A PRELIMINARY NOTE ON THE EFFECT OF SODIUM SILICATE IN INCREASING THE YIELD OF BARLEY.

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(With One Text-figure.)

1. Source of Data.

The permanent barley experiment at Rothamsted, of which the first crop was harvested in 1852, contained among others four plots receiving sulphate of ammonia; of these, two plots (2 and 4) received in addition 392 lb. per acre (439 Kg./Ha.) of superphosphate, while also two plots (3 and 4) received sulphates of potassium, sodium and magnesium at rates of 200, 100 and 100 lb. per acre (224, 112, 112 Kg./Ha.) respectively.

The comparison of the yields showed from the first a satisfactory response to the phosphatic manure, but little or no response to the potash and other sulphates.

For the harvest year 1864 and subsequently these four plots were each divided in two, making two series of four plots each. The first series (Series AA) continued the treatment of the previous years, while to the second series (Series AAS) a dressing of sodium silicate was added at the rate of 400 lb. per acre (448 Kg./Ha.). In 1868 the nitrogenous dressing of sulphate of ammonia was replaced by nitrate of soda at the rate of 275 lb. per acre (308 Kg./Ha.).

The remarkable effects of the addition of silicate have already attracted considerable attention, but for lack of analytical data and other reasons it appears that the effect of the addition of silicate has been in some manner misunderstood. This note presents a summary of the results of statistical analyses of the yield data, together with new chemical analyses, which appear to show conclusively that the view previously rejected that the silicate acts by making available to the plant the actual reserves of soil phosphates must be regarded as strongly established.

2. The Effect on the Average Crop.

It was early realised that the plots receiving silicate were yielding considerably heavier crops than those which received no silicate, and that this effect was especially clear on the plots which received no phosphate. Thus Hall and Morison (1) in 1906 give the following average yields in bushels per acre for the 41 years 1864–1904.

Table I. *Grain in bushels per acre.*

	Plot 1	Plot 2	Plot 3	Plot 4
Series AA (no silicate)	27·3	42·2	28·6	41·2
Series AAS (silicate)	33·8	43·5	36·4	44·5

Table II. *Straw in cwt. per acre.*

	Plot 1	Plot 2	Plot 3	Plot 4
Series AA (no silicate)	16·2	24·6	17·9	25·3
Series AAS (silicate)	19·8	25·8	21·7	27·6

In the absence of phosphate the addition of silicate has increased the yield from 28 to 35 bushels of grain, while in the presence of phosphate the increase is only from 41·6 to 44 bushels. Such results strongly suggest that the effect of the silicate, of whatever nature it may be, is intimately concerned with the phosphatic requirements of the crop. These might be either primarily a matter of soil chemistry, if the effect of the addition of silicates were to make available some portion of the phosphatic reserves of the soil, or primarily a matter of plant physiology, if its effect were to diminish the phosphatic requirements of the plant. Only analyses of the ash can settle this primary question.

It may be remarked at once, however, that the effect can scarcely be ascribed to the sodium rather than to the silicate in the manure added. For all plots receive a large quantity of sodium as nitrate, and plots 3 and 4 in addition receive further sodium, as well as potassium, as sulphate.

3. THE ASH ANALYSES.

Ash is available from samples of grain and straw for nearly every plot in every year. Their phosphatic content is, however, with some exceptions unknown. Hall and Morison give the phosphatic contents of the ash from grain and straw for these eight plots for the harvest years 1903 and 1904. The chemical department at Rothamsted has further supplied me this year with the values for two groups of six years each, namely 1868–73 and 1906–11. These 224 analyses thus supply data for 14 separate years.

For grain the mean content of phosphoric anhydride expressed per cent. of pure ash is shown in Table III.

