POTATO IMPROVEMENT BY HILL SELECTION

By

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POTATO IMPROVEMENT BY HILL SELECTION

By

GEORGE STEWART[1]

Potatoes are such an important food and are grown on so many farms in Utah that any method of permanently improving the crop is highly desirable. Commercial producers can of course capitalize any practical method of potato improvement.

This field of experimentation is not new, for many workers have attempted to improve the potato crop by selection. Success, however, has been neither uniform nor always appreciable; many of the experiments were of short duration, and many were not conducted on a sufficiently large scale to be good tests. It is apparent from this meager statement that the possibilities of potato selection are by no means exhausted.

To select individual plants of good appearance and high yield is easy. To get a pedigreed strain that is not only a good yielder itself but that transmits the power of superior yield to its offspring is another question, and one of infinitely greater importance. It is on this problem that the tests here reported have bearing.

REVIEW OF THE LITERATURE

As early as 1895 Wollny[2] reports an experiment wherein he tested whether it were possible to improve potatoes by selecting for high and low specific gravity. There was no effect on yield. He concluded that it was more promising "to improve varieties by developing their individual qualities."

Von Seelhorst[3] found in 1898 and 1899 that he could improve yields by selecting large plants. Some of his seed had been selected from as early as 1892.

Eustace[4] dug 500 hills of potatoes more or less at random. He planted the highest-yielding 125 hills in a test against the

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[1]This experiment was begun in 1911 by Dr. F. S. Harris who continued to supervise it for the next four years. During this time A. E. Bowman, H. W. Stucki, H. J. Maughan, and the author, in the order named, looked after the field work and the calculation of data. Since 1916 the author has been in charge of the experiment except for the school year 1916-17 when he was absent on leave.

[2]Forsch. Geb. Agr. Phys., Vol. 18 (1895), Nos. 3-4, pp. 359-364, (E. S. R., Vol. 7, p. 759).

[3]Jour. Landw., 48 (1900), No. 2, pp. 97-103. (E. S. R., Vol 13, p. 41).

[4]E. S. R. Vol. 16, p. 730.

lowest-yielding 125 hills and found the yields to be 362 bushels and 339 bushels, respectively. He thought continuous selection would make the gain materially greater.

Greene and Manly[1] of the Iowa Station selected those hills which had an average number of well-formed, medium-sized tubers. The best and the poorest hills, tested for only one year, showed a difference of 50 bushels in favor of the high-yielding hills.

Goff[2] of the Wisconsin Station reports a gain of 180 per cent when the yield of the most productive hills was compared with the yield from the least productive.

Dean[3] of New York State reported in 1913 that he had made considerable gain by hill selection. Since 1904 he had selected by weight high-yielding and low-yielding hills. Potatoes planted from the high-yielding hills produced 350 bushels an acre as opposed to 70 bushels from the low-yielding hills. He also reports small tubers unprofitable for seed.

A report[4] from the Crookston Substation in Minnesota shows that seed from selected hills gave an average acre-yield of 184.9 bushels as compared with 134 bushels from cellar-selected seed and 64.7 bushels from field run. In the same experiment the tuber-unit method gave 136.1 bushels.

Waid[5] of the Ohio Station reports a difference of 89 per cent gain for high-yielding plants over low-yielding and 25 per cent over common stock. His total yields, however, were greater at the beginning than were the 3-year averages, owing probably to the influence of season.

East[6] obtained rather high increases the first year after selection but thereafter the yield from his check hills was as high or higher than those from the selected hills. He is therefore doubtful with respect to the value of selection of this sort. He used stock all grown from a single hill two years previously. This does not represent the sort of seed that farmers are growing, since it is likely that there is a great variety of strains in most commercial fields of any considerable size.

Stuart[7] of the Department of Agriculture working at Honeoye, New York, with seed grown at Burlington, Vermont, selected hills and planted each tuber separately. He found that the yield

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[1]Iowa Exp. Sta. Bul. 49.
[2]Wisconsin Exp. Sta. Ann. Rpt. (1899), p. 304-308.
[3]Amer. Agr. 92 (1913), No. 13, pp. 3, 4.
[4]Minnesota Exp. Sta. Ann. Rpt. (1910-1916) Crookston Substation.
[5]Amer. Breeders' Assoc., Vol. 3, pp. 191-198 (1907).
[6]Conn. Exp. Sta. Ann. Rpt. (1909-10), pp. 130-131.
[7]U. S. D. A. Farmers' Bul. No. 535.

from strong plants was from 5 to 15 times that from the weak plants. He did not, however, report check strains, and it is therefore uncertain how much better his high-yielding selections were than unselected stock. His data are from the harvests of 1911 and 1912.

Straight hill selections of the Cobbler variety were made in 1911 near Portsmouth, Virginia. The 1912 crop was promising. The selections varied from 2 to 5 hills of seed. The calculated acre-yields varied from 22.2 barrels of culls with no primes to 115.5 barrels of primes and 36.7 barrels of culls. The selections were lost in the spring of 1913 when a severe frost injured the young plants thereby ruining the stock and causing the experiment to be discontinued. This was unfortunate since it would have been interesting to have found out how the progenies behaved. Stuart concludes that much good may come from hill- and tuber-unit selection, mainly by the elimination of weak or diseased plants.

Zavitz[1] selected seed for twenty-six years to find out whether home-grown seed could be made to maintain its yield. "No hill selection has taken place in any year in connection with this experiment. The fertility of the soil has probably remained about uniform * * * * * *." No deterioration took place. He also reports the selection of 241 tubers from a bulk lot. These were planted separately and one pound from the best hills was used as seed for the next season. The results for the best three strains after four years of selection were 181.4 bushels, 177.3 bushels, 175.9 bushels as against 162.5 bushels for the unselected seed of the variety. Hill selections made for two years in succession and then tested three years in duplicate gave yields of 243.4, 216.3, 190.8, and 136.2 bushels, respectively, as compared with 136.6 bushels for variety tests where no hill selection was used.

PLAN OF THE EXPERIMENT

In 1911 a number of the highest-yielding hills and also of the lowest-yielding hills were selected from the Majestic, Bangor, and Peerless varieties, then being grown at the Utah Station. Each hill was put in a separate paper bag and numbered. In 1912 the tubers from each hill were cut into sets weighing approximately 2 or 3 ounces and containing on the average two eyes. The sets were planted about 15 inches apart with rows three feet apart The row thus planted from the sets of each hill was marked with a numbered peg and regarded as a unit. No

[1] Ontario Department of Agriculture Bul. 239, pp. 14, 36, and 37.

effort was made to keep the sets from each tuber separate from those of other tubers in the same hill.

At harvest time each hill was dug separately and the tubers placed in a paper bag. During the fall and early winter the tubers from each hill were weighed, counted, and returned to their bag for storage until the data for the progeny-rows were calculated. The poorer rows in the good selections were all discarded. About half of the best hills from the best progeny-rows and a few high-yielding hills from the other good rows were chosen for planting the next spring. In the poor selections the lowest-yielding hills were used as seed. The same sort of selection was continued from 1912 to 1919 and is being further continued and supplemented, except that the poor selections were discarded in 1916.

Fig. 1.—Two selected hills. Note the great number of uniform potatoes in each.

Since no commercial fertilizer is used in the region, none was used in this experiment, the fertilizer being applied as farm manure in somewhat lighter applications than farmers generally use for large acreages, and much lighter than is the practice for small home-garden areas or for trucking potatoes. The seed-beds usually contained enough soil moisture to cause a vigorous early growth. Irrigation water was applied as needed to maintain continuous growth thruout the season.

