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# A detailed chemical and nutrient characterisation of Compost and Digestate including comparative releases of Nitrogen and Phosphorus

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# A detailed chemical and nutrient characterisation of compost and digestate fibre including a comparative release of nitrogen and phosphorus

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A detailed chemical and nutrient characterisation of compost and digestate fibre including a comparative release of Nitrogen and Phosphorus

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# NOMENCLATURE

MC – Composted Manure data obtained from EPA Strive Project
SBC – Composted Biowaste data obtained from EPA Strive Project
SGC – Composted Greenwaste, data obtained from EPA Strive Project
SADC – Anaerobic Digestate Composted data obtained from EPA Strive Project
SAD – Anaerobic Digestate obtained from EPA Strive Project
RC – rx3 Compost
RAD – rx3 digestate fibre
ILGC – Industry Led Greenwaste Compost
ILBC – Industry Led Biowaste Compost
UKD – UK Data Reference (Dimambro *et al*)
SWAD – Swiss digestate fibre
SWC – Swiss Compost Data

# LIST OF ABBREVIATIONS AND TERMS

BMW - Biodegradable municipal waste
MSW - Municipal Solid Waste
AD - Anaerobic digestion

# ABSTRACT (EXECUTIVE SUMMARY)

An add-on project was commissioned to run parallel to the large scale rx3 demonstration field trial to asses the benefits of compost and digestate fibre application to field crops. This add-on project involved a detailed chemical and biological characterization of the two materials used in the crop field trials. In addition an incubation experiment and grass growth experiment using the two materials was conducted. From the characterization data it is evident that the compost and digestate fibre were similar in most cases except for certain stability parameters and certain other plant nutrients. For example it showed the two materials were stable based on a number of stability parameters e.g. respiration index, but the compost was more stable than digestate as evidenced by humic acid content .The total nitrogen content was similar but total phosphorus was much higher in the digestate. The nitrogen content of digestates can vary a great deal not only due to nitrogen volatilization but also due to feedstock. It is very important to measure the inorganic nitrogen (mostly NH4-N) and express it as a % of total N. This gives a better indicator of crop nitrogen availability. In addition, one needs to conduct nitrogen analysis close to the time of application in the field due to the propensity of the ammonium contained within the digestate to volatilize. The nitrogen availability was very low in comparison to mineral fertiliser in both the incubation and pot trial.

With compost application, the phosphorus content is often the limiting factor on the amount of compost that can be applied to land as phosphorus availability is much higher than nitrogen availability. For fresh digestate fibre with a nitrogen content of 10 - 15% nitrogen and phosphorus content of 1 – 2 % nitrogen could be a limiting factor for its application rate. However if the nitrogen has been lost as in the case of the digestate fibre used in our investigation, phosphorus can become the limiting factor. We found phosphorus availability from digestate fibre and compost was high, 70 – 95% of superphosphate equivalent. Since it is generally agreed that the anaerobic digestion process does not change the phosphorus availability, high phosphorus anaerobic digestion feedstock based on poultry manure will have higher phosphorus availability than feedstock based on an energy crop e.g. maize.

# 1 Background

There is poor knowledge and public perception of the use of compost and especially digestate fibre and digestate liquor in agriculture as an organic fertiliser (plant nutrient source). Crop demonstration trials have been started in Ireland funded by rx3 to demonstrate the benefits of compost, digestate fibre and digestate liquor application to agricultural land. This project started in 2010.

An add-on project was commissioned in November 2011 to be conducted parallel to the crop demonstration project. This project involved;

I. comprehensive characterisation of the rx3 compost (RC) and rx3 digestate fibre RAD) that were used in the crop demonstration trials

II. a laboratory incubation trial

III. a greenhouse pot trial

The latter two trials were initiated to study the release of phosphorus and nitrogen from these materials including digestate liquor to help inform some of the findings from the demonstration trials.

