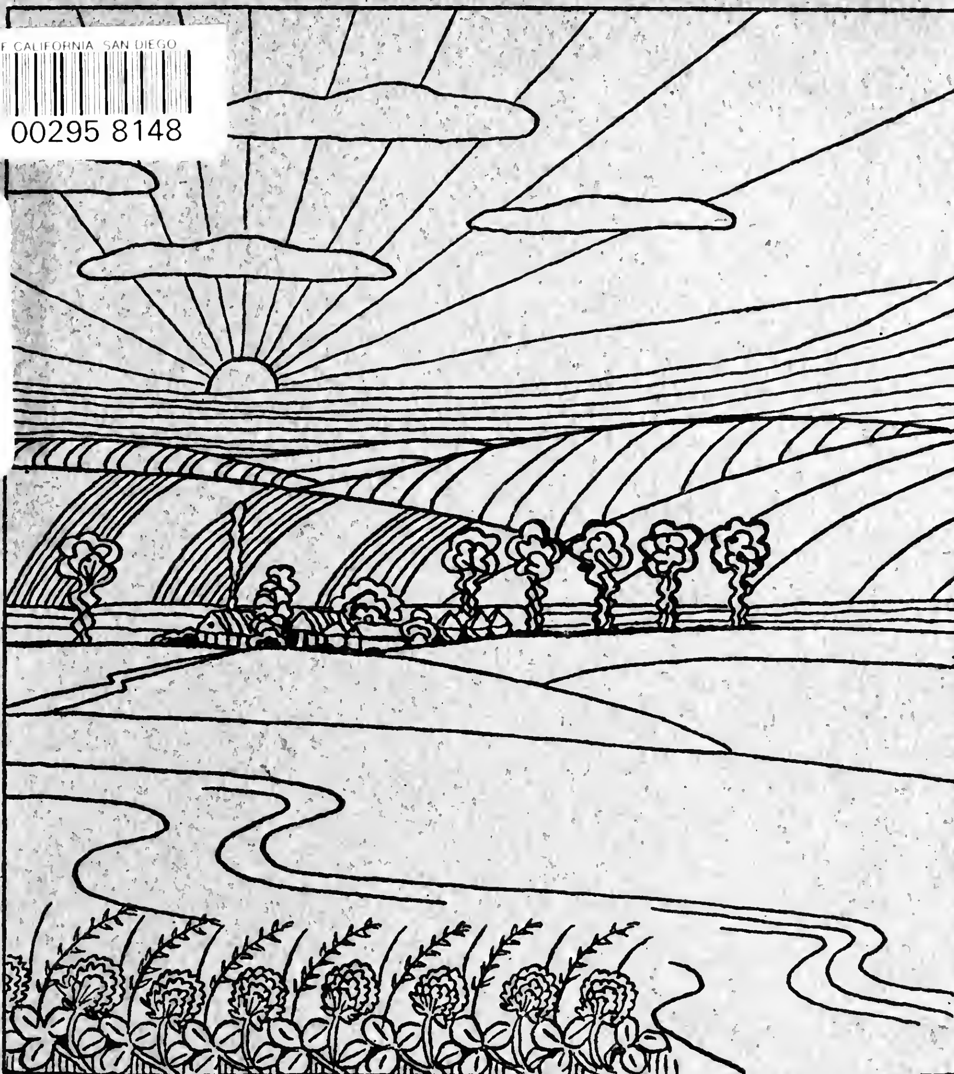

CAMBRIDGE AGRICULTURAL MONOGRAPHS

Basic Slags & Rock Phosphates

By G. S. Robertson

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BASIC SLAGS
AND
ROCK PHOSPHATES

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BASIC SLAGS
AND
ROCK PHOSPHATES

BY

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WITH A PREFACE BY

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D.Sc. (Lond.), F.R.S.

DIRECTOR OF THE ROTHAMSTED
EXPERIMENTAL STATION

CAMBRIDGE
AT THE UNIVERSITY PRESS
1922

DEDICATED TO THE
MEMORY OF MY BROTHER

WILLIAM SCOTT ROBERTSON

LIEUT., ROYAL AIR FORCE

BORN 1 JUNE, 1898, KILLED IN THE AIR
OVER THE GERMAN LINES 13 JULY, 1918

A YOUNG LIFE WHICH GAVE EARLY
PROMISE OF CONTRIBUTING
TO THE ADVANCEMENT
OF SCIENCE

PREFACE

By E. J. Russell, D.Sc., F.R.S.
Director of the Rothamsted Experimental Station

The utilisation of basic slag in agriculture is an excellent example of the help that modern science affords to the working farmer. A waste product of steel-making, resulting from a modification by Thomas and Gilchrist in 1878 of the Bessemer process, it was at first considered worthless and thrown on the refuse heap. The late Prof. John Wrightson made field experiments in 1884 and 1885 at Ferryhill and at Downton, and showed that the material had noticeable fertilising value: this discovery was confirmed and developed by the systematic pot experiments of Paul Wagner at Darmstadt, which began in 1885 and continued for several years afterwards. Extensive field tests were made during the 'nineties by Sir (then Professor) J. J. Dobbie and Prof. D. A. Gilchrist at Bangor, and by Prof. W. Somerville and later on by Sir T. H. Middleton at Cockle Park, with the result that a considerable body of information was accumulated as to the effectiveness of basic slag under the various conditions obtaining in practice. This has already been summarised by Prof. Somerville in the *Journal* of the Board of Agriculture for 1911, 1918, etc.

Some ten years ago, however, it became evident that the basic open hearth process would be a serious competitor with the Bessemer process, and chemical examination showed that the slag, though correctly described as 'basic slag,' was altogether different from the material with which the agriculturist had become familiar. The upheaval caused by war and post-war conditions gave an enormous impetus to the open hearth process, and it is now extending to so many works that before long the older process will probably cease to be operated.

This result is of course distinctly awkward for the agriculturist who sees a valuable fertiliser disappearing, and being replaced by one which is more costly and at first sight seems to be nothing like as good.

Dr Scott Robertson has the great advantage of being in close touch with the steel-making industry, and at the same time of being able to carry out agricultural experiments. At the outset of his investigations he made a careful selection of the types of slag likely to be produced in the future and in 1915 laid out field experiments in Essex to compare these newer types with the old familiar Thomas or Bessemer slag. These experiments were continued for five years and they gave a mass of data so important in character as to deserve widespread circulation among farmers and agricultural experts. Separate publication was therefore advised and the Syndics agreed to its inclusion in the Cambridge Agricultural Monographs.

Fortunately Dr Scott Robertson had included also some typical mineral phosphates in the trials so that valuable information has been obtained in regard to a second problem which, while not pressing in 1915, has grown in importance since and is likely to be serious in the future.

This second problem arises as a direct consequence of the circumstance that basic slag is a by-product only, and not a primary object of manufacture. From the steel-makers' point of view it is relatively unimportant. Some 4 cwts. only are obtained for each ton of basic steel produced, and while the ton of steel has been worth anything from £27 in 1920 to £10 in 1921, the 4 cwts. of slag is worth less than 5*s*. to the steel-makers and only about 15*s*. even after the slag grinder has graded, ground and bagged it. The steel-maker cannot afford to alter his processes in any way that would lengthen them or make them more costly or hazardous. The agriculturist must therefore take the slag as he finds it and cannot expect the consideration that would be shown him by the makers, say, of superphosphate, which is a primary object of manufacture and not a by-product. The practical result is that the composition of basic slag is determined by the conditions under which the steel-maker is working, and the total amount producible is regulated by the demand for steel; neither of which factors is in any way within the control of the agriculturist or influenced to any appreciable extent by his demands.

It is important that this distinction between basic slag and other fertilisers should be recognised. If the farmers of this country demanded double their present supplies of superphosphate, of nitrates, of sulphate of ammonia or of potassic fertilisers, the manufacturers could provide the additional material: if, however, basic slag were desired over and above the quantity determined by the demand for steel it could not be supplied except perhaps by importation.

The position thus created is being explored by the Permanent Committee set up by the Ministry of Agriculture to advise on basic slag. On the agricultural side there is evidence that the farmers of the United Kingdom might with advantage to themselves and the community use no less than 890,000 tons per annum, equivalent to 33,820,000 units of tricalcicphosphate. On the other hand the 1920 output of British steel yielded about 560,000 tons of slag of 15½ per cent. or higher content of phosphate, equivalent to 13,400,000 units of tricalcicphosphate. There is therefore a considerable gap between the farmers' potential demand and the visible supply. The difficult problems associated therewith are being fully and sympathetically studied by agriculturists and steel-making experts and no doubt various solutions will be devised. One obvious possibility is to use ground mineral phosphates to stiffen out the supplies, and here Dr Robertson's experiments will prove helpful.

Dr Robertson has not confined himself to the practical demonstration of increased yields: he has gone further and endeavoured to ascertain why the increases have been obtained, thus giving the monograph a scientific as well as an empirical interest. He examines the change in herbage and he shows that the physical properties of the soil and the bacterial actions in the soil are much influenced by the phosphate in the slag, thus throwing important light on the view now commonly held by experts that poor grassland should not be ploughed out till after it has been improved by slag.

The monograph contains a store of information about the new slags and is a model of thorough and systematic investigation. I have personally inspected the plots on several occasions and have seen much of the experimental work. It deserves close study by all who are interested.

E. J. R.

January, 1922.

AUTHOR'S PREFACE

THE main purpose of this book is to put on record the results of the field experiments with rock phosphates and open hearth basic slags conducted in Essex during the period 1915–20.

The field trials have been confined to grass land, and the results have been measured by increases in the weight of the hay crop, and by the improvement in the quality of the crop, as determined by botanical analyses. This plan has been adopted for two reasons: first, because it is on grass that the primary and secondary actions of phosphates are most apparent, and most readily measured; secondly, because on permanent grass, in Essex at any rate, the issue is not complicated by previous applications of artificial manures, and it is therefore easier to follow out the experiment year by year than under arable conditions.

The objection may be raised that increased weights of hay do not give a true test of the improvement which has taken place, and that such a test can only be obtained through the medium of the animal. While there is much to be said in favour of this contention, it may be safely assumed that, when botanical analysis shows the quality of the herbage is similar, the increased weights of hay bear a definite relationship to the live-weight gains, and do afford a satisfactory method of comparing the efficiency of the various phosphates. Moreover, it must be remembered that hay is an important crop, and in Essex, as elsewhere, it is the prevalent custom to graze and mow the permanent grass in alternate years.

The Essex results with ground rock phosphates indicate that there are soil conditions under which these types of phosphates may be expected to give as good and as quick results as the more soluble types of phosphatic fertilisers. It is equally clear, however, that under other conditions the advantage is decidedly in favour of the more soluble types. Experiments in progress in the North of Ireland on the turnip crop strikingly bear out this conclusion, and it would seem probable that an explanation of the different results secured elsewhere might be obtained by means of an examination of soil and climatic conditions.

I have to acknowledge my indebtedness to Dr E. J. Russell, F.R.S., for the great interest he has taken in the work here described. From

the discussions which took place during his annual visits to the various experimental centres many helpful suggestions came.

For the method of estimating nitrates I am indebted to Mr D. J. Matthews, till recently of the Rothamsted Experimental Station, and, for the nitrate determinations, to my former colleague, Mr R. G. Baskett. For the bacterial counts in Tables XLV and XLVI I am indebted to Mr James Bryce, B.Sc.; for the mechanical analyses in Table XXXIX to my former colleague Capt. H. H. Nicholson, M.A. (Cantab.); for the rainfall data to Mr Carle Salter, the Superintendent of the British Rainfall organization, and for the illustrations of Nauru and Ocean Islands to Mr A. F. Ellis, the Commissioner for New Zealand on the Board of the British Phosphate Commissioners.

I should also like to record my thanks to Messrs B. Smith, N. F. Miles, T. Wood, C. L. Petheybridge and A. Freshwater, on whose farms the more important of the field trials were laid down, for the care they have taken of the plots and for the ready help they have given through the whole period of the trials.

Finally, I have to express my keen appreciation of the kindness of the Agricultural Education Committee of the Essex County Council, who provided unique facilities for the work and gave me a free hand in the carrying of it out. To the generosity of the members of this Committee is due, in no small measure, the opportunity of submitting this book to all who are interested in the progress of Agriculture.

G. S. R.

THE QUEEN'S UNIVERSITY OF BELFAST,
January, 1922.

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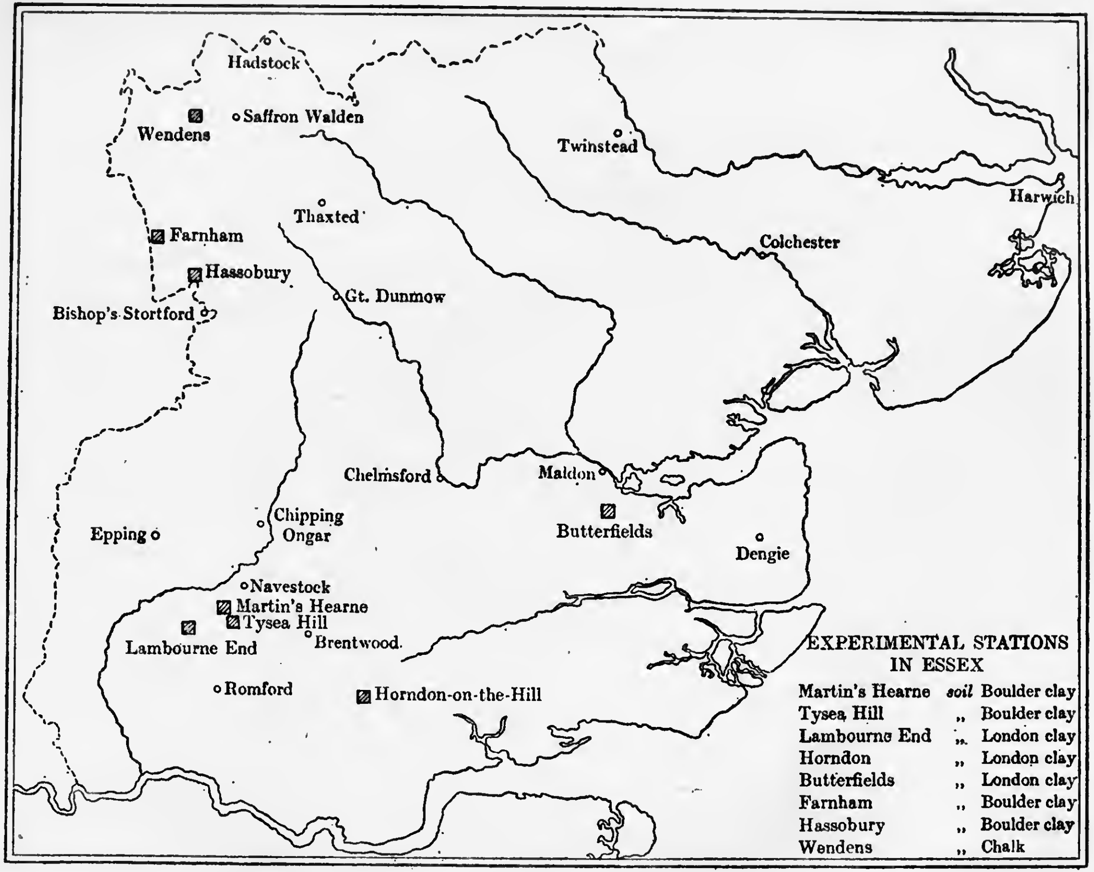
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INTRODUCTION

INSOLUBLE phosphates have been applied to the land in the form of bones for a very long time, and until the beginning of the nineteenth century it was generally assumed that they owed their value to the oil which they contained. Lord Dundonald in his *Treatise on the Connection of Agriculture with Chemistry*, published in 1795, seems to have been one of the first investigators to realise that the fertilising value of bones was due to the phosphoric acid which they contained. Kirkman writing in 1796 came to the same conclusion, and so did de Saussure in 1804. These opinions were accepted and repeated by Liebig, who was perhaps largely responsible for the widespread dissemination of this important piece of information. Dundonald in his *Treatise* goes a good deal further than the other investigators, in as much as speaking of the phosphate of lime in bones he records: "It is a saline compound, very insoluble. There is reason to believe a very considerable proportion of this nearly insoluble salt is contained in most fertile soils." It may therefore be said that Dundonald was the first investigator to establish the value of insoluble phosphates.

Towards the end of the eighteenth and the beginning of the nineteenth century the use of insoluble phosphates increased with great rapidity throughout Europe, but nowhere more so than in this country. By about 1815 the home supply began to prove insufficient to meet the large demand, and resort was had to importation from Europe. The import of bones grew rapidly, and some idea of the importance then attached to the supply of insoluble phosphates may be gained from Liebig's passionate outburst:

> England is robbing all other countries of their fertility. Already in her eagerness for bones, she has turned up the battlefields of Leipsic and Waterloo and of the Crimea; already from the Catacombs of Sicily she has carried away the skeletons of many successive generations. Annually she removes from the shores of other countries to her own the manurial equivalent of three million and a half of men, whom she takes from us the means of supporting, and squanders down her sewers to the sea. Like a vampire she hangs on the neck of Europe, nay of the whole world, and sucks the heart blood from nations without a thought of justice towards them, without a shadow of lasting advantage to herself!

The discovery of large deposits of rock phosphates in Spain, in this country and in other parts of Europe, eased the situation. Moreover these discoveries came close on the heels of Lawes's patent for dissolving bones in sulphuric acid, and at a time when his experiments with dissolved bones, and later with dissolved rock phosphates, at Rothamsted focussed attention very effectively on the superior value of water soluble phosphates. The Rothamsted experiments seem to have very rapidly convinced those farmers who followed such developments of the superior efficiency of water soluble phosphates, although attention was drawn at intervals to experiments which apparently showed insoluble phosphates to be as effective as water soluble phosphates.

BASIC BESSEMER SLAG

The introduction by Thomas and Gilchrist in 1878 of their process for removing phosphorus from the molten pig-iron provided in the resulting slag a new source of phosphate for agricultural purposes.

The presence of phosphorus in steel, except in very small amounts, renders the metal brittle and unfit to use for many manufacturing purposes. Most of the iron ores in this country are highly phosphatic, and until the coming of the Thomas and Gilchrist process it was not possible to remove phosphorus from the pig-iron and so produce a good quality of steel.

The first step in the manufacture of steel is the conversion of iron-ore into pig-iron under the reducing conditions which exist in the hearth of the blast furnace. Such reducing conditions are essential for the recovery of iron from the ores, but they prevent the oxidation of phosphorus, which therefore passes into the pig-iron.

The conversion of non-phosphatic pig-iron to steel is carried out in a Bessemer vessel with a siliceous lining—acid process. If phosphorus is present in the pig-iron phosphoric acid is formed, which, being unstable in the presence of an excess of iron, reverts to phosphide of iron, which is not removed in the slag.

The Thomas and Gilchrist modification of the Bessemer process consists in lining the furnace with a basic material instead of a siliceous lining, and of adding suitable quantities of lime to the molten iron. The phosphoric acid formed combines with the lime producing a stable phosphate of calcium, which is removed in the slag which floats on top of the molten metal in the converter.

The process was first tried on a large scale at Messrs Bolckow Vaughan and Co.'s Eston Works, in 1879, and a copy of the record which illustrates the manufacture of the first Basic Slag is reproduced in Table I by the courtesy of Mr Daniel Sillars, chief chemist to Messrs Bolckow Vaughan and Co.

TABLE I. RECORD OF THE EARLIEST MANUFACTURE OF BASIC SLAG (May, 1879)

Metal samples	Si	Graphite	Comb. Car.	Phos.	Time Min.	Sec.	Slags SiO_2	CaO	MgO	P_2O_5	Fe
Pig-iron	2·89	3·36	·06	1·52	—		—	—	Unusually high	—	—
1	2·21	2·64	·80	1·51	3	0	—	—		—	—
2	1·43	·06	2·55	1·51	6	0	—	—		—	—
3	·78	Trace	2·50	—	9	0	—	—		—	—
4		Bad sample									
5	·13	Nil	·53	1·36	12	0	34·07	43·53	9·64	·60	5·00
6	·10	,,	Nil	1·01	15	0	30·40	41·18	9·00	5·02	6·10
7	Trace	,,	,,	·77	17	30	29·73	36·58	8·16	5·18	15·90
8	Nil	,,	,,	·41	18	30	23·73	33·15	9·30	11·10	10·70
9	,,	,,	,,	·12	19	30	20·93	35·62	8·50	10·94	13·50
10	,,	,,	,,	·10	20	30		Bad sample			
Steel	,,	,,	,,	·18 Mn. ·15	21	10	21·10	32·84	9·95	10·78	13·60

In the first blow it will be noted the phosphorus fell from 1·52 % in the pig-iron to ·18 % in the finished steel.

When phosphorus has been removed to the required extent the converter is tipped forward and the slag allowed to flow over the top of the vessel into the slag pot where it is either allowed to cool or tipped molten on to the slag heap.

The production of steel by this process and the consequent accumulation of phosphatic basic slag increased with great rapidity, and attention was turned towards the possibility of using these basic slags for fertilising purposes. It was at first considered that on account of the insolubility of the phosphates in water the material would be of little value for direct application. Attempts to obtain a suitable fertiliser by dissolving the slag in acid proved unsuccessful.

To Wrightson and Munro we owe the discovery in 1885 that if basic slag is ground to a fine powder it has a very considerable fertilising value. Their experiments were followed by many others including the now classic experiments at Cockle Park, which were commenced in 1896 by Professor Somerville and subsequently continued and developed by Sir T. H. Middleton and Prof. D. A. Gilchrist. It is from the Cockle Park experiments that most of our information concerning the practical use of basic slag has been derived. These experiments continued over a period of 25 years do more than show that basic slag has a high fertilising value. They demonstrate that under the conditions at Cockle Park basic slag per unit of phosphoric acid is more effective than superphosphate, a result which was subsequently confirmed by the trials at Sevington, Cransley, Hatly and Yeldham(28). At Sevington where the soil is well supplied with calcium carbonate(32) the returns for the two types of phosphates are for practical purposes identical, there being only a difference of 3 lbs. live weight gain in favour of slag over a period of nine years.

The superior results from basic slag at the remaining centres is probably due to the fact that on 'sour' soils, and on soils where the calcium carbonate content is not high, as at Cockle Park (0·59 % $CaCO_3$), a certain proportion of the phosphoric acid in superphosphate is retained by the soil in the form of somewhat insoluble phosphates of iron and aluminium. With repeated dressings of superphosphate increasingly large proportions of the phosphoric acid revert to such insoluble forms. These experiments may therefore be said to have established the fact that insoluble basic phosphates have a distinct function in agriculture, and that under certain soil conditions they are to be preferred to the water soluble phosphates in superphosphate.

As a consequence of the Cockle Park experiments basic slag is used for the manuring of grass-land almost to the exclusion of other types of phosphatic fertilisers. Nor has its use been confined to grass-land, where perhaps rapidity of action is not of primary importance. In the south of Essex, basic slag is used on the arable land almost to the exclusion of superphosphate, and many of the most progessive farmers have attributed their success to the use of basic slag instead of superphosphate on their heavy clay soils, which are either devoid of calcium carbonate or have only a very poor supply.

Some idea of the extent to which basic slag has been appreciated, and the lessons which Cockle Park taught assimilated, may be obtained from the following figures (Table II) showing the production and consumption of basic slag during the period 1903–1920.

BASIC OPEN HEARTH SLAG

Unfortunately for agriculture important changes in the manufacture of steel have been taking place during the past few years. Economic conditions and to a certain extent the working out of the higher grade ores have made the basic Bessemer process uneconomical, and it has been replaced by the basic open hearth process. In this process iron-ore and lime are charged on to a basic hearth heated by producer gas, and the molten metal poured over the heated lime

Table II. Production and Consumption of Basic Slag in the United Kingdom. In Metric Tons (thousands)

	Production	Imports	Exports	Net
1903	148	?	?	?
1907	145	?	?	?
1910	160	?	?	?
1913	404	51	169	286
1914	404	17	134	287
1915	400	—	117	283
1916	360	—	39	321
1917	447	—	2	445
*1917–18	500	—	—	500
*1918–19	565	?	2	—
*1919–20	497	?	15	—

* Seasonal year June 1st to May 31st. The figures for 1913 to 1920 are taken from the Ministry of Agriculture returns.

Table III. Basic Bessemer Process

No.	Time from beginning	Metal		Slag					
		Si	P	SiO_2	FeO	MnO	MgO	CaO	P_2O_5
1	Pig-iron	1·22	2·183	—	—	—	—	—	—
	min. sec.								
2	2 46	0·72	2·148	41·15	2·40	9·03	4·13	41·27	0·84
3	5 21	0·15	2·224	36·30	3·97	11·02	3·39	39·50	3·12
4	8 5	0·007	2·157	34·41	3·60	10·72	3·35	42·80	2·99
5	10 45	0·012	2·096	31·94	4·23	9·94	4·01	43·12	4·02
6	13 28	0·005	2·053	16·64	8·42	8·51	7·34	44·37	7·15
7	15 13	0·008	1·910	14·65	7·15	7·39	6·34	46·63	11·60
8	19 14	0·005	0·230	12·94	5·84	4·25	6·00	47·76	18·83
9	19 31	0·005	0·139	12·20	6·79	4·01	6·26	48·59	18·66
10	19 49	0·004	0·087	11·71	7·19	4·05	6·38	48·19	18·15
11	Rail steel	0·01	0·145	12·77	5·94	4·80	6·75	47·87	16·92

Table IV. Z 603. Ordinary Basic Open Hearth Process

No.	Time p.m.	Metals		Slags					
		Car.	Phos.	Silica	Lime	Total iron	P_2O_5	Sol. P_2O_5	Cit. Sol. %
1	2.25	1·77	·300	20·30	33·2	8·60	17·08	15·36	89·92
2	2.40	1·68	·327	19·90	34·8	7·30	16·87	14·85	87·89
3	2.55	1·60	·35	18·80	35·70	8·40	17·30	15·49	89·53
4	3.10	1·57	·335	20·30	34·90	6·20	17·08	14·08	82·43
5	3.40	1·48	·321	20·20	37·00	5·60	15·85	11·90	75·70
6	4.45	1·10	·19	20·50	37·70	5·50	15·66	11·78	75·22
7	6.0	·74	·083	15·50	42·50	7·20	15·47	5·38	34·77
8	7.0	·63	·07	15·10	40·50	7·00	15·75	4·99	31·68
9	8.0	·14	·026	12·60	41·80	11·50	13·65	1·79	13·10
10	9.0	·09	·023	10·20	47·80	14·70	10·85	1·66	15·30

and ore. The oxygen necessary for the purification of the pig-iron is supplied to the extent of about 70 % by the action of the metalloids on the oxide of iron, the balance 30 % coming from the oxidising gases of the furnace. In the Bessemer process the oxygen comes entirely from the air blast, and the combustion of the phosphorus, silicon, and carbon generates sufficient heat to raise the temperature of the steel to the required extent. The slag formed in the basic open hearth process is much greater in volume and there is a corresponding decrease in phosphoric acid content compared with the basic Bessemer process. Tables III and IV show the changes in the composition of the slag by the two processes.

Commenting on Table IV Sillars says:

> The decrease in P_2O_5 content becomes quite sharp after the fourth sample, and this, it will be observed, coincides with the commencement of the period at which carbon elimination becomes predominant. If high grade slag is desired, it is removed at this stage, and after charging fresh lime and oxide of iron, the carbon elimination is proceeded with. It will be noticed that the phosphorus in the first metal sample is as low as in any of the four immediately following, and it may be asked why the slag could not equally well be removed at this stage instead of an hour later. The reason is that although the phosphorus is eliminated very rapidly (sometimes it is reduced to 3 % twenty minutes after charging), yet it is necessary to delay the removal of the slag until all frothing has ceased and until the whole of the lime and ore is dissolved in the bath and the heat is sufficiently high to allow the slag formed to flow freely through the tap hole. Unless the slag is removed when it has reached the maximum concentration of phosphoric acid, the further additions of lime and ore, and the denudation of the furnace structure under heat, cause an increase in the slag volume which reduces the phosphoric acid content until at the termination of the process it will contain from 7 to 10 % only. As the content of lime increases, the slag thickens and reaches a viscosity which slows the progress of the 'boil.' This may be corrected by the addition of oxide of iron in the form of scale, but if sulphur has to be eliminated from the metal it is essential to keep the slag as basic as possible; the slag is therefore thinned by the addition of fluorspar, and it is this addition more than any other condition which reduces the solubility of the phosphoric acid in 2 % citric acid. In Table IV 1 cwt. of fluorspar was added after the sixth sample was drawn, and the soluble phosphoric acid fell from 11·78 % to 5·38 % immediately afterwards.

High grade slag can be obtained by pouring the slag immediately before the addition of fluorspar.

In the basic open hearth process the steel and slag are tipped into a ladle—the steel ladle—which is only large enough to hold the steel. When the steel ladle is full the slag overflows into the slag ladle placed immediately under the spout of the steel ladle (Plate I).

The significance of the change may be better appreciated by a consideration of the following figures showing the output in 1920 of the various grades of basic slag.

TABLE V.

Grade	Production in 1920 (in tons)
1. Over 33 % $Ca_3P_2O_8$	46,300
2. 26–33 % „ „	121,400
3. 22–26 % „ „	90,900
4. 15–22 % „ „	302,500
5. 11–15 % „ „	118,000
6. Under 11 % „ „	22,000
Total all grades	701,100

The production of high grade basic slag, even if slag containing only 33 % of phosphate is so classed, had fallen by 1920 to less than one-tenth of the amount necessary to satisfy the demands of the farmer, and it is probable that a comparatively short time will see the last of this type of basic slag.

Of the basic slags forming grades 3, 4, 5 and 6, a large proportion, how large it would be difficult to say, are of low citric solubility due to the use of fluorspar. It has been shown that the action of fluorspar results in the replacement of the calcium silicate in the phosphate compound of high soluble slags by calcium fluoride (19) and Bainbridge has demonstrated that the resulting slag phosphate consists largely of apatite (2).

There are thus three types of slag available for agricultural purposes:

1. High grade containing 16–20 % phosphoric acid. Part of this supply consists of the rapidly diminishing remnants of the basic Bessemer slags and the other part of the slags obtained from the basic open hearth process by fractionating before the addition of fluorspar.

2. Open hearth basic slag containing 7—14 % phosphoric acid.

3. Open hearth fluorspar basic slag containing 6—12 % of phosphoric acid.

Numbers 1 and 2 have a citric solubility of 80–95 % whilst no. 3 has a citric solubility of from 6–50 %.

Open hearth fluorspar basic slag is a new material containing totally different phosphate compounds to those in nos. 1 and 2. It is not the type of basic slag which produced the remarkable results at Cockle Park and elsewhere. Its value compared with such slags is unknown, and its low solubility suggests that it will prove less effective as a fertiliser than the more soluble types.

