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Effects of compost on yields of winter wheat and barley, sugar beet, onion and swede in the fourth and fifth years of a rotation

by

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CONTENTS

ABBREVIATIONS

C, CO_2	carbon, carbon dioxide
cm	centimetre
DM	dry matter
FS	farm standard
g	gram
ha	hectare
K, K_2O	potassium, potash
kg	kilogram
l	litre
LSD	least significant difference
Mg, MgO	magnesium, magnesium oxide
mg	milligram
ml	millilitre
mm	millimetre
m/m	mass/mass
N, NH_4, NO_3	nitrogen, ammonium-N, nitrate-N
NVZ	Nitrate Vulnerable Zone
O	oxygen
OSR	oilseed rape
P=0.05	probability at 1 in 20 level of confidence
P, P_2O_5	phosphorus, phosphate
S, SO_3	sulphur, sulphur trioxide
SMN	soil mineral nitrogen
t	tonnes
Trt	treatment
μS	microSiemens
WHC	water holding capacity
yr	year

ABSTRACT

Background

This is the final report of a project investigating the use of green waste derived compost in agriculture, which received funding in part from the HGCA during 2005 and 2006. The project itself ran for five years: Initially a three year project was funded by GrantScape through the Landfill Communities Fund with support through the Applied Research Forum by the British Potato Council (BPC), the Home-Grown Cereals Authority (HGCA) and the Horticultural Development Council (HDC). The project was then extended by a further two years.

The project was managed by Phil Wallace of Enviros Consulting Ltd with Iain Turner and Will Baldwin of Envirofield carrying out the field trials management. Additional research was conducted by Dr Martin Wood of Earthcare Environmental Ltd. Soil nutrient balances and economics were carried out by Anna Becvar, an independent soil scientist.

Key benefits found

During the five year period of trials the following key benefits were quantified:

Soil physical condition

- Increased soil organic matter
- Increased soil water holding capacity
- Improved water infiltration giving less run off and risk of soil erosion
- Improved soil structure and workability

Soil chemistry and soil life

- Stabilised soil pH
- Increased biological population and microbial activity
- Increased soil available potassium and other nutrients
- Optimum use of applied fertiliser nitrogen when applied with compost

From all five years of trial results, these benefits led to an average yield increase of 7% where compost had been used regularly.

The trials

Seven sites were established in Eastern England on varying soil types in 2001/02 and, in Phase 2, five of these were used in 2004/05 and four in 2005/06. Fully replicated trials were laid out with eight treatments and four replicates, as follows:

1	UT	Untreated
2	N+PK	Farm Standard Nitrogen +PK
3	C30+N	30 Tonnes/ha annually + Nitrogen
4	C60+N	60 Tonnes compost/ha biennially + Nitrogen
5	C30	30 Tonnes/ha annually
6	C60	60 Tonnes compost/ha biennially
7	C30+LN	30 Tonnes/ha annually + Low Nitrogen
8	C60+LN	60 Tonnes compost/ha biennially+ Low Nitrogen

Farm standard fertiliser was mainly nitrogen on each site with phosphorus (P) and potassium (K) as required in treatment 2. The low N treatments (7 and 8) were designed to observe the effects of saving nitrogen inputs and costs.

Compost was applied annually for the 30 t/ha treatments, and every two years for the 60 t/ha treatments (Years 1, 3 and 5), to follow the Soil Code. The rates of compost application were reduced in Phase 2 compared with 50 and 100 t/ha in Phase 1 to reflect The COGAO Soil Code and Nitrate Vulnerable Zone (NVZ) requirements.

The sites, soil textures and crops grown were:

Table A1 Sites, soils and crops grown

	LOCATION	SOIL TEXTURE	CROPPING	
			YEAR 4	YEAR 5
1	SUFFOLK	SANDY LOAM	SUGAR BEET	WINTER WHEAT
2	SUFFOLK	CLAY LOAM	ONIONS	WINTER WHEAT
3	SUFFOLK	SANDY LOAM	ONIONS	SWEDES
4	SUFFOLK	SANDY CLAY LOAM	WINTER BARLEY	ONIONS
5	ESSEX	CLAY LOAM	NOT USED	NOT USED
6	LINCOLNSHIRE	SANDY SILT LOAM	WINTER WHEAT	NOT USED
7	LINCOLNSHIRE	SANDY CLAY LOAM	NOT USED	NOT USED

Results

During the first three years of the Compost in Agriculture field trials clear benefits were identified in the application of green composted material within the rotation. These benefits came from a combination of increased availability and uptake of nutrients, improved soil physical characteristics, an increase in soil biology and gradually rising organic matter levels.

The results gained led to more detailed investigations concerning the nitrogen release from compost in years 4 and 5 of the project. If soil moisture was adequate and temperatures were warm, mineralisation occurred and provided nitrogen from the soil and applied compost material. The added potential effect from applied compost was demonstrated in year 4 but was small in terms of crop uptake in year 5.

Soil moisture was measured in compost treated and fertiliser only plots at site 1 in years 4 and 5. Water infiltration rates were improved by the addition of compost and the water holding capacity of the soil was raised.

Physical and biological indicators of soil improvement were tested. Soil bulk density was reduced through the use of compost and nematode populations (predominantly non-pathogenic species) were increased.

Soil analysis was carried out on the remaining four trial sites. Soil pH was maintained compared with fertiliser alone, which tended to reduce pH due to the acidifying effects of artificial fertilisers. Compost was effective in supplying the crops' phosphorus, potassium and magnesium requirements and maintaining soil available nutrient levels.

Soil organic carbon and organic matter, measured by wet chemistry and loss on ignition respectively, and were raised by the addition of compost. Overall compost was effective as a means of improving soil fertility.

Yield benefits were seen in years 4 and 5 but hot dry periods affected crops in both years. The effect of compost on soil moisture may have contributed to the yield increases.

Additions of compost gave an average increase of 7 % over the whole 5 year period of the trials. Where nitrogen fertiliser rates were reduced, to take into account Nitrogen released from the compost and the effects of improved fertiliser-N use efficiency (up to 40 kg/ha less N fertiliser applied), the same yield increases were seen.

Table A2 Yields as a percentage of Farm Standard – all crops 2002 – 2006

		Treatment	All sites
1	UT	UNTREATED	74.4
2	N+PK	FARM STANDARD (FS)	100.0
3	C30+N	30 T/HA COMPOST + FS	106.7
4	C60+N	60 T/HA COMPOST + FS	109.0
5	C30	30 T/HA COMPOST	87.3
6	C60	60 T/HA COMPOST	89.4
7	C30+LN	30 T/HA COMPOST + LOW N	107.8
8	C60+LN	60 T/HA COMPOST + LOW N	110.4
Significance			***
LSD (P=.05)			6.7

Note: Compost rates were decreased from 50 and 100 t/ha to 30 and 60 t/ha, respectively, for 2005 and 2006.