This characterisation study was not conducted in isolation. It was informed by a larger EPA STRIVE project (2008-wrm-ms-n) which involved characterization of 25 composts from a range of feedstocks, as well as digestate fibre and composted digestate fibre. The EPA project also includes short term incubation and a pot trial using multiple cropping of young cabbage plants as a test crop to establish the release of phosphorus and nitrogen. In addition, other pertinent Irish and international data on digestate fibre and compost have been included in order to explain and support the findings.

Note: When we refer to “digestate fibre” in this report we always mean the solid, sometimes fibrous fraction remaining when liquor has been separated and removed from whole digestate. When we refer to “digestate liquor” in this report we always mean the liquid fraction remaining when digestate fibre has been separated and removed from whole digestate.

# 2 Materials

The rx3 compost (RC) was produced from a feedstock that was half food waste and half woodchip and was processed by Waddocks Composting Facility in Carlow.

The rx3 digestate (RAD) came from Lower Reule Biogas ltd in Shropshire England. It was a mixture of 10% cow slurry and 90% commercial food waste. The fibre was delivered about 5 weeks after it had been unloaded and separated – using a screw press for separation – and stored in a pile at the facility.

The liquor was separated and stored in a tank, then transported to Ireland and stored at the farm, prior to sampling. At all times it was stored undercover out of sunlight.

In order to make a comparison of the two products from the rx3 trial, digestate fibre (RAD) and compost (RC), the composts from the EPA STRIVE project were put into groups based predominantly on feedstock. The first group was composted manure (feedstock mainly manure), the second based on feedstock containing mainly source separated municipal bio waste and organic factory waste (e.g. dairy), food, catering waste mixed with small quantities of green waste. The third category consisted mainly of compost where the majority of the feedstock is green waste. These compost materials were mostly sourced from Ireland but some originate from Belgium, Austria and Germany.

The data from over 100 composts based on some separated green waste and source separated bio waste (Prasad & Foster 2008) was compared, where applicable, with the rx3 data.

In addition digestate fibre (feedstock municipal bio waste) (SAD) and SAD composted with green waste (SADC) from Germany were not put into group but compared individually. This is because information on digestate fibres, in relation to phosphorus and nitrogen release is very scarce on a worldwide basis as contrasted to the release of phosphorus and nitrogen from compost where some information is available.

In addition, the characterisation results will be compared with data from other countries where it is possible to make a valid comparison, as analytical methods varies and such comparison may not be possible.

Details of the testing methods used including definitions of the terms e.g. digestate are included in the Appendix.

# 3 Results

## 3.1 PH

pH is an indication of alkalinity or acidity of the compost and as such all composts range from marginal acidity to moderate alkalinity.

All of the pH measurements were within 6.5 to 8.0 range, which is normal for composts (Fig. 1).pH of 7.8 to 8.5 is considered normal by APEX (Dimambro *et al.*, 2007). The pH of RC and RAD were higher than all the materials assessed in the EPA Strive project. However, ILGC and ILBC and UK data were much higher. These values are within the range considered "normal"

