LOUIS BOLK INSTITUUT

The MAC trial

Results from a long-term organic inputs trial

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Results from the MAC trial

The *MAC field trial (Manure As a Chance)* is used to compare 13 different fertilisation strategies. The trial involved different types of animal manure, vegetable compost and mineral fertiliser.
In 2006, when the trial was well into its eighth year, a number of treatments were studied in detail. The results are summarised below

	Evaluation criterion	Yield and yield quality	Soil quality	Disease pressure	Environmen	Climate change	
Manure, compost type	Indicator	Yield of fresh product and dry matter content 1999	Potential nitrogen mineralisation	Parasitic nematodes	Phosphate surplus and nitrate leaching	Carbon sequestration	Overall score
Deep stable manure, fresh		+	+	0	0	+	+
Slurry		–	+	0	0	–	–
Mineral fertiliser		0	–	–	+	0	–
Household compost with slurry		0	+	+	–	0	0
Poultry manure		–	0	+	–	0	+
Plant compost		–	+	–	+	+	+

The effects can be measured for both the farmer and the broader public:

Yield Solid animal manures give the highest yields after 8 years. Fertilisers which supply little or no organic matter show a decline in yield over the years.

Quality A high yield often means lower quality. Some fertilisers, such as deep stable manure and plant-based compost, score well on both yield and quality.

Soil quality If soil quality is evaluated in terms of capacity to supply nitrogen, the deep stable manure, slurry and plant compost score highest.

Disease supression The combined household waste compost + slurry, and poultry manure treatments produce the least number of harmful nematodes. Deep stable manure suppresses Rhizoctonia.

Environment Plant compost and mineral fertiliser score highest in terms of low concentrations of phosphates and nitrate leaching.

Climate change It is important to retain or build up organic matter in order to limit carbon dioxide emissions.
In this respect deep stable manure and plant compost perform better than the other treatments.

Choosing the best fertiliser type

There are many factors to consider when deciding how to fertilise agricultural crops. Each fertiliser has its advantages and disadvantages, and they are not easy to weigh up. Multi-year research into the divergent effects of fertilisers can help considerably. In the first instance it is important to know how to achieve the maximum yield for the minimum cost. The next question is whether the choice of fertiliser based on this premise will continue to give a good yield over the slightly longer term. Think, for example, of the build-up of organic matter in the soil. Another question is whether a high yield will also give you a high-quality product. You also have to consider the effect of nitrogen and phosphates on surface water. There may be a link between fertiliser use and disease suppression; and this in turn affects production losses due to pests and diseases, and the use of crop protection products. In respect of climate change it is important to maintain, or (based on the field trial) even increase the organic matter content. Finally biodiversity is increasingly considered as an important end in itself. With so many issues to consider it is not easy to make the right choice. In this publication we discuss the work done in the field trial and the most significant results after eight years.

The MAC experimental plot was set up in 1999 as part of the ***Mest als Kans*** research project which ran from 1999 to 2001. In 2006 the effects of the different fertiliser and compost types were examined in detail as part of the *Investeren tot in de Bodem* (Investing down to the soil) project (2006, 2007).

Set-up The purpose of the trial was to demonstrate how to use organic fertilisers in agriculture. Many aspects were taken into account. Initially the emphasis was mainly on the impact of the choice of fertiliser on yield and product quality. Now agriculture has to move towards a balanced fertilisation (to balance mineral inputs and outputs). Is it important to apply large amount of organic matter, or can it be limited, or even omitted? And what are the long-term effects? To answer these questions we selected a number of commonly used fertilisers, which vary widely in nutrient levels, and in content and composition of organic matter.

Deciding how much fertiliser to apply There are three distinct groups among the selected fertilisers:

- Fertiliser used exclusively, or almost exclusively, for the purpose of crop nutrition: mineral fertiliser and slurry
- Fertiliser used both for crop nutrition and to build up soil characteristics: solid animal manure
- Fertiliser used almost exclusively to build up soil characteristics: plant-based composts.

Manure and compost addition was limited by a maximum nitrogen mineralization of 100 kg nitrogen per ha per year from the fertiliser applications. As fertiliser was applied two years in three, the average application of nitrogen mineralised from fertilisation was 67 kg per ha per year.

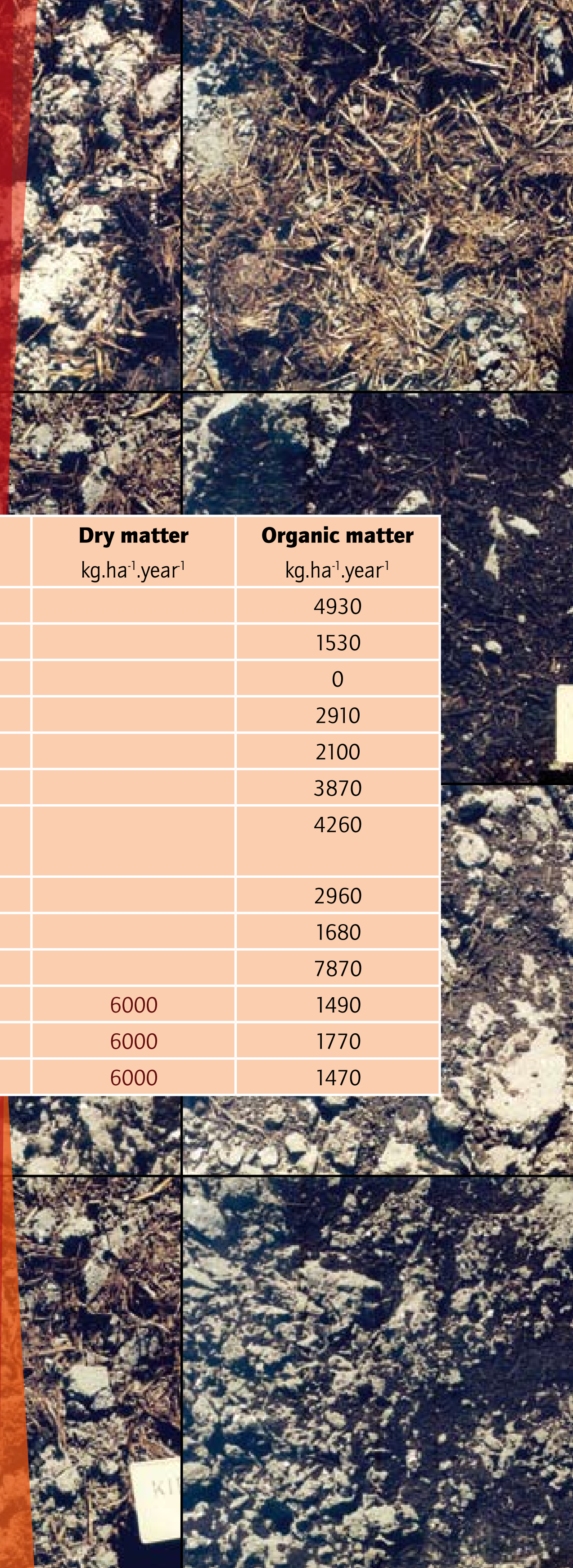
However, if 100 kg of mineralised nitrogen would mean applying more than 120 kg P_2O_5 per ha, then 120 kg P_2O_5 per ha was taken as the maximum instead. 120 kg P_2O_5 per ha could also be applied in the case of the plant compost (with low levels of heavy metals). With fertiliser being applied two years in three, an average of 80 kg P_2O_5 per ha was applied (the valid statutory norm at the start of the trial). As poultry manure is rich in phosphates, an extra treatment of poultry manure with cattle slurry was included. This gives a clearer picture of the practical use of poultry manure on the farm.

