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THE INFLUENCE OF COPPER SPRAYS ON THE YIELD AND COMPOSITION OF IRISH POTATO TUBERS.

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CONTENTS.

PURPOSE OF INVESTIGATION.

For years Bordeaux sprays have been applied to the potato plant to control fungous diseases, particularly in the northern parts of the country where the late blight (*Phytophthora infestans*) frequently causes serious losses. In those parts of the Central and Southern States where potatoes are grown the only spray ordinarily applied is an arsenical to control the Colorado potato beetle. Arsenicals are usually added to the Bordeaux sprays. The formulæ of Bordeaux sprays may vary in different localities. A 5–5–50 spray is one in which 5 pounds of copper sulphate and 5 pounds of lime are used and the spray is made to 50 gallons with water.

The fact that potato plants treated with Bordeaux spray give larger yields of tubers than those which do not receive such applications has been established by a series of experiments extending over many years at the Vermont, Maine, and New York agricultural experiment stations. The influence of the copper sprays on the composition of the tubers, however, has received no detailed study in this country. In view of the importance of the potato crop it is surprising that practically no detailed analyses of potato tubers grown in the United States are available.

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When in 1917 it was found that the solids, starch, and nitrogen contents of tubers from copper-sprayed potato plants were greater than those of tubers from unsprayed plants, an investigation was begun in the Bureau of Chemistry to determine the effect of Pickering sprays, barium-water sprays, and standard Bordeaux sprays as compared with that of noncopper sprays on the yield and on the composition of potatoes grown in different localities. The distribution of copper in the tubers, roots, stems, and leaves of the various sprayed and unsprayed potato plants was studied also.

RESULTS OF PREVIOUS INVESTIGATIONS.

YIELD OF POTATOES.

Giddings (*20*),[1] of the West Virginia station, fund that in 1909 three applications of Bordeaux increased the yield of potatoes 53.5 per cent and that in 1910 four applications increased the yield 39.3 per cent.

In New York Stewart and his associates (*46, 47, 48*) have conducted an extensive series of experiments to show the benefits of Bordeaux spraying. In discussing the results obtained at the New York station in 1911 Stewart stated: "There was no late blight whatever, only a very little early blight and very little flea-beetle injury. The unsprayed rows were affected by no disease of any consequence except tip burn and even of that there was only a moderate amount, * * * yet spraying increased the yield at the rate of 93 bushels per acre. Plainly we have here a striking example of the beneficial influence of Bordeaux in the absence of disease and insect enemies."

In 1912 Lutman (*32*) published data from Vermont showing that a greater yield of tubers was obtained from copper-sprayed potato plants at various stages of growth than from the unsprayed plants. Plants which received a Pickering spray, a Bordeaux spray in which part of the copper sulphate had been replaced by iron sulphate, and a commercial spray containing copper also gave higher yields than the check plants. The increased yield seemed to be in proportion to the amount of copper present in the spray. The application of a spray containing silver did not increase the yield. Lutman suggested that the Bordeaux mixture acts as a stimulant, bringing about an increase in the quantity of starch produced daily.

Clinton (*8*) in 1915 reported that homemade Bordeaux sprays used on potatoes in Connecticut uniformly increased the yields. The average increase for the sprayed plants during the 13 years that the tests were carried on was 36 bushels an acre.

In 1916 Lutman (*33*) reported the results he obtained in 1912 from using 5–5–50 Bordeaux and 2½–2½–50 Bordeaux on potatoes in Vermont. He concluded that "the amount of copper sulphate and lime used did not appear to be important providing the mixture was fairly strong. A little difference appeared in favor of the 5–5–50 combination over the 2½–2½–50. Frequent and early sprayings did not seem favorably to affect the yield of tubers. Some of the plants were sprayed ten times but they produced little or no larger crops than did those plants sprayed less often." He stated further that the use

[1] Italic figures in parentheses refer to literature cited at end of bulletin.

of Bordeaux under field conditions increases the yield of tubers from potato plants by preventing tip burn and flea-beetle injury. He believed that the yields are not increased when plants which are not troubled by tip burn or flea beetle are sprayed. According to this investigator, Bordeaux mixture seems in the long run to be neither beneficial nor harmful, but it is unnecessary to apply it to plants grown in the greenhouse or to those in regions where neither tip burn nor flea beetles are a factor in potato growing and where neither early nor late blight occurs.

Babcock (*4*) reported in 1917 that spraying potatoes thoroughly with a 4–4–50 Bordeaux mixture in Ohio when the plants were about 8 inches high and every 10 days to two weeks thereafter materially increased the yield, even in years when there were no disease epidemics.

Erwin (*16*) reported a difference in yield in favor of the Bordeaux-sprayed plots, indicating a definite response to the use of Bordeaux spray in Iowa. When tip burn was generally present and early blight practically absent the yields were higher on the sprayed plots, indicating that the plants had been stimulated and benefited by the Bordeaux application.

In 1919 Leiby (*29*) published data obtained in North Carolina showing an average gain of 51.6 bushels an acre, representing 64.2 per cent, as a result of the use of a 3–4–50 Bordeaux plus lead arsenate spray on potatoes. Bordeaux alone produced an increased yield of 35 bushels an acre.

During a 10-year period in New York an average gain of 60 bushels an acre was obtained by spraying with Bordeaux. At the Vermont station during 20 years, which covered all seasonal variations, an average gain of 105 bushels of potatoes an acre was effected by the use of Bordeaux. Experiments at the Maine station extending over a period of years showed that spraying with Bordeaux gave increased yields of tubers, even in years when no late blight was prevalent.

COMPOSITION OF POTATOES.

Although no detailed analyses of potatoes grown in the United States are available, the results of several analytical studies of European varieties have been reported.

Kreusler (*26*) gives the results of analyses of large, medium, and small tubers grown in Germany. They had the same general composition, the only difference being the presence of slightly more crude fiber and solids in the small than in the large tubers. The medium-sized tubers had more crude fiber than the large tubers but the same proportion of solids.

Appleman (*2*), who investigated the changes in Irish potatoes during storage, gives data on the moisture, total sugar, and starch contents.

Girard (*21*) in 1889 reported the changes taking place in tubers in France during growth. The sucrose content dropped from 1.48 to 0.02 per cent and the dextrose content from 0.67 per cent to none. Protein increased from 1.36 to 1.98 per cent, ash from 0.86 to 1.46 per cent, starch from 8.4 to 16.38 per cent, and cellulose from 0.84 to 1.66 per cent. The insoluble nitrogen dropped from 1.66 to 0.19 per cent and the insoluble ash from 0.16 to 0.06 per cent.

Pott (*37*) showed that the water content decreased, while the total nitrogen, starch, and crude fiber contents increased in the tubers as they matured.

Prunet (*39*) considered that during growth the nutritive substances are uniformly distributed in the tuber, but after full size has been reached there is a movement of these substances toward the apical buds.

Jones and White (*24*) in 1899 reported some experiments made on Delaware and White Star varieties of potatoes in Vermont. From analyses of tubers from both Bordeaux-sprayed and unsprayed plots, they concluded that the variations in yield were of more importance than variations in composition. The unsprayed tubers showed the presence of more water and ash than the sprayed tubers. As all of the tubers matured the solids and nitrogen-free extract decreased somewhat, while the ash, protein, and crude fiber increased slightly.

Stewart, Eustace, and Sirrine (*46*) in 1902 reported that one lot of tubers from Bordeaux-sprayed plants gave higher solids and starch results than a corresponding lot from unsprayed vines.

Woods (*51*) of the Maine station in 1919 published analyses showing that tubers from Bordeaux-sprayed potato vines averaged 19.1 per cent starch and that tubers in the same field from unsprayed vines averaged 17.5 per cent starch. The dry matter in the tubers from the sprayed portions of the field was also 1½ per cent higher than that in the tubers from the unsprayed portions.

PLANTS IN GENERAL.

Sorauer (*45*) observed that swellings were formed on the leaves of potato plants by the action of copper salts. Sections of these growths showed that they were composed of parenchyma cells so strongly hypertrophied as to break the epidermis.

Frank and Krüger (*19*) in 1894 obtained a definite improvement in growth by treating potato plants with a 2 per cent Bordeaux spray. The effect of the copper was most marked on the leaves and was chiefly indicated by physiological activity rather than morphological changes. The leaves were thicker and stronger and their life was lengthened. The chlorophyll content was apparently increased and correlated with this was a rise in the assimilating capacity, more starch being formed. A rise in transpiration also occurred. A subsidiary stimulation took place in the tubers, as the greater quantity of starch produced required space for its storage. The ratio of tuber formation on treated and untreated plants was 19:17 and 17:16. These investigators held that the action was catalytic, that is, an increase in photosynthesis resulted from the presence of copper.