Economics

The economics of applying compost to the rotation was examined. The value of compost was calculated from the increase in yields and fertiliser replacement costs. Additional value could be made from water savings where crops were irrigated. Water costs were in the region of £75 per hectare per 25 mm application.

Farm Standard N+PK fertiliser application costs were compared with the application of compost at 30 t/ha annually coupled with reduced nitrogen applications over a 5 year rotation (barley, potatoes, barley, sugar beet and wheat) on soils at Index 2 for phosphorus and potassium.

The total cost per hectare of farm standard fertilisers over 5 years was £636 compared with compost at 30 t/ha annually plus low nitrogen (less 40 kg N/ha) of £880. The value in the increase in yield was £827/ha so the net benefit was £583/ha over 5 years or £116/ha/year. This was after the costs of the compost/haulage (£2.50/t) and its application (£1.50/t) had been taken into account.

If the rate of applications/or frequency of applications were reduced benefits would still be seen but soil improvement, and hence yield increases, might occur at a slower rate. The rate of return would also depend on the value of the crops being grown and the size of the response in each particular soil.

Dissemination

Dissemination of the project findings was through the press and the Composting Association's annual conference. An A3 leaflet for farmers and composters was produced and is available, along with this report, from www.compost.me.uk. Presentations were also given to funders and at other events.

Information about BSI PAS100, the Quality Protocol for compost and sources of compost can be obtained from the Waste and Resources Action Programme www.wrap.org.uk or the Composting Association www.compost.org.uk 0870 160 3270. Compost certified to BSI PAS 100 and the Quality Protocol does not require a land spreading exemption from the waste management license regulations.

1. AIMS AND OBJECTIVES

The aims of the project were to assess the continued effects of the application of composted green waste to arable land through replicated field trials in Eastern England over a total of five years.

To achieve these aims, the objectives were:

- to assess the yield effects of the application of composted green waste to arable land through replicated field trials on five sites in 2004/05 and four sites in 2005/06 in Eastern England;
- to analyse composts used and soils on each of these sites every year;
- to assess the effects on nutrient release and water relations;
- to assess the effects on soil microbiology;
- to assess the economic benefits of using compost and
- to disseminate the information to the farming and composting industries.

2. FIELD TRIALS

The following treatments were applied to all of the sites:

1	UT	Untreated
2	N+PK	Farm Standard Nitrogen +PK
3	C30+N	30 Tonnes/ha annually + Nitrogen
4	C60+N	60 Tonnes compost/ha biennially + Nitrogen
5	C30	30 Tonnes/ha annually
6	C60	60 Tonnes compost/ha biennially
7	C30+LN	30 Tonnes/ha annually + Low Nitrogen
8	C60+LN	60 Tonnes compost/ha biennially+ Low Nitrogen

In year 4 the compost treatments were reduced from 50 and 100 t/ha to 30 and 60 t/ha respectively to more closely match Soil Code and NVZ requirements. In year 4, the 60 t/ha compost treatments were omitted in accordance with the Soil Code. The 30 t/ha compost applications were made every year. The compost used was analysed each year (Table 1) and results converted into nutrients per tonne of compost (Table 2).

Table 1 Compost analysis results

		Year 4	**Year 5**
Bulk density	g/litre	477	454
Moisture	% m/m	51.1	51.2
Organic matter	% dry matter	42.1	46.3
pH	units	8.4	8.8
Electrical conductivity	µS /cm	750	1180
Nitrogen (N)	% dry matter	1.38	2.03
Phosphorus (P)	% dry matter	0.19	0.27
Potassium (K)	% dry matter	0.80	1.21
Magnesium (Mg)	% dry matter	0.17	0.32
Sulphur (S)	% dry matter	0.15	0.21

Table 2 Total nutrients applied in compost

	Year 4	Year 5
	Nutrients applied @ 30 t/ha	Nutrients applied @ 30 t/ha
	total kg/ha	total kg/ha
N	202	297
P_2O_5	64	91
K_2O	141	213
MgO	42	80
SO_3	55	78
Organic matter	6,200	6,800

Note: P x 2.29 = P_2O_5, K x 1.2 = K_2O, Mg x 1.66 = MgO, S x 2.5 = SO_3

The trials, with four replicates of each treatment, were of randomised block design and statistically analysed accordingly. The sites were soil sampled and analysed after harvest for available nutrients, pH, organic carbon and organic matter (as loss on ignition 105°C-450°C).

The crops were assessed for colour and vigour during growth. At harvest, the yield of the crops was measured. Diseases were assessed as seen.

This consolidated report provides the main findings from the field trials during years 4 and 5 harvested in 2005 and 2006, respectively. Detailed data by year are available on request from the author.

2.1 Sites and soil analysis

The details of the seven sites are shown in Table 3 along with the cropping regime for years 4 and 5. Site 1 had been used in Levington Agriculture trials for compost work since 1999 and the same plots were continued with the same treatment design to give one site with as long a history of compost use as possible.

Table 3 The sites

	LOCATION	SOIL TEXTURE	CROPPING	
			YEAR 4	YEAR 5
1	SUFFOLK	SANDY LOAM	SUGAR BEET	WINTER WHEAT
2	SUFFOLK	CLAY LOAM	ONIONS	WINTER WHEAT
3	SUFFOLK	SANDY LOAM	ONIONS	SWEDES
4	SUFFOLK	SANDY CLAY LOAM	WINTER BARLEY	ONIONS
5	ESSEX	CLAY LOAM	NOT USED	NOT USED
6	LINCOLNSHIRE	SANDY SILT LOAM	WINTER WHEAT	NOT USED
7	LINCOLNSHIRE	SANDY CLAY LOAM	NOT USED	NOT USED