The total production of basic slag, including in that term slags containing from 11 % tricalcium phosphate upwards, amounted to 680,000 tons in 1920, but, if all slags below 22 % are excluded, to only 258,600. Of the totals a very large proportion was fluorspar slag. In 1919 there was a consumption of at least 560,000 tons and the demand is steadily increasing[1]. Whilst therefore the steel industry may continue to be a valuable source of insoluble phosphates for agricultural purposes, it is becoming increasingly evident that the supply can no longer keep pace with the demand and the agriculturist must turn to other sources of supply.

ROCK OR MINERAL PHOSPHATES

The increasing demand for basic phosphates can most readily be met by increasing the output of the apparently inexhaustible stores of rock or mineral phosphates and utilising these materials for direct application. Unfortunately there are no extensive deposits in Great Britain[2] and there are not many sources of supply within the British Empire. (Collins in *Chemical Fertilisers* gives a map showing the distribution of the chief deposits of rock phosphates.)

Broadly speaking the deposits may be divided into two types—the softer and woollier North African phosphate such as Gafsa, Egyptian and Algerian phosphates and the harder North American and Island phosphates such as Florida pebble, Carolina, Nauru Island, and Ocean Island phosphates.

The deposits in the majority of cases are close to the surface and can be worked, and, in the case of the Island phosphates, transported to the shore and shipped at a comparatively low cost. Plates I and II.

The North African phosphates are more soluble by the Wagner test than the harder American phosphates (20). They apparently contain more calcium carbonate and less calcium fluoride combined in the phosphate compound than is the case with the American phosphates (21). It may therefore be just as important to distinguish between these two types of rock phosphates as it is to distinguish between open hearth fluorspar basic slag and the open hearth basic slag produced without the use of fluorspar.

Rock phosphates have the great advantage of a high phosphatic content, ranging in the case of the North African, the Island phos-

[1] Middleton estimates our requirements of basic slag at 891,000 tons per annum.

[2] The deposits of coprolites in Cambridge and Suffolk can no longer be worked economically.

phates and American phosphates from 50–88 % of tricalcium phosphate. Moreover, it has been shown(14) that these phosphates are even more soluble in citric acid than the majority of open hearth fluorspar basic slags, and that they contain phosphate compounds which are in many respects similar to those in open hearth basic slags(20).

It is thus a matter of great urgency to ascertain their precise manurial value, as it is no exaggeration to say that the future of agriculture and our national prosperity will be largely determined by the extent to which suitable phosphates can be supplied at a comparatively low cost.

The problem is a big one, capable of attack from more than one point of view. Useful results are likely to be secured by investigating the effect of climatic conditions, particularly rainfall, on the availability of the rock phosphates. The question of soil conditions is also of great importance in this connection. Rock phosphates for example may prove a failure compared with superphosphate on a chalky soil under dry conditions, whilst on a sour soil and under a more humid climate the reverse may well be the case.

REVIEW OF PREVIOUS EXPERIMENTS

REVIEW OF POT EXPERIMENTS WITH INSOLUBLE PHOSPHATES

In order to ascertain with any degree of certainty the agricultural value of a suggested fertiliser two types of experiments are necessary —pot experiments and field trials. Russell (23) discussing the relative advantages of field and pot trials points out that as a general rule pot experiments are more accurate than field trials. The experimental conditions are more under control, and it is therefore possible to bring out small differences between materials which it might not be possible to secure under the conditions of a field trial. On the other hand, the conditions under which pot experiments are conducted are so artificial that a positive result is not always paralleled by a positive result in the field. Furthermore, though very considerable difference in the cropping power of the two materials may be shown by pot experiments, it by no means follows that the differences will be equally marked under field conditions. Whilst therefore pot experiments are of great value as a preliminary method of investigation, field experiments are always essential before any deductions can be made relative to the economic importance of the factor under investigation. If they are to be of real value such field experiments must be carried out under varying climatic and soil conditions and on different types of soil, and an attempt be made to interpret the results in the light of such conditions.

Dutton (6) during 1912 conducted a series of pot experiments designed to ascertain the fertilising effect of that portion of the phosphoric acid in basic slag which is not soluble in citric acid, and came to the conclusion that such insoluble phosphate is active enough to feed a short-lived plant like mustard.

Bainbridge (2), in a paper on "The Effect of Fluorspar Additions on the Phosphates in Basic Slag," describes a series of pot trials with barley, and shows that a very insoluble fluorspar slag possessing a citric solubility of only 6 %, when contrasted with a slag of 81 % solubility, gives a yield of 61 % compared with the high soluble slag yield of 100. These two experiments, although not conclusive, clearly indicate that even short-lived crops such as mustard and barley are capable of making considerable use of phosphates which are much more insoluble than those phosphates which are readily dissolved in dilute solutions of citric acid. In view of these results it is reasonable to expect that promising returns would be secured from similar trials with less resistant materials like rock phosphates.

Burlison (3) made an elaborate series of pot experiments with six types of rock phosphate, the trials extending over a period of three and a half years and embracing the results from 700 pot cultures. It is difficult to interpret the exact meaning of these experiments in terms of basic slag or superphosphate as neither of these forms of phosphatic fertilisers was included in the trials. The results from this elaborate series are nevertheless of considerable interest as they show that the phosphates in rock phosphates, even of the hard resistant type like Canadian Apatite, can be assimilated by farm crops in sand cultures under greenhouse conditions and in the absence of decaying organic matter. Three other conclusions from his work are worth noting. Burlison found that the plants could obtain their calcium as well as their phosphorus from rock phosphates, and that the addition of calcium carbonate to the rock phosphates did not produce better results. An attempt was made to ascertain the effect of fineness of grinding on the availability of such phosphates, and the work shows that better results were secured by grinding beyond the '100' grade. Finally the author gives it as his opinion that there is no particular relation between the citric acid, soluble phosphoric acid and the availability of rock phosphates to the plant.

These pot experiments, scanty and incomplete though they may be, agree in demonstrating that, under the conditions of the experiments, the insoluble phosphates in fluorspar basic slag and in rock phosphates may have a very considerable agricultural value.

REVIEW OF FIELD EXPERIMENTS WITH ROCK PHOSPHATES

American Experiments. Although by no means exhaustive, a large number of field experiments have been carried out with rock phosphates. The subject has perhaps received more attention in the United States than elsewhere. There considerable differences of opinion exist concerning the fertilising value of raw ground rock phosphates or 'floats.' In the States the controversy centres round the relative value of ground rock phosphates (floats) and acid phosphate (superphosphate). Most of the American experiments, a detailed account of which is given by Hopkins (11), are confined to this aspect of the question. Moreover many of the American State experiments, *e.g.* Maine, Massachusetts, and Rhode Island, compare the two phosphates by applying equal money values, and it is obvious that such trials have only a limited value as far as the application of the results to this country is concerned. Moreover, changing economic conditions must seriously detract from the value of their application to present day American practice. The Ohio, Illinois, and certain of the Massachusetts experiments compare equivalent quantities of the two forms of phosphate, alone and in combination with other manures. These experiments have extended through several rotations on duplicate, and in some cases triplicate, plots. After an exhaustive review of the American experiments up to 1908 Hopkins draws the conclusion that rock phosphates are much the more economical type of phosphate to use, and that from the point of view of the permanent fertility of the soil they are much to be preferred to acid phosphates.

A later review of the American experiments is given by Waggaman and Wagner (31), covering the period up to 1917. These writers give a table incorporating the results of 232 field experiments. Only 37 of these experiments extended over a period of five years or more. Their tabulation of these experiments is given in Table VI.

In explanation of this table they give the following notes:

Out of the 37 tests given in Table VI, 22 were carried on with a view to comparing the relative merits of raw rock and acid phosphates. The conditions under which such a comparison was attempted varied greatly, but it may be said that in a general way, 13 of these experiments, or 59·1 %, gave crop yields as favourable to raw rock as to the more soluble form of phosphoric acid. Of the 9 experiments in which raw rock did not compare favourably with acid phosphate, 2 were conducted on fields unresponsive to phosphate treatments and 2 gave results which could be classed as either favourable or unfavourable, depending on the method of interpretation employed.

Of the 15 experiments in which no comparison between raw ground rock and acid phosphate was attempted, 11, or 73·3 %, gave results strongly indicating beneficial effects from the application of the former material, and 2 of the remaining 4 experiments were conducted on fields showing little or no response to phosphate treatment.

In 21 experiments the applications of raw rock were relatively light (250 lbs. or less per acre), yet 15 of these experiments, or 71·4 %, showed distinctly favourable increases in yields on the fields treated with this material.

In 16 experiments where the raw rock applications were more liberal, 13, or 81·3 %, resulted favourably to raw rock phosphate, and the remaining 3 experiments were conducted on soils showing little or no response to phosphate treatment.

Raw rock phosphate was applied in connection with organic matter in 23 experiments. Out of this number, 18, or 78·3 %, gave distinctly favourable results, and of the 5 remaining experiments 3 were conducted on fields unresponsive to other forms of phosphoric acid.

TABLE VI. SUMMARY OF RESULTS OF FIELD EXPERIMENTS WITH RAW ROCK CONDUCTED BY THE STATE STATIONS OVER PERIODS OF FROM 5 TO 20 YEARS.

State	Total number of experiments	Experiments comparing raw rock with acid phosphate			Experiments making no comparison of raw rock with acid phosphate			Experiments where raw rock applications were relatively light			Experiments where raw rock applications were liberal			Experiments where raw rock was used in connection with organic matter			Apparent cumulative effect		
		Total	Number favour-able	Number unfavour-able	Total	Number favour-able	Number unfavour-able	Total	Number favour-able	Number unfavour-able	Total	Number favour-able	Number unfavour-able	Total	Number favour-able	Number unfavour-able	Effect evident Number	Effect none Number	Effect unknown Number
Ala.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Conn.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Del.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fla.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ga.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ill.	12	3	2	1*	9	7	2*	4	4	—	8	6	2*	11	9	2*	8	3*	1
Ind.	2	2	1	1*	—	—	—	—	—	—	2	1	1*	2	1	1*	—	—	2
Ky.	1	1	—	1	—	—	—	—	—	—	1	1	—	1	1	—	1	—	—
La.	3	3	1	2	—	—	—	2	—	2	1	1	—	—	—	—	1	1	1
Me.	2	2	1	1	—	—	—	2	2	—	—	—	—	—	—	—	1	—	1
Md.	2	2	2	—	—	—	—	—	—	—	2	2	—	1	1	—	—	1	1
Mass.	2	2	1	1†	—	—	—	1	1	—	1	1	—	1	1	—	—	—	2
Miss.	2	2	1	1	—	—	—	2	2	—	—	—	—	—	—	—	—	—	2
Mo.	4	—	—	—	4	2	2	4	2	2	—	—	—	4	2	2	4	—	—
N.J.	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N.Y.	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N.C.	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ohio	4	2	1	1†	2	2	—	3	2	1†	1	1	—	3	3	—	1	—	3
Pa.	1	1	1	—	—	—	—	1	1	—	—	—	—	—	—	—	—	1	—
R.I.	1	1	1	—	—	—	—	1	1	—	—	—	—	—	—	—	1	—	—
S.C.	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tenn.	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Va.	1*	1*	1*	—	—	—	—	1*	—	1*	—	—	—	—	—	—	—	1*	—
Wash.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W.Wa.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Wis.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	37	22	13	9	15	11	4	21	15	6	16	13	3	23	18	5	17	7	13

* Soil not responsive to phosphate treatment.

† Figures for this experiment are favourable according to one method of computation and unfavourable according to another.

In regard to the cumulative effect of raw ground phosphate rock it may be said that in 17 instances (46 % of the entire number of experiments) there was evidence of greater availability after raw rock had been applied for a number of years. In 13 out of the remaining 20 experiments the data are not sufficient to give evidence on this point, and in 4 out of the 7 cases where no cumulative effect was shown the soils were not responsive to phosphate treatments.

The same writers (quoted in the *Scottish Journal of Agriculture*[1]) in a survey of the above experiments conclude that:

To be efficacious as a fertiliser rock phosphate must be spread evenly over the ground as a fine powder. The presence of decomposing organic matter increases the efficacy, probably because of the greater bacterial activity produced and the higher percentage of carbon dioxide given off. Fineness of the powder and the presence of organic matter together prolong the efficacy of raw phosphate rock for another year, or even more. On the other hand, as the action of superphosphate is more rapid than that of bone powder, basic slag and mineral phosphates, it is probably preferable to any other phosphatic fertiliser when the aim is to obtain rapid growth of the plants cultivated.

To obtain the best results with powdered rock phosphates, they must be applied in larger quantities than superphosphate. Whether it be best to apply rock phosphates in a soluble or insoluble form to produce the most economical increase in yield depends on the nature of the soil, the cultural method, the price of the phosphates, the duration of the vegetative period, and other local factors. It is a question which, to a certain extent, must be solved by each farmer individually.

French Experiments. Grandeau, in the seventh volume of his *Etudes Agronomique*, gives an account of French experiments with dissolved and undissolved phosphates on potatoes, wheat and oats. The experiments are reviewed by Dyer (8), who records that "contrary to generally accepted theories (but conformably with results already arrived at in various parts of France) finely powdered mineral phosphates have given yields as large as those of superphosphate—the soil being an extremely poor non-calcareous one."

English Experiments. The earliest experiment on the value of rock phosphates was that carried out by Dr Daubeny, on the turnip crop, with Spanish phosphorite (5), at the Botanic Gardens at Oxford. Very satisfactory returns were obtained from the Spanish phosphorite, which, however, did slightly better when treated with sulphuric acid. In the same issue of the *Journal* Sir H. Verney, Bart. (30) gives an account of his experiments on barley with this material. The experiments were carried out on a heavy sandy loam. In these trials Spanish phosphorite gave quite as good results as superphosphate

[1] July 1920, p. 357.

of lime, but in this instance also it was not so effective as 'Spanish phosphorite and sulphuric acid.'

Dr Jamieson[1] reports two experiments, one conducted in Sussex and the other in Aberdeenshire, to test if basic slag really acted as effectively as coprolites, both being used in the same state of division and in such quantities as gave equal proportions of phosphate. The results were as follows:

	Wiston (in Sussex)		Glasterberry (in Aberdeenshire)	
	tons	cwts.	tons	cwts.
No phosphate ...	25	17	6	16
Coprolite	28	11	29	1
Slag	28	11	28	11
Superphosphate ...	30	7	24	19

Commenting on these results, Jamieson says:

> The Sussex soil turned out to be too rich to show distinctly the effect of any kind of phosphate, but the Aberdeenshire soil gave conclusive proof. The resulting crops of turnips showed that slag and coprolites, in equal state of division, are practically identical in their effects on crops.

Gilchrist records (12) a series of four field trials on three years' ley to compare the value of Belgian and Tunisian phosphates with basic slags of varying solubilities. Two of the series give results very favourable to Tunisian and Belgian phosphates. The third test, however, is not so favourable, and the fourth test had to be abandoned owing to the failure of the 'clover take.' In the first of Gilchrist's three year tests Tunisian phosphate does not do so well as Belgian, a result which Gilchrist attributes to this phosphate not being so rich in lime. It is worthy of note that in the second test Gilchrist gets somewhat better results from Belgian phosphate that has been calcined.

Oldershaw (16), working on a chalky boulder clay soil in Suffolk, found that on the hay crop, citric solubility was of great importance. Although low citric soluble slags and a Belgian rock phosphate effected a considerable improvement, the high soluble slag gave a much heavier hay crop than the rock phosphate or the low soluble slags. In discussing his results, Oldershaw makes the following observation, which is of considerable importance: "It is worthy of note that had all the plots been grazed and the results estimated by inspection only, the conclusion might easily have been drawn that Plots B (low soluble slag) were almost as good as Plots A (high soluble slag)."

[1] *The Farmer's Handbook*, p. 46.

Scottish Experiments. In *Bulletin* 10 of the North of Scotland College of Agriculture details are given of an experiment extending over three years, and designed to contrast the effect of superphosphate, bone meal, basic slag, and ground Florida phosphate, with and without farmyard manure, on turnips and the two succeeding crops, barley and hay. In the series of plots comparing the four phosphates without the addition of farmyard manure, the American rock phosphate gives the poorest result. It has approximately the same effect on the barley and hay crops as basic slag, but did not prove to be as effective on turnips.

On the other hand, where farmyard manure was given in addition to the various phosphates, Florida rock phosphate gave better results than any of the other phosphates, and the profit on the rock phosphate plot is more than twice as great as on any of the others. It is difficult to draw conclusions concerning the relative efficiency of these phosphates when used with farmyard manure. No plot with farmyard manure alone was included in the series, and it might well have happened that farmyard manure alone would have given as good results as farmyard manure plus phosphate.

Russell (24), in "Notes on Manures" for Jan. 1920, gives a table summarising 67 experiments on the turnip crop in Scotland during 1911–14 with various types of phosphates, including ground mineral phosphates. The results show that such phosphates are very nearly equivalent to basic slag. It is not clear from this summary, however, how much of the gain, amounting to 6 or 7 tons, of the treated plots over the untreated is due to the application of phosphoric acid, as the treated plots received in addition to the various types of phosphates a dressing of sulphate of ammonia and potash salts.

Welsh Experiments. Trials with basic slag, Gafsa rock phosphate, and superphosphate on Swedes were carried out by the University College of North Wales during the three seasons 1913–1915[1]. Each of the phosphates was applied so as to supply 200 lbs. of phosphoric acid per acre. The response to phosphoric acid is decided, and the results which are given below are of considerable value.

	Manure	Average Yield (3 years)	
		tons	cwts.
Plot 1	None	13	1
2	Basic slag	22	4
3	Gafsa	21	8
4	Superphosphate	22	9

[1] *Bulletin* 6.

Commenting on these figures the writer of the *Bulletin* says:

> Taking the average results of the three years, the crop from this plot (3) has been about one ton per acre less than that from the basic slag and superphosphate plots. Under normal conditions it is the cheapest form of phosphatic manure, and, provided that it is finely ground, it may be recommended for use in the wet climate of North Wales. It is, however, more likely to prove of general value for poor pastures on peat or upland soils, than for swedes on ordinary cultivated soils. Even an extra crop of one ton per acre of roots would more than cover the difference between the cost of suitable dressings of slag and mineral phosphates.

The above experiments with rock phosphates are by no means exhaustive, nor does this summary take account of all the countries where experimental work with such phosphates has been conducted. The Commonwealth Government of Australia, for example, has offered a prize for the discovery of new phosphate deposits, and an account of some preliminary experiments with these materials in Western Australia is given by Paterson (17).

The field experiments which have been conducted in this country are not convincing, as they have failed to establish the value of rock phosphates in the same sense that the Cockle Park and similar experiments established the fertilising value of basic slag. Moreover, no explanation has been forthcoming which satisfactorily accounts for the favourable results secured at Wiston in Sussex and in Aberdeenshire when compared with slag, and the unfavourable results at Saxmundham when compared with the same material.

It is obvious that data from many more field experiments is necessary, and if the trials are to be really helpful, each experiment must cover a series of years, and an endeavour be made to correlate the results with climatic and soil conditions.

THE ESSEX EXPERIMENTS

During the winters of 1915, 1916, 1918 and 1919 a series of manurial experiments under the auspices of the East Anglian Institute of Agriculture were laid down on permanent grass-land in Essex with the object of ascertaining:

(1) the relative fertilising value of the various forms of rock phosphate, the two types of open hearth basic slags, and

(2) the extent to which the permanent grass on the heavy clay soils could be profitably improved.

The choice of grass as the experimental crop was influenced by the fact that it is on grass, whether reserved for hay or pasture, that the direct and indirect response to phosphates is most clearly felt. Moreover, in Essex, out of a total area of 981,000 acres approximately 300,000 are covered by permanent grass, and as a very large proportion of this acreage is of the poorest quality, its improvement is of considerable economic importance.

CHARACTER OF THE SOIL

Slightly over 600,000 acres, or about two-thirds of the county, is covered by soils belonging to the London Clay and Boulder Clay formations.

The London clay beds form part of the Lower Eocene formation, and in many parts reach a thickness of over 500 feet. It is a stiff bluish grey or brown clay. Below the London clay lies a thin bed of Thanet sands varying in thickness up to 60 feet. The Thanet sands in turn rest upon an eroded surface of chalk.

The boulder clay soils dominate the northern part of the county, and vary considerably in thickness. In the extreme north and northwest of the county the boulder clay rests immediately above the chalk which comes close to the surface (see Map facing p. 1). South of the line Bishop's Stortford—Thaxted—Twinstead, the boulder clay lies immediately above the London clay. It nevertheless contains a considerable admixture of chalk, sometimes up to 11 %, and it is only the extreme southerly and easterly portions that are wholly devoid of calcium carbonate.

As a rule these heavy clay soils are very deficient in phosphoric acid, the London clays being also deficient in calcium carbonate. Unless the early autumn is favourable great difficulty is experienced

TABLE VII. ANALYSIS OF THE SOILS AT THE EXPERIMENTAL CENTRE.

Mechanical Composition

	LONDON CLAY			BOULDER CLAY				CHALK
	Great Mulgraves, Horndon-on-the-Hill	Butterfields, Latchingdon (clay loam)	Butcher's Farm, Lambourne End	Tysea Hill, Stapleford Abbotts	Martin's Hearne, Stapleford Abbotts	Hassobury, Bishop's Stortford	Farnham, Bishop's Stortford	Wendens, Saffron Walden
	%	%	%	%	%	%	%	%
Fine gravel ...	0·31	0·74	0·10	0·66	0·72	1·58	0·81	—
Coarse sand ...	1·59	6·27	19·49	7·53	5·15	26·91	8·98	—
Fine sand ...	15·09	26·73	26·87	21·58	24·25	21·07	18·34	—
Silt	21·97	21·12	14·29	9·46	18·51	13·10	19·71	—
Fine silt ...	11·60	11·50	15·78	18·60	13·90	9·50	14·70	—
Clay	29·58	16·69	9·78	18·23	17·61	11·53	20·51	—
Loss in solution	7·50	7·48	—	8·32	7·61	5·11	7·01	—
Loss on ignition*	14·50	11·82	11·72	18·09	15·29	12·61	11·30	—
	102·14	102·35	—	102·47	102·63	101·41	101·36	—

Chemical Analysis

	Great Mulgraves, Horndon-on-the-Hill	Butterfields, Latchingdon (clay loam)	Butcher's Farm, Lambourne End	Tysea Hill, Stapleford Abbotts	Martin's Hearne, Stapleford Abbotts	Hassobury, Bishop's Stortford	Farnham, Bishop's Stortford	Wendens, Saffron Walden
Loss on ignition	9·20	8·24	—	12·50	11·80	7·23	8·23	8·95
Nitrogen ...	0·212	0·248	—	0·406	0·299	0·180	0·208	0·219
Iron and aluminium oxide	14·21	9·24	8·35	11·68	11·70	11·63	11·81	8·04
Magnesia MgO ...	0·60	0·77	0·57	0·73	0·73	0·82	0·83	0·60
Lime CaO ...	1·02	0·94	0·32	0·50	0·49	0·38	0·87	23·14†
Carbon dioxide CO_2	0·12	0·17	0·00	0·00	0·00	0·00	0·20	15·97
equivalent to Calcium carbonate $CaCO_3$	0·25	0·37	0·00	0·00	0·00	0·00	0·45	36·31
Potash K_2O ...	0·857	0·607	0·508	0·541	0·704	0·435	0·644	0·594
Potash Available	0·030	0·0300	—	0·0239	0·0301	0·0194	0·0165	0·0165
Phosphoric acid P_2O_5	0·078	0·077	0·084	0·101	0·089	0·190	0·118	0·210
Available	0·0030	0·0066	0·0043	0·0051	0·0046	0·0123	0·0056	0·0013
Lime requirement 9 ins. sample	0·00	0·03	0·45	0·29	0·27	0·13	0·00	0·00

* Moisture, combined moisture and organic matter.

† Correction made for moisture content of air dried soil.

in cultivating these soils. After rain the land remains sticky and wet for a long time, and it is only too often necessary to postpone the sowing of oats and wheat until the spring. During May and June, which are dry months in Essex, the soil 'caps' and cracks, and the crops suffer severely from drought.

An inspection of the grass-land shows that much of it is of the poorest quality. It is but rare that the permanent grass receives any manurial treatment, and when reserved for hay it is only in favourable years that it passes the ton to the acre level in the western and moister part of the county, whilst in the eastern and drier part of the county crops of 7–16 cwts. of hay per acre are the rule, and it very frequently happens that the crop is not worth cutting and is fed off.

For the purposes of the experiments soils of the boulder clay and London clay formations were selected. A detailed mechanical and chemical analysis of these soils is given in Table VII. The soil at Horndon is a typical London Clay, that at Latchingdon is better described as a London clay-loam, whilst at Lambourne End the London Clay is covered by a thick matted turf which extends its influence to a depth of several inches. The soils at Tysea Hill and Martin's Hearne are typical heavy Boulder Clay soils lying immediately on top of the London clay. At Farnham and Hassobury the boulder clay rests immediately on top of the chalk, which is about 6–8 feet below the surface at Farnham, and 2 feet below the surface at Hassobury.

RAINFALL

The rainfall records from the various rainfall stations in the county show considerable fluctuations. If the county is divided into three equal portions by parallel lines running north and south, the most easterly portion might fairly be labelled the driest district in England, the average annual rainfall being approximately 20 inches. (For Shoeburyness the 35 years' average is 19·28 inches.) The middle portion of the county has an average annual rainfall of 23 to 24 inches, the 35 years' average for Chelmsford being 23·02 inches, for Bocking 23·82, and for Earl's Colne 23·42 inches. The westerly portion of the county is considerably wetter, the average annual rainfall varying from 25 to 30 inches, and for most of the stations, for which only short records are available, the average is nearer the latter than the former figure. In the east of the county the low rainfall during the month of May and the warm drying weather which is usually experienced dries up the heavy soils, and unless the season is particularly favourable it is during this month that the growth of the hay crop is checked. The western part of the county has the benefit of from ·6 to ·8 inch more rain during this month. Moreover the boulder clay, although a heavy soil, is not nearly so heavy as the London clay and does not 'cap' and crack so badly as the London clay during dry and warm spells of weather.

DETAILS OF EXPERIMENTS

The plots were all one-quarter of an acre in area, with the exception of those at Tysea Hill Farm, which were one-fifth of an acre. Three types of basic slag have been used. Basic Bessemer slag, basic open hearth slag without the addition of fluorspar, and basic open hearth slag with the addition of fluorspar. These basic slags have been compared with the following rock phosphates: Florida pebble, Florida soft, Tunisian, Algerian, Gafsa, Egyptian, Cambridge coprolites, and a ferruginous Cleveland phosphate. The composition of these phosphates is given in Table VIII. A more detailed analysis of many of these materials has been published elsewhere (4, 20). At two of the

TABLE VIII. PARTIAL ANALYSIS OF THE PHOSPHATES USED IN THE FIELD EXPERIMENTS

Name of phosphate		Total phosphoric acid P_2O_5	Total calcium oxide CaO	Silica sand etc.	Citric soluble		Citric solubility
					Phosphoric acid P_2O_5	Calcium oxide CaO	
		%	%	%	%	%	%
Basic Bessemer slag	1	17·84	48·82	9·45	16·40	—	92·0
	2	17·08	45·40	7·48	15·42	—	90·3
Open hearth high soluble basic slag	1	11·50	45·28	14·94	10·75	—	93·4
	2	9·69	46·50	—	7·99	37·13	82·25
	3	12·91	48·12	12·02	11·78	—	91·20
	4	9·80	44·90	15·39	8·00	—	80·2
Open hearth (fluorspar) basic slag	1	12·40	42·40	15·41	5·68	—	45·0
	2	11·74	42·12	17·35	2·36	22·22	20·1
	3	9·10	49·31	—	2·93	—	32·2
	4	4·75	—	—	—	—	—
Gafsa rock phosphate	1	26·21	43·51	6·37	10·05	18·54	38·3
	2	26·13	—	—	10·09	17·86	38·6
Egyptian rock phosphate		26·72	41·05	—	9·28	15·38	34·7
Tunisian ,, ,,		24·95	—	—	5·95	14·14	23·9
Algerian ,, ,,		29·32	—	—	9·79	16·82	33·4
Florida pebble ,,		33·19	48·12	—	6·06	9·06	18·2
,, soft ,,		25·34	—	—	7·01	—	27·7
Cambridge coprolites		26·76	—	—	6·74	—	25·2
Cleveland phosphate		10·28	—	—	2·01	—	19·5

experimental centres, namely Horndon and Hassobury, plots dressed with superphosphate, superphosphate and lime, and lime alone, have been included. With one or two exceptions the phosphates were sown during the period December to the end of February. Unless specifically mentioned the initial dressing given was equivalent to 200 lbs. of P_2O_5 per acre, and no further dressings have since been applied. The hay crop was cut during the latter part of June and July, and the whole of the crop on each plot weighed immediately before stacking.

In order to secure uniformity and accuracy the manures were sown, the hay crop cut, and weighed under the personal supervision of the writer. The necessary labour for weighing the crop on the experimental plots was brought direct from Chelmsford, and by such means interference in the usual routine of the farm during what is a busy season was minimised, and it was possible to keep the experiments under very effective control.

FIELD EXPERIMENTS ON BOULDER CLAY SOILS

Tysea Hill Farm. As far as can be ascertained this field has always been under grass, and for at least thirty years prior to the laying down of the plots in 1915 had been hayed and grazed in alternate years. It is known that prior to 1915 this field had received no treatment with artificial manures whatever, although it may, many years ago, have received occasional dressings of farmyard manure. The soil is sour judged either by the lime requirement figure or the Ph. value. The results are given in Table IX and are summarised in Fig. 1.

At Tysea Hill there was a rapid and marked response to the various phosphates. During the first season the Gafsa rock phosphate plot was backward, but during the succeeding years was quite as good as any of the other plots on the field, and over the period of the experiments the rock phosphate has proved quite as effective as the best quality basic Bessemer slag.

In the first year of the experiment there was an improvement in the quantity of clover present in the herbage on the treated plots, but at no period of the experiment was clover present to a very marked extent. Although during the last three seasons the untreated plots could be distinguished from the treated by the much smaller bulk of growth on them, there was never any striking difference between the amount of clover present on the untreated and treated plots. During the winter the untreated plots could always be distinguished by their darker, reddish, unhealthy appearance; the treated plots being able to retain their healthy green colour throughout the whole winter.