In the case of household waste and plant compost only the legally permissible level of 6000 kg dry matter per hectare per year was applied, which meant that the 100 kg nitrogen mineralised per ha and the 120 kg P_2O_5 per ha levels were not achieved in these treatments. As this did not constitute a complete fertilisation programme, an extra treatment was added. This was a combination of household waste compost and cattle slurry, with a total of 100 kg N-mineralised per ha. This created the following treatments:

Type	Fertiliser type	N mineralised kg.ha-[1].year-[1]	P_2O_5 total kg.ha[1].year[1]	Dry matter kg.ha[1].year[1]	Organic matter kg.ha[1].year[1]
1	Deep stable manure, fresh	67	66		4930
	Slurry, cattle	67	35		1530
	Mineral fertiliser	67	43		0
	Household compost with slurry	67	69		2910
	Poultry manure with slurry	67	80		2100
2	Poultry manure with slurry	45	80		3870
	Deep stable manure, intensively composted	45	80		4260
	Pig manure	41	80		2960
	Poultry manure	47	80		1680
	Plant compost	24	80		7870
3	Household compost	9	57	6000	1490
	Plant compost low quantity	8	48	6000	1770
	Plant compost (CMC method)	8	29	6000	1470

In the case of the type 3 treatments (household and plant compost) considerably less nitrogen was applied than in the other treatments. In the treatments with little or no organic matter, such as mineral fertiliser, poultry manure and slurry, far less soil mineralization (i.e. nitrogen from previous years' fertiliser applications) was built up than in, say, the stable manure treatment. This must be taken into account when evaluating the results.

Trial set-up The trial was laid out in a randomised block design with 13 treatments in four replications. The trial is located north of Lelystad in the centre of the Netherlands (52.32ºN,5.30ºE).



The soil of the experimental plot. A light sandy clay (loam) with 30 cm topsoil and a stratified subsoil typical of the Flevopolders. Dark seams are formed by the sedimentation of layers of peat.

The soil

The soil is a calcium-rich loam with 9% clay and 4.4 % lime. At the start of the trial the organic matter content of the topsoil was 1.6%. The topsoil was around 30 cm deep and beneath that was the stratified, uncultivated subsoil, with alternating light humus-containing and humus-poor strata. There were pores through to the subsoil. (This enables roots to take up moisture from the soil throughout the year). The groundwater depth varied from 90 to 120 cm.

Crop rotation

The trial was included in the organic rotation of the host farm. The intensity, without using green manures, is quite common in the Netherlands. The following crops were grown:

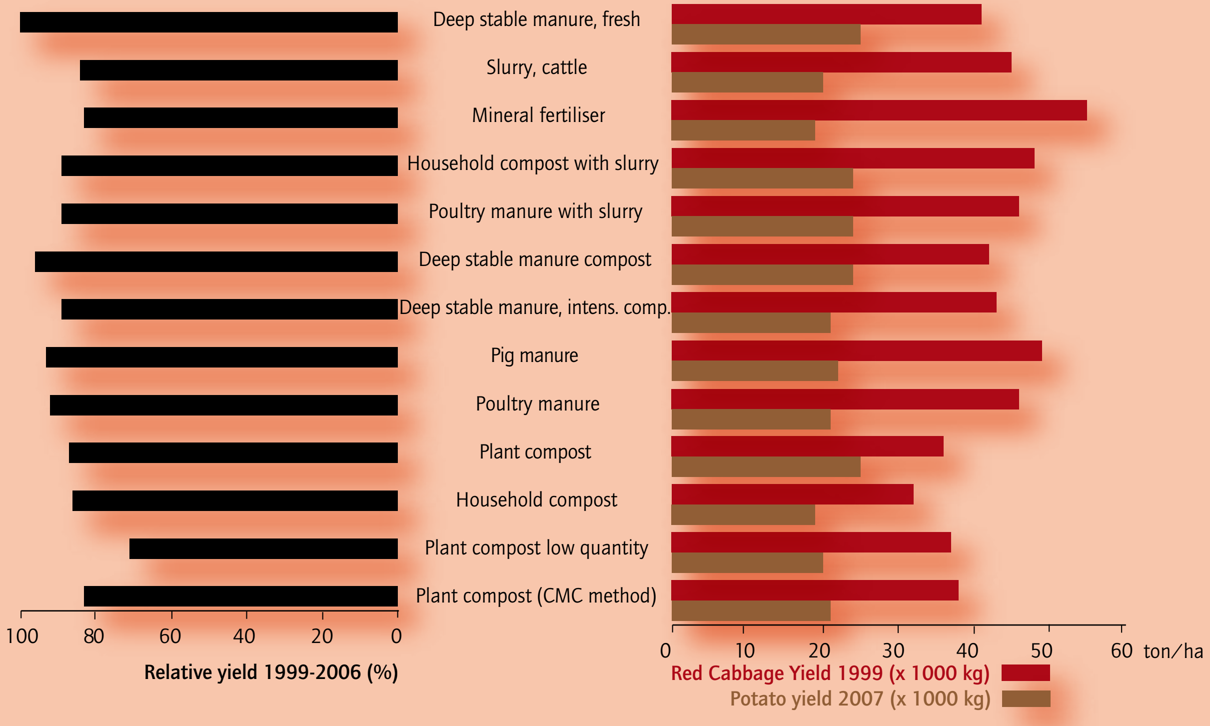
Year	Crop	Fertiliser applied
1999	Red cabbage	Yes
2000	Potato	Yes
2001	Autumn beet	Yes
2002	Carrot	No
2003	Parsnip	Yes
2004	Broccoli	No
2005	Squash	Yes
2006	Cauliflower	Yes
2007	Potato	No

The experimental plot was treated in accordance with the common operations of the host farm, including tillage and crop maintenance. There was no spraying or sprinkling. The Fertilisers were applied in May of each year.