When the potato plants became large enough to permit the rows to show readily, a one-row cultivator was run between the rows to loosen the soil and take out weeds. If any crust had formed on the surface of the ground this was broken up around the plants with a hand hoe. Enough hand weeding was done to keep weeds under control.

As the season advanced and the plants showed need of irrigation, water was applied by the furrow method in such a way that it did not come in contact with the plants. Some time later, when the furrows had dried out enough to bear a horse and cultivator, another cultivation was given. In some seasons this was all the cultivation given, as before the second irrigation the vines were sometimes large enough to spread across the furrows. In seasons that were dry, one or even two more cultivations were given.

Harrowing before and after the plants emerged had to be omitted on account of the pegs which were placed at planting time. Except for this, the cultivation was about the same kind as that given by farmers who grow several acres of commercial potatoes. Usually the farmers give the crop more intertillage and several harrowings. Small half-acre "patches" on the farms and trucking potatoes are usually given considerably more manure and much more cultivation than was the breeding plat.

Harvesting was done about the usual time, that is, when the vines died on account of autumn frosts, or because of maturity when the good weather continued well into October. In two or three seasons on-coming winter forced early harvesting. This was especially notable in 1919 when two more weeks of growing weather would have materially increased the yield. Harvesting was done with forks or shovels in order to keep the hills separate.

In 1917 and 1918 a study was made to find out the actual variety of each of the three kinds of potatoes tested, according to Stuart's[1] classification. The variety called Majestic is a white-skinned, late-maturing, flat-oval variety with deep blue sprouts. It was therefore decided that this is a Rural potato. The other two potatoes had been discarded because of inferior yielding power. As nearly as can be made out, the Bangor was a Triumph and the Peerless a Pearl.

DATA SECURED

Previous to 1911 the yield data for the three varieties chosen varied somewhat. These results are shown in Table 1.

[1]U. S. Dept. Agr. Bul. 176 (1915), 56 pp.

Table I. The Yields of the Three Varieties Used for Selection Average for 3 Years—1908, 1909, and 1910

Variety	Total Yield per Acre				Per cent Marketable
	1908 (bushels)	1909 (bushels)	1910 (bushels)	Average (bushels)	
Early Bangor	333.33	351.66	380.82	355.27	83
Peerless	280.47	304.60	317.91	300.99	85
Majestic			458.32	458.32	85

The year 1911 is shown separately because that was the crop from which the selections were made.

Table II shows the yield data for 1911 and also the weights for separate hills.

Table II. The Acre-yields and Average Weight of Hills in 1911

Variety	No. of Hills	Average Weight to the Hill (grams)	Acre-yield (bushels)
Early Bangor	146	448.4	114.05
Peerless	188	962.5	334.45
Majestic	184	1015.9	343.50

From the hill-yields when compared with acre-yields it is apparent that the distance between hills was not exactly uniform. There is a noticeable difference in the yield for each hill and for the acre when Early Bangor is compared with either of the two varieties. High-yielding and low-yielding hills were selected and kept separate for planting in the spring of 1912.

The good hills were to be designated by the small letter "g" and the poor ones by the small letter "p". The hill selections from each variety were given the annotation "B", "P", or "M" according as they were from Bangor, Peerless, or Majestic varieties, respectively. "Bg", "Pg", and "Mg" then stand for the good hill selections from the respective varieties, and "Bp", "Pp", and "Mp" for the poor hill selections, that is, for the low-yielding hills selected for test.

The number of mother hills planted, the number of daughter hills, the average number of tubers to the hill when harvested in the fall, the average weight to the hill and to the tuber, and the yield to the acre for the progeny-rows of good and poor selections are shown in Table III.

The poor hills when compared with the good ones gave fewer hills, smaller hills having fewer and smaller tubers in each hill,

and considerably smaller yields to the acre. Since no check rows of unselected stock were grown in the breeding plat, the yields cannot be compared in this respect. It was already apparent, however, that yields were spreading rapidly apart due to selecting good and poor hills for seed.

Table III. The Yield Data for the Good and Poor Selections for the Year 1912

Series	No. of Hills Planted	No. of Hills Harvested	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Bg ..	27	494	426.1	4.8	78.6	259.0
Bp ..	18	62	110.4	3.1	33.3	58.0
Pg ..	27	661	674.0	6.3	103.0	426.0
Pp ..	20	236	344.0	4.9	68.6	244.0
Mg ..	29	687	921.7	5.9	155.2	548.0
Mp ..	19	331	422.9	4.5	87.3	249.0

For planting the 1913 crop the best hills were selected from the highest-yielding and most uniform progeny-rows. For the poor selections the poorest hills from the rows planted from low-yielding hills were selected. Numbers were given each hill. The yield data for 1913 are shown in Table IV.

Fig. 2.—Grams to the hill for good and poor selections in 1912.

A wide difference is easily discernible between the yield of the good and the poor selections. It is nearly as noticeable that the potatoes are very small in the progeny of the poor hills. A large number of the hills in progeny rows of Majestic planted from poor hills failed to reproduce at all. This can be seen comparing *Mp 17* with *Mg25*. The weight to the harvested hill of *Mp 17* is only about one-twentieth as great as that of *Mg 25*, but there is even a greater discrepancy in acre-yield, the *Mp 17* strain being only one-fortieth as prolific as *Mg 25*. About half of the hills failed to produce at all, at least in quantities great enough to be found at harvest.

At planting time in 1914, all breeding material of the Bangor and Peerless varieties was discarded. The selections were made entirely from the Majestic variety both for good and poor selections. The data are shown in Table V.

In 1914 the running out of the poor strains is also apparent. Take strains *Mp 17-8* and *Mg 25-1* for example. The yield to the harvested hill is in the ratio of 1:27 whereas the acre-yield is in the ratio of 1:75 showing that about two out of every three hills of *Mp 17-8* failed to produce. Several other strains from the poor selections show a similar deterioration.

The same sort of selection was continued for the 1915 crop save that check rows were introduced. These check rows were

Table IV. The Yield Data for Good and Poor Strains Grown in 1913

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Mg 7.....	457.43	3.75	116.76	236.40
Mg 22.....	365.90	3.53	100.74	205.00
Mg 25.....	820.46	5.01	160.08	634.80
Mp 17.....	40.98	1.86	21.22	15.87
Bg 9.....	696.93	5.86	118.64	406.00
Bg 19.....	612.78	3.82	159.40	358.80
Bp 1.....	76.00	3.00	25.33	7.00
Bp 2.....	35.00	1.50	21.75	6.00
Bp 8.....	48.50	2.00	25.16	10.50
Bp 13.....	55.00	2.00	27.50	12.00
Bp 17.....	243.00	2.00	121.50	77.00
Pg 8.....	362.00	3.12	110.30	188.70
Pp 4.....	237.56	3.25	76.05	100.37
Pp 8.....	145.00	2.50	58.59	74.50
Pp 12.....	92.30	3.47	26.59	40.50
Pp 15.....	151.00	2.00	75.50	35.00
Pp 19.....	43.71	2.17	17.19	14.50

