EPA STRIVE Programme 2007-2013

A Literature Review on the Availability of Nitrogen from Compost in Relation to the Nitrate Regulations SI 378 of 2006

Small Scale Study Report

Prepared for the Environmental Protection Agency

by

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Executive Summary

The Statutory Instrument (SI) 378 of 2006 gives recommendations of nutrient input for a range of horticultural and agricultural crops. The availability of nitrogen (N) from pig, poultry, cattle, and other livestock manure, spent mushroom compost and other types of composts is taken to be between 25 to 40%. The SI 378 of 2006 has given the availability of nitrogen from compost the same as cattle manure. However, there is a special derogation if data can be provided regarding the release rate from compost. This report reviewed literature and has determined the release rate of nitrogen from compost.

To define application rates for using compost to achieve optimum crop growth and for compliance with the Nitrate regulations SI 378 of 2006, it is essential to be able to predict the fertiliser effect of the compost and the availability of the nutrients contained relative to conventional inorganic fertilisers. A pollution problem can be created where nutrient availability is underestimated.

This study investigated over a 100 scientific publications, and some unpublished work from Ireland on the release of nitrogen from compost made from various feedstocks.

The main findings of the study were;

- The literature reviewed showed that compost acted as a slow or medium, constant release source of N.
- This literature study shows clearly that nitrogen availability from composts is many times less (20% to minus 10% in the first year) than inorganic fertiliser sources. These results are consistent from laboratory/pot trials and field trials.
- These results show that N availability as a percentage of total N applied is often only 0-20% or even negative in the first year and 0-8% in the following years.
- These publications and results also show that feedstock has a major effect on rate of mineralisation of N. For instance, compost derived from source separated green waste (SSGW) the release of N is often negative (Prasad and Maher, unpublished), (Maher, 2005), (Bowden *et al.,* 2007), (Claasen and Carey, 2004). Compost derived from animal manures has the highest rate of mineralisation, followed by source separated biowaste (SSBW) compost, with SSGW compost having the lowest rate of those feedstocks studied.
- The release of nitrogen from compost manufactured from manure is very much lower than that of mineral fertiliser. Composted manure has a slower release rate of N than uncomposted manure.
- The release of N from composted sewage sludge was inconsistent. For example, N release from composted SSGW/sewage sludge was more than composted SSGW (*e.g.* He *et al.,* 2003). However, results also show that composted sewage sludge can fix nitrogen (Bowden *et al.,* 2007). Composted sewage sludge and composted cattle manure had similar mineralisation rate according to one study (Bar-tal *et al.,* 2004).
- The release of N is affected by the stability of the compost. Some unstable composts, *i.e.* SSGW derived compost

which has a high content of woody material, immobilised a great deal of nitrogen. It is necessary to add mineral nitrogen or other quicker release organic N at the composting phase and/or when compost is added to soil, as such compost is unlikely to provide adequate nitrogen for optimum crops.

Leaching of nitrate-N is unlikely due to a number of reasons.

- The slow release characteristic of compost-N.
- The rate of application of compost is likely to be low as it will depend on P availability. Compost P is much more available than compost N (Prasad, 2009).
- The application of compost can increase the water holding capacity of soils, particularly of sandy soil. Therefore, leaching of N is reduced.

SI 378 of 2006 governs the amount of compost which can be applied, based on the availability of the nitrogen and phosphorus content of compost. The release rate of phosphorus (P) occurs at a faster rate than the release rate of nitrate (Prasad, 2009). Subsequently, the limiting factor for compost application is the concentration of P in the compost. The amount of N applied as compost N is limited due to faster release of P. Leaching loses of nitrogen from compost appears to be not a problem so long as the compost rates are at the maximum N rate allowed in SI 378.

This document will be a valuable guide for crop consultants and advisors, if they use it in conjunction with SI 378 of 2006 for the application of compost in horticultural and agricultural crops.

Recommendations

- The availability of N from compost is effected greatly by the feedstock in which the compost was derived and stability (often only 0-20% or even negative in the first year and 0-8% in the following years). Until more detailed research is conducted it is recommended that the guidelines developed by Wallace (2006) of using the C:N ratio of the compost to determine the availability be used as outlined in the Table 1 below.

Table 1. C:N ratio in relation to potentially mineralisable N[1]

Compost C:N ratio	% of total N estimated to be mineralised after application
<10.0	Up to 25
12.5	17.5
15.0	10
17.5	5.5
>20.0	0.0

- There is a need to emphasise the interdependency of P and N in compost in the SI 376. It is not nitrate leaching from compost that could be a potential problem from compost application; rather it is P that could be potential problem.
- Standardised analytical methods need to be developed to predict the release of N from various feedstocks.

[1] The assumption is that compost used meets the requirements of the stability standard outlined in Prasad and Foster (2009).

- Field trials are needed to determine the release of nitrogen from Irish compost under Irish climatic and soil conditions.
- Beside compost as a source of nutrients, it also has other properties which other organic fertilisers do not have as a source of stabilised organic matter, disease suppression properties, improved water retention. As such, compost should be given as separate classification as a 'soil conditioner' as opposed to being just a fertiliser source.
- Up to 1 January 2011, there is a temporary rule in which more phosphorus can be applied on land than crops require, as long as it comes from manure produced by pigs, poultry or from spent mushroom compost and that the 170kg nitrogen is not exceeded. This rule should be extended to include all types of source-separated compost.
- This report must be read in conjunction with "*A Literature Review on the Availability of Phosphorus from Compost in Relation to the Nitrate Regulations SI 378 of 2006*" (Prasad, 2009), as the availability of nitrogen and phosphorus are required for compliance with SI 378 of 2006.

1. Introduction

This was carried out as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The project, titled *A Literature Review on the Availability of Nitrate from Compost in Relation to the Nitrate Regulations SI 378 of 2006* (Ref. 2006--SS-55), was a desktop literature review study.

The Nitrates Directive (91/676/EEC) – Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources was adopted in 1991 and has the objective of reducing water pollution caused or induced by nitrates from agricultural sources. The Directive has been implemented in Ireland since 1991 by way of extensive monitoring of nitrate levels in waters, the assessment of the trophic status of waters, the development and dissemination in 1996 of a Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates and a range of other measures which operate to protect water quality from pollution by agricultural sources.

Ireland's national Nitrates Action Programme was given statutory effect by the European Communities (Good Agricultural Practice for Protection of Waters) Regulations (SI 378 of 2006) 2006. These Regulations provide strengthened statutory support for the protection of waters against pollution from agricultural sources e.g. by phosphorus or nitrogen. The Regulations require the avoidance of careless practices by farmers, which create a risk of causing pollution and provide for inspections by local authorities.

New Nitrates Regulations (SI 101 of 2009) have been signed into law by the Minister for the Environment, Heritage and Local Government. The European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009 revise and replace the previous Regulations made in 2006 and 2007.

1.1 Background

Application rates are calculated (according to S.I. 378 of 2006) on the N concentration in composts due to lack of sufficient information. Due to the low N content of most composts (<2% N), the application rates of compost will be very low. The release or immobilisation of N from compost as a result of application of compost to soil depends on the compost itself (age, stability and parent feedstock from which the compost is made). In addition to these factors, the form of nitrogen in compost is a major factor which affects the release of nitrogen. It is known that almost all nitrogen in the compost is in an organic form and not water-soluble and that N release is often much less than inorganic nitrogen applied over a short to medium term.

Nitrogen

Nitrogen plays a central role in relation to agricultural soil use and ground water protection. Typically, soils are low in N. On the other hand, the N plant requirement in relation to many other nutrients is very high, and essentially the N supply has a major impact on yield levels of crops. It is normal farming practice to apply nitrogen to soils through fertiliser N or other agronomic culture techniques (*e.g.* growing of legumes *etc.*) to achieve high crop yields. The rate to be applied will depend on the plant needs amongst other factors. The concentration of the most significant plant available N (nitrate) is in water-soluble form and is thus not retained in the soil profile.

Release of N (also called mineralisation) from compost is due to conversion of organic forms of N (*e.g.* proteins, chitins, and amino sugars from microbial cell wall, nucleic acids) to inorganic N (as ammonium N (NH_4+). Organic N forms may be indigenous to the soil, or freshly added composted material. Nitrification is the conversion of NH_4^+ to nitrate (NO_2^-) and then nitrate (NO_3^-). The process is mediated by a diverse population of micro-organisms. Nitrate (and sometimes NH_4^+) can be used by plants or lost from the crop rooting zone by leaching, and also by denitrification and run off. Immobilisation is essentially the reverse of release and involves assimilation of inorganic N (NH_4+, NO_2-, and NO_3-) by soil organisms of these mineral forms into organic compounds during microbial metabolism and growth.

Nitrogen, compost and the role of C:N ratio

The carbon:nitrogen ratio (C:N) of added organic matter and particle size along with environmental and/or edaphic factors such as moisture, temperature, salinity, soil texture, and pH which regulate microbial population growth broadly control the amount of inorganic N which is released. It should be emphasised that C:N ratio as a predictor of N mineralisation is approximate as it depends very much on the type of carbon. It is generally agreed that a C:N ratio of around 25:1 is commonly used as the ratio where release and immobilisation are in balance. Adding materials to soil with wide (730:1) C:N ratio (*e.g.* unprocessed green waste, sawdust) can cause depletion of any added nitrogen and exogenous nitrogen. Conversely, a very low C:N ratio can produce excess of soluble nitrogen and must be managed to avoid N losses to sensitive parts of the environment.

The use of compost as N source cannot be based on N availability alone. Other nutrients and non essential elements in these materials can determine not only the application rate but also their suitability for various end uses (Pierzynski *et al.,* 1993). A separate report on P availability from compost has been prepared (Prasad, 2009).

Other Benefits Attributed to Compost Use in Soils

Recently the European Commission Joint Research Centre published a report “End of Waste Criteria”[2]. In this report it outlines the many other benefits attributed to the use of compost in soils. These comments are summarised as follows;

Ongoing decline of organic matter in soils as a result of agricultural activities is a well-known phenomenon and is depicted as one of the main threats to soil within the documents of the European Soil Strategy[3]. In many sections of the EU Soil Strategy papers, the need of combating EU soil’s organic matter depletion also by adding organic matter in form of compost is stated.

2 Anon. (2009) *End of Waste Criteria* Report. European Commission Joint Research Centre, Seville.

3 http://ec.europa.eu/environment/soil/index.htm#publications

Under the current draft Soil Framework Directive (SFD), Member States will be obliged to establish programmes for combating organic matter decline in priority areas. Consequently, organic matter substitution by compost use will be one of the promoted and recognised measures.

Humus also stores some of the biomass carbon contained in compost in soil for longer periods of time. This carbon can be considered sequestered (locking up carbon in soils) from the atmosphere, which acts against global warming and climate change. Composting and the production and use of compost can have a major role in helping Ireland implement its Climate Change Strategy.

Other potential positive environmental effects which have been attributed to compost include (Kehres and Luyten-Naujoks, 2006; Anon., 2009):

- Reduced soil erosion
- Compost of a good quality may help to control soil borne plant diseases and thus reduce the need for applying agricultural chemicals
- Water retention is improved, reducing the need for irrigation and reducing the risk of flooding
- The improved soil structure reduces the need to work the soil with agricultural machinery and the related use of fuel.

When compost can be used instead of peat in growing media, there is also a lower global warming potential, mainly because peat degrades relatively quickly under the release of 'long cycle' CO_2 when exposed to oxygen Replacing peat also plays a part in the protection of the biodiversity and landscape of peatlands (Anon., 2009).

