FIELD EXPERIMENTS ON CONCENTRATED ORGANIC NITROGEN FERTILIZERS

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Many vegetable growers use concentrated organic fertilizers such as hoof meal, horn meal, dried blood and similar materials for supplying nitrogen in preference to inorganic fertilizers. It is thought that organic materials are superior to inorganic salts and that they are almost indispensable if satisfactory crops of certain vegetables are to be grown. Specific advantages claimed for 'organics' are that they do not damage crops when applied carelessly or in excess, that nitrogen is released slowly throughout the growing season just as it is needed by crops, and that they are not removed by leaching and, consequently, have greater residual effects on following crops. It is also suggested that they may maintain or even build up soil organic matter.

Few field experiments have been carried out in this country to compare organic nitrogen fertilizers with inorganic materials. Such comparisons are important, since at the present time many 'organics' are more than three times as expensive per unit of nitrogen as inorganic fertilizers. The work described here was begun in 1941 to test a variety of products designed to improve the fertilizer value of waste leather. This war-time investigation was carried out at the request of the Ministry of Supply with the co-operation of the British Leather Manufacturers' Research Association and the Chemical Research Laboratory at Teddington. Work on leather products was concluded in 1943, but the field experiments were continued as a general investigation on the merits of organic nitrogen fertilizers. Laboratory and glasshouse studies associated with the early work on leather wastes will be described in later papers.

SCOPE OF THE EXPERIMENTS

Materials tested

Brief descriptions and analyses of the tested materials (as used) are given in Table 1.

One sample of leather fertilizer (S 2746) was prepared by a commercial firm by roasting with soda. All other samples were made on a pilot plant scale at the Chemical Research Laboratory. Pure crushed hoof and dried blood were obtained from commercial sources. The formalized casein tested was a waste product from plastics manufacture; in later years a course fraction, obtained by sieving, was compared with finer material. A sample of formalized hoof was prepared on laboratory scale by soaking crushed hoof with 10 % formaldehyde solution for 2 days. This was followed by washing with water during the next 4 days. In all but the first two washings the treated hoof was soaked for several hours before the water was replaced. The formalized hoof was then thoroughly air dried. Both formalized hoof and the course fraction of formalized casein were included in the series to provide materials which were expected to act more slowly than the standard organic fertilizers.

Table 1. *Descriptions of the fertilizers tested*

Reference no.	Description	N (%)
	Leather wastes	
S 2746	Leather roasted commercially with soda	5·8
S 2811	Ground roasted Puritan leather extracted with 2 % Na_2CO_3	8·0
S 2823		8·7
S 3149	Mixed sole leather, extracted with 0·1 N-NaOH and then roasted	11·3
S 3152		11·7
S 3206		12·9
	Dried blood	
N 200	—	13·9
	Crushed hoof (particle size $\frac{1}{8}$–$\frac{1}{4}$ in.)	
S 2790	Pure samples of crushed hoof, uncalcined	15·2
N 202		14·0
N 227		14·0
N 254		14·0
	Formalized hoof	
N 233	Prepared on laboratory scale	14·0
N 234		14·0
N 261		14·0
	Fine formalized casein (85 % less than 2 mm.)	
S 2787	—	12·3
N 204		12·0
N 215		12·0
N 228		10·7
	Coarse formalized casein (all passing 7 mm. sieve, retained on 5 mm. sieve)	
N 215	Prepared from samples of formalized casein by sieving	12·0
N 228		10·7

(The formalized casein material also contain phosphorus equivalent to 3·5–4·0 % P_2O_5.)

Experimental sites and crops

The field experiments were carried out on sites provided at the following centres:

Cleobury Mortimer (Salop), Childe's Council Senior School.

Dulwich, James Allan's Girls' School, East Dulwich Grove, London, S.E. 22.

Norwich, City of Norwich School.

Rickmansworth (Herts), Masonic School.

Rothamsted Experimental Station (old allotment soil).

Studley College, Warwickshire.

Woburn Experimental Station (Beds).

Vegetables had been grown on all sites for a number of years and all the soils, except that at Woburn, contained higher percentages of organic matter than are common on ordinary arable land. At each centre the same site was used for the duration of the experiment, fresh dressings of fertilizers being applied before planting each crop. Common vegetables were grown generally, exceptions being that potatoes were taken at Norwich in 1942 and at Rothamsted in 1948, and that residual effects at the latter centre were measured by growing ryegrass for 3 years after manuring had stopped. The year to year at any one centre. The experimental treatments were arranged in randomized block or Latin-Square layouts. There were three blocks at Rothamsted and Studley, four blocks were laid down at Woburn, Dulwich and Rickmansworth. At Cleobury Mortimer and Norwich 5×5 and 4×4 Latin Squares were used. As land was limited individual plots were small at all centres.