Rumm (*40*) in 1895 noted that grape foliage sprayed with Bordeaux showed thickened leaves of a blue-green color which outlived the leaves of the unsprayed vines. After measuring leaves from sprayed and unsprayed vines Rumm presented data showing that the thickness of the leaf, the epidermis, the palisade tissue, and the parenchyma was increased in the case of the sprayed vines. These data suggest that copper was taken into the growing leaf where it produced certain morphological changes.

Lodeman (*31*) found that the thickness of plum leaves and prune leaves was increased by the application of Bordeaux spray.

Working with a large number of greenhouse plants, Zucker (*52*) concluded that plants sprayed with Bordeaux have greater resistance to etiolation than the unsprayed plants. The sprayed plants also showed an increase of chlorophyll and an increased power of assimilation, and their shoots lived longer. All of the sprayed plants transpired more than the unsprayed plants or those sprayed with lime alone.

Harrison (*22*) found that Bordeaux-sprayed plum, peach, and pear leaves were slightly thickened and that a marked development of chlorophyll granules occurred in their cells.

According to Chuard and Porchet (*6*), copper spray causes a slight increase in the sugar content of matured fruits. Injection of solutions of copper salts into the tissues of such plants as the grapevine produced more vigorous growth, more intense color, and greater persistence of the leaves. The copper seemed to act as a stimulant to all the cells of the organism. Other metals, such as cadmium and iron, are said to give a similar effect. Injecting small quantities of copper salts into the branches of a currant bush caused an acceleration in the maturation of the fruit identical with that obtained by the application of Bordeaux to the leaves. If the quantity of copper introduced into the vegetable organism was increased, the toxic action of the metal was brought into play. These investigators attribute the stimulus, as shown by the earlier maturation of the fruit, to a greater activity of all the cells of the organism and not to an excitation of the chlorophyll functions alone.

Treboux (*49*), in 1903, demonstrated the harmful effect of solutions of copper salts on leaves, measuring the activity of photosynthesis by a determination of the rate of emission of bubbles of oxygen.

Kanda (*25*) undertook to ascertain whether copper had a stimulating action on plants. He found that very small amounts of copper sulphate were toxic to peas grown in distilled water.

Schander (*41*) believes that the copper in a Bordeaux spray penetrates the leaf to a very small extent, perhaps less than one in a hundred million parts, and that the copper there produces changes in assimilation and in transpiration. He considers that the shading effect of the Bordeaux spray on the leaves is beneficial to the absorption of carbon dioxid.

Ewert (*17*) states that in the morning Bordeaux-sprayed potato plants contain more starch than the unsprayed plants, not because they are making more starch, but because they are unable to get rid of it as rapidly. The starch is piled up in the chlorophyll bodies as the minute amount of copper absorbed checks the diastase action. Bordeaux spraying, shading the plants with cloth, and a combination of the two procedures diminish the yield of tubers. This author demonstrated by its effect on diastase that copper is present in the sprayed leaf in minute amount and concludes that the organic life of the plant is hindered rather than stimulated by the application of Bordeaux sprays.

Von Schrenk (*50*), working with cauliflower, also observed that swellings were formed on the leaves owing to the action of copper salts.

Amos (*1*) studied the effect of Bordeaux mixture on the assimilation of carbon dioxid by the leaves of plants to determine whether any stimulation resulted. He found a diminished assimilation by the sprayed leaves for a time. This effect, however, gradually disappeared. It is suggested that the stomata are blocked by the Bordeaux mixture, so that less air is diffused into the intercellular spaces and less carbon dioxid comes into contact with the absorption surfaces. This then is a mechanical and not a physiological action that reduces assimilation.

Duggar and Cooley (*14*) showed that potted potato plants when sprayed with Bordeaux transpire more water than unsprayed plants.

Duggar and Cooley (*14*), using potted potato plants, studied the effects of surface films on the rate of transpiration. The use of Bordeaux and other films increased the rate of transpiration. The plants treated with weak Bordeaux (2–3–50) were in good condition at the close of the test, while those sprayed with stronger Bordeaux (4–6–50) showed injury from too much transpiration. These investigators stated that it does not follow that the same results will be obtained in the open.

After measuring the cells of Bordeaux-sprayed and unsprayed potato leaves, Lutman (*33*) concluded that in general the leaves from the Bordeaux-sprayed plants had thicker palisade and pulp parenchymas than those from the check plants. He believed also that the number of chlorophyll bodies was increased in the sprayed leaves. An increased turgor is probably the immediate cause of these unusually large cells. He considered that a small quantity of copper enters the leaf and that a chemical combination takes place between the chlorophyll and the copper. The chlorophyll is less easily removed from sprayed plants, showing that it has been rendered less soluble. Greenhouse tests and experiments conducted for one year in Germany by Lutman showed no stimulation effects. Lutman considers that in this country the physiological effects of Bordeaux on the potato are quite as important as its fungicidal effects. The physiological effect observed in Vermont is ascribed to lessened tip burn and flea-beetle injury and not to a stimulation and daily increase of starch formation as suggested earlier by him.

Edgerton (*15*) decided that Bordeaux applied in Louisiana delayed the ripening of tomatoes, while any increase in yield was uncertain. Pritchard and Clark (*38*) concluded that treatment with copper sprays increased the yield of tomatoes in Virginia, Maryland, Indiana, and New Jersey.

In some of Montemartini's experiments (*36*) one side of a plant was sprayed while the other was not. Leaves sprayed in the morning with dilute copper sulphate solution and removed and measured in the evening had a greater dry weight per unit area than the untreated leaves. When leaves were treated at night and removed in the morning they had a lower dry weight per unit area than the untreated leaves. According to Montemartini, these results indicate that the treatment stimulated the formation and translocation of organic matter.

Ball (*5*) has definitely established the fact that the potato leafhopper causes "burning" of potato leaves, to which the term "hopperburn" has been applied. He states also that it has long been recognized that spraying with Bordeaux mixture reduces tip burn, probably because it acts as a partial repellent against the leafhoppers.

Dudley and Wilson (*13*) report that the potato leafhopper is one of the most important enemies of the potato in the United States. Bordeaux repels the leafhopper and therefore effectively controls the potato leafhopper and hopperburn. According to Fenton and Hartzell (*18*), the leafhopper can be effectively controlled and hopperburn can be prevented by covering the potato plants with Bordeaux spray. This spray keeps the adult insects from laying their eggs on the plants and kills many of the young insects.

EXPERIMENTAL PROCEDURE.

Three kinds of sprays containing copper were used in the experimental work reported here: (*a*) Ordinary Bordeaux spray, prepared by mixing milk of lime and copper sulphate solutions; (*b*) Pickering spray, prepared by mixing a saturated solution of limewater with a dilute solution of copper sulphate; and (*c*) a barium-water spray, prepared by mixing barium hydroxid with a dilute copper sulphate solution. These sprays are discussed fully in United States Department of Agriculture Bulletin 866.

The yield data were obtained from the two middle rows of a 4-row plot. Care was taken to select for these experiments plants which were as free as possible from late blight, mosaic, leaf roll, etc. The tubers from six plants receiving the same treatments were placed in a sack and immediately taken to the laboratory for analysis. For each analysis six medium-sized tubers were selected from the sample and the analyses were made the day on which the tubers were dug. All of the samples were run through a Herles press which gives a very finely divided product. All determinations were made in duplicate, the average figures being recorded in the tables. With the exception of the 1921 data, which include detailed analyses, only solids, starch, and total nitrogen determinations are reported.

Solids, ash, insoluble ash, sugars, total nitrogen, and phosphorus were estimated by the methods of the Association of Official Agricultural Chemists (*3*). Starch was determined by the Herles method (*23*) which depends upon the conversion of the insoluble starch to a soluble starch by means of hydrochloric acid and a reading of the percentage of soluble starch in the polariscope. Copper (*9*) was estimated on 10 grams of the dried sample by the colorimetric procedure, using potassium ferrocyanid. Soluble nitrogen, soluble phosphorus, ammonia nitrogen, coagulable nitrogen, and nitrogen as monoamino and amid nitrogen were estimated on water extracts of the finely-divided samples of tubers as previously outlined by the writer (*10*). The pH data were obtained on the water extracts of the tubers, using the colorimetric procedure of Clark and Lubs (*7*).

RESULTS OF EXPERIMENTAL WORK.

CHANGES IN COMPOSITION OF TUBERS DURING GROWTH.

During the season of 1921 tubers from four varieties of potatoes grown at Presque Isle, Me., were analyzed. Some of the plants had been sprayed with copper sprays, while others had not. The tubers were analyzed at various periods during their growth in order to determine when the influence of the copper sprays was exerted, and also to show the changes that take place in the composition of American-grown tubers during their development. These data are given in Table 1.