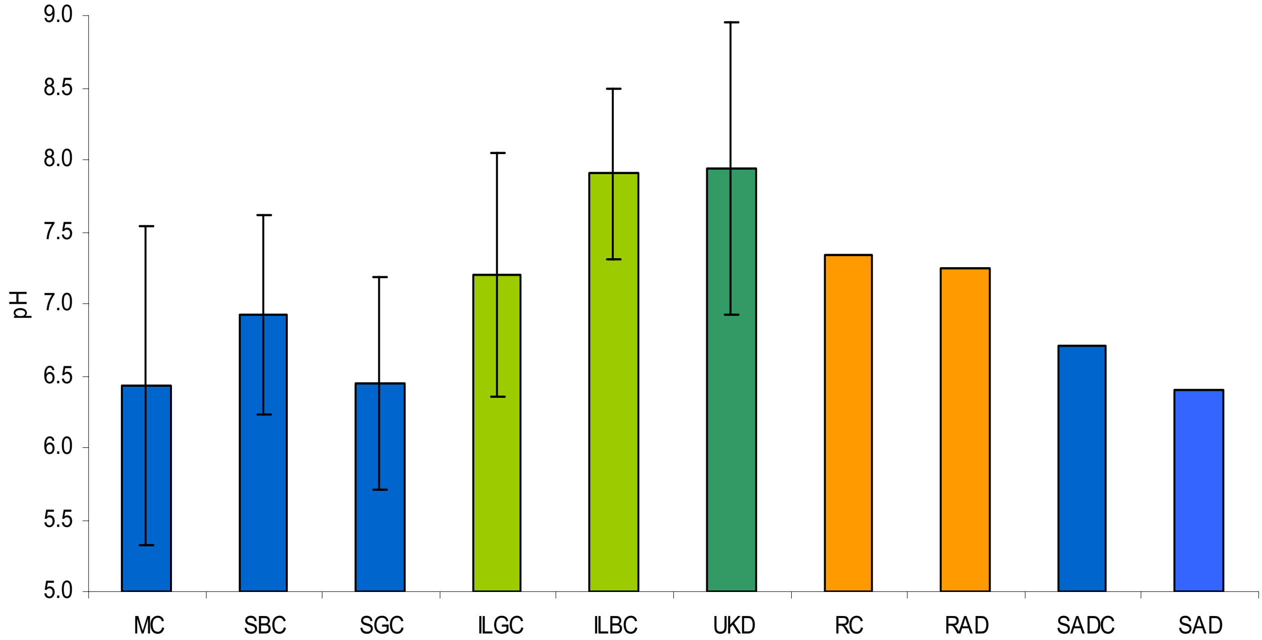


**Figure 1: Comparison of the pH values of composts and digestate fibre**[1]

[1] Note Error bars reflect Standard Deviation in all figures where shown

## 3.2 ELECTRICAL CONDUCTIVITY (EC)

Electrical Conductivity (EC) is a measure of the salinity of the compost. RAD and RC have relatively low EC and much lower than SWAD (Fig. 2). The UK compost average is particularly low (Range 0.6 – 3.3 mS/m$^3$; n=12). High EC in compost can have a detrimental effect on plant growth, particularly the roots. However, when the composts / digestate materials are applied in the field dilution of the compost / digestate material takes place and usually the salinity of the compost is not generally detrimental under these conditions. The EC values are moderately high to very high in all materials and if they are to be used as a growing media they must be diluted with a low EC product.