Table IX. Weight of Hay at Tysea Hill Farm

Manures sown: December, 1915

Plot $\frac{1}{8}$ acre	Manure 200 lbs. P_2O_5 per acre	Citric solubility %	Hay (in cwts. per acre) 1916	1917	1918	1919	1920	Average 4 years 1916–19
1	Basic Bessemer slag ...	92·0	45·5	28·2	27·4	22·4	40·2	30·9
2	Gafsa rock phosphate...	38·3	37·1	30·0	31·6	23·2	41·2	30·5
3	No manure	—	31·6	20·4	17·7	11·6	38·3	20·3
4	Open hearth (fluorspar) basic slag	45·0	47·3	33·5	29·1	21·2	46·4	32·8
5	Open hearth basic slag	93·4	46·9	33·9	28·7	21·7	45·2	32·8
6	Open hearth ,,	82·2	40·1	35·9	29·7	23·6	42·1	32·3
7	No manure	—	34·6	22·2	19·8	14·6	45·6	22·8
	100 lbs. P_2O_5 per acre							
8	Gafsa phosphate ...	38·3	42·6	33·2	29·8	23·5	48·3	32·3
9	Open hearth basic slag (same as 5)	93·4	45·2	29·8	32·3	24·3	44·8	32·9
10	Open hearth (fluorspar) basic slag	45·0	50·8	31·2	29·5	21·7	44·8	33·3
	Average gain Plots 1, 2, 4, 5 and 6 over Plot 3		% 37·3	% 57·8	% 66·1	% 93·1		
	Rainfall, May 1st till harvest (in inches)...		5·94	5·36	4·47	2·87	9·34	
	Plots cut		July 19	July 12	July 6	July 9	Aug. 23	

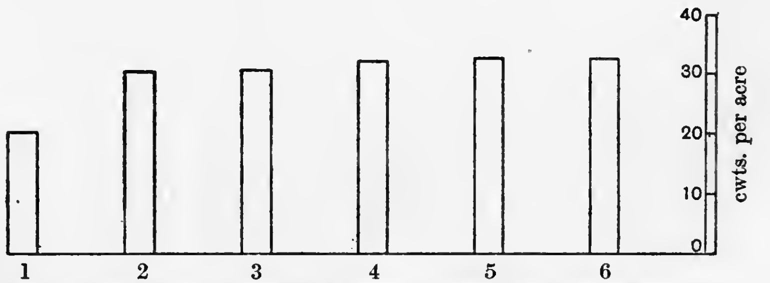


Fig. 1. Yield of Hay (average of 4 years) from the various Phosphate Plots at Tysea Hill. *Soil* Boulder clay.

1, Untreated. 2, Gafsa rock phosphate. 3, Basic Bessemer slag. 4, Open hearth (fluorspar) basic slag. 5, Open hearth high sol. basic slag. 6, Open hearth high sol. basic slag.

Equally good results it will be noted have been given by the lighter dressing of 100 lbs. of phosphoric acid over a period of five years, and it would appear that under the soil and climatic conditions of this experiment nothing is to be gained by a heavier dressing than that represented by 100 lbs. of phosphoric acid per acre. This result is interesting, as the soil is as deficient in available phosphoric acid as that at Cockle Park, where the heavier dressing of 200 lbs. of phosphoric acid per acre proves much superior to the smaller dressing of 100 lbs. applied at more frequent intervals (13).

The effectiveness of the various types of phosphates during the dry seasons of 1918 and 1919 is of considerable interest. The drier the season the greater has been the percentage increase due to phosphates.

Martin's Hearne Farm. The experimental field at this farm is only half a mile distant from that at Tysea Hill Farm. The soils on the two fields are similar in appearance and in chemical composition. The only noteworthy difference shown by the chemical analysis is the higher potash content of the soil at Martin's Hearne Farm. As far as can be ascertained this meadow has been down to grass for at least eighty years before the experiments began. During this period no artificial manure of any description has been applied, but the meadow has received during the past twenty years at intervals of seven to eight years a dressing of about ten loads of farmyard manure per acre. The herbage is of the poorest quality, weeds such as *Rumex acetosa*, *Centaurea nigra*, *Stellaria media* and *Ranunculus* forming a very large proportion of the herbage.

The results of the experiment at Martin's Hearne are shown in Table X and in Fig. 2. The improvement which followed the application of the various phosphates was even more noticeable than at Tysea Hill. During 1917 a thick mat of wild white and red clover began to cover the various plots, and during 1918 it was so thick on some of the plots as to practically exclude the grasses. The appearance of plots 1, 2, 3 and 4 on June 3rd, 1918 is shown in Plates III and IV. During the first season (1917) the open hearth high soluble basic slag (plot 2) proved more effective than the fluorspar slag or any of the rock phosphates. In 1918, however, the harvest was late, and the season on the whole moister. In this year all the rock phosphates gave results superior to that of the high soluble slag, the superiority of the Gafsa phosphate being quite distinctive. In the dry season of 1919, with an early cutting, the high soluble slag again proved the most effective, whilst in 1920, when the harvest was again late, and the season exceptionally moist, the advantage was once more with the rock phosphates. In each of the four years the open hearth (fluorspar) basic slag (plot 1) was considerably less effective than the other types of phosphate.

The dense growth of clover which covered the plots in 1918 failed to make an appearance in 1919 and all the plots were practically

TABLE X. WEIGHT OF HAY AT MARTIN'S HEARNE FARM

Manures sown: February 20th, 1917

Plot ¼ acre	MANURE 200 lbs. P_2O_5 per acre	Citric solubility of phosphate (%)	HAY (in cwts. per acre)					
			1917	1918	1919	1920	1921	Average 5 years
1	Open hearth (fluorspar) basic slag	20·1	23·0	28·6	16·4	28·4	9·9	21·3
2	Open hearth basic slag ...	91·2	30·4	33·4	27·0	31·9	13·4	27·2
3	No manure	—	14·3	23·4	10·4	23·0	9·4	16·1
4	Gafsa rock phosphate ...	38·6	23·8	38·6	24·8	35·2	15·6	27·6
5	Egyptian rock phosphate	35·0	22·8	35·9	21·9	29·0	10·8	24·1
6	Algerian " "	35·7	23·2	35·0	21·0	34·6	12·7	25·3
A	Farmyard manure* ...	—	—	—	—	40·3	17·5	—
	Rainfall, May 1st till harvest (in inches) ...	—	6·27	11·51	2·85	8·37	2·44	
	Plots cut	—	July 23	Aug. 10	July 9	Aug. 9	July 5	

* Applied at the rate of 10 loads per acre in the autumn of 1919.

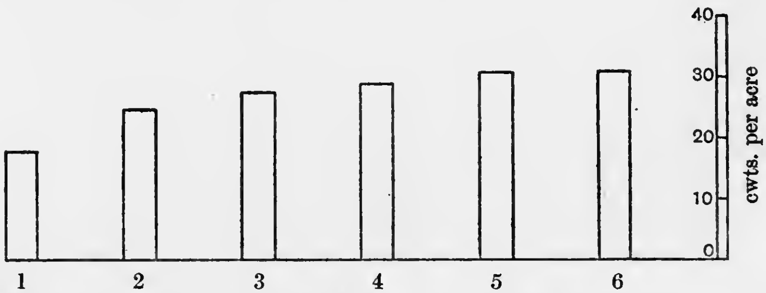


FIG. 2. Yield of Hay (average of 4 years) from the various Phosphate Plots at Martin's Hearne. *Soil* Boulder clay.

1, Untreated. 2, Open hearth (fluorspar) basic slag. 3, Egyptian phosphate. 4, Algerian phosphate. 5, Gafsa phosphate. 6, Open hearth (high sol.) basic slag.

destitute of clover. During the more favourable season of 1920 the clover reappeared towards the middle of June and, although it was not so dense as in 1918, it constituted about 30 % by weight of the crop (Table XXV). Throughout the whole of the winter the untreated plot could be picked out a mile away owing to the contrast afforded by its dark, reddish, unhealthy colour compared with the healthy green of the treated plots.

As at Tysea Hill, the effectiveness of the various phosphates during the dry seasons (1917 and 1919) is again very noticeable, the crop on the treated plots being about double that on the untreated.

Hassobury—Bishop's Stortford. The experimental field at Hassobury has been down to grass for over 90 years. The soil, although classified as boulder clay, is of much lighter texture than the average boulder clay soil. At Hassobury it lies immediately above the chalk, which is only from two to four feet below the surface. (The photograph shown in Plate V was taken standing in the ditch at the bottom of the field. The chalk can be clearly seen rising to within two to three feet from the surface.) The chemical and mechanical composition of the soil, as will be seen by an examination of the data in Table VII, differs considerably from that of the two previous centres. At Hassobury the soil is comparatively well supplied with phosphoric acid and is noticeably poorer in potash. Although so close to the chalk, the surface 9 inches of soil is sour, judged either by its lime requirement or its Ph. value.

The pasture is of very poor quality, the bottom half of the plots being covered with a thick almost impenetrable thatch of coarse grass. From three-quarters to the whole of Plots 13 to 18 are covered with a thick, matted growth, and it is only during favourable seasons, and towards the end of the season, that the clover plant seems to be able to push its way through in small scattered patches consisting of a few plants.

The meadow has been cut for hay practically every year owing to the difficulty of getting water to the field, and the aftermath as a rule grazed chiefly by horses.

At this centre a large number of rock phosphates were tried, each of them being applied in two degrees of fineness[1]. The weights of hay on the various plots over a period of three years are given in Table XI.

[1] The coarse grade was ground as fine as is usual in the manufacture of superphosphate (90–95 % to pass a '60' sieve). The finer grade was obtained by setting the Griffin mill so as to grind as fine as possible. It is not possible to sieve finely ground North African phosphates satisfactorily owing to their woolly nature.

It is obvious from the results presented in Table XI that some other factor than phosphoric acid is limiting the production of hay on this soil. Only in the dry year of 1919 was the response to the various types of phosphate in any way marked. Under such conditions no useful purpose can be served by discussing the effect of the various phosphates. Any differences that may exist must be meaningless in view of the smallness of the response and the obvious variations in the soil. The soil on Plots 15, 16 and 17, for example, is considerably richer in phosphoric acid than the soil on Plots 1, 2 and 3.

TABLE XI. WEIGHT OF HAY AT HASSOBURY

Manures sown: January, 1917

Plot ¼ acre	MANURE 200 lbs. P_2O_5 per acre	Citric solubility of phosphate (%)	HAY (in cwts. per acre)		
			1917	1918	1919
1	Florida pebble phosphate (fine) ...	19·2	19·5	28·0	15·7
2	,, ,, ,, (coarse)	18·2	19·5	25·0	15·6
3	Algerian phosphate (fine)... ...	35·7	18·5	27·8	20·8
4	,, ,, (coarse) ...	33·4	15·7	27·5	23·8
5	Basic Bessemer slag	90·3	13·4	25·1	17·5
6	Untreated	—	11·1	23·4	10·9
7	Gafsa phosphate (fine)	41·4	12·4	26·8	19·5
8	,, ,, (coarse)... ...	38·6	12·1	25·7	19·4
9	Tunisian ,, (fine)	26·0	12·2	29·7*	16·7
10	,, ,, (coarse)... ...	23·9	10·7	33·8†	14·2
11	Egyptian ,, (fine)	37·0	10·7	35·0	13·3
12	,, ,, (coarse)... ...	34·7	11·0	34·6	13·7
13	Superphosphate	—	14·3	31·4	13·1
14	,, (at the rate of 50 lbs. of P_2O_5 per acre)... ...	—	13·6	32·8	10·7
15	Superphosphate (200 lbs. P_2O_5 per acre) + 1 ton of ground lime per acre	—	11·5	34·1	12·1
16	Untreated	—	8·6	26·2	7·8
17	Open hearth high sol. basic slag...	91·2	10·5	34·3	9·5
18	,, (fluorspar) basic slag	20·1	10·4	31·6	8·9
	Rainfall, May 1st till harvest (in inches)	—	4·82	7·73	0·58
	Plots cut	—	July 7	Aug. 1	June 16

* Plot 9 raked and half cocked. Plots 1–8 lying in the swathe. Hay-making interrupted by two days' rain, plots not being weighed till four days later.

† Plots 10–18 inclusive raked and cocked before the rain.

Farnham Hall. The manures at this centre were not applied until the end of February, 1917. The results for 1917, 1918, 1919 and 1920 are given in Table XII.

Table XII. Weight of Hay at Farnham Hall

Manures sown: February 22nd, 1917

Plots ¼ acre	Manure 200 lbs. P_2O_5 per acre	Citric solubility of phosphate (%)	Hay (in cwts. per acre)			
			1917	1918	1919	1920
1	Open hearth (fluorspar) basic slag	20·1	26·8	6·3	7·2	9·8
2	Open hearth (high soluble) basic slag	91·2	28·2	6·0	7·0	11·5
3	Untreated	—	24·2	4·9	7·9	11·1
4	Gafsa rock phosphate ...	38·0	25·7	6·6	8·6	11·1
	Rainfall, May 1st till harvest (in inches) ...	—	3·86	2·97	1·73	2·64
	Plots cut	—	June 23	June 29	June 26	June 30

Table XIII. Percentage of Ground Space occupied by the Vegetation on the Plots at Farnham Hall: August, 1919

Type of vegetation	Farnham (Boulder Clay Soil)			
	Plot 1 Open hearth basic slag (solubility, 20%)	Plot 2 High citric soluble basic slag (solubility, 91 %)	Plot 3 No manure	Plot 4 Gafsa rock phosphate
Clovers	27·1 %	50·2 %	16·2 %	35·9 %
Grasses	45·0	33·3	18·4	45·5
Weeds	16·0	13·5	25·0	10·6
Bare space ...	11·9	3·0	40·4	8·0

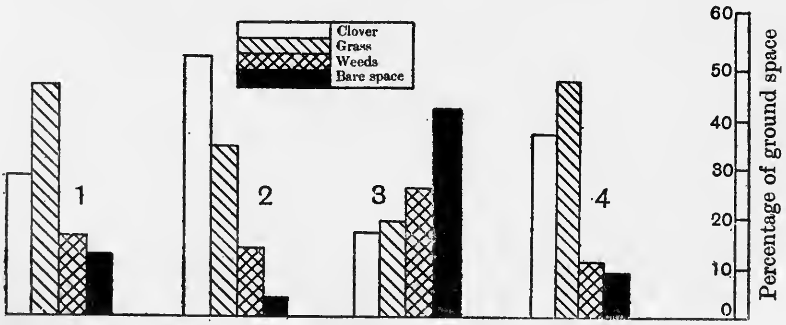


Fig. 3. Percentage of Ground Space occupied by the Vegetation at Farnham, August, 1919. *Soil* Boulder clay.

1, Open hearth (fluorspar) basic slag. 2, Open hearth high soluble basic slag. 3, Untreated. 4, Gafsa rock phosphate.

In spite of the fact that the amount of available phosphoric acid in this soil is very low, the response to the various phosphates, judged by the yield of hay, is insignificant. The improvement in the three treated plots was, however, obvious on walking over them. The clover bottom on the untreated plot was very patchy and a considerable area of the plot was bare. Plots 1, 2 and 4 were covered with a thick bottom of wild white and red clover. In the earlier years of the experiment Plot 2 had undoubtedly the better bottom, but was closely followed by Plot 4, which in 1920 was probably slightly the better plot. Plot 1—open hearth fluorspar slag—was inferior to Plot 2 during the first three years of the experiment, but during 1920 this plot made considerable progress and was quite comparable with the other two treated plots.

During August, 1919, a determination of the ground space occupied by the various species on each of the four plots was made and the results set out in Table XIII and illustrated in Fig. 3. The high citric soluble slag has produced a vast improvement in the herbage, and it is quite clear from these comparative results that up till then it had been the most effective phosphate.

Although the meadow is an early one, being generally cut during the last week in June or the first week in July, still it is somewhat surprising that the effect of the phosphate should be confined to stimulating the bottom growth and that the improvement so brought about should have practically no effect on the yield. The results seemed to indicate that until some other requirement of the soil is satisfied the yield of hay will not be greatly affected by the application of phosphate.

Discussion of the Results on the Boulder Clay Soils

At Tysea Hill and Martin's Hearne the two types of soluble slag, namely, the basic Bessemer and open hearth basic slag without fluorspar, produce in equivalent quantities the same results. The open hearth fluorspar basic slag of 45 % citric solubility gives returns strictly comparable with the other two types of slag. The fluorspar slag of very low solubility (20 %) does not do so well and it is distinctly inferior at Martin's Hearne (Table X) and Farnham (Table XIII) to the more soluble types of slag. The soils at the two centres—Martin's Hearne and Tysea Hill—are practically identical, and it would be reasonable to expect that the fluorspar slag of 45 % solubility would have done equally well at Martin's Hearne and *vice versa*; that the slag of very low solubility 20 % would have also given inferior results at Tysea Hill. The rock phosphates both at Martin's Hearne and Tysea Hill give consistently good results. On this type of soil Gafsa rock phosphate may safely be said to be equivalent to the better grades of basic slag. Other North African phosphates, such as Egyptian and Algerian phosphate, are not far behind Gafsa phosphate in this respect.

Although at Tysea Hill there is apparently no discernible difference between the various types of phosphate, yet on a very similar soil though slightly poorer in phosphoric acid, such as that at Martin's Hearne, a study of the results reveals some important variations in their action. During a moist season with a long growing period the rock phosphates are on the whole more effective than even the highest soluble basic slag. When the season is dry and the growing period consequently short the advantage is decidedly with the more highly soluble phosphate.

Under the soil and climatic conditions existing at Martin's Hearne, there is over a period of years nothing to choose between the effectiveness of rock phosphate and the best grades of basic slag for the improvement of grass-land. The open hearth basic slags of 20 % solubility or less, although they give good and profitable results, are clearly less effective even in favourable seasons than the high soluble types.

The lack of response to phosphates at Farnham and Hassobury indicates that phosphates are not the most important manurial factor on all the boulder clay soils in Essex, and that even where the soil is very deficient in available phosphoric acid as at Farnham, a deficiency in some other constituent may prevent a profitable response to phosphatic manuring.

FIELD EXPERIMENTS ON LONDON CLAY SOILS

Horndon-on-the-Hill. A 20 acre meadow which had been laid down to grass in or about the year 1890 was selected for these trials. The soil is a heavy, impervious London clay, known in Essex as three-horse land and always put up in 7 ft. 6 in. stetches so as to secure the maximum amount of surface drainage.

The field, as do all the fields whether grass or arable on this type of soil, lies cold and wet during the autumn and winter, and unless there is a good natural slope and good under drainage, water stands in the furrows during the greater part of the winter and early spring.

Table XIV. Weight of Hay at Great Mulgraves, Horndon-on-the-Hill

Dressing 200 lbs. P_2O_5 per acre unless otherwise stated

Plot ¼ acre	Manure	Citric solubility of the phosphate %	Hay (in cwts. per acre)		
			1918 *	1919	1920
A	No manure	—	—	Plots grazed by cattle and sheep	4·5
B	Cambridge coprolites	25·0	—		15·9
C	Lime at rate of 1 ton per acre ...	—	—		5·0
D	Rough slag (double dressing) ...	—	—		17·2
1	Florida pebble phosphate (fine) ...	19·2	14·2		17·0
2	,, ,, ,, (coarse)	18·2	13·7		14·7
3	Algerian phosphate (fine)... ...	35·7	14·7		21·5
4	,, ,, (coarse) ...	33·4	14·9		19·7
5	Open hearth basic slag: high sol.	91·2	18·8		23·2
6	No manure	—	11·1		6·4
7	Gafsa rock phosphate (coarse) ...	38·6	17·8		22·3
8	,, ,, ,, ,, ...	38·6	18·4		22·2
9	Tunisian ,, (fine) ...	26·0	17·9		23·2
10	,, ,, (coarse) ...	23·9	19·2		23·8
11	Egyptian ,, (fine) ...	37·0	23·6		23·6
12	,, ,, (coarse) ...	34·7	22·5		25·1
13	Superphosphate (200 lbs. P_2O_5 per acre)	—	27·0		23·0
14	Superphosphate (50 lbs. P_2O_5 per acre)	—	25·9		12·3
15	Superphosphate (200 lbs. P_2O_5 per acre)—1 ton of ground lime per acre	—	23·4		27·2
16	No manure	—	15·5		6·4
17	Open hearth basic slag: high sol.	91·2	22·5		28·8
18	,, ,, (fluorspar)	20·1	18·8		16·8
19	1 cwt. ferrous sulphate per acre ...	—	13·6		6·4
E	Lime at rate of 1 ton per acre ...	—	—		5·4
F	Cambridge coprolites	25·0	—		15·1
G	Rough slag...	—	—		10·4
H	Cleveland phosphate	19·5	—		19·0
K	No manure...	—	—		5·0
L	Florida soft phosphate	27·7	—		13·0
	Average gain, Plots 1 to 5 and 7 to 13 and 15, 17 and 18, over plots 6 and 16	—	—	—	250 %
	Rainfall, May 1st till harvest (in inches)	—	2·25	1·78 †	5·34
	Date of cutting	—	July 8	—	Aug. 16

* Phosphates not applied till Feb. 27th.
† Rainfall, May 1st to June 30th.

The summer is equally trying on this type of soil. The dry and hot weather which is usually experienced in Essex in June and the latter part of May 'caps' or bakes the soil—the soil sets hard and cracks and the crops receive a check. It is but seldom that the crop of hay exceeds 10 cwts. to the acre, and it is only too frequently left uncut altogether. The meadows which have recently been laid down contain a small reserve of calcium carbonate, a residuum from the heavy dressing of lump chalk (40–60 tons per acre) fairly frequently applied up to the eighties or nineties.

The soil is exceedingly poor in both 'total' and 'available' phosphoric acid, but is well supplied with potash.

Nineteen quarter-acre plots (1–19) were laid down on this field in 1918, and the manures sown on February 27th, 1918. Subsequently Plots A, B, C, D, E, F, G, H and K were added and sown on February 3rd, 1919, and finally Plot L was sown during May, 1919.

The weights of hay on the various plots for the seasons 1918 and 1920 are given in Table XIV.

In this experiment an attempt was made to ascertain whether better effects could be obtained from rock phosphates by finer grinding. With this object in view the Florida pebble, Algerian, Gafsa, Tunisian and Egyptian phosphates mentioned in the above tables were specially ground under the writer's supervision by Messrs Walter Packard, of Ipswich.

All the phosphates were passed through a Griffin mill. For coarse grinding the mill was set to grind for the standard usually adopted when the rock phosphates are used for the manufacture of superphosphates (90 % to pass a '60' sieve). In actual fact about 80 % of the material will pass the '100' sieve. For fine grinding the mill was closed down so that the output per hour was reduced by a half. A much finer product was obtained, but it has not been practical, owing to the 'woolly' nature of the rock phosphates, to satisfactorily distinguish by means of sieves between the 'fine' and the 'coarse' grinding. During 1918 no superiority due to fine grinding was noticed.

Throughout the whole season of 1920 the writer was able to visit this centre at least every week, and a close watch was kept on the progress of the various plots. The high soluble slag and the "superphosphate and lime" plots were the first to make a start, followed by those plots receiving the finer ground rock phosphates. During the whole of May the superiority of the plots receiving the finer ground rock phosphates over those receiving the same phosphate only more coarsely ground could be distinctly seen. As the season progressed the distinction became less and less visible, until at the beginning of July it was quite impossible to see any difference.

The high soluble basic slag, Plots 5 and 17, and Plot 15 (super and lime) were distinctly ahead during the whole season, but the rock phosphate plots gradually lessened the difference as the season progressed, although they never actually succeeded in catching up.

The weights of hay for the season of 1920, which was particularly favourable to the hay crop, give some indication of the contrast which existed between the various phosphate plots and the untreated portions.

It may be of interest to mention that only the plots were cut, and no attempt was made to harvest the rest of the field, as the crop was not considered to be worth the labour involved in doing so.

When the wild white clover came into flower the contrast was remarkable. Plate VI, showing a general view down Plot K (untreated) and Plot H (Cleveland phosphate), gives some idea of the contrast which met the eye. So thick was the crop of wild white clover that the farmer decided to seed the plots.

Plots 1–19 are strictly comparable, having been sown at the same time, and a useful comparison of the effectiveness of the various phosphates may be made from the respective yields of hay.

There can be little doubt that the highest soluble types of open hearth basic slag and basic superphosphate have proved the most effective phosphates at Horndon. At the same time, however, some of the rock phosphates are nearly as effective. From June onwards, for example, it was always difficult to say which of the two, Plots 3 or 5, was the better, although there was no doubt that Plot 3 was inferior to Plot 17, which is a duplicate of Plot 5. The hard American Florida pebble phosphate is inferior to the softer North African phosphates. The inferiority is not only apparent in the weights of hay, but is plainly to be seen on walking over the plots, a result which agrees with Tacke's conclusion[1].

No gain from fine grinding is apparent in the weights of hay, but an earlier start was undoubtedly made by the plots receiving the finer ground phosphate, and where a meadow is reserved for grazing it is possible that the extra cost of grinding would be well repaid.

The open hearth fluorspar slag, after giving promising results during the first two years, proved a poor plot in 1920 when compared with the high soluble slag, Plot 17. All the rock phosphate plots,

[1] *Inter. Inst. of Agr. Bulletin*, September, 1913.

with the exception of the two receiving Florida pebble, were much superior to the open hearth fluorspar basic slag.

Plots C and E unmistakeably show that lime without phosphate has little or no effect in improving this type of pasture.

It is difficult to interpret the results from Plots B, D, F, G, H and L in terms of the other plots. They were not sown until 1919, and the exceedingly dry season prevented a rapid response. As all the plots were grazed throughout this season, these particular plots would not receive the same benefit from the grazing as those sown the year previously, which, at the beginning of the grazing period, were already covered with a thick and close bottom of wild white clover.

During the latter part of May, 1920, Plots B, D, F and H, at first backward, made rapid progress, and at harvest time there seemed to be more heads of clover on some of these plots than on the majority of the others. Plate VI illustrates the appearance of Plot H in July, 1920.

It has been quite obvious during the past two years that the light dressing of superphosphate on Plot 14 has not been effective. The improvement was much less than the weight of hay would appear to indicate, and during the seasons 1919 and 1920 Plot 14 looked very like an untreated plot. The heavy dressing of superphosphate on Plot 13 was much more effective. It was not, however, nearly so good as the high soluble slag plots or the "superphosphate and lime" plot. Even on a soil of this character, very deficient in phosphoric acid and with a small reserve of calcium carbonate, an acid manure like superphosphate is not suitable. On Plot 15 the same dressing of superphosphate as on Plot 13, namely 200 lbs. P_2O_5 per acre, plus one ton of lime per acre, were sown together. Under such circumstances the reversion of the water soluble phosphate in the superphosphate would be practically instantaneous (22) and the dressing would become a basic one comparable to the application of a dressing of basic superphosphate. It is of interest to note that Plot 15 gives results practically identical with those secured on the plots receiving the most soluble type of basic slag. A close observation was kept on Plots 15 and 17 throughout the 1920 season, and the only noticeable difference was the somewhat earlier start made by Plot 15. The difference in this respect was not great, probably not more than 7 to 10 days, and had visits to the plots been less frequent, might have been entirely overlooked.

During the season of 1919 the long drought lasting from the

Table XV. Percentage of Ground Space occupied by the Vegetation on the Plots at Horndon

Analysis made: August, 1919

Plot ¼ acre	Manure (Dressing 200 lbs. P_2O_5 per acre)	Clover %	Grass %	Weeds %	Bare space %
C	Lime alone	15·1	34·6	30·0	20·3
1	Florida pebble phosphate	46·0	30·6	13·3	10·1
3	Algerian phosphate	47·4	30·1	7·4	15·1
5	Open hearth high sol. basic slag ...	44·1	28·6	13·7	13·6
6	Untreated	4·2	14·8	31·0	50·0
8	Gafsa phosphate	41·3	32·3	17·6	8·8
9	Tunisian phosphate	38·5	36·9	21·0	3·6
12	Egyptian ,, ...	55·5	41·0	0·7	2·8
13	Superphosphate (200 lbs. P_2O_5 per acre)	23·9	57·3	0·7	18·1
14	,, (50 lbs. P_2O_5 per acre)	18·8	25·3	18·8	37·1
15	Superphosphate (as for Plot 13) plus 1 ton of lime per acre	60·0	32·7	1·4	5·9
16	Untreated	9·4	19·1	26·0	45·5
17	Open hearth high sol. basic slag (same as for Plot 5)	46·2	47·2	1·4	5·2
18	Open hearth (fluorspar) basic slag (low soluble)	43·8	31·8	13·3	11·1
H	Cleveland phosphate...	43·1	33·3	5·6	18·0

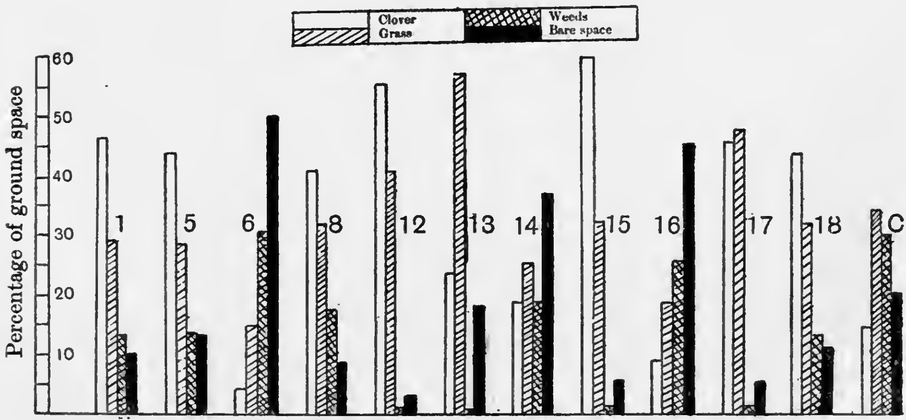


Fig. 4. Percentage of Ground Space occupied by the Vegetation at Horndon, August, 1919. *Soil* London clay.

1, Florida pebble phosphate. 5, Basic slag. 6, No manure. 8, Gafsa phosphate. 12, Egyptian phosphate. 13, Superphosphate heavy dressing. 14, Superphosphate light dressing. 15, Superphosphate and lime. 16, No manure. 17, Basic slag. 18, Open hearth fluorspar basic slag. C, Lime.

beginning of May until the third week in June made a hay crop out of the question, and the plots were therefore grazed by cattle and sheep during the remainder of the season. The contrasts between several of the plots were, however, so great, that on the suggestion of Dr Russell a detailed examination of the ground space covered by the various types of vegetation was made on several of the plots, using the method recommended by Armstrong (1).

The results are set out in Table XV, and illustrated in Fig. 4. Photographic representations of several of the plots are given in Plates VII and VIII.

The poverty of the untreated plots is difficult to describe, but some idea of their unproductiveness is afforded by Table XV, by Fig. 4 and the lower figure on Plate VI. Amongst the weeds on the untreated plots *Hypochaeris radicata*, *Leontodon hispidus*, *Ranunculus*, *Prunella vulgaris*, *Potentilla reptans*, *Bellis perennis* and *Plantago lanceolata* are prominent, and amongst the grasses *Holcus lanatus*, *Hordeum pratense*, *Agrostis vulgaris*, *Cynosurus cristatus*, *Lolium perenne* are also prominent, whilst traces of *Dactylis glomerata*, *Phleum pratense* and *Alopecurus pratensis* can be found.

The transformation which has been brought about by the various phosphates is remarkable. Weeds have been largely crowded out and the bare space reduced in some cases to vanishing point. On the untreated plots the crop was left practically untouched, whilst on the plots receiving phosphates the growth had been grazed to the ground, and even the clover runners were being eaten by the sheep. The contrast remained equally striking right through the whole winter. The untreated plot was clearly defined by its dark unhealthy appearance and the black heads of the uncropped crested dog's tail. On the plots receiving phosphates the mat of wild white clover runners remained green throughout the whole winter, and continued to afford feed for the stock wintered on the meadow.