Separate Classification for Compost

SI 378 of 2006 gives details on Nutrient Management. Nutrient Management gives the crop requirement in relation to the application of fertilisers to promote the growth of a crop. This means the amount and types of fertilisers are reasonable to apply for the promotion of growth of the crop having regard to foreseeable nutrient supply available to the crop from the soil and other sources. It is stated that if compost is applied onto land for two years in a row, the nitrogen index[4] is reduced by 1. This means that a farmer gets penalised for using compost, even though it has reduced the availability of nutrients compared to other ‘organic fertilisers’.

Beside compost as a source of nutrients, it also has other benefits mentioned above which other organic fertilisers do not have. As such, compost should be given a separate classification as a ‘soil conditioner’ as opposed as a fertiliser source.

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[4] The soil nitrogen (N) index system indicates the soil's ability to supply N during the growing season and depends on the previous cropping history and previous organic manure applications. An estimation of soil reserves is not completed by taking and analysing a soil sample, unlike phosphorus and potash.

There are four N indices ranging from 1 to 4, index 1 soils containing small soil nitrogen reserves and index 4 soils having the largest soil nitrogen reserves. Where a crop is sown into a soil at index 1, then most of the crop requirements are supplied to the crop from chemical or applied organic nitrogen during the growing season.

1.2 Study Purpose and Objective

The specific objectives of this comprehensive desk study are:

- To quantify the release / immobilisation of nitrogen from different types of composts based on published and unpublished world-wide data with emphasis on Irish data
- To quantify any leaching losses
- To explore the properties of compost which have been shown to affect mineralisation/ immobilisation
- To produce a Standard Reference Document for use by all (composting sector, Local Authorities, EPA) in relation to SI 378 of 2006.

1.3 Methodology

Publications on the release of nitrogen from source separated material derived compost were obtained from: Cré Technical committee members, online scientific databases (Science Direct, Web of Science), Commonwealth Agricultural Bureaux International (CABI), the European Compost Network and ORBIT[5] members. Contact was also be made with a long-term crop trials research at the Agricultural Research Station in Stuttgart, Germany to obtain data. In addition to the literature available, a database of the nitrogen content of 300 Irish compost results was used in this report.

Approximately one hundred publications were reviewed. In this review, the following external factors were not considered such as soil microbial activity, soil moisture and temperature which can also affect the release of nutrients from all types organic matter. These factors have been reviewed in other publications.

After sourcing the references, the literature publications were reviewed under the following headings;

- Amount of N in compost, type of tests/trials *i.e.* laboratory tests, incubation trial (measures release of nutrients without plants under standard temperature and moisture), pot trial (pot trials have plants in them), and field trials
- The type and source of compost
- Location of field trial and year of work, availability of nitrogen over a number of years, the effect of soil management including cropping.
- Parameters (C:N ratio, and stability measurement *e.g.* CO_2 evolution) which can predict release N dynamics from compost were also examined.

Publications in relation to fieldwork will be the primary focus. However, data from pot trials and laboratory incubation were examined in relation to N release. Any information on leaching of nitrate has also been presented. In summary, the availability of nitrogen from compost was determined after reviewing publications on pot trials, incubation trials, field and leaching trials. Based on the information from the publications, a judgement was made on the approximate availability of nitrogen.

[5] Non-profit organisation that promotes scientific development of biotechnology

2. Review of Laboratory and Pot Trials Publications

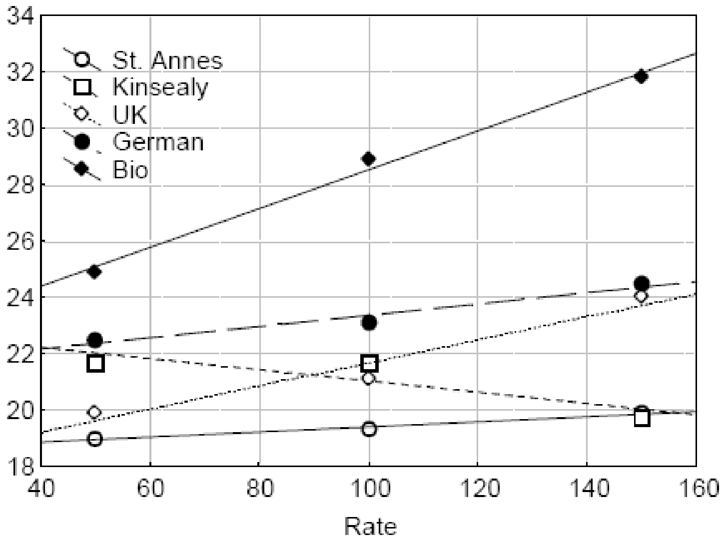
A number of publications using source separated green waste (SSGW), source separated biowaste consisting of green waste, food and non recyclable paper (SSBW), and other miscellaneous source separated materials (MISC) (including sludges, food processing residual spent grain, *etc.*.) manure and sewage sludge based compost are summarised in the following section. 'Pot trials' are trials where composts are mixed into the soil at various rates or less frequently on it's own in pots and seed or seedlings are sown or transplanted and plant performance is measured under normal growing conditions. 'Incubation trials' involve the monitoring of nutrient concentrations of compost under standard temperature and moisture conditions. At the end of this section, Table 2 provides examples of nitrogen release from various composts from pot and incubation trials reviewed.

Trials using Mostly Greenwaste Compost

A study at the Kinsealy Research Centre (Prasad and Maher 1995, unpublished) investigated the release of N from five different composts using pot trials. The different composts used in this study were; two from Irish composted SSGW from St. Anne's Park Dublin, SSGW with added N from Kinsealy; two from Germany; one biowaste (BW) and one greenwaste (GW) obtained as part of a CEN project in 1995 and one SSGW from the United Kingdom**.**

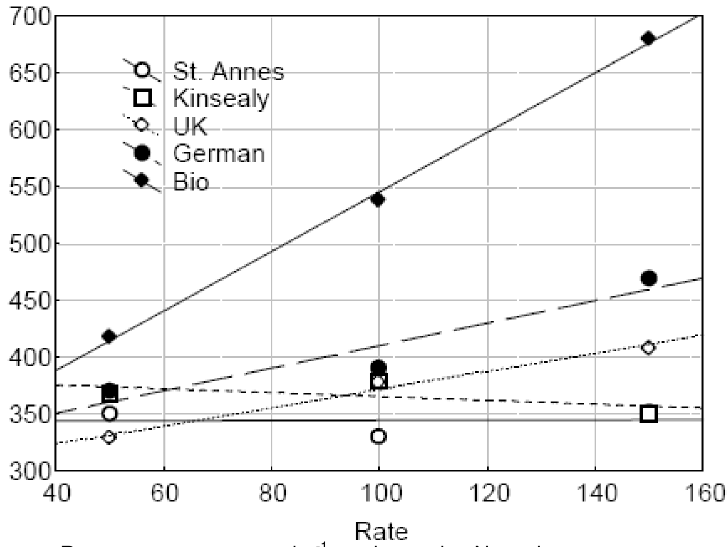
Ryegrass was grown in a soil which had a very low organic matter content (podsolic) with all 5 composts applied at 50t/ha, 100t/ha and 150t/ha and three cuts of grass were taken over a 12 week period. Dry weight and N uptake were calculated from N concentration in the foliage. The dry matter production and N uptake over the 12 weeks against rate are given in Figure 1. The uptake was highest in SSBW. The N recovery[6] in relation to total N added was 6.4 to 8.1% from SSBW, 3.5 to 5.1% from the German SSGW, 0.4 to 2.9%, 0.41-2.9% from the UK SSGW, 0.72 to 2.3% from the Kinsealy SSGW and 0.42-1.9% from the St. Anne's Park SSGW. There was a poor relationship (R^2=0.336) between C:N ratio and N uptake but a better relationship with total N (R^2=0.409) (Figure 2). These findings are in agreement with other researchers that only a small amount of total N in compost is available to the plant and there can be a reduction in N uptake in relation to some composts.

6 N Recovery is the percentage nitrogen uptake in relation to the total nitrogen added.



Rate = compost tonnes ha$^{-1,}$ x axis, y axis= dry matter g per pot

Figure 1: **Effect of source separated greenwaste and biowaste rate on dry matter production** (Prasad and Maher 1995, unpublished)



Rate = compost, tonnes ha$^{-1,}$ x axis, y axis= N uptake mg per pot,

Figure 2: Effect of source separated greenwaste and biowaste rate on N uptake (Prasad and Maher 1995, unpublished)

A further study investigated the effect of five compost materials (spent mushroom compost (SMC), onion waste (OW) and two samples of SSGW and one sample of SSBW on plant growth and nutrient uptake was investigated at Teagasc, Kinsealy (Maher, 2005). Investigations into the effectiveness of these composts as a source of N for plants were conducted. In the experiment, the composts were added to the soil at rates equivalent to 0, 25 and 50t/ha. Successive harvests were taken in three successive crops of brassica seedlings.

No significant increase in dry weight was seen in any of the composts studied.

However, SSGW1, SSGW2 and onion waste (OW) reduced plant dry weight in relation to control. There was a significant response to the addition of calcium ammonium nitrate (CAN), a N fertiliser commonly used in Ireland. CAN increased N uptake as did the 50t/ha rate of SSBW. SSGW1 and SSGW2 reduced N uptake compared with the control. The N recovery was estimated by subtracting the N uptake in the control treatment from the N uptake in the other treatments and then expressing that quantity as a proportion of the N applied. In the case of the inorganic fertiliser (CAN), the recovery was estimated at 46%. SMC and SSBW showed much lower rates of uptake (0.5 to 4.5% and 0.9% to 3.7% respectively) while SSGW1 and SSGW2 resulted in a negative rate of uptake *i.e.* a loss of available N (-8% to -30%) over 3 successive harvests. The higher N uptake figures (4.5% and 3.7%) were for the higher rate of compost application. This result indicates that all the composts studied are not efficient sources of N. SMC and SSBW can be expected to make a small contribution to N nutrition of a crop but the SSGW treatments in particular will actually reduce N availability to the crop. These results indicate at least over the short term these fertilisers will make little or no contribution N nutrition and some of them may deplete available N in the soil.

The N release behaviours of several compost materials produced within California were evaluated by Claassen and Carey (2004) during a long-term, 586-day aerobic incubation. Two general types of compost were tested, including SSGW compost materials (lawn clippings and chipped brush) and biosolids composted with SSGW materials. Nitrogen release from composted material was measured using periodic soil solution extraction and soluble N analysis. Nitrogen release rates varied widely between source materials (green waste or biosolids/green waste) during the initial incubation period, with biosolid/greenwaste compost having much greater release rates (outlined below) than the SSGW compost.

SSGW composts which were improperly cured or had high woody fibre content showed net immobilisation of N during the initial incubation periods. This could potentially lead to N–limitations for plant growth in field conditions. Following additional curing in the soil, however, all SSGW compost materials had positive net N mineralisation rates. The release[7] rates were 1-7% of total N applied for SSGW compost and 27% for the co-composted material. Because the cumulative N release from green waste compost materials was a small fraction of the material's total N content, N leaching losses in field conditions are expected to be small and of short duration. Steady, long-term N release patterns were observed from composts throughout the second half of the study and would be expected to continue for an extended period in the field. Composts are shown to provide a suitable replacement source of slowly available N for plant establishment on drastically disturbed, low nutrient soils e.g. roadside verges.