TABLE 1.—*Data on tubers from sprayed and unsprayed potato plants, Presque Isle, Me., 1921.*

Date of digging.	Serial No.	Variety.	Treatment.	Solids.	Starch.	Sugars.		Sugars to starch ratio.	Ash.	Insoluble ash.	Proportion of total ash that is insoluble.	pH of water extract.	Nitrogen (N).					Percentage of total nitrogen as—				Undetermined material (fiber, etc.).
						Reducing as dextrose.	Sucrose.						Total.	Soluble.	Coagulable.	Monoamino and amid.	Ammonia.	Soluble.	Coagulable.	Monoamino and amid.	Ammonia.	
				P. ct.	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
July 26	25	Irish Cobbler	Bordeaux	16.75	9.95	0.39	1.04	1- 7.0	0.97	0.128	13.2	6.2	0.319	0.212	0.027	0.078	0.0030	66.5	8.5	24.4	0.94	2.99
Do	26	do	Pickering	15.56	9.60	.38	1.28	1- 5.8	.95	.137	14.4	6.2	.303	.207	.030	.078	.0033	68.3	9.9	25.7	1.09	2.01
Do	27	do	Check	15.21	9.25	.51	1.41	1- 4.8	.93	.147	15.8	6.2	.286	.198	.023	.076	.0027	69.2	8.0	26.6	.94	1.88
Aug. 15	35	do	Bordeaux	18.16	12.40	.10	.90	1-12.4	.87	.085	9.8	6.5	.289	.246	.112	.112	.0026	85.1	38.7	38.7	.90	2.51
Do	36	do	Pickering	18.28	10.70	.20	.96	1- 9.2	.83	.087	10.5	6.4	.286	.246	.106	.104	.0040	86.0	37.1	36.4	1.40	3.85
Do	37	do	Check	18.70	11.60	.24	1.05	1- 9.0	.81	.081	10.0	6.3	.269	.235	.101	.104	.0028	87.4	37.5	38.7	1.04	3.75
Sept. 17	51	do	Bordeaux	22.67	16.80	trace.	.37	1-45.4	.93	.100	10.8	6.0	.347	.292	.102	.149	.0030	84.1	29.4	42.9	.86	3.00
Do	52	do	Pickering	20.86	15.90	do	.44	1-36.1	.99	.102	10.3	6.0	.333			.134	.0034			40.2	1.02	2.02
Do	53	do	Check	20.86	15.90	do	.36	1-44.2	.96	.085	8.9	6.0	.336			.134	.0044			39.9	1.31	2.12
Aug. 2	28	Early Rose	Bordeaux	16.98	9.20	.29	1.50	1- 5.1	.89	.103	11.6	6.3	.280	.230	.068	.090	.0028	82.1	24.3	32.1	1.00	3.94
Do	29	do	Check	16.05	8.25	.33	1.75	1- 4.0	.86	.106	12.3	6.3	.252	.226	.065	.084	.0030	89.7	25.8	33.3	1.19	3.88
Aug. 19	40	do	Bordeaux	17.27	10.85	.15	.76	1-11.9	.82	.137	16.7	6.4	.297	.263		.134	.0034	88.5		45.1	1.14	3.38
Do	41	do	Check	14.44	10.80	.14	.72	1-12.6	.87	.133	15.3	6.4	.269	.230	.062	.112	.0030	85.5	23.0	41.6	1.12	3.80
Sept. 14	49	do	Bordeaux	18.77	12.50	.07	.62	1-18.1	.79	.070	8.9	6.3	.319	.292	.079	.180	.0028	91.5	24.8	56.4	.88	3.50
Do	50	do	Check	19.28	13.15	.02	.31	1-39.9	.76	.077	10.1	6.3	.303	.272	.073	.172	.0026	89.8	24.1	56.8	.86	3.89
Aug. 3	30	Early Ohio	Bordeaux	18.64	11.40	.29	1.12	1- 8.1	.94	.092	9.8		.308	.269	.055	.095	.0032	87.3	17.9	30.8	1.04	3.70
Do	31	do	Check	16.72	9.55	.49	1.38	1- 5.1	.91	.098	10.8		.286	.257	.047	.087	.0030	89.8	16.4	30.4	1.05	3.33
Aug. 18	38	do	Bordeaux	18.90	12.75	.18	.97	1-11.1	.83	.098	11.8	6.5	.300	.258	.084	.120	.0028	86.0	28.0	40.0	.93	2.89
Do	39	do	Check	18.54	12.40	.17	1.10	1- 9.8	.85	.086	10.1	6.3	.305	.263	.084	.127	.0026	86.2	27.5	41.6	.85	2.74
Sept. 13	47	do	Bordeaux	22.49	15.80	.05	.29	1-46.5	.98	.073	7.5	6.3	.375	.345	.076	.133	.0026	92.0	20.3	35.5	.69	3.90
Do	48	do	Check	21.44	14.45	.04	.32	1-40.1	.93	.077	8.3	6.1	.364	.336	.101	.141	.0048	92.3	27.8	38.7	1.32	4.18
Aug. 9	32	Green Mountain	Bordeaux	14.93	8.80	.23	1.15	1- 6.4	.92	.074	8.0	6.3	.301	.231	.068	.090	.0040	76.7	22.6	29.9	1.33	2.46
Do	33	do	Barium	17.80	9.90	.30	1.16	1- 6.8	.90	.080	8.9	6.3	.290	.224	.067	.070	.0036	77.2	23.1	24.1	1.24	4.28
Do	34	do	Check	16.89	10.05	.27	1.17	1- 7.0	.84	.074	8.8	6.3	.285	.221	.067	.067	.0030	77.5	23.5	23.5	1.05	3.26
Aug. 23	42	do	Bordeaux	17.71	11.80	.11	.54	1-18.2	.69	.073	10.6	6.4	.303	.258	.073	.112	.0036	85.1	24.1	37.0	1.19	3.25
Do	43	do	Pickering	18.44	12.70	.11	.66	1-16.5	.71	.066	9.3	6.5	.283	.230		.104	.0024	81.3		36.8	.85	2.94
Do	44	do	Check	18.02	12.50	.06	.48	1-23.1	.71	.078	11.0	6.4	.319	.258	.073	.112	.0022	80.9	22.9	35.1	.69	2.86
Aug. 29	45	do	Barium	20.83	14.30	.07	.50	1-25.1	1.00	.095	9.5	6.2	.347	.252	.062	.120	.0024	72.6	17.9	34.6	.69	3.43
Do	46	do	Check	18.65	12.30	.16	.57	1-16.9	1.01	.092	9.1	6.2	.297	.235	.061	.120	.0024	79.1	20.5	42.8	.81	3.30
Sept. 20	54	do	Bordeaux	20.86	14.60	trace.	.66	1-22.1	.95	.088	9.3	6.0	.317	.252	.073	.119	.0060	79.5	23.0	37.6	1.89	3.24
Do	55	do	Barium	20.12	13.80	do	.37	1-37.0	.97	.094	9.7	6.2	.364	.297	.079	.149	.0035	81.6	21.7	40.9	.96	3.40
Do	56	do	Pickering	18.31	12.90	do	.48	1-26.9	.79	.087	11.0	6.2	.378	.319	.073	.164	.0024	84.4	19.3	43.4	.64	2.55
Do	57	do	Nickel	19.57	13.30	do	.24	1-55.4	.81	.082	10.1	6.1	.356	.348	.034	.180	.0044	97.7	9.5	50.6	1.24	3.99
Do	58	do	Check	17.53	12.30	do	.31	1-40.0	.92	.085	9.3	6.2	.333	.297	.107	.127	.0034	89.2	32.1	38.1	1.02	2.53

The proportion of solids in most cases showed a gradual increase during the growth of the tubers. With the exception of the Green Mountain sample, the proportion of solids was higher in the tubers from copper-sprayed plants than in those from the unsprayed plants at the time of the first analysis, that is, when the tubers were less than an inch in diameter. This indicates that the effect of the copper was exerted very early in their development.

The solids for all the tubers from the Bordeaux-sprayed plants averaged 18.63 per cent; for all those from the unsprayed plants, 17.87 per cent; for all those from barium-water-sprayed plants, 19.58 per cent; and for all those from Pickering-sprayed plants, 18.29 per cent.

The following average ash figures were obtained for all the samples analyzed: Tubers from unsprayed vines, 0.87 per cent; tubers from Bordeaux-sprayed plants, 0.88 per cent; and tubers from Pickering-sprayed plants, 0.85 per cent. The percentage of the total ash found as insoluble ash decreased in most cases during the growth of the tubers.

The pH data obtained on the water extracts of the tubers showed no significant change.

The proportion of total nitrogen, which increased during the growth of all four varieties of tubers, was somewhat higher for the tubers from copper-sprayed plants than for those from the unsprayed plants. The percentage of nitrogen was higher for the tubers from copper-sprayed plants than for those from the unsprayed plants at the time of the first analyses, showing again that the action of the copper on the metabolic activities of the plant was exerted very early.