The botanical examination of the flora reveals differences between the various phosphates which do not appear so prominently in the yields of hay. Whilst the various basic phosphates show but small differences, the three plots receiving superphosphate show significant contrasts. A very decided improvement has followed the heavy dressing of superphosphate, but the small dressing of 50 lbs. of P_2O_5 in the form of superphosphate has had little effect. The addition of lime at the rate of 1 ton per acre, sown immediately the superphosphate had passed through the drill, produces an effect which affords a significant contrast with the same dressing of superphosphate applied alone. Superphosphate alone has had most effect on the grasses, whilst superphosphate and lime together—basic superphosphate—has told mostly on the clovers.

Armstrong's method of interpreting the results fails to bring out any marked distinction between the types of basic phosphates. It merely demonstrates that the improvement in quality is approximately the same. When the plots are left for hay the differences between the phosphates are reflected in the hay yields, but when the plots are grazed or when the growth is short inspection of the plots gives the impression that there is little to choose between them. This difficulty in interpreting results under such conditions is also noted by Oldershaw (16).

Butterfields, Latchingdon. The soil at Latchingdon is not so heavy as that at Horndon, containing only 16·5 % of clay, against 30 % at the latter centre. The soil would be better described as a clay loam, resting on a stiff London clay subsoil. In other respects it is very similar to Horndon. It is very poor in both total and available phosphoric acid, but contains a small reserve of calcium carbonate. Eight years before the commencement of the experiments in 1915, the experimental field had received a small dressing of about 4–5 cwts. of basic slag per acre—a dressing which probably accounts for the comparatively high proportion of citric soluble phosphoric acid to total at this centre (Table VII).

The meadow, however, was in an exceedingly poor condition when the experiments began, and it is evident from the response to the various phosphates that the effect of the small dressing applied 13 years ago was practically exhausted.

The plots have been cut every year, and the hay crop weighed. The figures are set out in Table XVI and the results are shown diagrammatically in Fig. 5.

The figures in Table XVI give some idea of the remarkable response to the various phosphates. The improvement in the quality of the herbage was equally marked. During the seasons 1916, 1917 and 1918 the treated plots contained a dense and vigorous growth of clover. The open hearth fluorspar slag was quite as effective in this respect, during the initial stages of the experiment, as any of the high soluble slags, and was in fact superior to either of the two open hearth high soluble basic slags on Plots 5 and 6. It has already been pointed out that it was not until the second year that the yellow suckling clover and bird's foot trefoil, which formed the natural leguminous flora of the untreated plot, were replaced on Plot 2 (Gafsa

TABLE XVI. WEIGHT OF HAY AT BUTTERFIELDS, LATCHINGDON

Manures sown: December, 1915

Plot ¼ acre	MANURE 200 lbs. P_2O_5 per acre	Citric solubility of phosphate (%)	HAY (in cwts. per acre) 1916	1917	1918	1919	1920	Average 5 years
1	Basic Bessemer slag ...	92·0	44·4	24·3	22·2	35·9	20·0	29·4
2	Gafsa rock phosphate ...	38·3	44·2	19·1	27·0	28·3	17·8*	27·3
3	No manure	—	31·4	14·5	20·1	20·6	16·1	20·5
4	Open hearth (fluorspar) basic slag	45·0	44·7	23·5	26·2	28·7	21·4	28·9
5	Open hearth basic slag—high citric soluble (1) ...	93·4	37·6	21·9	32·4	34·5	22·6	28·9
6	Open hearth basic slag—high citric soluble (2) ...	82·2	40·9	22·7	36·3	35·7	25·7	32·3
	Percent. increase of Plots 1, 2, 4, 5 and 6 over the unmanured plot (Plot 3)	—	34·4	53·8	43·4	62·2	39·2	—
	Average rainfall May 1st to June 30th (in inches)	—	3·41	2·32	2·51	1·47	2·28	—
	Date of cutting	—	July 25	July 19	July 29	July 21	July 19	—

* During the late winter and early spring of 1919–20 cattle were driven without the knowledge of the farmer across a portion of this meadow on their way to a more distant pasture. Their track lay right along the length of Plot 2, which they poached badly. As a result, although this plot had the best bottom, there was not such a vigorous growth as on the other treated plots.

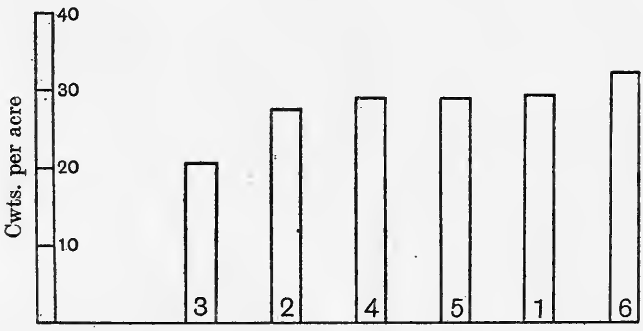


FIG. 5. Yield of Hay (average of 5 years) for the various Phosphate Plots at Butterfields, Latchingdon. *Soil* London clay.

3, Untreated. 2, Gafsa rock phosphate. 4, Open hearth (fluorspar) basic slag. 5, Open hearth (high soluble) basic slag 1. 1, Basic Bessemer slag. 6, Open hearth (high soluble) basic slag 2.

phosphate) by a bottom of wild white clover comparable to that on the other plots. During 1919 and 1920, and to a certain extent during 1918, it was noticeable that the open hearth fluorspar slag on Plot 4 was not doing quite so well as some of the other slags, and the weights of hay for these years confirm this opinion. The inferiority of both the Gafsa phosphate and the open hearth fluorspar slag plots during the dry season of 1919 was also obvious to the eye.

The behaviour of the clover was the outstanding difference between this centre and Horndon. Whereas at Horndon the clover runners ramified over the whole of the plots receiving basic phosphates and persisted throughout the whole winter, at Latchingdon the clover seldom made its appearance before the end of May or the beginning of June, and seemed to vanish completely from the plots by the end

TABLE XVII. PERCENTAGE OF THE GROUND SPACE OCCUPIED BY THE VEGETATION ON THE PLOTS AT BUTTERFIELDS, LATCHINGDON

Type of vegetation	Plot 1 Basic Bessemer slag	Plot 3 No manure	Plot 4 Open hearth (fluorspar) basic slag
Clovers	18·1%	7·8%	22·2%
Grasses	56·2	41·5	42·4
Weeds	0·0	1·6	0·0
Bare space ...	25·7	49·1	35·4

of October. During the dry season of 1919 the clover bottom on the treated plots, although vastly superior to the unmanured plot, was much inferior to what it had been during previous years, or during the following year 1920. Not till the rain came at the end of June in 1919 did the clover make any real show, and had the plots been cut early in July as was intended there would have been little, if any, clover in the hay.

The examination of the flora covering the ground space of Plots 1, 3 and 4 was made during the third week of September 1919, and the results are given in Table XVII.

As far as the composition of the herbage is concerned, the open hearth (fluorspar) basic slag compares very favourably with the basic Bessemer slag, and both are greatly superior to the untreated plot.

Butcher's Farm, Lambourne End. These trials were not commenced until 1919, the manures being sown on January 4th, 1919. The writer had been offered a supply of a new 'ferruginous phosphate' recently discovered in Cleveland (N.R. of Yorkshire), and, through the courtesy of Dr Stead, a small quantity of two open hearth slags from the same Steel Works, but of widely different solubilities.

It was therefore decided to start a new experimental centre in order that a fair comparison between the different phosphates might be secured. The size of the plots was one-quarter acre, and the usual dressing of 200 lbs. P_2O_5 per acre was given of the various phosphates. The plots have received no further treatment.

Table XVIII. Weight of Hay at Butcher's Farm, Lambourne End

Manures sown: January 4th, 1919

Plot ¼ acre	Manure 200 lbs. P_2O_5 per acre	Citric solubility of the phosphate (%)	Hay (in cwts. per acre)			
			1919	1920	1921	Average 3 years
A	Cambridge coprolites...	25	25·0	32·3	33·3	30·2
1	Open hearth (fluorspar) basic slag ...	20	26·6	34·7	38·5	33·3
2	Open hearth basic slag	91	24·5	36·2	31·0	30·6
3	No manure	—	13·2	21·4	18·4	17·7
4	Egyptian phosphate	35	18·0	34·4	27·4	26·6
5	Florida pebble phosphate	18	16·9	37·8	30·5	28·4
6	Tunisian phosphate	24	19·0	38·1	34·0	30·3
7*	Open hearth (fluorspar) basic slag (Wigan)	32	16·0	34·1	29·4	26·5
8*	Open hearth basic slag (Wigan) ...	80	23·7	38·0	28·5	30·1
9	Cleveland phosphate	19	19·9	38·9	34·4	31·1
	Rainfall, May 1st till harvest (in ins.)	—	3·08	5·27	2·44	
	Date of cutting	—	July 17	July 17	June 25	

* Plots 7 and 8 = $\frac{1}{10{\cdot}2}$ of an acre.

The condition of the meadow was very different from that of the other centres. Instead of a bare open surface as at Horndon, the surface was covered with a thick matted turf. Down to a depth of about 12 inches the soil was of a fibrous peaty character, and although it rested on a London clay sub-soil, the first 9 or 12 inches of soil resembled a sour peat soil. Scarcely a trace of leguminous plants has been visible on the untreated plot throughout, the hay consisting largely of water grasses and the type of weeds characteristic of sour soils.

The soil, as will be seen in Table VII, was very deficient in total and available phosphoric acid, it contained no calcium carbonate, had the high lime requirement of ·45 %, and was highly charged with organic matter.

The results are given in Table XVIII.

Although there are considerable differences between the effect of the various phosphates at this centre during the dry season of 1919, there are no decided indications that high citric solubility has been of any great importance. The noticeable difference between the returns from the two types of open hearth fluorspar basic slag (Plots 1 and 7) is somewhat surprising, especially as it is the more soluble of the two slags which gives the poorer result. It has, however, been pointed out (18) that a modification of the solubility test, so that 1 gm. instead of 5 gms. of the phosphate is used in performing the test, reverses the order of solubility of these two slags. The slag on Plot 1 becomes 60·6 % soluble whilst that on Plot 7 is only 37·7 % soluble. Difference in the nature of the phosphates in the two slags is evidently in this case of greater importance than any question of solubility by the Wagner citric acid test.

During the dry season of 1919 clover was practically absent from these plots, and it was not until May of 1920 that it began to force its way through the matted turf on the treated plots. In June the progress made was remarkable, and by the end of the month the treated plots were covered with a thick and vigorous growth of red and white clover, which over large areas practically precluded the growth of any other type of vegetation (Table XXVIII). The clover on Plot 2 (high soluble slag) made better progress than that on Plot 1 (low soluble slag), and on the whole the high soluble slag was the better of the two. The difference was noticeable at the beginning of the season, but towards the end it became less and less visible. Throughout the whole season Plot 7 (open hearth fluorspar basic slag) was much inferior to any of the other plots, and it was rather surprising to find it weigh out so heavily. The Cleveland phosphate plot was perhaps the best plot on the field, although the superiority was not great. The Florida pebble phosphate was slow in making a start, but this plot made rapid progress and was ultimately one of the best plots on the field.

In spite of the dry season the 1921 hay crop was quite a heavy one, whereas at Martin's Hearne, only a short distance away, the crop was practically a failure (Table X). The contrast is probably due to the difference in the soils. The heavy soil at Martin's Hearne 'bakes and cracks' during a hot and dry spell of weather, and under such circumstances it is likely that the greater part of the heavy fall of rain on May 26th (1 inch) was lost by surface drainage. At Lambourne End the soil is not heavy and its peaty character no doubt enabled it to retain a much greater proportion of the rain which fell on the 26th.

Over a period of three years the heaviest average crop of hay has come from the plot receiving open hearth (fluorspar) basic slag of 20 % solubility—the slag which has given comparatively poor results at other centres (Martin's Hearne, Table X, and Horndon, Table XIV). As if to emphasise the peculiarity the next best return is given by the least soluble of the mineral phosphates used in the experiments. At Lambourne End citric solubility is clearly of minor importance and the difference in the behaviour of the open hearth (fluorspar) basic slag (Plot 1) at this centre and at Martin's Hearne is probably accounted for by soil conditions. The Lambourne End soil has a much higher lime requirement figure (·45 % compared with ·27 % at Martin's Hearne) but it is by no means certain that this difference alone suffices to explain the results.

Discussion of the Results on the London Clay Soils

At all the centres on the London clay formation there has been a marked response to phosphates. The effect of the manures on the whole is even more striking than on the boulder clay soils. Differences between the relative efficiency of the various phosphates have been noticeable. Where the pasture has been down for many years, and where as a consequence big stores of organic matter have accumulated and the soil has a high 'lime requirement,' and where the rainfall is adequate, then rock phosphates prove quite as efficient as the best grades of basic slag. Under these conditions open hearth (fluorspar) basic slags do not give consistent results. One type of open hearth fluorspar slag of very low solubility proves quite as efficient as the highest citric soluble type of slag, whilst another open hearth fluorspar slag, apparently more soluble than the former one, proves decidedly inferior.

Where the pasture is comparatively new (30 years or so), where the summer rainfall is low, and where a small reserve of calcium carbonate still exists in the soil, the best results are secured by the highest citric soluble types of basic slag. The improvement effected by the best grades of basic slag is, however, closely approximated to by the North African rock phosphates. In fact in some years, noticeably at Latchingdon, rock phosphates may do considerably better than the best grades of basic slag (Table XVI).

The open hearth fluorspar slag of 45 % solubility on the average of five years seems to be quite as effective at Latchingdon as the most soluble types of slag, although it seems to be somewhat less effective during the fourth and fifth years of the experiment.

The low soluble open hearth fluorspar slag (20% soluble), although it gave promise of good results at Horndon during the first two seasons, fell far behind during the favourable season of 1920, and proved to be inferior to the more insoluble types of rock phosphate. This slag also proved less effective on the boulder clay soil at Martin's Hearne (Table X). It is not suggested that this slag is of little value. On the contrary the improvement effected is really very marked in all cases, and only suffers by comparison with the other phosphates.

FIELD EXPERIMENTS ON CHALK SOILS

Wendens, Saffron Walden. The lower photograph on Plate VII illustrates the character of the soil at this centre. The chalk is covered by a thin layer of boulder clay soil, mixed with a large proportion of chalk. The first nine inches of soil at Wendens contains upwards of 36 % of chalk. It is naturally comparatively rich in phosphates, and although the available phosphoric acid figure is low (Table VII) this is no doubt due to the calcium carbonate neutralising the citric acid. This type of soil dries out quickly. It therefore makes an early start in the spring, and the meadow hay is always ready to cut during the second or third week of June. In this respect, therefore, the conditions are somewhat different from those at the other experimental centres, which are known as late meadows and which are not harvested before the second week of July.

The experimental field at Wendens was allowed to fall out of cultivation about 25 years ago. No seeds of any description were sown, and the meadow is therefore a natural one. The general practice has been to cut the field every year for hay, and to fold the aftermath with sheep. The pasture is of a much superior type to that on any of the other experimental centres. The same phosphates were used at this centre as at Latchingdon and Tysea Hill Farm. The weights of hay for the five years 1916–1920 are given in Table XIX, and are represented diagrammatically in Fig. 6.

The results at this centre are of considerable interest because they show that even on an early meadow the more insoluble types of phosphate, such as those represented by rock phosphates and the better types of open hearth (fluorspar) basic slag, are capable of

TABLE XIX. WEIGHT OF HAY AT WENDENS, SAFFRON WALDEN
Manures sown: January, 1916

Plot ¼ acre	MANURE 200 lbs. P_2O_5 per acre	Citric solubility of phosphate (%)	HAY (in cwts. per acre)					
			1916	1917	1918	1919	1920	Average 5 years
1	Basic Bessemer slag ...	92·0	68·5	30·4	42·6	23·4	39·8	40·9
2	Gafsa rock phosphate...	38·3	62·8	31·5	39·7	20·7	36·2	38·1
3	No manure	—	51·2	25·4	33·4	14·3	28·0	30·4
4	Open hearth (fluorspar) basic slag	45·0	64·9	35·1	42·3	17·7	39·7	39·9
5	Open hearth basic slag (high soluble), (1) ...	93·4	54·8	34·4	35·7	15·9	36·7	35·5
6	Open hearth basic slag (high soluble), (2) ...	82·2	60·3	40·4	42·6	17·8	34·1	39·2
	Average increase of Plots 1, 2, 4, 5 and 6 over Plot 3	—	21·6	36·0	21·6	33·5	32·2	—
	Rainfall, May 1st till harvest (in inches) ...	—	4·00	4·00*	2·44	0·53	2·42	
	Plots cut		June 17	June 16	June 29	June 19	June 22	

* 2·3 inches fell on May 20th.

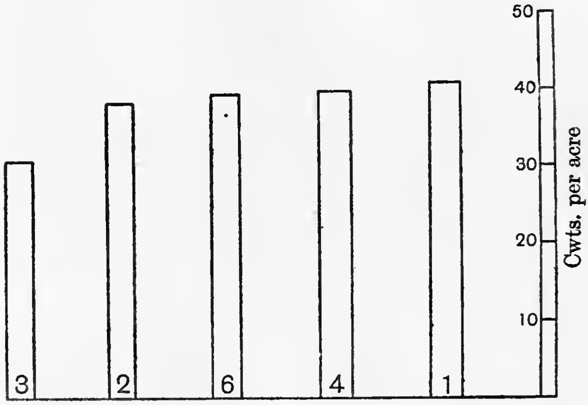


FIG. 6. Yield of Hay (average of 5 years) for the various Phosphate Plots at Wendens, Saffron Walden. *Soil* Chalk.
3, Untreated. 2, Gafsa rock phosphate. 6, Open hearth (high soluble) basic slag. 4, Open hearth (high soluble) basic slag. 1, Basic Bessemer slag.

giving returns comparable to those obtained by the use of the old basic Bessemer slag. The explanation probably rests on the fact that rainfall is the most important limiting factor on this type of soil. (It will be observed that the hay crop varies from 14·3 cwts. per acre in the dry season of 1919 to 51·2 cwts. during the favourable season of 1916.) Shortage of phosphate is possibly the second limiting factor, and the original dressing applied is more than is essential.

Conclusions drawn from the Field Experiments

With two exceptions the field experiments show a marked response to phosphates. The failure at Hassobury is probably partly due to the fact that the soil is comparatively rich in phosphoric acid, and partly to the fact that it is very much poorer in potash than the soil at those centres where a response to phosphates was secured. The failure at Farnham is not due to the soil being well supplied. in phosphoric acid, but to a deficiency in some other factor.

If the centres where a definite response has been secured are considered, it is quite apparent that good results can be expected on both the London clay and boulder clay soils from the various types of rock phosphates, and that, considered over a period of four or five years, it is reasonable to expect these phosphates to give results approximately equivalent to those secured from the high citric soluble types of basic slag. Seasonal differences have, however, been apparent which suggest that the rock phosphates require a considerably higher rainfall to produce the maximum effect than is the case with the high soluble slags. These differences are clearly apparent at Martin's Hearne, Latchingdon and Lambourne End. The seasons 1917 and 1919 were dry, or comparatively so, whilst those of 1916, 1918, and 1920 were moist. If the results for the two dry years on the high soluble slag plot and the Gafsa rock phosphate plot, and the corresponding results from the moist season, are compared as is done in Table XX the influence of the season on the availability of the rock phosphates will be seen to be very pronounced.

During dry seasons high soluble basic slag gives considerably better results both at Martin's Hearne and at Latchingdon. Latchingdon is in the eastern and drier portion of the county, whilst Martin's Hearne is in the western and moister section, and it is of interest to note that, as might be expected, the advantage of the high soluble slag over the Gafsa rock phosphate is greater at Latchingdon than at Martin's Hearne.

The relative position of the two types of phosphate during the wet seasons is curious. At Martin's Hearne the rock phosphate has a decided advantage. It also does a trifle better at Latchingdon, but the advantage is so small as to be well within the limits of experimental error.

The results at Lambourne End (Table XVIII) for the dry season of 1919 and the moist season of 1920 fully bear out the results recorded above.

The soil at Martin's Hearne has considerably more organic matter in it than the soil at Latchingdon. Moreover it is a 'sour' soil, with a lime requirement of ·27 %, whilst the soil at Latchingdon has a

TABLE XX. EFFECT OF RAINFALL ON THE AVAILABILITY OF ROCK PHOSPHATES

Centre	Average Weight of Hay (in cwts. per acre)			Average rainfall May 1st till harvest (inches)	Lime requirement of soil %
	Gafsa phosphate	High soluble basic slag	Average increase due to solubility		
Dry seasons, 1917 and 1919.					
Martin's Hearne ...	24·3	28·7	4·4	4·06	·27
Latchingdon ...	23·7	30·1	6·4	3·74	·03
Moist seasons, 1916, 1918 and 1920.					
Martin's Hearne ...	36·9	32·6	−4·3	8·92	·27
Latchingdon ...	29·7	28·9	−0·8	6·09	·03

small reserve of calcium carbonate and has only a negligible lime requirement. It would seem therefore that, on 'sour' soils well supplied with organic matter and situated in districts with a moderately high rainfall, rock phosphates may give even superior results to those secured from basic slag.

In Table XXI the average returns from rock phosphates and basic Bessemer slag on the 'sour' soils are contrasted with the corresponding results from those centres where the soil is 'sweet,' that is, has a reserve of calcium carbonate and no lime requirement.

The differences, although small, are probably real. The figures for Martin's Hearne, for example, are compiled from four rock phosphate plots over a period of four years, for Lambourne End from five rock phosphate plots over a period of two years, and two high soluble slags over a similar period. Those for Latchingdon and Saffron Walden represent one rock phosphate plot and one basic Bessemer slag plot over a period of five years, whilst at Horndon the results are made up from ten rock phosphate plots and two open hearth high soluble basic slag plots for a period of two years.

TABLE XXI. COMPARISON OF RESULTS ON SOUR AND SWEET SOILS

Centre	Lime requirement of soil %	Ph. value of soil	Rock phosphate. Average cwts. per acre	Basic Bessemer slag. Average cwts. per acre
Sour soils:				
Tysea Hill ...	0·29	5·7	30·5	30·9
Martin's Hearne	0·27	6·1	28·8	30·7*
Lambourne End	0·45	—	28·0	30·6*
Average	—	...	29·1	30·7
Sweet soils:				
Latchingdon ...	0·03	7·8	27·3	29·4
Saffron Walden	0·00	—	38·1	40·9
Horndon ...	0·00	7·7	19·5	23·4*
Average	—	...	28·3	31·2

* Open hearth high soluble basic slags.

The results shown in Table XXI, although they do not agree with those secured by Pfeiffer[1], yet demonstrate that rock phosphates compare more favourably with basic slag on 'sour' soils than on chalky soils.

Had the seasons of 1917 and 1919 been as favourable as those of 1916, 1918 and 1920, it is probable that the contrast would have been more marked.

Open hearth fluorspar basic slags are very uncertain in their action. The improvement effected by their applications has in every instance been considerable, but the lower soluble types have undoubtedly proved to be less effective than either the high soluble slags or the rock phosphates. At only one experimental centre (Lambourne End) has the open hearth fluorspar slag of 20 % solubility given results comparable with the high soluble slag. The open hearth slag of 45 % solubility has proved quite as effective as the best grades of slag and rock phosphates. On the other hand, an open hearth slag of 30 % solubility has given at Lambourne End inferior results to a similar slag of 20 % solubility. The relation of citric solubility to the value of the phosphate has been discussed elsewhere (18).

[1] Pfeiffer is quoted in the *Inter. Inst. of Agric. Bulletin*, September, 1913, p. 1316, as follows: "on sour soils and on peat moss soils crude earthy phosphates (Algerian, Gafsa, etc.) do better than basic slag."

The Applicability of the Results

It must be borne in mind when considering these experiments that the rainfall conditions in Essex are not favourable to insoluble phosphate. In view, therefore, of the fact that rock phosphates have proved, even under unfavourable conditions, to be but little inferior to the best grades of basic slag, it seems fair to conclude that the results detailed here are applicable to the heavy clay pasture and meadow land which cover large areas in this country.

The impression gained from close observation of the various experiments over a period of five years leads to the conclusion that rock phosphates are slower in their action during the spring and early summer, but if the crop continues to grow until the latter end of July this disadvantage disappears. If, however, the harvest is early, the advantage is with the higher soluble phosphate. It is probable, therefore, that for root crops where the growing period continues well into the autumn, rock phosphates will prove almost as effective as the best grades of basic slag[1], and in the northern and western parts of the country, where the corn harvest is late and the rainfall high, rock phosphates of the North African type may reasonably be expected to prove a suitable substitute for the high grade basic slags of the past.

[1] *Journal Department of Agric. and Tech. Institute for Ireland*, Jan. 1917.

AN INVESTIGATION INTO THE REASON WHY BASIC PHOSPHATES HAVE CAUSED INCREASED YIELDS

THE EFFECT OF PHOSPHATES ON THE BOTANICAL COMPOSITION OF THE HERBAGE

MIDDLETON (15) in his paper on "The Improvement of Poor Pastures" puts to himself the following question: "Why do phosphates produce so rapid an increase?" He states that a study of tables recording live weight gains or yields of hay will not supply the answer, but "that the pastures themselves when closely examined clearly explain the action of the manures." He attributes the results to: (1) the very rapid increase in the leguminous herbage which takes place; (2) a rapid improvement in the quality of the surface soil; and (3) the accumulation of atmospheric nitrogen fixed by the nodule organisms. He gives it as his opinion, formed from his careful inspection of the various experiments, that phosphates have little or no direct action on the grasses, and that it is the lime in the basic slag acting on the nitrogen accumulated by the nodule organisms which brings about the improvement in the grasses. This improvement does not take place until the clover has been well established. Finally Middleton concludes that it is impossible to obtain a purely leguminous herbage, that clovers will partly and sometimes almost completely disappear in three or four years as a consequence of the competition of the grasses encouraged by the nitrogen accumulated in the soil by the clover nodule organisms. Gilchrist comes to very much the same conclusions in his reports on the Tree Field results.

In order to obtain more detailed information concerning the effect of phosphates on the composition of the hay crops in Essex, botanical analyses of the hay on the plots at several centres were made during the season of 1919, the samples being taken the same day as the hay was cut.

Martin's Hearne and Tysea Hill. The results from the experimental centres at Martin's Hearne and Tysea Hill are set out in Tables XXII and XXIII.

Several points of interest are brought out by these two tables. The luxurious bottom of red and white clover which covered the treated plots at Martin's Hearne in 1918 (see Plates III and IV) had all but vanished during the 1919 season, and Leguminosae formed only a fraction of a per cent. of the hay crop at both the above centres. Nevertheless, the contrast in the botanical analysis of the treated

TABLE XXII. BOTANICAL COMPOSITION, BY WEIGHT, OF THE HAY AT MARTIN'S HEARNE FARM

Soil: Boulder clay. Manures sown: Feb. 28th, 1917.
Sample taken: July 9th, 1919

Species	Plot 1 Open hearth (fluorspar) basic slag %	Plot 2 Open hearth high soluble basic slag %	Plot 3 No manure %	Plot 4 Gafsa rock phosphate %	Plot 5 Egyptian rock phosphate %	Plot 6 Algerian rock phosphate %
Clovers	trace	trace	trace	trace	trace	trace
Grasses	85·2	88·1	58·5	82·6	96·7	95·8
Weeds	14·8	11·9	41·5	17·4	3·3	4·2
Composition of the grasses by weight						
Lolium perenne	9·9	22·0	6·8	26·9	19·8	17·0
Phleum pratense	6·0	7·7	2·8	4·5	5·7	1·9
Cynosurus cristatus ...	20·6	14·7	10·8	25·2	28·7	10·6
Poa trivialis	1·3	12·0	0·6	10·9	7·3	9·5
Avena flavescens ...	1·3	1·4	0·6	1·0	1·3	0·6
Festuca ovina	—	0·9	—	—	—	—
Holcus lanatus	32·5	29·7	44·3	18·0	17·0	29·0
Agrostis alba	0·7	2·6	6·8	4·5	4·8	11·2
Anthoxanthum odoratum	27·7	9·0	27·3	9·0	15·4	20·2
	100·0	100·0	100·0	100·0	100·0	100·0
Superior grasses	39·1	58·7	21·6	68·5	62·8	39·6
Inferior grasses	60·9	41·3	78·4	31·5	37·2	60·4

and untreated plots is very striking indeed. The hay on the untreated plots at both centres consists largely of weeds, and poor undesirable grasses such as *Holcus lanatus*, *Agrostis alba* and *Anthoxanthum odoratum*. The application of phosphates has either directly or indirectly considerably affected the botanical composition of the grasses. The better types of grasses such as *Lolium perenne*, *Phleum pratense*, *Cynosurus cristatus* and *Poa trivialis* show a general increase on all the treated plots. With the exception of the open hearth (fluorspar) basic slag at Martin's Hearne, all the phosphates seem to be equally effective in bringing about the change. Although the clovers have

TABLE XXIII. BOTANICAL COMPOSITION, BY WEIGHT, OF THE HAY AT TYSEA HILL FARM

Soil: Boulder clay. Manures sown: December, 1915.
Samples taken: July 9th, 1919

Species	Plot 1 Basic Bessemer slag %	Plot 2 Gafsa rock phosphate %	Plot 3 Untreated %	Plot 4 Open hearth (fluorspar) basic slag %	Plot 5 Open hearth high soluble basic slag 1 %	Plot 6 Open hearth high soluble basic slag 2 %	Plot 7 Untreated %
Clovers	trace	trace	trace	trace	trace	trace	trace
Grasses...	89·1	90·5	66·7	93·7	91·0	94·5	71·8
Weeds	10·9	9·5	33·3	6·3	9·0	5·5	28·2
	100·0	100·0	100·0	100·0	100·0	100·0	100·0
Composition of the grasses by weight							
Lolium perenne ...	31·1	22·5	15·3	21·2	20·6	21·5	5·4
Phleum pratense ...	2·0	1·3	—	5·0	4·1	4·6	—
Cynosurus cristatus ...	18·4	19·5	13·0	22·4	18·5	16·0	16·0
Avena flavescens ...	2·4	4·2	—	1·0	1·2	0·9	2·3
Hordeum pratense ...	2·4	1·3	3·9	1·2	2·5	5·0	5·9
Holcus lanatus ...	27·6	27·4	41·5	24·8	27·7	19·6	25·0
Agrostis alba	5·6	14·3	14·0	12·2	14·4	21·4	14·4
Anthoxanthum odoratum	10·5	9·5	12·3	12·2	11·0	11·0	31·0
	100·0	100·0	100·0	100·0	100·0	100·0	100·0
Superior grasses ...	53·9	47·5	28·3	49·6	44·4	43·0	23·7
Inferior grasses ...	46·1	52·5	71·7	50·4	55·6	57·0	76·3

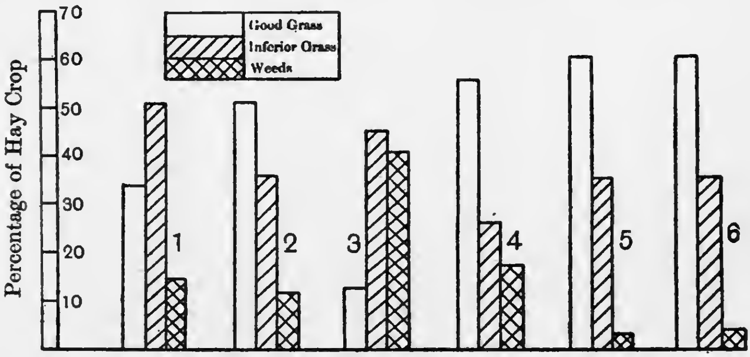


FIG. 7. Botanical composition of the Hay, by weight, at Martin's Hearne. Season, 1919. *Soil* Boulder clay.