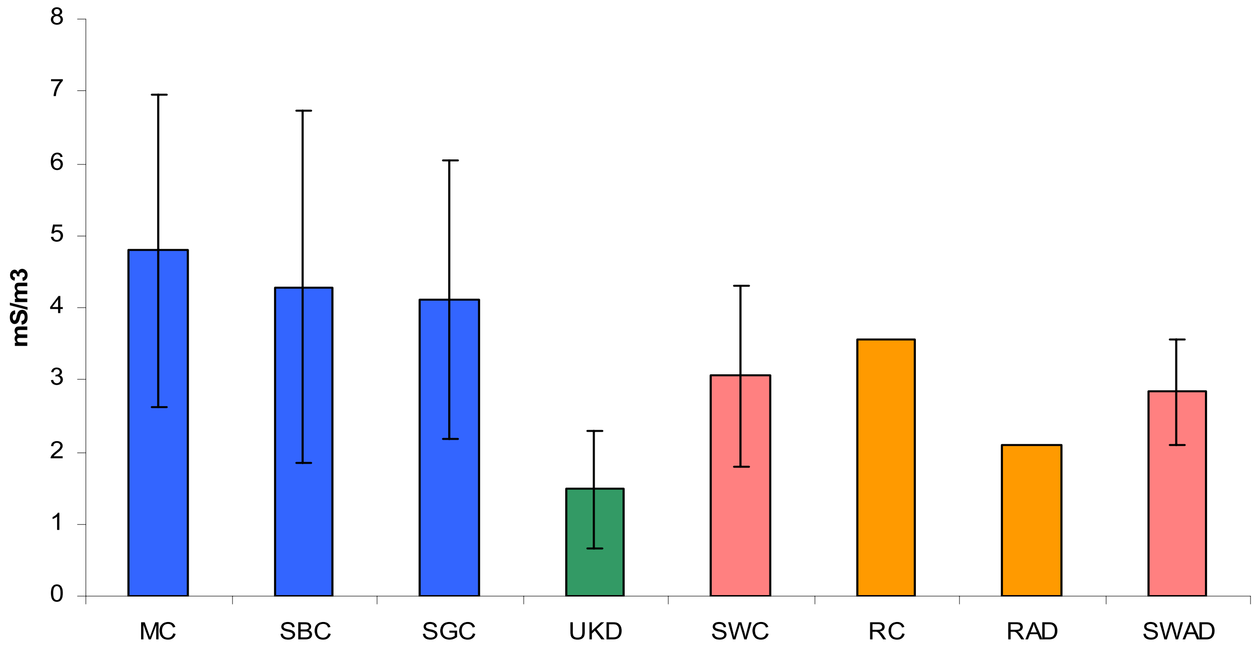


Figure 2: Comparison of the EC values of composts and digestate fibre[1].

## 3.3 ORGANIC MATTER

RAD has very high levels of organic matter that are just slightly lower than MC (Fig 3). Similarly SAD has high levels of organic matter. The SWAD also has higher levels than SWC. The SADC has lower levels of OM as a result of composting. Lower levels of organic matter (higher ash content) can indicate the presence of minerals and soils. Organic matter content is an important parameter but it does not give any indication of the quality of the organic matter. Measurements such as C:N ratio, lignin content and humic acid content which have been tested in this project give a better insight into the quality of the organic matter.