At the start of the trial, the mineral fertiliser treatment had the highest yield with red cabbage. Over the years the yields in the mineral fertiliser treatment declined because of a lack of soil building over time.

Yields

Yield is a significant factor, as growers are usually paid according to yields. Thus the highest yielding treatment seems preferable to the other treatments. However, that is not necessarily the case. Changes in legislation towards an equilibrium fertilisation might also affect decisions about which fertiliser to use. Fertilisers which improve soil fertility could raise yields slightly in the long term. When evaluating yields it is important to distinguish between the three groups of fertilisers: those with an average of 67 kg N-mineralised per ha per year (group 1); those with an average of 80 kg P_2O_5 per ha per year (group 2) and those with an average of 6000 kg dry matter per ha per year (group 3).



Relative yields as a percentage of maximum yields found in the deep stable manure calculated over all crops from 1999 to 2006. Solid manure types scored higher than compost types.

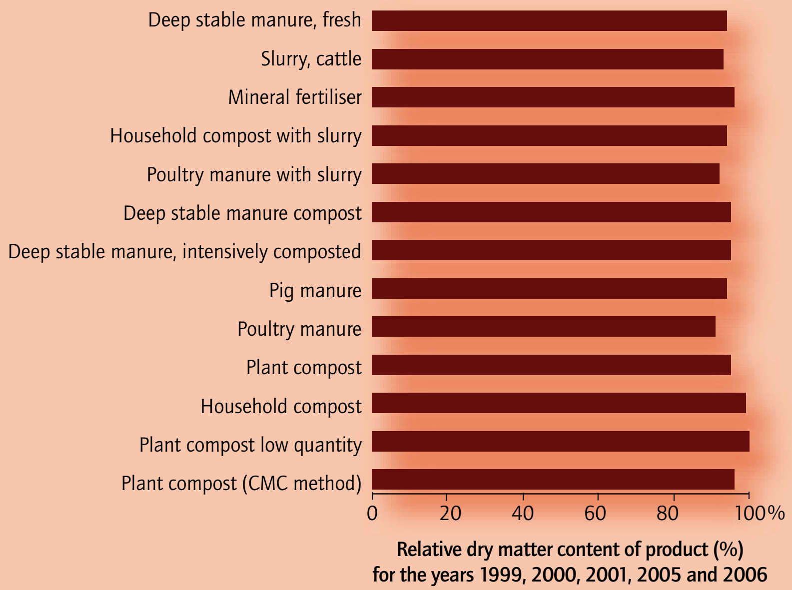
The yields of cabbage in 1999 at the start of the trial and those of potato in 2007 show interesting differences. In 1999 the mineral fertiliser treatment had the highest yield. In 2007 the deep stable manure and plant compost showed highest yields. This may be explained by the soil building capacity of the plant-compost treatment.

Over the years fresh deep stable manure produces a relatively high yield.
The intensively composted stable manure gives a lower yield than the non-composted equivalent, and aged compost. Intensive composting means that the compost is turned frequently by machine over a six-week period. This leads to nitrogen losses, which probably explains the lower yield.
It is interesting that the slurry + household waste compost treatment (6000 kg dry matter per year on average) showed a higher yield than slurry on its own. This is because the household waste compost improves soil fertility. Mineral fertiliser gave low yields. The same amount of N-mineralised was applied with the mineral fertiliser as with the stable manure types, but mineral fertiliser does not lead to a build up of N mineralization in the soil. Plant compost low quantity, CMC compost and household waste compost resulted in relatively low yields. In these cases only 6000 kg dry matter per year was applied, which is apparently not enough for an optimal growth under these conditions. Yields increased in the range plant compost low quantity, CMC compost, and household waste compost. A logical sequence if the richness of the composts is taken into consideration.

In 2001 red beet on the plant compost treatment had the best taste and a high dry matter content.

Product quality

Product quality is a broad concept: it includes taste and health, as well as appearance. Different aspects play a role in each different product and often there are no unequivocal standards. Over the course of the trial we determined the dry matter content of several products. The dry matter content is related to the sugar content, and so to taste.



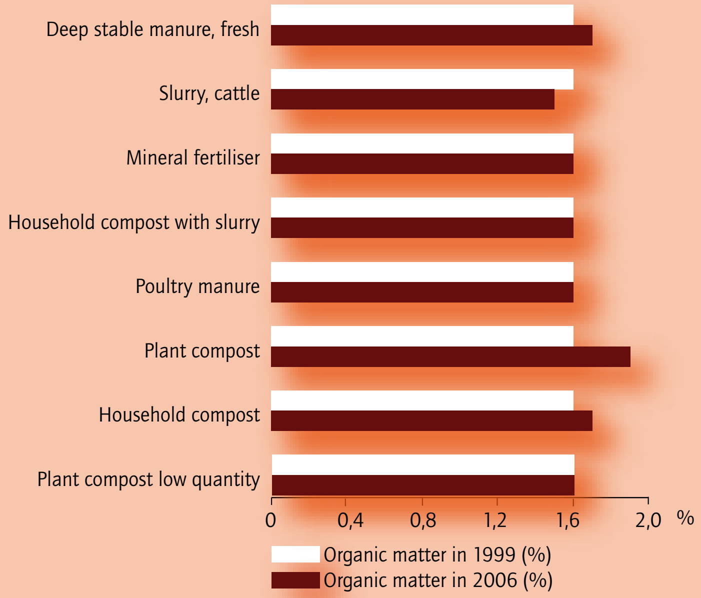
The treatments with low yields such as mineral fertiliser and the low-dose plant- and householdcompost types produced high dry matter contents over the years. Deep stable manure, whether composted or not, combined a higher yield with a higher dry matter content.