2.1.1 Soil measurements

Soil organic matter and nitrogen 2005

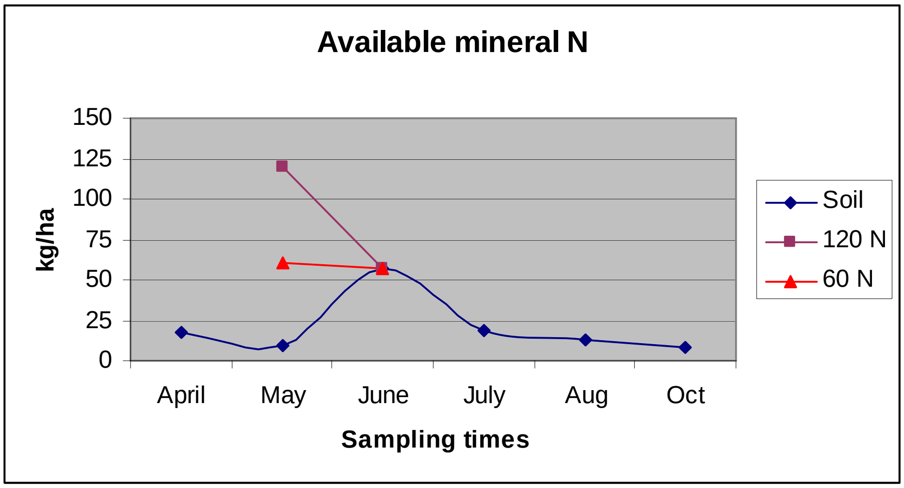
In 2005, the long term site was assessed during the season with repeated soil sampling and measurements between April and October whilst under sugar beet. Treatments 1, 2, 3, 5 and 7 were sampled, being the untreated, the farm standard and the low compost rate with varying nitrogen rates.

<u>Soil available mineral nitrogen</u>

Nitrogen fertiliser was applied to treatments 2, 3 and 7 after sampling 2 on 18 May 2005. Available mineral N was higher in the 0-30 cm soil depth than in the 30-60 and 60-90 cm soil depths. There were no significant effects of treatment on available mineral N at 30-60cm and 60-90 cm at all sampling times. There was no consistent significant effect of treatment on available mineral N at 0-30 cm at all sampling times. Plant uptake may have masked effects.

Available mineral N was significantly higher at sampling 3 (22nd June 2005) than at other sampling times, and this was reflected in the concentrations of ammonium and nitrate in the soil (Figure 1). This reflects a high rate of ammonification and nitrification in the soil during the period prior to sampling due to the warm and wet soil conditions (optimum conditions for mineralisation and similar to the conditions used in the laboratory for the mineralisable N measurement are discussed below).

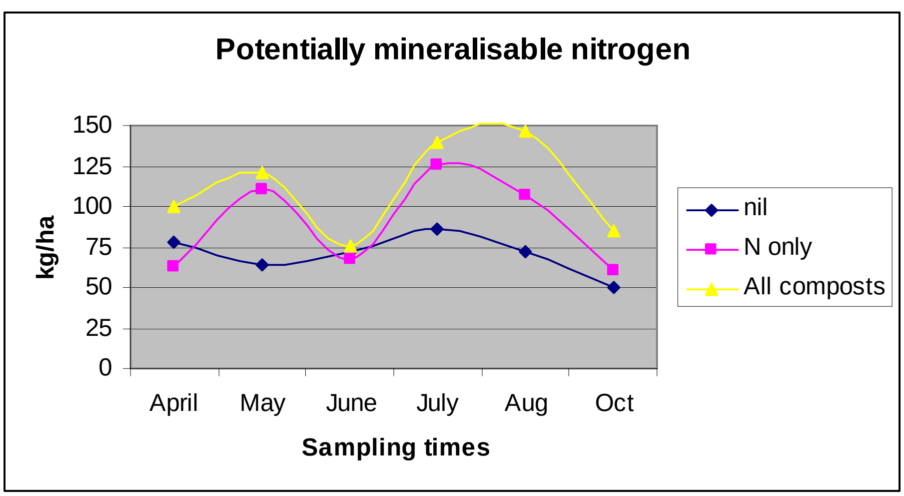
Figure 1 Soil available nitrogen kg/ha



<u>Soil mineralisable nitrogen</u>

The amount of N potentially available from mineralisation varied at the different sampling times (Figure 2). For example, the amount was lower at Sampling 3 in June, which probably reflects the fact that a large amount of N had been mineralised from the soil prior to that sampling (see above), and was therefore not available for mineralisation in the laboratory incubation.

Figure 2 Soil mineralisable nitrogen kg/ha



Mineralisable N was higher in the 0-30 cm soil depth than in the 30-60 and 60-90 cm soil depths. There were no significant effects of treatment on mineralisable N at 30-60cm and 60-90 cm at all sampling times. There were no significant effects of treatment on mineralisable N at 0-30 cm at Sampling times 1,2,3,4, however, at Sampling times 5 and 6 the compost treated soils (Treatments 3,5,7) produced significantly higher amounts of mineralisable N than the soils receiving no compost (Treatments 1 and 2).

Total nitrogen

The soils treated with compost had significantly higher total N contents than the soils which did not receive compost, and this was found at all sampling times (Table 4). Total nitrogen at 30-60 cm was an average of 0.057 % and at 60-90 cm was 0.036% with no significant treatment effects found at these depths.

Table 4 Soil total nitrogen % 0-30 cm

	April	May	June	July	August	October
Treatment						
1 UT	0.078	0.068	0.077	0.080	0.075	0.073
2 N+PK	0.079	0.070	0.077	0.074	0.070	0.066
3 C30+N	0.102	0.097	0.105	0.098	0.098	0.093
5 C30	0.094	0.089	0.096	0.101	0.097	0.092
7 C30+LN	0.102	0.094	0.099	0.095	0.092	0.086
LSD	0.007	0.014	0.011	0.011	0.012	0.011
Mean	0.091	0.084	0.091	0.090	0.086	0.082
Significance	significant	significant	significant	significant	significant	significant

Total organic carbon

The soils treated with compost had significantly higher organic carbon contents than the soils which did not receive compost, and this was found at all sampling times (Table 5).

Table 5 Soil total organic carbon % 0-30 cm

	April	May	June	July	August	October
Treatment						
1 UT	0.58	0.54	0.67	0.57	0.53	0.53
2 N+PK	0.67	0.56	0.59	0.51	0.59	0.60
3 C30+N	0.89	0.83	0.88	0.78	0.92	0.81
5 C30	0.77	0.82	0.85	0.73	0.76	0.81
7 C30+LN	0.84	0.82	0.87	0.79	0.78	0.88
LSD	0.13	0.16	0.11	0.10	0.15	0.15
Mean	0.75	0.71	0.77	0.67	0.71	0.72
Significance	significant	significant	significant	significant	significant	significant

Soil organic matter and nitrogen 2006

Measurements were made at Site 1 and Site 2 in 2006 (Table 6 & 7, respectively), both sites being under winter wheat. Some residual nitrogen from the onion crop appeared to be in the soil at Site 2 in winter 2006. Available and mineralisable nitrogen were tracked during the season. Total organic carbon and total nitrogen were measured in April 2006, a number of months after compost application.

