns 3 to 6 of Table 6. The averages for the whole period considered, 1911 to 1925, are given in columns 7 and 8.

TABLE 6.—*Averages of correlations measuring the interrelationship of yields for crops grown on plots at Huntley, Mont., in different years*

Year	Crop	1911–1919		1920–1925		1911–1925		1911–1921		1923–1924	
		N	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*
1911	Sugar beets	18	−0.0772	12	−0.0286	30	−0.0578	22	−0.0927	6	−0.0013
1912	Alfalfa	18	+.2421	12	+.0282	30	+.1566	22	+.2170	6	+.0499
	Alfalfa I	16	+.3456	12	+.0009	28	+.1978	20	+.3525	6	−.2832
1913	Alfalfa II	16	+.4026	12	−.0606	28	+.2041	20	+.3614	6	−.3106
	Alfalfa I and II	16	+.4412	12	−.0345	28	+.2373	20	+.4224	6	−.3480
	Alfalfa I	14	+.4012	12	−.0220	26	+.2059	18	+.4108	6	−.4015
	Alfalfa II	14	+.3542	12	−.0920	26	+.1483	18	+.3454	6	−.4167
1914	Alfalfa I and II	14	+.4068	12	−.0639	26	+.1896	18	+.4066	6	−.4427
	Alfalfa III	14	+.3661	12	−.0200	26	+.1879	18	+.3426	6	−.2187
	Alfalfa I to III	14	+.4276	12	−.0917	26	+.1879	18	+.3961	6	−.4100
1915	Ear corn	18	+.1673	12	−.0865	30	+.0658	22	+.1031	6	−.0573
1916	do	18	+.4863	12	−.0765	30	+.2612	22	+.4602	6	−.4458
	Oats: Grain	16	+.2893	12	−.0547	28	+.1419	20	+.2913	6	−.3630
1917	Oats: Straw	16	+.2013	12	+.1244	28	+.1683	20	+.1983	6	+.0632
	Oats: Total	16	+.2925	12	+.0659	28	+.1954	20	+.2912	6	−.1310
1918	Silage corn	18	+.2259	12	−.0467	30	+.1169	22	+.1813	6	−.0751
	Barley: Grain	16	+.1405	12	+.0591	28	+.1056	20	+.1200	6	+.0929
1919	Barley: Straw	16	+.0863	12	−.0229	28	+.0395	20	+.0485	6	+.0237
	Barley: Total	16	+.1264	12	−.0629	28	+.0453	20	+.0950	6	−.0593
1920	Silage corn	19	+.0285	11	+.1010	30	+.0551	22	+.0780	6	−.0452
	Barley: Grain	19	+.1736	9	+.0322	28	+.1282	20	+.1916	6	−.1618
1921	Barley: Straw	19	+.2549	9	−.1108	28	+.1373	20	+.2525	6	−.2374
	Barley: Total	19	+.2614	9	−.0394	28	+.1647	20	+.2701	6	−.2252
1922	Alfalfa III	19	+.1535	11	+.2258	30	+.1800	23	+.2056		
	Alfalfa I	19	−.1008	9	+.1736	28	−.0126	23	−.0882		
1923	Alfalfa III	19	−.1671	9	+.1052	28	−.0796	23	−.1740		
	Alfalfa I and III	19	−.1584	9	+.1718	28	−.0522	23	−.1497		
	Alfalfa II	19	−.1894	9	+.1813	28	−.0702	23	−.1924		
1924	Alfalfa III	19	−.3065	9	+.0125	28	−.2039	23	−.2886		
	Alfalfa II and III	19	−.2697	9	+.1409	28	−.1377	23	−.2645		
1925	Silage corn	19	+.0024	11	+.0315	30	+.0131	23	−.0021	6	+.0425

The number of constants averaged is larger than the number of years of experimentation because of the fact that more than one yield is available for certain of the crops (small grains and alfalfa). The correlations considered, however, have not involved relationships between two different measures of one and the same crop grown in a given year. Thus, correlations between yields of grain and straw, or between grain or straw and total yield, in the cereal crop of a given year have been excluded. Similarly, correlations between the different cuttings of alfalfa in the same year have been omitted.

