ROTHAMSTED RESEARCH

Mechanization and British Agriculture

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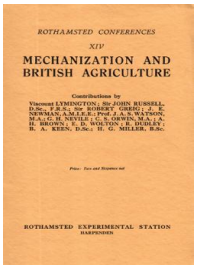

The Maintenance of Soil Fertility Under Mechanized Farming Systems

Sir E. J. Russell

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THE EFFECT OF MECHANIZATION ON SOIL FERTILITY

By Sir E. J. RUSSELL.

Under the old four or five course rotation the fertility of the soil was maintained by four different processes :

(1) the straw was converted into farmyard manure.
(2) clover was grown once in four years, as far as possible ;
(3) the roots and the aftermath of clover were fed off on the land by sheep which received purchased feeding stuffs ;
(4) artificial fertilisers were given in the root break and sometimes also to each crop.

These four methods when properly worked sufficed to keep the land permanently in a good state of fertility.

On a four course rotation per 100 acres of arable land the annual yield of straw would be of the order of 80 tons, producing about 300 tons of farmyard manure and this would give a dressing of 10 tons per acre to the roots and leave a little over for the " waistcoat " of dung which the old farmers like to give to a piece of backward wheat. The dung together with the feeding of the roots and the aftermath on the land ensured a dressing of animal manure for almost every crop.

The reduction of the root area, and in the amount of sheep feeding on the land, has greatly reduced the amount of animal manure available and also it has reduced the amount of treading which the land receives.

Further, the change in method of feeding animals, whereby more use is made of grass and less of arable land, greatly diminishes the amount of farmyard manure available. We do not yet know whether farmers can afford to continue an exclusive grass system for live stock, with the resulting glut of fat stock in autumn and consequent low prices. But we have to reckon with a continuance of the system because of its cheapness and we must assume that the glut will be remedied by the simple expedient of lessened production.

These tendencies become more and more intensified as mechanization advances. It is, as Prof. Watson shows (p. 27) quite possible to combine a considerable degree of mechanization with live stock farming, as indeed we are doing on the Rothamsted farm, but we must recognise that over large parts of the eastern and south-eastern counties live stock and arable farming do not now work together

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as economically as they did, and farmers are now trying instead machines and arable farming, in the hope of reducing their financial losses.

The problem thus arises: can fertility be maintained on an arable farm without the dressings of animal manure formerly given?

For some years past we have been engaged on this subject at Rothamsted and a considerable amount of information has now been obtained. We find that the importance of animal manure depends on the kind of crop.

Cereals

Wheat.—Our experiments on wheat have gone on ever since 1843, but in recent years they have been extended to deal more fully with this problem. The experiments show that yields of the order of 30 to 40 bushels can be obtained by the use of artificial fertilisers only, and without any organic manure so long as the cultivation processes keep the land free of weeds. The results are confirmed by the practical experience of John Prout of Sawbridgeworth, Essex, who, with his son William Prout, as a profitable commercial venture grew large acreages of wheat almost continuously from 1861 to 1911 on purely mechanized lines—one of the first examples of mechanization in this country. He occasionally took a red clover crop, but it is not at all clear that this was necessary although it was probably an advantage. He used no farmyard manure but artificials only, and his scheme of manuring was based on the recommendations of Dr. Augustus Voelcker, father of our present Dr. Voelcker[1]. There was no sign of deterioration of yield: for the first 19 years (1862–1880) it had been 32 to 36 bushels per acre, and for the 25 years 1880–1904 it averaged 35 bushels per acre, with 2 loads of straw. The average price during this second period was 31/9 per qr. for the wheat and 25/- a load for the straw: the average cost of growing (including 25/- per acre rent) was £6 8s.: the average return was £9 8s. 10d., leaving an average profit of £3 0s. 10d. So long as the straw was saleable at 25/- and grain and wages stood at their old levels all went well.