The percentage of insoluble nitrogen in the tubers showed a tendency to decrease during growth. The percentage of soluble nitrogen increased during growth. The percentage of coagulable nitrogen increased during growth in the case of the Irish Cobbler, the Early Ohio, and the Early Rose varieties, but not in the Green Mountain variety. The monoamino and amid nitrogen, which includes the nitrogen not precipitated by phosphotungstic acid, showed a marked increase for all four varieties during growth. The average percentage was slightly higher in the tubers from copper-sprayed plants than in those from the unsprayed plants. The ammonia nitrogen content showed no regular change.

During tuber development the percentage of starch increased somewhat more rapidly than the percentage of solids. A larger percentage of starch was usually found in the tubers from copper-sprayed plants from the first analysis to the last than in the check tubers. The average data for the content of starch in the tubers were: Bordeaux-sprayed, 12.24 per cent; check, 11.73 per cent; barium-sprayed, 12.67 per cent; and Pickering-sprayed, 12.36 per cent.

The sugars, calculated as dextrose and sucrose, were present in the young tubers in relatively large proportions. At the time the tubers had reached maturity the dextrose had practically disappeared and the quantity of sucrose had markedly decreased. The unsprayed tubers of the three early varieties contained a higher percentage of sugars in the first stages of development and usually a lower percentage at maturity than the tubers from copper-sprayed plants.

This means that the copper sprays may in some way accelerate the transformation of sugar to starch during the active stages of growth. The Green Mountain tubers did not show this tendency. The ratio of sugars to starch decreased greatly during growth, the percentage of sugars decreasing while the percentage of starch increased. The ratio of sucrose to dextrose increased during the growth of the tubers, the dextrose practically disappearing at maturity. At the time the first and second analyses were made the three early varieties of potatoes contained a higher percentage of dextrose plus sucrose than the late variety (Green Mountain). This higher sugar content may be characteristic of early varieties and may be associated with the rapid growth which these varieties make. The unsprayed tubers, with the exception of the Green Mountain, usually showed a higher ratio of sugar to starch than the tubers from the copper-sprayed plants.

It is evident that marked changes take place in the potato during development. Apparently these changes are influenced in some way by the copper sprays, higher percentages of solids, starch, and nitrogen usually following the application of copper sprays to potato vines.

These data may be of value in determining when a potato is mature. It appears that the sugar to starch ratio, as suggested by Appleman (*2*), as well as the ratio of protein to amid nitrogen and the percentage of total nitrogen as amid nitrogen, is of value. The percentage of starch in terms of total solids may be used. Apparently certain changes in the ash constituents may be applied to solve the question.

EFFECT OF COPPER SPRAYS ON YIELD AND COMPOSITION OF TUBERS.

1917 AND 1918 DATA (MAINE).

In 1916 and again in 1917 potato plants which received copper sprays gave higher yields than those which received no copper spray. It was therefore thought that the copper sprays might influence the composition of the tubers as well as the yield. Late blight was severe in 1917 in this locality but was slight in 1916 and 1918. During the season of 1917 Green Mountain potatoes were sprayed at Presque Isle, Me., using 5–5–50 Bordeaux, Pickering sprays containing various amounts of copper, and a barium-water-copper-sulphate spray containing 0.7 per cent of copper sulphate. Duplicate determinations for solids were made on four samples of tubers from (*a*) 5–5–50 Bordeaux-sprayed vines (1.25 per cent copper sulphate); (*b*) Pickering-sprayed vines (0.64 per cent copper sulphate); and (*c*) unsprayed vines grown in the same field. All of the vines were sprayed seven times during the season, lead arsenate being used on all of the plants.

The four samples of tubers from the Bordeaux-sprayed vines averaged 21.45 per cent solids; those from the Pickering-sprayed vines, 21.49 per cent solids; and those from the check vines, 20.65 per cent solids. Similar results were obtained with this variety of potatoes in Maine during the season of 1918.

1919 DATA.

Arlington Experimental Farm, Va.—The 1919 experiments at the Arlington Experimental Farm of the Department of Agriculture were conducted on the Early Rose and Irish Cobbler varieties of potatoes. All plots were sprayed four times, lead arsenate being applied to both unsprayed and copper-sprayed plots. The field was uniformly fertilized, using 4–8–4 mixture which was applied at the rate of 1,200 pounds to the acre. The tubers were analyzed the day they were dug.

TABLE 2.—*Yield and composition of tubers from copper-sprayed and unsprayed (check) potato plants, Arlington Experimental Farm, 1919.*

Variety.	Treatment.	Yield from 2 rows, each 100 feet long.	Solids.	Nitrogen.
		Pounds.	*Per cent.*	*Per cent.*
Early Rose	No copper spray (check)	50.0	13.96	0.293
Do	Bordeaux 4–4–50 (1 per cent copper sulphate)	87.6	14.30	.272
Do	Pickering spray (0.5 per cent copper sulphate)	90.3	15.83	.325
Irish Cobbler [1]	No copper spray (check)	124.0	16.41	.346
Do	Bordeaux 4–4–50 (1 per cent copper sulphate)	134.0	18.14	.347
Do	Pickering spray (0.5 per cent copper sulphate)	123.0	18.57	.364

[1] Average of 3 determinations given in each case.

The data in Table 2 indicate that the copper sprays increased the yield for the Early Rose variety and the solids content of tubers of both varieties in a locality where late blight is unknown and where Bordeaux or other copper sprays are not employed generally.

Seven States.—The yield and composition of tubers from Bordeaux-sprayed and unsprayed plants in seven States (Virginia, Maine, Minnesota, Pennsylvania, New York, Connecticut, and New Jersey) are recorded in Table 3. The analytical data are average figures for 62 samples. Data for Pickering-sprayed plots are included with the Arlington Experimental Farm results. The tubers analyzed were from sprayed and unsprayed potato plants grown in the various States under the direction of plant pathologists and were sent to the writer by express the day on which they were dug. Arsenical sprays were used on all plots.

The average increase in yield per acre of potatoes was 25 per cent. The average increase of solids in the tubers was from 20.77 per cent, in the tubers from the check plots, to 21.99 per cent in those from Bordeaux-sprayed plants, an increase of 5.9 per cent. The average figures for pounds of solids of the tubers per acre were 2,591 for the noncopper-sprayed and 3,430 for the copper-sprayed plants, an average increase of 32.4 per cent or 48 bushels, due apparently to the use of copper sprays. It is important to note that the tubers from Virginia, Maine, and Minnesota, where practically no late blight occurred, showed the same general results as those from the other four States, where more or less late blight was noted. This means that prevalence of late blight was apparently not the important factor or necessarily a factor at all. The potato plants grown in

TABLE 3.—*Yield and composition of tubers from copper-sprayed and check potato plants from seven States, 1919.*

Source.	Number of samples analyzed.	Variety.	Treatment.	Solids.	Nitrogen.	Yield of tubers per acre.	Solids of tubers per acre.	Remarks on condition of plants.
				Per cent.	*Per cent.*	*Pounds.*	*Pounds.*	
Arlington Experimental Farm, Va.	4	Irish Cobbler[1] and Spalding Rose.	Unsprayed (check)	15.80	0.33	5,275	833	No late blight present on any of the sprayed or unsprayed vines.
	4	do	Bordeaux sprayed	17.18	.33	6,120	1,051	
	4	do	Pickering sprayed[3]	17.89	.35	5,741	1,027	
Presque Isle, Me.	1	Green Mountain	Unsprayed (check)	26.05	.35	18,315	4,771	No late blight until Sept. 1 on either plot; after Sept. 1 traces of blight; all killed Sept. 12 by frost.
	1	do	Bordeaux sprayed	26.96	.38	19,305	5,205	
St. Paul, Minn.	1	Early Ohio	Unsprayed (check)	19.25	.40	7,448	1,434	Seed from unsprayed crop of 1918; no late blight present.
	1	do	Bordeaux sprayed	22.79	.48	12,015	2,738	Seed from sprayed crop of 1918; no blight present.
State College, Pa.	1	Heath's Late Beauty	Unsprayed (check)	20.89	.36	13,750	2,873	Vines had severe late blight and died early.
	1	do	Bordeaux sprayed	22.02	.36	18,550	4,084	Vines had slight late blight and died early.
Bath, N. Y.	2	Scott's Magnum Bonum,[1] and Dibble Russet.	Unsprayed (check)	23.99	.41	12,700	3,046	Vines blighted Sept. 15; nearly dead from late blight when dug.
	2	do	Bordeaux sprayed (3 sprayings).[3]	25.32	.37	12,700	3,215	Vines moderately blighted; killed by frost Oct. 7.
	2	do	Bordeaux sprayed (6 sprayings).	25.61	.40	15,900	4,072	Vines slightly blighted; killed by frost Oct. 7.
Mt. Carmel, Conn.	8	8 different varieties	Unsprayed (check)	20.92	.40			All the check and sprayed vines died early in the season from late blight, before the spray could exert any beneficial action. Tubers held in cellar in Connecticut for 2 weeks, and in storage in District of Columbia for 3 or 4 days before analysis.
	8	do	Bordeaux sprayed	20.44	.40			
New Jersey	11	Irish Cobbler[2] and American Giant.	Unsprayed (check)	18.50	.34			A little early blight and tip burn present.
	11	do	Bordeaux sprayed	18.90	.36			
		Average	Unsprayed (check)	20.77	.37	11,498	2,591	Average increase of yield per acre, 25 per cent.
		do	Bordeaux sprayed	21.99	.39	14,378	3,430	Average increase of solids per acre, 32.4 per cent.