Table III. *Phosphoric anhydride per cent. of ash.*

	Plot 1	Plot 2	Plot 3	Plot 4	Standard error
Series AA	31·37	35·57	30·51	35·47	0·1735
Series AAS	32·51	35·42	32·74	35·94	

The differences in percentage are comparatively small, but those induced by a dressing of superphosphate are so regular that their statistical significance can scarcely be doubted. In order to test the significance of the smaller effects it is necessary to form an estimate of the standard error of these average values. It is now becoming increasingly realised that a standard error based on the agreement of duplicate chemical determinations is not a sufficient safeguard unless such errors as arise in sampling the produce and the ash can be exhaustively examined. In order to obtain one inclusive estimate we may utilise the close parallelism between plots 1 and 2 receiving no sulphates of potash, soda and magnesium, and plots 3 and 4 which receive them. The differences between these two pairs of plots were therefore calculated for each year, and their deviations from the means of the six early and the six late years respectively provide the estimate of error given in the table, this estimate being based on 40 degrees of freedom.

Judged by this standard there is a clearly significant increase due to silicates in plots 1 and 3, but no significant change in plots 2 and 4.

In Table IV are shown the averages obtained from the analyses of the straw.

Table IV.

	Plot 1	Plot 2	Plot 3	Plot 4	Standard error
Series AA	1·997	3·598	1·830	3·533	0·0399
Series AAS	1·962	3·336	1·816	3·559	—

None of the silicate comparisons can be regarded as significant, except the somewhat large reduction of phosphatic content in the ash from plot 2. There is besides a marked increase on the plots receiving superphosphate and some decrease on those receiving potash.

The data for two years given by Hall and Morison gave indications similar to those of the average of 14 years here presented. These authors, however, write as though the ash analyses showed that phosphoric acid was less abundant in the straw (although somewhat more so in the grain), whereas the analyses in reality only show the proportion of phosphoric acid in a 100 parts of ash. They argue, therefore, that the silicate "gives the plant such a stimulus as enables it to develop more vigorously and obtain more phosphoric acid from the soil"; although on the view that additional phosphate is not made available, it is difficult to explain why the phosphoric acid in the ash from the grain should not be somewhat decreased. The essential fact that appears to have been overlooked is that the increase of any one ingredient in the ash will *ceteris paribus* tend to diminish the percentage of other ingredients, and this effect will be most clearly apparent when we are concerned with two ingredients such as silica and phosphoric acid which contribute largely to the ash.

We may now turn to the very different picture presented by the total weight of phosphoric anhydride removed in the crop.

4. WEIGHT OF PHOSPHORIC ANHYDRIDE IN THE CROP.

The total ash content of the crop, both in grain and straw, being known, it is an easy matter to calculate from the percentage of phosphoric anhydride in the ash the total content of the crop in this ingredient. This is shown with a standard error, calculated as before, in Table V.

Table V. *Phosphoric anhydride in crop (lb. per acre).*

	Plot 1	Plot 2	Plot 3	Plot 4	Standard error
Series AA	10·50	22·47	10·31	22·40	0·3873
Series AAS	13·82	22·84	15·20	25·67	—

In the absence of all phosphoric fertiliser the crops on plots 1 and 3 have depleted the reserves of phosphoric anhydride to the extent of 10·4 lb. per acre (11·7 Kg./Ha.) in each year. The effect of adding silicates to these plots has been to increase the quantity removed to 14·5 lb. per acre (16·7 Kg./Ha.), or by about 40 per cent. For comparison, the addition of superphosphate, containing, at 16·5 per cent., over 64 lb. of phosphoric anhydride per acre (72 Kg./Ha.) annually, has only increased the amount removed in the crop by 12 lb. (13·5 Kg./Ha.); and when silicate is present in addition this is further increased by nearly 2 lb. In view of these figures it is difficult to avoid the conclusion that, in the presence of silicate, phosphoric acid is made available to the plant, even in plots which have been long depleted in this ingredient without replacement, in very considerable quantities.