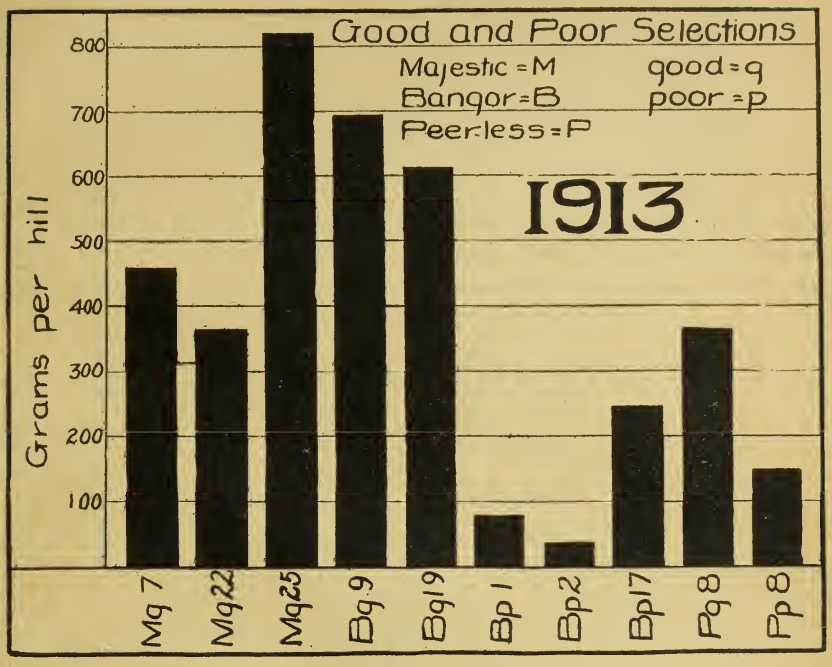

Fig. 3.—Grams to the hill of good and poor selections in 1913.

planted from unselected potatoes that had been grown at the Station since 1911. They were of the stock out of which the 1911 hill selections were made. They were not, however, grown in the breeding plat until this year and could not therefore be used as a check on the yields of the selected strains. Since the plat was short, the check rows were run through the entire length as whole rows instead of being planted here and there thruout the plat, as they were in later years. Counts were also made of those hills that could readily be said to be diseased. Data are shown in Table VI.

For the first time check rows make possible a direct comparison between the selected and unselected strains. It was apparent that good and poor selections were spreading apart, but it was not known whether the selection of good hills had increased the yield. In the 1915 crop, when this was possible for the first time, the average for the four selected strains was 993.86 grams to the hill as against 643.02 grams for the unselected. The acre-yields were in the same proportion, 301.03 bushels and 179.30 bushels, respectively, for the selected and unselected strains. All the selected strains bear the number

Mg 25-1, showing that these are all the progeny of one hill, number 25 in the 1911 selection of good hills of Majestic variety.

When seed for the 1916 crop was selected all the good selections, save that which bore the pedigree number of *Mg 25-1-9*, were discarded. The results of the harvest are shown in Table VII.

Here again the selected strains yield more to the hill and to the acre. There is a greater difference in the acre-yield than in

Table V. The Yield Data for the Good and Poor Strains of the Majestic Variety Grown in 1914

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Mg 25-1..	727.04	7.82	92.41	225.39
Mg 25-4..	603.57	8.80	63.01	215.37
Mp 17-2..	39.75	3.00	13.19	8.44
Mp 17-4..	141.77	4.00	33.59	37.31
Mp 17-5..	173.00	4.00	43.25	48.57
Mp 17-6..	56.00	2.00	28.00	4.15
Mp 17-7..	16.00	1.00	16.00	1.74
Mp 17-8..	28.00	1.00	28.00	2.99

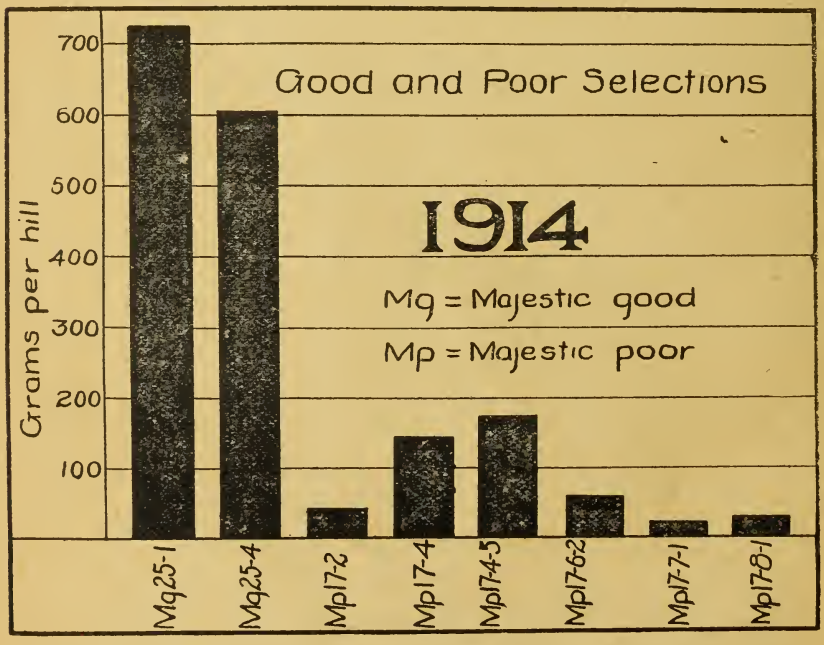

Fig. 4.—Grams to the hill for good and poor selections in 1914.

the average weight of the hills, showing an appreciably greater loss of hills in the unselected stock.

The poor selections were merely saved. The most degener-

Table VI. Yield Data and Number of Diseased Hills of Good and Poor Strains in the 1915 Crop

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)	No. of Hills	
					Good	Diseased
Mg 25-1-4..	974.41	5.86	169.41	303.04	30	2
Mg 25-1-9..	1050.91	5.84	182.11	316.72	38	1
Mg 25-1-13	993.98	5.42	183.64	298.97	42	1
Mg 25-1-14	956.13	4.64	205.92	285.40	33	0
Average of Good Selections	993.86	5.44	185.27	301.03	35.7	1
Unselected Avg. 3 Rows	643.02	4.48	143.56	179.30	44	10
Mp 17-2-1..	523.50	3.25	161.08	173.13	4	1
Mp 17-2-2..	673.00	2.00	336.50	89.02	1	0
Mp 17-4-2..	456.50	6.50	70.53	103.85	1	1
Mp 17-4-3..	371.75	5.00	74.35	73.95	2	4

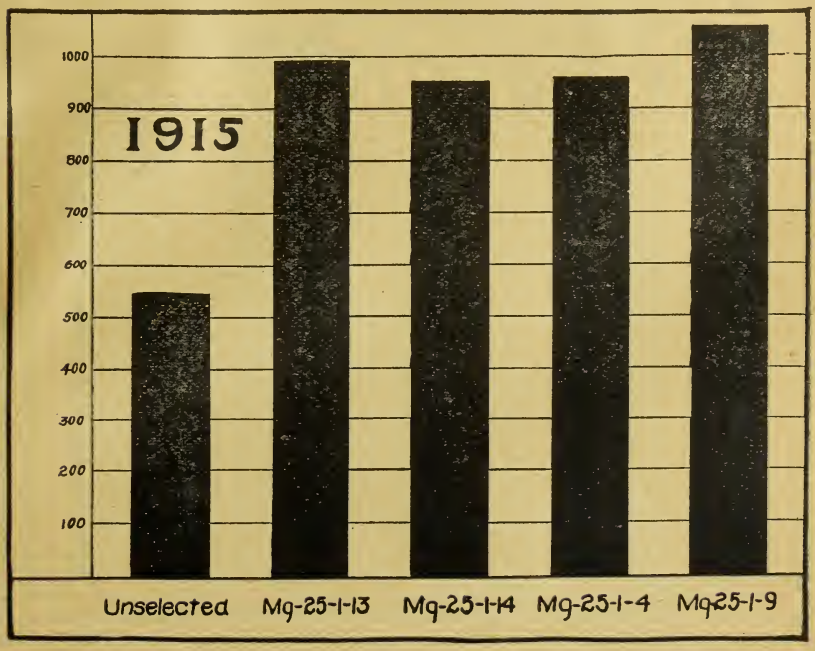

Fig. 5.—Grams to the hill for unselected stock and for good selections of pedigree-strain in 1915.

ate or the most diseased, whichever the case may have been, had either failed to reproduce or had been discarded. Only a few of the best hills of this strain were planted in 1916. It is not therefore alarming to find these giving a high yield. Thruout, the data for the poor selections are not really comparable because of the fact that no account was made of the hills which died or failed to reproduce.