[1] Figures given are averages of separate analyses of an equal number of samples of the 2 varieties.
[2] Average figures for separate analyses of 5 samples of Irish Cobbler and 6 of American Giant.
[3] Results not included in average.

Connecticut were well infected with late blight before any Bordeaux spray was applied. All the plants died early; consequently, it is not surprising that the tubers showed no effect of the Bordeaux spray, probably because they were formed before the first spray was applied and were therefore too far advanced to derive any benefit from the sprays. The New Jersey results for solids were not higher for the tubers from the copper-sprayed than for those from the unsprayed plants in the case of all samples examined, although the average figures were higher for the tubers from the Bordeaux-sprayed plants. A discussion of the use of Bordeaux spray on potatoes in New Jersey by Lint (*30*) is interesting in this connection. He considers the climate, cultivation, and fertility of the field to be important factors in determining to what extent Bordeaux is beneficial to the potato. According to this author, Bordeaux prolongs the life of the vines and affords the best control of flea beetle, although increased yield of tubers does not consistently result from the application of Bordeaux to potato plants in New Jersey.

It has been the writer's experience that an occasional sample of tubers from a check plot will run higher in solids, starch, and nitrogen than a sample from a Bordeaux- or other copper-sprayed plot. This is the exception to the rule, however, and may be due to the inclusion among the tubers selected for analysis of a potato or several potatoes that are not hard and firm. Sometimes one of the tubers in a hill is a little softer than the rest, probably because the food supply has been limited or checked in some way. In work of this kind average figures are undoubtedly the only criterion.

1920 DATA.

Arlington Experimental Farm, Va.—In the spring of 1920 experiments were carried out at Arlington Experimental Farm, using Irish Cobbler, Early Ohio, and Early Rose varieties of potatoes. Spalding Rose, Gold Coin, Irish Cobbler, and McCormick potatoes were grown in the fall. A 4–4–50 Bordeaux spray, a Pickering spray, a 10–10–50 Bordeaux, and a 0–4–50 spray were used. The check plots and all the copper-sprayed plots received a lead arsenate spray. The figures reported in Table 4 are the averages for 53 sets of tubers separately analyzed.

TABLE 4.—*Yield and composition of tubers from sprayed and unsprayed potato plants, Arlington Experimental Farm, Va., August and October, 1920.*

Variety.	Treatment.	Yield from 2 rows, each 100 feet long.	Composition of tubers.		
			Solids.	Starch.	Nitrogen.
Early potatoes (August):		*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
Irish Cobbler [1]	4–4–50 Bordeaux	357	19.91	14.20	0.372
Do [2]	Check (no copper)	321	19.59	13.70	.368
Do [1]	Pickering spray	340	20.64	14.50	.383
Do [1]	10–10–50 Bordeaux	341	20.42	14.70	.367
Do [1]	0–4–50 spray (no copper)	350	19.85	13.90	.356
Early Ohio [1]	4–4–50 Bordeaux	217	19.17	13.90	.412
Do [1]	Check (no copper)	216	19.28	13.90	.410
Do	Pickering spray	211	19.44	14.70	.433
Early Rose [1]	4–4–50 Bordeaux	245	20.18	14.38	.367
Do [1]	Check (no copper)	228	18.97	13.60	.326
Do [1]	Pickering spray	229	20.86	14.83	.364

[1] Average of 2 sets. [2] Average of 4 sets.

TABLE 4.—*Yield and composition of tubers from sprayed and unsprayed potato plants, etc.*—Continued.

Variety.	Treatment.	Yield from 2 rows, each 100 feet long.	Composition of tubers.		
			Solids.	Starch.	Nitrogen.
Late potatoes (October):		*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
Spalding Rose	0-4-50 spray (no copper)	153	19.36	16.80	0.406
Do	Pickering spray	221	21.48	19.20	.397
Do	4-4-50 Bordeaux	250	21.45		.430
Do	Check (no copper)	248	19.81		.409
Gold Coin	4-4-50 Bordeaux	242	22.09	17.00	.485
Do	0-4-50 spray (no copper)	232	21.12		.461
Do	Pickering spray	296	23.80	17.90	.457
Do	Check (no copper)	294	19.52	14.50	.444
Irish Cobbler [2]	4-4-50 Bordeaux	303	22.69	17.20	.443
Do [1]	0-4-50 spray (no copper)	245	20.14	15.13	.400
Do [1]	10-10-50 Bordeaux	291	22.43	17.15	.444
Do [2]	Pickering spray	261	21.92	16.73	.443
Do [2]	Check (no copper)	288	20.66	15.68	.429
McCormick [1]	Check (no copper)	245	21.72	15.85	.430
Do [1]	0-4-50 spray (no copper)	237	21.36	15.50	.419
Do [1]	Pickering spray	259	21.88	15.90	.456
Do [1]	4-4-50 Bordeaux	241	21.32	15.50	.436
Do [1]	10-10-50 Bordeaux	226	21.47	15.75	.457

[1] Average of 2 sets. [2] Average of 3 sets.

The 10–10–50 Bordeaux spray showed no particular advantages over the 4–4–50 Bordeaux spray or the Pickering spray in either the early or late tests. The vines receiving the 0–4–50 spray, which contained no copper but did contain lime, usually showed yield results lower than those of the checks, but the results of the analyses of the tubers usually agreed rather closely with those obtained for tubers from the check plants. The yield data are variable, but on an average are higher for the copper-sprayed than for the check plants. The data for solids, starch, and nitrogen are generally higher for the copper-sprayed than for the lime-sprayed or check plants. This indicates that copper is the essential constituent of the spray.

Maine, New York, New Jersey, and Pennsylvania.—Thirty-three samples of tubers from Bordeaux-sprayed plants from Maine, Pennsylvania, and New Jersey and from Bordeaux-sprayed and Bordeaux-dusted and unsprayed potato vines in New York (Table 5) were examined. All of the plants were sprayed with an arsenical. Sander's Bordeaux dust was used. The sprays and dusts were applied five times during the season.

TABLE 5.—*Composition of tubers from sprayed and unsprayed potato plants, Maine, Pennsylvania, New Jersey, and New York, 1920.*

Source.	Variety.	Treatment.	Composition of tubers.		
			Solids.	Starch.	Nitrogen.
			Per cent.	*Per cent.*	*Per cent.*
Maine	Irish Cobbler	5-5-50 Bordeaux	20.45	15.95	0.367
Do	do	Check (no copper)	18.39	13.80	.353
Do	Spalding Rose	5-5-50 Bordeaux	18.23	13.80	.356
Do	do	Check (no copper)	18.13	13.95	.319
Do	McCormick	5-5-50 Bordeaux	21.70	16.80	.371
Do	do	Check (no copper)	20.91	16.00	.356
Do	Early Rose	5-5-50 Bordeaux	21.65	17.00	.316
Do	do	Check (no copper)	21.93	16.95	.339

TABLE 5.—*Composition of tubers from sprayed and unsprayed potato plants, Maine, Pennsylvania, New Jersey, and New York, 1920*—Continued.

Source.	Variety.	Treatment.	Composition of tubers.		
			Solids.	Starch.	Nitrogen.
			Per cent.	*Per cent.*	*Per cent.*
Pennsylvania	Blight Proof	5-5-50 Bordeaux	25.55	20.80	0.395
Do	do	Check (no copper)	21.92	17.30	.353
Do	Dibble Russet	5-5-50 Bordeaux	21.79	16.75	.362
Do	do	Check (no copper)	23.36	18.53	.334
Do	Blight Proof Union Co	5-5-50 Bordeaux	24.42	21.04	.340
Do	do	Check (no copper)	19.80	15.20	.363
New Jersey	American Giants [1]	4-4-50 Bordeaux	18.20	12.73	.334
Do	do [1]	Check (no copper)	18.33	12.35	.290
New York	Variety 9 (Wilkes)	4-4-50 Bordeaux	23.12	19.50	.274
Do	do	Bordeaux dust	22.96	19.00	.311
Do	do	Check (no copper)	23.16	19.10	.297
Do	Variety 9 (White)	4-4-50 Bordeaux	22.74	18.60	.412
Do	do	Bordeaux dust	22.74	18.40	.403
Do	do	Check (no copper)	22.35	18.20	.367
Do	Heavyweight (Edwards)	Bordeaux dust	23.80	18.90	.401
Do	do	Check (no copper)	21.72	17.30	.356
Do	Goldson	4-4-50 Bordeaux	28.16	22.30	.455
Do	do	Bordeaux dust	26.42	21.00	.478
Do	do	Check (no copper)	26.62	21.40	.416
Do		4-4-50 Bordeaux	24.03	19.60	.236
Do		Check (no copper)	20.34	15.40	.290
Do	Dibble Russet (Slayton)	Bordeaux dust	27.61	22.75	.348
Do	do	Check (no copper)	27.37	22.80	.347

[1] Average of 2 sets.