1, Open hearth (fluorspar) basic slag. 2, Open hearth (high soluble) basic slag. 3, Untreated. 4, Gafsa rock phosphate. 5, Egyptian rock phosphate. 6, Algerian rock phosphate.

disappeared, the improvement in the grasses has succeeded in reducing the amount of weeds to about one-third of that present in the hay from the untreated plots. The main points of difference are illustrated in Figs. 7 and 8.

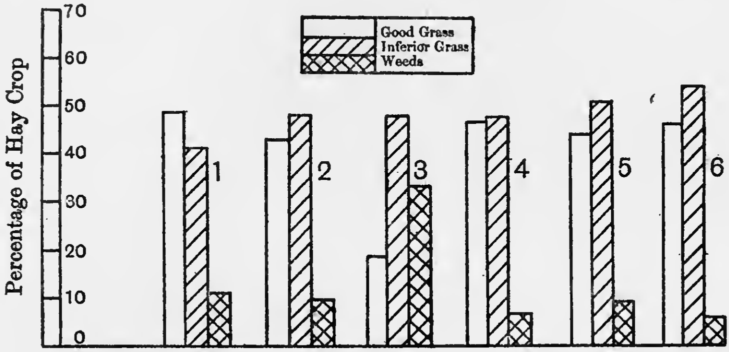


FIG. 8. Botanical composition of the Hay, by weight, at Tysea Hill. Season, 1919. *Soil* Boulder clay.

1, Basic Bessemer slag. 2, Gafsa rock phosphate. 3, Untreated. 4, Open hearth (fluorspar) basic slag. 5, Open hearth (high soluble) basic slag 1. 6. Open hearth (high soluble) basic slag 2.

TABLE XXIV. PERCENTAGE OF GROUND SPACE OCCUPIED BY THE VEGETATION AT TYSEA HILL AND MARTIN'S HEARNE

	Tysea Hill		Martin's Hearne	
	Plot 1 Basic slag	Plot 3 Untreated	Plot 2 Basic slag	Plot 3 Untreated
Clovers	—	0·3	6·3	2·0
Grasses	50·0	34·8	30·5	19·2
Weeds	—	—	0·7	1·9
Bare space	50·0	64·9	62·5	76·9
	100·0	100·0	100·0	100·0

The aftermath on both sets of plots was grazed by cattle, and during the first week of October 1919 a determination of the ground space occupied by the various species was made, and the results are set out in Table XXIV.

The clover had not reappeared at either centre in spite of the favourable climatic conditions, and although the treated plots could be distinguished from the unmanured more than a mile away throughout the whole winter and early spring, there was never any visible difference in the clover content between the treated and untreated plots.

A chemical examination of the soils on the treated and untreated plots showed that at least one-half of the original dressing of phosphoric acid was still present in an available form in the treated plots (see p. 105). The disappearance of the clover during 1919 was not therefore due to lack of phosphates.

TABLE XXV. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT AT MARTIN'S HEARNE

Sample taken: August 9th, 1920

	Plot 2 Basic slag high soluble %	Plot 3 Untreated %	Plot 4 Gafsa rock phosphate %
Clovers	27·5	11·2	35·0
Grasses	63·0	58·5	54·2
Weeds	9·5	30·3	10·8

TABLE XXVI. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT AT TYSEA HILL

Sample taken: August 23rd, 1920

	Plot 1 Basic Bessemer slag %	Plot 2 Gafsa phosphate %	Plot 3 Untreated %
Clovers	5·9	4·4	4·4
Grasses	85·5	89·6	88·5
Weeds	8·6	6·4	7·1

From March 1920 onwards the plots were inspected closely every week, and towards the end of May it became evident that the clover plant was again beginning to make headway, and by the end of July all the plots at Martin's Hearne, and particularly the rock phosphate plots, were covered with a vigorous growth of red and white clover. At Tysea Hill, less than half a mile away, there was very little clover showing, any difference there may have been between the treated and untreated plots in this respect was not discernible. Samples of hay from both centres were taken when the crops were cut, and the results of a partial botanical analysis are set out in Tables XXV and XXVI.

A comparison of Tables XXV and XXVI brings out several points of considerable interest. In the first place the all but complete disappearance of clover from the herbage at Martin's Hearne and Tysea Hill during the dry season of 1919, and the return of the clover at Martin's Hearne but not at Tysea Hill during the moist favourable season of 1920 is curious. Secondly, it will be noted that during the dry season of 1919 weeds formed about 30 % of the small crop on the untreated plot at both centres. In 1920 weeds still formed about 30 % of the crop by weight at Martin's Hearne, but at Tysea Hill the crop on the untreated plot was a heavy one and the hay on this plot was as free from weeds as on any of the treated plots.

TABLE XXVII. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT AT LAMBOURNE END (LONDON CLAY)

Sample taken: July 17th, 1919. Manures sown: Jan. 4th, 1919

	Plot 2 Basic slag high soluble %	Plot 3 No manure %
Clovers, etc.	0·3	0·0
Grasses	88·7	86·9
Weeds	11·0	13·1
	100·0	100·0
Composition of the grasses by weight		
Cynosurus cristatus ...	7·4	6·3
Avena flavescens... ...	4·3	11·3
Agrostis alba	32·0	36·9
Holcus lanatus	48·9	34·2
Anthoxanthum odoratum	7·4	11·2

Lambourne End (London clay). The botanical composition of the hay at Lambourne End is shown in Table XXVII. As will be seen from this table, the phosphates were sown six months before the plots were cut. The season (1919) was a dry one, and the phosphates were without any appreciable effect on the clovers, which could therefore not act as an intermediary in encouraging the growth of the grasses. Nevertheless the basic slag plots yielded almost twice the crop secured on the unmanured plot, a result which appears to indicate that phosphates have a direct and not an indirect action on the grasses, and that it is quite possible to obtain a specific and marked response to phosphates on pastures where clover plants are absent.

The moist season of 1920 was more favourable to the growth of clover, and during the latter part of May and the month of June the plots were rapidly covered with a luxurious growth of red and white clover.

The botanical examination of the hay crop in 1920 is set out in Table XXVIII and is illustrated in Fig. 9.

TABLE XXVIII. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT AT LAMBOURNE END, 1920

Sample taken: July 17th

	Plot 1 Open hearth (fluorspar) basic slag %	Plot 2 Open hearth high soluble basic slag %	Plot 3 No manure %	Plot 4 Egyptian phosphate %	Plot 7 Open hearth (fluorspar) basic slag Wigan %	Plot 8 Open hearth high soluble basic slag Wigan %	Plot 9 Cleveland phosphate %
Clovers	22·7	25·6	2·3*	33·5	15·2	33·7	38·6
Grasses	67·8	61·9	70·3	59·3	72·5	57·9	55·7
Weeds	9·5	12·5	27·4	7·2	12·3	8·4	5·7
	100·0	100·0	100·0	100·0	100·0	100·0	100·0

* Practically all bird's foot trefoil, purple vetch and *Vicia sativa.*

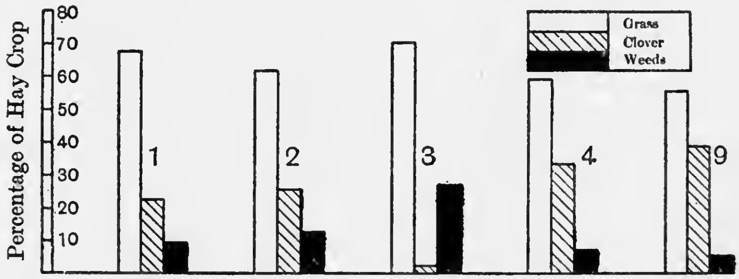


FIG. 9. Botanical composition of the Hay, by weight, at Lambourne End. Season, 1920. *Soil* London clay.

1, Open hearth (fluorspar) basic slag. 2, Open hearth (high soluble) basic slag. 3. Untreated 4, Egyptian phosphate. 9, Cleveland phosphate.

The results recorded in the above table simply afford another illustration of the effect of the various phosphates in encouraging the development of the clover plant.

It would be difficult to secure poorer quality hay than that obtained even on the slag plot in 1919. When conditions are favourable to the development of clover as was the case in 1920, phosphates, in addition to an increased crop, produce a vastly better quality of hay.

TABLE XXIX. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT AT BUTTERFIELDS, LATCHINGDON. SEASON, 1919

Soil: London clay. Sample taken: July 21st.
Manures sown: December, 1915

	Plot 1 Basic Bessemer slag %	Plot 2 Gafsa rock phosphate %	Plot 3 No manure %	Plot 4 Open hearth (fluorspar) basic slag %	Plot 5 Open hearth high soluble basic slag 1 %	Plot 6 Open hearth high soluble basic slag 2 %
Clovers	20·8	15·8	5·3	17·6	15·0	18·0
Grasses	74·4	81·0	87·9	80·4	82·8	80·9
Weeds	4·8	3·2	6·8	2·0	2·2	1·1
	100·0	100·0	100·0	100·0	100·0	100·0
Composition of the grasses by weight						
Lolium perenne ...	14·4	15·2	10·8	19·4	24·1	17·9
Phleum pratense ...	23·3	21·3	14·8	19·0	23·3	25·6
Cynosurus cristatus	15·7	18·3	11·6	20·4	22·3	19·3
Poa trivialis ...	8·5	10·8	7·6	12·4	15·7	10·8
Bromus mollis ...	33·9	8·7	3·6	4·2	—	—
Hordeum pratense	3·8	21·8	35·6	19·6	10·0	15·5
Agrostis alba ...	—	3·0	6·8	2·0	2·0	2·4
Holcus lanatus ...	0·4	0·9	8·3	3·0	2·0	8·5
Anthoxanthum odoratum ...	—	—	0·9	—	0·6	—
	100·0	100·0	100·0	100·0	100·0	100·0
Superior grasses ...	61·9	65·6	44·8	71·2	85·4	73·6
Inferior grasses ...	38·1	34·4	55·2	28·8	14·6	26·4

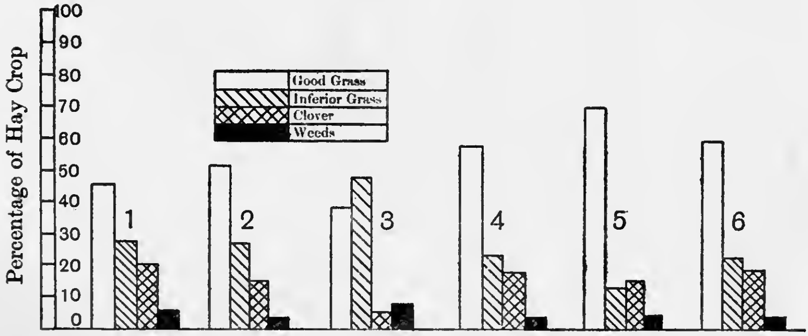


FIG. 10. Botanical composition of the Hay, by weight, at Butterfields, Latchingdon. Season, 1919. *Soil* London clay.
1, Basic Bessemer slag. 2, Gafsa phosphate. 3, No manure. 4, Open hearth fluorspar basic slag. 5, Basic slag. 6, Basic slag.

Butterfields, Latchingdon. The effect of the various phosphates on the composition of the flora at Latchingdon is similar to that at Martin's Hearne and Tysea Hill. The botanical composition of the hay is shown in Table XXIX and in Fig. 10. The contrast between the treated and untreated plots is not so marked as at the other two centres mentioned, but the pasture on the untreated plot at Latchingdon is much superior to that at Martin's Hearne and Tysea Hill (compare Figs. 7, 8 and 10). On all the treated plots the better grasses, such as *Lolium perenne*, *Phleum pratense*, *Cynosurus cristatus* and *Poa trivialis*, have improved their position at the expense of the poorer quality grasses, such as *Hordeum pratense*, *Agrostis alba*, *Holcus lanatus*, etc. It is worthy of note, moreover, that at Latchingdon clover forms a fair proportion of the crop by weight, whereas at Martin's Hearne and Tysea Hill it was practically absent during 1919.

TABLE XXX. BOTANICAL COMPOSITION OF THE HAY CROP BY WEIGHT AT WENDENS, SAFFRON WALDEN.

Soil: chalk. Sample taken: June 19th, 1919
Manures sown: January, 1916

	Plot 1 Basic Bessemer slag %	Plot 2 Gafsa rock phosphate %	Plot 3 No manure %	Plot 4 Open hearth (fluorspar) basic slag %	Plot 5 Open hearth high soluble basic slag 1 %	Plot 6 Open hearth high soluble basic slag 2 %
Clovers	11·0	10·1	7·8	8·2	8·0	6·9
Grasses	86·9	80·9	82·2	88·8	84·5	86·9
Weeds	2·1	9·0	10·0	3·0	7·5	6·2
	100·0	100·0	100·0	100·0	100·0	100·0
Composition of the grasses by weight						
Lolium perenne ...	64·4	50·0	45·4	56·9	43·4	51·3
Phleum pratense ...	—	—	0·7	—	—	—
Dactylis glomerata	3·7	3·5	3·8	1·2	8·0	1·6
Cynosurus cristatus	8·6	14·8	14·6	10·5	11·9	6·9
Poa trivialis ...	3·7	4·0	6·1	3·6	4·3	5·9
Avena flavescens ...	5·8	14·1	13·9	16·4	13·5	14·7
Festuca ovina ...	—	—	0·8	—	—	—
Holcus lanatus ...	3·7	1·3	2·4	2·7	1·9	2·6
Bromus mollis ...	10·1	12·3	12·3	8·7	17·0	17·0
	100·0	100·0	100·0	100·0	100·0	100·0

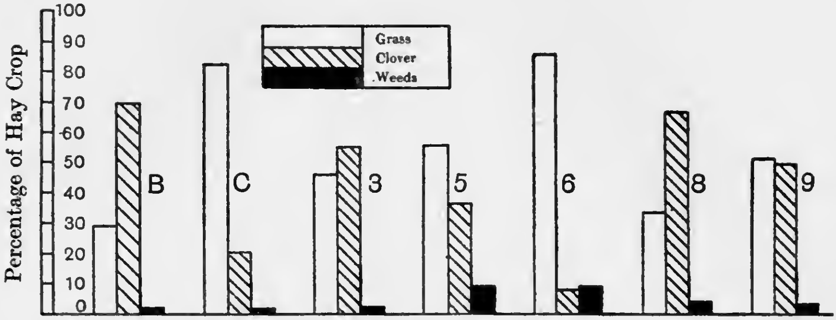
Wendens, Saffron Walden. The botanical composition of the grass at Wendens, Saffron Walden (chalk) is shown in Table XXX. The quality of the meadow is obviously much superior to that at any of the other centres, and it is therefore not surprising to find that the various phosphates have had a comparatively small effect on the quality of the herbage.

TABLE XXXI. BOTANICAL ANALYSIS OF THE HAY CROP BY WEIGHT AT HORNDON.

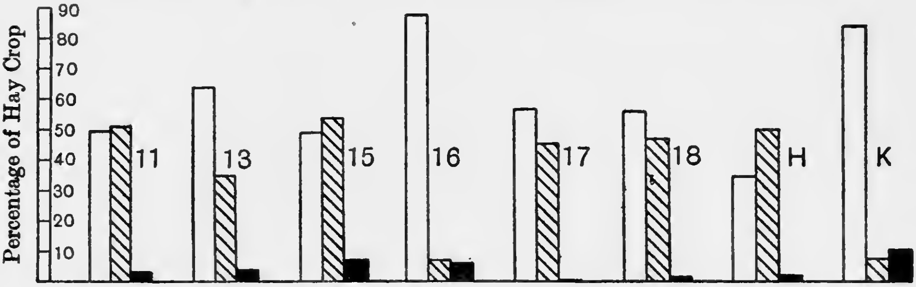
Soil: London clay. Sample taken: Aug. 16th, 1920
Manures sown: Feb. 27, 1918. Plots B, C, D and H: Feb. 3rd, 1919

Plot	Manure	Clovers	Grasses	Weeds
B	Cambridge coprolites	67·5	28·7	3·8
C	Lime	20·6	77·8	1·6
D	Coarse ground open hearth (fluorspar) basic slag	56·9	38·1	5·0
1	Florida pebble phosphate	51·9	40·0	8·1
3	Algerian phosphate...	51·3	45·8	2·9
5	Open hearth basic slag (high citric soluble)	45·4	53·3	1·3
6	Untreated	8·7	81·4	9·9
8	Gafsa phosphate	63·8	32·0	4·2
9	Tunisian ,, ...	47·7	49·2	3·1
11	Egyptian ,, ...	49·3	47·7	3·0
13	Superphosphate	34·0	61·4	4·6
15	Superphosphate and lime	51·4	47·9	0·7
16	Untreated	7·6	85·5	6·9
17	Open hearth basic slag (high citric soluble)	44·1	53·4	0·5
18	Open hearth (fluorspar) basic slag (low citric soluble)	45·5	53·2	1·3
H	Cleveland phosphate	58·9	38·5	2·6
K	Untreated	8·0	80·1	11·9

Horndon (London clay). These plots were grazed during 1919, and samples of hay for botanical analysis were not removed until the 1920 crop was cut on August 16th. The results which are set out in Table XXXI, and illustrated in Fig. 11, show an extraordinary contrast between the treated and untreated plots. In view of the effect of grazing during 1919 on the growth of the herbage on the plots receiving phosphates (see Table XV and Plates VI and VII), it is, however, not surprising to find that clover was the dominant constituent of the hay crop in 1920.



B, Cambridge coprolites. C, Lime. 3, Algerian phosphate, 5. Open hearth (high soluble) basic slag. 6, Untreated. 8, Gafsa phosphate. 9, Tunisian phosphate.



11, Egyptian phosphate. 13, Superphosphate. 15, Super phosphate and lime. 16, Untreated. 17, Open hearth (high soluble) basic slag. 18, Open hearth (fluorspar) basic slag. H, Cleveland phosphate. K, Untreated.

FIG. 11. Botanical composition of the Hay, by weight, at Great Mulgraves, Horndon-on-the-Hill. Season, 1920. *Soil* London clay.

DISCUSSION OF THE RESULTS OF THE BOTANICAL ANALYSIS

Although a rapid and large increase in the amount of clovers present in the herbage has followed the application of phosphates at the various experimental centres, and although the various phosphates appear to be equally effective in this respect, there are clear indications that the effect of the phosphates on the herbage is not confined to the clovers alone. At Martin's Hearne, Tysea Hill and Latchingdon for example (see Figs. 7, 8 and 10), the better types of grasses are greatly encouraged as a result of the application of phosphates. The meadows at Martin's Hearne and Tysea Hill have been down for a considerable time. The nitrogen content and the organic matter content of the soil are already high, and it is difficult to believe that the accumulation of a comparatively small amount of nitrogen by the nodule organisms and its subsequent nitrification is responsible for the double crop which the treated plots bore in 1919 when no clover was present. It seems more probable that the double crop is due either to the grasses benefiting by the direct fertilising effect of the phosphates or to the phosphates having some action on the production of nitrates in the soil, or to the operation of both these causes. This contention is borne out by the results at

TABLE XXXII. BOTANICAL COMPOSITION OF THE HAY BY WEIGHT ON THE PLOTS RECEIVING HIGH SOLUBLE BASIC SLAG. SEASON, 1919

	Boulder Clay			London Clay			
	Martin's Hearne %	Tysea Hill %	Farnham* %	Lambourne End %	Latching-don %	Wendens %	Horndon* %
Clovers	trace	trace	50·2	0·3	20·8	11·0	44·1
Grasses	88·1	89·1	33·3	88·7	74·4	86·9	28·6
Weeds	11·9	10·9	13·5	11·0	4·8	2·1	13·6
Lime requirement	0·27	0·29	0·00	0·45	0·03	0·00	0·00
Rainfall† (inches)	2·85	2·87	1·73	3·08	1·47	0·53	1·78

* The figures for Farnham and Horndon indicate the percentage of ground space covered by the various species and not the botanical composition of the hay. It is obvious however that had a hay crop been cut at these centres clover would have formed a large proportion of the crop by weight.

† May 1st till Harvest.

Lambourne End, where a very large increased crop of grasses follows the application of phosphates, the response of the clovers to the dressing not being manifest until the following year (see Tables XXVII and XXVIII).

Table XV clearly shows the superior effect of basic phosphates in encouraging the growth of clovers, but this effect once produced is not maintained on all the soils until the dressing of basic phosphates is exhausted or nearly so.

At Horndon, Latchingdon, Saffron Walden and Farnham no difficulty has been experienced in maintaining the clover even during a dry and unfavourable season like 1919. At Martin's Hearne, Tysea Hill and Lambourne End, however, the clover completely disappeared from the treated plots during 1919. This result at Martin's Hearne was rather surprising in view of the fact that clover covered the treated plots in 1918 almost to the exclusion of the grasses (see Plate IV).

These differences between the various centres are brought out clearly in Table XXXII.

At Latchingdon and Wendens clover has persisted on the untreated plots as far as can be ascertained ever since the fields went down to grass. There are, moreover, no signs of the clover which was encouraged by the application of slag five years ago tending to 'go off,' although, of course, it is subject to seasonal fluctuations.

It will be noted that it is on the sour soils, and only the sour soils, that the clover failed during the season of 1919.

If, however, the results for the 1920 season are tabulated, as is done in Table XXXIII, it will be seen that sourness is not the only factor.

TABLE XXXIII. BOTANICAL COMPOSITION OF THE HAY CROP BY WEIGHT ON PLOTS RECEIVING HIGH SOLUBLE BASIC SLAG. SEASON, 1920

	MARTIN'S HEARNE		TYSEA HILL		LAMBOURNE END (average) 2 plots	HORNDON
	Basic slag alone %	Slag plus lime* %	Basic slag alone %	Slag plus lime* %		
Clovers	27·5	18·7	5·9	8·5	29·7	45·4
Grasses	63·0	73·3	85·5	84·9	59·9	53·3
Weeds	9·5	8·0	8·6	6·6	10·4	1·3
Lime requirement	0·27	—	0·29	—	0·45	0·00
Rainfall† (inches)	8·37	—	9·34	—	5·27	5·34

* At the rate of 35 cwts. of CaO per acre. † May 1st till Harvest.

On the sour soils at Lambourne End and Martin's Hearne clover forms more than 25 % of the crop, and it will be noted that a dressing of lime in addition to the slag has not improved the position of the clover at Martin's Hearne. It is, of course, quite possible that the clover on this plot will benefit by the dressing of lime should another unfavourable season succeed.

The application of lime at Tysea Hill has not succeeded in bringing a vigorous growth of clover even in a favourable season like 1920, and it is quite clear that some other factor besides climate, lime and phosphate is responsible for the failure of the clover plant.

Chemically the soil at Tysea Hill differs from that at Martin's Hearne in having a lower content of available potash, and it seems probable that an inadequacy of potash is responsible for the failure of the clover.

The effect of grazing and continuous cutting on the condition of the botanical flora is well illustrated in Table XXXIV and Fig. 12, which show the percentage of the ground space covered by the flora on the slag plots at Latchingdon and Horndon during 1919.

TABLE XXXIV. PERCENTAGE OF THE GROUND SPACE OCCUPIED BY THE VEGETATION ON THE BASIC SLAG PLOTS AT LATCHINGDON AND HORNDON

Determinations made: Aug. and Sept. 1919

	LATCHINGDON Cut 4 years in succession	HORNDON Cut 1918 grazed 1919
Clovers	18·1	45·2
Grasses	51·2	37·9
Weeds...	0·0	7·5
Bare space	30·7	9·4

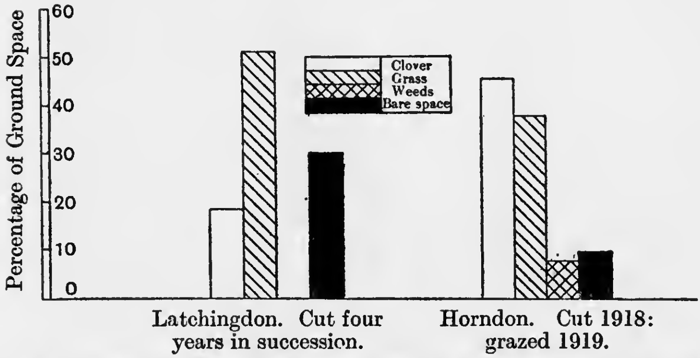


FIG. 12. Percentage of Ground Space occupied by the Vegetation on the Basic Slag Plots at Latchingdon and Horndon. Season, 1919. *Soil* London clay.

The bottom at Latchingdon, it will be seen, is an open one, and although it shows a great improvement in this respect over the untreated plot, it is not nearly so close as that at Horndon. At Latchingdon the clover disappears in the autumn and come again the following year towards the end of May or the beginning of June. At Horndon on the other hand the surface is covered with a network of clover runners, and there is practically no 'bare space' on the plot. The Essex farmer still holds to the practice of grazing and cutting his meadows in alternate years, and in view of these results and the climatic conditions of the county, there is much to be said for this practice.

The botanical analyses from all the centres agree in showing that as far as the quality of the herbage is concerned there is nothing to choose between the effectiveness of rock phosphates and high citric soluble basic slags. There are, however, indications that the open hearth (fluorspar) slags of very low solubility are less efficient in this respect than the high soluble basic slags.

EFFECT OF PHOSPHATES ON THE MOISTURE CONTENT AND TEMPERATURE OF THE SOIL

It has already been stated that one of the great difficulties experienced on the clay soils—particularly the London clay soils of Essex—is the wet condition under which they lie throughout the winter and late spring. As a rule a hot and dry spell of weather succeeds, lasting during the greater part of May and June. The soil whether under pasture or arable conditions dries up rapidly, sets as hard as a brick (caps), and cracks badly.

These unfavourable conditions were very obvious at the Horndon Experimental centre during 1919. Following a wet April the remains of a heavy fall of snow were still visible on the plots on May 3rd. A spell of dry hot weather set in and lasted without any recordable rain falling until the third week in June. The condition of the untreated plot was difficult to describe. There was practically no growth and the surface was covered with innumerable cracks, some of them wide enough to allow of the insertion of the greater part of the arm. What little growth there was shrivelled up by the second week in June. It was obvious, however, that the plots receiving phosphates were not suffering nearly so badly. The cracks were fewer, and required looking for, and the thick matted bottom of clover provided a continuous feed for the grazing stock throughout the season (Plate VI). The marked difference between the condition of the soil on the slag plot and untreated plot suggested a better regulation of the moisture supply on the former plot.

It was unfortunately not possible during 1919 to follow up the enquiry which these observations suggested, but during the season of 1920 a series of moisture determinations and temperature records were made on Plot 17 (basic slag) and Plot 16 (untreated) at Horndon.

Moisture

Commencing in March 1920 the moisture was determined each week in a 9 inches sample of soil from each plot, and a little later 3 inches samples were taken. At the same time temperature records were obtained at a depth of 9 inches and 3 inches. All the samples were taken by the writer and were secured by means of a 15 inches sampler of ⅝ inch diameter which could be adjusted to remove a core of 3 inches, 9 inches or 12 inches in length. The sample for each plot consisted of from 10–14 cores.

Table XXXV. Moisture Content of the Soil at Horndon on Plots 16 and 17 at Various Depths

Date 1920	Moisture (%) 0–3 inches		3–9 inches	
	Plot 17 Basic slag	Plot 16 Untreated	Plot 17 Basic slag	Plot 16 Untreated
April 26	29·1	28·6	24·0	29·6
May 5	26·1	28·6	22·8	22·6
10	26·2	29·3	22·6	25·0
17	22·8	22·6	17·8	21·6
25	20·1	18·4	22·0	21·5
31	23·7	19·0	15·4	15·4
June 8	18·0	15·9	12·8	15·1
14	19·5	16·8	15·6	17·0
21	21·5	19·9	18·3	18·1
29	18·7	17·6	13·4	16·2
July 8	26·1	25·8	20·2	23·8
12	26·3	27·0	24·3	21·8
20	18·4	18·4	17·2	19·1
26	23·2	24·7	21·0	22·0
Aug. 4	24·2	25·6	19·6	20·8
9	22·0	24·9	16·9	19·1
16	18·8	19·2	15·5	15·4
31	—	19·0	—	17·8
Sept. 7	17·9	18·7	16·9	17·2
20	26·8	26·8	23·2	23·2
Nov. 24	25·3	27·9	19·1	21·4

The moisture contents of the first three inches of soil and of the soil from 3 inches to 9 inches on both plots are given in Table XXXV. The results are plotted together with the rainfall record in Figs. 13 and 14.

Broadly speaking the 1920 season was a moist one, and particularly favourable for the hay crop. At the beginning of May the ground, as the result of a wet April, was saturated with water. May, however, was a dry, and on the whole a hot month, and the soil rapidly began

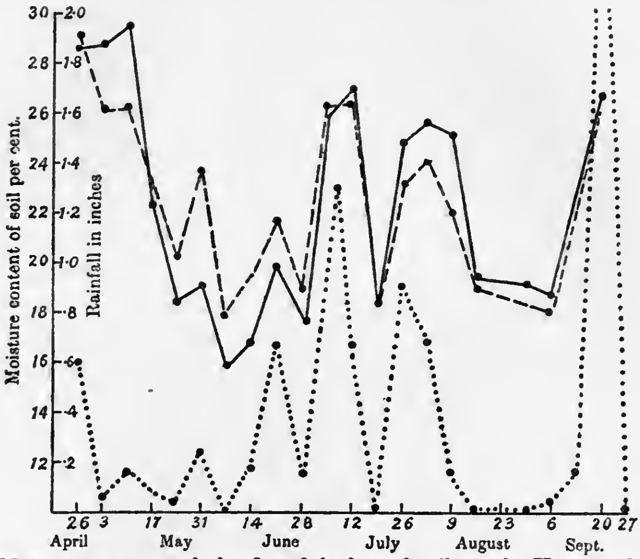


FIG. 13. Moisture content of the first 3 inches of soil on the Untreated and Basic Slag Plots at Great Mulgraves, Horndon-on-the-Hill. *Soil* London clay.
Plot 16, Untreated ———. Plot 17, Basic Slag — — —. Rainfall ....

