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The Woburn Market-garden Experiment: Summary 1944-60

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N from 1.0 to 1.5 cwt decreased the yield of sugar, but after ryegrass (sown with or without N) yields of sugar were increased by the additional "Nitro-Chalk". This suggests that using ryegrass as a green manure may not only increase the yield of sugar directly but also allow more nitrogen fertiliser to be used profitably.

Without nitrogen fertiliser the yields in the two experiments were not very different (Table 4); in 1961 responses to N were small, whereas in 1962 they were very large. By contrast, green manures had smaller effects in the 1962 experiment.

TABLE 4
Sugar beet, sugar: cwt/acre

	Mean without N	Mean increase for: N: cwt/acre			Mean without green manure	Mean increase for:		
		0.5	1.0	1.5		T	R	RN
1961	37.4	7.7	8.9	8.9	37.4	9.1	5.2	11.1
1962	44.5	22.9	30.1	29.3	61.9	6.7	0.7	5.4

Green manures: trefoil (T), ryegrass (R), ryegrass with 0.6 cwt N/acre (RN).

The results of the experiments on sugar beet show that green manuring at Woburn can produce worthwhile increases in sugar yields, even when the beet is given much "Nitro-Chalk". For this reason, and because stunted trefoil, providing only 6–7 cwt of dry matter per acre (and perhaps 0.1 cwt N), gave an increase of 8 cwt sugar it is clear that some unknown factor is involved. Autumn ploughing, as done on the plots without green manures, may have depressed yields; this is being studied in a new series of experiments at Woburn.

The Woburn Market-garden Experiment: Summary 1944–60

By H. H. Mann and H. D. Patterson

This experiment was started in 1942 on a soil containing little humus or nitrogen to study the effects of annual heavy dressings of four bulky organic manures on the crops of an intensive market-garden rotation. Cropping and manuring were changed in 1951 and again in 1961. The experiment is therefore divided into three periods: up to 1950, 1951–60 and 1961 onwards. This report deals with results in the first and second periods. As the full range of treatments was not tested until 1944, the results for 1942 and 1943 are omitted.

Originally four crops were grown in a 2-year rotation as follows (with dates of sowing or planting, followed by dates of harvesting):

1st phase	Globe beetroot	(April, July)
	Winter cabbages	(August, December–March)
2nd phase	Green peas	(March–April, June–July)
	Leeks	(July, January–March)

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From 1951 onwards three crops were grown in the two phases, initially as follows:

1st phase	Globe beetroot	(April–May, July–August)
	Spring cabbages	(September–October, April–May)
2nd phase	Leeks	(June–July, March–April)

The spring cabbages transplanted in 1955 failed and were replaced in the spring of 1956 and later years by early potatoes. In the first period the beetroot was harvested as bunched young beet; in the second period the beet was allowed to mature.

The four organic manures were:

Farmyard manure made at Woburn farm.

Sewage sludge (West Middlesex).

Compost made with straw and farm waste activated by farmyard manure in alternate layers (compost Cd). The FYM constituted a third of the total weight.

Compost as in Cd but activated with sewage sludge instead of FYM (compost Cs).

These were contrasted with plots receiving no organic manures. Each manure was tested at two rates, 15 and 30 tons/acre applied to the globe beet and peas in the first period, and 10 and 20 tons/acre applied to every crop in the second period. Thus, throughout the experiment, the total dressings were 30 and 60 tons/acre every 2 years.

N fertiliser was also tested in combination with the above treatments at the following rates (cwt N/acre):

Period	Form of N	Crops	With organics	No organics
1942–50	Sulphate of ammonia	Globe beet, peas	0, 0.2	0, 0.2, 0.4, 0.6
		Cabbages, leeks	0, 0.4	0, 0.4, 0.8*, 1.2*
1951–60	“Nitro-Chalk”	All crops	0, 0.3	0, 0.3, 0.6*, 0.9*

The rates marked with an asterisk were given half before sowing or planting, half later, for beet, cabbages and leeks in the 2nd period and for cabbages and leeks in some years of the 1st period.