In relative terms the composts applied resulted in the highest dry matter content of the produce. These were the treatments with lowest yields. Treatments with relatively high yields, such as pig manure, poultry manure + slurry and poultry manure alone, produced a low dry matter content. The combination of a relatively high yield and a higher dry matter content was found in the case of composted deep stable manure and fresh deep stable manure. Slurry produced a low yield and low dry matter content.

Ridges for parsnip growing in 2003. The soil is easy to work, but the sheer number of mechanical operations inhibits the build up of organic matter.

Organic matter in the soil

The organic matter content is an important characteristic of the soil. For the plant it is important that the soil provides moisture and nutrients but also enough oxygen. All these characteristics are influenced by the organic matter content. It is harder to build up organic matter on light soils and calcareous soils where the rate of decomposition is faster compared to heavy soils. When the soil is heavily worked to create ridges for root crops and then to harvest them, it is more difficult to build up organic matter. On the trial plot we were dealing with a light and calcareous soil, which was also intensively worked. Thus it is not surprising that the organic matter content was only 1.6 % at the beginning of the trial.



The greatest increase in organic matter content was found in the plant compost treatment.

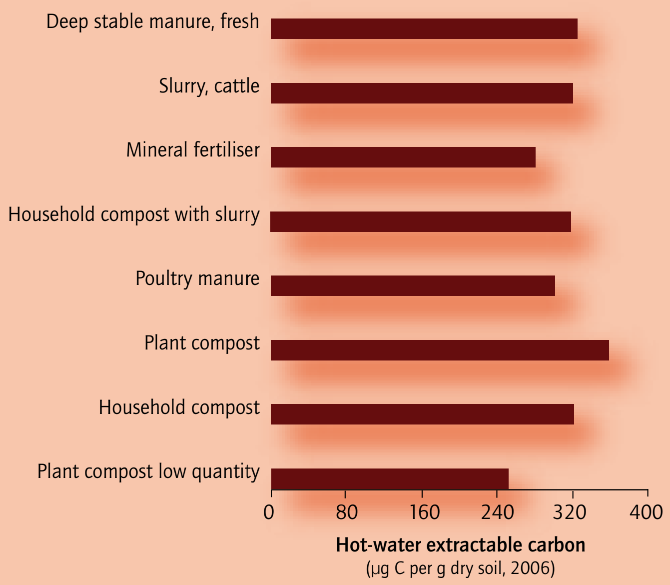
In 2006, after a good 7 years, the organic matter content had clearly risen in the plant compost treatment, with the high dose of organic material. The fresh deep stable manure and household waste compost treatments also resulted in a higher organic matter content. The organic matter content fell slightly in the slurry treatment. There were no clear changes in the other treatments.

High quantity plant compost just before it is incorporated >

Given the low organic matter content in the experimental plot, the quality of the organic matter is especially important.

The quality of the organic matter in the soil

The organic matter content is an important characteristic of the soil, but the content itself does not indicate how much the organic matter nurtures soil life, whether it affects the soil structure or provides nutrients: these things are determined by the quality of the organic matter. There are many ways to characterise the quality of the organic matter. One is to measure the hot-water extractable carbon. The bacteria population and the formation of small aggregates are linked to the quantity of extractable carbon. It has also been shown that the bacterium E. coli O157:H7 breaks more rapidly where there is a higher level of soluble carbon. This bacterium is increasingly common in animal manure.



Plant compost, deep stable manure and household waste compost + slurry produce more easily extractable carbon in the soil.

Poultry manure, mineral fertiliser and plant compost low quantity produce little extractable carbon. It should be noted here that plant compost was applied in small quantities in this trial (1770 kg organic matter per year). However, household waste compost applied in roughly the same quantity (1500 kg organic matter per year) gave a higher value. Deep stable manure and plant compost in a higher quantity produced the most solute organic matter (4930 and 7870 kg organic matter per year respectively).

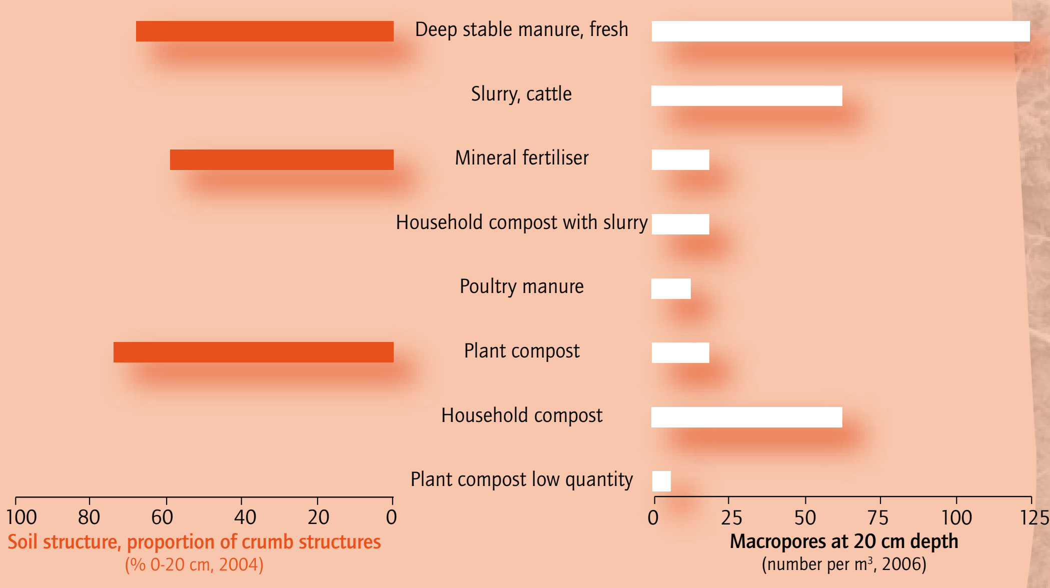
After growing pumpkin in 2005 the soil was highly compacted. The soil structure was better in the case of broccoli growing in 2004, particularly in the treatments using deep stable manure and plant compost.

Soil structure

There are three distinct layers in the soil profile: the topsoil, around 30 cm deep, a compacted layer of about 20 cm below that, and the subsoil.

The soil structure of the topsoil varies considerably. If a crop has intensive root growth and the soil is well covered, the structure remains good for a long time. Compaction is more rapid where rooting is less intense, and the soil is more open.