Mr. George Bayliss also grew wheat continuously without farmyard manure, but using a scheme of artificials based on Rothamsted results: here also the process was for many years profitable, and it was all done on purely mechanized lines[2]. Both Mr. Prout and Mr. Bayliss worked in the days of horses, and it was the growing cost of horse labour that finally drove them out of wheat growing. It is possible that they could have continued, had they so desired, by using tractors.

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[1] For full particulars see "Profitable Clay Farming Under a Just System of Tenant Right," John Prout, 1881; and for the later years, W. A. Prout and J. A. Voelcker, Jour. Roy. Agric. Soc., 1905, *66*, 35.

[2] Described by C. S. Orwin, "Progress in English Farming Systems. III. A Specialist in Arable Farming." Oxford, 1930.

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Barley, like wheat, is independent of farmyard manure and can be grown quite well with artificials alone. It was indeed included in the schemes of Mr. Prout and of Mr. Bayliss.

Our experience at Rothamsted has, however, brought out one important result which holds both for wheat and for barley: farmyard manure steadies the yield, and saves it from dropping so low in bad seasons as it is liable to do when artificials alone are given. Some of the results are given in Table I. This is generally true of all crops and it is one of the good qualities of farmyard manure not easily reproducible by artificials.

TABLE I.

FARMYARD MANURE COMPARED WITH ARTIFICIALS FOR WHEAT. BROADBALK FIELD, WHEAT EVERY YEAR, 1852–1930.

Plot No.	*Annual Manuring.*	*Average Yield. Bushels per acre.*	*Average difference between one year and the next. Bushels per acre.*	*Average difference as percentage of average yield.*
3	Unmanured ..	11.7	4.0	34.5
8B	Complete Artificials	34.5	9.3	26.8
2B	Farmyard manure	33.5	7.0	20.8

The general conclusion is that wheat and barley could perfectly well be grown with artificial fertilisers alone, and without farmyard manure, but at a risk of some depression of yield in bad seasons. This difficulty can be mitigated by using larger quantities of artificials, but we have no evidence that it is much affected by ploughing in occasional clover leys. (Table V).

Potatoes and Sugar Beet need farmyard manure or similar material

When we come to potatoes and sugar beet, however, the case is entirely different. It is not usually possible to obtain with artificials alone as good yields as when farmyard manure is used. Smaller dressings of farmyard manure can be given when necessary, but in that case the dressings of artificials should be increased, especially the potassic fertiliser. Examples from our results are given in Table II.

Mangolds and Swedes

Mangolds come into rather a different group. So long as yields of only about 25-30 tons per acre are produced, these can be obtained almost as well by artificials supplemented with rape dust or similar organic as by farmyard manure, and the cropping can be on the

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TABLE II.

FARMYARD MANURE COMPARED WITH ARTIFICIALS. LITTLE HOOS FIELD.

	Potatoes.—Tons per acre.		*Roots—Tons per acre.*							
			Mangolds.				*Swedes.*			
	Dung and Complete Artificials	Complete Artificials (larger quantity) without dung	Year	Rich Dung	Poor Dung	Complete Artificials	Year	Rich Dung	Poor Dung	Complete Artificials
Rothamsted—										
1921	3.6	3.8	1906	25.6	18.2	24.1	1904	15.7	13.1	12.2
1922	9.4	8.4	1911	17.1	15.8	14.2	1908	22.4	19.1	16.9
1922	9.4	8.3	1915	15.5	13.5	7.2	1920	21.7	18.4	16.3
1923	12.2	12.0					1926	21.1	21.8	15.5
1924	9.0	7.5								
Average	8.7	8.0	*Average*	19.3	15.8	15.2		20.2	18.1	15.2
*Seale Hayne** 1927	7.61	6.45								

* Equivalent artificials.

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same land year after year. Our Barnfield has carried mangolds every year since 1876 excepting in two years 1908 and 1927 when the crop failed owing to bad weather.