The 20 treatments, consisting of 16 combinations of organic manures and N and four rates of N in the absence of organic manures, were accommodated on two series of 40 plots each, one series for each phase of the rotation.

Basal P and K dressings (superphosphate and muriate of potash) were broadcast on the seedbed at the following rates:

Period		cwt P ₂ O ₅ /acre	cwt K ₂ O/acre
1942–50	Globe beet, peas	0.4	0.5
	Cabbages, leeks	—	—
1951–60	All crops	0.3	0.3

Much more N, P and K were added in the farmyard manure than in the fertilisers (Table 1). Even larger amounts of N and P were added in the sewage sludge, but this contained little K. Soil analyses by the Chemistry Department in 1960 showed large accumulations of P and K on the

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farmyard manure plots and of P on the sewage sludge plots. Farmyard manure at 30 tons/acre/year produced a "saturation" level of 30–35 mg K/100 g of soil to a depth of at least 24 in. (*Rep. Rothamst. exp. Sta.* for 1960, pp. 46–47).

TABLE 1

Estimated amounts of organic matter, total N, P and K in 10 tons of manure

Manure	Organic matter (tons/acre)	N (cwt/acre)	P ₂ O ₅ (cwt/acre)	K ₂ O (cwt/acre)
FYM	1.52	1.3	1.4	2.0
Sewage sludge	2.33	3.0	3.8	0.2
Compost Cd	1.30	1.1	1.1	1.1
Compost Cs	1.63	1.5	1.9	0.3

Table 2 shows estimated percentages of nitrogen in the top 9 in. of soil in 1951 and 1960. In 1942 the mean percentage was 0.082%. The 1951 results were reported in detail by Mann & Barnes (1956); the 1960 determinations were made by T. W. Barnes. During the first 9 years of the experiment amounts of nitrogen on the sewage-sludge plots increased about three times as much as on the corresponding FYM and Cd plots and about 50% more than on the Cs plots. In the next 9 years the nitrogen increased more slowly on plots with FYM or compost and scarcely at all on the sewage-sludge plots.

TABLE 2

Nitrogen percentages in the top 9 in. of soil

Treatment	Rate of manuring (tons/acre/year)	1951	1960
No organics, no N		0.089	0.093
No organics, with N (mean of 3)		0.088	0.099
FYM	15	0.110	0.137
	30	0.140	0.176
Sewage sludge	15	0.176	0.180
	30	0.247	0.259
Compost Cd	15	0.122	0.149
	30	0.142	0.173
Compost Cs	15	0.141	0.168
	30	0.182	0.217

Tables 3 and 4 show the mean yields from each crop in the two periods (total produce except where indicated). The globe beet failed in 1946 and 1953, winter cabbages in 1947 and spring cabbages in 1952 and 1955.

The organic manures produced large increases in the yields of all crops grown in the experiment except peas. Although the increases were partly from the much N added in the manures, it is clear that other factors were also involved. All crops except peas responded to N, but the responses to the highest rates of application were generally much smaller than responses to the manures.

Factors other than amounts of N that may have contributed to the differences in yields between manure and fertiliser plots include:

(a) The very small amounts of P and K given to the fertiliser plots.

Deficiencies in these and possibly other nutrients may have limited

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TABLE 3
Mean yields, 1944-50 (tons total produce/acre)
First crops after organic manures