Trials using Mostly Biowaste Compost

The objective of work by Elhassania-Elherradi *et al.,* (2005) was to evaluate the nitrogen fertilising value of household solid waste compost of two soils with contrasting properties: a sandy soil and a loamy-clay soil

[7] Amount of nitrogen released

in Morocco, The inert material was separated from the feedstock and the organic fraction was composted. A study of nitrogen availability of the compost was carried out in a soil-compost crop system under greenhouse conditions using lettuce as a test crop. Four increasing compost rates of 0, 10, 20, and 30 tons/ha were applied to the soils. The effect of the compost rate on nitrogen mineralisation was statistically significant in the two soils studied. The quantities of mineralised nitrogen of the compost varied between 15 and 24% of the total nitrogen applied to the sandy and the loamy-clay soils during the lettuce-growing season. The authors concluded that the use of household solid waste compost as soil amendment constitutes a beneficial alternative in Mediterranean soils. Although this study was conducted in Morocco it is relevant because it shows that it is possible to produce compost with relatively high nitrogen availability.

A cattle manure compost (CMC) and a municipal waste compost (MWC) were applied at a rate of 5 or 15% to two soils, differing in their mineralisation capacity based on the land that had received organic amendment or no organic amendment over past 30 years and incubated for 33 weeks at 30°C and optimal soil-water content (Hadas *et al.,* 1997). CO_2 evolution rates and inorganic N concentrations were measured in the soils, periodically. The rate of compost-N recovered[8] as inorganic N, was independent of the soil nutrient history and compost application rate. The recovery of total N applied after 33 weeks was 22% of MWC–N and 23–27% of CMC–N, of which 13% was initially inorganic. Better definitions of the insoluble material could improve the prediction of decomposition of composts. The wider C:N ratio of MWC explains the lower rate of inorganic N release. C:N ratio can often give indication to the N release potential.

Trails using Mostly Manure Compost

A four-month laboratory incubation study was conducted by Cabral *et al.,* (2006) in a sandy loamy soil under controlled conditions to determine the nitrogen mineralisation rate of five on-farm composts and three commercial organic fertilisers, all of them filling the requirements of organic farming. The three organic fertilisers were based on fermented manure of free range hens, fermented manure of poultry, sugar beet residues, horse manure compost, and grape oil cake. All composts contained cattle manure, rice husks, orange peel, tannery waste, and grape stalks in various proportions. Results show no significant differences of N release between the on-farm composts. At the end of the incubation study only 1.9 to 12% of the organic N added was mineralised. Converse trends were observed for commercial organic fertilisers, the mineralisation occurred more intensely at the initial stage of incubation. Towards the end of the incubation period, the mineralisation rate varied in the range between 26.6 to 42.5%.

In a study by Eghball *et al.,* (2002), they define nitrogen (N) availability from applied manure as the inorganic N (NO_3–N and NH_4–N) in manure plus the amount of organic N mineralised following application. Nitrogen mineralisation varies for different

8 The amount of nitrogen take up by the plant or extractant

manure types due to the variation of the inorganic/organic fraction and quality of organic N. Mineralisation of organic N is expected to be low for composted manure (~18%) and high for swine or poultry (hens) manure (~55%) (Eghball *et al.,* 2002).

Helgason *et al.,* (2007), carried out a 425-day canola (*Brassica napus*) bioassay to observe the release of N from eight composted cattle manures applied to soil at 20kg^{-1}. Two stockpiled manures, one inorganic fertiliser and an unamended control were also included for comparison. Eight consecutive 30-day growth cycles were conducted in a controlled environment chamber (20°C). Plant N uptake was also measured. Total N uptake was greatest from the N fertiliser and least from the woodchip bedded manure (probably due to high C:N ratio). Nitrogen uptake from compost was directly proportional to its inorganic N content (r^2=0.98; P<0.0001) showing that the initial inorganic N content of compost, analysed prior to its application can be used to predict plant available N. In seven of the eight composts studied, less than 5% of organic N was mineralised over 425 days, suggesting that little of the organic N in compost becomes available in the year following application.

Trials using Mostly Sewage Sludge Compost

Field incubation and laboratory analyses were conducted by He *et al.,* (2000) in Florida, USA, to evaluate the mineralisation rate and transformation of N in biosolids (BSD) and SSGW. Each of the composts or biosolids were packed into PVC columns (8cm height, 5cm diameter) and inserted vertically into the upper layer of an Oldsmar fine sand of raised citrus beds. The top end of the PVC column was capped to prevent excessive leaching of nutrients from the columns. A set of the incubated columns was removed at monthly intervals, and the soil underlying each column (a core of 20cm height and 5cm diameter) was sampled to analyse for KCl-extractable NH_4-N and NO_3-N. Total C and N of the incubated samples were determined at the end of the 1 year incubation period. Organic N mineralisation rates during the 1 year incubation period were 23.3 and 48.4% of the total organic N in the SSGW and BSD, respectively, as estimated by the organic N decrease method. He *et al.,* (2000) recommended that application rates of composts similar to the BSD, which contain high N concentration, should be adjusted for high N release to minimise the risk of NO_3-N leaching into groundwater.

The overall objective of a study by Bar−Tal *et al.,* (2004) was to determine the loading limits of composts which should be applied annually to irrigated wheat. A container experiment was conducted in a greenhouse for four years. It included eight treatments; sewage sludge compost (SSC) and cattle manure compost (CMC), and two controls, one fertilised and one unfertilised. Each compost type was applied annually to a sandy soil, at rates equivalent to 3, 6, and 12kg m^{-2}. Total dry matter (DM), grain production, and the amount of N, P, and K taken up by plants increased with increasing compost rate. Plants grown in the fertilised control showed much higher nitrogen uptake was than by the plants grown in the highest rate of compost. pH and K uptake by the plants grown in soils amended with the highest compost rate was much higher than by the fertilised control plants. Inorganic N concentration in the soil increased with increasing compost rate and with successive applications. The net N mineralisation during the first year of wheat growth was very low, less than 3.5% of the applied organic N under all compost application rates. The contribution of the organic N mineralisation increased during the second and third year which is generally not in agreement with most other data. Most of the N increase in the compost treatment was found in the upper layer of 0 to 15 cm. In the fertiliser treatment, higher concentrations of N were found in the surface of the container, graduatin to the lower concentrations at the bottom of the container.

A laboratory incubation study was conducted by Tester *et al.,* (1979)[9] to determine the rate and extent of decomposition of sewage sludge compost in loamy sand soil amended with three fractions of compost (<6 mm, 1 to 6mm, and <1mm) at a rate of 89.6 metric tons/ha (dry wt). Rates of mineralisation and decomposition were determined by monitoring CO_2 and NH_3 evolution and measuring changes in the organic (TOC) and inorganic fractions of C N, and P with time. CO_2 evolution was directly related to the amount of C in the compost–soil mixtures. Approximately 8% of the compost C from all fractions evolved as CO_2 in 45 days. The quantity of N mineralised ranged from 3 to 13% for the different fractions, and was inversely related to the C;N ratio. Ammonia evolution paralleled N mineralisation in these mixtures. When the pH of the soil was adjusted to 6.6, decomposition of the native soil C increased 82%, but neither N mineralisation nor the amount of extractable P was affected. These results again show low N mineralisation from compost and in this study no significant effect of pH on N release.

A greenhouse study carried out by Bowden *et al.,* (2007), used tall fescue as a bioindicator to evaluate nitrogen availability of two biosolids composts, two mixed SSGW-poultry manure composts, and one commercially processed poultry litter. Five inorganic nitrogen (as NH_4/NO_3-N) treatments applied at 0, 22.5, 45, 67.7, and 90mg N/kg soil were employed to establish an N calibration curve. Fescue grass was sown in each treatment, as an indicator crop, in pots. Yield, fescue biomass total nitrogen (as total Kjeldahl N (TKN)), soil TKN NO_3^- N and NH_{4+} N (KCl extractable) concentrations were determined. The concentrations of the organically amended treatments were compared to the inorganically fertilised treatments to determine amendment N mineralisation rates and N fertiliser equivalent values (NFEV). Nitrogen mineralisation rates were greatest in the poultry litter (21%) and SSGW compost (5%) amended pots. The fertiliser equivalent values (NFEV) of these amendments were 49% and 10%, respectively. Biosolids compost and green waste compost immobilised N (-5% and 0.18%, respectively), and had NFEV of -0.66% and 0.19%, respectively. Biosolids compost immobilised N (-15%), but the NFEV was 30% due to the relatively high inorganic N content in the amendment. Nitrogen mineralisation and NFEV were generally greater in amendments with greater total N concentrations and lower C:N values (Negative NFEV values indicate nitrogen

9 Although this publication is 30 years old, it is still regularly referenced in other publications too.

immobilisation). These results indicate that SSGW compost mixed with biosolids can immoboblise N and that C:N ratio can give an indication of N availability.

Shi *et al.,* (2004) compared N mineralisation kinetics (rate of reaction) and examined microbial N transformations in soil receiving dairy-waste compost vs. lagoon effluent[10]. Mineralisation kinetics was examined with a 70-day laboratory incubation. Approximately 6% of compost N was mineralised within 2.5 months. In contrast, up to 90% lagoon effluent organic N was released during the same period. They suggested that dairy waste compost has the potential to continue to mineralise N probably due to its slow release characteristics.

The N-mineralisation was investigated after application of SSBW compost with different degrees of stability (Seibert *et al.,* 1998). Stable compost was added at 65t/ha and unstable compost was added at a rate of 70t/ha to three contrasting soils. The mixtures were incubated for 552 days at 5°C and 14°C. The N mineralisation increased with the addition of compost on the soils. 5 to 7% of N was released in all mixtures of soil and compost. The rate of mineralisation was affected by the degree of stability. The stable compost (Grade V in Self Heating Test[11]) showed a faster release of inorganic N. The unstable compost, (Grade III in Self Heating Test) which had a higher level of organic nitrogen, showed N immobolisation. There were varying N dynamics dependent on the degree of compost stability and soil type during the incubation period. They conclude that over a long period of time the amount of N released from both types of compost would be the same. However over a shorter period unstable compost can immobolise N.
Ambus *et al.,* (2002a) examined the gross N mineralisation and immobilisation in sandy loam soil amended with compost SSBW and sewage sludge (collected from Denmark) on seven occasions during one year using ^{15}N[12] pool dilution and enrichment techniques. Gross N mineralisation was stimulated as a result of compost application and accelerated through the first 112 days of incubation, peaking at 5mg N kg^{-1} day^{-1} for compost compared with 4mg N kg^{-1} day^{-1} in the control and sludge treated soil. The magnitudes of mineralisation rates exceeded those of immobilisation by on average 6.3 (compost) and 11.4 (sludge) times, leading to a persistent net N mineralisation cumulating up to 160mg N kg^{-1}/soil (compost) and 54mg N kg^{-1}/ soil (sludge) over the season from May to November. Sludge exhibited an early season N-release, whereas compost released only 10% of the N during the first two months of incubation. Because the compost releases the N slowly, this indicates that compost should be applied well in advance of sowing in order to match with specific crop N demands.