Table VII. The Yield Data for the Good and Poor Selections and for the Unselected Strain of the 1916 Crop

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Mg 25-1-9-2....	650.9	3.64	178.3	236.8
Mg 25-1-9-12..	708.5	3.98	178.6	269.1
Mg 25-1-9-15..	773.0	4.27	181.5	291.4
Mg 25-1-9-20..	839.4	4.58	184.2	330.7
Average.....	742.9	4.12	180.4	282.0
Unselected	583.7	3.84	152.8	191.2
Mp 17-2-2-1....	672.7	6.00	112.1	282.5
Mp 17-4-3-2....	388.7	5.73	70.6	136.0

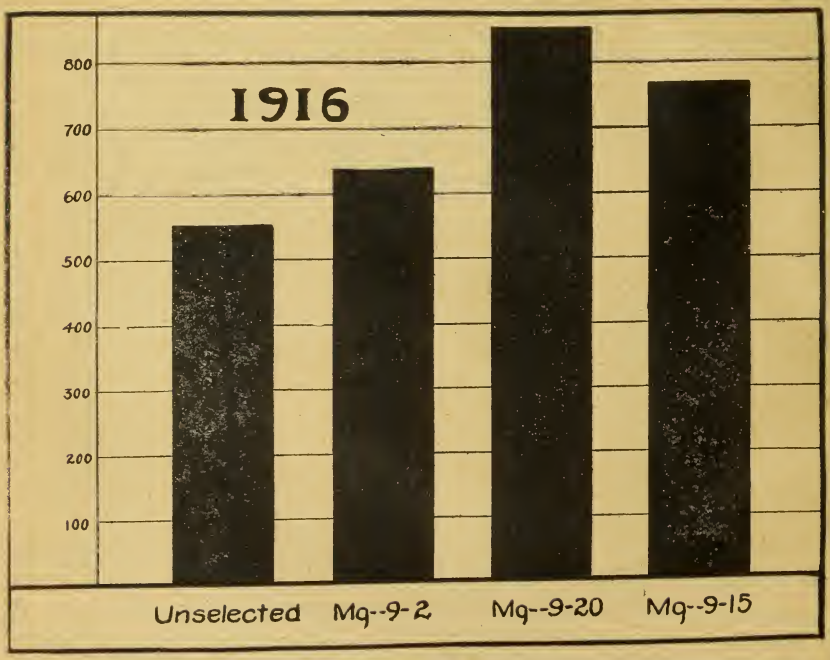

Fig. 6.—Grams to the hill for unselected stock and for the good selections of the pedigree strain in 1916.

The 1917 crop was planted entirely from hills selected from the stock bearing the pedigree number *Mg 25-1-9-20*. All other strains, good and poor as well, were discarded. Two sections of the selected strain, arising from hills 3 and 5, respectively, were retained. After the best hills were selected out, the remnant ones were thrown together and formed a strain known as "mixed." The other good strains, aside from the *Mg 25-1-9-20-3* and *Mg 25-1-9-20-5*, were thrown together and labelled "general." There were one or two mediocre strains thrown in. The breed-

Table VIII. The Yield Data for the 1917 Crop of Pedigree, General, Mixed, and Unselected Strains

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Mg 25-1-9-20-3	810.66	5.22	153.39	382.4
Mg 25-1-9-20-5	690.27	5.38	133.27	311.9
General	762.26	5.28	151.76	259.7
Mixed	747.96	5.59	134.07	295.3
Unselected	678.39	4.50	151.63	269.3

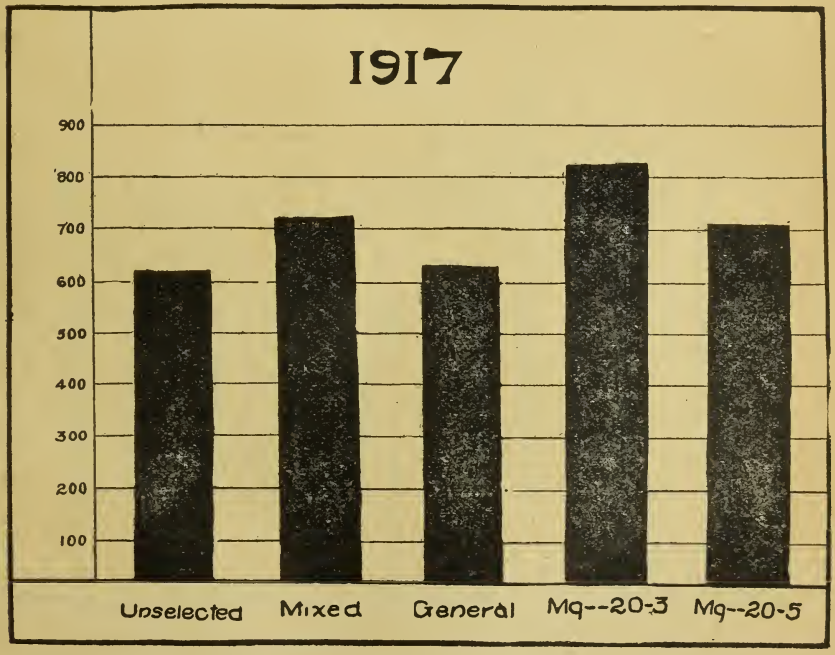

Fig. 7.—Grams to the hill for unselected, mixed, and general stocks and for good selections of pedigree strains in 1917.

Table IX. The Yield Data of the 1918 Crop for Yield and Foliage Selections and for Mixed, General, and Unselected Strains

Series	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (bushels)
Mg 25-1-9-20..				
3-6	614.72	4.28	149.23	204.5
3-12	815.88	4.88	167.11	296.3
3-13	722.06	3.95	183.28	257.3
3-15	771.57	4.10	187.43	311.9
3-16*	450.68	3.55	125.46	152.2
3-17*	359.95	3.24	105.37	334.7
3.19*	614.05	3.97	152.97	295.0
3-22*	382.81	2.98	130.20	111.0
3-24*	677.13	5.58	122.88	254.3
5-7	614.18	4.37	149.45	226.3
5-13*	231.38	2.92	79.24	98.1
5-16	612.98	4.89	125.10	314.2
Mixed	712.74	3.99	177.48	151.4
General	661.86	4.87	135.79	172.3
Unselected	580.11	4.49	127.87	202.4

*Selected for foliage characters.