The average yield for 50 years 1876–1928 has been, on plots receiving the best combination of artificials, in tons per acre :

	Artificials alone. Plot 4N (*b*)	*Artificials with Rape dust.* Plot 4 AC	*Artificials with farmyard manure.* Plot 2AC
Roots ..	17.8	26.1	27.6
Leaves ..	4.1	5.3	6.3

Where higher yields of 40 to 50 tons per acre are desired it may be essential to use farmyard manure.

Swedes can do without farmyard manure in regions where yields are normally only about 15 tons per acre or less : where higher yields are possible farmyard manure is required.

The return of the Straw to the Land

So long as any form of indoor winter feeding of animals remains profitable the straw can be made into farmyard manure, and this is the best way of using it. But if as commonly happens, the winter feeding is itself unprofitable one cannot charge the animals with much for the farmyard manure : at present prices of artificials I should not be disposed to allow more than 10/- per ton for farmyard manure. It is very easy nowadays to lose money over winter feeding.

For some years past at Rothamsted we have been trying to use the straw in some other way. Three methods have been tried.

(1) The straw has been ploughed direct under the ground. The immediate effect of this is to reduce the amount of available plant food in the soil because the micro-organisms that decompose the straw feed on nitrate and phosphate, just like plants, and so take up for themselves what the plant ought to have had. This does not much matter in the autumn, when the plant food might be washed out if the micro-organisms did not take it, but it is a serious loss in the spring when the young plant is ready for food. So far as our older experiments went—they were done on Broadbalk—the ploughing in of the straw even in the autumn was useful only on land short of potash and here its effect was very slight. The experiment is being repeated on broader lines to see if this is the general rule.

(2) A more useful method, which has been widely adopted in many countries by farmers who do not practise animal husbandry, is to treat the straw with the necessary food for the micro-organisms so that they can decompose it before it gets into the soil. This is the basis of the so-called Adco process, discovered at Rothamsted and developed on the large scale by the Adco Syndicate, Harpenden.

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The resulting manure is quite good : some of their results are given in Table III. The practical difficulty on an English farm is usually to supply the water to wet the straw.

(3) A method now being tried at Rothamsted is to leave the straw on the ground and in autumn to drill over it a mixture of complete artificials, then to plough it under and let it rot.

In order to compare straw treated in these last two methods with farmyard manure a rotation was started on Hoos field in 1930, and is to continue for many years, in which the following are compared :

Farmyard manure.
Straw treated by the Adco process.
Straw left on ground, treated with artificials and ploughed in.
Complete artificials.

For the first two crops the two treated straws seem to be comparing very favourably with farmyard manure but we shall not be in a position to speak definitely about this till the experiment has run on for a longer period.

TABLE III.

CONVERSION OF STRAW INTO MANURE : FARMYARD MANURE AND ADCO.

YIELDS PER ACRE.

	Rothamsted, 1930.				Orsett, Essex.	Wye, Kent.
	Wheat. Cwt. per acre.	*Barley. Cwt. per acre.*	*Turnips. Tons per acre.*	*Seeds* Hay. Cwt. per acre.*	*Potatoes§ Tons per acre.*	*Mangolds§ Tons per acre.*
Adco ..	17.2	22.8	9.7	27.9	12.6	21.5
Farmyard Manure ..	15.9	16.2	9.0	22.5	11.9	21.0
Artificials alone ..	19.8	21.3	9.5	21.8	10.1	19.0
No Manure	14.7	11.8	4.2	10.9	—	17.5

* As dry matter.

§ Artificials added to the farmyard manure and the Adco.

Green Manuring

This is a very promising method of supplying organic matter to the soil ; it is, however, more difficult than is usually supposed.

In the older farming systems it was common to grow a mustard, tares or other crop and either feed them to sheep on the land or, if they were not wanted for the sheep, to plough them in as green

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manure. Many farmers however sowed the crop even when there was no likelihood of it being wanted for the animals : it was ploughed in. This green manuring is a recognised practise on light land.