The rates of dressing used for each crop were:

	cwt./acre			
	N			
	1 unit	2 units	P_2O_5	K_2O
Spring- and summer-planted crops				
Leeks	0·6	1·2	0·8	0·8
Lettuce	0·3	0·6	0·75	0·75
Onions	0·5	1·0	1·0	1·0
Potatoes	0·4	0·8	0·8	1·0
Tomatoes	1·0	2·0	1·0	3·0
Brussels sprouts	1·4	2·8	1·0	0·75
Peas	0·2	0·4	0·75	0·75
Autumn-planted crop				
Cabbage	0·6	1·2	0·4	0·5

The organic materials were applied immediately before planting each crop, ammonium sulphate was applied for all spring-planted crops at the same time in one dressing; for autumn-planted cabbage half of the ammonium sulphate was given at planting and half as a top-dressing in spring. Basal dressings of superphosphate and muriate of potash were given to all plots of each experiment immediately before planting at rates suitable for each crop. No allowance was made for the extra phosphorus supplied by the formalized casein. All fertilizer dressings applied before planting were forked into the soil. Since individual plots were small all cultivations were given by hand-tools (except at Woburn), particular care was taken to avoid mixing the soil at plot boundaries. After planting all crops were treated according to normal vegetable-growing practice. They were harvested when ready for market and only yields of total saleable produce are discussed here.

Table 2. *Plot sizes and analyses of the soils used in the field experiments*

	Plot size (acres)	pH	Acid-soluble (mg./100 g.) P	Acid-soluble (mg./100 g.) K	Organic C (%)	N (%)
Cleobury	0·0014	7·5	15	15	3·9	0·37
Dulwich	0·0040	8·2	27	22	3·1	0·29
Norwich	0·0040	7·6	36	18	1·8	0·18
Rickmansworth	0·0022	7·8	28	21	5·7	0·49
Rothamsted	0·0014	7·7	30	19	2·8	0·26
Studley	0·0014	7·8	51	26	2·3	0·23
Woburn	0·0016	6·7	12	13	0·8	0·09

Rothamsted experiment was continued from 1941 to 1953, most of the other experiments carried only three or four consecutive crops. Lettuce (six crops), spring cabbage (five crops) and leeks (six crops) predominated, there were also three experiments on onions, two each on tomatoes and potatoes, one on brussels sprouts and one on peas.

Experimental treatments

In each experiment ammonium sulphate was used as the standard inorganic nitrogen fertilizer; it was applied at 0, 1 and 2 units of N at all centres except Norwich (where a single rate was used), the organic nitrogen fertilizers being applied to supply 2 units of N except at Woburn where 1 and 2 units were given. Crushed hoof was tested in all experiments as a second nitrogen standard, the other materials tested varied at the different centres, and also from

RESULTS OF THE EXPERIMENTS

Due to the limitations of the sites available most of the experiments were rather imprecise. Generally there were significant responses to the fertilizers tested, but there were few significant differences between yields given by the different forms of nitrogen. *Detailed comment on results of individual experiments is only made here where the yield difference exceeds the standard error of the comparison.*

Crushed hoof and fine formalized casein

Mean results of all similar experiments on each crop are stated in Table 3. On average hoof was slightly inferior to ammonium sulphate for cabbage and slightly superior for leeks and lettuce. For onions hoof gave an average yield similar to that given by the half-rate of ammonium sulphate (the full dressing gave a lower mean yield). In two experiments each on tomatoes and potatoes hoof gave slightly lower average yields than ammonium sulphate.

Table 3. *Mean results of all comparable experiments testing ammonium sulphate, hoof and fine formalized casein*

(Yields of total saleable produce (tons/acre))

Crop	No. of expts.	Without nitrogen	With ammonium sulphate		At full rate	
			Half rate	Full rate	With hoof	With casein
Cabbage	5	3·76	6·24	7·08	6·54	6·58
Leeks	4	6·66	9·02	9·60	9·93	10·40
	5	7·09	9·15	9·48	9·78	—
Lettuce	4	11·80	13·99	13·28	13·74	14·02
	6	11·63	13·87	14·17	14·42	—
Onions	3	8·88	11·72	11·24	11·80	11·22
Potatoes	2	10·36	—	15·70	14·57	—
Tomatoes	2	13·98	17·64	18·06	17·04	18·06
Brussels sprouts	1	6·03	6·05	6·98	6·36	6·39
Peas	1	5·70	5·87	6·05	5·84	5·51

