

V.—*On the Application of Iron Sulphate in Agriculture, and its Value as a Plant-food.*

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In this paper, details are given of some of my most recent work on the use of ferrous sulphate as a manure. This year, I have grown leguminous, root, and cereal crops with and without an iron manure. The experimental plots of land were (as in the experiments last year) in the vicinity of Bromsgrove, Worcestershire. The soil consists chiefly of clay and loam derived from the Lias, or the upper members of the New Red Sandstone formations, and in a former paper, "Experimental Investigations on the Value of Iron Sulphate as a Manure for Certain Crops," (this Journal, Trans., 1884, p. 71), analyses of this soil are given.

This year, six plots of well-drained land were chosen all about the same area. On plots Nos. I and II, the experiments performed last year on a leguminous crop (beans) were repeated. Plot No. I was manured with crystallised ferrous sulphate of commerce (the quantity applied being $\frac{1}{2}$ cwt. to the acre). Plot No. II was left in its normal condition. As in former experiments, the same number of *bean seeds* were planted on the same day, on each plot of land. At the end of the season the yield of each plot of land was as follows:—

TABLE I.

	Plot of land (manured with FeSO_4).		Plot of land (normal).	
	(1.) Weight when gathered.	(2.) Weight when dry.	(1.) Weight when gathered.	(2.) Weight when dry.
Total weight of crop (grain + straw)	6215 lbs.	5325 lbs.	4793 lbs.	4105 lbs.

The crop of beans (*Vicia faba*) grown by the aid of the iron manure yielded 44 bushels of grain, whilst the crop grown without the iron manure yielded only 28 bushels, so again there is a marked difference in the weight of the produce of the two plots of land. Last year (*loc. cit.*), the iron manure gave an increase of 21 bushels of beans, and now there is an increase of 16 bushels.

TABLE II.—*Analyses of Ashes of Entire Plants.*

	Plants grown <i>with</i> iron manure.	Plants grown <i>without</i> iron manure.
<i>Iron oxide</i> , Fe_2O_3	4·910	1·002
Potash, K_2O	17·965	20·984
Soda, Na_2O	18·021	18·213
Lime, CaO	5·999	7·125
Magnesia, MgO	8·002	8·839
Silica, SiO_2	1·734	2·836
<i>Phosphoric oxide</i> , P_2O_5	40·831	37·814
Sulphuric oxide, SO_3	1·162	1·396
Sodium chloride.....	1·376	1·790
	100·000	99·999

TABLE III.—*Analyses of Ashes of Pods minus the Seeds.*

	Grown <i>with</i> iron manure.	Grown <i>without</i> iron manure.
<i>Iron oxide</i> , Fe_2O_3	2·094	0·924
Potash, K_2O	40·999	42·332
Soda, Na_2O	2·986	3·715
Lime, CaO	7·001	6·548
Magnesia, MgO	7·142	7·231
Silica, SiO_2	0·552	0·525
<i>Phosphoric oxide</i> , P_2O_5	36·235	34·400
Sulphuric oxide, SO_3	2·582	3·442
Chlorine.....	0·407	0·883
	99·998	100·000

TABLE IV.—*Analyses of Ashes of the Seeds.*

	<i>With</i> iron manure.	<i>Without</i> iron manure.
<i>Iron oxide</i> , Fe_2O_3	0·575	0·574
Potash, K_2O	42·502	42·498
Soda, Na_2O	1·362	1·365
Lime, CaO	4·783	4·779
Magnesia, MgO	7·111	7·124
Silica, SiO_2	0·800	0·810
<i>Phosphoric oxide</i> , P_2O_5	38·799	38·800
Sulphuric oxide, SO_3	2·546	2·531
Chlorine.....	1·511	1·519
	99·989	100·000

The analyses were performed in duplicate.

From the tables (pp. 46, 47), it will be seen that the crop of beans was greatly increased by manuring the land with iron sulphate; in fact as much as 1422 lbs. when gathered, and 1220 lbs. when dry, also with an increase of 16 bushels of grain. Comparing them with the results obtained last year, the analyses of the ashes of the various parts of the plant agree very remarkably. Last year an increase of 1573 lbs. was obtained with the iron manure when the crop was gathered, and 1395 lbs. when dry, and an increase of 21 bushels of grain over the crops grown without the iron manure. From last year's analyses and in those given in the present paper, it will be seen that the percentage of ferric oxide in the ashes of the various parts of the plant is much larger when the plants have been grown with ferrous sulphate than without it; and also that the phosphoric oxide in the ash increases as the ferric oxide increases. In Table IV, which is the result of the analyses of the ashes of the seeds, it is plain that there is no difference whether the crop is grown with or without an iron manure. Thus confirming for a second time on a large scale that the ash of the seed or embryo of a plant is very constant in its composition whatever manure is applied to the land.