Gale *et al.,* (2006) designed a study to provide data to support advisory recommendations for farmers for organic amendments (*e.g.* compost, manure *etc.*) Amendment samples were aerobically

10 cattle manure effluent collected in a lagoon

11 Self Heating test classes

Degree Celsius (°C)	Self Heating Stage	Description
>60	I	Raw material compost
60 to 50.1	II	Fresh compost
50 to 40.1	III	Fresh compost
40 to 30.1	IV	Mature compost
< or equal to 30	V	Mature compost

12 Nitrogen-15 is a stable, non-radioactive isotope of nitrogen.

incubated in moist soil in the laboratory at 22°C for 70 days to determine decomposition and plant-available nitrogen (PAN) (n=44). Amendment samples (n=37) were applied before planting to a sweet corn crop to determine PAN via fertiliser N equivalency. Composted materials (n=14) had a single decomposition rate (release over time), averaging 0.003 d^{-1}. For uncomposted materials, decomposition was rapid (>0.01 d^{-1}) for the first 10 to 30 days. The laboratory incubation trials and the field trials had similar PAN results.

This study by Cambardella *et al.,* (2003) evaluated the impact of composting process conditions and the extent of compost decomposition on soil C and N mineralisation after compost incorporation. Dried, ground composts were blended with equal parts of quartz sand and soil and incubated aerobically for 28 days at 30°C. Cumulative respired CO_2 and net mineralised N were quantified. The results indicates (1) that organic substrates, which did not degrade due to suboptimal conditions during the composting process, can readily mineralise after incorporation in soil; (2) C and N cycling dynamics in soil after compost incorporation can be affected by compost feedstock, processing conditions, and time; and (3) denitrification after compost incorporation in soil can limit N availability from compost. This study shows that unstable compost[13] (due to sub optimal conditions) will release (mineralise N) faster. These results are not in agreement with earlier studies but there is not an obvious explanation.

After reviewing the publications described in details and the following publications Hébert *et al.*, (1991) (manure compost) Hartz (2000) (manure compost and SSGW compost); Berner *et al.,* (1995) (SSGW compost); Tester *et al.,* (1977) (sewage sludge compost). Amlinger *et al.,* (2003) concluded the following:

1. N immobilisation or very low rate of N mineralisation occurs with unstable compost
2. Composting of fresh organic material reduces N immobilisation significantly and so increases availability
3. The mineralisation rate of various composts was between 4.6% (mean of minimum values) and 19.5% (mean of maximum value) of the total N under optimal temperature and moisture conditions of an incubation experiment, and
4. When compost is mixed with light sandy soil the mineralisation rate is higher than with clayey soil probably due to better aeration within the sandy soil..

Table 2 shows examples of nitrogen release from various composts from pot and incubation trials of papers reviewed.

[13] Cambardella *et al.,* (2003) when talking about stability does not referring to analytical stability testing of the compost, but the duration of composting. The longer the material is composted, the more stable it will be.

Table 2: Examples of nitrogen release from various composts from pot and incubation trials

Author and year	Type/Source compost	Availability of nitrogen as% of Total N	Availability of nitrogen as% of applied inorganic N	Trial type	Crop Grown	Duration of Trials and Comments
Amlinger *et al.,* 2003 (review article)	Various	2.6 mean of minimum values to 10.7% mean of maximum value in year 1.	NA	Pot	Various	Time period -In year 2 and 3 usually between 2 to 3% of added N. 47% in 21 years.
Bar Tal *et al.,* 2004	Sewage sludge compost cattle manure compost	< 3.5%	NA	Pot	Wheat	Time period One year
Bowden *et al.,* 2007	Biosolid compost, greenwaste + poultry manure compost, SSGW	-15% to 5%, poultry manure on its own 21%	Poultry manure 49%, SSGW 10%, biosolid 30%	Pot	Grass	Time period 168 days
Cabral *et al.,* 2006	"On-farm compost" made from rice husks. orange peel, tannery waste and grape stalks	1.9 to 12%	NA	Incubation	NA	Commercial organic fertiliser N release was 27 to 43%
Claassen and Carey 2004	SSGW and SSGW +biosolids	1 to 7% SSGW, 27% co-composted material	NA	Incubation	NA	Time period 586 days. SSGW poorly cured led to immobilisation
Eghball *et al.,* 2002	Composted manure	18%	NA	Incubation	NA	Swine and poultry manure 55%
Elhassania - Elherradi *et al.,* 2005	Household solid waste	15% to 24%	NA	Pot	Lettuce	Time period -1 growing season
He *et al.,* 2000	SSGW, biosolids and Co compost	23%,25% and 48.4%	NA	Incubation	NA	One year
Helgason *et al.,* 2007	Composted cattle manure	< 5% in 7 out of 8 composts	NA	Pot	Canola (*Brassica napus*)	Time period 425 days
Prasad and Maher unpublished	SSGW, SSBW	0.6% to 8.1%	N.A	Pot	Grass	Time period 12 weeks
Shi *et al.,* 2004	Dairy waste compost	6%	NA	Incubation	NA	Time period 2.5 months, 90% of lagoon effluent was mineralised
Siebert *et al.,* 1998	SSBW of two levels of maturity	5-7%, Immature compost = immobolisation	NA	Incubation	NA	Time period 552 days at two temperatures 5C and 14C
Tester *et al.,* 1979	Sewage sludge compost	3 to 13%		Incubation	NA	Time period 1.5 months

NA =information not available

3. Review of Field Trials Publications

A number of publications of studies using compost made from various feedstocks (SSGW, SSBW, spent mushroom compost, manure and sewage sludge) were reviewed and are summarised in this section. Examples of the release of nitrogen from some publications are summarised in Table 4 at the end of the section.

Trials using Mostly Greenwaste Compost

Long-term effects of compost application are expected, but rarely measured. A seven-year growth trial was conducted by Sullivan *et al.,* (2003) to determine nitrogen availability following a one-time compost application. Six SSBW composts and a control were produced in a pilot scale project using two composting methods (aerated static pile and aerated turned windrow) and using three bulking agents SSGW, SSGW and mixed paper waste, and wood waste and sawdust. For the growth trial, composts were incorporated into the top 8 to 10cm of a sandy loam soil at application rates of approximately 155 mg ha^{-1}/ (about 7 yd^3/ 1000 ft^2). Tall fescue (grass) was seeded after compost incorporation, and was harvested 40 times over a seven-year period. Grass yield and grass N uptake for the compost treatments were greater than those produced without compost at the same equivalent N fertilising rate. The one-time compost application increased grass N uptake by a total of 294 to 527kg ha^{-1} during the seven-year field experiment. The greatest grass yield response to compost application occurred during the second and third years after compost application, when annual grass N uptake was increased by 93 to 114kg ha^{-1}/ $year^{-1}$. Grass yield continued at about the same level for years four through seven. Grass N uptake increased by 42 to 62kg ha^{-1}/ $year^{-1}$ during this same time period. The study demonstrated the long term benefits of a high-rate compost application in providing slow-release N for crop growth over a 7 year period.

Maher (2005) investigated the effect of two types of compost, (spent mushroom compost (SMC) and SSGW on the performance of autumn harvested cabbage in a field at Teagasc, Kinsealy, Co Dublin. The soil was a heavy textured grey-brown podzolic with moderate to good drainage and a history of vegetable crop production.

Both composts were applied at three rates, 25, 50 and 250t/ha of fresh material. The first two rates were chosen to represent normal agronomic practice compliant with environmental regulations to avoid nutrient overloading. The highest rate was used because this is the order of rate currently deemed necessary by the researchers involved in this project to achieve suppression of soil borne diseases. At all rates, each compost was applied with or without the addition of inorganic N at the rate of 150kg/ha supplied as calcium ammonium nitrate (CAN). CAN was applied (150kg N/ha) as a control treatment and N uptake of was measured in all treatments.

An estimate of the N fertiliser efficiency of these two composts compared with calcium ammonium nitrate (CAN) is shown in Table 3. The recovery of N from the compost and CAN was estimated by subtracting the N uptake in the control treatment from the compost or CAN treatments. In this analysis, treatments receiving both compost and CAN were not included. The recovery was then expressed as a percentage of the total amount of N added. The recovery of N from SMC was fairly constant between 14 and 17% while the SSGW resulted in a negative value at the highest rate. In contrast the N recovery from CAN was 99%.

The N efficiency of plant dry matter production was also calculated. This is the increase in dry matter production (kg) over the control treatment per kg of N added. N efficiency of plant dry matter production decreased from a ratio of 5.7 to 3.3 as the SMC rate increased from 25 to 250t/ha. This parameter fell from 2.5 to -0.7 for SSGW over the same range. The value for CAN was 21.6, which remained constant over the same range.

The estimation of N fertiliser efficiency indicates that SMC makes a positive contribution to N nutrition but at a fraction of the efficiency of inorganic N, approximately 15% in terms of N recovery and from 26 to 15% for dry matter production. For SSGW, the corresponding ranges were 12.3 to -1.6% for N recovery and 2.5 to -0.7 for dry matter production.

Table 3: Estimated recovery of N from SMC and SSGW and N efficiency of dry matter production in a field cabbage experiment.

Compost	**Rate**	**N**	**N efficiency**
	(t/ha)	Recovery (%)	of DM production
SMC	25	16.0	5.7
	50	14.0	5.4
	250	17.0	3.3
SSGW	25	12.3	2.5
	50	1.9	0.9
	250	-1.6	-0.7
CAN	0.545	99.3	21.6

[1] Recovery = Uptake – N uptake in the Control treatment (134kg/ha)
[2] N efficiency of DM production = Increase in kg DM over control per kg of N applied

Valenzuela-Solano and Crohn (2006) of the University of California investigated the influence of chemical composition on the decomposition and N release rates from samples of 11 organic mulches enclosed in nylon mesh bags under field conditions. The temperature effect was taken away from the time temperature-adjusted days (tad). The cumulative tad were used to model the pattern of the decay and N release. The chemical composition of the mulches significantly affected their decay. In descending order of significance, the concentration of the polar (solvent) extractable carbon fraction (C_P) and the acid insoluble fraction (C_{AI}) were significantly correlated with decomposition during the 1 year of study and the acid insoluble fraction (C_{AI}) (This means it is not soluble in acid). Correlation was positive with C_P and N and negative with C_{AI} (mostly lignin). The C_P was selected as the best predictor for mulch decomposition during the early and intermediate phases of this process (36 and 195 tad), but C_{AI} was selected as the best variable for predicting the fraction of the initial mulch mass remaining at the end of the study (397 tad). N was immobilised, as indicated by temporary increases in N masses in mulches above initial conditions, in shredded redwood, pine trimmings and in two of three compost mulches.

Immobilisation was most pronounced during the first 36 tad of the study, with a maximum rate which varied from 6 to 11.5% above the initial N concentrations. At the end of the study N releases ranged from 97% of initial N (grass clippings) to only 8% (one of the composts). The C_P was selected as the best prediction for N remaining in the four sampling dates (397 tad) and explained from 52 to 68% of the variation in N release as a percentage of initial N content.

Gabrielle *et al.,* (2005) used a deterministic soil crop model to simulate C:N dynamics in an arable field, amended with three types of composts (SSBW, SSGW+ sludge, and municipal solid waste), and a reference amendment (farmyard manure). The stability was measured using a biochemical index (a fractionation technique, cellulose, carbohydrate and lignin determination). A field trial was set up in 1998 in the Paris area, and managed as a maize and wheat rotation. After 4 years, the composts had on average, mineralised 3-8% of their initial organic N content. This was dependent on the stability of the compost. According to the authors the difference in crop recovery of compost derived N is evidenced by the issue of N application timing. It could be expected that a fresher compost would mostly mineralise (release) during the period between the application in autumn and the planting in spring. More stable composts on the other hand are better suited to the timing as used in this experiment. In such a situation composts with slower N release had higher N availability for the crops.