Effects of ammonium sulphate, and comparisons of the organic fertilizers with ammonium sulphate are examined in Table 4. The data set out in Table 4 are summarized in Table 5 by stating numbers of positive effects for all experiments having the full set of treatments. The single dressing of ammonium sulphate increased yields of all crops at all centres where it was tested except in the lettuce experiment at Studley (sixteen significant effects). The double dressing gave higher yields in ten experiments out of twenty-one (three significant effects). Hoof was also superior to equivalent ammonium sulphate in half of the experiments, casein was superior to ammonium sulphate in eight out of twenty-one experiments (one significant effect only). There was only one significant difference between yields given by organic nitrogen fertilizers and by ammonium sulphate (formalized casein giving a significantly higher yield of leeks at Rothamsted in 1944). The data in Table 4, therefore, is further summarized in Table 5 by stating for each crop and each comparison the numbers of positive and negative effects which exceed the appropriate standard error (corresponding approximately to $P = 0{\cdot}3$). The experiments do not provide any clear indication of the superiority of 'organics' over 'inorganics', except in some of the experiments where the high rate of ammonium sulphate reduced yields. For crops which had a high requirement for nitrogen and responded well to the second dressing of ammonium sulphate (such as cabbage or potatoes), organic nitrogen fertilizers often tended to give lower yields than equivalent inorganic nitrogen. For other crops which, under the conditions of these experiments, needed less nitrogen and for which the double dressing of ammonium sulphate was not better than the single dressing crushed hoof tended to be superior to equivalent ammonium sulphate.

In later years the experiment at Rothamsted compared ordinary crushed hoof with a product made by treating it with formalin; coarse (5–7 mm.) formalized casein was also compared with ordinary fine formalized casein; the results are summarized in Table 6. None of the differences between yields given by the two forms of hoof, or the two grades of formalized casein were significant. For potatoes in 1948 and for cabbage in 1950 formalized hoof gave markedly higher yields than the unformalized product, coarse casein was notably superior to the fine product for the 1950 cabbage crop.

Leather wastes

Comparisons of yields given by leather wastes with those given by hoof and by ammonium sulphate are made in Table 7. Several batches of leather products were tested in the experiments and there were not sufficient experiments on any one material on each crop to justify the calculation of average yields. One batch (S 2746) was prepared commercially by roasting leather waste with soda; tested in one experiment on cabbage it gave lower yields than ammonium sulphate and was significantly inferior

to crushed hoof. The other materials were made by detanning leather wastes with solutions of alkalis. Three products made in this way gave yields of cabbages similar to those given by ammonium sulphate, but they were inferior to crushed hoof in two experiments. For leeks there were no significant differences between yields given by the N fertilizers tested, but one leather waste (S 2823) gave somewhat higher yields than both ammonium sulphate and hoof meal in experiments at Rothamsted and Studley. Two products (S 2823 and S 3206) gave higher yields of lettuce than ammonium sulphate in two experiments, the differences being significant at Studley. S 3206 also gave a significantly higher yield than hoof at Studley. In one experiment on tomatoes two processed leather wastes (S 2811 and S 3149) gave lower yields than ammonium sulphate.

Comparisons of various batches of leather products with ammonium sulphate and with hoof are summarized in Table 8 for all crops by stating the numbers of positive effects. The earlier products with low percentages of nitrogen were generally less effective than the later products containing more nitrogen. Two materials (S 2823 and S 3206) were each tested in six experiments, they were superior to ammonium sulphate in more than half of the experiments and were roughly equivalent to hoof meal. Leather products were notably inferior to

Table 4. *Unmanured yields of vegetables, gains from ammonium sulphate and comparisons of crushed hoof and formalized casein with ammonium sulphate*

(Yields of total produce in cwt./acre)

Centre and year	Unmanured yield	Gain from ammonium sulphate: At half rate	Gain from ammonium sulphate: From full rate over half rate	Gain over ammonium sulphate from: Hoof	Gain over ammonium sulphate from: Formalized casein	S.E. of increase
Cabbage						
Cleobury, 1942	114	38**	−10	0	−12	11·9
Norwich, 1943	145	—	—	36	—	17·1
Rothamsted, 1942	77	25*	5	20	−2	10·8
Rothamsted, 1943	98	56**	15	−1	8	8·9
Rothamsted, 1948	38	67**	56*	−41	−41	19·5
Rothamsted, 1950	49	62**	18	−33	−3	17·8
Leeks						
Cleobury, 1944	155	3	−3	20	−9	10·8
Dulwich, 1944	176	17	−13	3	—	28·1
Norwich, 1944	152	—	—	−25	2	18·9
Rothamsted, 1944	103	72**	−30	−11	46*	19·9
Rothamsted, 1951	187	90*	89*	−11	31	30·6
Studley, 1943	88	24*	−9	7	−3	8·6
Lettuce						
Cleobury, 1943	414	35	30	−9	15	18·4
Dulwich, 1943	141	41	70	−19	—	44·4
Dulwich, 1944	311	55	21	10	—	36·8
Rothamsted, 1943	186	80**	−58*	36	41	19·9
Rothamsted, 1947	82	71**	−7	−8	−3	22·6
Studley, 1943	261	−10	−23	19	7	13·9
Onions						
Cleobury, 1945	206	39**	−4	18	23	10·7
Rothamsted, 1945	224	76*	−19	6	−20	32·5
Rothamsted, 1949	104	55*	−5	11	−4	18·5
Potatoes						
Norwich, 1942	269	—	—	−10	—	7·7
Rothamsted, 1948	145	104**	71**	−35	−10	19·4
Tomatoes						
Rothamsted, 1942	271	60*	45	−53	−11	26·0
Rothamsted, 1944	288	86**	−28	12	12	19·8
Brussels sprouts						
Rickmansworth, 1942	121	0	19	−12	−12	—
Peas						
Cleobury, 1944	114	3	4	−4	−11	6·8