For the New York data several varieties of potatoes grown near Bath and one variety from Geneva were analyzed. From the limited number of samples tested it is impossible to state definitely whether Bordeaux dust has the same favorable effect on the potato plant as Bordeaux spray has, although the results in Table 5 are not particularly favorable to the dust, with the exception of those for the Heavyweight variety. Average figures for three sets grown in New York gave 24.67 per cent of solids for tubers from Bordeaux-sprayed plants, 24.04 per cent for tubers from Bordeaux-dusted plants, and 24.04 per cent for tubers from unsprayed plants. The average starch results for these three sets are 20.13 per cent for tubers from plants receiving Bordeaux spray, 19.47 per cent for those from plants treated with Bordeaux dust, and 19.57 per cent for those from the check plants. The average nitrogen data for the three sets are: Tubers from Bordeaux-sprayed plants, 0.38 per cent; tubers from Bordeaux-dusted plants, 0.397 per cent; and tubers from unsprayed plants, 0.36 per cent. Comparing all five dusted plots with the five corresponding checks gives an average of 24.71 per cent solids against 24.24 per cent, and comparing all four Bordeaux-sprayed plots an average of 24.51 per cent solids against 23.12 per cent for the checks. In general, the results for the New York tubers were higher when Bordeaux spray was used than when no spray was used.

Data were secured for four varieties of potatoes grown in Maine, two varieties from Pennsylvania, one variety having been grown in two different places, and one variety from New Jersey. Three of the four samples of tubers from Maine were higher for Bordeaux and they averaged 20.51 per cent solids from the Bordeaux-sprayed plants and 19.84 per cent from the check plants. Two of the three sets of tubers from Pennsylvania were higher for the Bordeaux samples and the average solids content for the three sets was 23.92 per cent from the Bordeaux-sprayed plants, as compared with 21.69 per cent for the tubers from the check vines. The two samples of the American Giant variety from New Jersey had practically the same content of solids and the tubers from the Bordeaux-sprayed vines had but slightly higher contents of starch and nitrogen.

The average results for the tubers from the four States show that the general effect of the copper sprays is to increase the solids content of the tubers.

1921 DATA.

Presque Isle, Me.—The 1921 experiments were conducted at Presque Isle, Me., to determine the influence of Bordeaux, Pickering, and barium-water sprays, all containing copper, on the yield of tubers. The data were compared with data obtained from check or noncopper-sprayed plants in each case. All of the plants received an arsenical spray.

TABLE 6.—*Yield from 3 varieties of potatoes, Presque Isle, Me., 1921.*

Variety.	Front plots.			Rear plots.			Total.[3]
	Plot No.	Spray used.	Yield.[1]	Plot No.	Spray used.	Yield.[1]	
Aroostook farm:			*Pounds.*			*Pounds.*	*Pounds.*
Early Rose	2	Bordeaux	[2] 128	1	Check (no copper)	[2] 107	
Early Ohio	4	....do	[2] 106	3	....do	[2] 99	
Irish Cobbler	5A	Check (no copper)	868	5B	....do	724	1,592
Do	6	Bordeaux	864	7	Pickering	780	1,644
Green Mountain.	8A	Check (no copper)	1,020	8B	Check (no copper)	821	1,841
Do	9	Bordeaux	1,070	10	Barium	850	1,920
Do	11A	Pickering	1,046	11B	....do	909	1,955
Kneeland farm:							
Green Mountain.	1A	Bordeaux	723	1B	Bordeaux	636	2,751
Do	2A	Proprietary spray	639	2B	Proprietary spray	707	2,682
Do	3A	Check (no copper)	583	3B	Check (no copper)	532	2,376
Do	3C	Barium spray	671	3D	Barium spray	733	2,859
Do	4A	Bordeaux	732	4B	Bordeaux	660	
Do	5A	Pickering	664	5B	Pickering	716	2,760
Do	6A	Check (no copper)	648	6B	Check (no copper)	613	
Do	6C	Barium spray	744	6D	Barium spray	711	
Do	7A	Proprietary spray	625	7B	Proprietary spray	711	

[1] Yield from 2 rows, 300 feet long, in case of Aroostook farm potatoes; yield from 2 rows, 225 feet long, in case of Kneeland farm potatoes.
[2] Yields from 50 hills each.
[3] Yield from 2 plots in case of Aroostook farm; yield from 4 plots in case of Kneeland farm.

From the data from the Aroostook farm and from the Kneeland farm (Table 6) it is evident that the copper-sprayed plants generally gave an increased yield of tubers. In 1921 there was no late blight (*Phytophthora infestans*) in northern Maine. The reason for using copper sprays in this locality is to control this fungus. Increased yields seem to follow the application of these sprays in seasons when no late blight was prevalent.

PROPORTION OF TUBERS TO VINES PLUS TUBERS.

The weights of vines and tubers were determined at Presque Isle, Me., at the time the analyses of the tubers reported in Table 1 were made. As a rule, eight healthy potato plants were pulled and the potatoes under them dug. The dirt was shaken from the vines and the adhering roots, and the soil was wiped from the tubers. The vines and tubers were then weighed together and separate weighings of the tubers were made. From these data the percentage of tubers in terms of the total weight of the vines plus tubers was calculated.

TABLE 7.—*Weight of potato vines and tubers, Presque Isle, Me., 1921.*

Variety.	Date weighed.	Bordeaux-sprayed.			Pickering-sprayed.			No copper spray (check).		
		Vines.	Tubers.		Vines.	Tubers.		Vines.	Tubers.	
		Lbs.	*Lbs.*	*Per ct.*	*Lbs.*	*Lbs.*	*Per ct.*	*Lbs.*	*Lbs.*	*Per ct.*
Irish Cobbler	July 26 [1]	7.50	3.00	28.5	7.25	2.50	25.6	9.75	2.50	20.4
Do	Aug. 15 [2]	5.25	5.75	52.3	7.00	7.00	50.0	5.25	5.25	50.0
Do	Sept. 17 [3]	3.50	8.50	70.8	3.25	9.00	73.5	2.50	11.25	[6] 81.8
Early Rose	Aug. 2 [1]	6.00	2.75	31.4				6.00	2.75	31.4
Do	Aug. 19 [2]	6.75	6.75	50.0				6.75	6.75	50.0
Do	Sept. 14 [3]	6.25	13.75	68.8				4.75	13.00	[6] 73.2
Early Ohio	Aug. 3 [1]	6.50	2.75	29.7				8.25	2.50	23.3
Do	Aug. 18 [2]	7.25	6.75	48.2				8.25	8.00	49.2
Do	Sept. 13 [3]	4.25	8.25	66.0				4.00	8.00	[6] 66.7
Green Mountain	Aug. 23 [1]	10.75	4.00	27.1	[4] 11.50	[4] 5.00	[4] 30.3	8.50	2.75	24.4
Do	Aug. 23 [2]	7.00	5.50	44.0	5.25	4.00	43.2	5.75	4.00	41.0
Do	Aug. 29 [2]				[4] 4.25	[4] 4.00	[4] 48.5	5.00	5.00	50.0
Do	Sept. 20 [3]	3.38	7.38	68.6	[4] 4.00	[4] 8.75	[4] 68.6	2.25	7.25	[6] 76.3
Do	Sept. 21 [3]				4.00	10.50	72.4			
Do	do				[5] 3.00	[5] 9.50	[5] 76.0			

[1] Date of first analysis.
[2] Date of second analysis.
[3] Date of last analysis.
[4] Barium-sprayed.
[5] Nickel-sprayed.
[6] The check vines at time of last analyses were dead or partly dead and therefore lighter than the vines of the copper-sprayed plants. These figures are not comparable with the other data.

The data presented in Table 7 show that when the potato vines were growing, that is, while they were green, a higher proportion of tubers to vines plus tubers was usually found in the copper-sprayed than in the unsprayed plants. At the time the first weighings were made, as soon as the tubers were about an inch in diameter, the influence of the copper sprays was shown. The results in Table 7 indicate that the stimulating effect of the copper is largely shown by the increased weights of tubers rather than by increased weights of the vines and that it is exerted early in their development. As the tubers are the storehouse for the starch formed in the leaves, the percentage of starch in the tubers would naturally increase. At the time the last analyses of the tubers were made the unsprayed vines had partly dried and therefore were lighter than the corresponding vines for the copper-sprayed plants. The data for these samples are not directly comparable with the rest of the data.