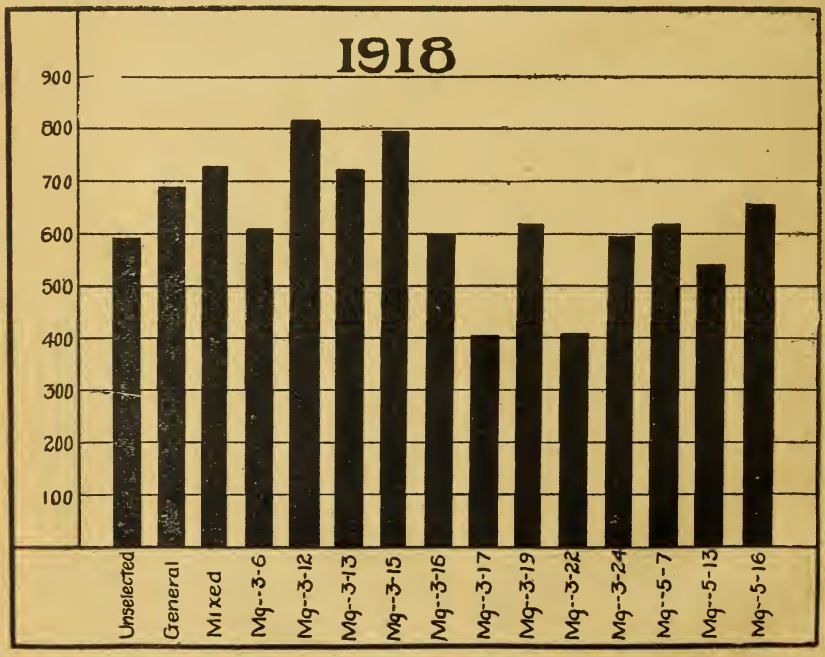

Fig. 8.—Grams to the hill for unselected, mixed, and general stock and for selections for high yield and for foliage characters. Strains 3-16, 3-17, 3-19, 3-22, 3-24, and 5-13 were selected for foliage—the others for yield.

ing plat in 1917 consisted of five strains, two of them pedigree, two of them remnant material from two or more pedigree stocks, and one entirely unselected. The yield data for this crop is shown in Table VIII.

For some reason that could not be discovered at harvest time there was a considerably poorer stand in the "general" strain than in the others. Comparing the general and unselected strains it can be seen that the general had larger hills but a smaller yield to the acre, explained by the poorer stand. This point was never satisfactorily cleared up—that is, no explanation of the irregularity could be found.

The 1918 breeding plat was increased in size by increasing the number of yield selections and also by making selections for foliage variations that became visible. The vines of the selected races as a whole are semi-erect with medium coarse stems and leaves of a uniformly dark-green color. One progeny row had large, coarse stalks and one dwarf but leafy vines; three others showed a marked tendency to chlorosis in the leaves. Selections were made from all of these in the fall of 1917 and planted with the 1918 crop. The yield data are given in Table IX.

In 1918 the data are a little questionable on account of ir-

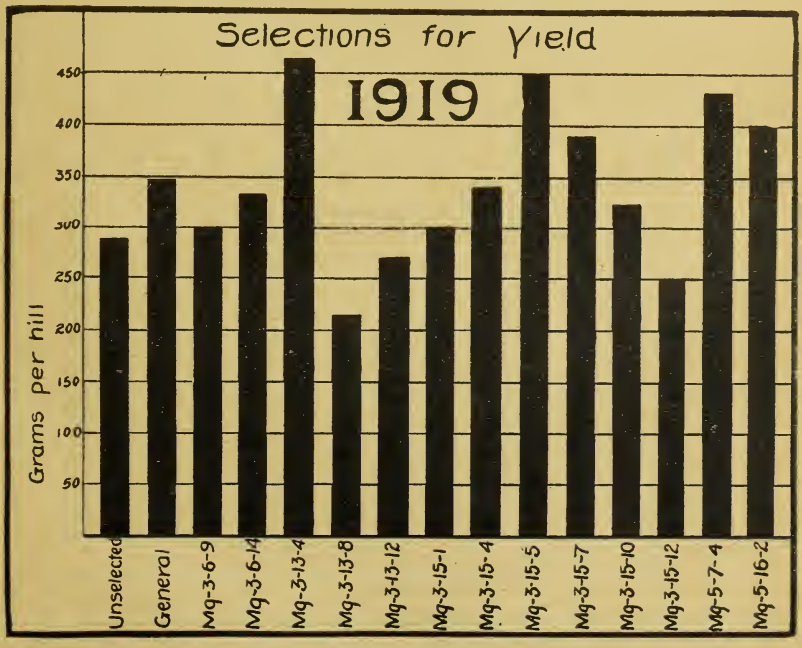

Fig. 9.—Grams to the hill of all strains grown in 1919. The yield selections and foliage selections are shown separately in Figs. 10 and 11.

Table X. The Yield Data of the 1919 Crop for Yield and Foliage Selections and for Mixed, General, and Unselected Strains

Series Mg 25-1-9-20-	Average Weight to the Hill (grams)	Average No. of Tubers to the Hill	Average Weight to the Tuber (grams)	Acre-yield (busnels)
3- 6- 9	322.78	2.96	109.75	92.4
3- 6-14	278.66	3.13	87.95	97.0
3-12- 1*	224.50	2.78	81.49	78.0
3-13- 4	373.12	3.50	106.60	192.5
3-13- 8	284.09	2.93	97.59	115.6
3-13-12	277.30	2.71	100.92	82.7
3-15- 1	341.63	3.04	112.39	143.4
3-15- 4	355.08	3.48	103.96	154.1
3-15- 5	480.50	4.14	114.65	206.2
3-15- 7	389.50	3.94	98.71	175.6
3-15-10	328.73	3.34	98.95	95.1
3-15-12	273.84	2.55	105.63	107.0
3-16- 2*	262.37	3.19	82.09	100.0
3-17- 1*	165.50	1.73	94.81	54.3
3-19- 3*	220.11	2.56	83.92	96.0
3-22- 2*	90.65	1.78	50.78	27.7
3-24- 1*	164.76	2.42	67.19	63.6
5- 7- 4	439.67	3.01	146.33	139.8
5-16- 2	397.23	2.91	137.30	121.3
Mixed	262.4	3.02	82.57	104.2
General	305.4	3.14	96.71	129.0
Unselected	270.2	3.26	82.83	117.3

*Selected for foliage characters.

regularity of treatment. The irrigating was poorly done,—to such a degree that the yield of hills at the top of the rows was fully three times what it was at the bottom of the same row. Irregularities of such magnitude of course upset the value of data. Averages balance these up in a small degree, but some pedigrees were borne on more heavily than others. For example, it happened that the general and mixed strains were largely at the bottom, whereas series 3-17 and 3-19 were near the top. Luckily the unselected strain was well scattered thruout, as were most of the other series.

In the crop of 1919 the size of the plat was again considerably increased in order to check out the irregularities of the 1918 crop. The data are shown in Table X.

The season of 1919 was by all odds the most unfavorable for potatoes since the experiment was begun. All things considered, it was extremely disastrous to potatoes thruout the Mountain Region. The breeding plat suffered in about the same proportion as commercial fields. This was reflected in small

yields to the hill and also in a poor stand, particularly in strain 3-15-10, which yielded only 95.1 bushels altho the hills were good. In many cases the plants started satisfactorily, but mortality was unusually high during the first four weeks after the plants emerged, but not more so than in the farm fields of the vicinity. Moreover, there was no regularity in the loss of stand. The trouble seemed to come in spots. One strain that lost heavily in one part of the plat lost moderately in another. The different series were probably affected in somewhat the same way as the unselected strain. It seems probable therefore that the data are comparable at least in a general way.