In a field trial, compost from a composting plant consisted of (i) source separated organic waste, (ii) biowaste, and (iii) SSGW (Hartl *et al.,* 2003). The composts were applied as follows; 20 tonnes ha^{-1} (annually) 40 tonnes ha^{-1} every second year and 60 tonnes ha^{-1} every third year. At the end of this trial, potentially released fraction of total N, the soil component of hot water (method of extraction) extractable N was 81-91mg/kg /ha. In the compost treatment, it ranged from 86 to 95mg-kg-ha after 5 years. However, the differences were not significant. In general, the chemical properties of the soil were scarcely influenced despite applying 130t/ha in total over 7 years. The higher total and water soluble N content in the soil indicate long-term increase in the N release (mineralisation) of compost in the soil indicating residual effect (what is left over from previous years) of compost. In a treatment, which received two doses of 60-70 t/ha compost, the nitrate content in Autumn was significantly increased in three out of nine sampling dates. Nevertheless the maximum increase through compost application was 49kg/ha (0-9cm depth). Based on yield and soil nitrate content, no justification was found to warrant a reduction in the amount of single application to as low as 20t/ha. The N availability early in the vegetation period with compost fertilisation was not significantly different from the control (no compost application) in the first 4 years of the experiment. In the final three years, there was a tendency towards higher spring soil nitrate concentrations in the compost treatments which indicate an increase in soil fertility which manifests itself as an increased release (mineralisation). Leaching losses into the ground water were measured by lysimeter measurements adjacent to the field experiment. These were below 10kg/ha/yr without treatment indicating low leaching losses. The analysis of yield components of the cereal indicates that the compost acted as a slow or medium, constant release source of N.

De Neve *et al.,* (2004) have studied the possibilities of manipulating N mineralisation from high N vegetable crop residues by the addition of organic materials, with the aim of initially immobilising the mineralised residual N with a view to stimulating remineralisation at a later stage. Residues of leek (*Allium porrum*) were incubated with soil, alone and in combination with straw, two types of green waste compost (with contrasting C:N ratios) and tannic acid. Evolution of mineral N was monitored by destructive sampling. After 15 weeks, molasses were added to part of the samples in each treatment, and incubation continued for another 12 weeks. All materials added during the first incubation stage, except the low C:N compost, resulted in significant immobilisation of the residue N. The immobilisation with the high C:N compost (41.4mg N kg^{-1}/ soil) was significantly larger than with tannic acid and straw (both immobilised about 26mg N kg^{-1}/ soil). In the straw treatment, remineralisation started in the first stage of incubation from day 50 onwards. The addition of molasses caused a strong and significant remineralisation in the second stage (equivalent to 73% of the N initially immobilised) in the treatment with the high C:N ratio compost. In the case of tannic acid, there was no consistent effect on mineralisation from the addition of molasses. This was attributed to the fact that the immobilisation observed was due to chemical rather than biological fixation of the residue N. A number of non-toxic organic wastes could be considered for use in mediating release of immobilised N from high N crop residue materials in an attempt to synchronize residue N availability with crop N demand. This study shows that by manipulating feedstock a tailored compost can be produced which can be synchronise with plant N uptake.

Trials using Mostly Biowaste Compost

Sullivan *et al.,* (2003) studied the application of SSBW compost on land. The compost was made from SSBW with SSGW, food waste with SSGW and paper waste and SSBW with sawdust. The application rate was 155 t/ha^{-1}. Soil mineralisable N tests done at 3 and 6 years after application also demonstrated higher N availability with compost higher than controls. (Sullivan *et al.,* 2003). The increase in grass N uptake accounted for 15 to 20% of compost N applied after 7 years for food waste composts produced with any of the bulking agents. After 7 years, increased soil organic matter (N) in the compost-amended soil accounted for approximately 33% of compost-N applied. This study confirmed the long-term value of compost amendment for supplying slow release N for crop growth (Sullivan *et al*., 2003).

The effects of SSBW compost was compared to mineral fertiliser in a field experiment in a long-term trial, beginning in 1992, Erhart *et al.,* (2008). The crop rotation was 75% cereals and 25% potatoes. The rate of compost application was 8, 15 and 22 t/ha per year (fresh matter) on average over 13 years. The yields of the compost treatment increased by 7-10% compared to unfertilised control and the nitrogen recovery by the crops was between 3 and 7% of the total nitrogen applied. These low recovery figures are possibly due to very dry conditions. The N content of the soil increased significantly in the compost treatment during the experiment while it remained more or less unchanged with mineral fertilisation.

A field trial was set up to investigate the performance of the SSBW compost in agriculture on a fertile soil under relatively dry climatic conditions, as is typical for eastern Austria (Erhart *et al.,* 2005). The results presented in this publication are based on yields and crop quality results of the first 10 years. The experiment included;

- three treatments with compost fertilisation; 9, 16 and 23 t/ha^{-1}/year^{-1} fresh matter (FM) on average of 10 years),
- three treatments with mineral nitrogen fertilisation (25, 40.5 and 55.9kg N ha^{-1}/ year^{-1}/ on average),
- five treatments with combined fertilisation, and
- an untreated control with a practical local crop sequence.

Yield response to the compost applications was very low in the beginning and increased slightly with the duration of the experiment. According to the authors this is likely due to the dry climatic conditions (552 mm precipitation), also to the average C:N ratio of 23 in the composts used, and the high level of fertility of the Fluvisol (a soil type) on the site. The analysis of the yield components of the cereals showed that: the plants in the compost treatments were sufficiently supplied with nitrogen in the early growth stages and after pollination, but at booting, when N-uptake is highest, the N-supply in the compost treatments was comparable to that with mineral fertilisation at up to 30kg N ha^{-1}. Crop quality was not negatively affected by compost fertilisation, in some cases it improved. The results suggest that on fertile soils the fertilising effect of SSBW compost is low, but increased with time. The yields and the results concerning nitrogen availability during the vegetation period and crop quality show that the compost acted as a slow release source of nitrogen on a moderate level.

Gross N turnover rates were followed for 1 year by examining ^{15}N pool dilution in a field experiment in Denmark with controlled application of anaerobically treated sewage sludge (424g dry matter (DM) m^{-2}, 2.9% N) and SSBW compost (1784g DM m^{-2}, 1.7% N) (Ambus *et al.,* 2002b). Gross mineralisation and immobilisation rates were measured on 7 occasions at various intervals, from weekly to monthly. Gross N mineralisation showed distinct seasonal patterns for all the treatments, with maximum rates during the summer, possibly associated with higher soil temperatures. Soil inorganic N availability increased markedly with the sludge and compost treatments. Although the N addition with compost was 2.5-fold greater than sludge, compost additions showed only an initial transient increase in soil inorganic N. After 4 weeks of incubation, there was no further detectable effect on inorganic N. Results indicate that anaerobically treated sewage sludge has a relatively high fertiliser value compared to SSBW compost which extends over a growing season, despite minor effects on the soil gross N mineralisation. SSBW compost, on the other hand, has relatively little fertiliser value. The implication of this is that additional nitrogen fertiliser has to be added when compost is added to soil to get an optimum crop yield. N mineralisation increased with the application of SSBW compost compared to the treated sewage sludge. These results further confirm the slow release nature of compost nitrogen.

Field studies were conducted by Wolkowski (2003) in 1993 and 1994 on a silt loam and a loamy sand soil in Wisconsin to determine the effect of municipal solid waste compost (MSWC) on corn (*Zea mays L.*) yield, plant nutrient concentration, and soil nitrate N content. Municipal solid waste composts with ages of 7, 36 and 270 days were applied at rates of 22.5, 45 and 90Mg[14] ha^{-1} to small plots. Rates of commercial nitrogen (N) fertiliser, ranging from 0 to 179kg N ha^{-1}, were applied to separate plots to determine the N availability from the MSWC. Nitrate N was measured in the top 90cm of soil. Treatments receiving the recommended N fertiliser showed higher nitrate N throughout the growing season when compared with any of the MSWC treatments. It was estimated that 6 to 17% of the total N in the 270 day MSWC became available in the first year. The land application of stable[15] MSWC at the studies rates would be an agronomically and environmentally admissible practice.

Nevens and Reheul (2003) studied the effects of the application of composted vegetable, fruit and garden waste (VFG), VFG compost + cattle slurry, and cattle slurry only, on silage maize on a sandy loam soil, in Flanders. A yearly application of 22.5Mg of VFG compost ha^{-1}, and 42 Mg of cattle slurry ha^{-1} resulted in economically optimum dry matter yields with a substantial saving of mineral fertiliser N. During the first four years of this compost and slurry application, an additional amount of mineral fertiliser N of, respectively, 94, 43, 22, and 12kg N ha^{-1} was needed probably due to lack of adequate release of compost N. Silage maize N uptake and N concentration in maize were higher (higher than control) when compost was applied. Despite the compost application, it did not result in an excessive amount of residual soil nitrate-N, provided that the additional mineral fertiliser N was adapted at the optimum rate. Four years of VFG compost application resulted in significantly higher soil organic matter and total nitrogen concentrations in soil compared to slurry application

The objectives of this study by Sullivan *et al.,* (2002) were (i) to determine SSBW compost effects on N fertiliser uptake efficiency across a range of N fertiliser rates, (ii) evaluate the effect of SSBW composts on grass yield and N uptake by tall fescue and (iii) estimate the residual effects of compost application on N fertiliser requirements. The trial used a split plot design with two compost treatments and a non-compost control as main plots, and ammonium nitrate (34-0-0) applied at rates of 0, 17, 34, 50, and 67kg ha^{-1} per grass harvest as subplots. The effects of two composts were studied: (i) SSBW, SSGW and paper compost and (ii)

[14] Mg is different term meaning tonnes

[15] Wolkowski (2003) when talking about stability does not referring to analytical stability testing of the compost, but the duration of composting. The longer the material is composted, the more stable it will be.

SSBW, wood waste and sawdust. The composts were applied at rates of approximately 78t/ha^{-1} (870–1,000kg N ha^{-1}) before seeding tall fescue. Grass N uptake increased linearly with fertiliser N application rate in all years. Compost did not affect fertiliser N uptake efficiency (the linear slope describing grass N uptake versus. fertiliser N application). Nitrogen fertiliser requirements during the midseason growth period were reduced by 0.22 to 0.37kg N ha^{-1} per day during the second season after compost application and by 0.13 to 0.26kg ha^{-1} per day during the third season after compost application. Results of this study suggest that compost alone may not supply adequate nitrogen. However when compost and fertiliser are used together they can supply N for optimum crop growth.

First year and residual effects of municipal solid waste (MSW) compost application on maize grain yield were evaluated on a Verndale sandy loam in Minnesota, and on a Hubbard loamy sand in Minnesota (Mamo *et al.,* 1998). Three different sources of MSW compost were used (A, B & C). At both locations, compost 'A' was applied at 0, 20, 40, and 80 dry tons/acre in 1992, and two other composts, ‘B' at Staples and 'C' at Becker, were applied at 40 tons/acre in the same year. The N fertiliser treatments were 0 or 220lb N/acre applied each growing year. With the low C:N ratio mature composts 'B' and 'C', yield was equal to or greater than that of the unamended control at 220lb N/acre during the first growing season. Based on the difference between N uptake due to compost and N uptake in the unamended control, about 8% of the total compost N was available from the low C:N ratio composts 'B' and 'C' in the first year while compost 'A' which had a high C:N ratio reduced number of plants per area and induced N immobilisation at Staples. Nitrogen availability from compost 2 to 3 years after application ranged from 3 to 10% of the total compost N per year and depended on the rate of compost application. The first year, autumn soil nitrate N concentrations were elevated with compost 'B' and 'C', especially with the addition of 220 lb N/acre. In subsequent years, autumn nitrate N concentrations increased with compost in combination with N fertiliser. The study showed that when MSW compost is used, additional fertiliser is required for optimum crop growth.