The layer under the topsoil is currently compacted. This is due to intensive use of machinery. As a result water pools form periodically on the soil surface. The subsoil is stratified, but penetrable: once the roots reach the subsoil they are well able to penetrate it. This is extremely important for the supply of moisture.



The soil structure varies widely during a single year and over several years. In 2004 the soil structure was better in the plant compost and deep stable manure treatments than in the mineral fertiliser treatment.

The large numbers of macropores in the deep stable manure treatment indicates greater earthworm activity.

The soil structure was studied in 2004 and 2006. In 2004 the study was limited to the deep stable manure, mineral fertiliser and plant compost treatments. At that time the proportion of crumb in the top 20 cm was significantly lower in the mineral fertiliser treatment. This may have been due to less active soil life.

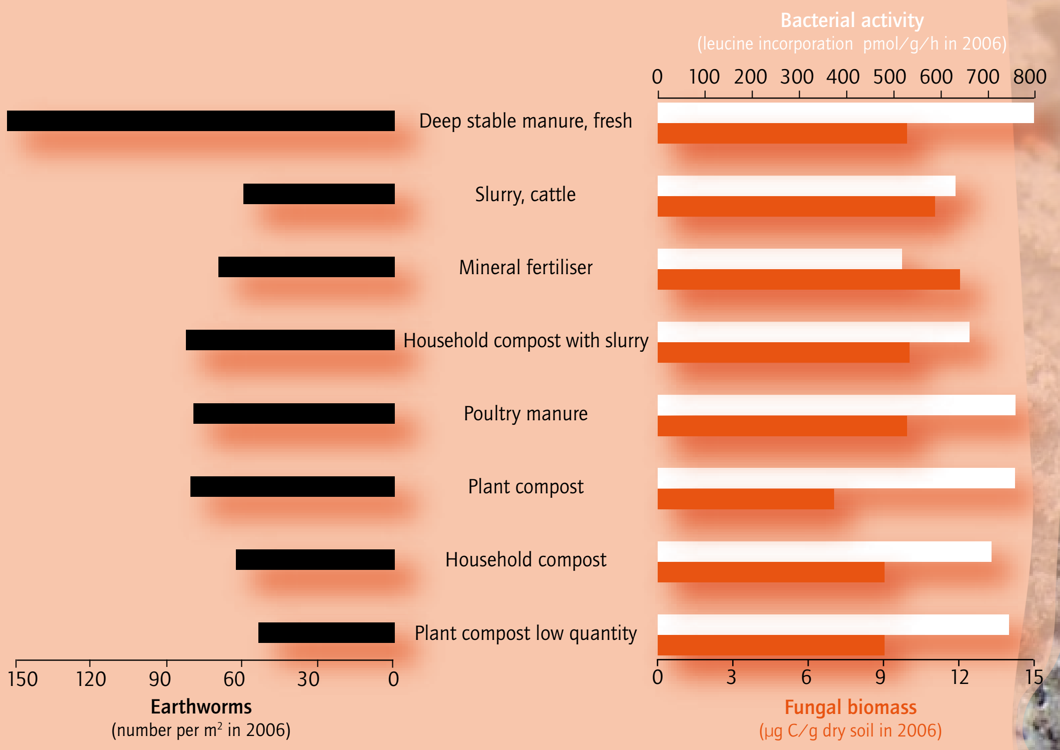
In 2006 there was no demonstrable difference in soil structure between the 8 treatments investigated at the time. However, in 2006, a higher number of vertical pores were measured at a depth of 20 cm with a diameter over 2 mm in the deep stable manure treatment. These pores are mainly formed by earthworms and, among other things, help the roots to penetrate the subsoil.

At a depth of 20 cm there were significant differences in the numbers of macropores. These pores are largely formed by earthworms. The greatest number of macropores was found in the deep stable manure treatment.

Soil life

Soil life is very diverse. Earthworms, springtails, mites, nematodes, bacteria and fungi are important groups. All these groups to some extent affect the nutrient supply, soil structure and disease suppression of the soil.
By applying fertilisers year after year which contain widely varying amounts of food for the soil life, one might expect to see changes in the composition of the soil life.

The most important study of the soil life took place in 2006.



On average the number of earthworms was higher in the deep stable manure treatment. The bacterial activity was also higher in this treatment. The quantity of fungi was not significantly influenced by the choice of fertiliser.

The composition of the earthworm population was very unbalanced. Only the grey worm *A. caliginosa* was found. The fertilisation regime therefore had no effect on the number of species. The number of earthworms was considerably higher with deep stable manure than with the other treatments. However, due to the distribution, the difference was not significant. There was clearly more bacterial activity in the deep stable manure, poultry manure, plant compost and plant compost low quantity treatments than in the slurry and mineral fertiliser treatments. No differences were observed in the fungal biomass.

Rhizoctonia in potato in 2007. Deep stable manure seems to limit Rhizoctonia infection.

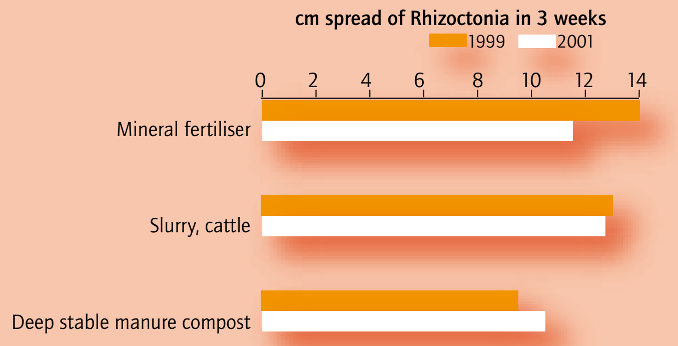
Disease suppression of the soil

Soil-borne diseases, caused largely by harmful nematodes and fungi, are a considerable problem in agriculture. Problems with nematodes are more evident in light soils. Infection by T. nematodes is significant in the soils to the north of Lelystad. When organic farms started up here this type of infection was a perennial problem. It has eased over time, probably thanks to improvements in the soil structure. As no infection by T. nematodes was found at any time on the trial plot, no differences could be established between the treatments. Various laboratory techniques have been developed to test soil suppression to fungal diseases. One of these was applied in 1999 and 2001 by J. Postma of Wageningen University and Research Centre (WUR). *Rhizoctonia solani* was inoculated into oblong containers, filled with soil from the field trial treatments. The speed at which the fungal disease spread through the soil of the different treatments was evaluated by tracking the infection of cauliflower plants on the other side of the container.