Table 6 April OC and N soil analysis – Site 1

	Treatment	OC %	N %	C:N ratio
1 UT	UNTREATED	0.46	0.077	6.0
2 N+PK	FARM STANDARD (FS)	0.49	0.077	6.4
3 C30+N	30 T/HA COMPOST + FS	0.81	0.105	7.7
5 C30	30 T/HA COMPOST	0.75	0.126	6.0
7 C30+LN	30 T/HA COMPOST + LOW N	0.70	0.105	6.7

Table 7 April OC and N soil analysis – Site 2

	Treatment	OC %	N %	C:N ratio
1 UT	UNTREATED	0.78	0.126	6.2
2 N+PK	FARM STANDARD (FS)	0.81	0.133	6.1
3 C30+N	30 T/HA COMPOST + FS	1.11	0.154	7.2
5 C30	30 T/HA COMPOST	1.00	0.154	6.5
7 C30+LN	30 T/HA COMPOST + LOW N	1.16	0.182	6.4

Nitrogen uptake into the wheat was monitored at each site over the season by sampling biomass and analysis. At Site 1 there was no evidence of release of N from the compost, even from that applied in previous years (Figure 3). At Site 2 the N uptake was greater where compost plus N had been applied but there may have been residual effects from the previous onion crop. More research is needed on the N release from a range of composted materials to understand the N release rates.

Figure 3 Site 1 N uptake kg N/ha

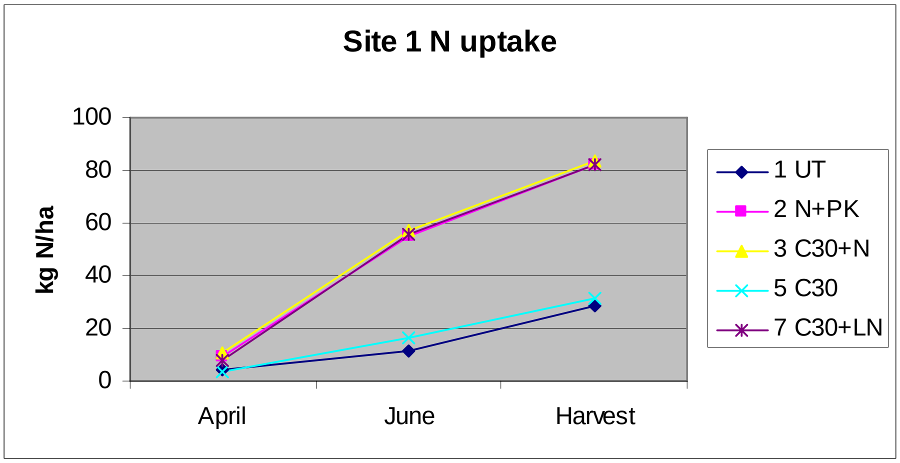
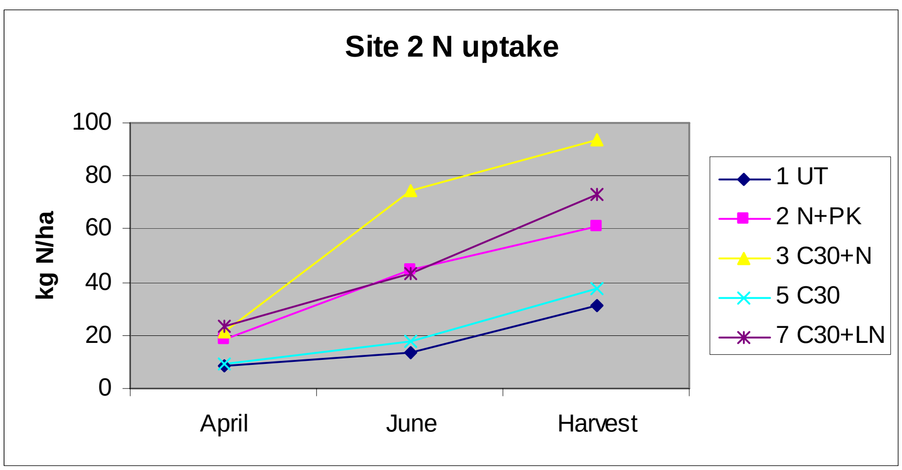