5. THE PHOSPHATIC CONTENT OF THE CROP BY DRY WEIGHT.

The quantities of phosphoric anhydride removed in the crop, although striking in quantity and long sustained, are not competent to provide a decisive disproof of the suggestion that the effect of silicate in increasing the phosphate removed is an indirect consequence of a stimulus to the growth of the plant. Such disproof must be sought in the phosphatic content of the crop expressed as a fraction of its dry weight. For it is evident that if the increased growth of the crop is not due to increased abundance of available phosphate but to some other nutrient or stimulus, the phosphatic content of the plant reckoned as a fraction of the total organic matter present could not be increased, but must, if any change is perceptible, be diminished; whereas, on the contrary, an increase in growth directly stimulated by an increase of available phosphates might reasonably be expected to be accompanied by an increase of phosphatic content in the organic matter. A strict application of this test would perhaps require that the phosphatic content should be reckoned per 1000 parts of dry matter *less ash*; since, however, the absolute amounts of ash, though variable, are not large, only quite negligible errors will be introduced by expressing the phosphoric anhydride in 1000 parts of dry matter.

In view of the importance of this measure we shall give the averages separately for the three periods.

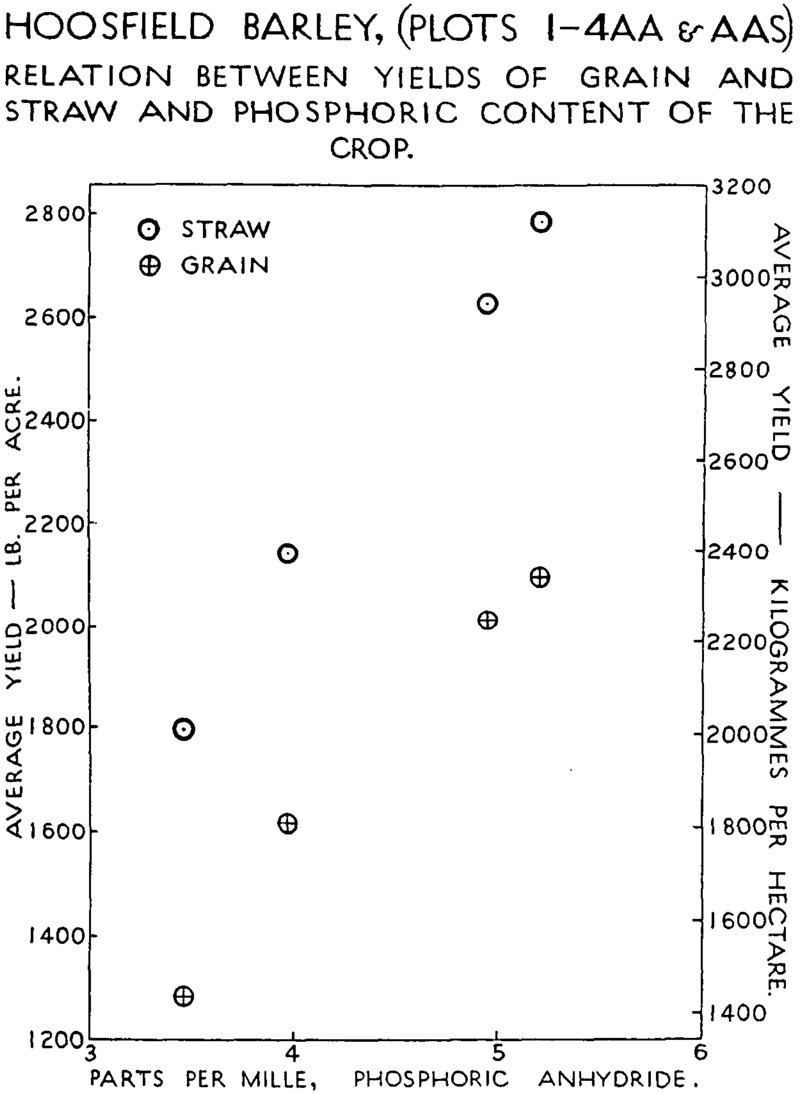
Table VI. *Phosphoric anhydride per mille dry matter.*