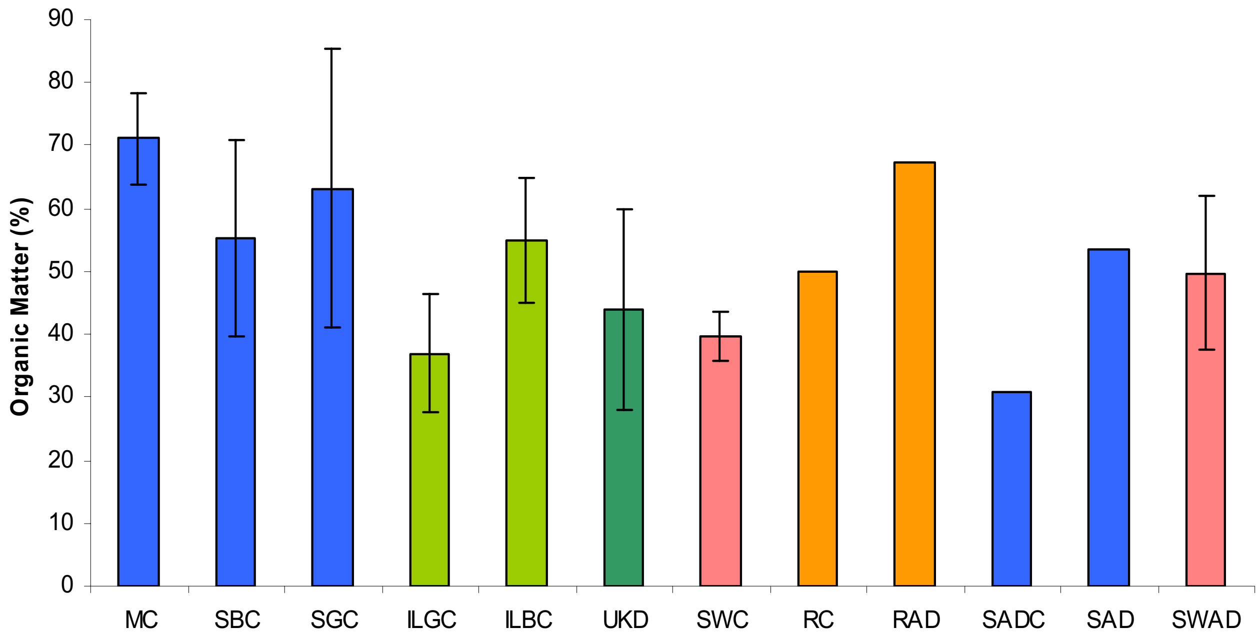


**Figure 3: Comparative percentage of Organic matter content of composts and digestate fibre[1].**

## 3.3 C:N RATIO

This parameter gives an indication of nitrogen release from compost but it is a relatively crude measurement since it does not take into account the nature of the carbon for example if the carbon is mostly lignin or cellulose. Where composts are being applied for their fertilising value a number of maximum C: N ratios are recommended including 15:1, 20:1 and 30:1, since at values greater than 30:1, composts' use soil nitrogen to aid compost decomposition and will therefore lead to nitrogen immobilisation (Dimambro *et al*., 2007). The C: N ratio of RAD was low and RC was even lower (Fig 4). Similarly, SAD and SADC had very low C: N ratio. Only the ILGC had a C: N ratio higher than 20, indicating the possibility of nitrogen immobilisation when these composts are applied to the soil or used as a component of a growing medium.