In considering the values in this table it may be noted that, with the exception of the 1911 tonnage of sugar beets and the 1923 and 1924 cuttings of alfalfa, all of the average correlations for the period 1911 to 1919 are positive.

Before turning to a more general discussion of these averages, it may be noted that the yields of the single crop of sugar beets grown in 1911 have shown anomalies in correlation from the first. Unfortunately, no very precise information is available concerning the exact conditions prevailing during the first year of these experiments. Prior to the growing of sugar beets in 1911 the field had not been cropped uniformly. These antecedent differences of treatment may have led to diversities in the 1911 yields, but this is not at all certain. The writers are inclined to the view that owing to necessary difficulties in initiating these experiments in 1911 the preparation and leveling of the land may not have been as well done as in later years when the details could be cared for by men more experienced in the work. In view of these uncertainties, the data for sugar beets must be essentially disregarded in the interpretation of the results of the experiments as a whole. They have been included in the averages in order to avoid introducing any question of bias in selecting the constants on which conclusions are based. The averages of the correlations of each of the yields for the 15-year period 1911 to 1925 with the yields for 1920 to 1925 (columns 5 and 6 of Table 6) are by no means so consistent as those for the period 1911 to 1919. Of the 31 averages for 1920 to 1925, 15 are positive and 16 are negative.

An examination of the averages for the whole period of 15 years (columns 7 and 8 of Table 6) furnishes a suggestion as to the possible source of the discrepancy between the first two series of averages.

The mean correlations for the period 1911 to 1925 are positive for each of the 31 crop yields considered with the exception of the one crop of sugar beets and the cuttings of alfalfa for 1923 and 1924. This suggests that the yield of alfalfa for 1923 and 1924 may be a primary source of the frequent negative values in the series of averages for the period 1920 to 1925.

Turning back to Table 4, which gives the distribution of the various interannual correlation coefficients with regard to signs for each of the crop yields, it is noted that of the 268 correlation coefficients which are more negative than -0.050 (i. e., those which fall to the left of the class which is considered to represent essentially zero correlation), 101 occur with the crops of alfalfa of 1923 and 1924.

Two new series of averages, therefore, have been determined. The first represents all crop yields from the beginning of the experiment to 1921, or until the time when the area was again put into alfalfa. The second represents the average correlation of the yields of alfalfa in 1923 and 1924 with each of the other crops (excepting 1922, 1923, and 1924 alfalfa) grown during the period 1911 to 1924.

The first of these two series of averages, presented in columns 9 and 10 of Table 6, are positive values except for the sugar-beet yield of 1911 (which has proved anomalous in practically all cases), the alfalfa yields of 1923 and 1924, and the yield of silage corn in 1925, which is sensibly zero.

The second series of averages (columns 11 and 12 of Table 6) shows 19 negative averages as compared with only 5 which are positive.

In the earlier investigation (*7*) emphasis was placed on certain peculiarities of the correlation for alfalfa, particularly those associated with repeated cuttings and with the after effect of the alfalfa crop.

In this connection it is worth while to lay side by side (*a*) the correlations between the yields of alfalfa as given in the first stand (1912–1914) and the yield of subsequent crops up to the times of reseeding to alfalfa (1915–1921) and (*b*) the correlation between the yields of alfalfa grown in the second stand (1922–1924) and the yields of antecedent crops back to the previous stand of alfalfa (1915–1921). Since, as already noted (*7*), it is quite reasonable to assume that in a crop harvested more than once a year thickness of stand and variation in the size of the individual plants will have a large influence on the yields of the different plots in the same year, the averages of the correlations between the different cuttings of the same year as well as of those between single cuttings and total cuttings in the different years of the same stand have been placed beside the above averages. The results for the correlations of alfalfa yields with the yields of subsequent crops are given in Table 7. Those for the correlation of alfalfa with the yields of antecedent crops are set forth in Table 8.