Treatment	Rate of manuring (tons/acre)	Globe beet (1944-45, 1947-50) (excluding unmarketable produce)				Green peas (1944-50)			
		cwt N/acre		Mean	Diff.	cwt N/acre		Mean	Diff.
		0	0.2			0	0.2		
No organics		(±0.404)		(±0.286)	(±0.571)	(±0.166)		(±0.118)	(±0.235)
		2.03	2.75	2.39	0.72	1.81	1.84	1.82	0.03
		3.02*	3.16†	3.09	0.14	1.86*	1.82†	1.84	-0.04
FYM	15	4.84	4.90	4.87	0.06	2.38	2.23	2.31	-0.15
	30	6.52	6.64	6.58	0.12	2.27	2.04	2.16	-0.23
Mean		5.68	5.77	5.72	0.09	2.32	2.14	2.24	-0.18
		(±0.286)		(±0.202)	(±0.404)	(±0.118)		(±0.083)	(±0.166)
Sewage sludge	15	4.21	4.64	4.43	0.43	1.84	2.04	1.94	0.20
	30	5.31	4.94	5.13	-0.37	1.68	1.84	1.76	0.16
Mean		4.76	4.79	4.78	0.03	1.76	1.94	1.85	0.18
Compost CD	15	3.87	4.57	4.22	0.70	2.36	2.22	2.29	-0.14
	30	5.74	5.98	5.86	0.24	2.06	2.20	2.13	0.14
Mean		4.80	5.27	5.04	0.47	2.20	2.21	2.21	0.01
Compost Cs	15	3.76	3.73	3.74	-0.03	2.24	2.10	2.17	-0.14
	30	4.61	5.24	4.92	0.63	2.27	2.12	2.20	-0.15
Mean		4.18	4.48	4.33	0.30	2.26	2.11	2.18	-0.15

* 0.4 cwt N/acre. † 0.6 cwt N/acre.

Second crops after organic manures

Treatment	Rate of manuring (tons/acre)	Winter cabbages (1944-46, 1948-50)*				Leeks (1944-50)*			
		cwt N/acre		Mean	Diff.	cwt N/acre		Mean	Diff.
		0	0.4			0	0.4		
No organics		(±0.246)		(±0.174)	(±0.348)	(±0.160)		(±0.113)	(±0.226)
		2.63	4.32	3.48	1.69	2.20	2.67	2.44	0.47
		5.24†	5.67‡	5.46	0.43	2.71†	2.90‡	2.80	0.19
FYM	15	4.17	5.41	4.79	1.24	3.16	3.07	3.11	-0.09
	30	5.12	6.17	5.64	1.05	3.84	3.89	3.86	0.05
Mean		4.64	5.79	5.22	1.15	3.50	3.48	3.49	-0.02
		(±0.174)		(±0.123)	(±0.246)	(±0.113)		(±0.080)	(±0.160)
Sewage sludge	15	5.21	6.56	5.88	1.35	3.11	3.06	3.08	-0.05
	30	6.97	7.11	7.04	0.14	3.47	3.66	3.56	0.19
Mean		6.09	6.84	6.46	0.75	3.29	3.36	3.32	0.07
Compost Cd	15	3.87	5.04	4.46	1.17	2.89	3.25	3.07	0.36
	30	4.85	5.91	5.38	1.06	3.52	3.50	3.51	-0.02
Mean		4.36	5.48	4.92	1.12	3.20	3.37	3.29	0.17
Compost Cs	15	3.87	4.97	4.42	1.10	2.89	3.33	3.11	0.44
	30	4.40	6.17	5.28	1.77	3.15	3.18	3.16	0.03
Mean		4.14	5.57	4.85	1.43	3.02	3.25	3.14	0.23

* Years of sowing and transplanting. † 0.8 cwt N/acre. ‡ 1.2 cwt N/acre.

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TABLE 4
Mean yields, 1951-60 (tons total produce/acre)

Treatment	Rate of manuring (tons/acre)	Globe beet (1951-52, 1954-60)				Leeks (saleable produce) (1951-60) ‡			
		cwt N/acre		Mean	Diff.	cwt N/acre		Mean	Diff.
		0	0.3			0	0.3		
No organics		(±0.784)		(±0.554)	(±1.109)	(±0.190)		(±0.134)	(±0.269)
		4.21	6.19	5.20	1.98	2.56	3.77	3.16	1.21
		8.52*	7.43 †	7.98	-1.09	4.39*	4.07 †	4.23	-0.32
FYM	10	9.25	12.24	10.74	2.99	4.47	5.16	4.81	0.69
	20	15.74	16.89	16.31	1.15	5.77	6.01	5.89	0.24
Mean		12.49	14.56	13.52	2.07	5.12	5.58	5.35	0.46
		(±0.554)		(±0.392)	(±0.784)	(±0.134)		(±0.095)	(±0.190)
Sewage sludge	10	10.99	11.45	11.22	0.46	5.08	5.02	5.05	-0.06
	20	12.61	14.18	13.39	1.57	5.10	5.39	5.25	0.29
Mean		11.81	12.82	12.30	1.02	5.09	5.20	5.15	0.11
Compost Cd	10	10.18	12.38	11.28	2.20	4.71	5.21	4.96	0.50
	20	12.35	16.07	14.21	3.72	5.49	5.81	5.65	0.32
Mean		11.27	14.22	12.74	2.95	5.10	5.51	5.31	0.41
Compost Cs	10	10.00	11.95	10.98	1.95	4.87	5.23	5.05	0.36
	20	13.78	15.29	14.53	1.51	5.20	5.60	5.40	0.40
Mean		11.89	13.62	12.75	1.73	5.03	5.42	5.22	0.39