(Significant effects in this and subsequent tables are marked * for $P = 0{\cdot}05$–$0{\cdot}01$; ** for $P > 0{\cdot}01$.)

ammonium sulphate and to hoof for cabbages. Table 8 also gives the numbers of positive and negative effects which were greater than the appropriate standard error. The only striking effects were the superiority of leather wastes for leeks and lettuce and their inferiority for cabbages and tomatoes.

Dried blood

Dried blood was tested for three crops in the experiment at Dulwich, comparisons with standard materials are given in Table 9. Blood was slightly superior to the other two fertilizers for lettuce grown in 1944 and inferior for the same crop in 1943. This experiment does not provide any sure evidence that blood manure behaves very differently from the other materials tested.

Times of application of nitrogen fertilizers

For crops which mature quickly it is generally satisfactory to apply all nitrogen fertilizers before planting. With longer growing seasons there is risk that inorganic nitrogen may be lost by leaching before it can be used, particularly with crops like spring cabbage which stand through the winter. Two experiments (Rothamsted Experimental Station, 1939–47) carried out on spring cabbage at Woburn are summarized in Table 10. The soil used was a light sand low in organic matter, in contrast most of the other soils used in the work described here were heavy textured and contained considerable amounts of organic matter; for these reasons the Woburn experiments have not been included in the comparisons made above. Hoof meal, two types of detanned leather waste, finely divided formalized casein and also ammonium sulphate were each compared at 0·6 and 1·2 cwt. N/acre. Comparisons were made of ammonium sulphate applied wholly at the time of planting, wholly in spring, and as a split dressing—half at planting and half in spring. Both experiments were rather inaccurate and do not

Table 5. *Numbers of increases in yields of vegetables given by ammonium sulphate and comparisons of hoof and fine formalized casein with ammonium sulphate*

	No. of experiments	Gains in yield from: Low rate of ammonium sulphate	High over low rate of ammonium sulphate	Hoof over ammonium sulphate	Casein over ammonium sulphate
		Numbers of increases in yield			
Cabbage	5	5	4	2	1
Leeks	4	4	1	2	2
Lettuce	4	3	1	2	3
Onions	3	3	0	3	1
Tomatoes	2	2	1	1	1
Potatoes	1	1	1	0	0
Brussels	1	0	1	0	0
Peas	1	1	1	0	0
Total of all crops	21	19	10	10	8

Numbers of increases or decreases exceeding the standard errors of the comparisons

		+	−	+	−	+	−	+	−
Cabbage	5	5	0	3	0	1	2	0	2
Leeks	4	3	0	1	2	1	0	2	0
Lettuce	4	3	0	1	2	2	0	1	0
Onions	3	3	0	0	0	1	0	1	0
Tomatoes	2	2	0	1	1	0	1	0	0
Potatoes	1	1	0	1	0	0	1	0	0
Peas	1	0	0	0	0	0	0	0	1
Total of all crops	20	17	0	7	5	5	4	4	3

Table 6. *Comparisons of formalized and unformalized hoof and of coarse with fine formalized casein at Rothamsted*

(Yields in cwt./acre)

Year	Crop	'Formalized hoof' minus 'hoof'	'Coarse' minus 'fine' casein	S.E.
1948	Cabbage	− 7	−17	19·4
1950	Cabbage	+22	+23	17·8
1949	Onions	− 6	+14	18·5
1948	Potatoes	+20	− 6	19·4
1947	Lettuce	+10	−16	22·6
1951	Leeks	−16	− 6	30·6

Table 7. *Comparisons of yields of vegetables given by processed leather wastes with yields given by ammonium sulphate and by crushed hoof*