Figure 4 Site 2 N uptake kg N/ha

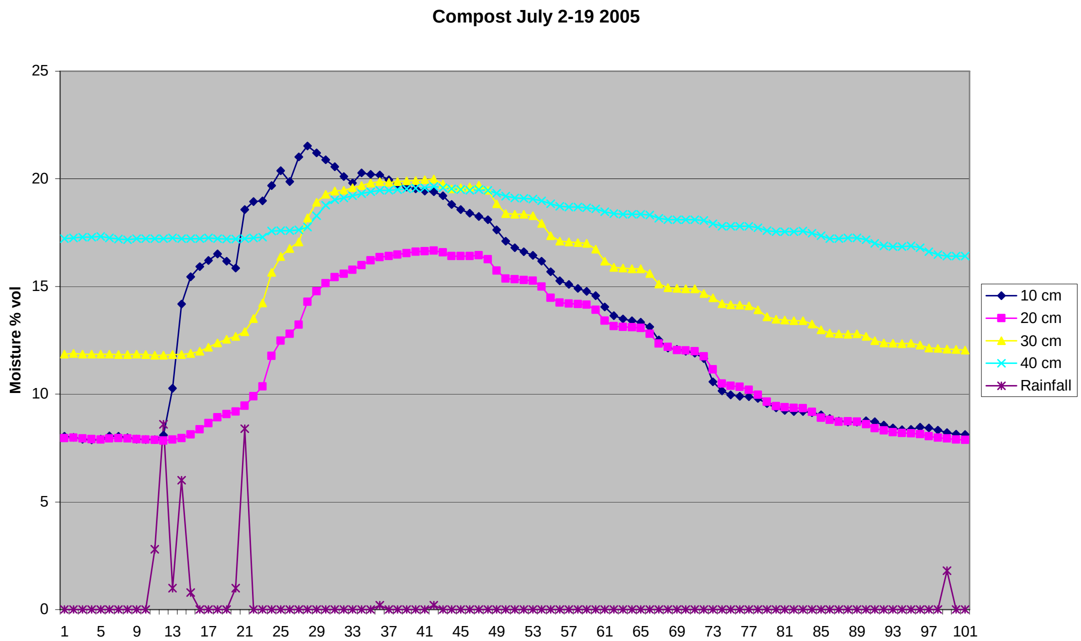


Soil moisture 2005

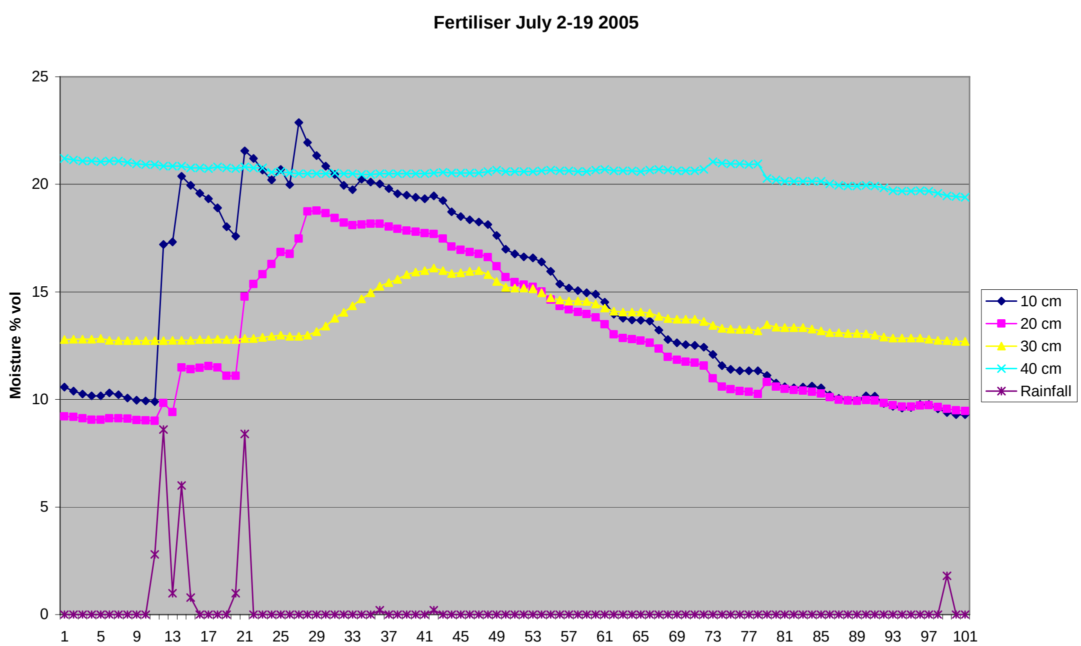
Moisture was recorded at 10, 20, 30, 40, 60 and 100 cm depths every 4 hours using Delta-T PR2 sensors and a DLT2e datalogger. Two probes were used, one in each of T3, with compost, and T2, without compost. During June the soil dried rapidly but thereafter rainfall kept the moisture between 10 and 15 %.

There were indications that where compost was present (T3), that the rainfall penetrated more deeply and more rapidly, i.e. that infiltration rate was improved compared with no compost plot T2 (Figure 5).

Figure 5 Rainfall infiltration



Note: x-axis is 4 hourly periods.



Note: x-axis is 4 hourly periods.

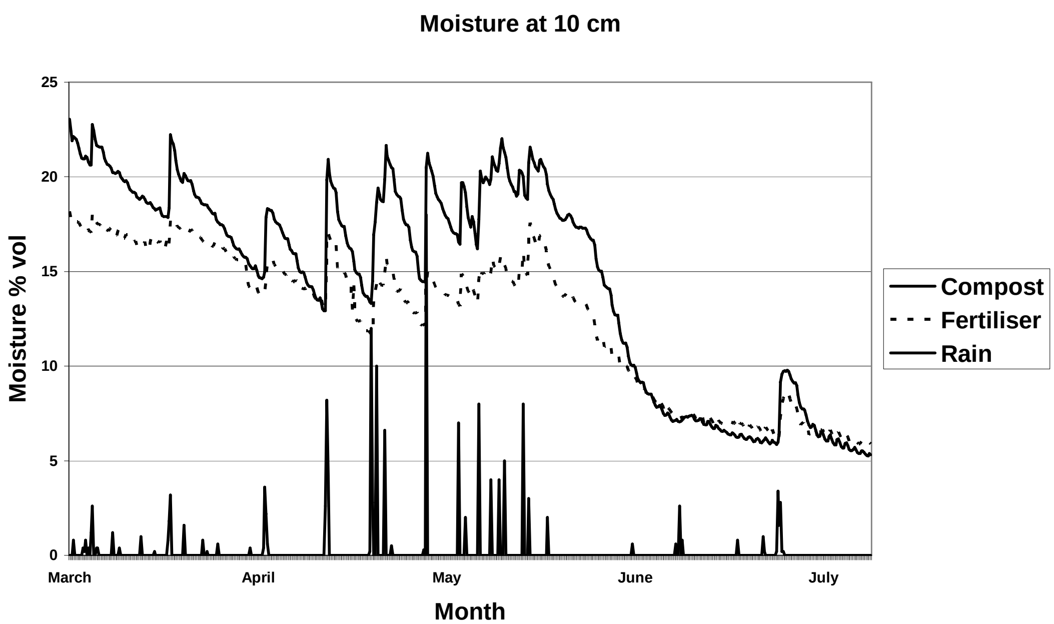
Soil moisture 2006

Wilting occurred in the winter wheat at Site 1 but no clear effect from compost was able to be seen visually. Compost use resulted in significantly less wilting in the onions at Site 4 in June 2006. A PR2 probe was installed in T2 and T3 as in 2005 in Site 1 and data was logged every 4 hours. In June 2006, the soil dried out rapidly as there was little rain. Soil temperatures rose. Mineralisation of soil organic matter and compost may have been restricted in July as it remained dry.

At 10 cm, compost amendment clearly resulted in greater ability to absorb water and water appeared to be being <u>used</u> by the crop (Figure 6). At 20 cm depth, compost amended soil showed greater fluctuations in moisture indicating that rainfall was penetrating more often to 20 cm depth.

Over April, May and June 2006 at each main rainfall event extra water was absorbed and used by the crop equal to 25 mm in all. This is 250 m^3 over a hectare.

Figure 6 T2 vs T3 moisture at 10 cm



Water infiltration 2006

Infiltration of water into the soil is perhaps the best single indicator of soil physical properties. A well structured soil can absorb rainfall better by resisting (a) the impact of raindrops and (b) the internal pressure exerted as air is forced out of the soil.