The first serious tests in this country were made with mustard and tares at the Woburn Experimental farm, then under the Royal Agricultural Society, now part of the Rothamsted organisation. The soil is light, and was expected to respond well to green manuring but it did not : the green manure was entirely without effect.

For a long time this result was regarded as exceptional due to some undiscovered peculiarity. In 1920 and 1921, however, the Rothamsted workers, H. J. Page and his colleagues, made a number of experiments here and in different parts of England by aid of a grant from the Research Fund of the Royal Agricultural Society and only in few of these was green manuring successful.

Yet there is no denying that many farmers have obtained very good results with green manuring.

The subject has recently been fully examined at Rothamsted and an explanation of the discrepancy can now be given. Green manuring succeeds only when the time of ploughing in the green crop fits in with the time of sowing of the next one. The green crop must be allowed sufficient time to decompose and produce nitrates, but the following crop must be ready to take up the nitrate before it is washed out from the soil. Those farmers who succeeded with green manuring had got the timing right : others had not. Further experiments are being made to find out more precisely how to work out the timing but meanwhile green manuring should not be trusted blindly. If it is succeeding that is proof of correct timing, but if it is not known to be successful the timing should be looked into. Once this is right, however, green manuring becomes a valuable aid to mechanized farming.

The ploughing in of a clover ley in September in preparation for wheat in October seems usually to be successful, while the ploughing in of the June clover crop instead of cutting it, followed by a bastard fallow during July, August and September is probably the most satisfactory of all methods of keeping up fertility on a mechanized cereal farm, so long as *July, August and September are dry*. But if these months be wet most of the advantage may be lost. Green manuring is by no means entirely safe.

Fallowing

Recent Rothamsted experiments have shown that the old problem of the fallow is by no means cleared up. The Broadbalk wheat field has carried wheat every year since 1843 : never has there been a complete break. In 1926 and 1927, however, part of the field was fallowed : in 1928 the wheat grown after the two years fallow gave extraordinary yields.

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	Plot.	1928.		Average 77 years, 1852–1928.	
		Grain. Bushels per acre.	*Straw. Cwt. per acre.*	*Grain. Bushels per acre.*	*Straw. Cwt. per acre.*
No manure since 1839	3	27.9	27.8	11.8	9.9
Complete artificials ..	13	55.2	32.0	29.2	30.8
No potash	11	56.9	31.4	21.4	21.8
No potash or phosphate	10	47.0	25.8	18.8	18.1
No nitrogen	5	35.2	34.8	13.6	10.6
Farmyard manure ..	2B	48.4	61.4	33.2	34.5

The result was a remarkable increase in the yield of grain. Never in the 86 years of successive wheat growing had Broadbalk grown a crop so thick set with grain, and we are unable at present to explain it. The season was very favourable, but probably not more so than some of the great wheat seasons of the past, 1854, 1857, 1863 1894, yet in none of these was so much grain produced. Much of the effect is probably attributable to the fallow, but whether the action is the suppression of weeds, the decomposition of vegetable and other matter, or some physical change in the soil, we cannot decide. Something more seems to be involved than an increase in plant nutrients, for no fertiliser scheme we have yet tested produces so remarkable a result. The effect lasted only one year, however ; the 1929 yield was about 10 per cent. below the average for the 74 years while in 1930 it had fallen about 40 per cent. below the average.

Even the sandy soil at Woburn was greatly improved for barley, but not so much for wheat, by two years fallowing ; the results, however, were not nearly so striking as on Broadbalk.

Under mechanized conditions fallowing would become relatively inexpensive and could therefore be practised. Our experiments suggest that a two year fallow may be much more effective than one year. The unmanured land on Hoos field gave in 1928 after one year's fallow only 10.5 bushels instead of the 28 bushels after the two years' fallow on Broadbalk. The subject is being further studied.