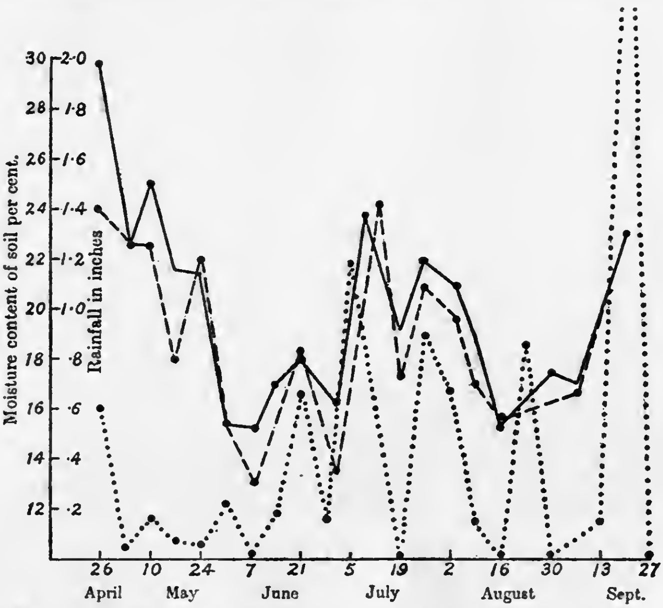


FIG. 14. Moisture content of the Soil at a depth of 3 to 9 inches on the Untreated and Basic Slag Plots at Great Mulgraves, Horndon-on-the-Hill. *Soil* London clay.
Plot 16, Untreated ———. Plot 17, Basic Slag — — — —. Rainfall ....

to dry up. By May 25th the untreated plot had begun to crack and by June 7th it was difficult to find a square yard of this plot that was not traversed by a big crack. On this date also the first signs of 'cracking' were observed on the slag plot, but the cracks required looking for and were of small dimensions. The dense growth on Plot 17 was obviously taking much more water from the soil than was the case on Plot 16 where the growth was negligible and where a large proportion of the surface was bare (see Table XV). The data presented in Table XXXV and Figs. 13 and 14, however, afford some explanation of these differences. On May 10th, Plot 16 (untreated) contained 29 % of water, whilst Plot 17 contained approximately 26 %. By the 17th the moisture content of both plots had fallen to 23 %, Plot 16 having evidently lost its moisture at a more rapid rate than Plot 17. On the 25th the moisture content had fallen to 18·4 % on Plot 16, whilst Plot 17 in spite of the very much larger transpiration which was taking place from this plot contained 20·1 % of moisture, a difference of 1·7 % in favour of the slag plot. The week following the 25th was showery and hot, and on the 31st of May, when samples were again taken, there was a surprising difference between the moisture contents of the two plots to a depth of 3 inches. Plot 16 contained only 19 % of moisture, whilst Plot 17 had a moisture content of 23·7 %, a difference of 4·7 % in favour of the phosphate plot. Plot 16 received very little benefit from the showers during the week; much of the rain must have run down the cracks, and the bulk of the remainder, falling on a bare surface exposed to the direct rays of the sun, was evaporated rapidly. The following eight days from May 31st to June 8th were dry and hot, no rain whatever falling. The moisture content of both plots fell rapidly, but on the 8th, Plot 17, notwithstanding the much greater demand made upon it, contained 18 % of moisture in the first three inches of soil, compared with 15·9 % (the lowest moisture content recorded throughout the season) on the untreated plot. The advantage of a dense crop on this type of soil is fairly obvious, and it is in fact the only practical method of conserving the soil moisture.

It is difficult to emphasise the importance of this indirect action of basic phosphates on this type of soil during a dry season when the absence of rainfall in May and June or a small precipitation makes the growth of a hay crop impossible.

On the 10th of June the fine weather broke and during the subsequent fortnight unsettled conditions prevailed. Even at the end of a fortnight Plot 17, in spite of the rapid growth which was taking place, still contained a higher moisture content in the surface 3 inches of soil than on Plot 16, where as far as the eye could judge the growth was all but negligible. Apparently a good deal of the rain had drained down the cracks on Plot 16, which were still as prevalent as during the preceding fortnight. On July 1st a spell of wet weather set in, there being only two dry days during the first twelve days of the month. For this period a total of 1·97 inches of rain was recorded. On July 8th and 12th, when the samples were taken, both plots appeared to be equally wet and the cracks had all disappeared. The analytical results showed that on both these dates the surface three inches of soil on both plots had approximately the same moisture content. The third week of July was dry and growth on Plot 17 was rapid. At the end of the week both plots had the same moisture content, namely 18·4 %. The remaining week and the first week in August were wet and the moisture content of the surface three inches varied from 23–26 %; the treated plot during the period 26th July to 9th August being distinctly drier. From the 9th of August to the 19th no rain fell, the untreated plot dried more rapidly and on the 16th the moisture content of both plots was approximately the same. On this date the plots were cut dead ripe; they were weighed on the 21st and carted to the stack and subsequently threshed for wild white clover seed. The weights of hay on the two plots were, Plot 17, 28·8 cwts. and Plot 16, 6·4 cwts. per acre.

It will be noted that from the 16th of August onwards (Plot 17 no longer being covered by a dense crop) the moisture on both plots remained practically the same.

By determining the moisture content of the soil to a depth of 9 inches and 3 inches on both plots it was possible to calculate the moisture content of the layer of soil 3 inches to 9 inches on both plots. This was done, and the figures are given in Table XXXV, and are shown graphically in Fig. 14. The calculations were made with a view to ascertaining whether the crop on the basic slag plot was able to draw more water from the lower depth than was the case on the untreated plot. It is natural to expect this to be so under dry climatic conditions for either or both of two reasons. Firstly because of the increased root action which follows the application of basic phosphates to clay pastures, and secondly because it seemed possible that the remarkable root development which took place on Plot 17 would affect the texture of the soil to some extent and thereby facilitate the upward passage of capillary water. An inspection of Fig. 14 shows that though the first three inches of soil on the basic slag plot remained moister than on the untreated plot, throughout the dry periods, the opposite was the case as far as the moisture content of the 3rd to 9th inch was concerned. Whenever a period of wet weather succeeded a dry spell, as for example during June 14th to 21st, the moisture content on both plots at a depth of 3–9 inches rose to approximately the same level. A dry spell invariably resulted in the moisture content of the 3rd to 9th inch on Plot 17 falling more rapidly than on the untreated plot. In view therefore of the high moisture contents which have prevailed at various periods throughout the season, it seems evident that the crop on Plot 17 has been able to utilise the moisture at this depth, particularly during dry spells, to a much greater extent than was the case on the untreated plot. Mechanical analysis (admittedly imperfect for this purpose) fails to detect any difference in the mechanical structure of the soil on these two plots, and it is therefore probable that during the first years which follow the application of basic phosphate to this type of meadow land, the crop on the slag plot is able to draw upon the moisture content of the soil at lower depths than is the case on the untreated plot largely because of the increased root development. The behaviour of the two plots from August 16th, when the plots were cut, until September 20th[1] tends to confirm this view. It will be seen that the moisture content of the section of the soil from 3–9 inches remained practically the same on both plots during this period and as far as the eye could judge no growth took place.

Temperature

The temperature records were taken by means of a special thermometer recording between 0° and 30° C., and graduated to one-tenth of a degree. During the latter stages of the work this thermometer was replaced by one registering only to one-fifth of a degree. It was, however, a simple matter to get results to one-tenth of a degree by interpolation.

The temperature records of the soil on Plots 16 and 17 are given in Table XXXVI and are recorded graphically in Figs. 15 and 16. Examined in conjunction with the figures in Table XXXV (represented in Figs. 13 and 14) the results have an important bearing upon the action of slag under dry climatic conditions on such heavy London clay soils. During the whole of the period from May 17th till the crop was carted off the plots on August 21st, the surface three

[1] Unfortunately the sample drawn from Plot 17 on August 31st met with an accident.

TABLE XXXVI. TEMPERATURE OF THE SOIL AT HORNDON ON PLOTS 16 AND 17, AT DEPTHS OF 3 INCHES AND 9 INCHES

Date 1920	TEMPERATURE (degrees Centigrade) At a depth of 3 inches: Plot 17 Basic slag	At a depth of 3 inches: Plot 16 Untreated	At a depth of 9 inches: Plot 17 Basic slag	At a depth of 9 inches: Plot 16 Untreated
May 5	—	—	9·8	10·3
10	—	—	—	—
17	14·0	16·0	12·5	13·5
25	17·2	20·3	14·7	17·7
31	15·4	21·4	14·8	16·2
June 8	14·4	18·1	13·5	15·4
14	17·0	20·0	15·0	18·0
21	16·3	20·0	15·8	17·5
29	17·5	20·5	16·4	19·2
July 8	15·3	16·8	14·8	16·1
12	17·5	19·8	15·4	17·9
20	16·5	20·0	15·6	17·6
26	15·3	16·3	14·9	16·2
Aug. 4	14·6	17·6	14·6	16·2
9	15·2	17·4	14·9	16·6
16	15·5	19·2	15·0	16·8
21	13·0	13·8	—	—
31	15·3	14·7	14·2	13·9
Sept. 7	15·8	15·5	15·3	14·8
20	12·2	12·5	12·6	12·7
Oct. 4	13·4	13·5	13·6	13·4
Nov. 24	4·5	4·2	5·2	5·0

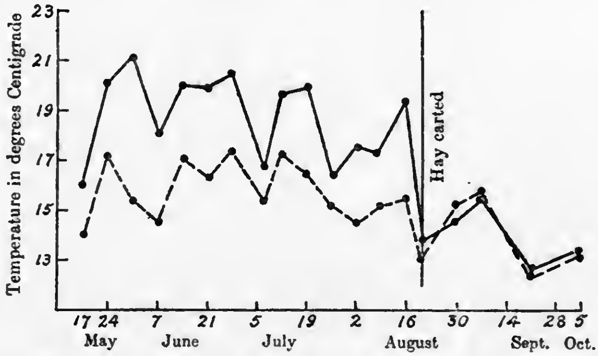


FIG. 15. Temperature of the Soil at a Depth of 3 inches on the Untreated and Basic Slag Plots at Great Mulgraves, Horndon-on-the-Hill. *Soil* London clay. Plot 16, Untreated ———. Plot 17, Basic Slag — — — —.

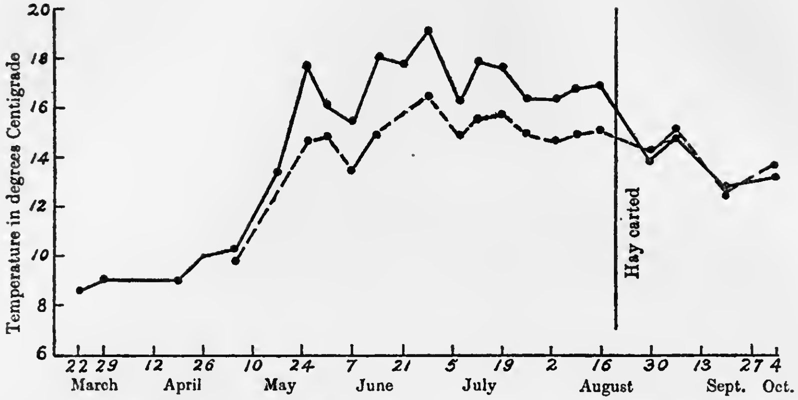


FIG. 16. Temperature of the Soil at a Depth of 9 inches on the Untreated and Basic Slag Plots at Great Mulgraves, Horndon-on-the-Hill. *Soil* London clay. Plot 16, Untreated ———. Plot 17, Basic Slag — — — —.

inches of soil on the slag plot remained considerably cooler than the surface soil on the untreated plot. The importance of securing an efficient covering of the surface soil, so as to protect it from the direct rays of the sun, is well brought out in Fig. 15. The thick bottom of clover has not only succeeded in retaining the moisture on Plot 17, but it has very effectively kept the plot cool during the hot spell of weather in May and June. A comparison of Figs. 13 and 15 shows quite clearly moreover that the lower temperature of the surface soil on Plot 17 is not due to the higher moisture which it contains, but is almost entirely due to the superior covering effect of the crop on this plot.

During the hot period May 17th–25th the temperature of the surface soil on both plots rose considerably, and on the 25th there was a difference of 3·1° C. between them. The subsequent week was showery, a total of ·24 inch falling on four of the seven days. Of this amount ·14 inch fell on the 29th. On the 31st the temperature of Plot 17 had fallen from 17·2° C. the previous week to 15·4°. Plot 16 on the other hand had risen from 20·3° on the 25th to 21·4° on the 31st there being now a difference of 6·0° C. between the two plots. In degrees Fahrenheit the temperatures at a depth of 3 inches on the two plots were—on Plot 16, 70·5° and on Plot 17, 59·7°.

During the whole of May and June, Plot 17 (slag) at a depth of 3 inches was never less than 3° C. cooler than the untreated plot. During the wet month of July the temperature on the two plots more closely approximated, but whenever a warm and dry spell of weather ensues the difference between the two plots becomes greatly accentuated. On August 16th the plots were cut shortly after the temperature readings were taken, and the hay lay on the swathe until the 21st, when it was raked up, weighed and carted. The reason for the difference in temperature which had existed throughout the season soon became apparent. With the removal of the dense covering from Plot 17 the temperature records corresponded very closely with those of Plot 16, and in fact on several occasions were a trifle higher.

The temperature records taken at a depth of 9 inches on each plot serve to emphasise the importance of an adequate covering of the soil. The beneficial effect of the covering action of the clover on the slag plot is very marked even at a depth of 9 inches, and during the warmest periods there is often a difference of 3° C. between the two plots, Plot 17 being invariably the cooler, despite the fact that the moisture content at this depth was generally lower than on Plot 16, the untreated plot. With the removal of the crop on August 21st this difference in the temperature records of the two plots at a depth of 9 inches becomes negligible and the two curves follow each other very closely indeed.

It is of course difficult to say how far this 'secondary effect' of the action of slag has contributed to the difference in the cropping power of the two soils (28·8 cwts. on Plot 17 and 6·4 cwts. on Plot 16), but there can be little doubt that it is of very considerable importance, and that during a dry season it may well be the most important action.

To retain moisture and keep the soil cool is the great difficulty experienced on this type of soil during the late spring and early summer. It is obvious therefore that whatever is possible should be done to maintain a thick close bottom, and for this purpose it is very desirable that the meadows should not be cut every year, but should be cut one year and grazed the next or two following years. To reserve a meadow for hay for several years is far from desirable under the climatic conditions prevailing in the east of the county, unless a hay crop varying from 1–7 cwts. of hay per acre should prove sufficiently profitable.

Martin's Hearne. It is of interest to compare the results at Horndon with those at Martin's Hearne. At Martin's Hearne the plots were cut for four years in succession and are known to have been cut for hay during the two years prior to the commencement of the experiments. There is no close bottom of clover at this centre such as that at Horndon (compare Tables XV and XXIV). At Martin's Hearne the clover dies down at the end of the season and in the following year makes its appearance towards the end of May if the season is a suitable one. During a dry unfavourable season like that of 1919 clover was almost entirely absent (Table XXII). Moisture and temperature determinations were made on Plot 2 basic slag, and Plot 3 untreated, throughout the season of 1920, and the records are shown in Table XXXVII.

TABLE XXXVII. EFFECT OF BASIC SLAG ON THE MOISTURE CONTENT AND TEMPERATURE OF THE SOIL AT MARTIN'S HEARNE

Date 1920	TEMPERATURE (degrees Centigrade)				MOISTURE	
	Plot 2 Basic slag 3 ins.	Plot 2 Basic slag 9 ins.	Plot 3 Untreated 3 ins.	Plot 3 Untreated 9 ins.	Basic slag Plot 2 %	Basic slag Plot 3 %
Apr. 19	—	—	—	—	32·2	35·1
26	—	10·5	—	—	34·1	33·2
May 5	—	9·9	—	9·7	29·9	31·6
10	—	—	—	—	36·7	34·6
17	—	13·5	—	13·5	25·3	25·5
25	18·5	15·9	—	—	19·9	21·3
31	16·9	16·8	16·8	15·8	27·9	28·5
June 8	—	—	—	—	—	—
14	17·6	15·6	18·1	16·0	23·3	25·2
21	17·1	16·8	17·4	16·8	24·8	23·4
29	17·8	16·7	17·8	17·5	16·7	17·5
July 8	—	—	—	—	—	—
13	17·0	16·2	17·3	16·4	25·6	24·3
19	18·2	15·8	17·8	16·4	17·0	18·3
26	14·7	14·8	14·6	14·7	25·1	23·5
Aug. 4	14·9	14·6	14·9	15·0	26·8	26·8
9	15·2	14·6	15·5	14·8	26·0	23·6
Plots cut Aug. 9th						
Aug. 16	17·8	16·4	17·8	16·4	21·1	20·2
24	15·7	15·2	15·6	14·7	22·8	24·3
31	14·6	14·0	14·7	14·3	20·2	18·6
Sept. 7	15·1	15·1	15·4	15·3	19·5	20·0
20	14·8	14·6	14·8	14·5	25·3	25·2
Oct. 4	14·0	13·8	14·1	14·0	—	—

At Martin's Hearne there is no appreciable difference in the temperature records of the two plots either at a depth of 3 inches or at 9 inches. There is a big difference in the yield of hay on the two plots, namely, 31·9 cwts. per acre on Plot 2, and 22·0 cwts. per acre on Plot 3. The bottom in both plots however is an open one, due to the recent practice of cutting every year, and the better growth on the slag plot does not act as a cover to any appreciable extent.

The moisture figures also present no important point of difference. During the dry spells the slag plot, as might be expected considering the heavier crop which it carries, loses moisture at a more rapid rate than the untreated.

The rainfall at Martin's Hearne and in the west of the county generally is considerably heavier than at Horndon-on-the-Hill, which is situated in the eastern part of the county.

As a general rule it would be quite a safe practice in the west of the county to cut the meadows for hay every year, and little would be gained by alternating with grazing, except perhaps during a particularly dry season like 1919.

THE EFFECT OF PHOSPHATES ON THE TEXTURE OF THE SOIL

Collins (4), discussing the effect of phosphates on grass-land, states that on the untreated plot at Cockle Park yellow clay still remains close to the surface, yet on the plot which has been manured with basic slag for over twenty years a very useful loam extends to 10 or 12 inches below the surface. The steady downward trend of the roots on the slag plot opens up the clay soil, and by admitting air and supplying organic matter gradually transforms the soil into a kindly loam. Such a transformation must of necessity have an important influence upon the movement of water in the soil. The experiments described here have only been running for a comparatively short time, and such an effect as Collins indicates would only be starting, and would not be readily noticed. The records of the moisture content at various depths on the two plots at Horndon (16 and 17), and the extraordinary contrast afforded by the root development, suggested that an appreciable alteration in the mechanical condition of the soil might have been brought about on the slag plot. In order to ascertain whether this difference is measurable by the ordinary methods of mechanical analysis, samples to a depth of 9 inches were removed from the slag and untreated plots at several of the centres during the autumn of 1919, and subjected to mechanical analysis. It cannot be said that the results, which are given in Table XXXVIII, afford much positive information. At Tysea Hill, Martin's Hearne and Butterfields, the clay fraction is appreciably less on the slag plots. At Farnham there is no difference, whilst at Horndon, where the experiment had only been in progress for a year, the results are contradictory. In any case, the positive differences are so small as to be in each case within the limits of experimental error.

TABLE XXXVIII. MECHANICAL ANALYSIS OF THE SOIL ON BASIC SLAG AND UNTREATED PLOTS

Fraction	Boulder Clay						London Clay				
	Tysea Hill		Martin's Hearne		Farnham Hall		Butterfields		Horndon-on-the-Hill		
	Un-treated Plot 3	Basic slag Plot 1	Un-treated Plot 3	Basic slag Plot 2	Un-treated Plot 3	Basic slag Plot 2	Un-treated Plot 3	Basic slag Plot 1	Supers. and lime Plot 15	Un-treated Plot 16	Basic slag Plot 17
Fine gravel	0·66	0·83	0·72	0·95	0·81	0·78	0·74	0·22	0·41	0·31	0·27
Sand	7·53	9·53	5·15	4·74	8·98	8·08	6·27	7·61	1·70	1·59	1·89
Fine sand	21·58	21·48	24·25	24·01	18·34	23·27	26·73	21·76	13·07	15·09	13·07
Silt	9·46	10·48	18·51	19·76	19·71	16·96	21·12	23·96	27·25	21·97	19·98
Fine silt	18·60	16·60	13·90	14·20	14·70	13·70	11·50	14·00	12·00	11·60	15·70
Clay	18·23	16·65	17·61	16·70	20·51	20·17	16·69	16·19	26·79	29·58	31·31
Loss in solution ...	8·32	8·54	7·61	7·15	7·01	7·09	7·48	6·76	7·52	7·50	7·60
Loss on ignition ...	18·09	17·42	14·88	15·29	11·30	11·24	11·82	11·23	12·41	14·50	13·80
	102·47	101·53	102·63	102·80	101·36	101·29	102·35	101·73	101·15	102·14	103·62

It seemed probable in view of these results that three inch samples might show more clearly any alteration in the mechanical composition which were in progress on the slag plots. Three inch samples were accordingly carefully removed from Plots 16, 17 and C at Horndon during August 1920 (two and a half years after the manures were sown), and submitted to mechanical analysis. The results are given in Table XXXIX. The differences between the figures for Plots 16 and 17 are smaller than the experimental error.

It would seem therefore that the effects of basic slag on the moisture content of the soil which are described in the preceding section are not due to any improvement in the mechanical structure of the soil that can be disclosed by the ordinary methods of mechanical analysis. This result must not of course be taken as indicating that the application of basic phosphates to heavy clay pastures, and the consequent development of the clover, does not affect the mechanical condition of the soil, but simply that under the conditions of this particular experiment the differences in the behaviour of Plots 16 and 17 at Horndon with regard to moisture cannot be attributed to changes in the mechanical condition of the soil on the respective plots.

TABLE XXXIX. MECHANICAL ANALYSIS OF THE SOIL AT HORNDON TO A DEPTH OF 3 INCHES

Fraction	Plot 17 Basic slag %	Plot 16 Untreated %	Plot C Lime %
Fine gravel, Coarse sand	2·03	1·82	2·27
Fine sand	10·30	10·98	13·33
Coarse silt	19·63	18·61	22·16
Fine silt	18·73	18·62	17·38
Clay	27·55	27·74	25·25
Loss in solution, „ on ignition	Undetermined	Undetermined	Undetermined

THE EFFECT OF PHOSPHATES ON THE ACCUMULATION OF NITROGEN IN GRASS-LAND

Field experiments at Rothamsted, and later at numerous other places, have conclusively demonstrated that leguminous plants leave the soil richer in nitrogen in spite of the fact that they are highly nitrogenous themselves. Collins (4) has shown that the application of phosphates, whether in the form of superphosphate or basic slag, on

Tree Field, Cockle Park, has resulted in a considerable increase in the nitrogen content of the soil. In 1908 the percentage of nitrogen in the soil receiving phosphates was ·236 %, whereas the untreated soil contained only ·185 %.

From analyses of the Tree Field soils in 1919 the results shown in Table XL were obtained.

TABLE XL. PERCENTAGE OF NITROGEN IN THE SOIL OF TREE FIELD, COCKLE PARK

Plot		Nitrogen %
4	Basic slag	·249
6	Untreated	·172
8	Super and lime till 1905. Basic slag and lime 1905–1919	·228

Analyses of the soil at the various Essex experimental centres after intervals of four, three and two years show that the gain in nitrogen on the plots receiving phosphates is considerable. The results are given in Table XLI.

TABLE XLI. PERCENTAGE OF NITROGEN IN FIRST 9 INCHES OF SOIL

	BOULDER CLAY		LONDON CLAY		CHALK
	Martin's Hearne 3 years	Farnham 3 years	Butterfields, Latchingdon 4 years	Horndon 2 years	Wendens 4 years
Phosphate plots ...	·338	·231	·260	·234*	·244
Untreated plot ...	·299	·208	·248	·210†	·219

* Average of 8 plots. † Average of 2 plots.

At Horndon samples were withdrawn from several of the plots in order to ascertain whether there was any difference in the influence of the various phosphates on the collection of nitrogen by the nodule organisms. The figures are set out in Table XLII.

The sampling errors are probably considerable, and it would be unfair to argue too much from the comparison of one plot with another. If, however, the various rock phosphate plots are grouped together, the two basic slag plots, and the two untreated plots, more reliable data are obtained, as appears in the lower part of Table XLII.

The figures suffice to demonstrate that there is no difference between rock phosphates and basic slag so far as their effect on the collection of nitrogen is concerned, a conclusion which is borne out by the botanical analysis of the 1920 hay crop (Table XXXI, Fig. 11) and also by the botanical examination of the pasture in 1919 (Table XV, Plate VI).

TABLE XLII. PERCENTAGE OF NITROGEN IN VARIOUS PLOTS AT HORNDON

Plot		% nitrogen
1	Florida pebble phosphate	·240
3	Algerian phosphate ...	·239
5	Basic slag	·244
6	Untreated	·212
7, 8	Gafsa rock phosphate ...	·227
11	Egyptian phosphate ...	·247
13	Superphosphate ...	·226
15	Superphosphate and lime	·222
16	Untreated	·208
17	Basic slag	·226
Average of	Rock phosphate plots ...	·238
,,	two basic slag ,, ...	·235
,,	,, untreated ,, ...	·210

THE RELATION OF PHOSPHATES TO THE ACCUMULATION OF NITRATES IN GRASS-LAND

It has been suggested by Middleton (15) that the secondary action of basic slag on pastures is due to the nitrification of the nitrogen accumulated by the nodule organisms, and that this resulting nitrate nitrogen is responsible for the vigorous growth of grasses which follows after the clover has been stimulated.

In order to ascertain what effect the application of phosphates had on the production of nitrates in grass-land it was decided to make as far as possible weekly determinations of the nitrate nitrogen content of the soil on the basic slag and untreated plots at three of the experimental centres. The centres selected were Martin's Hearne, where the soil has a lime requirement of ·27 %, Lambourne End, a more sour type of soil with a lime requirement of ·45 %, and Horndon-on-the-Hill, a 'sweet' soil containing a small reserve of calcium carbonate.

It was realised, however, that the experiment was complicated by the fact that the growing crops would probably remove nitrate as rapidly as it was formed, and that the much heavier crops on the slag plots would make a bigger demand on the nitrate supplies than would the crop on the untreated plots.

To overcome this difficulty a supply of soil, taken to a depth of 9 inches, from the slag and untreated plots at Martin's Hearne and Horndon-on-the-Hill was removed, transferred to Chelmsford, broken up, all the green growth removed, and then firmly packed into 10-inch glazed pots provided with a suitable drainage outlet. Particular care was taken to consolidate the soil in the pots by placing weights on the surface for some time and ultimately by tramping. The pots were placed in an open space under atmospheric conditions, and the nitrate nitrogen in the soil determined every fortnight. Samples for analysis were removed both from the field and from the pots by means of a small soil sampler similar to a cheese sampler.

Estimation of the Nitrate Nitrogen. As soon as possible after the samples were taken—generally 4–5 hours in the case of the field soils and 30 minutes in the case of the pots—they were dried at a temperature of about 50° C. When dried the samples were finely ground and bottled. The nitrate nitrogen was estimated in the dry ground sample within four days of the sample being removed from the field.

Method. From 50–100 gns. of soil were placed on a Büchner funnel and washed with several portions of distilled water until about 400–500 c.c. of filtrate were collected. The filtrate was transferred to a conical flask and then rapidly concentrated to a very small bulk—about 50–60 c.c. with 10 c.c. of normal caustic soda. The concentrated liquid so obtained was diluted with distilled water and boiled again for 10 minutes. The flask was cooled and 1 gram of finely powdered Devarda's alloy added. The contents were distilled into 10 c.c. of N/50 sulphuric acid, a specially prepared trap being used to prevent spitting. The burner was adjusted so that distillation proceeded slowly for about 5–10 minutes, at the end of which period distillation was quickened so that about half the liquid passed over in 30 minutes. Methyl red (·05 % solution in alcohol) was used as an indicator.

The accumulation of Nitrate in the Pots. The soils representing Plots 2 and 3 at Martin's Hearne were potted on March 29th, and 16 days later the first nitrate determinations were made. The soils from Plot 16 (untreated) and Plot 17 (basic slag) at Horndon were not removed and potted till April 19th, the first nitrate determination being made sixteen days afterwards on May 5th.

The nitrate contents of the potted soils as determined at various dates throughout the season are given in Table XLIII.

TABLE XLIII. ACCUMULATION OF NITRATE IN THE POTTED SOILS FROM MARTIN'S HEARNE AND HORNDON-ON-THE-HILL

Date 1920	MARTIN'S HEARNE Boulder clay		HORDON-ON-THE-HILL London clay		Rain-fall in inches	Mean max. temp. °C.	Remarks
	Basic slag	Un-treated	Basic slag	Un-treated			
	Nitrate nitrogen parts per million of dry soil						
March 29	0·96	1·12	—	—	—	—	—
April 14	6·16	3·92	—	—	1·89	55·3	Drains had run
19	—	—	2·24	1·12	—	—	—
21	5·60	3·50	—	—	1·00	54·4	Drains had run
May 5	6·16	3·04	5·04	1·68	0·68	66·0	,, ,,
19	9·52	6·16	5·60	1·68	0·24	61·6	—
June 5	12·88	5·04	9·52	5·04	2·10	69·4	Drains had run
17	17·04	5·60	12·88	6·72	0·22	64·3	—
July 2	22·96	7·28	22·40	7·00	1·04	68·8	—
14	25·76	7·84	17·36	6·84	1·04	63·3	—
29	22·40	7·54	20·14	5·04	1·55	69·6	Drains had run
Aug. 11	14·56	8·40	16·24	5·60	1·37	67·7	,, ,,
25	20·16	18·48	25·20	4·48	0·98	71·6	,, ,,
Sept. 9	19·36	20·72	28·00	4·48	0·21	65·6	—
15	23·52	25·56	—	—	0·13	69·6	—
27	26·32	10·64	14·56	7·84	3·19	68·8	Drains had run

The general trend of the figures for both centres is very similar. There is a rapid accumulation of nitrate on the slag plots during the period May 19th to July 2nd. The results are illustrated in Figs. 17 and 18. The curves indicate a much greater and a much more rapid accumulation of nitrate in the soil from the slag plots than in the soil from the corresponding untreated plots. This can only be due to one or both of two causes:

1. The nitrification of the nitrogenous matter accumulated in the slag plots by the nodule organisms.

2. The direct effect of the slag on the soil organisms which bring about nitrification.

It is difficult to understand how the addition of a comparatively small amount of nitrogenous organic matter to the already big accumulation in the experimental soils can be responsible for such a difference. Particularly is this the case at Martin's Hearne where the untreated soil contain··299 % of nitrogen and 11·80 % of organic matter (loss on ignition). It seems far more probable, therefore, that the result is mainly due to the direct effect of the phosphates on the soil organisms bringing about nitrification.