Simple measurements of saturated hydraulic conductivity can be made, for example as used in the USDA Soil Quality Assessment Guide. However, such measurements allow water to pass down large cracks and channels in the soil (e.g. root channels), and in most situations this macropore flow is undesirable (e.g. it causes rapid leaching of pesticides and fertiliser). A disk infiltrometer with variable suction was therefore used operating under a suction of 1-2 cm to prevent water flowing down macropores. Preliminary measurements were made in 3 plots only using 3 replicate measurements in each plot. The rate of infiltration of water into the compost treated plot was far greater than the control or the farm standard plots.

Clear benefits on soil water have been demonstrated over the two years. Yield increases have been linked more closely to soil improvement, leading to better plant establishment and water infiltration/usage, than to nitrogen supply.

With increasing demands on water from housing, etc, in especially the east of England, improved water relations through the use of compost to improve soil organic matter may prove to be highly significant.

Soil indicator measurements

During 2006 a number of additional measurements were made at Site 1, with a view to identifying easy-to-measure indicators that could be used to assess the improvement in soil quality in response to compost use. Particular emphasis was given to the assessment of soil physical and biological properties, areas which are not covered by standard soil analyses. Use was also made of the Visual Soil Indicators guide produced by the Soil Management Initiative.

Bulk density

Bulked soil samples were weighed in the field, analysed for gravimetric water content in the lab, and bulk density values calculated. The compost treated plots had a significantly lower bulk density than the control and farm standard plots. The data support the observation when walking over the plots that the compost treated plots had more spring under foot. This decrease in bulk density has implications for the workability of the land (less energy required to cultivate), and the pore space (improved aeration and water supply to the plants).

Nematode population

Previous attempts to show a benefit in terms of the biological activity of the soil in response to compost application at Site 1 showed mixed results. Field measurements of CO_2 flux had shown an increased rate of CO_2 production from soil in the compost-treated plots compared to control plots.

An additional measurement was made on a group of organisms which have been suggested to provide a holistic measure of the biotic and functional status of soil (Ritz and Trudgill, 1999, Plant and Soil 212, 1-11), the nematode population.

Samples of soil taken in September were analysed for total nematode populations using direct extraction and counting. These nematodes are predominantly non-pathogenic nematodes which feed on organic matter, bacteria, and other soil organisms. Nematodes are particularly important in the mineralisation of N from microbial biomass and organic matter.

The data showed that the compost plus N plots had a significantly higher population of nematodes than the other plots. This is the first indication we have seen of a link between a measure of soil biological status (in this case the nematode population) and crop yield and productivity. Further work is needed to confirm these findings.

2.2 Site responses

The number of sites was reduced to 5 in 2005 and 4 in 2006 due to funding constraints. The most responsive sites were retained. The soil analysis post 2004 of the Farm Standard treatments per site is shown in Table 8 to indicate fertility levels.

Table 8 Soil analysis post 2004

	LOCATION	SOIL TEXTURE	PH	P INDEX	K INDEX	MG INDEX	ORGANIC MATTER %
1	SUFFOLK	SANDY LOAM	7.2	3	1	1	1.9
2	SUFFOLK	CLAY LOAM	8.0	3	3	3	3.4
3	SUFFOLK	SANDY LOAM	7.5	3	1	2	1.5
4	SUFFOLK	SANDY CLAY LOAM	7.2	3	1	2	1.8
6	LINCOLNSHIRE	SANDY SILT LOAM	5.8	3	2	2	3.6

2.2.1 Site 1 responses

Soil characteristics

This long term site had had compost applied in the same treatments and plots since 1999. By the end of 2006, the soil pH, available nutrients and organic matter levels were raised where compost was applied, see Table 9.

Table 9 Site 1 Soil analysis post harvest 2006

Trt	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic carbon	Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%	%
1 UT	7.3	29	3	79	1	47	1	0.47	2.2
2 N+PK	7.2	33	3	112	1	38	1	0.51	2.1
3 C30+N	8.0	36	3	140	2-	60	2	1.10	3.1
4 C60+N	8.1	37	3	242	3	76	2	0.86	3.5
5 C30	8.0	41	3	165	2-	58	2	0.70	2.9
6 C60	8.0	40	3	216	2+	68	2	0.89	3.4
7 C30+LN	8.0	43	3	159	2-	66	2	0.76	2.9
8 C60+LN	8.0	45	3	277	3	72	2	1.13	3.7

Yields

In 2005, there was an indication (not significant) of improved plant establishment in the final beet numbers per hectare, with a very slight reduction in beet size, from compost. Yield increases (not significant) of 4.7 t/ha beet and 0.9 t sugar/ha were seen from compost use above farm standard fertilisers. Reducing inorganic nitrogen from 120 to 60 kg N/ha did not significantly reduce yields where compost was applied. Compost alone raised yields above untreated control.

The site was not irrigated and there were times of stress during a very warm, dry June and July. The extra 4.7 tonnes of beet, possibly due to improved plant establishment and water relations, was worth £141 per hectare.

In 2006 wheat was grown. There was an increase in yields from compost alone above untreated. Compost with reduced nitrogen (less 40 kg/ha) maintained yields whilst the high rate of compost with farm standard N raised yields by 1.9 tonnes/ha and increased the grain specific weight. The winter wheat was drilled late and so the fertiliser N may have been over applied as the reduced N treatments achieved good yields.

2.2.2 Site 2 responses

Soil characteristics

Soil organic matter and available potassium were raised by compost addition, as shown in Table 10, after the fifth year.

Table 10 Site 2 Soil analysis post harvest 2006

Trt	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic carbon	Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%	%
1 UT	8.2	12	1	144	2-	115	3	0.51	3.6
2 N+PK	8.2	19	2	225	2+	103	3	0.64	3.3
3 C30+N	8.2	14	1	242	3	109	3	0.74	4.1
4 C60+N	8.2	15	1	292	3	107	3	0.95	4.0
5 C30	8.2	16	2	254	3	125	3	1.01	4.2
6 C60	8.2	17	2	320	3	133	3	0.78	4.1
7 C30+LN	8.1	14	1	265	3	102	3	1.01	3.9
8 C60+LN	8.1	16	2	335	3	136	3	0.91	4.3

Yields

There were significant effects in the onion yields in 2005. The rate of nitrogen in the farm standard rate may have been too high as the best yields were obtained with the lower N rate and even no nitrogen but plus compost gave good yields. Yields were in general higher where compost had been applied.