TABLE 7.—*Comparison of the averages of the correlations of alfalfa in the cuttings of 1912–1914 (a) with the yields of subsequent crops of other kinds and (b) with cuttings of alfalfa in the three different years of the same stand*

[Compare Table 8]

Year	Alfalfa crops of first stand	Average correlation with— (a) Other crops in 1915–1921 N	(a) r	(b) Alfalfa yields in 1912–1914 N	(b) r	Difference
1912	One cutting	13	+0.1986	8	+0.3305	+0.1319
1913	First cutting	13	+.2565	6	+.6107	+.3542
1913	Second cutting	13	+.2802	6	+.6038	+.3236
1913	First and second cuttings	13	+.3146	6	+.7202	+.4056
1914	First cutting	13	+.3654	4	+.6660	+.3006
1914	Second cutting	13	+.2971	4	+.6293	+.3322
1914	First and second cuttings	13	+.3559	4	+.6988	+.3439
1914	Third cutting	13	+.3146	4	+.5243	+.2097
1914	First, second, and third cuttings	13	+.3377	4	+.7063	+.3686

TABLE 8.—*Comparison of the averages of the correlations of alfalfa in the cuttings of 1922–1924 (a) with the yields of antecedent crops of other kinds and (b) with cuttings of alfalfa in the three different years of the same stand*

[Compare Table 7]

Year	Alfalfa crops of second stand	Average correlation with— (a) Other crops in 1915–1921 N	(a) r	(b) Alfalfa yields in 1922–1924 N	(b) r	Difference
1922	One cutting	13	+0.2661	6	+0.0810	−0.1851
1923	First cutting	13	−.0421	4	+.3758	+.4179
1923	Third cutting	13	−.1052	4	+.4738	+.5790
1923	First and third cuttings	13	−.0954	4	+.4758	+.5712
1924	Second cutting	13	−.1342	4	+.5820	+.7162
1924	Third cutting	13	−.2031	4	+.2508	+.4539
1924	First, second, and third cuttings	13	−.1853	4	+.5405	+.7258

87884—28——3

Table 7 shows that the averages of the correlations between the various yields for the stand of alfalfa which occupied the land from 1912 to 1914 and the yields of subsequent crops of other kinds for the period 1915 to 1921, inclusive, are without exception positive values which range from +0.20 to +0.37. These averages are much lower than those which are found for the correlations between the yields of alfalfa in the different years of this stand. The magnitudes of the differences between the correlations between the yields of alfalfa and alfalfa and between alfalfa and other crops are clearly shown by the entries in the final column.

Turning to the averages of the correlations between the yields of alfalfa for the stand of 1922 to 1924 and the yields of antecedent crops of a different kind for the period 1915 to 1921, as shown in Table 8, a very different result is noted. These averages are negative with the exception of that for the single cutting of 1922. The averages of the correlations between the various cuttings of alfalfa in the three different years of the period 1922 to 1924 are of material positive value.

The final column shows the difference between the correlations for (*a*) the alfalfa cuttings of the stand and the yields of other crops and for (*b*) the yields of alfalfa.

A comparison of the averages in these two tables shows clearly (1) that the correlations between the yields of alfalfa in the different years are high in the case of both stands, which were separated by a period of seven years, but (2) that the correlations of subsequent crops with the stand of 1912 to 1914 are on an average positive, whereas those for antecedent crops with the stand for 1922 to 1924 are on an average negative.

It is evident that something connected with the stand or rankness of growth of the alfalfa in the latter period has been of primary importance in modifying the characteristics of the plots (as measured in terms of crop yield) as they prevailed during the first 10 years of the experiments.

In connection with the problem of changes in the heterogeneity of the field the realtionships between the various yields of alfalfa in the first and second periods are of particular interest.

The individual constants required can be obtained from data given in Table 3, pages 22 and 23.

The 63 correlation coefficients for the relationship between the two different stands of alfalfa designated in Table 3 are prevailingly negative in sign. Only 13 values are positive, as compared with 50 which are negative. Of these 13 positive values, 9 are found in the correlations between the yield of alfalfa in 1922 and the yields of alfalfa in 1912, 1913, and 1914. Of the 54 correlations between cuttings of 1923 and 1924 and cuttings of 1912, 1913; and 1914, only 4 are positive.