An interesting and instructive fact is brought out when the yield selections and the foliage selections are compared with the unselected strain. Several of the yield selections fall below the unselected in acre-yield usually on account of poor stand, but as a whole the races selected for high yield stand well above the unselected, whereas the yield of every one of the strains selected for foliage characters is below that of the unselected. This is

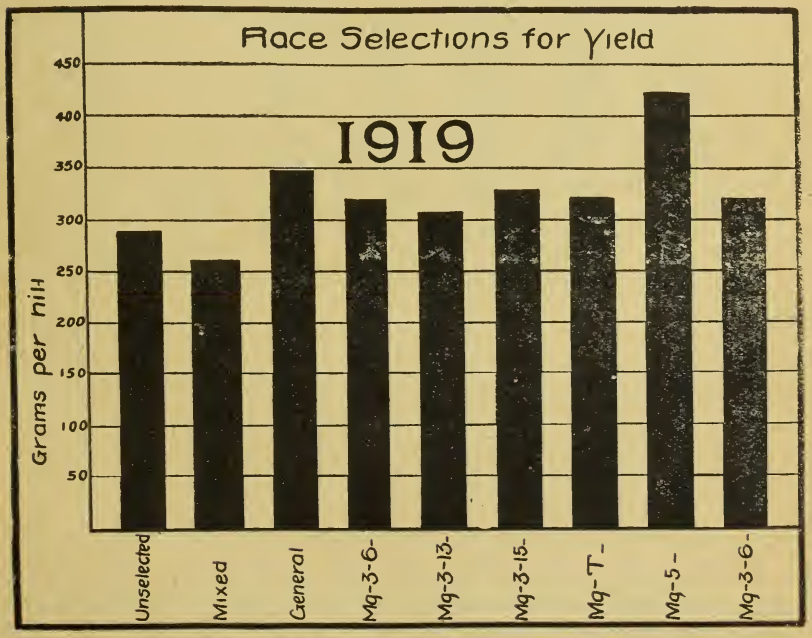

Fig. 10.—Grams to the hill of race selections for yield. Unselected, mixed, and general stocks are also shown. All except the "mixed" strain are superior to unselected.

accentuated when it is borne in mind that the best-yielding hills of each of the foliage strains were chosen for seed.

Sometimes valuable information may be made to show when the biometrical constants are known. Accordingly, a study was made of the *Mg* strains from 1912 to 1919, inclusive. Unselected, general, and mixed strains are added as check comparisons. The weight to the hill in grams was the character studied. In Table XI the constants for standard deviation ($_0$—), mean weight of the hills (M), and the coefficient of variation (C) are reported together with the probable error of the mean (M). In 1918 and 1919 selections for foliage characters were made. These strains are marked with an asterisk (*).

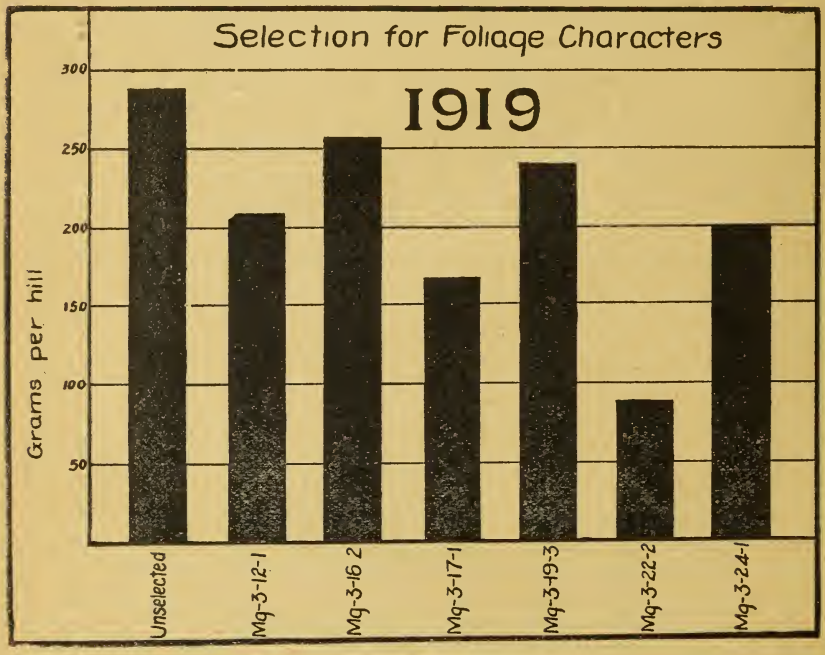

Fig. 11.—Grams to the hill for unselected stock and for foliage selections in 1919. Note that all are poorer than the unselected stock. Selection for foliage does not give good yields.

ANALYSIS OF DATA

In Table XII are given the summary data for the pedigree selection *Mg 25-1-9-20-3-15* and for the unselected stock for the years in which it was grown as a check, 1915 to 1920, inclusive.

The pedigree-selected strain produced somewhat more than a hundred bushels higher yield than did the unselected strain,

Table XI. The Biometrical Constants of Weight to the Hill in Grams for the Mg, Unselected, General, and Mixed Strains from 1912 to 1919, inclusive

Year	Series	Standard Deviation (grams)	Mean Weight (grams)	Probable Error of the Mean (grams)	Coefficient of Variation
1912	Mg	560.4	916.86	12.81	61.1
1913	Mg 22	300.51	576.31	46.49	52.1
	Mg 25	455.00	870.83	23.66	52.2
1914	Mg 25-1	422.00	727.58	7.96	58.0
	Mg 25-4	360.90	541.06	10.30	66.7
1915	Mg 25-1-4	363.90	960.94	10.07	37.9
	Mg 25-1-9	351.40	1058.33	8.90	33.2
	Mg 25-1-14	379.70	951.22	20.00	39.9
	Mg 25-1-13	337.60	992.47	18.91	34.0
	Unselected	404.50	549.69	24.02	73.5
1916	Mg 25-1-9-2	278.70	639.34	10.09	43.6
	Mg 25-1-9-15	264.60	771.22	10.12	34.3
	Mg 25-1-9-20	336.20	855.42	13.21	39.3
	Unselected	382.08	553.21	16.33	69.1
1917	Mg 25-1-9-20-3	492.20	827.35	12.61	59.5
	Mg 25-1-9-20-5	367.08	711.92	9.97	51.6
	Mixed	561.10	721.97	10.34	77.8
	General	290.90	651.12	20.81	44.6
	Unselected	299.2	621.12	13.77	48.1
1918	Mg 25-1-9-20-3-6	375.4	616.12	11.43	60.8
	Mg 25-1-9-20-3-12*	356.0	820.53	59.98	43.3
	Mg 25-1-9-20-3-13	545.3	722.61	18.70	75.5
	Mg 25-1-9-20-3-15	577.0	791.68	19.39	72.9
	Mg 25-1-9-20-3-16*	312.1	598.64	24.48	52.3
	Mg 25-1-9-20-3-17*	273.2	405.55	43.46	67.4
	Mg 25-1-9-20-3-19*	349.6	621.07	21.44	56.3
	Mg 25-1-9-20-3-22*	185.4	410.00	29.97	45.2
	Mg 25-1-9-20-3-24*	249.2	597.83	24.79	41.7
	Mg 25-1-9-20-5- 7	404.7	621.15	26.76	65.2
	Mg 25-1-9-20-5-13*	183.1	540.91	18.63	33.8
	Mg 25-1-9-20-5-16	455.8	658.06	39.06	69.2
	Mixed	524.2	726.70	24.35	72.1
	General	387.4	686.02	15.84	56.5
	Unselected	358.6	591.10	15.75	60.7
1919	Mg 25-1-9-20-3- 6	196.66	319.13	14.74	61.6
	Mg 25-1-9-20-3-12*	135.33	208.97	14.63	64.8
	Mg 25-1-9-20-3-13	244.36	307.79	13.28	79.4
	Mg 25-1-9-20-3-15	221.68	328.04	6.47	67.5
	Mg 25-1-9-20-3-16*	124.50	242.59	11.18	51.3
	Mg 25-1-9-20-3-17*	24.69	180.00	5.01	13.7
	Mg 25-1-9-20-3-19*	155.84	243.33	17.75	64.0
	Mg 25-1-9-20-3-22*	20.05	103.84	2.82	19.3
	Mg 25-1-9-20-3-24*	24.80	150.00	3.57	16.5
	Mg 25-1-9-20-5	198.37	411.64	32.06	48.2
	Mixed	180.08	261.10	11.18	68.0
	General	173.57	347.70	12.14	49.9
	Unselected	177.83	288.77	9.90	61.5