There may have been some residual nitrogen from the onion crop's fertiliser that resulted in some mineral nitrogen being available to the following winter wheat crop. Alternatively there may have been some mineralisation of soil organic matter and compost in the autumn. The compost alone treatments did record a higher wheat yield than untreated. Compost increased yields with full nitrogen by over 1.3 tonnes/ha and also increased yields by 0.8 tonnes/ha with reduced nitrogen (by 40 kg/ha) compared with farm standard.

2.2.3 Site 3 responses

Soil characteristics

On this sandy soil, organic matter was raised by compost addition (Table 11).

Table 11 Site 3 Soil analysis post harvest 2006

Trt	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic carbon	Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%	%
1 UT	7.4	44	3	104	1	90	2	0.25	1.6
2 N+PK	7.3	41	3	142	2-	83	2	0.23	1.6
3 C30+N	7.3	41	3	111	1	80	2	0.25	1.8
4 C60+N	7.4	44	3	140	2-	101	3	0.53	2.1
5 C30	7.7	48	4	135	2-	90	2	0.42	1.9
6 C60	7.7	46	4	176	2-	104	3	0.40	2.2
7 C30+LN	7.6	46	4	169	2-	99	2	0.47	2.2
8 C60+LN	7.7	44	3	113	1	93	2	0.42	2.1

Yields

In year 4, the onion crop was harvested but there were no significant differences in yield between treatments. It would appear that the nitrogen rate may have been too high in the farm standard but that compost was able to help overcome this.

Swede yields in 2006 were somewhat variable on this sandy site but benefit from compost was seen.

2.2.4 Site 4 responses

Soil characteristics

On this light soil, organic matter levels and pH improved relative to the controls due to the application of compost (Table 12).

Table 12 Site 4 Soil analysis post harvest 2006

Trt	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic carbon	Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%	%
1 UT	7.1	31	3	161	2-	82	2	0.34	1.7
2 N+PK	6.9	34	3	159	2-	79	2	0.52	1.9
3 C30+N	7.2	37	3	161	2-	84	2	0.48	2.4
4 C60+N	7.2	44	3	173	2-	91	2	0.73	2.6
5 C30	7.3	42	3	189	2+	96	2	0.59	2.5
6 C60	7.3	37	3	177	2-	81	2	0.51	2.3
7 C30+LN	7.2	42	3	161	2-	78	2	0.48	2.2
8 C60+LN	7.4	37	3	132	2-	76	2	0.52	2.3

Yields

There were no significant differences in the yields of winter barley at this site in 2005, probably as cereals tend to be less responsive to compost due to the slow nitrogen release rate.

In 2006, compost improved onion yields but only significantly so in treatment 4 compared with farm standard. The farmer was pleased with the effects compost was having on the soil condition and improved ease of irrigation management. Benefits were apparent in the visibly reduced stress in the crop and an indication of improved yields.

2.2.5 Site 6 responses

Soil characteristics

Organic matter levels were increased at this site even though the initial site organic matter was relatively good, possibly due to interactions with the clay content of the soil (Table 13). There were also indications of improved available potassium levels from the use of compost. This site was only used until year 4, 2005.

Table 13 Site 6 Soil analysis post harvest 2005

Trt	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%
1 UT	6.4	30	3	159	2-	65	2	3.8
2 N+PK	6.1	29	3	180	2-	67	2	4.2
3 C30+N	6.8	31	3	208	2+	74	2	5.1
4 C60+N	6.5	32	3	225	2+	88	2	5.3
5 C30	6.5	26	3	267	3	86	2	5.1
6 C60	6.5	31	3	237	2+	70	2	4.9
7 C30+LN	6.4	34	3	269	3	100	2	5.8
8 C60+LN	6.4	29	3	161	2-	84	2	4.2

Yields

Untreated plots yielded less wheat than all other treatments but there were no other differences between treatments.

2.3 Conclusions from field trials

2.3.1 Soil analysis

Soil pH was marginally raised by the addition of compost compared with farm standard fertilisers alone. Compost was equal to fertiliser in maintaining the soils' available phosphate levels. Available potassium was raised by the use of compost and magnesium levels were maintained. Organic carbon was increased, but not greatly, by compost but further work is required to determine if all compost organic matter is measured by the Walkley-Black method for oxidisable carbon. Organic matter as measured by loss on ignition was shown to be increased by compost (Table 14).

Table 14 Soil analysis post harvest 2006 All 4 trials

Field Name	pH	Phosphorus (P)		Potassium (K)		Magnesium (Mg)		Organic Carbon	Organic matter
		mg/l	Index	mg/l	Index	mg/l	Index	%	%
1 UT	7.5	29.0	3	122.0	2-	83.5	2	0.4	2.3
2 N+PK	7.4	31.8	3	159.5	2-	75.8	2	0.5	2.2
3 C30+N	7.7	32.0	3	163.5	2-	83.3	2	0.6	2.9
4 C60+N	7.7	35.0	3	211.8	2+	93.8	2	0.8	3.1
5 C30	7.8	36.8	3	185.8	2+	92.3	2	0.7	2.9
6 C60	7.8	35.0	3	222.3	2+	96.5	2	0.6	3.0
7 C30+LN	7.7	36.3	3	188.5	2+	86.3	2	0.7	2.8
8 C60+LN	7.8	35.5	3	214.3	2+	94.3	2	0.7	3.1
Significance	*	*		*		NS		**	***
LSD (P=0.05)	0.26	4.6		57		13.8		0.2	0.33

2.3.2 Yields

All yields have been shown as a percentage relative to Farm Standard treatment.

The yields in 2005 were rather variable, possibly due to the very warm June and July. The overall indication was that yields were increased through the use of compost and that annual applications were more effective (no compost applied this year where 60 t/ha indicated) (Table 15).

Table 15 Year 4 Yield responses % relative to Farm Standard

Sites:	1	2	3	4	6	
	Sugar beet	Onions	Onions	Barley	Wheat	Mean
1 UT	74	88	115	84	83	89
2 N+PK	100	100	100	100	100	100
3 C30+N	104	116	144	100	101	113
4 C60+N	105	109	133	105	91	109
5 C30	83	114	168	95	103	112
6 C60	89	105	157	89	103	108
7 C30+LN	98	115	171	111	103	120
8 C60+LN	96	120	170	100	110	119
Significance	***	*	NS	NS	*	
LSD (P=0.05)	13	16			16	

In 2006, year 5, there was again a very dry period in the summer (Table 16). The onions were irrigated.