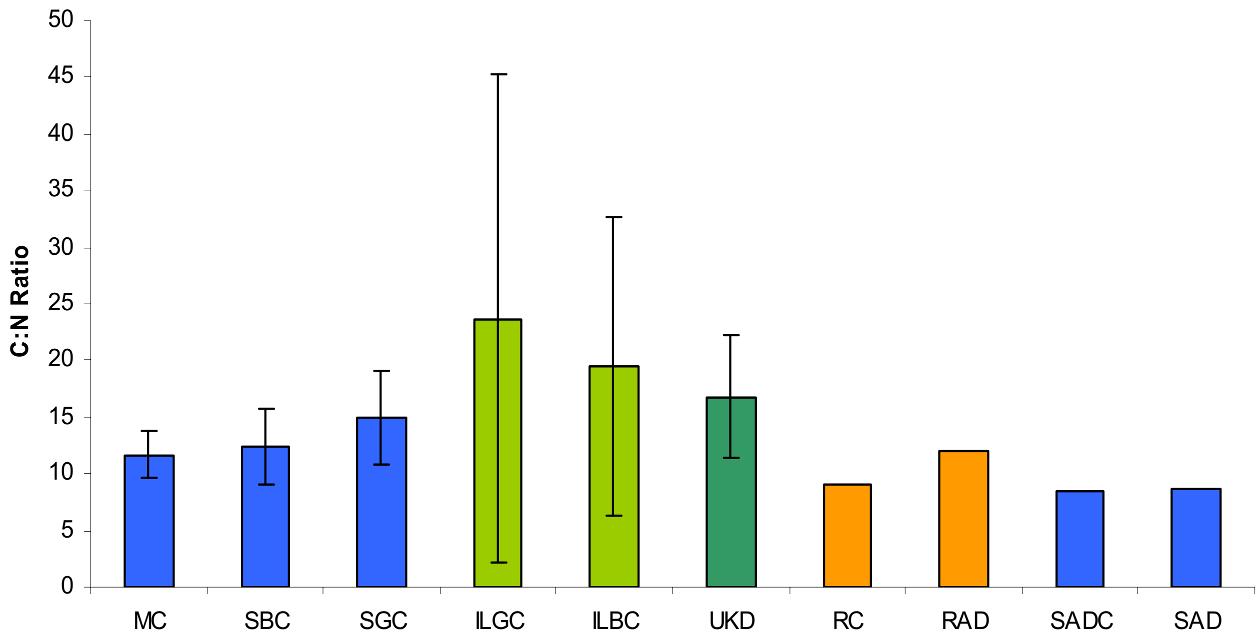


**Figure 4: Comparative Carbon: Nitrogen ratios of composts and digestate fibre[1].**

## 3.4 STABILITY

Respiration tests are most common and highly favoured methods when one is measuring the stability of compost. It measures the microbial activity and the bio availability of organic matter and therefore the user can understand the degree of stabilisation of the organic matter. Most research in this field has been done during the composting process, with samples of similar origin and therefore the results are dead weighted by their limited scope and their conclusions are only valid for each material studied and might have limited application to other materials. In the EPA STRIVE project therefore, most composts used in the investigation were stable or close to stable as would be the case in finished composts and they had been produced from a range of feedstocks. Therefore, findings from the EPA Strive project this investigation would be more robust.

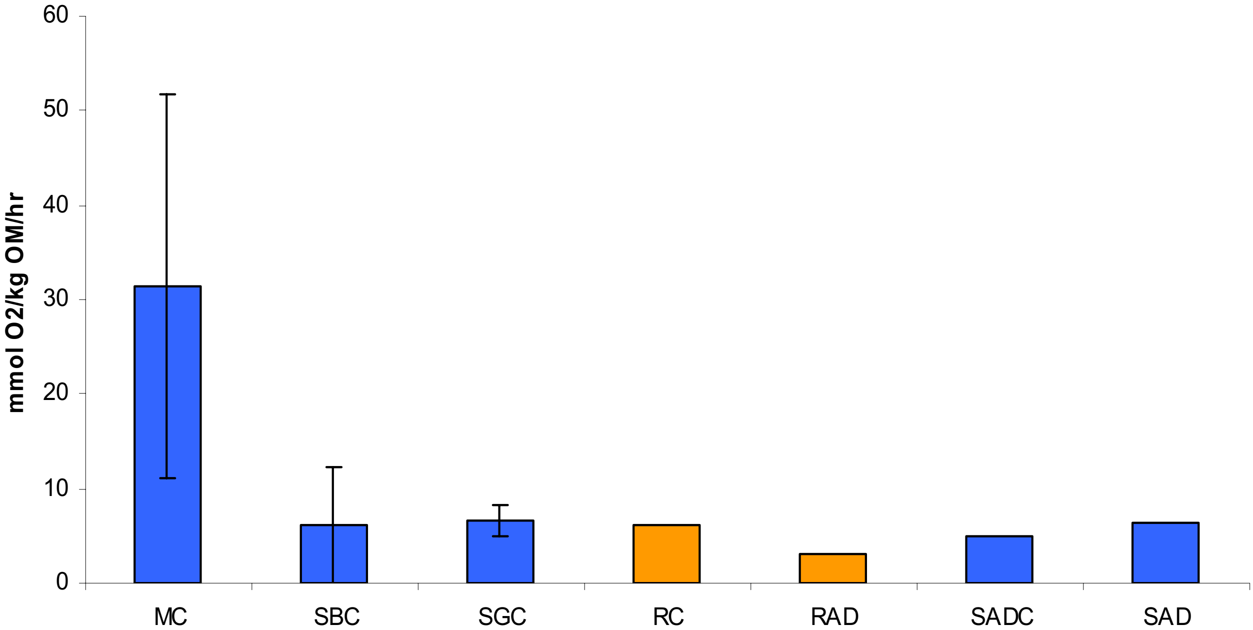


**Figure 5: Comparative Stability values (Oxygen Uptake Rate) of composts and digestate fibre[1].**

RAD was very stable, while SADC and SAD were also very stable and MC was unstable. Irish Standard 441:2011, quality requirements for a compost manufactured from source segregated, separately collected, biodegradable materials sets the limit value at 13 mmol $0_2$/kg OM/hr. Holland sets the limit value at 15 mmol $0_2$/kg OM/hr.