Centre and year	Sample no.	Extra yields (in cwt./acre) from leather fertilizers: Over ammonium sulphate	Over hoof	S.E.
		Cabbages		
Rothamsted, 1942	S 2746	−15	−35**	10·8
	S 2811	− 1	−22	
Rothamsted, 1943	S 2823	− 4	− 3	8·9
	S 3206	− 1	0	
Norwich, 1943	S 3206	1	−36	17·1
		Leeks		
Rothamsted, 1944	S 2823	25	36	19·9
	S 3206	1	12	
Studley, 1943	S 2811	− 3	−10	8·6
	S 2823	16	9	
		Lettuce		
Rothamsted, 1943	S 2823	27	− 9	19·9
	S 3206	28	− 8	
Studley, 1943	S 2823	36*	18	13·9
	S 3206	58**	40*	
		Brussels sprouts		
Rickmansworth, 1942	S 3206	− 9	4	—
		Potatoes		
Norwich, 1942	S 2823	1	11	7·7
		Tomatoes		
Rothamsted, 1942	S 2811	−53	0	26·0
	S 3149	−30	24	

Table 8. *Comparisons of processed leather wastes with ammonium sulphate and with crushed hoof for vegetables*

Leather product: Sample no.	N (%)	No. of comparisons	Gain in yield from leather product over: Ammonium sulphate	Hoof
Numbers of positive effects from each batch of leather waste (averaging all crops)				
S 2746	5·8	1	0	0
S 2811	8·0	3	0	0
S 2823	8·7	6	5	4
S 3149	11·3	1	0	1
S 3206	12·9	6	4	3
Numbers of positive effects on each crop (averaging all batches of leather waste)				
Crop				
Cabbage		5	1	0
Leeks		4	3	3
Lettuce		4	4	2
Brussels sprouts		1	0	1
Potatoes		1	1	1
Tomatoes		2	0	1
Numbers of increases or decreases in yield* exceeding the standard error of the comparison				
			+ −	+ −
Cabbage		5	0 0	0 2
Leeks		4	2 0	2 1
Lettuce		4	4 0	2 0
Potatoes		1	0 0	1 0
Tomatoes		2	0 2	0 0
Total of all crops		16	6 2	5 3

(* Excluding the material (S 2746) made by simple roasting.)

provide precise comparisons between the organic fertilizers tested. In 1942 all organic fertilizers except crushed hoof at the low rate of application had only small effects on yields. In 1943 one of the leather wastes (S 2746) gave sizeable increases in yields, the other organic fertilizers gave only small effects. In both experiments the single dose of ammonium sulphate applied at planting had only a small effect on yield, but when applied in spring it gave larger increases in yield of cabbage. When the double dressing was applied (half in autumn, half in spring) much higher yields were obtained.

and compared them with the cumulative effects of continued dressings of hoof, formalized casein, and ammonium sulphate. Final measurements of residual effects were made when the experiment was completed. After the last leeks were harvested early in 1951 perennial ryegrass was sown, but no further fertilizers were applied. The grass was harvested in in 1951, 1952 and 1953 and was analysed to determine the uptake of nitrogen. The increases in yields of the vegetable crops grown to measure residual effects of leather wastes are stated in Table 11 and the results for the grass in Table 12.

Table 9. *Comparisons of dried blood with ammonium sulphate and with crushed hoof in a field experiment at Dulwich*

		Extra yield from dried blood over		
Year	Crop	Ammonium sulphate	Hoof	S.E.
1944	Lettuce	42	31	36·8
1943	Lettuce	−60	−41	44·4
1943/4	Leeks	15	12	28·1

Residual effects in the Rothamsted experiment

In the main series of experiments fertilizer dressings were applied for each crop, and the increases in yields measured were due to both the direct effect of the current fertilizer dressings and any residual effects of previous dressings. There were two opportunities to measure residual effects in the experiment at Rothamsted. From 1941 to 1943

Table 10. *Yields of spring cabbage in experiments at Woburn testing organic nitrogen fertilizers*

	Yields in cwt./acre			
	1942		1943	
Without nitrogen	36		55	
S.E.	±6·0		±11·0	
	Low rate	High rate	Low rate	High rate
Leather products				
S 2811	38	43	61	65
S 2746	45	30	84	78
Formalized casein	47	47	37	53
Hoof	75	51	49	73
Ammonium sulphate				
At planting	52	—	55	—
In spring	66	—	101	—
Half at planting, half in spring	48	99	91	154
S.E.	±8·5		±15·6	

dressings of leather wastes and other fertilizers were given for five crops; no further dressings of leather products were given for tomatoes (1944), onions (1945) and lettuce (1946), increases in crop yields measured the residual effects of the leather wastes

The residual effects of the dressings of leather wastes were surprisingly large. In 1944 residues of both materials tested gave yields of tomatoes approaching those given by a fresh dressing of crushed hoof. In 1945 one material (S 3206) had little residual effect but the other (S 2823) gave an increase equal to that from a direct dressing of the other fertilizers. In 1946 there were still worthwhile increases in yield of lettuce from residues of leather fertilizers last applied 3 years before.