*Selections for foliage characters.

except in the year 1919 when the yield was only 29.6 bushels greater. The yield to the hill was about in the same proportion as the acre-yield, except in the year 1919 when the pedigree strain yielded 358.20 grams to the hill as compared with 270.20 grams for the unselected. With the unselected yield at 117 bushels, the pedigree stock should have yielded 156 bushels, but it made only 147 bushels, due to low yield of the pedigree strain *3-15-10* on which the stand was poor. Attention has already been called to the fact that 1919 was highly unfavorable for potatoes.

Table XII. *Summary Data for the Pedigree Selection Mg 25-1-9-20-3-15 and for the Unselected Stock, 1915-1920, inclusive*

Year	Pedigree Selection Mg 25-1-9-20-3-15		Unselected Stock		Gain over Unselected (bushels)
	Weight to the Hill (grams)	Acre-yield (bushels)	Weight to the Hill (grams)	Acre-yield (bushels)	
1915 ..	1050.91	316.7	643.02	179.3	137.4
1916 ..	839.40	330.7	583.70	191.2	139.5
1917 ..	810.66	382.4	698.39	269.3	113.1
1918 ..	771.57	311.9	580.11	202.4	109.5
1919 ..	358.20	146.9	270.20	117.3	29.6
1920[1]..	962.12	353.4	517.60	184.8	168.6
Avg. ..	789.61	307.0	548.83	190.7	116.3

Table XIII. Summary Data for Pedigree Strain Mg 25-1-9-20-3-15 and for the Unselected Stock with Respect to Number of Tubers to the Hill and the Average Size of Tuber, 1915-1919, inclusive

Year	Pedigree Selection Mg 25-1-9-20-3-15		Unselected Stock	
	Average No. Tubers to the Hill	Average Weight to the Tuber (grams)	Average No. Tubers to the Hill	Average Weight to the Tuber (grams)
1915 ..	5.84	182.11	4.48	143.56
1916 ..	4.58	184.20	3.84	152.80
1917	5.22	153.39	4.50	151.63
1918 ..	4.10	187.43	4.49	127.87
1919 ..	3.83	112.38	3.26	82.83
Avg. ..	4.89	163.90	4.14	131.74

[1]At the time of publication only the yields for the 1920 harvest had been obtained. The other data required 3 or 4 months for tabulation and calculation.

The number of tubers to the hill is greater and the average size of tubers is larger in the pedigree strain than in the unselected. Table XIII, which contains a summary of these data, shows that there is an appreciable difference in these two respects.

There is an increase in the average number of tubers to the hill from 4.14 to 4.89 in favor of the pedigree strain, or 18.1 per cent. In average size of tuber there is an increase from 131.74 grams for the unselected to 161.90 grams for the pedigree strain,—a gain in size of 24.4 per cent. Both of these increases are desirable.

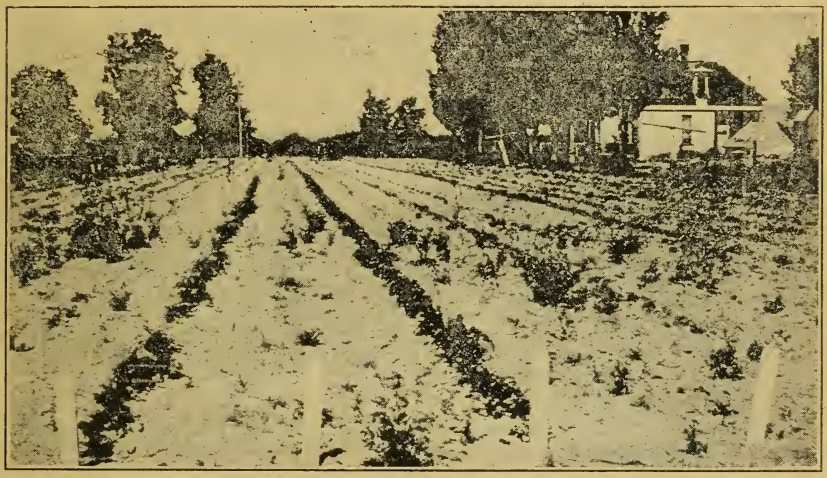

Fig. 12.—A row of unselected stock between two rows of pedigree stock. Note how much sooner the pedigreed stock began to grow. It kept this lead thruout the season.

As a six-year average, from 1915 to 1920, inclusive, there is a gain in acre-yield of 60.9 per cent, and a further gain of 24.4 per cent in average size of tuber. Altho the percentage of marketable tubers was not recorded thruout the experiment, it seems safe to conclude that an increase of 24.4 per cent in size of tuber means an appreciable gain in percentage of marketable tubers. The last two years, the only ones in which the percentage of the marketable tubers was obtained, show 78.6 per cent marketable for unselected stock and 90.5 per cent for the pedigree-selected strain, a gain of 11.9 per cent for the selected strain.

DISCUSSION OF RESULTS

Merely to select high-yielding hills has not been effective in this experiment, because many such hills have produced progeny rows of only mediocre quality. Early in the experiment it was found necessary to test the power of selected hills to transmit their quality to the next generation. A good hill may have become such not because of any inherent virtue in itself but because of having had more favorable surroundings, such as more fertile soil, more moisture, or more room in which to grow.

J. Arthur Harris[1] of the Carnegie Institution has marshalled many data that show even the most uniform soils to be highly variable. F. S. Harris[2] of the Utah Station demonstrated that both too little and too much moisture in the soil produced lower yields of potatoes than the more favorable medium degree of wetness. Stewart[3] found that missed hills gave an appreciable advantage to both adjacent hills. In this experiment with hills planted 15 inches apart, one missed hill increased the yield of each neighbor 23.2 per cent, of 46.4 per cent for the two. From the above, it is apparent that one potato hill may far outyield a neighboring hill owing to some environmental advantage. Because selection of such a hill is made on purely *somatic* characters, that is, body characters that are visible, it is not possible to predict the extent of transmission of the selected quality to its offspring.