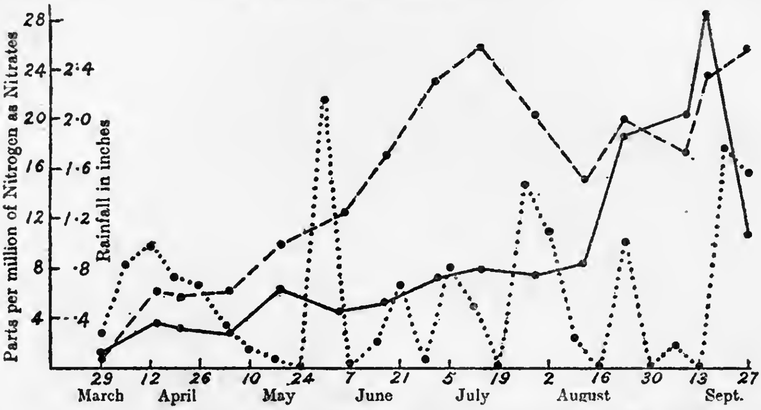


Fig. 17. Nitrate content of the Potted Soil from the Untreated Plot and the Basic Slag Plot, at Martin's Hearne. *Soil* Boulder clay. Season 1920. Soil from Untreated Plot (3) ———. Soil from Basic Slag Plot (2) – – – –. Rainfall ··········.

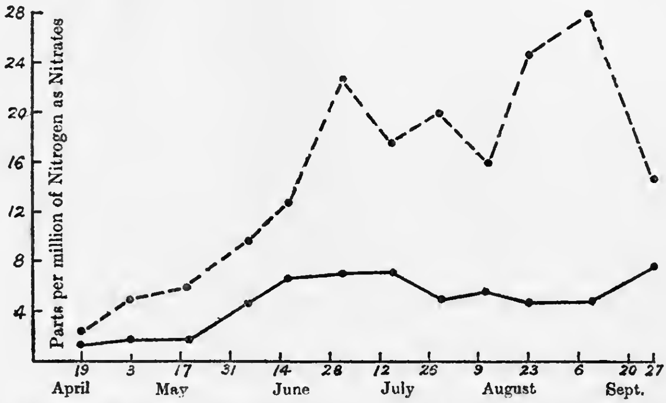


Fig. 18. Nitrate content of the Potted Soil from the Untreated and the Basic Slag Plots at Great Mulgraves, Horndon-on-the-Hill. *Soil* London clay. Season 1920. Soil from Untreated Plot ———. Soil from Basic Slag Plot – – – –.

The difference between the slag and untreated plots is striking, and seems to indicate, in view of the fact that the Martin's Hearne soil is sour, that on both these types of soil a deficiency in phosphates is a more important factor in limiting nitrification than a deficiency in lime.

There is a slightly greater accumulation of nitrate in the pot representing the untreated soil at Martin's Hearne than in the corresponding pot for Horndon-on-the-Hill, which may be due to the fact that the former is a more open soil. On the other hand, it may be due to the fact that, although the soil at Martin's Hearne is sour, it has a considerably higher content of total and available phosphoric acid than the soil at Horndon. The figures are as follows:

	Martin's Hearne	Horndon-on-the-Hill
	%	%
Total P_2O_5	·089	·078
Available P_2O_5	·0046	·0030
Lime requirement ...	0·27	0·00

At no period throughout the season does the nitrate content of the untreated soil from Horndon ever approach that of the soil receiving basic slag. The two pots representing the treated and untreated soils from Martin's Hearne behave somewhat differently. Until August 11th the figures are comparable with those representing the Horndon pots, but during the hot spell which succeeded, there is a rapid accumulation of nitrate in both the Martin's Hearne pots, and when sampled on August 25th and September 9th and 15th, the nitrate content of the slag and untreated pots was approximately the same. The temperature during the period August 11th to September 15th was higher than at any other period during the season, and although the pot drains did not run, there was a sufficient precipitation to keep the soil moist. On August 18th–19th ·88 inch of rain fell, and there was a fall of ·10 inch on two consecutive days out of the remaining 13 days in August. Four out of the first five days in September were showery with a total precipitation of ·21 inch. There was no further rain until September 14th, when ·13 inch fell. After the 15th September (which was the last date on which the nitrate content of the two pots was similar) until the 22nd the weather was wet, 3·19 inches of rain falling between the 15th and 22nd inclusive. The drains from both pots ran freely, but unfortunately the drainage water was not collected. From the 22nd to the 27th the weather was dry and hot, no rain falling, and on the 27th when the pots were sampled the slag pot contained 26·32 parts per million of nitrate and the untreated pot 10·64 parts. The relative nitrate content of the two pots was therefore similar to what it had been up to August 11th.

It is difficult to account for the curious results obtained during the period August 11th to September 15th. It may be that under the climatic conditions then prevailing the untreated soil at Martin's Hearne is capable of yielding sufficient phosphate to enable nitrification to take place at a much more rapid rate than at any other time during the season.

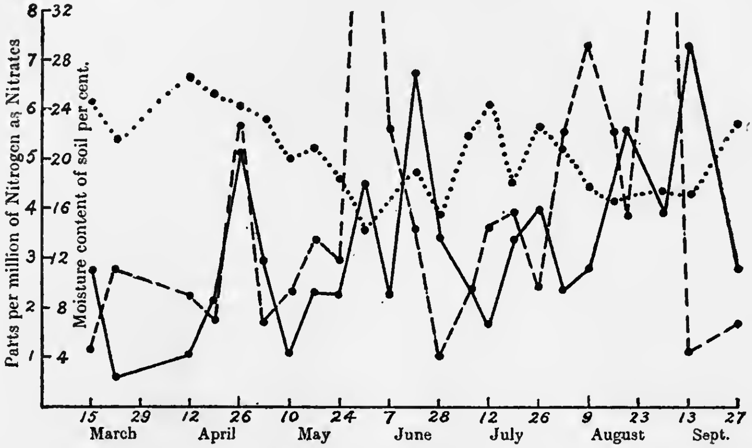


FIG. 19. Nitrate content of the soil on the Untreated and the Basic Slag Plots at Great Mulgraves, Horndon. *Soil* London clay. Season 1920.

Untreated Plot ———. Basic Slag Plot — — — —. Moisture Content ....

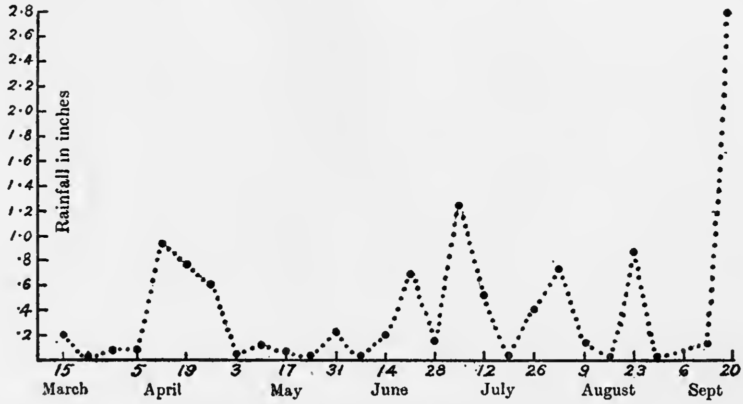


FIG. 20. Rainfall at Great Mulgraves, Horndon. Season 1920.

If, as is postulated here, it is correct, in view of these results, to assume that the main effect of phosphates on the production of nitrate in soils well stored with nitrogenous organic matter is due to their action on the nitrifying organisms, it is possible to explain the large increase in the hay crop obtained on the treated plots at

Lambourne End in 1919. The various phosphates were not sown until January, 1919, and although clover was absent from all the plots throughout the season, the treated plots gave almost twice the yield of the untreated. The result was not due to any stimulation

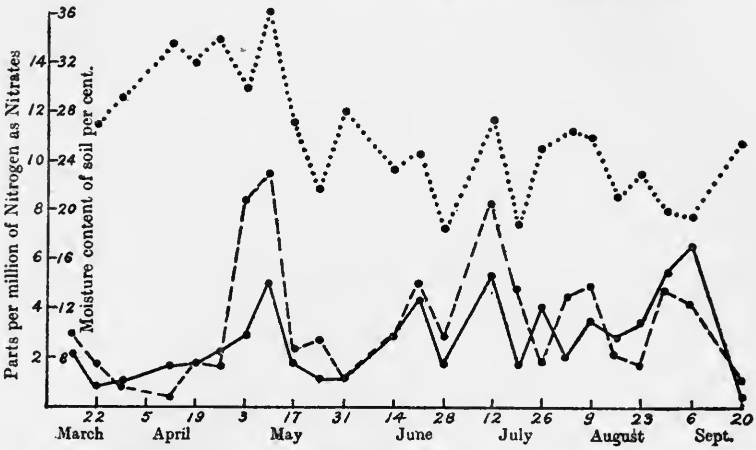


FIG. 21. Nitrate content of the soil on the Untreated and Basic Slag Plots at Martin's Hearne. *Soil* Boulder clay. Season 1920.

Untreated Plot ———. Basic Slag Plot — — — —. Moisture Content ....

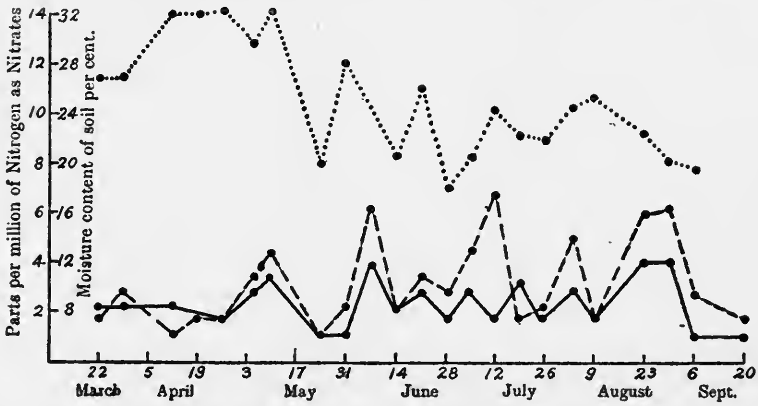


FIG. 22. Nitrate content of the soil on the Untreated and Basic Slag Plots at Butcher's Farm, Lambourne End. Season 1920. *Soil* London Clay.

Untreated Plot ———. Basic Slag — — — —. Moisture Content ....

of the clover, and as the crop was composed entirely of grass and weeds, it seems probable that the much heavier crop on the treated plots was mainly due to the direct effect of the phosphates in stimulating the production of nitrates.

Field Results. The nitrate figures for the samples of soil taken weekly from the slag and untreated plots at Horndon, Martin's Hearne, and Lambourne End are given in Table XLIV and the results are shown graphically in Figs. 19, 20, 21 and 22.

TABLE XLIV. NITRATE CONTENT OF THE SOILS ON THE BASIC SLAG AND UNTREATED PLOTS DURING 1920

Date	Horndon		Lambourne End		Martin's Hearne	
	Plot 16 Untreated	Plot 17 Basic slag	Plot 3 Untreated	Plot 2 Basic slag	Plot 3 Untreated	Plot 2 Basic slag
	Parts per million of nitrogen as nitrate					
Mar. 15	—	—	5·04	2·8	2·24	2·80
22	2·8	1·12	2·24	1·68	1·12	1·68
29	·56	2·80	2·24	2·8	1·12	·96
Apr. 12	—	—	2·24	1·12	1·68	·56
19	1·12	2·24	5·6	1·68	1·68	1·68
26	2·24	1·68	1·68	1·68	2·24	1·68
May 5	4·4	5·6	2·8	3·36	2·80	8·40
10	3·36	1·68	3·36	4·48	5·04	9·52
17	1·12	2·24	—	—	1·68	2·24
25	2·24	3·36	1·12	1·12	1·12	2·80
31	2·24	2·8	1·12	2·24	1·12	1·12
June 8	4·48	12·32	3·92	6·16	—	—
14	2·24	5·60	2·24	2·24	2·80	2·80
21	6·7	3·64	2·8	3·36	4·48	5·04
29	3·36	1·12	1·68	2·8	1·68	2·80
July 5	—	—	2·8	4·48	—	—
8	2·24	2·24	—	—	—	—
12	1·68	3·36	—	—	—	—
13	—	—	1·68	6·72	5·60	8·40
19	—	—	3·36	1·68	1·68	5·04
20	3·36	3·92	—	—	—	—
26	3·92	2·24	1·68	2·24	3·92	1·68
Aug. 4	2·24	5·60	2·80	5·04	2·24	4·48
9	2·8	7·28	1·68	1·68	3·36	5·04
16	2·8	5·6	—	—	2·8	2·24
21	5·6	3·36	—	—	—	—
23	—	—	3·92	5·92	—	—
24	—	—	—	—	3·36	1·68
31	3·92	10·64	3·92	6·16	5·6	5·04
Sept. 7	7·28	1·12	1·12	2·80	6·72	4·48
20	2·80	1·68	1·12	1·68	0·56	1·12

The curves at all three centres have a general similarity of appearance, and they demonstrate that at certain periods during the season there is a much greater accumulation of nitrate in the slag plots than in the untreated.

Even on the very sour soil at Lambourne End nitrification seems to be much more active in the slag plots than in the untreated. There is a distinctly greater accumulation of nitrate during the periods May 5th to 10th, May 31st to June 8th, July 5th to 17th, August 4th and August 23rd to September 7th. Reference to Fig. 19 shows that these periods roughly correspond to those periods at Horndon during which there is a much greater accumulation of nitrate in the slag plots, and with two exceptions, viz., May 31st to June 8th, and August 23rd to September 7th, these dates hold good for Martin's Hearne. On June 8th samples were not taken from Martin's Hearne, so this exception is easily accounted for. The figures for this centre for August 23rd to September 7th are curious. There is an accumulation on both the treated and untreated plots, but it is greater on the untreated than on the slag plot. Reference to Fig. 17 shows that the same result was obtained from the pots, and that at this period, and only at this period, did the nitrate in the untreated pot accumulate to an extent at all comparable with the slag pot. This result in the field would seem to lend some weight to the suggestion that at this period of the season the soil on the untreated plot has been able to furnish sufficient phosphoric acid to meet the requirements of those organisms engaged in the production of nitrates.

These results are not in accordance with the conclusions come to by Russell(25). As the result of his work on the "Nitrate Content of Arable Soils," he says: "that only in one year (1911) was there any evidence of the organisms responsible for nitrification being retarded by a deficiency of phosphates and potash." It must be noted, however, that the soil even on the untreated plot of Broadbaulk Field contains considerably more phosphoric acid (·114 %) than the soils at Horndon, Martin's Hearne, or Lambourne End.

It is of interest to note that at Martin's Hearne and Lambourne End periods of high nitrate accumulation coincide as a rule with high moisture content of the soil, whilst at Horndon they coincide with periods of low moisture content. At Martin's Hearne and at Lambourne End the periods of high nitrate accumulation on the slag and untreated plots occur as a rule at the same time (Figs. 21 and 22).

At Horndon, on the other hand, periods of high nitrate accumulation on the untreated plot follow, about a week later, similar periods on the slag plot. This difference might possibly be due to some influence the crop may have on nitrate production, but Russell(25), when investigating this subject, was unable to secure any definite data supporting such a contention.

It may be that an inadequate supply of available phosphoric acid on the untreated plot prevented the crop from utilising the accumulated nitrate when suitable conditions occur, and that the subsequent depressions in the nitrate content are due to rain washing the nitrate down to below the 9 inch level.

THE INFLUENCE OF PHOSPHATES ON SOIL BACTERIA

At the suggestion of Dr Russell an attempt was made to ascertain what effect, if any, the application of phosphates has had on the soil bacteria. Preliminary counts were made at Rothamsted during the autumn of 1919, but the results were contradictory.

Phosphates are essential for the development of all types of bacteria. Fred and Hart (9) in an investigation on the comparative effect of phosphates and sulphates on soil bacteria show that phosphates increase the number of soil bacteria, and they suggest that increased crop production of a soil resulting from the application of soluble phosphates is in part due to the promotion of bacterial activity. The work of Hoffman and Hammer (10) demonstrates that phosphates greatly increase the amount of nitrogen fixed by Azotobacter and they came to the conclusion that for this purpose di- and tri-calcium phosphates are more effective than mono-calcium phosphates.

The soils at Martin's Hearne and Horndon are very deficient in phosphoric acid and if any positive results were to be obtained it seemed probable that it would be at these two centres. Samples for bacteriological examination were taken every month from March to August. The samples were secured by means of a small soil sampler which removed a 9 inch core of about ½ inch diameter. The sample from each plot consisted of four cores. Before use, the soil sampler was sterilised by means of a methylated spirit lamp, and the samples when drawn were placed in previously sterilised bottles.

The total counts for the treated and untreated plots at Martin's Hearne and Horndon are given in Table XLV.

There is very little difference between the bacterial counts representing the two plots at Martin's Hearne, and apparently phosphate has had little effect in this direction.

The two plots at Horndon show decided differences. During the months of May, June and July there are twice as many bacteria in the slag plot as on the untreated, but in April and August the position of the two plots in this respect is reversed.

Whenever possible during the season counts of the Azotobacter and nitrate organisms were made. The results are set out in Table XLVI.

TABLE XLV. BACTERIAL COUNTS (IN THOUSANDS) AT MARTIN'S HEARNE AND HORNDON. (Agar-Albumose media)

Date	Martin's Hearne		Horndon	
	Plot 3 Untreated	Plot 2 Basic slag	Plot 16 Untreated	Plot 17 Basic slag
1920				
March 6	2935	4632	—	—
29	575	1234	—	—
April 26	1540	1638	5430	2783
May 25	6869	3810	8235	19550
June 25	6206	6039	5349	9303
July 20	5347	4500	4120	8568
Aug. 17	7070	7211	8609	4000

TABLE XLVI. COUNTS OF AZOTOBACTER AND NITRATE ORGANISMS IN THE SOIL AT MARTIN'S HEARNE AND HORNDON. (Thousands per grm.)

Date	Azotobacter				Nitrate Organisms			
	Martin's Hearne		Horndon		Martin's Hearne		Horndon	
	Plot 3 Untreated	Plot 2 Basic slag	Plot 16 Untreated	Plot 17 Basic slag	Plot 3 Untreated	Plot 2 Basic slag	Plot 16 Untreated	Plot 17 Basic slag
1920								
May 25	4722	4837	1800	7828	149	298	483	2903
June 21	2154	1735	1082	3171	—	—	—	—
July 19	1330	1771	1031	4983	—	—	1600	6401
Aug. 17	3302	4685	—	—	—	—	2680	8411

There are no important differences between the numbers of Azotobacter present on the treated and untreated plots at Martin's Hearne, but at Horndon these soil organisms have been considerably developed by the application of phosphates.

The numbers of nitrate producing organisms have been greatly increased on the basic slag plots at Horndon, a result which is in keeping with the much greater amounts of nitrate found in this soil throughout the season. (Tables XLIII and XLIV and Figs. 18 and 19.)

It is difficult to explain why at one centre the numbers of bacteria should show marked increases as the result of the application of basic slag, whilst at another centre, where the effect of the basic slag on the crop is quite as marked, the bacterial content does not appear to have been appreciably affected by the application of basic slag. It may be that the lack of effect at Martin's Hearne is due to the sourness of the soil, but counts made on the portion of the basic slag plot which had received a dressing of ground lime in April 1920 showed no appreciable advantage in this respect over that portion of the plot which had not been so dressed.

FACTORS LIMITING THE YIELD OF HAY AND THE ACTION OF PHOSPHATES ON HEAVY CLAY SOILS

THE EFFECT OF RAINFALL ON THE YIELD OF HAY FROM THE UNTREATED PLOTS

The weight of the hay crop on the untreated plot at each of the experimental centres varies within very wide limits from year to year. When a dry season is experienced the crop is often a failure, whilst the same plot given a moister and more favourable season may reach the comparatively high production level of two tons to the acre.

In Table XLVII the yield of hay on the untreated plots for the years 1916–20 is compared with the rainfall for the period May 1st till harvest at the corresponding rainfall stations. The results for four of the centres are shown graphically in Figs. 23 and 24.

TABLE XLVII. COMPARISON OF THE WEIGHTS OF HAY ON THE UNTREATED PLOTS AND THE RAINFALL FROM MAY 1ST TILL HARVEST AT THE VARIOUS EXPERIMENTAL CENTRES

EXPERIMENTAL CENTRE		1916	1917	1918	1919	1920
Tysea Hill	Hay cwts. per acre	31·6	20·4	17·7	11·6	38·3
	Rainfall in inches	5·94	5·36*	4·47	2·87	9·34
Martin's Hearne	Hay cwts. per acre	—	14·3	23·4	10·4	22·0
	Rainfall in inches	—	6·27	11·51	2·85	8·37
Lambourne End	Hay cwts. per acre	—	—	—	13·2	21·4
	Rainfall in inches	—	—	—	3·08	5·27
Hassobury	Hay cwts. per acre	—	11·1	23·4	10·9	—
	Rainfall in inches	—	4·82	7·73	0·58	—
Wendens, Saffron Walden	Hay cwts. per acre	51·2	25·4	33·4	14·3	25·0
	Rainfall in inches	4·00	4·00†	2·44	0·53	2·42‡
Butterfields, Latchingdon	Hay cwts. per acre	31·4	14·5	20·1	20·6	16·1
	Rainfall in inches§	3·41	2·32	2·51	1·47	2·28

* ·71 inch of rain fell three days before plots were cut.
† 2·32 inches of rain fell on May 20th, 1917.
‡ ·57 inch of rain fell two days previous to cutting.
§ Rainfall figures for period May 1st till June 30th.

The figures for the centre at Wendens are perhaps the most striking, the hay crop on the untreated plot varying from 51 cwts. to 14 cwts. per acre. Similar, although not quite so marked, fluctuations occur at all the other centres. The yearly rainfall figures afford no adequate explanation of these differences. At Wendens, for example, the rainfall for the year was 27·33 inches in 1917, and in 1918 when a bigger yield of hay was obtained, 25·68 inches. The distribution of the rainfall, however, seems to be of great importance, particularly during

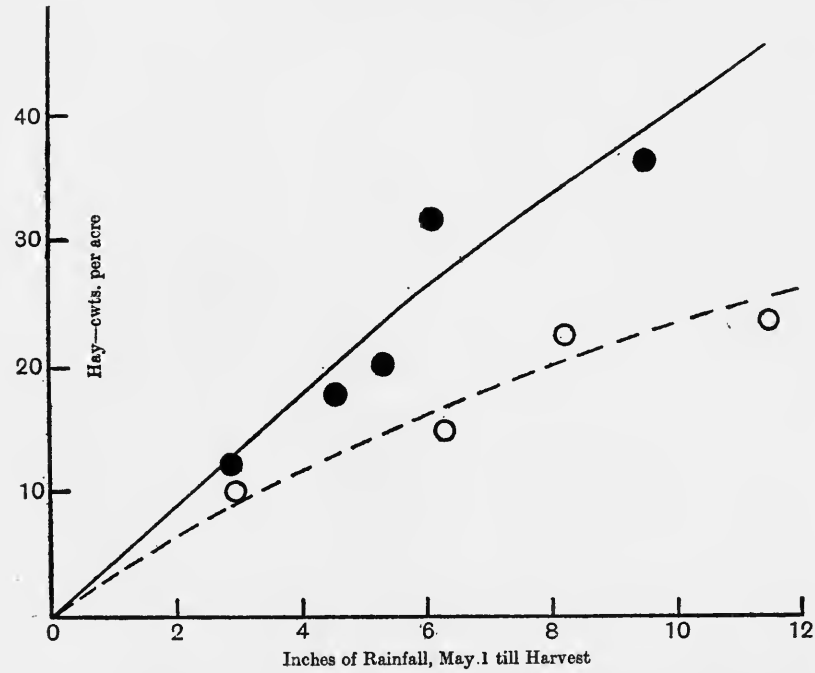


Fig. 23. Influence of Rainfall on the Yield of Hay on the Untreated Plots at Tysea Hill ———● and Martin's Hearne — — — —○.

the months of May and June. If the rainfall figures for the period May 1st till harvest are tabulated with the yield of hay on the untreated plot, as is the case in Table XLVII, it will be seen that, with one or two exceptions which can be readily accounted for, there is a very close connection between the two sets of figures.

The rainfall figures have been taken from the records of the British Rainfall Organisation. Their station at Havering-atte-Bower is within two miles of each of the first three experimental centres. At Hassobury there is a rainfall station on the farm, whilst at Saffron Walden and Latchingdon the respective rainfall stations are within from two to four miles of the experimental centres.

The curve representing the correlation of the hay yield with the rainfall at Saffron Walden is a very steep one, and shows quite distinctly that rainfall is the most important factor.

At Tysea Hill and Martin's Hearne even a high rainfall from the 1st of May till harvest of 9·34 inches and 11·51 inches respectively

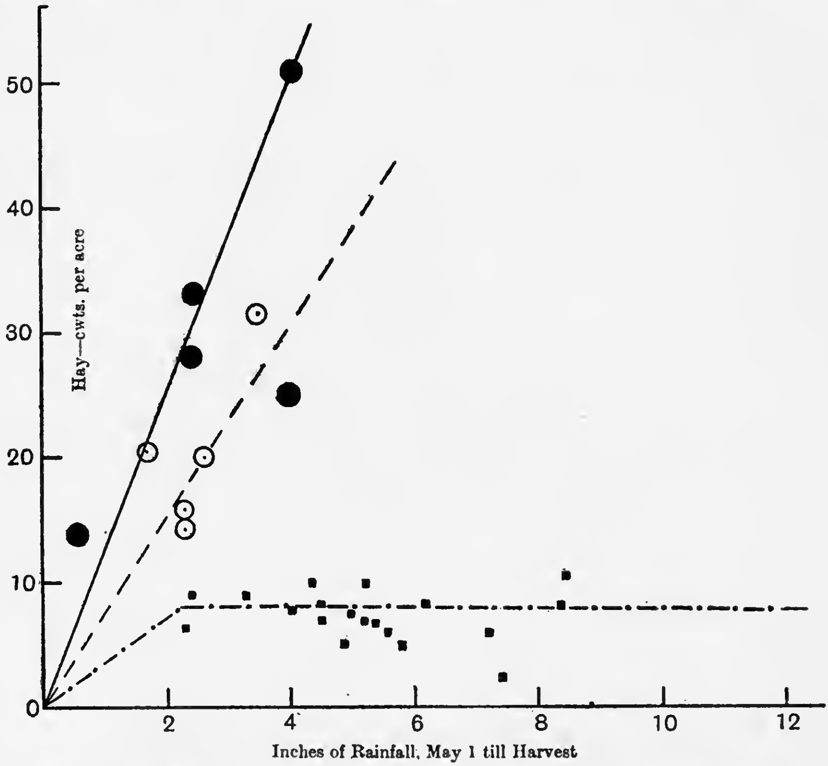


FIG. 24. Influence of Rainfall on the Yield of Hay on the Untreated Plots at Wendens ——— ●, Butterfields — — — —⊙, and Cockle Park —·—·—■.

produce crops of only 38·3 cwts. and 23·4 cwts. The manurial factor is clearly of greater importance at these two centres and particularly at Martin's Hearne. The curves are not nearly so steep as at Saffron Walden, and there is a much greater response to manuring.

At Latchingdon the rainfall has more influence on the crop than at Martin's Hearne or Tysea Hill and less than at Saffron Walden. It was difficult to get any correlation between the rainfall and the yield of hay on the untreated plot at this centre. Owing to a wet July in 1918 and 1920 the crops had to remain uncut during a spell of wet weather, which had little or no influence on the growth of the crop. In order to overcome this difficulty the rainfall figures from 1st May to June 30th have been taken for each year. One point in the curve falls far out of line, namely that representing the rainfall and the hay yield for 1919. The reason for this divergence, however, is clear. After an exceptionally dry May and June, the first week of July was wet, ·47 inch of rain falling on the 2nd of the month and ·29 inch on the 3rd. The crop was not cut till three weeks later, and during that time considerable growth was made, particularly by the clover plants. If the rain falling on the first four days of July is taken into consideration the divergence of this particular point is rectified.

In Fig. 24 the effect of rainfall on the yield of hay from the untreated plot at Tree Field, Cockle Park, is shown, and the curve affords an interesting contrast to those representing the Essex centres. At Cockle Park rainfall does not influence the yield of hay on the untreated plot, whilst in Essex rainfall at certain centres is the most important limiting factor, and at all centres it has a great influence on the yield of hay.