There were marked and consistent residual effects of dressings of the organic fertilizers and of ammonium sulphate applied from 1941 to 1951 on the grass crops of 1951 and 1952. After the grass was cut in 1953 legumes began to invade the crop and the experiment was abandoned. The extra nitrogen in the crops on the plots which had received nitrogen manures ranged from 0·1 cwt. N/acre, for the single rate of ammonium sulphate, to 0·7 cwt. N/acre for formalized hoof residues. These additional amounts of nitrogen were due mainly to the high crop yields, but part of the gain resulted from increases in the percentages of nitrogen in the crops in the first residual year. The values were 10–20 % higher than the level of nitrogen in the crop on the untreated plots. This effect on crop composition did not recur in the second or third residual years. Both formalized hoof and coarse formalized casein were expected to act more slowly than the corresponding normal materials. Data given in Table 12 show that in each year residues of formalized hoof gave higher yields than residues from untreated hoof; coarse formalized casein had slightly greater residual effects than the normal (fine) material, but the differences in yields due to using the coarse materials were not

larger than the standard error of the comparison in 2 of the 3 years.

Changes in the soil of the Rothamsted experiment

Soil samples were taken from the plots at the beginning of the experiment in 1941 and again after the harvesting of the last vegetable crop in 1951. Total nitrogen, pH, calcium carbonate and readily soluble phosphorus and potassium were determined on both sets of samples. The results are summarized in Table 13.

The site of the experiment was land that had been an allotment since 1850, and although it had received very little farmyard or stable manure during the 10 years before the experiment it must have been generously treated in the earlier years. The organic-matter content of the soil at the beginning of the experiment was very similar to that of the farmyard manure plot on Broadbalk which had received about a hundred annual dressings of farmyard manure. The level of readily soluble phosphorus was very high and, like the organic-matter content, it was

Table 11. *Residual effects of leather products on vegetables at Rothamsted*

(Yields (cwt./acre))

		Gain from residues of leather products		Gain from continued dressings of Ammonium sulphate				
	Without nitrogen	S 2823	S 3206	Single rate	Double rate	Hoof	Formalized casein	S.E. of increase
Tomatoes, 1944	288	53*	68**	86**	58*	70**	69**	19·8
Onions, 1945	224	62	9	76*	57	62	37	32·5
Lettuce, 1946	212	97**	55	91*	151**	198**	279**	31·7

Table 12. *Residual effects of ammonium sulphate, hoof and formalized casein on grass at Rothamsted*

		Gain in yield or nitrogen content on plots treated from 1941 to 1950 with						
		Ammonium sulphate						
	Yield without nitrogen	Single rate	Double rate	Hoof	Formalized† hoof	Fine formalized casein	Coarse‡ formalized casein	S.E. of increase
		Yields of dry matter (cwt./acre)						
1951	7·7	2·2	3·8**	4·4**	7·2**	2·7*	4·2	1·23
1952	14·2	3·1	10·6	4·2	15·3**	8·8	11·3*	4·92
1953	16·7	−0·2	8·7*	−3·2	8·2*	2·6	5·4	3·56
		Nitrogen in grass crops (cwt./acre)						
1951	0·140	0·056	0·108	0·104	0·262	0·092	0·128	—
1952	0·302	0·051	0·178	0·072	0·319	0·197	0·208	—
1953	0·292	−0·010	0·127	−0·027	0·139	0·032	0·084	—
1951–3	0·734	0·097	0·413	0·149	0·720	0·321	0·420	—

† Leather product S 2823 1941–3; formalized hoof 1947–50.
‡ Leather product S 3206 1941–3; coarse formalized casein 1947–50

Table 13. *Analyses of soils from the Rothamsted experiment*

		Ammonium sulphate					
	Without nitrogen	Single rate	Double rate	Hoof	Formalized hoof	Fine formalized casein	Coarse formalized casein
		Total N %					
1941	0·264	0·262	0·248	0·245	0·256	0·259	0·252
1951	0·249	0·257	0·251	0·248	0·269	0·256	0·260
Gain	−0·015	−0·005	+0·003	+0·003	+0·013	−0·003	+0·008
		Readily soluble P (mg./100 g.)					
1941	38	30	23	33	28	27	32
1951	47	42	35	44	41	47	46
		Readily soluble K (mg./100 g.)					
1941	17	24	18	19	20	18	17
1951	33	31	23	23	24	22	24
		pH (in water)					
1941	7·6	7·7	7·6	7·7	7·5	7·5	7·6
1951	7·5	7·3	6·3	7·2	7·1	7·2	7·2

similar to the value for the Broadbalk plot. In potassium the allotment site was lower but still at a satisfactory level. The figures for the readily soluble phosphorus and potassium for the years 1941 and 1951 in Table 13, show that the basal PK fertilizers applied during the course of the experiment had been adequate. There was a build-up of both these nutrients, the increase was small for potassium but appreciable for phosphorus. The soil contained small amounts of calcium carbonate with an average value of 0·5 %. The distribution of the carbonate was, however, irregular, but all plots contained a minimum of 0·2 % at the beginning of the experiment. All three replicates of the double rate of ammonium sulphate happened by chance to be sited on some of the areas with the lower amounts. By the end of the experiment these were reduced to mere traces by this treatment and the soil was made slightly acid.