	Plot 1	Plot 2	Plot 3	Plot 4	Standard error
		1868–73.			
Series AA	3·67	4·69	3·60	4·82	—
Series AAS	4·09	4·88	4·08	5·21	
		1903–4.			
Series AA	3·46	5·36	3·08	5·19	—
Series AAS	4·21	5·54	3·92	5·80	
		1906–11.			
Series AA	3·36	5·10	3·34	4·97	—
Series AAS	3·85	5·25	3·80	5·20	
		14 years.			
Series AA	3·51	4·96	3·42	4·94	0·049
Series AAS	4·00	5·13	3·94	5·29	

The table (Table VI) shows at all periods separately that the phosphatic content of the dry matter of the crop is increased in all four plots. It is to be noticed that the two years for which analyses are given by Hall and Morison are not the least striking in this respect. Once the results are expressed in this form, however, there can be little doubt that the addition of silicate has had at all periods, and on all the plots, the effect of making more phosphoric acid available to the crop, and not merely of stimulating growth with the secondary effect that more phosphoric acid is absorbed.

6. CROP INCREASE IN RELATION OF ABUNDANCE OF PHOSPHATE.

The conclusion of the last section raises the further question as to whether the crop increase associated with the addition of silicate is not



wholly accounted for by the increased abundance of available phosphate which such addition produces. We have no direct evidence of the amount of crop increase which would have been induced by smaller additions of superphosphate than that actually employed. It is, however, reasonable to suppose that if we had the results of applying phosphate in a number of separate increments, the relation between average yield either in grain or straw and the phosphatic content of the plant would be represented by a smooth curve.

For this purpose plots 1 and 3 which differ only in the potassic fertiliser, and plots 2 and 4, may be thrown together and we obtain the results of Table VII.

Table VII.

	Phosphoric anhydride per mille dry weight	Grain. Mean yield 59 years bus. per acre	Straw. Mean yield 59 years lb. per acre
Plots 1 and 3	3·462	24·66	1794
Plots 1 S and 3 S	3·971	31·06	2144
Plots 2 and 4	4·951	38·68	2625
Plots 2 S and 4 S	5·210	40·30	2782

The values are represented graphically in the figure.

It will be seen that the values for the grain follow a very regular curve, while those for straw are somewhat less regular. Considering, however, that the standard error of our values for phosphatic content is about 0·035, it appears that neither curve can be regarded as indicating any significant departure from the simple view that the whole of the increased yield both in grain and straw associated with the dressing of sodium silicate is solely ascribable to the increased availability of the phosphatic reserves of the soil. If the results can at all be expressed in terms of stimulus, it is a stimulus to phosphatic intake only, and not to plant growth, that must be postulated.

Summary.

The addition of sodium silicate has been found to increase the yield of barley to a considerable extent, this effect being most marked when no superphosphate is added.

The phosphatic content of the ash is not greatly increased in the grain, and is diminished in one case in the straw; the conclusion from this observation that the silicate does not act by releasing soil phosphates, but as a plant stimulus, overlooks the fact that the addition of silica to the ash naturally reduces the percentage of other constituents, and should be discounted.

The phosphate removed annually in the crop is greatly increased on the plots receiving silicate, even when this removal has continued for many years without replacement.

That additional phosphate is actually made available to the crop on the plots receiving silicate is shown by the increase in the proportion of phosphate in the dry weight of the crop, which appears on all the plots, and at all periods.

This increase is quantitatively sufficient to account for the increased yield in grain and straw, without postulating the aid of any stimulus to plant growth.

REFERENCE.

(1) HALL, A. D. and MORISON, C. G. T. On the Function of Silica in the Nutrition of Cereals. *Proc. Roy. Soc.* (1906), B, **77**, 455–477. (Rothamsted Memoirs, vol. VIII.)

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