The effect of fallowing depends a great deal on the weather : crops following a fallow are therefore liable to greater variations in yield than those following another crop. This is well shown by comparing the wheat yield on Broadbalk where wheat always follows wheat, with the yield on Hoosfield where it follows a fallow : the average yield is raised by the fallow, but so also is the variation from season to season. (Table IV).

The "Golden Hoof" on Sandy Soil

It is a commonplace that light soils are improved by the folding of sheep, both the manuring and the treading being important. Apparently the manuring can be satisfactorily imitated but so far the treading cannot. Experiments at Woburn showed that the

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compacting of the soil by sheep is different from that produced by implements; it extends to a greater depth and lasts longer; the top three inches of the soil is mainly affected. It also gives a coarser tilth. In the experiments so far made it did not increase the water holding power of the soil, indeed, the trodden part was, if anything, somewhat drier than the cultivated part: the work, however, is being continued.

TABLE IV.

EFFECT OF ONE YEAR'S FALLOW ON SUCCEEDING WHEAT CROP. HOOSFIELD. ALTERNATE WHEAT AND FALLOW (NO MANURE). DRESSED GRAIN IN BUSHELS PER ACRE.

	Mean Yield.	*Average difference between one crop and the next.*	*Average difference as percentage of Mean Yield.*
After fallow in 1857, 1859 and alternate years to present time	14.2	7.4	52.2
After previous wheat crop, Broadbalk ..	11.7	4.1	35.1
After fallow in 1856, 1858 and alternate years to present time	14.2	5.9	41.4
After previous wheat crop, Broadbalk ..	11.7	3.4	29.5

TABLE V. COMPARISON OF CLOVER LEY WITH FALLOW AS PREPARATION FOR WHEAT.

AGDELL. FOUR COURSE ROTATION. WHEAT.

DRESSED GRAIN IN BUSHELS PER ACRE.

Plot No.	*Treatment.*	*Mean Yield.*	*Average difference between one crop and the next.*	*Average difference as per centage of Mean Yield.*
5	Unmanured, after fallow ..	24.0	9.5	39.4
6	,, ,, clover ..	22.3	9.6	42.9
	After wheat, Broadbalk ..	11.7	2.9	24.6
1	*Complete Artificials*—			
	After fallow	28.9	10.0	34.5
2	After clover	30.4	10.9	35.8
	After wheat, Broadbalk ..	34.5	7.2	20.8
	Minerals only—			
3	After fallow	28.1	9.2	32.9
4	,, clover	30.6	10.4	33.8
	,, wheat, Broadbalk ..	13.5	4.8	35.2

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Conclusions

(1) For cereals no difficulty need be feared in keeping up soil fertility by artificial manures alone: farmyard manure is not essential. Artificials, however, are apt to give smaller yields in bad seasons than farmyard manure, though they may give better yields than it does in good seasons. Their range of yield is higher.

(2) Potatoes and sugar beet require for the best results farmyard manure or something that has the same action in the soil.

(3) Mangolds up to about 25 tons per acre can be produced without farmyard manure by using artificials and rape dust or similar substance. We have done this regularly on the same land each year ever since 1876. Larger crops probably require farmyard manure.

(4) Swedes up to 15 or 20 tons can be produced without farmyard manure: where larger crops are possible they probably require farmyard manure.

(5) Where animals are not kept it is possible to convert the straw into an effective manure by the treatment discovered at Rothamsted and taken over by the Adco Syndicate, Harpenden.

Experiments are being made with an alternative method of leaving the straw on the ground, drilling artificials on top of it, and ploughing the whole lot under.

The ploughing under of the straw by itself has not so far given satisfactory results.

(6) Green manuring as an alternative to farmyard manure is more difficult to practise successfully than is usually supposed: the ploughing in of the green crop has to be so timed that it supplies plant food to the next crop just when the crop needs it and not before, otherwise it is liable to be washed out.

(7) The treading of sheep on light land produces effects which the cultivation implements so far tried do not produce.

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