The changes in nitrogen contents of the soils resulting from the treatments during the period 1941–51 were small. The largest differences were a reduction of 0·015 % N on the plots without nitrogen and a gain of 0·013 % N from formalized hoof. The changes for hoof, fine formalized casein and the two rates of ammonium sulphate were very small. These treatments were therefore just able to maintain the original level of nitrogen and organic matter in the soil. The extra organic matter to replace the normal loss by oxidation must be ascribed to the greater root growth of the crops grown by these manures. The net loss of organic matter in the soil which did not receive nitrogen was approximately 4 cwt. per acre each year. In the Hoosfield Barley Experiment at Rothamsted an annual loss of a little less than 2 cwt. of organic matter per acre has been estimated (Warren, 1956) for the soil of plot 7[1], which contains residues of organic matter from farmyard manure applied many years ago. This lower rate of loss compared with that in the concentrated organic manure experiment is consistent with the lower level of soil organic matter (equivalent to 0·15 % N for Hoosfield and 0·26 % N for the organic manure experiment), the closer spacing of the crop, and the shallower and fewer cultivations in the Hoosfield experiment.

Although the soil of the concentrated organic manure experiment contained a large store of organic nitrogen, it was not able to provide sufficient mineral nitrogen for full crops of either vegetables or grass. Even in the residual years of the experiment the ammonium sulphate, hoof, formalized hoof, coarse and fine formalized casein treatments gave substantial increases in yields of grass. Hoof and fine formalized casein decompose quickly in the soil, so that the residual effects of these two materials and also ammonium sulphate must be ascribed to the mineralization of the organic nitrogen in the extra amount of roots of the vegetable crops grown in the preceding years. Some ammonium may also have been fixed by the clay fraction of the soil during the years in which nitrogen manures were applied and later released, but the amount is likely to be small in the Rothamsted soil. In the first and second residual years the extra amounts of nitrogen taken up by the grass ranged from one-quarter to three-quarters of the total nitrogen in the crops on the untreated soil. The amounts of organic matter that had accumulated from the greater root growth were small compared with the amount already present, as there were no measurable increases in the total nitrogen contents of the soils. Thus, the small but newer additions of organic matter gave proportionally more mineral nitrogen than the large quantity of old organic matter. This greater ease of release of mineral nitrogen from root residues was reported by Lawes, Gilbert & Warington (1883) in the discussion of their work on nitrification in the Broadbalk soils.

Formalized hoof and coarse formalized casein were applied only in the later years of the experiment and were preceded by applications of leather materials. No comparison of their residual effects can therefore be made with the other nitrogen treatments as smaller amounts were applied. In addition, the leather materials gave surprisingly good residual effects in the years 1944–6 and may have continued to provide some nitrogen in later years. The possibility that part of the residual effects of formalized hoof and coarse formalized casein (as measured in the years 1951–3) was due to the residues of the leather materials previously used on the plots to which they were applied cannot be excluded.

DISCUSSION

The experiments described here were carried out on soils which had grown vegetables for a number of years. At Cleobury, Dulwich, Rickmansworth and Rothamsted organic matter had been built up to levels which are uncommon in ordinary arable soils and these experiments are therefore relevant to normal market garden practice. Although most of the soils used were 'rich' by agricultural standards ammonium sulphate increased yields in practically all experiments.

Both hoof and formalized casein tended to be slightly inferior to ammonium sulphate for spring cabbage, this crop received the full dressings of organic fertilizers in autumn, whereas half of the ammonium sulphate was applied in autumn and the remainder as a top-dressing in spring. The Woburn experiment (Table 10), carried out on poor soil, showed that autumn-planted cabbages may benefit greatly from extra inorganic nitrogen applied in spring. Organic materials may have been at a disadvantage for cabbage, either because they decomposed too rapidly in autumn and the nitrate was

lost by winter leaching, or because they failed to decompose sufficiently rapidly in spring when the soil was cold and the crop needed the stimulus of quick-acting nitrogen.