Table 16 Year 5 Yield responses % relative to Farm Standard

Sites:	1	2	3	4	
	Wheat	Wheat	Swedes	Onions	Mean
1 UT	53	40	69	80	60
2 N+PK	100	100	100	100	100
3 C30+N	108	113	136	111	117
4 C60+N	126	115	132	124	124
5 C30	73	55	85	92	76
6 C60	79	58	124	89	88
7 C30+LN	105	108	151	112	119
8 C60+LN	105	109	129	110	113
Significance	***	***	**	***	
LSD (P=0.05)	16	9	38	18	

The combination of benefits brought by additions of compost gave an average yield increase of 7 % over the whole 5 year period of the trials (Table 17). Even at the 'low N' rates, reduced by up to 40 kg N/ha to take into account N released from the compost plus the effects of improved fertiliser-N use efficiency, the same yield increases were realised.

Table 17 All yields relative to Farm Standard 2002-2006

Treatment	All sites
	%
1 UT	74.4
2 N+PK	100.0
3 C30+N	106.7
4 C60+N	109.0
5 C30	87.3
6 C60	89.4
7 C30+LN	107.8
8 C60+LN	110.4
Significance	***
LSD (P=.05)	6.7

3. ECONOMICS

It has been shown that compost used at an average of 40 t/ha annually (or at a higher rate but only every two years) resulted in an average increase in yield over the whole period of 7%. The increase in yields may be from improved soil conditions, nutrient supply, water availability, etc. The value of compost can therefore be ascertained from the increase in yields and fertiliser replacement costs. Additional value could be added from water savings where irrigation is practised. Water costs were in the region of £75 per hectare per 25 mm application.

Farm Standard fertiliser application costs were compared with the application of compost coupled with reduced nitrogen applications over a 5 year rotation (barley, potatoes, barley, sugar beet and wheat) on soils at Index 2 for phosphorus and potassium. The crop yields and values are shown in Table 18.

Table 18 Crop yields and values

	Barley	Potatoes	Barley	Sugar beet	Wheat	5 yr Total
Value £/t	60	150	60	30	65	
Yield t/ha	8	50	8	90	10	
Value £/ha	480	7,500	480	2,700	650	11,810
Yield + 7% t/ha	8.56	53.5	8.56	96.3	10.7	
Value £/ha	514	8,025	514	2,889	695	12,637

Fertiliser costs were based on nitrogen at 0.46 £/kg, phosphate at 0.235 £/kg and potash at 0.30 £/kg. Compost cost delivered and spreading were £2.50 and £1.50 per tonne respectively. An annual application rate of 30 t/ha has been assumed in line with NVZ regulations. Based on the nutrients in Table 19 and these costs, the costs per treatment are shown in Table 20.

Table 19 Fertiliser recommendations kg/ha

	P	K	N	Low N
Soil index	2	2-		
Barley	60	45	180	140
Potatoes	180	300	160	120
Barley	60	45	150	110
Sugar beet	50	100	100	60
Wheat	75.6	56.2	220	180

Table 20 Costs £ per treatment

				FS	C30 + LN
	P	K	N	Total	Total
Barley	14.10	13.50	82.80	110.40	184.40
Potatoes	42.30	90.00	73.60	205.90	175.20
Barley	14.10	13.50	69.00	96.60	170.60
Sugar beet	11.75	30.00	46.00	87.75	147.60
Wheat	17.77	16.86	101.20	135.83	202.80
Total Cost/ha	100.02	163.86	372.60	636.48	880.60

The total cost per hectare of farm standard fertilisers (N+PK) over 5 years is £636 compared with Compost plus low nitrogen (C30 + LN) of £880. The value in the increase in yield is £827/ha and so the net benefit is £583/ha over 5 years or £116/ha/year. This is after the costs of the compost and its application have been taken into account. If the rate of applications/or frequency of applications are reduced benefits will still be seen but soil improvement, and hence yield increases, may occur at a slower rate. The rate of return will also depend on the value of the crops being grown and the size of the response in each particular soil.

4. CONCLUSIONS

These long term trials tested the theory that the addition of organic matter and nutrients from the application of compost improves soil fertility. Key benefits were quantified relating to the physical condition of the soil: organic matter, soil structure and water relations; soil chemistry: soil pH, nutrients; and soil biology: increased microbial populations and activity.

It was demonstrated that these benefits contributed to an average yield increase of 7% where compost had been used regularly. Where transport costs can be kept low, it was shown that regular use of compost is economically viable on arable soils. The rate of return will depend on the value of the crops being grown and the size of the response in each particular soil.

Up to 30 tonnes of compost per hectare, applied annually, led to the 7% average increase in yields on the trial sites. It was shown that the use of nitrogen fertilisers can be reduced below RB209 recommendations without losing the yield increase found by using compost. However, if the rate of applications/or frequency of applications are reduced benefits will still be seen but soil improvement, and hence yield increases, may occur at a slower rate.

5. DISSEMINATION

Significant effort was placed into the dissemination of the results of the project. In the last two years, the following activities and articles were undertaken or written:

An article appeared in ‘Farmers Weekly’ in March 2005 on compost use.

An edited version of the executive summary of the first consolidated report (2002-2004) appeared in the summer edition of the Composting Association News in time for the Royal Show 2005.

Phil Wallace attended the Royal Show 2005 and made the Compost Use in Agriculture leaflets available to ReMaDe Essex on their stand. 500 copies were also printed and made available at Cereals 2005 in June through a spreading contractor, Keith Mount Liming, who is diversifying into compost applications.

A presentation on the project was given to the HGCA in London in December 2005 and to the BPC in February 2006.

Phil Wallace met with Defra and the EA on 17th January 2006 as part of a WRAP funded project on guidelines for compost use in crop production. They were made aware of the results which have contributed greatly to our understanding of the benefits of compost use in agriculture and the development of the guidelines.

On 20th June 2006 representatives of WRAP were given a tour of the trials.

Phil Wallace presented an outline of the project at the r^3 Environmental workshop due on 21st July 2006 At Reading University.

An article was prepared and appeared in the ‘Crops’ magazine in November 2006.

An updated A3 sized leaflet was produced for the Composting Association’s annual conference on December 6-7 2006. Over 400 have been distributed.

Phil Wallace was a speaker at the Composting Association’s annual conference in Brighton in December 2006 where the results from the trials were presented.

Martin Wood gave a talk on the project to an HGCA meeting, and Phil Wallace gave a talk to the HGCA steering group. Martin Wood also gave a talk to the South East England Soils Group during the autumn.

WRAP funded the production of an A1 sized poster and this was presented at the AICC conference in January 2007.

Articles were written in February 2007 for ‘Anglian Farmer’, ‘Farming Wales’, ‘FarmLife’ and ‘Scottish farmer’.

All reports and leaflets have been made available through the website www.compost.me.uk.