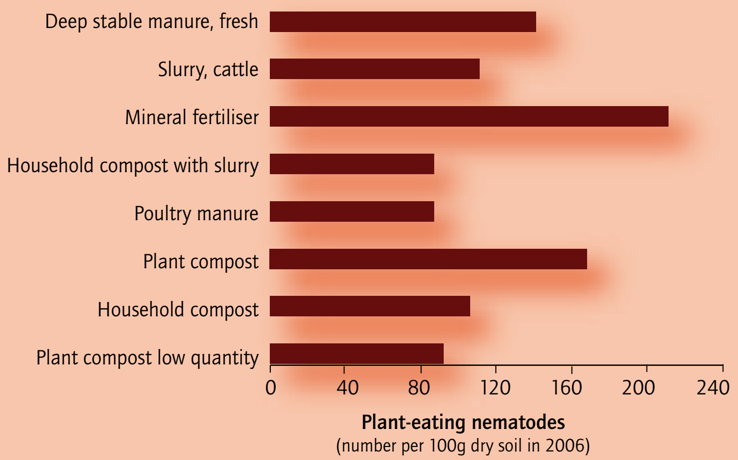
Harmful nematodes

Nematodes which feed on living plants can cause damage to the crop. A study in 2006 showed that highest number of plant-eating nematodes occurred in the mineral fertiliser and plant compost treatments. This may be due to the less diverse soil life. It is striking that the plant compost applied in fairly large quantities of 7800 kg organic matter per ha per year also had a large nematode population. Is the organic matter in plant compost somewhat too one-sided to produce a balanced soil life?

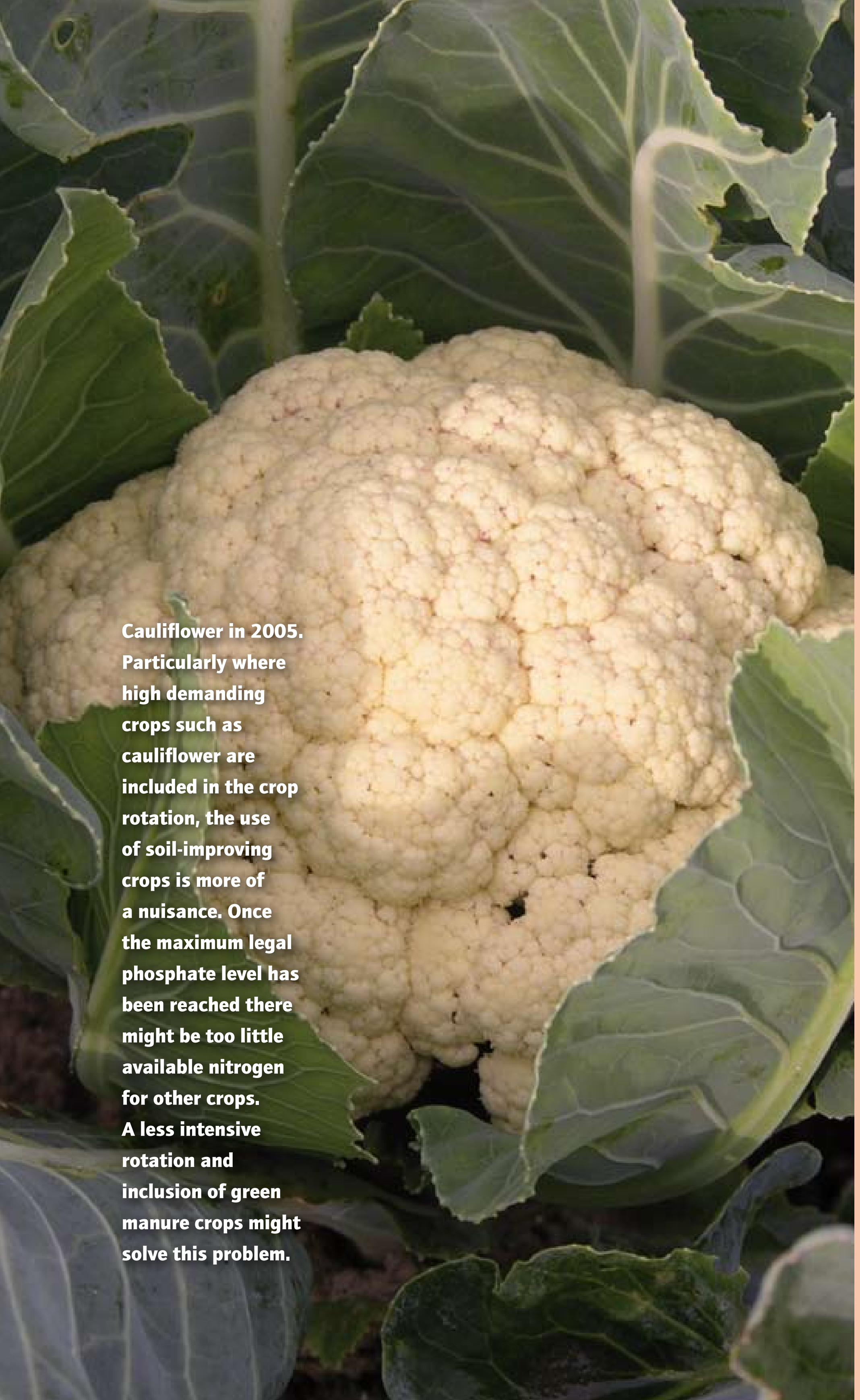
In 1999 deep stable manure compost showed a significantly slower spread of Rhizoctonia compared with slurry and mineral fertiliser. This indicates better disease suppression with deep stable manure compost. In 2001 the disease again spread most slowly in the deep stable manure compost, but the differences were not significant.
Deep stable manure showed the least Rhizoctonia infection, but the difference was not significant. We may conclude that there are indications for differences in disease suppression to Rhizoctonia solani, but further research is required for clarification.



Deep stable manure compost showed a significantly slower spread of Rhizoctonia compared with slurry and mineral fertilizer.



Mineral fertiliser and plant compost in particular stimulate plant-eating nematodes.



Cauliflower in 2005. Particularly where high demanding crops such as cauliflower are included in the crop rotation, the use of soil-improving crops is more of a nuisance. Once the maximum legal phosphate level has been reached there might be too little available nitrogen for other crops. A less intensive rotation and inclusion of green manure crops might solve this problem.