THE EFFECT OF RAINFALL ON THE YIELD OF HAY FROM THE PLOTS RECEIVING PHOSPHATES

The field experiments recorded show that at all these centres the application of phosphates results in a considerable increase in crop. The increase is least at Saffron Walden and greatest at Horndon. The results at Tysea Hill indicate, however, that even poor as this soil is in phosphoric acid, the heavy dressing of 200 lbs. of phosphoric acid per acre is more than the soil requires over a period of five years, as equally good results accrue from the lighter dressing of 100 lbs. In Figs. 25 and 26 the increase resulting from the application of phosphates at each centre is correlated with the rainfall. It will be seen that at Latchingdon and Saffron Walden the increase in the hay crop on the phosphate plots steadily progresses with the rainfall, clearly demonstrating that rainfall is the controlling factor, and that with the limited rainfall at these centres little or no increase may be expected from other than phosphatic manures. At Tysea Hill and Martin's Hearne on the other hand the increase in the yield of hay due to phosphate varies within extremely narrow limits, and is not dependent upon the rainfall. The curve for Tysea Hill is a perfect limiting factor curve and indicates that some factor other than the rainfall and phosphates is limiting the yield of hay. The absence of any increase in yield due to phosphates in 1920 is curious. The season was a particularly favourable one, and owing to the rainy weather in July and the beginning of August the crop was not cut until August 23rd. As will be shown later, at least half of the original dressing of phosphoric acid applied in 1915 was still present in the

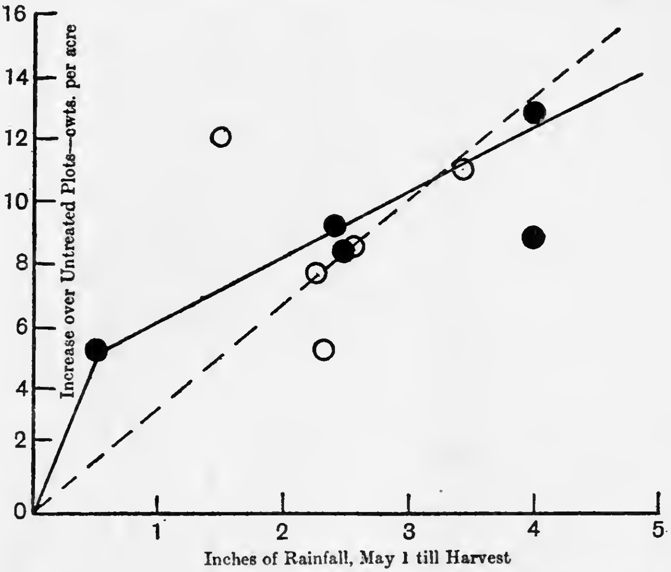


Fig. 25. Influence of Rainfall on the Increase due to Phosphates at Wendens ——— ● and Butterfields — — — — ○.

soil in an available form in October, 1919, so that the negligible increase of the treated plots over the untreated in 1920 cannot be due to a deficiency in phosphates. It can only be concluded, therefore, that with a high rainfall (9·34 inches from May 1st till harvest) and a long growing period, no increase will be obtained from phosphates, unless the second limiting manurial factor is first satisfied. The curve for Martin's Hearne closely resembles that at Tysea Hill, and as the two fields are on the same soil formation, have practically identical chemical and mechanical compositions, and are only a short distance apart; the result at Martin's Hearne satisfactorily confirms the conclusion that a second limiting factor comes into operation as soon as the need for phosphates is satisfied. The soil at Martin's Hearne is appreciably poorer in total and available phosphoric acid than at Tysea Hill, and even with a rainfall of 11 inches from May 1st

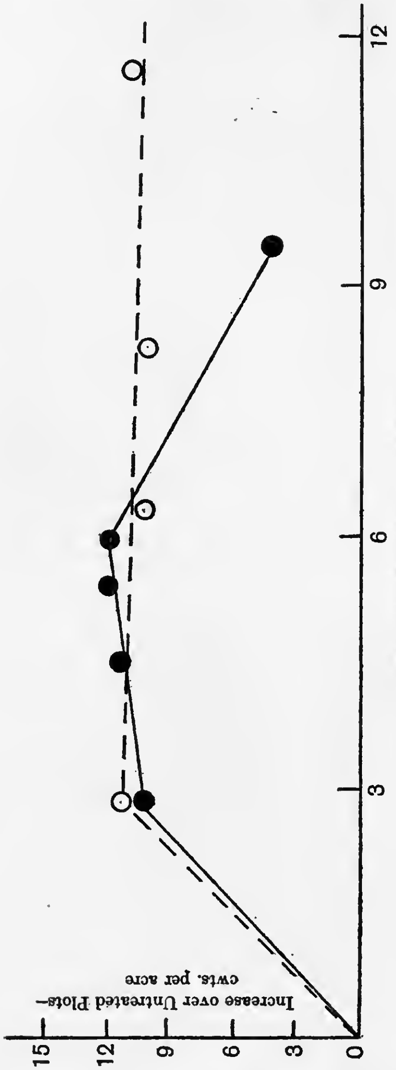


FIG. 26. Influence of Rainfall on the Increase due to Phosphates at Tysea Hill ——● and Martin's Hearne – – – –○.

till hay harvest and a long growing period (cut August 10th), the soil cannot provide an adequate supply of phosphates.

It is too soon to draw definite conclusions from the results at Lambourne End and Horndon-on-the-Hill. There are indications that once the need for phosphates has been satisfied at Lambourne End the hay crop could be increased by the addition of some other essential plant food. It seems very probable, however, that at Horndon-on-the-Hill, after the need for phosphates has been satisfied, rainfall is the limiting factor as far as the hay crop is concerned.

THE SECOND LIMITING MANURIAL FACTOR

It has been previously stated that the experiments were started with the object of ascertaining the relative manurial value of various types of insoluble phosphates. No attempt was therefore made to include dressings of potassic and nitrogenous manures. Out of the eight experimental centres dealt with here there are two—Hassobury and Farnham—at which the response to phosphates, measured by the hay crop, is negligible. A very marked improvement in the quality of the meadow has resulted at Farnham, as has already been pointed out (Table XIII), but even in a favourable season the increased weight of hay resulting from the application of the various phosphates has been very small indeed. Moreover, the productive level of this type of soil is exceedingly low, and the same remark applies to Hassobury, where also the crop seldom passes the 10 cwts. per acre level.

An examination of the analytical data presented in Table VII shows that the Hassobury soil is reasonably well supplied with phosphoric acid, and has, in fact, practically twice as much available phosphoric acid as any of the other experimental soils. The percentage of available phosphoric acid is well above Dyer's limit of 0·01 %(7). This is not the case at Farnham, where the soil is markedly deficient in available phosphoric acid, and it seems reasonable to conclude that a deficiency of another essential plant food is the cause of the low productivity at Hassobury, and is preventing a response to the dressings of phosphates applied at Farnham.

Both soils are well supplied with nitrogen, and as readily available nitrogen has been slowly accumulating at Farnham without having any appreciable effect on the hay yield, it does not seem that a lack of nitrogen is responsible for the poor crop returns. The Hassobury soil, though devoid of calcium carbonate and possessing a Hutchinson and MacLennan lime requirement of ·13 %, gives no response to the heavy dressing of lime applied to Plot 15. Moreover, the soil at Farnham has an adequate supply of calcium carbonate. The low level of production at these two centres is clearly not due to soil sourness or lack of lime.

TABLE XLVIII. CHEMICAL ANALYSIS OF THE SOILS AT HASSOBURY AND FARNHAM

	Hassobury %	Farnham %
Nitrogen	0·180	0·208
Loss on ignition	7·23	8·23
Calcium carbonate	0·00	0·45
Total phosphoric acid ...	0·190	0·118
Available „ „ ...	0·0123	0·0056
Total potash	0·435	0·644
Available potash	0·0194	0·0165
Lime requirement	0·13	0·00

The Hassobury soil has a lower content of 'total potash' than the other centres, but the Farnham soil is better off in this respect than several of the other centres. At both stations, however, the 'available potash' is markedly lower than in any of the other clay soils, and although in both cases the figure is distinctly above Dyer's(7) limit, it seems difficult to come to any other conclusion than that a soil deficiency in available potash is responsible for the poor yields of hay at these two centres.

At two of the remaining centres, namely Tysea Hill and Martin's Hearne, the curves in Fig. 26 show the operation of a second limiting factor which comes into play after the need for phosphates has been satisfied.

The soil at both these centres is very similar in composition. It is well supplied with organic matter and nitrogen, and as this store has been considerably added to by the accumulated residues from clover plants, it does not seem probable that there is any deficiency in nitrogen.

Both soils are sour. They contain no calcium carbonate and have a high lime requirement. Nevertheless the production of nitrates in this soil compares very favourably with that at other centres better supplied with calcium carbonate and where the soil is sweet. (Compare Figs. 21 and 19.)

At Martin's Hearne and Tysea Hill the plots were cross dressed with lime at the rate of 35 cwts. per acre during the early part of 1920, and at Martin's Hearne another plot was marked off and received a dressing of approximately 10 tons of farmyard manure to the acre. The results are recorded in Table XLIX.

There is a small gain due to lime at Martin's Hearne, but considering that the 1920 season was a particularly favourable one for the hay crop the result suggests that very little can be expected from lime until some other fertilising constituent is supplied*. The same conclusion holds true for Tysea Hill, where the increase due to lime is insignificant. In taking the average it is probably not fair to include

TABLE XLIX. EFFECT OF CROSS DRESSING WITH LIME AT MARTIN'S HEARNE AND TYSEA HILL

Martin's Hearne			Tysea Hill		
Plot	Hay cwts. per acre, 1920		Plot	Hay cwts. per acre, 1920	
	Unlimed	Limed		Unlimed	Limed
1. Open hearth (fluorspar) slag	28·4	28·5	1. High grade basic slag	40·2	40·1
2. Ditto, high soluble	31·9	36·3	2. Gafsa rock phosphate	41·2	43·6
3. Untreated	23·0	25·5	3. Untreated	38·3	36·0
4. Gafsa phosphate	35·2	39·6	4. Open hearth (fluorspar) slag	46·4	49·9
5. Egyptian phosphate	29·0	31·6	5. Ditto, high soluble	45·2	47·2
6. Algerian phosphate	34·6	34·7	6. Ditto ,,	42·1	41·6
A. Farmyard manure (applied Autumn of 1919)	40·3	38·7	7. Untreated	45·6	42·7
			Half dressing of phosphate		
			8. Same as 2.	48·3	48·4
			9. Same as 6	44·8	43·0
			10. Same as 4	44·8	46·3
Average ...	31·8	33·5	Average ...	43·7	43·9
Inches of rain, May 1st till harvest	8·37			9·34	
Lime requirement	·27 %			·29 %	

the results from the untreated plots, because it may with reason be argued that no result from the application of lime could be expected until the need for phosphates was first met. If the figures for the untreated plots at Tysea Hill are excluded, the average yield becomes 44·1 cwts. per acre on the unlimed plots and 45·0 cwts. per acre on the limed plots, giving an average increase of 0·9 cwt. in favour of lime.

The response to farmyard manure on Plot A at Martin's Hearne is significant. Assuming that 10 loads of farmyard manure are equivalent to 8 tons, and that the farmyard manure contained ·4 % of phosphoric acid and ·4 % of potash, this plot received in addition

* The yields of hay for 1921 show equally poor returns from the use of lime.

to other materials a dressing of phosphoric acid and potash equivalent to about 72 lbs. of each per acre. This amount of phosphoric acid was presumably sufficient to meet the requirements of the 1920 season, and it is therefore interesting to note what effect the dressing of potash had[1].

There was no doubt throughout the whole season that the farmyard manure plot was the best on the field. For the first time that portion of the field not within the experimental area, and which had received a similar dressing of dung, looked better and bore a better crop than the experimental plots.

The average weight of hay on the phosphate plots was 31·8 cwts. per acre, and on the plot receiving a small dressing of phosphates and potash in the form of dung 40·3 cwts., leaving a gain of 8·5 cwts. per acre which can only be attributed to potash.

During the whole season the plots were inspected once a week, and it was early evident that the clover was making a more vigorous growth on the farmyard manure plot. Owing to an oversight a sample of hay was not removed from this plot for botanical analysis.

The aftermath was allowed to grow until the beginning of October, and not only was there a more vigorous growth, but the bottom of clover on the farmyard manure plot was closer and more regular than on any of the other plots.

In view of the evidence there can be little doubt that on this type of soil, after the need for phosphate has been met, potash is the second limiting manurial factor. Moreover it is very probable that in all but the exceptionally dry years a profitable return from the application of potash will be secured. It should be possible by judicious application of phosphates and potash to raise the production of meadow hay to the 2 tons an acre level in all but exceptionally dry years.

Such results serve to confirm the conclusion that potash is the second limiting manurial factor at Hassobury and Farnham, and they incidentally suggest that on grass-land in Essex profitable results from the application of potash are likely to accrue when the soil contains less than ·03 % available potash—a figure considerably above Dyer's limit.

[1] It is very improbable in view of the particularly moist season that the organic matter or the nitrogen in the farmyard manure plot had any effect on the yield of hay. The meadow has been down to grass for at least 80 years, and a large store of organic matter and nitrogen has been accumulated. The action of lime would presumably be to release these materials for the plant, and the lack of response to the application of lime suggests that the soil can normally provide all the nitrogen the crop requires in a suitable form.

THE ACTION OF BASIC SLAG ON THE ACIDITY OF THE SOIL AS MEASURED BY THE 'LIME REQUIREMENT' AND HYDROGEN ION CONCENTRATES OF THE SOIL

It is a matter of common knowledge that clovers, particularly wild white clover, are very sensitive to what is vaguely called soil acidity. The extent to which the clover plant is able to persist on a 'sour' soil probably depends, however, not only upon the degree of acidity as measured by the soil lime requirements, but upon such other factors as climatic conditions and the water holding capacity of the soil.

On the Harpenden Common, Hutchinson and MacLennan[1] found that wild white clover persisted where the soil had a lime requirement of ·22 %, and they illustrate this by the following table.

TABLE L. RELATION OF LIME REQUIREMENTS OF THE SOIL TO THE VEGETATION ON HARPENDEN COMMON

Average lime requirement of soil			Dominant flora
Approx.	0·22 %	$CaCO_3$	Wild white clover
,,	0·26	,,	Fescues
,,	0·31	,,	Mixed; yarrow, woodrush and moss
,,	0·39	,,	Gorse
,,	0·43	,,	Yorkshire fog
,,	0·53	,,	Sorrel

The botanical analyses of the hay at the various Essex experimental centres shows that on poor heavy clay soils basic slag is able to induce a vigorous growth of clover even if the soil has as high a lime requirement as ·45 %. The ability of the clovers to persist on such sour soils is, however, in Essex at any rate to a great extent dependent upon the distribution of the rainfall.

A comparison of Tables XXXII and XXXIII shows that during a moist growing season clovers form a large proportion of the hay crop on the basic slag plots, even when the soil has as high a lime requirement as ·45 %. On a dry season, however, clovers are absent

[1] *Journal of Agric. Science*, VII. p. 102.

from the hay crops on all soils with a lime requirement between ·13 and ·45 %, but are present on meadows which contain a small reserve of calcium carbonate, and whose lime requirement is negligible. The absence of clover (which 'fills up the bottom') during a dry season adversely affects the yield of hay, and any factors which tend to produce conditions unfavourable to the clover plant obviously limit the yield.

The acidity of the soil as measured by its 'lime requirement' does therefore to some extent limit the action of basic slag, and it becomes of importance to ascertain to what extent the application of basic slag affects favourably or unfavourably the acidity of the soil.

TABLE LI. LIME REQUIREMENT AND PH. VALUE OF THE SOILS IN THE BASIC SLAG AND UNTREATED SOILS AT THE VARIOUS EXPERIMENTAL CENTRES

Centre	9 inches samples		Ph. value		3 inches samples	
	Lime requirement				Lime requirement	
	Basic slag %	Untreated %	Basic slag	Untreated	Basic slag %	Untreated %
Tysea Hill	·30	·29	6·2	6·2	·35	·31
Martin's Hearne ...	·29	·27	6·3	6·2	—	—
Farnham	·01	·00	7·4	7·5	·03	·04
Latchingdon ...	·04	·03	7·5	7·6	—	·13

Samples of soil to a depth of nine inches and three inches were removed from the basic slag and untreated plots at several of the experimental centres during October 1919. The lime requirements of all the soils were ascertained and in some cases the Ph. value also. The results are set out in Table LI.

In every case the lime requirement figures are higher for the soil on the basic slag plots than on the untreated, and although the differences are not great, they suggest that the application of even a heavy dressing of basic slag is not sufficient to counteract the acidity which develops from the decaying organic matter which accumulates on such plots. The Ph. values also show but small differences, and with one exception, namely, the soils from Martin's Hearne, they confirm the lime requirement figures and indicate a tendency towards greater acidity on the basic slag plots.

As it seemed probable that the continued use of basic slag over a long period of years would accentuate this tendency, samples of soil were secured from Plots 4, 6 and 8 at Tree Field, Cockle Park, through the courtesy of Professor Gilchrist, and the lime requirement of the soil determined with the results given in Table LII.

The acidity of the soil on Plot 4 is quite appreciably greater than on the untreated plot in spite of the fact that it has received, during the twenty-four years the experiment has been in progress, a total dressing of about two tons of basic slag to the acre. The botanical analyses of the hay from Plot 4 show moreover that it is not possible to maintain a permanent bottom of clover on this plot, and were it not for the comparison with Plot 8, it might reasonably be assumed that the sourness of the soil was responsible for the partial failure of the clover plant. Plot 8, however, has received a dressing of lime

TABLE LII. LIME REQUIREMENT OF SOIL SAMPLES FOR PLOTS 4, 6 AND 8 AT TREE FIELD, COCKLE PARK

Soil Samples taken 1919

Plot	TREATMENT (Dressing of phosphate equivalent to 100 lbs. P_2O_5 per acre)	Lime requirement $CaCO_3$ %	$CaCO_3$ content of soil %
4	5 cwts. of basic slag every three years (1897–1919). Last dressing 1918	0·23	0·00
6	Untreated	0·20	0·028
8	Superphosphate + 10 cwts. ground lime every three years (1897–1905). 5 cwts. basic slag + 1 ton ground lime every three years (1905–1919). Last dressing 1918	0·07	0·29

every three years since 1897, and since 1905 each application has been at the rate of 1 ton per acre, the plot receiving in the form of basic slag the same amount of phosphate as has been applied to Plot 4. In all five tons of lime have been applied to the plot, more than four times the amount required to satisfy the lime requirement of Plot 4. There is now a small reserve of calcium carbonate in the soil on Plot 8, but in spite of this fact the soil has still a small 'lime requirement' and neither the crop nor the herbage are any better than on Plot 4.

It seems fair to conclude from this evidence that the continued application of heavy dressings of basic slag over intervals of three years does not suffice to supply the lime requirement of heavy clay soils under grass. On the contrary the results indicate that such soils are liable to become even more sour than similar soil left untreated.

Although on sour clay soils basic slag fails to maintain a permanent plant of clover, yet the addition of heavy dressings of lime fails to improve matters in this respect. At Cockle Park, a more vigorous growth of clover follows each successive dressing of slag, whilst in Essex on soils well supplied with calcium carbonate there is no difficulty in maintaining a permanent bottom of clover by the application of phosphates. (See results from Saffron Walden.)

Why the Clover Plant Fails at Cockle Park

The most important conditions necessary for the proper growth and development of the clover plant in conjunction with the various grasses are:

1. A suitable supply of phosphate.
2. A suitable supply of potash.
3. The presence of calcium carbonate in the soil.
4. Constant grazing to prevent the grasses shutting out the light and air, and thereby choking out the clover plant.

At Cockle Park the plots have been grazed by sheep annually, so that the conditions in this respect are the most favourable possible for the permanent establishment of a bottom of clover. Potash in addition to basic slag on Plot 7 has not materially increased the returns, nor has it benefited the clover plant, and as has been indicated previously, no better results have attended the addition on Plot 8 of ground lime to the standard dressing of basic slag.

A comparatively heavy dressing of phosphates (equivalent to 100 lbs. P_2O_5 per acre) has been given to Plot 4 every three years and it would seem scarcely probable that a lack of phosphate was the cause of the wild white clover plant being unable permanently to establish itself. Nevertheless, if the botanical composition of the herbage is examined over a period of years, it will be noted that following every dressing of basic slag there is a marked response by the clover plant. The results on Plot 8 apparently preclude any possibility of the lime in the basic slag being responsible for the improvement. By a process of elimination one is forced to conclude that the various dressings of basic slag have never sufficed to meet the need for phosphates, and that at Cockle Park the level of production could be still further raised by increasing the dressing of phosphoric acid or by repeating the present standard dressing at more frequent intervals.

With the object of obtaining more precise information on this point, the total phosphoric acid in the soils from Plots 4, 6 and 8 was determined with the following results:

	1919
Plot 4	·088 % P_2O_5
„ 6	·052 „
„ 8	·076 „

Plot 6 untreated at the beginning of the experiment contained ·071 % of phosphoric acid. Plots 4 and 8 have each received 800 lbs. of phosphoric acid during the period of the experiment, sufficient, were there no losses, to raise the soil content of phosphoric acid to ·107 %. Although the soil samples were removed less than two years after the previous dressing of basic slag had been supplied, it will

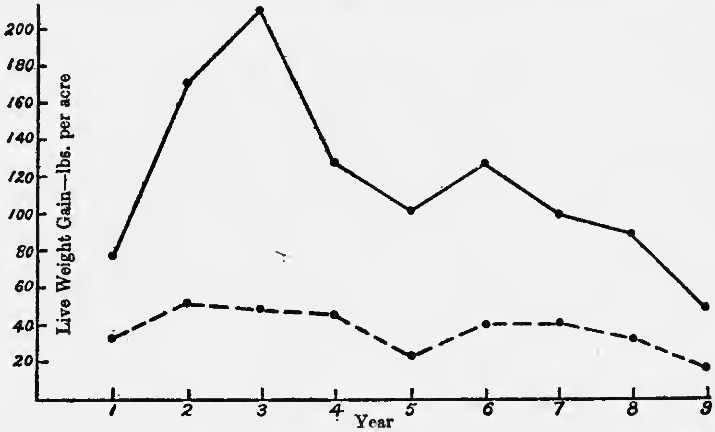


Fig. 27. Live Weight Gains on Basic Slag and Untreated Plots at Cockle Park. First Period, 1897–1905. Basic Slag Plot (3)———. Untreated Plot (6)— — — —.

be noted that the content of phosphoric acid in the soil on Plot 8 is little better than at the beginning of the experiment, and that the reserve of phosphoric acid in the soil from Plot 4 is much less than might have been anticipated. If the suggestion that phosphoric acid is still the limiting factor is correct, it would be natural to expect Plot 4 to give superior results to Plot 8. This is in fact the case (13), and the inferiority of this latter plot over Plot 5 is not due to the depressing effect of lime on the live weight gain, but to the fact that the soil on this particular plot contains a smaller supply of phosphoric acid than on Plot 4.

If the increase in live weight gain from Plot 3* over Plot 6 at Cockle Park during the period of the experiment is plotted out as is done in

* Receives 200 lbs. of phosphoric acid as Basic Slag every six years.

Figs. 27 and 28, it will be seen that each successive application of basic slag results in a big increase in live weight gain during the two seasons following its application. Thereafter the live weight increases rapidly decline until a fresh dressing is applied, clearly indicating that during the third, fourth, fifth and sixth seasons following the application of the heavier dressings of basic slag bigger returns could be obtained by a further dressing of phosphates. Gilchrist (14) and Somerville (29) have pointed out that far from there being a falling off in the response to basic slag at Cockle Park, the live weight gains are gradually increasing over each six year period. The improvement is slow, but it is due to the very slow building up of the phosphoric

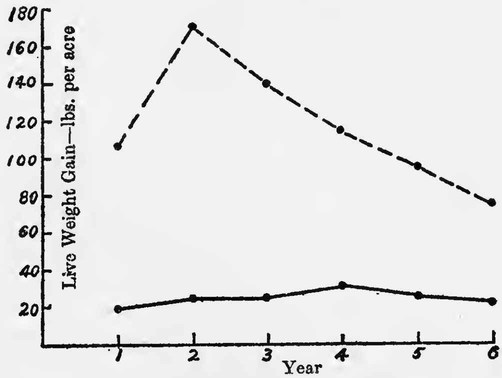


FIG. 28. Live Weight Gains on Basic Slag and Untreated Plots at Cockle Park. Second Period, 1906–1911. Untreated Plot————. Basic Slag Plot — — — —.

acid content of the soil. Such a result serves to confirm the conclusion that phosphoric acid is still the limiting factor at Cockle Park, and that until the demand for phosphates is satisfied it will not be possible to establish a permanent plant of clover and no improvement in the condition of the clover plant or in the live weight gains can be anticipated by either the addition of lime or of potash.

WHY THE CLOVER FAILS ON SOME PASTURES IN ESSEX DURING THE DRY SEASON

If the failure to secure a permanent bottom of clover on Tree Field at Cockle Park is due to an inadequate supply of phosphates in the soil, such is not the case at the experimental centres in Essex where this difficulty has been experienced.

An inspection of Fig. 26 shows quite convincingly that at Martin's Hearne and Tysea Hill phosphoric acid is no longer a limiting factor on the treated plots. A chemical analysis of the treated soils, moreover, reveals the fact that even after four years one-half of the original dressing of 200 lbs. of phosphoric acid is still to be found in the first nine inches of soil. Table LIII gives the total and available phosphoric acid found in the soil from the basic slag and untreated plots during the autumn of 1919. By assuming that one acre of soil to the depth of 9 inches weighs 1000 tons, the actual quantity of available phosphoric acid in the two plots has been calculated, and the excess in the basic slag plot taken to represent the amount of the original dressing still left in the soil.

TABLE LIII. TOTAL AND AVAILABLE PHOSPHORIC ACID IN THE SOIL FROM BASIC SLAG AND UNTREATED PLOTS, IN THE AUTUMN OF 1919

Samples taken Autumn of 1919	BUTTERFIELDS, LATCHINGDON. Manures sown winter of 1915–16		MARTIN'S HEARNE. Manures sown winter of 1916–17		TYSEA HILL. Manures sown winter of 1915–16		HORNDON. Manures sown Feb. 1918	
	Basic slag	Untreated	Basic slag	Untreated	Basic slag	Untreated	Super. and lime, 15	Untreated, 16
	%	%	%	%	%	%	%	%
Total P_2O_5 ...	·088	·077	·101	·089	·109	·101	·082	·078
Available P_2O_5	·0134	·0066	·0108	·0046	·0102	·0051	·0106	·0030
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Amount of P_2O_5 added ...	200	—	200	—	200	—	200	—
Amount found in citric acid solution ...	300·2	147·8	241·9	103·0	228·5	114·2	237·4	67·2
Excess of available phosphoric acid	152·4	—	138·9	—	114·3	—	170·2	—

The above table shows that from a half to three-quarters of the original dressing of 200 lbs. of phosphoric acid still remains in the soil in an available form, and such results but confirm the conclusion that lack of phosphates can not be the cause of the clover failing at Martin's Hearne and Tysea Hill during the dry season of 1919.

The application of lime at Tysea Hill and Martin's Hearne at the rate of 35 cwts. per acre of ground lime is more than sufficient to satisfy the lime requirements of these soils, and it would be reasonable to expect that if soil sourness is the only limiting factor to the growth of clover, a pronounced improvement in this respect will follow the application of such a dressing.

Throughout the whole of the 1920 season the plots were examined carefully every week. At Tysea Hill clovers were practically absent from the limed and unlimed portions of the plots, and it was quite obvious that some other factor than lime and phosphates was preventing the development of clovers.

At Martin's Hearne there was a good bottom of clover on all the plots although it was not so good as in 1918 (see Plate IV), and no improvement in this respect was evident on those portions receiving a dressing of lime.

TABLE LIV. BOTANICAL ANALYSIS OF THE HAY ON LIMED AND UNLIMED PLOTS AT TYSEA HILL AND MARTIN'S HEARNE

TYSEA HILL

	Per cent. of Clovers in the Hay by weight				
	Plot 1 Basic slag	Plot 2 Gafsa rock phosphate	Plot 3 Untreated	Plot 7 Untreated	Plot 10 Open hearth slag light dressing
Unlimed portions of plot ...	5·9	4·4	4·4	0·8	3·8
Limed portions	8·5	6·4	7·1	2·6	—

MARTIN'S HEARNE

	Per cent. of Clovers in the Hay by weight		
	Plot 2 Basic slag	Plot 3 Untreated	Plot 4 Gafsa phosphate
Unlimed portions ...	27·5	11·2*	35·0
Limed portions ...	18·7	7·2*	20·0

* Mostly purple vetch and bird's-foot trefoil. Less than 3 % clovers.

These observations were fully borne out by the botanical analysis of the hay at both centres on the unlimed and limed portions of the various plots. The figures are given in Table LIV.

Whether the application of lime will enable the clovers to maintain their position at Martin's Hearne remains to be seen. If they fail in a dry season as was the case in 1919, then clearly some other essential, probably potash, is the factor limiting their growth.

There can be little doubt that at Tysea Hill no further improvement in the yield or quality of the hay can be secured without the application of potash, and that neither lime nor phosphates nor a combination of the two will suffice to maintain a permanent bottom of clover.

One other result calls for explanation. The superphosphate plot at Horndon, in spite of the fact that the soil contains a small reserve of calcium carbonate, has never held the same bottom of clover as any of the basic phosphate plots (see Plate VII and Fig. 11). Samples of soil were drawn in the autumn of 1919 from this plot, and from Plot 15, which received the same dressing of superphosphate (200 lbs. P_2O_5 per acre), and in addition 1 ton of lime per acre. On both samples the amount of citric soluble phosphoric acid and the lime requirement were determined, the results being as follows:

	Plot 13 Superphosphate %	Plot 15 Superphosphate and lime %
Total phosphoric acid	·084	·082
Available phosphoric acid ...	·0046	·0106
Lime requirement	·10	·05
Calcium carbonate	·00	·13

The figures indicate that the inability of the clover to grow so vigorously on Plot 13 as on Plot 15 is not caused by sourness alone, but is mainly due to the phosphoric acid having been retained by the soil in a more unavailable form than is the case on Plot 15.

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INDEX

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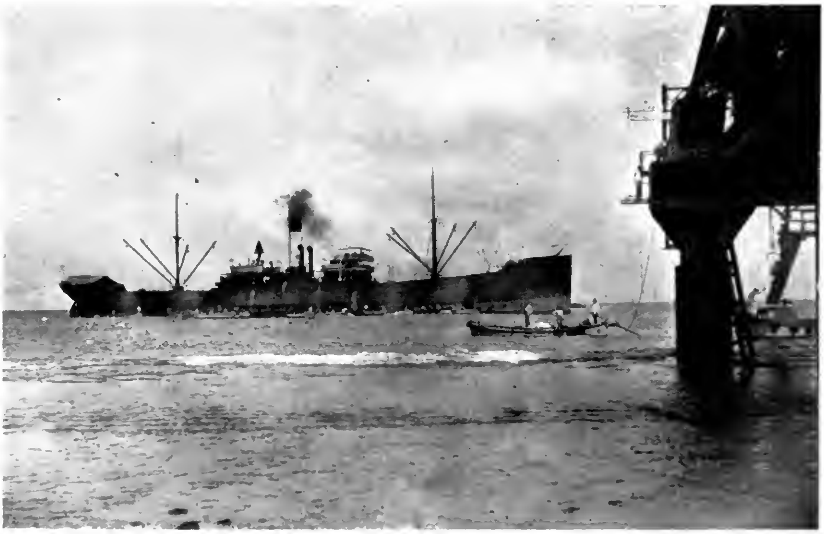
Pouring Slag and Metal from Basic Open Hearth Furnace. The molten slag is seen overflowing from the steel ladle into the slag ladle.



Nauru Island. Shipping phosphate in bulk from Nauru Island. The phosphate has to be lightered off in surf-boats—over 1000 tons can be shipped in 9 hours. The steamer is lying in 150 fathoms of water.

PLATE II

Ocean Island Phosphate Workings. Coral pinnacles after most of the phosphate has been removed. A few feet more phosphate available below rail level.

Ocean Island Phosphate Workings. Foreground: Most of the phosphate has been removed exposing the coral limestone pinnacles. Background: Phosphate deposit is intact and exists mostly in the form of gravel with occasional large boulders of phosphate rock.

Coco-nut and other vegetation all growing in phosphate.

Plot 1. Open Hearth Fluorspar Basic Slag. Martin's Hearne. June 3rd, 1918.

Plot 2. Open Hearth High Citric Soluble Basic Slag. Martin's Hearne. June 3rd, 1918.

Plot 3. Untreated. Martin's Hearne. June 3rd, 1918.

Plot 4. Gafsa Rock Phosphate. Martin's Hearne. June 3rd, 1918.

Section of the Soil at Hassobury showing the presence of chalk about 3 feet below the surface. (Photograph taken from the ditch at the bottom of the experimental field.)

View looking down Untreated Plot K. Horndon. July 1920.

View looking down Cleveland Phosphate Plot H. Horndon. July 1920.

Basic Slag plot at Horndon. August 1919.

Untreated plot at Horndon. August 1919.

Gafsa Rock Phosphate plot at Horndon. August 1919.

Photograph of chalk pit at Saffron Walden illustrating character of soil at Wendens' Experimental Centre.