TABLE 9.—*Averages of correlations between cuttings of alfalfa in the first and the second stands*

[Original constants are given in Table 3]

Year	Alfalfa crops	N	Average correlation with alfalfa yields
			1922–1924
1912	One cutting	7	+0.0707
	First cutting	7	−.2342
1913	Second cutting	7	−.2368
	First and second cuttings	7	−.2762
	First cutting	7	−.3020
	Second cutting	7	−.3403
1914	First and second cuttings	7	−.3486
	Third cutting	7	−.1787
	First, second, and third cuttings	7	−.3249
			1912–1914
1922	One cutting	9	+0.1630
	First cutting	9	−.1739
1923	Third cutting	9	−.2839
	First and third cuttings	9	−.2477
	Second cutting	9	−.2978
1924	Third cutting	9	−.4413
	Second and third cuttings	9	−.4071

The average values of these correlations of yields of alfalfa with other yields of alfalfa are set forth in Table 9.

With the exception of the correlations based on the single cutting for 1912 and 1922, these averages are negative throughout.

It is clear, therefore, that plots which showed superiority in alfalfa-yielding capacity in 1913 and 1914 proved on an average inferior in 1923 and 1924.

The final explanation of these results, in the opinion of the writers, must await the analysis of further data of agronomic experimentation. It is proper, however, to suggest possible explanations of observed results, since such tentative interpretations may serve to guide further work.

First of all, it is conceivable that wholly accidental differences of stand in these two periods (1912–1914 and 1922–1924) might be a source of such correlations as those which have been demonstrated. Other explanations, however, seem more probable.

The space and elevation relations of the field have already been discussed. It has been shown that the field is located within a loop of the main canal of a project that carries 400 second-feet of water. The water in this canal is 5 to 6 feet above the level of the field. The land slopes to the north and west. The southeast corner of the field, the high corner, is within 100 feet of the main canal. A shallow open ditch touches the southwest corner of the field, but curves away to the northwest.

There is a layer of sandy subsoil of possibly an acre in extent but of undetermined thickness which underlies these experimental areas. There is now definite evidence of seepage from the main canal through this sandy subsoil. A number of observation wells have been sunk around the field, three near the southeast corner and five along the north border, by which the rise and fall of the underground water may be observed. These observations have been made since the spring of 1923 only. Before that time no information was available as to the fluctuations of water in the subsoil, which is probably a phenomenon of relatively recent occurrence due to erosion in the main canal. There is reason to believe that the underground water has been rising each summer in recent years higher than it did in the earlier years of the experiment. The annual fluctuation of this underground water table is approximately 6 to 9 feet. It reaches its high point in August or September and its low point in April. In recent years the subsoil has been saturated at 1 or 2 feet below the surface in the southeast corner of the field, and it is believed that the root zone has been materially restricted throughout most of the east series (Series II).

The relationship between the yields of different portions of the field may be brought out roughly by computing the relative yields of different areas of the field. Retention of the yields of the individual plots (46 in number) results in such confusing irregularities that it is necessary to reduce the number of the plots in order to eliminate in some measure these individual variations. Since there are 23 plots in each of the two series, grouping into larger plots can be made only by taking fractions of the yields of certain of the plots occupying intermediate positions. Each of the two series has been divided into four larger plots by grouping as follows:

(1) Plots 1 to 5 plus 75 per cent of plot 6.
(2) Plots 7 to 11 plus 25 per cent of plot 6 plus 50 per cent of plot 12.
(3) Plots 13 to 17 plus 50 per cent of plot 12 plus 25 per cent of plot 18.
(4) Plots 18 to 23 plus 75 per cent of plot 18.

This divides the whole field into eight larger plots of uniform size.

After obtaining the total yields for areas of quarters of each of the two sections (eighths of the entire field), the yields have been expressed as percentages of the average yields of the eight plots. Such percentages show at a glance whether the yield of the individual plots is lower (percentages less than 100) or higher (percentages over 100) than those of the field as a whole. The numerical values can best be expressed graphically as in Figures 5 and 6. In these diagrams the four groupings of plots on the two sections of the field are represented by four panels. The relative yields for Series II are represented by solid dots connected by solid lines. The relative yields of Series III are represented by circles connected by broken lines. These yields are distributed above and below the heavy transverse bars representing 100 per cent of the average yields for the areas as a whole. Dots or circles falling below the heavy line, therefore, represent lower yields than those which are normal for the field as a whole for the given crop and year. Circles or dots falling above the line indicate yields which are above the normal for the given crop. Inspection of these diagrams shows at once that the results for sugar beets in the eight larger plots are irregular. This is in accordance with other findings for sugar beets, and the point need not be considered further.