The objective of a study by Elhassania *et al.,* (2005) was to evaluate the nitrogen fertilising value of household solid waste compost in two soils of Morocco with contrasting properties: a sandy soil and a loamy-clay soil. The compost used in this study was prepared by aerobic biodegradation using the organic fraction after its separation from the non-compostable materials. A study of nitrogen availability of the compost was carried out in a soil compost crop system under greenhouse conditions using lettuce as a test crop. Four increasing compost rates of 0, 10, 20, and 30 t/ha were applied to the soils. The results show a high stock of mineral nitrogen in the loamy clay soil before crop installation. Unlike the loamy-clay soil, the sandy soil generated a better yield increase and a better response to mineral fertilisers. The effect of compost rate on nitrogen mineralisation was significant in the two studied soils. The quantities of mineralised nitrogen of the compost varied between 15 and 24% of the compost total nitrogen applied to the sandy and the loamy clay soils during the lettuce-growing season. Therefore, the use of household solid waste compost as soil amendment constitutes a beneficial alternative in Mediterranean soils because it permits the use of compost with high nitrogen availability. Although this study was conducted in Morocco it is relevant because it shows that it is possible to produce compost with relatively high nitrogen availability.

Aram and Rangarajan (2005) used two types of commercial compost produced from manure/food waste and brewery waste solids to test for supplying the N requirements of a bell pepper crop in a drip irrigated plasticulture system over two seasons. Composts were tested at 40 and 80Mg ha^{-1}, and combined with 67 and 133 or 0 and 67kg/ha^{-1} N applied as mineral fertiliser in the first and second seasons, respectively. Both types of compost increased total soil carbon and N content relative to unamended soil. Compost amendment also increased soil NO_3-N, NH_4-N and N mineralisation potential throughout the season, but yields were not affected. Increasing compost application rate from 40 to 80Mg/ha^{-1} did not increase N levels in soil or plants. Yield was not affected and season biomass accumulation was inconsistently affected by compost amendment. Commercial composts thus released mineral N in the first year of application, but supplementation with mineral fertiliser may be necessary depending on seasonal variation of N release and crop need.

In this study, compost was manufactured from SSBW which was mixed with various bulking agents such as SSGW, wood waste, sawdust (Sullivan *et al.,* 1998). The compost was applied at a relatively high rate of 150t/ha in a sandy loam. Tall fescue was used as a test crop. In the first year, there was no N uptake. Various reasons are suggested by the authors such as an infestation of annual grasses, supply of plant available nitrogen from non-compost sources that was higher than in succeeding years. The results for the second and third year after compost application show that the average slow release rate N for food waste compost was 0.7kg N/ha/day during April to August growth period. This rate of N release should be sufficient for turf receiving minimal care (Cook and Whistler, 1994). For high quality turf (golf course, athletic fields) the rate of N release demonstrated in the second and third year of our study should provide about 30 to 60% of the annual fertiliser N requirement (Lawson, 1989). These results showed that compost can only partially replace inorganic nitrogen even for golf turf which needs small quantity of fertiliser.

A four-year experiment was conducted (1998-2001) to determine the effect of once a year application of co-compost (municipal solid waste and biowaste) on N uptake (Zhang *et al.,* 2006). The compost was applied in the first year of the study at a rate of 50, 100 and 200t/ha at two sites. Each year, crops of barley, wheat and canola were rotated and harvested annually and N uptake was determined. The results showed that release of N from the compost was higher in the first year and then declined in each subsequent year. The overall N use efficiency for 3 crops on the two sites was 11% (1st year), 3% (2nd year), 1% (3rd year), and 2% in the fourth year.

In a review on N nutrition from compost from field trials, Amlinger *et al.,* (2003) came to the following conclusion:

1. In the first harvest, the N uptake was 2.6% (mean of minimum value) and 10.7% (mean of maximum value). A number of researchers have reported an average approximately 5% of compost N is plant available (Amlinger *et al.,* 2003).
2. In the following years (three years after compost application), the cropping system effects the N mineralisation dynamics and is usually between 2 to 3% of the added N.
3. The maximum value of 47% minerilisation was reached after 21 years.
4. High plant nutrient requirements increases mineralisation rate.
5. Stable[16] compost can have a lower mineralisation rate compared to unstable compost.
6. Compost with a high C:N ratio can as a rule, lead to N immobilisation.

These conclusions are based on the work of Timmerman *et al.,* (2003), Gutzer and Claassen and Carey (1994), Döhler (1996), VDLUFA (1996), Schlegle (1992), Ebertseder and Gutser (1995), and Aichberger and Wimmer (1999).

Mostly Manure Compost

A study was conducted in Nebraska, USA, from 1992 to 1996 to evaluate effects of P and N based manure, and compost application on maize yield, N and P uptake, soil P level, and weed biomass (Eghball and Power, 1999b). Composted and non-composted beef cattle manures were applied to supply N needs of maize for either a 1 or 2 year period. Fertilised and unfertilised controls were also included. Estimated N availability was 40% for manure and 15% for compost in the first year and was 18% for manure and 8% for compost in the second year after application. N uptake from fertilisers nitrogen was similar to manure indicating that N uptake from manure can have similar uptake as N fertiliser but compost has much lower N uptake.

An experiment was conducted by Eghball and Power (1999a) in Nebraska, to determine the effects of composted (compost) and non-composted manure from beef cattle feedlots on maize yield and N uptake under two tillage systems in 4 years. First year N availability was approximately 38% for manure and 20% for compost in both tillage systems. Apparent N use efficiency was 17% for manure, 12% for compost, and 45% for the fertiliser treatment across 4 years showing much lower N efficiency from compost.

Eghball *et al.,* (2002) state that when using manure or compost to fulfill the nutrient requirements of a crop, knowledge of the amount of nutrients mineralised following application is needed. Nutrient mineralisation from applied manure depends on temperature, soil moisture, soil properties, manure and compost characteristics, and microbial activity. Since these factors cannot be accurately predicted, nutrient mineralisation from applied manure can only be approximated. Nitrogen (N) availability from applied manure includes the inorganic N (NO_3–N and NH_4–N) in manure plus the amount of organic N mineralised following

16 The author only gives details that the compost is frisch (fresh) compost and Reif (ripe) compost. The author also refers to time of compost in relation to stability.

application. Nitrogen mineralisation differs for different manure types since the inorganic/organic fraction and quality of organic N varies among manure types. Mineralisation of organic N is expected to be low for composted manure (~18%) and high for swine or poultry (hens) manure (~55%).

Nitrogen mineralisation from composted and non-composted beef cattle feedlot manure applied to non-till and conventional tillage systems was determined by Eghball (2000) under field conditions at a site in Nebraska, USA, for 3 years. The nitrogen mineralisation of manure, composted manure, and inorganic fertiliser was studied using maize as a test crop. A non-treatment control was also included. An *in situ* resin method was used to determine N mineralisation from a soil receiving manure, compost, and no treatment during the growing season (June-October). Of the organic N applied the previous autumn, ~11% was mineralised from composted manure and 21% from non-composted manure during the succeeding growing season. Lower N availability from compost reflects the loss of easily convertible N compounds during composting and the presence of stable N compounds. Nitrogen mineralisation was similar in the non-till and conventional tillage systems even though manure and compost were surface-applied in the non-till systems. The author does not give an explanation but obviously this was not expected. Nitrogen mineralisation was significant, but not closely (R^2=0.21), related to ambient soil temperature (cumulative mean daily temperature >0℃). Mineralisation rate constants indicated that availability of residual manure and compost N was less than expected. The release of N is less from composted manure than non composted manure.

Nitrogen and carbon emissions and, plant nutrient leaching during storage of solid deep litter from dairy cow houses were examined in a study in Denmark (Sommer, 2001). Included was an assessment of the potential for reducing emission and leaching losses by compaction, mixing and by covering the deep litter. The effect on the growth of barley was studied too. During a composting period of 132 days from October 1998 to March 1999, emissions of NH_3, N_2O and CH_4 and leaching of nutrients during composting were measured. During mixing of the deep litter, N was lost and the emission and leaching losses during composting were consequently low when compared with the other treatments. Covering the compost with a porous tarpaulin or compacting the compost reduced emission losses to 12–18% of total-N compared with a loss of 28% during composting of untreated deep litter. Most of the nitrogen loss was due to NH_3 volatilisation. Leaching accounted for about one fifth of the N losses and only a little N was lost due to denitrification. Leaching of potassium (K) was 8–16% of the initial concentration; Compaction and the use of a cover reduced the volume of leachate produced and K loss from the heaps. Less than 0.3% of the total-N was emitted as N_2O, and the CH_4 emission was between 0.01 and 0.03% of the C in the stored deep litter. The yield level of barley was poor in this study and the fertiliser effect of compost was low. The yield response of barley showed that composted deep litter had significantly lower fertiliser efficiency than fresh deep litter applied to the soil.

The objective of Miller *et al.,* (2006) was to assess the effects of treated dairy waste on soil N pools, nitrification, plant N availability, and yield in a silage corn field (*Zea mays*) treated with ammonium sulphate (AS), dairy waste compost (DC), or liquid dairy waste (LW) as N sources at 2 rates (100 and 200kg/ha) of application over 5 years. The field plots were established in Utah, USA. Increases in soil C and N, nitrate, and available P and K were observed for the DC treated soils throughout the 5 year period. The highest nitrate accumulation was at the 60-90cm depth for soils receiving high level of DC (200kg N ha^{-1}), which moved to lower depths in subsequent years. While N from AS and LW were available for plant uptake almost immediately, the organic N in compost continued to mineralise throughout the growing season, after harvest and in subsequent years.

Effects of compost and N fertiliser management strategies on maize yield and NO_3 leaching were evaluated in a 3-year study on a Hubbard loamy sand soil by Mamo *et al.,* (1999). Two composts based on municipal solid waste were each applied at either 90t/ha per year from 1993 to 1995, or at 270t/ha in one application in 1993. The compost and non-amended plots were side-dressed annually with N fertiliser as urea at 0, 125, and 250kg/ha. Plant N uptake increased with N fertiliser rate, except in the 270t/ha compost treatments in year 1. Over the 3-year period, NO_3 leaching with the 270t/ha compost application was 1.8 times greater compared to that with the annual application. The estimated N mineralisation ranged from 0 to 12% and 3 to 6% in the annual and single compost addition, respectively. Under the conditions of this study, annual compost application with reduced supplemental N fertiliser was the best management strategy to reach optimum crop yield while minimising NO_3 leaching losses.

The dynamics of mineral N in soil as affected by either organic or mineral N fertilisation during cabbage (April-July 1997) and spinach (September 1997-May 1998) cultivation were observed in a field trial in Ljubljana, Slovenia (Jakse and Mihelic, 1999). Farmyard manure (FYM) and compost from chicken manure and bark were compared to mineral fertilisation (NPK) and to non-fertilised control plots. The amount of added fertiliser was adjusted to a total N supply of 200kg/ha for cabbage production and 100kg/ha for the following spinach production. Soil samples taken from 0-30, 30-60 and occasionally 60-90 cm, were analysed for mineral N content several times during the growing season. Treatments with NPK had the highest soil mineral N content throughout the experiment and N uptake was closely related to cabbage yield (R^2=94%). Compost induced N immobilisation during cabbage and spinach cultivation, despite its relatively low C:N ratio (C:N=17) indicated that C:N can occasionally give anomalous results.