INFLUENCE OF STRENGTH AND NUMBER OF APPLICATIONS OF COPPER SPRAYS ON COMPOSITION OF TUBERS.

Several samples of tubers grown in New Jersey during the season of 1920 were analyzed for solids and nitrogen. Some of the plots from which samples were taken had received a 10–10–50 Bordeaux spray; others had received a 5–5–50 Bordeaux spray; a third plot had been treated with a 2½–2½–50 spray; while some of the plots had received no copper spray. The results for solids and nitrogen in the tubers from copper-sprayed plants were: 10–10–50 spray, 17.9 per cent solids and 0.38 per cent nitrogen; 5–5–50 spray, 18.5 per cent solids and 0.34 per cent nitrogen; 2½–2½–50 spray, 20.1 per cent solids and 0.33 per cent nitrogen. The check tubers contained 18.3 per cent solids and 0.33 per cent nitrogen. The tubers from the plots receiving the 2½–2½–50 spray were highest, and those from the 10–10–50-sprayed plots were lowest in solids.

These results suggest the possibility that a certain proportion of copper in a spray gives the maximum stimulating effect in this locality and that a spray containing a greater proportion of copper may have a toxic rather than a stimulating effect. Tubers grown at Arlington Experimental Farm in 1920 from vines that were sprayed with a 10–10–50 Bordeaux spray (p. 13) seemed to have no advantages over the tubers from plants sprayed with a 4–4–50 Bordeaux. It is, of course, probable that the stimulating effect of the copper varies with the climatic conditions, variety of potatoes used, etc. Tubers from vines in New Jersey sprayed with a 5–5–50 spray eight times during the season were compared with tubers from vines sprayed only four times with Bordeaux spray of the same strength. The average data for four sets were 18.6 per cent of solids and 0.37 per cent of nitrogen in the tubers from vines sprayed eight times and 19.1 per cent of solids and 0.35 per cent of nitrogen for the tubers from vines sprayed only four times. These variations are small and may not be due to the differences in the spray applications. These data also indicate that too much copper may have reached the vines by the eight applications, whereas the amount of copper present in the four applications was nearer the quantity required to give the best protective effect or a maximum stimulation to the plants.

INFLUENCE OF ENVIRONMENT ON COMPOSITION OF TUBERS.

The following data were obtained during the 1919 season. Early Rose tubers grown in Connecticut contained 21.59 per cent solids and 0.38 per cent nitrogen and the same variety grown at Arlington Experimental Farm contained 15.83 per cent solids and 0.33 per cent nitrogen. Irish Cobbler tubers grown in Connecticut contained 22.28 per cent solids and 0.43 per cent nitrogen, while the same variety grown at Arlington Experimental Farm contained 18.57 per cent solids and 0.36 per cent nitrogen. Dibble Russets from New York contained 25.38 per cent solids and 0.39 per cent nitrogen and the same variety grown at Mt. Carmel, Conn., contained 21.24 per cent solids and 0.30 per cent nitrogen. Early Ohio tubers from Minnesota contained 22.79 per cent solids and 0.48 per cent nitrogen and the same variety from Connecticut, 20.52 per cent solids and 0.48 per cent nitrogen. These results again suggest that the composition of the tubers is influenced by the environment.

Although these tubers were not grown from the same stock, the results in each case seem to indicate that a northern tuber is higher in solids than a southern tuber. This may explain why a northern grown potato is a better seed potato than one grown in the South. The data also show that there is a decided variation in the percentage of solids in tubers of different varieties grown in the same locality. In this connection it is interesting to recall the findings of LeClerc and Yoder (*27*) who, working with wheat in four different parts of the United States, concluded that environment rather than heredity is the major factor in determining the physical and chemical characteristics of the wheat crop.

COPPER CONTENT OF VINES, STEMS, ROOTS, AND TUBERS OF SPRAYED AND UNSPRAYED PLANTS.

Copper is widely distributed in nature. Apparently all plants and animals contain small amounts of this metal.

In 1816 Meissner (*35*) reported that copper was present in the ash of various plants in small quantities. Dieulafait (*12*) in 1880 showed that the amount of copper present in vegetation was largely determined by the nature of the soil.

Lehmann (*28*), in 1895 and 1896, estimated the copper in wheat, rye, barley, oats, maize, buckwheat, potatoes, beans, linseed, apricots, pears, breads, cocoa, and chocolate. He found that only in the plants grown in soil relatively high in copper does any appreciable amount of copper get into the plant. The species of plant is apparently of less importance than the copper content of the soil in determining the amount of copper found in the plant. In wheat and buckwheat the copper was chiefly in the stems and leaves, little being found in the fruits and seeds. Therefore a high copper content in the soil does not necessarily mean that much copper is present in the grain and seed. The form in which the copper exists in plants is not known. Lehmann gives data showing that the quantity of copper in any species of plant varies with the individuals of the species, even when grown on the same soil in the same year, and under similar conditions.

MacDougal (*34*) examined microscopically and analyzed various parts of a tree which had grown in copper-bearing soil. He found metallic copper in relatively large quantities throughout the tissues, indicating an absorption of copper by the tree over a period of years.

TABLE 8.—*Copper in tubers from copper-sprayed and noncopper-sprayed plants.*

[Parts per million.]

Variety.	Place grown.	Copper in dry tubers from vines treated with [1]—				
		Calcium arsenate (no copper).	Bordeaux spray.	Pickering spray.	Lead arsenate (no copper).	Check (no copper).
Spalding Rose	Arlington Experimental Farm, Va.	8	11	15		
Irish Cobbler	do	11	13	9		
Do	do	11	15	14		
Do	do	14	16	15		
Average		11	14	13		
American Giant	New Jersey		15		11	
					10	11
			9		10	
Early Ohio	Minnesota		10			13
Green Mountain	Presque Isle, Me.		10			9
Magnum Bonum	New York		11			10
Dibble Russet	do		[2] 8			
			[3] 8			7
	Pennsylvania		8			10
Average			10			10

[1] All of the copper-sprayed plants received an arsenical spray as well.
[2] Sprayed twice.
[3] Sprayed 6 times.

Some of the tubers from copper-sprayed and from unsprayed potato plants grown at Arlington Experimental Farm during the season of 1920 were analyzed for copper (Table 8). The average figure for tubers from copper-sprayed plants grown at Arlington was 13.5 and for those from plants receiving no copper, 11 parts of copper per million. Average figures for tubers grown in other localities were 10 parts of copper per million for those from both the Bordeaux-sprayed and unsprayed vines. The writer (*11*) has shown that tubers contain only traces of copper, while the roots, stems, and leaves of potato plants contain appreciable quantities.

During the season of 1921 three separate samples of leaves, stems, and roots from four varieties of potatoes were analyzed for copper. At the time of each analysis nine plants were dug and immediately taken to the laboratory, where they were washed in water. The plants were next dipped in 4 per cent hydrochloric acid for 30 seconds and then held in water for 5 minutes. This process was repeated three times. The plants were finally placed in a large tub, covered with water, and allowed to remain overnight. The next day all of the plants were thoroughly rinsed in running water and then in distilled water, after which they were dried in the air. The leaves were used for analysis directly. The stems and roots of all the samples were carefully scraped with a knife to remove the outer layers of plant tissue. The scraped samples were then washed in distilled water to remove any possible copper contamination during the scraping process. Five grams of the dried sample were used for copper analysis by the colorimetric method. The acid and water treatments apparently removed all the external copper from the plants, as the results for copper in the roots are higher than those for copper in the leaves.

TABLE 9.—*Copper in leaves, stems, and roots of Bordeaux-sprayed and unsprayed potato plants, 1921.*

(Parts per million on the dry basis.)

Date of digging.	Variety.	Leaves.		Stems		Roots.	
		Sprayed plants.	Unsprayed plants.	Sprayed plants.	Unsprayed plants.	Sprayed plants.	Unsprayed plants.
Aug. 2	Early Ohio	6.6	5.0	3.4	2.6	6.7	3.8
Do	Early Rose	13.0	10.0	6.6	4.0	18.4	7.6
Do	Irish Cobbler [1]	11.0	9.0	9.3	8.9	21.5	16.9
Do	Green Mountain [2]	8.0	7.4	4.6	5.8	7.5	8.0
Aug. 18	Early Ohio	10.6	12.0	9.4	8.1	16.2	9.9
Do	Early Rose	9.6	9.6	6.0	8.0	8.6	10.4
Do	Irish Cobbler	12.0	8.0	7.6	10.2	8.4	8.0
Do	Green Mountain [2]	11.4	10.6	7.0	7.0	10.1	8.6
Sept. 13	Early Ohio	17.3	10.0	14.0	11.2	26.0	13.8
Do	Early Rose	13.0	9.0	5.0	8.5	19.4	9.1
Do	Irish Cobbler	11.0	9.0	8.1	6.3	8.3	9.0
Do	Green Mountain	9.0	6.8	6.3	4.4	9.1	6.6

[1] Sprayed with Pickering spray. [2] Sprayed with barium-water spray.