The next two tables illustrate the percentage of Fe_2O_3 and P_2O_5 in the ashes of the two seasons' crops.

TABLE V.—*Entire Plant.*

	1883.			1884.		
	<i>With iron manure.</i>	<i>Without iron manure.</i>	<i>Difference.</i>	<i>With iron manure.</i>	<i>Without iron manure.</i>	<i>Difference.</i>
Fe_2O_3 .	4·221	1·063	3·158	4·910	1·002	3·908
P_2O_5 .	41·902	37·941	3·961	40·831	37·814	3·017

TABLE VI.—*Pods minus Seeds.*

	1883.			1884.		
	<i>With iron manure.</i>	<i>Without iron manure.</i>	<i>Difference.</i>	<i>With iron manure.</i>	<i>Without iron manure.</i>	<i>Difference.</i>
Fe_2O_3 .	2·021	0·911	1·110	2·094	0·924	1·170
P_2O_5 .	36·061	34·240	1·821	36·235	34·400	1·835

From the above, it is evident that there is an increase of about 3 per cent. of ferric oxide and phosphoric oxide in the ashes of the *entire* plant, when grown in a soil containing an iron manure; and an increase of about 1 per cent. of ferric oxide, and nearly 2 per cent. of phosphoric oxide in the ashes of the *Pods*.

I am fully convinced that the proposition I advocated nearly two years ago (*Chem. News*, 47, 27), that a "*fairly large proportion of soluble iron in a soil is favourable to the growth of plants developing a large amount of chlorophyll*," is a proved fact; and this has been confirmed by all my subsequent researches, and by the recent determinations of chlorophyll which Dr. W. J. Russell has performed on plants grown with and without an iron manure.

I shall refer again to Dr. Russell's experiments in the latter part of this paper.

Cereal Crops.

The next crop to be considered is the cereal. As in the experiments with beans, these wheat crops were grown on well-drained land and under like conditions as to sunshine and rainfall. Of two plots each of the same area, one was manured with iron sulphate ($\frac{1}{2}$ cwt. to the acre) and the other was left in a normal condition.

At the end of the season, the yield of each plot was as follows:—

TABLE VII.

	Plot of land manured with FeSO_4 .		Plot of land (normal).	
	(1.) Weight when gathered.	(2.) Weight when dry.	(1.) Weight when gathered.	(2.) Weight when dry.
Total weight of crop (grain + straw)	5021 lbs.	4301 lbs.	5030 lbs.	4360 lbs.

The crop of wheat grown by the aid of the iron manure yielded 28 bushels of grain, whilst the crop grown without the aid of the iron manure yielded 27 bushels of grain.

From these investigations, an iron manure does *not* appear to be of so great a value as a plant-food in the case of the cereal as in the leguminous crop; for the yield is much the same whether an iron manure is used or not. But there is one well ascertained fact in favour of the use of ferrous sulphate for wheat crops, and that is, the plants

were healthier and completely resisted the attack of the wheat mildew ("rust"): whilst the other crop not manured with iron was attacked to a certain extent; and this may account for the increase of 1 bushel of grain over the crop grown on the normal plot of land.

As in the experiments with the leguminous crop, analyses (in duplicate) of the ashes of the various parts of the plants of each plot of land were made with the following results:—

TABLE VIII.—*Analyses of Ashes of Entire Plant.*

	Grown with iron manure.	Grown without iron manure.
<i>Iron oxide</i> , Fe_2O_3	2·521	2·000
Potash, K_2O	12·024	12·561
Soda, Na_2O	2·135	2·410
Lime, CaO	3·634	3·710
Magnesia, MgO	5·412	5·334
Silica, SiO_2	64·846	64·724
<i>Phosphoric oxide</i> , P_2O_5	4·424	4·524
Sulphuric oxide, SO_3	4·511	4·222
Chlorine	0·493	0·514
	100·000	99·999

TABLE IX.—*Analyses of Ashes of Seeds.*

	Grown with iron manure.	Grown without iron manure.
<i>Iron oxide</i> , Fe_2O_3	1·142	1·124
Potash, K_2O	31·024	32·392
Soda, Na_2O	2·504	2·497
Lime, CaO	10·503	10·668
Magnesia, MgO	3·676	3·784
Silica, SiO_2	1·937	1·964
<i>Phosphoric oxide</i> , P_2O_5	46·222	45·269
Sulphuric oxide, SO_3	1·300	1·294
Chlorine	0·692	1·007
	100·000	99·999

The leaves of the wheat gave 3·814 per cent. of ferric oxide when the crop had been grown with iron, and only 1·642 per cent. when not so treated.