Turning to alfalfa, which has been shown to be of particular interest, it is noted that for the first group of alfalfa yields (1912–1914) the yields per plot are in general higher than the average for the field as a whole in the case of Series II. In the case of the stand for 1922 to 1924 the reverse appears to be true in three of the four comparisons of the results for Series II and III.

This result is a somewhat different expression for the negative correlation between the alfalfa yields of the first and second series as indicated above. It extends these results by indicating that whereas in the earlier crops Series II was better for alfalfa, Series III was better for alfalfa in the later period. The writers feel inclined

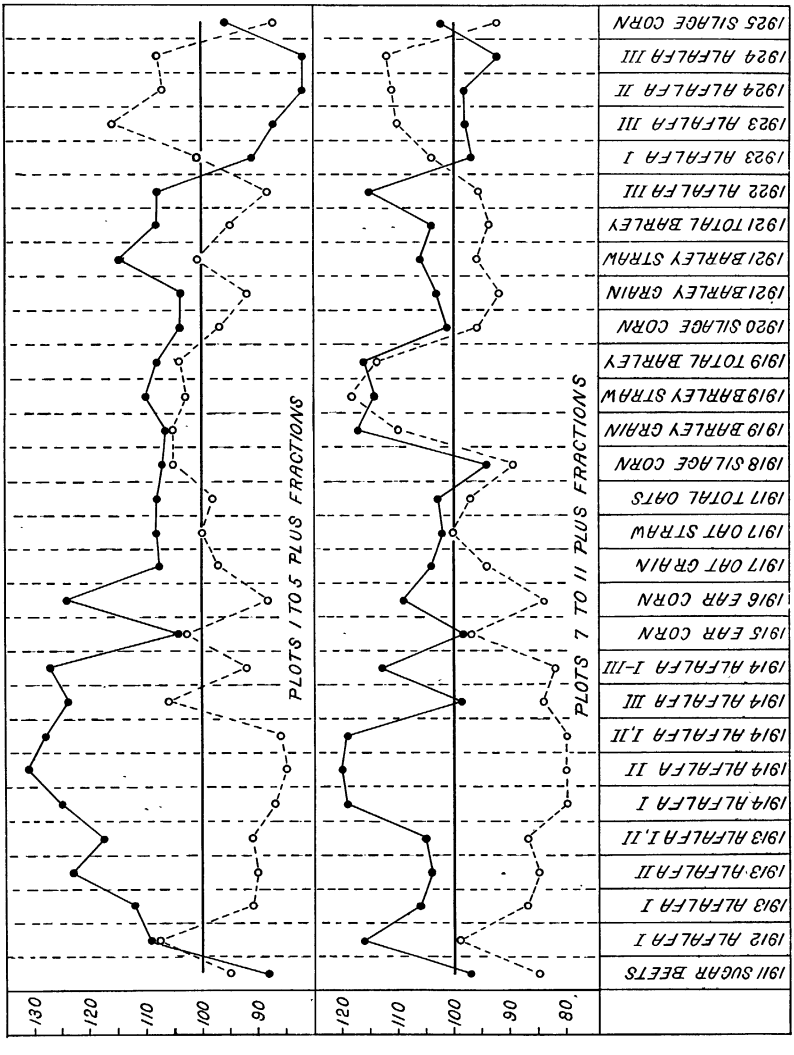

FIG. 5.—Distributions of relative (percentage) yields in 8 larger plots resulting from the combination of the 23 plots of Series II and III of field B into 4 equal plots for each series. Solid dots and firm lines represent the relative yields of the 4 plots of Series II. Circles and broken lines represent the relative yields of the 4 plots of Series III. This figure represents the yields for the north half of the two series. (Compare fig. 6)

to suggest that in the earlier experiments the height of the water table had no harmful effect upon a deep-rooted crop such as alfalfa. It is quite possible that during drier periods the higher water table actually favored alfalfa growth on Series II. The higher water tables of recent years have probably had a deleterious influence, which has been especially marked on Series II, where the water apparently comes nearer to the surface than in Series III.