Kumar and Goh (2003) state that although amounts and patterns of nitrogen mineralisation from decomposing crop residues and other organic materials are known to be affected by their initial chemical composition and quality (*e.g.* C:N ratio, lignin and soluble polyphenol concentrations), published results differed as to which properties correlated best with the N release. In the present study, 3 topsoils (0–15cm depth: Templeton silt loam, Templeton sandy loam and Temuka clay loam), varying in texture, were collected and air-dried in New Zealand. Six crop residues (leguminous and non-leguminous) and two organic materials (spent mushroom compost and dairy pond sludge) used as amendments were incubated to determine the release of mineral N and its relationships to residue chemical composition. They used Plant residue quality index-modified (PRQIM) to include C:N, lignin:N and polyphenol:N ratios of crop residues and organic materials so as to integrate these three major variables, which control the residue decomposition and nutrient release. The PRQIM was significantly and highly correlated with N release, not only for the data obtained in the present study but also for three independent data sets obtained from the literature (Kumar and Goh, 2003) for a wide variety of organic materials ranging from arable crop residues, tropical savanna woodland litter and leguminous tree prunings. The PRQIM has a potential to be used a predictor of N release from compost.

Table 4: Examples of nitrogen release from various composts from field trials

Author and year	Type/Source compost	Availability of nitrogen as% of Total N	Availability of nitrogen as% of applied inorganic N	Crop Grown	Duration of Trials and Comments
Amlinger *et al.,* 2003 (review article)	Various	2.6 mean of minimum values to 10.7% mean of maximum value in year 1.	NA	Various	In year 2 and 3 normally between 2 to 3% of added N. 47% in21 years.
De Neve *et al.,* (2004)	SSGW	Lower N immobilisation with compost with lower C:N ratio			
Eghball (2000)	Manure compost	18% N			
Eghball and Power 1999a	Cattle manure compost	15% for first year, and 8% for second year for compost For manure 40% and 18% respectively	NA	Maize	1 to 2 years trial
Eghball and Power 1999b	Cattle manure compost	20% for compost and 38% for manure	27% for compost and 38% for manure	Maize	1 year
Erhart *et al.,* (2008).	SSBW			Cereal and potatoes	
Gabriele *et al.,* 2005	SSGW + sludge, solid waste, biodegradable waste	3-8%	NA	Maize	52 weeks
Jakse and Mihelic, 1999.	Manure compost	Compost induced N immobilisation			
Maher, 2005	SMC, SSGW	SMC 16 – 17% SSGW -1.6 – 12.3% CAN 99%	NA	Cabbage	N efficiency of DM production: SMC 3.3 to 5.7% SSGW -0.7% to 2.5%, CAN 21.6%
Mamo *et al.,* 1998	Municipal solid waste	3 to 10% per year	NA	Maize	2 to 3 years
Mamo *et al.,* 1999	NA	0 to 12% annual application. 3 to 6% single compost application	NA	Maize	3 years
Sullivan *et al.,* 1998.	SSBW	No release in the first year, second and thirdyear had slow release of N			
Sullivan *et al.,* 2003	6 SSBW compost (mixed with SSGW, paper and wood waste)	15 to 20%	NA	Grass	7 years
Wolkowski (2003)	Municipal solid waste compost	6 to 17%	NA		270 days

NA= Information not available

4. Review of Publications on Leaching

This section reviews a number of publications on the leaching of nitrogen from compost.

The aim of the study by Chaves *et al.,* (2005) was to examine whether the incorporation of organic biological waste (OBW) materials mixed with a high N crop residue (celery) had an effect on N_2O emission from horticultural soil. This was studied under optimised laboratory conditions over a short time. Chaves *et al.,* (2005) laboratory trials indicated that apart from reducing NO_3 negative leaching, OBW application may at the same time reduce N_2O emissions from soils after incorporation of high N crop residues. Chaves *et al.,* (2005) also stated that the N_2O reduction potential can be expected to be lower under field conditions.

Trials at three different winter wheat fields (sandy textured soil) were conducted in 2005/2006 by Gibbs *et al.,* (2008. The researchers found that there was no difference ($P<0.05$) in over winter nitrate leaching losses of the untreated control compared with the compost treatments (source separated green/food waste compost) that were applied in the autumn of 2005.

In a trial where treatments included application of compost 90Mg ha-1 year-1 over 3 years or 270 Mg in one application, the NO_3-N leaching with the 270 compost applications was 1.8 times greater compared with annual application, Mamo *et al.,* (1999). They concluded that under conditions of the study, annual compost application with reduced supplemental fertiliser was the best management strategy to reach optimum yield while minimising nitrate-N leaching losses.

Borklen *et al.,* (2004) assessed the risk of nitrogen leaching following a single compost (biowaste) application to a silty and sandy soils in a forest. The rate was high at 6.3 kg $m\text{-}^{2}$. They reported that 0.2 to 7.8% of applied N was leached below the depth of 100cm following application of 1,440kg/ha of total N of low C:N compost (10:1) over a 32 month period. Most of leaching of these amounts occurred during the first 17 months but there was no significant difference in total N outputs between the control and compost plots during the remaining 15 months.

Maynard (1994) showed that the nitrate concentrations in groundwater under composted amended plots (0, 25, 50, 100 t dm/ha) did not exceed 10mg/L and did not show any significant differentiation between variants.

Leclerc *et al.,* (1995) demonstrated the high efficiency of manure compost and the beneficial reduction of nitrate leaching elicited by organic fertilisers during a five year rotation on a sandy soil using a lysimeter. Leclerc *et al.,* (1995) calculated mean nitrogen losses due to leaching were highest in the case of mineral fertilisers. The loss as percentage of applied N was 47%, 35%, 8.5% and 0% for inorganic fertiliser, manure compost, SSBW compost and SSGW compost, respectively.

In a review on N nutrition from compost field trials, Amlinger *et al.,* (2003) came to the following conclusion regarding leaching of nitrogen from compost:

1. In lysimeter experiments, it has been shown that, there is no increase in groundwater N, as a result of compost application, in spite of an increase in N balances. Extreme unfavourable conditions (for example wet weather after autumn application together with low plant N uptake that often occurs under Irish condition) may result in the leaching of N.
2. In many trials, compost showed similar leaching to the unfertilised control, whereas mineral fertiliser or slurry showed increased leaching compared to compost and unfertilised control treatments.
3. From the analysis of field trial data Amlinger *et al.,* (2003) came to the conclusion that mature compost with high rate of application (for example 100 tonnes per ha) in sandy soils results in leaching.
4. According to Timmerman *et al.,* (2003) after studying many experimental results, came to the conclusion that through regular application of compost at moderate rates (10 tonnes), there is no danger to the ground water.

In addition, as it is shown in the report on the availability of phosphorus (Prasad, 2009), the release of P is much higher from compost in relation to N release. Therefore the limiting factor for almost all compost application will be phosphorus and hence nitrogen leaching from composts will not be an important factor.

5. Predicting Nitrogen Release

5.1 Nitrogen availability

Factors which affect the rate of availability of nitrogen from organic materials include soil moisture, temperature and microbial activity. It is proposed that compost with a C:N ratio of 15 could reasonably be expected to have up to 15% of its total nitrogen available to a following crop through microbial mineralisation of the organic matter (Wallace, 2006). In the following years, 5%, 3% and then 2% would be available. Such a compost, having a total N of 12.5 g N kg^{-1} and applied at a rate to supply a total N loading of 250kg N ha^{-1} (20 tonnes dry matter (DM) basis), would have 37.5kg N (15%) available in the first year, 10kg in the second, 6kg in the third, and 4kg in the fourth and subsequent years (Wallace, 2006).

5.2 Nitrogen, C:N Ratio and Extractable Nitrogen in Various Irish Composts

The total nitrogen is generally not a good indicator of how much N will become available. However, it is interesting to look at total N values from various composts as it gives a rough idea on the potential availability. The mean total N content of source separated green waste (SSGW), source separated biowaste (SSBW) and miscellaneous (fish waste, vermicompost *etc.*) were 1.30% (0.27-2.34%), 2.10% (0.20-4.34%) and 1.28 (0.22-2.21%), respectively. However, there was a great deal of variation with figures as low as 0.2% (Prasad and Foster, 2009)

Extractable NO_3-N, is not buffered by soil, and is susceptible to leaching. Extractable NO_3-N data for Irish composts was examined and a mean values of 90mg/L, 263mg/L and 332mg/L were observed for SSGW, SSBW and Miscellaneous. As a percentage of total N it was a very small fraction, for SSGW, SSBW and Miscellaneous were 0.7%, 1.3% and 1.6% respectively. This indicates that most of these composts would not cause leaching when compost is applied to soil.

A formula has been proposed for nitrogen availability by Waste and Resource Action Programme (WRAP) (Wallace, 2006) based on their review of their research. This is a model for the prediction of N availability from composted materials (Table 5). It is an interim proposal and they recommended that research is undertaken to test this theory. In view of the lack of another test to predict N, the study will be using this test as the basis for N application rates from compost.

Table 5: C:N ratio in relation to potentially mineralisable N (Wallace, 2006)

Compost C:N ratio	% of total N estimated to be mineralised after application			
	Over 3 years	In year 1	In year 2	In year 3
10.0	25	12.5	7.0	5.5
12.5	17.5	8.0	5.0	4.5
15.0	10	5.0	3.0	2.0
17.5	5	2.5	1.5	1.0
20.0	0	0.0	0.0	0.0

Irish compost samples laboratory analysis were compiled into one database (Prasad and Foster, 2009). If the premise is accepted that C:N ratio >10 would lead to 12.5% of the total N mineralisation in year 1, the percentage of Irish compost samples falling in this category for SSGW, SSBW and Miscellaneous would be 2%, (n=67), 8.4% (n=71) and 11% (n-37) respectively.

The percentage of figures in category C:N ratio 10-15 (% release 8.5% in year 1) for SSGW, SSBW and Miscellaneous would be 40%, (n=67), 39.3 (n=112) and 27% (n-37) respectively.

The percentage of figures in Category C:N ratio 15-20 (% release 2.5% in year 1) for SSGW, SSBW and Miscellaneous would be 27 (n=67), 22 (n=112) and 24% (n-37) respectively. If it is accepted, the premise that a C:N ratio of >20 would lead to immobilisation then the figures for SSGW, SSBW and Miscellaneous would be 30%, 30% and 38% respectively. These results indicate that a significant amount of the Irish compost samples would tend to immobilise N and less than 10% would mobilise around 12.5% of the total N in the first year.

5.3 Interdependency of Nitrogen and Phosphorus

In order to understand fully the recommendation which follows, SI 378 of 2006 should be read. To explain how the recommendation for compost applied to soil can be used; the following scenario can be examined. For example, a grower wants to grow a crop of lettuce. When SI 378 of 2006 is examined, it is found that the rate recommended for nitrogen and phosphorus in their Table 6 and 7 respectively are as follows:

Table 6. Rates of nitrogen for Lettuce based on soil N index (as given in Table 19 SI 378 of 2006)

Crop	Nitrogen Index			
	1	2	3	4
	Available Nitrogen kg/ha as Mineral Fertiliser			
Lettuce	100	90	80	70

Table 7. Rates of phosphorus for Lettuce based on soil P index (as given in Table 18 SI 378 of 2006)

Crop	Phosphorus Index			
	1	2	3	4
	Available Phosphorus kg/ha as Super phosphate			
Lettuce	60	45	35	20

If compost is applied as a N source the nitrogen requirement for lettuce is 100 kg to 70 kg/ha (Table 6). The compost rate to give this amount, of assuming a compost of say total N of 1%, C:N ratio of 15 and N availability of 5% (see Table 5) it will require 200 tonnes of dry compost 9,400 tonnes fresh weight assuming moisture content of 50%) to give 100 kg/ha N in the first year (for a requirement of 70kg/ha the dry compost requirement would be 140 tonnes/ha, (280 tonnes/ha). Assuming a P content of compost of 0.2% and 75% availability (Prasad, 2009) it will supply 300 kg/ha of P which is 5 times the P requirement. of lettuce (Table 7) This illustrates clearly that the limiting factor of compost application is phosphorus rather than N.