The ash analyses in the case of the *entire* wheat plant show that there is an increase of about $\frac{1}{2}$ per cent. of ferric oxide in the plants manured with iron; but this is all that can be said, and the phosphoric oxide is increased by nearly 1 per cent.

Root Crops.

As before, two plots of land were chosen; one was manured with iron sulphate ($\frac{1}{2}$ cwt. to the acre) and the other was left normal. On these two plots of land, turnips were grown; the yield of each plot was as follows:—

TABLE X.

	Plot of land manured with FeSO_4 .	Plot of land normal.
	Weight when gathered.	Weight when gathered.
Total weight of crop (root + leaves)	50,104 lbs.	44,216 lbs.

The plot of land manured with ferrous sulphate gave $16\frac{1}{2}$ tons, whilst the plot of land in its normal state gave only 13 tons of turnip roots. It is evident that there is a great increase in the produce by manuring the land with iron sulphate.

The next two tables give the analyses of the ashes of this root-crop.

TABLE XI.—*Analyses of Ashes of Turnip Roots.*

	Grown with iron manure.	Grown without iron manure.
<i>Iron oxide</i> , Fe_2O_3	1·210	0·321
Potash, K_2O	43·843	50·124
Soda, Na_2O	3·862	3·621
Lime, CaO	12·962	13·024
Magnesia, MgO	1·900	2·000
Silica, SiO_2	0·816	1·215
<i>Phosphoric oxide</i> , P_2O_5	17·910	16·412
Sulphuric oxide, SO_3	5·010	6·954
Chlorine	3·487	6·328
	100·000	99·999

The analyses in XI and XII (which were done in duplicate) show that there is an increase of nearly four times the amount of ferric oxide in the turnip roots grown with the iron manure over those grown without it; and in the turnip leaves there is more than three times the per-

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centage of ferric oxide in the ashes of the crop grown with iron as compared with that grown without iron.

TABLE XII.—*Analyses of Ash of Turnip Leaves.*

	Grown <i>with</i> iron manure.	Grown <i>without</i> iron manure.
<i>Iron oxide</i> , Fe_2O_3	3·202	0·986
Potash, K_2O	26·124	27·921
Soda, Na_2O	6·210	7·024
Lime, CaO	34·452	35·620
Magnesia, MgO	2·541	4·199
Silica, SiO_2	1·462	2·134
<i>Phosphoric oxide</i> , P_2O_5	6·943	4·218
Sulphuric oxide, SO_3	13·910	11·999
Chlorine	5·154	5·898
	99·998	99·999

Nitrogen in the Crops.

The next set of three tables gives my determinations of the *percentage* of nitrogen in each crop.

TABLE XIII.—*Nitrogen in Beans (Vicia faba).*

	Grown <i>with</i> iron manure.	Grown <i>without</i> iron manure.
Grain	4·920	4·869
Straw	2·188	1·198
	7·108	6·067

TABLE XIV.—*Nitrogen in Wheat (Triticum vulgare).*

	Grown <i>with</i> iron manure.	Grown <i>without</i> iron manure.
Grain	1·899	1·802
Chaff	0·820	0·821
Straw	0·674	0·363
	3·393	2·986

TABLE XV.—*Nitrogen in Turnips (Brassica rapa).*

	Grown with iron manure.	Grown without iron manure.
Root	2·189	2·181
Leaf	4·280	3·265
	6·469	6·446

I have also estimated the *percentage* of soluble carbohydrates (soluble in dilute acids), woody fibre (insoluble in dilute acids), and fat. Table XVI details the results.

TABLE XVI.

	Plants grown with iron manure.				
	Beans.	Bean straw.	Wheat.	Wheat straw.	Turnip.
Soluble carbohydrates..	55·81	44·23	72·14	36·00	8·97
Woody fibre.....	10·21	39·91	5·53	49·25	2·54
Fat.....	2·94	1·82	3·41	2·09	0·81

	Plants grown without iron manure.				
	Beans.	Bean straw.	Wheat.	Wheat straw.	Turnip.
Soluble carbohydrates..	49·32	38·24	66·21	31·95	6·29
Woody fibre.....	7·93	33·67	2·98	43·69	1·45
Fat.....	1·65	1·03	1·32	1·48	0·32

The above table shows that the carbohydrates, woody fibre, and fat are all more or less increased when the plants have been grown by the aid of ferrous sulphate.