Turning to relative yields of other crops for the period 1915 to 1921, it is noted that they are clustered irregularly but more closely around the 100 per cent line indicating normal yield. This suggests

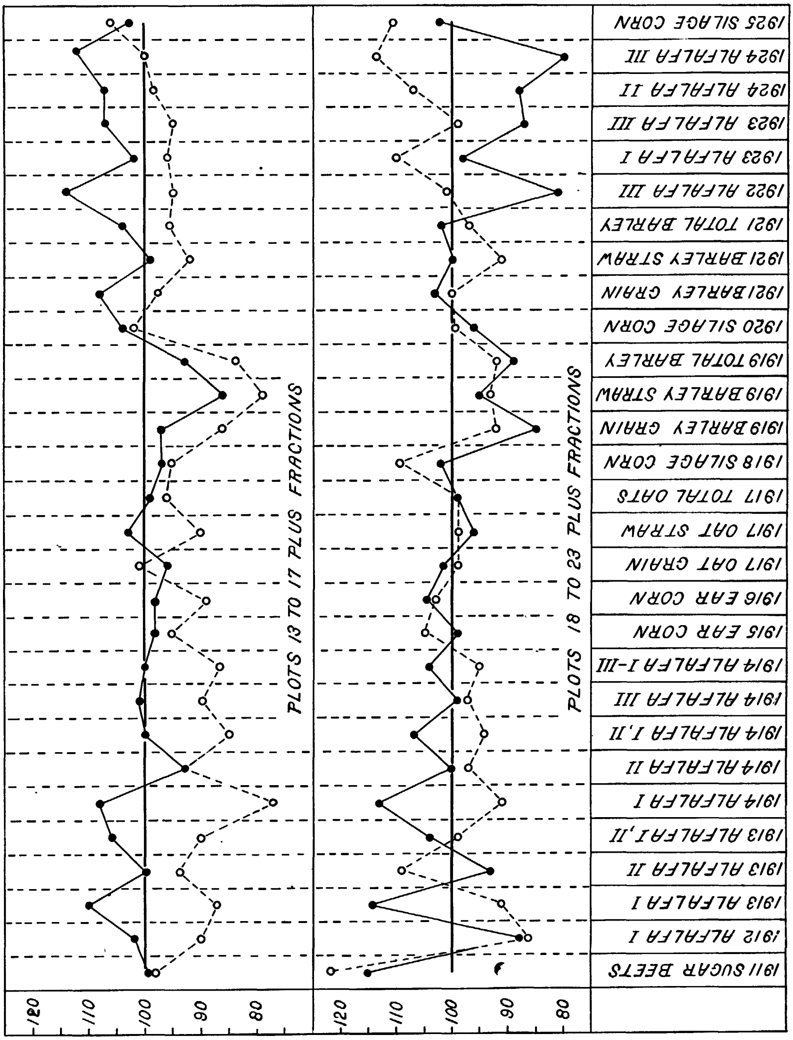

FIG. 6.—Distributions of relative (percentage) yields in 8 larger plots resulting from the combination of the 23 plots of Series II and III of field B into 4 equal plots for each series. Solid dots and firm lines represent the relative yields of the 4 plots of Series II. Circles and broken lines represent the relative yields of the 4 plots of Series III. This figure represents the yields for the south half of the two series. (Compare fig. 5)

that these more shallow-rooted crops have not been influenced in the same way as the deeper rooted alfalfa crops by the seepage water. The first crop of alfalfa in the case of both of the two stands gives results more in accordance with those for the annual crops than do the cuttings for the second and third years. Possibly this may be due to a more superficial root system in the first year.