The data for the leaves, stems, and roots, given in Table 9, show certain variations, but in the majority of the samples the corresponding figures for the copper-sprayed were higher than those for the unsprayed samples. The roots held the most and the stems the least copper for all four varieties of potato plants. The three early varieties of potato plants contained more copper than the Green Mountain, a late variety. An appreciable quantity of the copper was present in all of the check plants.

GENERAL DISCUSSION.

In the case of copper sprays it is generally recognized that a small quantity of copper is gradually rendered soluble either by the juices of the plant or by the carbon dioxid of the air, and this copper thus rendered soluble may protect the plant and may stimulate its metabolic activities. The intensity of action of the copper compounds varies with the kind of plant used and with the quantity of copper applied. This difference in the ability of plants to withstand the action of copper sprays was illustrated by the drastic effect of Pickering sprays (*9*) on the grape and apple compared with its favorable action on the potato and cranberry. The influence of environment, soil, climate, etc., must also be considered in this connection, as a Bordeaux spray may be used on a certain plant in one section of the country but can not be used without severe injury on the same plant in another locality. The data show that increased growth and tuber formation of the potato following the use of copper sprays may be secured. The fact that a certain amount of hopperburn was present in most of the fields where these tests were conducted is recognized. It was not severe in any case and practically none was observed on the plants at Arlington Experimental Farm. Some of the increased yield of tubers from copper-sprayed potato plants was undoubtedly due to the action of the copper sprays in controlling potato leafhoppers and thereby reducing hopperburn. It is difficult to explain it all on the basis of protective action alone.

Analyses of grapes from copper-sprayed and from unsprayed vines reported by the writer (*9*) showed that the composition of the grape had apparently been altered by the application of the copper sprays. Evidently copper sprays alter the composition of the potato and the grape and there is no reason to believe that their action is restricted to these two plants.

Several theories have been advanced to explain the increased yield of tubers from Bordeaux-sprayed potato plants:

(*a*) Bordeaux spray increases the transpiration rate of potato plants, according to Lutman, Duggar, and others. This effect would apparently be an advantage in wet seasons or wet localities but a disadvantage in dry seasons or dry localities. Differences in humidity cause differences in the transpiration of plants, and this may react on the growth of the plant and the composition of the tubers.

(*b*) It is possible that changes in the rate of respiration or in the general metabolism of potato plants may follow the application of copper sprays. A small quantity of copper may be absorbed by the plant and stimulate it to increased activity. There are several examples of stimulation brought about by a small amount of a substance which in large quantities is toxic. There is evidence that copper stimulates some plants and the fact that stimulation can not be shown to exist does not prove that it is not there. Analyses of the leaves, vines, and roots of sprayed and unsprayed potato vines in most cases showed a higher proportion of copper in the leaves, stems, and roots of the sprayed potato plants than in those of the unsprayed plants.

(*c*) Variations in sunlight or stimulation resulting from the application of copper sprays may influence the photosynthetic processes.

(*d*) The copper sprays protect the vines which are thus kept freer from tip burn, disease, and insect injury. Vines treated in this way are therefore more vigorous and their tubers may show an increase in solids, as well as in yield. It is now recognized that potato leafhoppers are the direct cause of hopperburn and that Bordeaux mixture repels the hoppers. Bordeaux spray is a protection against potato leafhoppers, flea beetles, and other insects, as well as against fungous diseases. It is not clear why the tubers should be higher in solids unless it is simply taken for granted that a vigorous plant produces a tuber higher in solids than a less vigorous plant. There is a possibility that the protective effect of Bordeaux is the only effect produced, but copper salts have such a pronounced effect on all living tissue that a stimulation is generally suspected and even accepted by many investigators in this field.

Some suggestions from the recent work of Sherman and his coworkers are of interest in this connection. They studied the effects of certain antiseptics upon the activity of amylases (*42*), all of which were very sensitive to copper sulphate. They also studied the influence of certain amino acids upon the enzymic hydrolysis of starch (*43*), finding that glycine, alanine, phenyl alanine, or tyrosine caused an undoubted increase in the rate of hydrolysis of starch by purified pancreatic amylase, commercial pancreatin, saliva, or purified amylase. The favorable effect is not due to any influence on hydrogen ion concentration nor to a combination of the amino acid with the product of the enzymatic reaction. The addition of 1 per cent of these amino acids was shown to be a very effective means of protecting the enzyme from the deleterious effect of copper sulphate and may even serve to restore to full activity any enzyme which has been partially inactivated by copper. Arginine and cystine have a favorable influence upon the hydrolysis of starch by purified pancreatic amylase, while histidine and tryptophane do not (*44*). The effect of histidine and tryptophane differs from that of all the other amino acids studied, possibly because of their heterocyclic structure or their position in the protein complex which doubtless constitutes either the enzyme itself or an essential part of it.

There is evidence that a somewhat larger quantity of copper is present in copper-sprayed potato plants than in the unsprayed plants, and also that the proportion of amino and amid nitrogen in potato plants increases during growth. Data showing that copper had a favorable effect on the yield and composition of tubers were obtained. Possibly the amino acids protect the cell activity from any toxic action of the copper, thus permitting the copper to exert a stimulating effect on the cells.

It is recognized that it would be desirable to have data showing the normal variation for the different varieties of tubers under the same conditions, but time did not permit the securing of such data. Analyses of several hundred tubers, both copper-sprayed and check, were obtained and the average data from this large number of tubers should overcome individual variation.

The results reported in this paper appear to establish the fact that copper sprays not only increase the yield of potatoes in various sections of the country, but favorably influence their composition.[2] Bordeaux sprays, Pickering sprays, and barium-water sprays seemed to give the increased yield and increased solids of the tubers which apparently depend on the presence of copper in the spray. In addition to plant-disease control and insect control, the copper appears to exert a stimulating action on the potato plant.

Bordeaux and other sprays containing copper are usually applied to the potato to control the late blight. In some States such a spray is applied as a repellent to the flea beetle and the potato leafhopper, thereby reducing the injury to the foliage from these two insect pests and at the same time lessening tip burn and hopperburn. The importance of the effect of copper sprays on the yield of potatoes, in addition to their control of diseases and insects, has not been generally recognized or at least emphasized. Nor has the fact that tubers from copper-sprayed plants may be stored more satisfactorily—that is, with less loss from rot—than tubers from noncopper-sprayed plants been widely advertised. When, in addition, an increased yield of potatoes and a higher proportion of solids in them follow the application of copper sprays, important additional reasons for their more general use become evident.

SUMMARY.

Tubers from copper-sprayed potato plants at the time they were large enough for analysis (about one inch in diameter) were usually higher in solids, starch, and nitrogen than the tubers from unsprayed vines. The starch content increased approximately 50 per cent as the tubers matured, while the dextrose disappeared and the sucrose was materially reduced. The early varieties of potatoes showed a decrease in their sugar content to accompany an increased starch content in the copper-sprayed tubers during the early stages of development. The proportion of insoluble ash decreased during the growth of the tubers, although the total ash content remained constant. The total nitrogen increased. The figures for soluble, coagulable, and particularly the monoamino and amid nitrogen increased as the tubers matured.

The proportion of tubers to green vines appeared to be higher for the copper-sprayed than for the unsprayed plants.

Average data for seven States obtained in 1919 showed the food value of an acre of copper-sprayed potatoes to be 839 pounds more than that for an acre of noncopper-sprayed potatoes. Two factors, increased yield (48 bushels an acre) and an increase of solids (5.6 per cent), are involved.

Some results obtained at Arlington Experimental Farm, Va., comparing a 10–10–50 Bordeaux and a 5–5–50 Bordeaux, suggest that the former spray has no advantage over the latter and may possibly furnish too much copper for the maximum stimulating or protective effects. Results from New Jersey, where a 4–4–50 Bordeaux spray was applied eight times, compared with results where the same spray

[2] Attention is called to the experiments of Gray and Ryan, Monthly Bull. Dept. Agr. State of California, Chemical Number, vol. 10, no. 1, pp. 11–33, 1921. They showed that the acidity of oranges was reduced by the arsenical spray.

was applied four times, show that the tubers were lower in solids in the former than in the latter case, suggesting again that too much copper may have reached the plant for the best results in the absence of any late blight.

Tubers from several varieties of potatoes grown in a northern State were higher in solids than tubers of the same varieties grown in a State farther south.

A larger yield of potatoes was secured from copper-sprayed than from check or noncopper-sprayed vines. Late blight (*Phytophthora infestans*) is eliminated as a necessary factor in the case.

When a lime spray containing no copper was used at Arlington Experimental Farm, Va., the yields of tubers were decreased. Pickering-limewater spray and a barium-water spray gave practically the same increase in yield and in solids of the tubers as a Bordeaux spray. The copper in the spray seems to be the essential factor.

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