The interdependency of phosphorus and nitrogen can also be shown from the following example. The N/P ratio of compost is around 5.2 for SSGW, 4.70 for SSBW and 3.66 from Miscellaneous (these are mean values taken from data of Prasad and Foster, 2009). The ratio is somewhat similar for plants such as wheat and corn (Gilbertson et al., 1979). However the release of N from compost is in the order of a negative value to 20% (Prasad, 2009, this document) of total N while P release is 60 to 100% of total P (Prasad, 2009). Thus if N based rate of compost is used the amount of P applied will be in excess of the plant P requirement and potential environmental problem. Vice versa if P based rates of compost used the amount of available N will be well below the plant N requirement and additional inorganic or organic N would need to be applied to get optimum growth.

6. Conclusions

- The literature reviewed showed that compost acted as a slow or medium, constant release source of N.
- This literature study shows clearly that nitrogen availability from composts is many times less (20% to minus 10% in the first year) than inorganic fertiliser sources. These results are consistent from laboratory/pot trials and field trials.
- These results show that N release is often only 0 to 20% or even negative in the first year and 0 to 8% in the following years.
- These publications and results also show that feedstock has a major effect on rate of mineralisation of N. For instance, compost derived from source separated green waste (SSGW) the release of N is often negative (Prasad and Maher, unpublished), (Maher, 2005), (Bowden *et al.,* 2007), (Claasen and Carey, 2004). Compost derived from animal manures has the highest rate of mineralisation, followed by source separated biowaste (SSBW) compost, with SSGW compost having the lowest rate of those feedstocks studied.
- However, the release of N from compost manufactured from manure is lower than mineral fertiliser. Composting of manure leads to much lower release rate than uncomposted manure and these findings are significant when considering nutrient management plans.
- The release of N from composted sewage sludge was inconsistent. For example, N release from composted SSGW/sewage sludge was more than composted SSGW (*e.g.* He *et al.,* 2003). However, results also show that composted sewage sludge can fix nitrogen (Bowden *et al.,* 2007). Composted sewage sludge and composted cattle manure had similar mineralisation rate according to one study (Bar-tal *et al.,* 2004).
- The release of N is affected by the stability of the compost. Some unstable composts, *i.e.* SSGW derived compost which has a high content of woody material, immobilised a great deal of nitrogen. It is necessary to add mineral nitrogen or other quicker release organic N at the composting phase and/or when compost is added to soil, as such compost is unlikely to provide adequate nitrogen for optimum crops.

Leaching losses of nitrate-N is generally likely to be non-existent due to various reasons:

- First and foremost, the slow release character of compost-N and the relatively small amount of total n released in the first year and subsequent years.
- Secondly, the rate of application of compost is likely to be low as the rate of compost application will depend on P availability. Compost P is much more available than compost N (see Prasad, 2009).
- Thirdly, the application of compost increases the water holding capacity of soil particularly sandy soil, hence water flow through the soil will be reduced and leaching of N reduced.
- At present, no analytical method exists to predict correctly the nitrogen

mineralisation rate. The C:N ratio is currently used as a crude estimation. However, there are disadvantages to using this method, as it does not take into account the type of carbon present, *e.g.* whether it is lignin or cellulose based. The accuracy of using the C:N ratio as a predictor of N mineralisation improves if it is used in conjunction with compost stability indices, *e.g.* the Oxygen Uptake Rate (OUR) method. Specific analytical methods must be developed to accurately estimate the nitrogen mineralisation rate, but until these are developed the C:N ratio along with stability indices can be used.

In relation to the above conclusions it should be borne in mind that there is certain weakness/limitation in relation to the objective of the review which was to quantify the release of N from compost, the weakness/limitation is the lack of clear information regarding feedstock or stability which has been shown in this review to affect N availability from composts. Many authors have different interpretation on what stability means and what is stable and unstable.

In addition there is confusion regarding terminology, For instance the term MSW widely used in the US and in Europe probably the equivalent term in Europe is non source biowaste. It should also be remembered that the publications reviewed encompasses up to 30 years and during the early part of the period things like separate collection and stability measurements were not commonplace. Nevertheless in spite of these shortcomings the conclusion from the review can be drawn with a great deal of confidence as there is remarkable agreement with the results of different authors.

7. Recommendations

The recommendations for future work are:

- The availability of N from compost is effected greatly by the feedstock in which the compost was derived and stability (often only 0-20% or even negative in the first year and 0-8% in the following years). Until more detailed research is conducted it is recommended that the guidelines developed by Wallace (2006) of using the C:N ratio of the compost to determine the availability be used as outlined in the Table 8 below.

Table 8. C:N ratio in relation to potentially mineralisable N[17]

Compost C:N ratio	% of total N estimated to be mineralised after application
<10.0	Up to 25
12.5	17.5
15.0	10
17.5	5.5
>20.0	0.0

- There is a need to emphasise the interdependency of P and N in compost in relation to the SI 376. It is not nitrate leaching from compost that could be a potential problem from compost application; rather it is P that could be potential problem.
- Standardised analytical methods need to be developed to accurately ascertain the release rate of N from compost.
- Field trials are needed to determine the release of nitrogen from Irish compost under Irish climatic and soil conditions.
- Beside compost as a source of nutrients, it also has other properties which other organic fertilisers do not have as a source of stabilised organic matter, disease suppression properties, improved water retention. As such, compost should be given as separate classification as a 'soil conditioner' as opposed to being just a fertiliser source.
- Up to 1 January 2011, there is a temporary rule in which more phosphorus can be applied on land than crops require, as long as it comes from manure produced by pigs, poultry or from spent mushroom compost and that the 170kg nitrogen is not exceeded. This rule should be extended to include all types of source-separated compost.
- This report must be read in conjunction with *"A Literature Review on the Availability of Phosphorus from Compost in Relation to the Nitrate Regulations SI 378 of 2006"* (Prasad, 2009), as the available of nitrogen and phosphorus are required for compliance with SI 378 of 2006.

[17] The assumption is that compost used meets the requirements of the stability standard outlined in Prasad and Foster (2009).

8. Glossary of Terms

Acid insoluble fraction (C_{AI})
This means is not soluble in acid.

Biowaste (Biodegradable Material)
Source-segregated biodegradable waste of an organic or putrescible character.

Biodegradable Municipal Waste
Municipal waste which is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard.

Compost
Compost means the stable, sanitised and humus-like material rich in organic matter and free from offensive odours, resulting from the composting process of separately collected biowaste.

Compost stability is associated with the microbial activity. Maturity is sometimes confused with stability but maturity is related to the absence of phytotoxic substances for the growth of plants. Maturity is determined basically by biotests with plants (phytotoxicity tests), in which the germinating power of seeds in compost is determined. More details on stability levels of compost is given in Prasad and Foster (2009). The author changed the word maturity to stability in this report when stability should have been used.

Fertiliser N equivalency
This means the nitrogen fertilising value of a material in comparison to inorganic fertiliser.

Green Waste (Garden and Landscape Material)
Vegetation waste from gardens and parks including tree cuttings, branches, grass, leaves, prunings, plants and flowers.

Holding
Holding means an agricultural production unit and, in relation to an occupier, means all the agricultural production units managed by that occupier.

Municipal Waste
Waste from households, as well as commercial and other waste which, because of its nature or composition, is similar to waste from households.

Median
The middle value in a set of numbers arranged in increasing order.

Mean
The mean is the mathematical average of a set of numbers.

Nitrogen Fertiliser Equivalent Values (NFEV)
This means the nitrogen fertilising value of a material in comparison to inorganic fertiliser.

Oxygen Uptake Rate (OUR)
If compost is biologically active, it will consume oxygen and respire carbon dioxide. The OUR method measures the respiration rate of compost by indirectly measuring (using a pressure sensor) the carbon dioxide evolution as a pressure drop in a bottle. The pressure drop is created by soda lime pellets absorbing the carbon dioxide.

Polar (solvent) extractable carbon fraction (C_P)
Polar means materials where electric charge is unequally distributed. Solvent extractable means carbon can be extracted using solvent such as acetone.

Plant-available nitrogen (PAN)
This the amount of nitrogen available to plants for growth.

Plant Residue Quality Index-Modified (PRQIM)
This is based on taking into account not only the C:N ratio but also lignin and plyphenols.

Recovery
The amount of nitrate taken up by a plant or extractant.

Release
The amount of N released.

Stabilised Biowaste
Waste resulting from the mechanical/biological treatment of unsorted waste or residual municipal waste, including treated biowaste, which does not comply with specified minimum standards of environmental quality set out in EPA Waste Licenses and Local Authority Waste Permits.

Separate Collection
The separate collection of certain categories of biodegradable municipal waste, such as paper/cardboard and organic waste, in such a way to avoid the different waste fractions or waste components being mixed, combined or contaminated with other

potentially polluting wastes, products or materials.

VFG Compost

Vegetables, fruit and garden waste. It has special significance in regions in the Netherlands where brown bin collection is restricted to pure non-meat sources of source separated organic waste.

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10. Acronyms and Notation

[referring to Ireland, except where otherwise specified]

AS	Ammonium Sulphate
BSD	Biosolids
BW	Biowaste
C	Carbon
CABI	Commonwealth Agricultural Bureaux International (United Kingdom)
CAN	Calcium Ammonium Nitrate
CEN	*Comité Européen de Normalisation* - European Committee for Standardization (Belgium)
CMC	Cattle Manure Compost
DC	Dairy Waste Compost
DM	Dry Matter
EPA	Environmental Protection Agency
ERTDI	Environmental Research Technological Development and Innovation
FM	Fresh Matter
FYM	Farm Yard Manure
GW	Greenwaste
GWF	Green Waste and Food Waste
K	*Kalium* (L) - potassium
LW	Liquid Dairy Waste
MWC	Municipal Waste Compost
Mg	Mega grams (tonne)
N	Nitrogen
NA	Not Available / Not Applicable
NFEV	Fertiliser Equivalent Values
NPK	Nitrogen, Phosphorus, *Kalium* (potassium)
OBW	Organic Biological Waste
OUR	Oxygen Uptake Rate
OW	Onion Waste
PAN	Plant-available Nitrogen
PRQIM	Plant Residue Quality Index-Modified
PVC	Polyvinyl Chloride
RTDI	Research Technological Development and Innovation
SI	Statutory Instrument
SMC	Spent Mushroom Compost
SSBW	Source Separated Biowaste
SSGW	Source Separated Green Waste
STRIVE	Science, Technology, Research, and Innovation for the Environment
t/ha	ton(s) per hectare
tad	Temperature-Adjusted Days
Teagasc	The Irish Agriculture and Food Development Authority
VDLUFA	*Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten* (De) – Association of German Agricultural Experimental and Research Institutes (Germany)
VFG	Vegetable, Fruit and Garden [(waste])
WRAP	Waste and Resources Action Programme (United Kingdom)