SUMMARY

This paper gives the results of a biometric analysis of crop yields obtained over a period of 15 years in a uniform cropping experiment conducted by the Office of Western Irrigation Agriculture at Huntley, Mont., during the years 1911 to 1925. The records are considered with particular reference to crops grown during the period 1920 to 1925.

The results show clearly that the problem of the permanence of the heterogeneity of the agricultural experimental field is capable of treatment by the method of interannual correlation.

In general it appears that, even in small experimental tracts, there is a positive correlation between the yields of a series of plots throughout a period of years. In other words, plots which show a heavier yield one year will in general show heavier yields in other years during the period under investigation.

Under some conditions, however, negative correlations may be found—i. e., plots which produce superior yields under the conditions of one year may produce on an average inferior yields another year. In the case of the present experiments it has been suggested that fluctuations in the level of the water table in irrigated land may play a large part in determining the relative crop-yielding capacity of the different plots. A deep-rooted crop, in the present case alfalfa, seems to be more affected by these conditions than the cereals.

The importance of these results for agricultural experimentation is increased rather than diminished by the finding of significant negative as well as positive relationships between the yields of crops in different years. Both positive and negative correlations may indicate the importance of a preceding crop in determining the characteristics of an experimental field. Studies in this field have been made by Hartwell and Damon (*8*, *9*), by Hartwell, Pember, and Merkle (*10*), by Garner, Lunn, and Brown (*1*), and by others. On the other hand, such correlations may indicate changing environmental conditions such as may be induced by variations in the level of the water table in the case of irrigation agriculture. Too great caution can not be exercised by agronomists in the selection of plots for tillage, fertilizer, or variety tests. It is clear from these results that not merely the physical and chemical characteristics of the soil but the nature of the preceding crop and changes in physical conditions from year to year must be taken into account in planning any such experiments.

Finally, it will be at once evident to agriculturists that the methods here employed may be of great value in the investigation of the after effect of the growth on land of a particular crop, or of temporarily changed physical conditions.

LITERATURE CITED

(1) GARNER, W. W., LUNN, W. M., and BROWN, D. E.
1925. EFFECTS OF CROPS ON THE YIELDS OF SUCCEEDING CROPS IN THE ROTATION, WITH SPECIAL REFERENCE TO TOBACCO. Jour. Agr. Research 30: 1095–1132, illus.

(2) HARRIS, J. A.
1915. ON A CRITERION OF SUBSTRATUM HOMOGENEITY (OR HETEROGENEITY) IN FIELD EXPERIMENTS. Amer. Nat. 49: 430–454.

(3) ———
1915. THE VALUE OF INTER-ANNUAL CORRELATIONS. Amer. Nat. 49: 707–712.

(4) ———
1920. PRACTICAL UNIVERSALITY OF FIELD HETEROGENEITY AS A FACTOR INFLUENCING PLOT YIELDS. Jour. Agr. Research 19: 279–314.

(5) ———
1926. THE SERVICE OF STATISTICAL FORMULAE IN THE ANALYSIS OF PLOT YIELDS. Jour. Amer. Soc. Agron. 18: 247–273, illus.

(6) ———
1926. THE RELATIONSHIP BETWEEN THE CONCENTRATION OF THE SOIL SOLUTION AND THE PHYSIOCHEMICAL PROPERTIES OF THE LEAF-TISSUE FLUIDS OF EGYPTIAN AND UPLAND COTTON. Jour. Agr. Research 32: 605–647, illus.

(7) ——— and SCOFIELD, C. S.
1920. PERMANENCE OF DIFFERENCES IN THE PLOTS OF AN EXPERIMENTAL FIELD. Jour. Agr. Research 20: 335–356.

(8) HARTWELL, B. L., and DAMON, S. C.
1916. A TWENTY-YEAR COMPARISON OF DIFFERENT ROTATIONS OF CORN, POTATOES, RYE AND GRASS. R. I. Agr. Expt. Sta. Bul. 167, 38 p.

(9) ——— and DAMON, S. C.
1918. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. I. R. I. Agr. Expt. Sta. Bul. 175, 30 p., illus.

(10) ——— PEMBER, F. R., and MERKLE, G. E.
1919. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. II. R. I. Agr. Expt. Sta. Bul. 176, 47 p., illus.