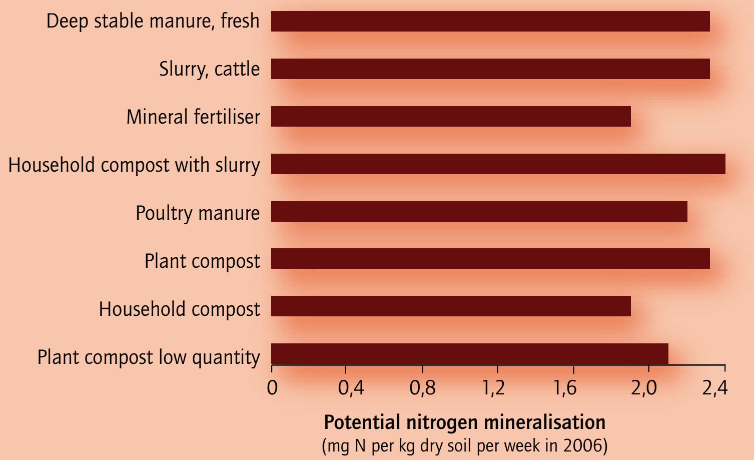
Phosphate, nitrogen and equilibrium fertilisation

Where fertiliser is applied to this soil largely to provide minerals to the crops, the soil will retain little organic matter. The crops grown leave little organic matter behind after harvest.

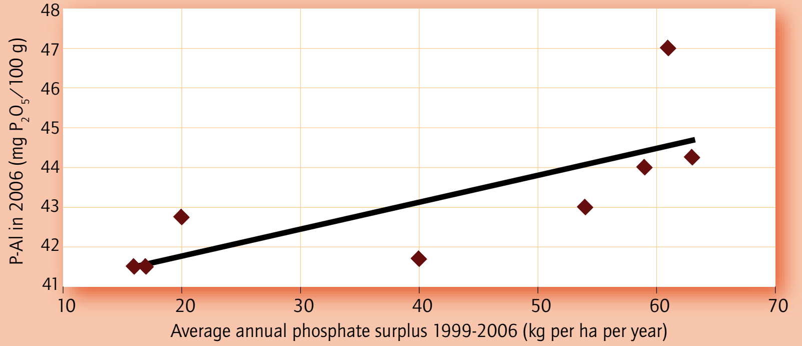
The development of the organic matter content and the composition of soil life show that soil organic matter is rapidly decomposed in this type of soil. It might seem desirable to apply large amounts of organic matter, but this all too soon results in phosphate levels which make such a regime unsustainable. So how do we achieve the right balance?

For nitrogen supply of crops it is important that the soil itself mineralises a stable source of nitrogen, and that the fertiliser application is not the only source. Do the fertilisers contribute to soil organic matter building and soil nitrogen mineralization over years?

At the moment all the treatments generally meet the current statutory usage standard of a maximum of 85 kg P_2O_5 per ha. The aim in the Netherlands is to achieve a phosphate equilibrium by 2015, which would mean no more than 60 kg P_2O_5 could be applied per hectare. This is also desirable in view of the increase in phosphate levels in the soil in this trial in the treatments with a high phosphate surplus. The deep stable manure, plant compost, household waste compost + slurry and poultry manure treatments do not meet the 60 kg P_2O_5 per ha target. These are the very treatments that produce a lot of organic matter and also show various other positive characteristics. To achieve the lower limit these fertilisers will have to be nitrogen-rich and phosphate-poor. Alternatively the crop rotation could be extended and green manures used.

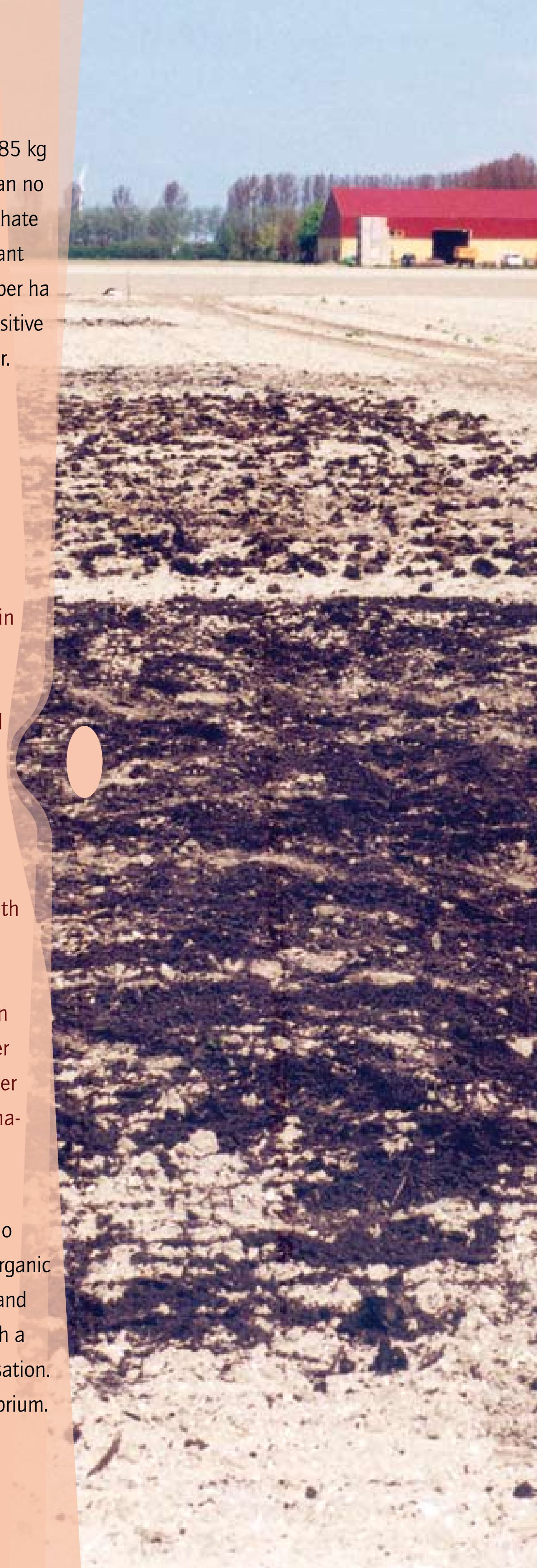


The potential nitrogen mineralization is lower in the case of mineral fertiliser and the compost types which are applied in low doses.