The next table gives the determinations by Dr. W. J. Russell of the *relative* amounts of chlorophyll in samples of the leaves from each of my crops. He has kindly determined the relative amounts in equal weights and in equal areas of each sample, with the following results:—

TABLE XVII.—*Dr. Russell's Estimation of the Relative Amount of Chlorophyll in the Leaves.*

No. of Sample.	Leaves.	In equal areas.	In equal weights.
1	Beans (grown <i>with</i> FeSO_4)	100	100
2	Beans („ <i>without</i> FeSO_4)	79	76
1	Turnip (grown <i>with</i> FeSO_4)	59	61
2	Turnip („ <i>without</i> FeSO_4)	40	39
1	Wheat („ <i>with</i> „)	115	72
2	Wheat („ <i>without</i> „)	100	81

The leaves were collected on the same day, and were of the same age in each case. From the above determinations, it is evident that iron nourishes the chlorophyll granules, a proposition I advanced some few years ago. From Dr. Russell's analyses, it will be seen that in each plant—with the exception of wheat—when the plants have been grown with an iron manure, the chlorophyll in “equal areas” and in “equal weights” has been greatly increased. And now comes the question, what has increased the chlorophyll? The iron, because it nourishes the granules, and always is to be found near to the granules themselves in the crystallised condition when sections of the leaves are examined microscopically. (See my paper, *Chem. Soc. J., Trans.*, 1883, p. 195.)

General Conclusions.

My enquiries on this subject have led me to the following conclusions as to the effect of ferrous sulphate as a plant-food:—

I. In the case of those plants which develop a large amount of chlorophyll, for examples, beans, cabbages, and turnips, an iron manure is most beneficial, considerably increasing the harvest. (See the present paper and *Trans.*, 1884, pp. 71—75; *Chem. News*, **47**, 27—78.)

II. An iron manure greatly increases the percentage of soluble carbohydrates, woody fibre, and fat in certain plants, this, of course, being an outcome of the increase in the amount of chlorophyll in the leaf; for the chlorophyll forms starch, which is converted into “carbohydrates,” cellulose, &c. (See the present paper.)

III. I have found monoclinic crystals of ferrous sulphate near to the chlorophyll granules when sections of the leaves are examined under the highest powers of the microscope, the crystals being tested chemically and proved to be ferrous sulphate. (See *Trans.*, 1883, pp. 125—197; also *Journal Royal Microscopical Society*, 1883, p. 536.)

IV. That in certain cases the phosphoric oxide in the ashes of plants grown with this new manure increases as the ferric oxide increases. (See present paper; also Trans., 1884, pp. 71—75; *Chem. News*, **47**, 27—28.)

V. That ferrous sulphate is a good plant-food, proved by the increase in the harvest as shown above; yet in *excess* it acts as a poison to plant-life, a solution containing $\frac{1}{2}$ per cent. of FeSO_4 being fatal to most plants; and when the amount of *ferric oxide* in the ash of all the plants examined was 10 *per cent.* the plant previously died. (See *Chem. News*, **50**, 167; *Chemiker-Zeitung*, 1884, p. 757; and *Chem. News*, **50**, 193.)

VI. The sulphur of the ferrous sulphate acts as a food for the protoplasm of the cell, and the iron for the chlorophyll itself. (See *Chem. News*, **49**, 237, 265; **50**, 32; also *Chemiker-Zeitung*, 1884, p. 863; this Journal, Abstr., 1884, p. 848.)

VII. The nitrogen in the plants grown with ferrous sulphate is to some extent increased. (See present paper.)

VIII. Iron sulphate increases the amount of chlorophyll in the leaf. (See Dr. Russell's estimations in present paper.)

IX. Iron sulphate acts in the soil as an antiseptic agent, destroying to some extent certain parasitic diseases which attack our crops. (See *Chem. News*, **49**, 279; Abstr., 1884, p. 1070.)

X. My experiments have also led me to conclude that the most active rays of white light for *root-absorption* are between Fraunhofer's lines D and E. (See Trans., 1884, pp. 74—75.)

In conclusion, I wish to tender my best thanks to Dr. W. J. Russell, F.R.S., for his determinations of the relative amounts of chlorophyll in the plants. I also wish to thank Dr. T. L. Phipson, F.C.S., and my friends Mr. T. P. Wright, Dr. J. Johnstone, M. E. C. Conrad, F.C.S., of Bordeaux, and Mr. E. L. Rhead (Demonstrator in Chemistry, Technical College, Manchester), for many kind suggestions.