Generally for the other crops grown, crushed hoof and formalized casein were roughly as effective as an equivalent amount of N as ammonium sulphate, 'organics' tending to be slightly inferior for rapidly growing crops with a heavy nitrogen fertilizer requirement, and slightly superior for crops which required only small dressings of nitrogen or where the high rate of ammonium sulphate gave lower yields than the half rate. Organic fertilizers may have been superior to ammonium sulphate in some experiments because they contain no salts, or because they released nitrogen more slowly and did not promote unnecessary vegetative growth at the expense of the saleable portion of the crop.

Individual batches of processed leather wastes were tested in too few experiments to provide reliable average yields, and rigid comparisons between the different products used are not possible. The better products behaved in much the same way as crushed hoof. Dried blood was tested on three crops at one centre and there was no reason to suggest that it behaved very differently from ammonium sulphate or hoof. Laboratory work by others has shown that organic nitrogen fertilizers may nitrify quite quickly. Owen, Rogers & Winsor (1950) stated that the traditional view that hoof and horn is a slow-acting fertilizer, in contrast with dried blood which was thought to be quick-acting, could not be substantiated. Hamence (1950) also showed that organic materials commonly thought to be slow-acting, nitrified quickly when incubated with soil for a few days. Bremner & Shaw (1957) also state as a result of laboratory work that hoof cannot be regarded as a genuinely slow-acting nitrogen fertilizer.

Continuous treatment with fertilizers from 1941 to 1950 had striking effects on grass grown in 1951 and 1952, but the 'residual effects' of unformalized hoof and of finely divided formalized casein were not larger than the residual effects of ammonium sulphate. The extra yields of grass given by all nitrogen fertilizers after dressings had ceased indicate simply the difference between fertility levels of soils which had received nitrogen continuously for 10 years and of soils which had received no nitrogen for that period. If this increased fertility is a general effect due to extra organic nitrogen added by crop roots, it is likely that the form in which the available fertilizer nitrogen was applied will be of little importance to both yield of crop and build-up of soil fertility.

The series of experiments as a whole did not provide any clear and consistent indications that organic nitrogen fertilizers were either markedly superior or inferior to ammonium sulphate; for this reason comparisons of inorganic and organic materials were not pursued after 1950. The experiments were, however, too few and the cropping was too diversified, to allow reliable estimates to be made of the efficiency of the organic fertilizers in terms of ammonium sulphate. The work gives no reason for using expensive organic nitrogen fertilizers for the crops grown in preference to inorganic materials. Growers should work out correct methods of using cheap inorganic nitrogen for most kinds of vegetables grown in the open, and special attention should be given to the timing of the dressings. For glasshouse crops organic materials may have special merits where nitrate is quickly leached away by heavy watering, or where inorganic materials raise the salt content of the soil to dangerously high levels.

SUMMARY

Hoof, formalized hoof, formalized casein, leather wastes and dried blood were compared with ammonium sulphate for vegetables in several field experiments which were continued for a number of years. Residual effects were measured in one experiment at Rothamsted.

For crops which had a high requirement for nitrogen, hoof and formalized casein tended to give somewhat lower yields than equivalent ammonium sulphate. Organic nitrogen fertilizers tended to be slightly superior to ammonium sulphate for less responsive crops, and also in experiments where the high rate of ammonium gave lower yields than the medium rate.

Crushed hoof and a formalized casein product gave similar yields of most crops. There were no marked gains from treating hoof with formalin; a coarse (5–7 mm.) sample of formalized casein did not give materially different yields from the ordinary fine (2 mm.) product.

One leather product made by simple roasting was inferior to ammonium sulphate and to hoof. Other leather wastes processed by alkalis did not behave very differently from crushed hoof or from ammonium sulphate. Dried blood was tested in a few experiments, there were no significant differences between yields given by blood and by ammonium sulphate.

In experiments on a light soil, spring cabbages planted in autumn were very sensitive to the time of applying nitrogen fertilizer; there were much larger gains in yield from ammonium sulphate applied half at planting and half in spring, than from either ammonium sulphate or organic nitrogen fertilizers applied wholly at planting.

Plots which had received either organic nitrogen fertilizers or ammonium sulphate continued to give significantly larger yields of grass than untreated plots for several years after manuring was stopped. The apparent 'residual effects' of organic nitrogen

fertilizers were similar to those of ammonium sulphate. Residues of formalized hoof gave slightly larger yields than residues of untreated hoof. Coarse formalized casein did not have appreciably larger residual effects than the fine material.

There were only small changes in the nitrogen contents of the soils of the plots at Rothamsted during the 10 years when fertilizers were applied. Soil nitrogen decreased on plots receiving no nitrogen fertilizer; hoof, formalized casein, and ammonium sulphate dressings maintained soil nitrogen at its original level, and there was a slight increase where formalized hoof had been applied for a number of years.

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