On the other hand, when the selection can be so made as to select for an inherent quality, that is, for a *gametic* character, then a fair degree of transmission may be expected. So far as the nature of material permitted, this was this type of selection that has been followed during the experiment here reported. To accomplish this, it was necessary to delay selection until the second year, or even until later years, in order to tell whether a given potato mother-hill had the power to transmit its yielding power to the daughter-hills and thereby leave its imprint on the race. Such plant-breeding is not far removed from the problem a cattle breeder is attempting to solve when he chooses a sire for his herd.

In the beginning, when the three varieties were being tested, Bangor and Peerless were not discarded at once but were carried three years in order to make sure that the Majestic had not

[1]Jour. Agr. Rsch., Vol. 19, No. 7, pp. 279-314.
[2]Utah Exp. Sta. Bul. No. 156.
[3]New York (Geneva) Exp. Sta. Bul. No. 459, pp. 45-69.

produced a higher yield merely on account of some environmental advantage. The 1913 crop showed a considerably higher yield for hill *Mg-25* than for any other progeny. It was only after this test that the other strains were discarded. In fact, had not transmission tests been used this hill would have been

Fig. 13.—The breeding plat in 1920. The foliage selections are on the row on which the kodak case is standing. To the left of it are three rows of pedigree selections; on the right of it, a row of unselected stock; on the extreme right are several rows of pedigree stock.

discarded two seasons previously, because in 1911 it was surpassed in yield by 24 other hills out of a total of 29. The history of this hill illustrates both sides of transmission: (1) a hill ranking only twenty-fifth in 1911 gave progeny in 1912 that was better than any other; (2) in 1913 it was again tested against two others of the best progenies and again produced the highest yield. It was therefore concluded that here was a strain that carried at least some inherent high-yielding qualities. When the 1915 harvest permitted, for the first time, a comparison with the unselected bulk strain of the same stock the yield was 301 bushels as compared with 179 for the unselected.

The 1919 harvest may have given cause to question the superiority of the selected strain, for after showing an increased yield of about a hundred bushels for four years, the selected progeny suddenly relapsed to a yield of only 29.6 bushels greater than that of the unselected strain, but this was a gain of 25.2

per cent. During 1920, there was a decidedly better stand, an earlier start, a thriftier growth, and greater freedom from disease in the selected stock. In every way the pedigreed strain promised to be much better. The gross acre-yield was 353.4 bushels as compared with 184.8 bushels for the unselected stock, overturning completely the 1919 result and bearing out the results of former years, namely, that the pedigreed strain was greatly superior to the unselected stock of the same variety when grown under the same conditions.

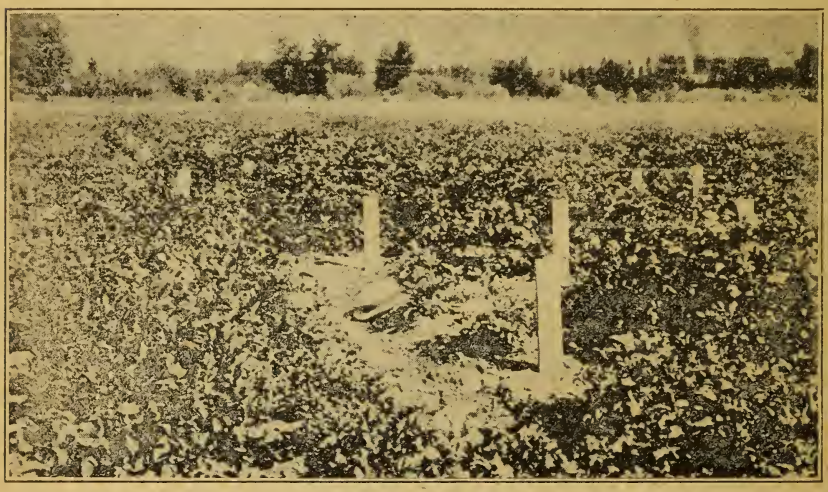

Fig. 14.—The short row with the hat on it is a foliage selection—plants dwarf with the leaves about half yellow. No disease was identified.

The poor yields obtained from the "mixed" and "general" stocks show that remnants of even selected stock are not good for seed after the best hills or the best strains are taken out.

In the degenerate strains that formed part of the experiment until 1916 there was much disease, particularly Rhizoctonia. It is probable that there were present also the diseases of degeneration, such as curly dwarf, leaf-roll, spindling sprout, and mosaic studied by Stewart[1] in New York and reported by Whipple[2] in Montana. Degeneration, however, does not seem to be always due to disease, at least to any now recognized, for among the foliage selections is a strain (Mg 25-1-9-20-3-19-) selected in 1917 for chlorosis to the extent of more than half

[1]New York (Geneva) Exp. Sta. Bul. No. 422, pp. 319-357.
[2]Montana Exp. Sta. Bul. No. 130, pp. 3-29.

the leaf-area. Another strain showed about one-fifth of the leaf-area to be chlorotic. These two strains have continued to breed true, the plants bearing leaves that are chlorotic to about the extent of one-half and one-fifth the leaf-areas, respectively. Other chlorotic selections failed to breed true. During 1920 M. Shapavolov, potato pathologist for the U. S. Department of Agriculture, kindly examined these strains for disease. He could not recognize any disease. Either there must be degeneration without disease, or some disease not yet segregated from the others. Possibly there may be a chlorotic condition other than mosaic, or hiding mosaic, that should take rank with curly dwarf and mosaic.

SUMMARY

In 1911 high-yielding and low-yielding hills were selected from three potato varieties—Bangor, Peerless, and Majestic. These hills were planted in individual progeny rows and so harvested as to keep each hill separate. Similar selection was continued until 1914 when Bangor and Peerless stocks were discarded on account of inferiority in yield of both these varieties to Majestic. Good and poor selections were made from this variety until 1916, but thereafter until the present the only selections made were for high yield, with the exception of a few strains that developed unusual foliage characters.

The experiment was so conducted as to avoid selection for somatic characters and to secure selection for gametic qualities. This was done by growing all of the best strains for two or more years in order to get a progeny test of the power of a strain to transmit its desirable qualities to the succeeding generations. In no important cases were selections made on the results of one season; usually three to five years were regarded as necessary to show whether a strain should be selected or discarded.

By 1915 the high-yielding strains yielded an average of 301.03 bushels to the acre as compared with 179.30 bushels to the acre for unselected. From 1915 to 1920 the selected strain has outyielded the unselected stock of the same variety by more than a hundred bushels an acre, except in 1919 when there was a difference of only 29.6 bushels. Possibly the extremely unfavorable growing season of 1919 may have caused this wide fluctuation. At any rate, the superiority of the selected strains manifested itself again in 1920, outyielding the unselected strain by 168.6 bushels.

Not only were the acre-yields of selected strains higher than those of unselected stock but there were more tubers to the

hill; the individual tubers were larger; and, as a consequence, there was a higher percentage of marketable potatoes than in the unselected stock.

As a six-year average, 1915-1920, the acre-yield of the selected strain was 60.9 per cent greater than that of the unselected and the average size of tuber 24.4 per cent greater than that of the unselected. Remnant hills and strains, after the best had been selected out for seed, gave somewhat poorer yields than did unselected stock.

The germination of the selected strain is more rapid, the stand is better, the growth thriftier, and diseases less apparent than for the unselected potatoes of the same variety.

A degenerate strain of highly chlorotic foliage has been isolated. A potato pathologist could recognize no known disease on the strain.

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