The phosphate surplus (the amount applied with fertiliser minus phosphate removed with the product) varied between the treatments. A higher surplus resulted in higher P-Al-extractable phosphate content of the soil.

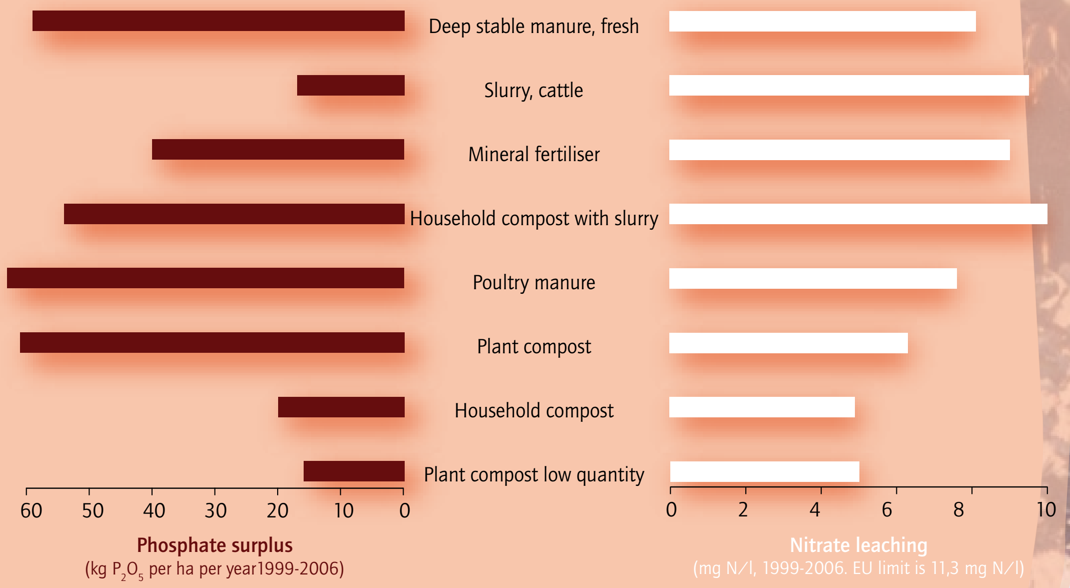
The potential nitrogen mineralization of the soil is significantly lower in the treatments in which little or no organic matter is applied, such as household waste compost, plant compost and mineral fertiliser. Little organic matter is applied with poultry manure or slurry, either, but the nitrogen content of these inputs is higher and that may account for the greater nitrogen mineralization capacity of the soil. However, plant compost with a high dose of organic matter (over 7800 kg per ha per year) does not result in a greater nitrogen mineralisation. This may change in the long term as the build-up and breakdown of organic matter reaches a new equilibrium.



Slurry resulted in a high nitrogen leaching.

Environment

Energy use, carbon sequestration, emissions of greenhouse gases in production and application, accumulation of heavy metals and leaching of nutrients all determine the environmental impact of the use of different organic manures and composts. Not all these impacts could be considered. It is very important to know whether different fertilisation strategies can facilitate an equilibrium fertilisation from the mineral point of view. Nitrate leaching and phosphate surpluses are aspects which could be compared. Nitrate leaching was estimated using the NDICEA nitrogen and carbon model. NDICEA calculates the nitrogen lost to deeper soil layers from the topsoil. Not all of this nitrogen lost will end up in the groundwater: some will be converted in the topsoil to nitrogen gas (N_2) and will not pollute the environment. Since we know how much phosphate is administered with the fertiliser, and how much phosphate is removed with the crop, it is possible to calculate the phosphate surplus. This surplus will be incorporated into the organic matter, with limited environmental impact. As the build-up of organic matter is a slow process, a large phosphate surplus may in time cause the potential for leaching.



With deep stable manure and plant compost, in which much effort goes into building up humus, more phosphate is applied than is removed. Poultry manure is worse: still more phosphate is applied, with less build up of humus.

The average nitrate leaching is high in the case of slurry and the combination of household waste compost + slurry.

Treatments which are poor in terms of both nitrate leaching and phosphate surplus are plant compost, deep stable manure, poultry manure, household waste compost + slurry and slurry. The better ones are plant compost low quantity, household waste compost and mineral fertiliser. The last 3 are applied in smaller quantities than required to produce high yields. Plant compost and deep stable manure also fix phosphate in the organic matter. Among the fertilisers with relatively high yields, household + slurry, slurry (alone), and poultry manure are best in terms of both nitrate leaching and phosphate surplus.

Looking ahead

The *MAC field trial* provides insight into the long-term effects of different fertiliser and compost types. These relate to different aspects such as crop growth, the environment and climate change.
The issues raised by these themes will become increasingly important in future. The project is unique: it is the only multi-year field trial with so many different types of fertiliser and compost. We therefore intend to continue the trial, and we anticipate that the differences in results between the different fertiliser and compost types will become greater over time.

Acknowledgements

This field trial would not have been possible without the help of many people who often worked voluntarily on the fertilisation schemes and yield determination. We are particularly grateful to Jan van Geffen, manager at the host farm, Arenosa; to the farms and companies who supplied the fertilisers: L. Kruit, S. Kok, F. de Heer, R. Ticholt, Conviro, van Iersel and Fokker, and to Luc Steinbuch, who has been involved in the trial from the outset. The trial was sponsored by the Ministry of Agriculture, Nature and Food Quality, the Rabobank and the Dutch Waste Management Association.

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Vereniging Afvalbedrijven

A full report on this field trial has been published as *Investeren tot in de bodem; evaluatie van het proefveld Mest als Kans (Investing down to the soil: evaluation of the Mest als Kans field trial)*. This report can be ordered from www.louisbolk.nl, citing reference number LD11.

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t h e s o u r c e o f k n o w l e d g e , n a t u r a l l y

The MAC trial

Results from a long-term organic inputs trial

Applying fertiliser is the easiest measure a farmer can vary to maintain soil quality. Uncertainty about the different characteristics of fertilisers means that the choice of fertiliser varies widely between farms. The *MAC field trial* in Lelystad, The Netherlands, shows the effect after 8 years of different fertiliser treatments, ranging from animal manure to plant compost to mineral fertiliser. We discuss the impact on yield, product quality, soil quality, environment and climate change. This trial is unique in monitoring the effect of so many types of fertiliser over so many years.