Treatment	Rate of manuring (tons/acre)	Spring cabbages (1951, 1953-54) *				Potatoes (tubers) (1956-60)			
		cwt N/acre		Mean	Diff.	cwt N/acre		Mean	Diff.
		0	0.3			0	0.3		
No organics		(±0.696)		(±0.492)	(±0.984)	(±0.260)		(±0.184)	(±0.367)
		2.20	4.68	3.44	2.48	4.03	5.38	4.70	1.35
		6.28 †	6.31 ‡	6.30	0.03	6.43 †	6.35 ‡	6.39	-0.08
FYM	10	5.48	6.47	5.98	0.99	6.72	7.54	7.13	0.82
	20	7.44	8.65	8.05	1.21	7.79	8.26	8.03	0.47
Mean		6.46	7.56	7.02	1.10	7.25	7.90	7.58	0.65
		(±0.492)		(±0.348)	(±0.696)	(±0.184)		(±0.130)	(±0.260)
Sewage sludge	10	7.07	8.19	7.63	1.12	6.44	6.75	6.59	0.31
	20	9.02	10.05	9.54	1.03	7.06	7.37	7.21	0.31
Mean		8.04	9.12	8.58	1.08	6.75	7.06	6.90	0.31
Compost Cd	10	5.19	6.92	6.05	1.73	6.43	7.45	6.94	1.02
	20	6.32	7.90	7.11	1.58	7.39	7.80	7.59	0.41
Mean		5.75	7.41	6.58	1.66	6.91	7.62	7.27	0.71
Compost Cs	10	5.73	7.21	6.47	1.48	6.59	6.95	6.77	0.36
	20	7.16	8.37	7.77	1.21	7.55	7.86	7.70	0.31
Mean		6.44	7.79	7.12	1.35	7.07	7.40	7.24	0.33

* Years of sowing and transplanting. † 0.6 cwt N/acre. ‡ 0.9 cwt N/acre.

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yields and responses to N fertiliser on these plots, whereas plots with FYM or compost Cd received large amounts of P and K, and those with sewage sludge or compost Cs received large amounts of P.

(b) Differences in positions between nutrients added in the manures and fertilisers. The manures were ploughed in, whereas the fertilisers were broadcast after ploughing. An indication of possible positional effects is provided by the significant responses to small seedbed dressings of N fertiliser on manured plots, even though the manures themselves contained large amounts of N. These responses were smallest on plots with sewage sludge, the manure containing most nitrogen.

At present the effects of these factors cannot be estimated, but in 1961 the experiment was redesigned to compare greatly increased dressings of N, P and K fertilisers and dressings of magnesium sulphate with continued applications of FYM. On some plots part of the N, P and K fertilisers is ploughed in at the time of ploughing in the manures. Eventually the experiment may enable any effects of FYM other than supplying nutrients to be assessed.

Among individual manures, the greatest contrasts were between FYM and sewage sludge. Sewage sludge gave better yields of cabbages than the other manures whether applied directly for the crop (second period) or for the preceding beet (first period). The cabbages responded well to N fertiliser, and part of the effect of the sludge probably reflected N. The residual effect of FYM and the two composts applied at 15 tons/acre and 30 tons/acre to the preceding beet (first period) were smaller than the effects of seedbed dressings of 0.4 cwt N fertiliser/acre and 0.8 cwt N/acre respectively. Even when applied directly for the cabbages in the second period, dressings of 10 tons/acre of these three manures were less effective than 0.6 cwt N fertiliser/acre. In contrast, sewage sludge was of no value to peas, the one crop not responding to N fertiliser. The other manures produced small but significant effects in this crop.

All four manures were very effective for leeks, beet and potatoes, giving as good or better responses than N fertilisers at the lower rate of application and much better responses at the higher rate. The effects on globe beet in the second period were particularly striking, with responses to 20 tons manure/acre between two and three times as large as the best responses to N fertiliser. Provided it was applied at the heavier rate, FYM gave larger effects than the other manures on each of these crops. Thus, in the second period 20 tons FYM/acre produced about 3 tons beet, $\frac{1}{2}$ ton leeks and $\frac{3}{4}$ ton potatoes/acre more than sewage sludge. The corresponding effects of the two composts were intermediate between those of FYM and sewage sludge.

One of the main purposes of the experiment was to determine whether yields would improve progressively with repeated applications of the organic manures. This point can be tested by comparing the estimated increases in yield per year shown in Table 5 for plots with and without organic manures. Yields of beet and leeks in the second period cannot be compared with those in the first period because of the changes made in the experiment in 1951. Only beet in the second period shows any real evidence

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of cumulative effects from the manures. For this crop the rates of increase in yield were large on plots with organic manures, particularly FYM or compost, but not on plots with fertilisers only. The large rates of increase in the first period on all plots receiving nitrogen, whether in manures or fertiliser, must be largely attributed to improvements in farming methods and conditions in the later years of the period.

TABLE 5
Mean rates of increase in yield (tons/acre/year)
1st period, 1944-50

Treatment	Rate of manuring tons/acre/year	Globe beet (saleable) produce)	Green peas	Cabbages	Leeks
No organics, no N		0.06 ± 0.147	0.36 ± 0.064	0.17 ± 0.123	0.42 ± 0.072
No organics, with N (mean of 3)		0.33 ± 0.085	0.42 ± 0.037	0.36 ± 0.071	0.77 ± 0.042
FYM	15	0.23 ± 0.104	0.59 ± 0.045	0.17 ± 0.087	0.72 ± 0.051
	30	0.60	0.44	0.54	0.76
Sewage sludge	15	0.59	0.33	0.63	0.89
	30	0.65	0.23	0.47	0.98
Compost Cd	15	0.40	0.53	0.48	0.69
	30	0.34	0.43	0.46	0.66
Compost Cs	15	0.30	0.49	0.44	0.77
	30	0.44	0.57	0.58	0.88
Mean of organics	15	0.38 ± 0.052	0.48 ± 0.023	0.43 ± 0.043	0.77 ± 0.026
	30	0.51	0.42	0.51	0.82

2nd period, 1951-60

Treatment	Rate of manuring tons/acre/year	Globe beet	Leeks (saleable) produce)	Potatoes (tubers)
No organics, no N		-0.11 ± 0.172	0.13 ± 0.053	0.20 ± 0.122
No organics, with N (mean of 3)		-0.02 ± 0.099	0.26 ± 0.030	0.41 ± 0.070
FYM	15	0.33 ± 0.121	0.16 ± 0.037	0.48 ± 0.086
	30	0.69	0.22	0.28
Sewage sludge	15	0.01	0.38	0.44
	30	0.23	0.34	0.68
Compost Cd	15	0.38	0.34	0.24
	30	0.53	0.24	0.08
Compost Cs	15	0.55	0.36	0.41
	30	0.81	0.28	0.67
Mean of organics	15	0.32 ± 0.061	0.31 ± 0.019	0.39 ± 0.043
	30	0.56	0.27	0.43

From time to time throughout the experiment measurements were made relating to possible effects of organic manures on the character of the crops. Analysis of these shows the following contrasts between plots with and without organics:

- (1) The number of plants of beet/acre on the manure plots averaged 5-10% more than on the fertiliser plots.
- (2) The ratio of the weight of bulbs of beetroot to whole plants was increased by about 40% by the manures.
- (3) Marketable beet were produced earlier by the organic manures than the fertilisers.