## 3.5 HUMIC ACID

Humic acids are part of the stable organic matter in composts. During composting and presumably in the anaerobic digestion process, there is an increase in the concentration of humic acids as lignin breaks down and its degradation products combine to form increasingly recalcitrant molecules. Due to their favourable properties for composts/digestate fibres (and soil) and plants and their role in carbon sequestration they are considered a quality criterion for composts and probably also for digestate fibres. These results showed that RAD had a low level of humic acid.

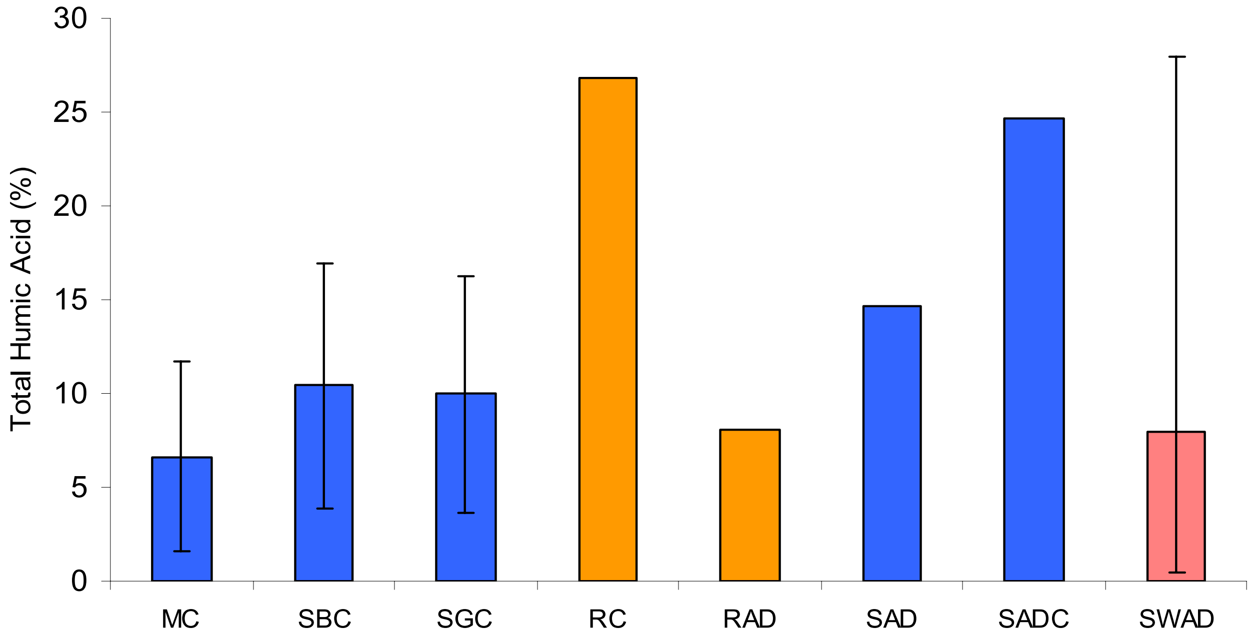


**Figure 6: Humic acid content of composts and digestate fibres**[1]

However SAD had higher levels of humic acid, while composting of the digestate fibre (SADC) resulted in increased levels of humic acid. SBC and SGC had moderate levels but within these groups there were large variations. Levels of 20 and as low as 3% was recorded in SGC, while SBC also had a low of 3% and a high of 15%. A study carried out in Switzerland (Fuchs *et al.*, 2008) showed that SWAD digest had the lowest level of humic acid 8%, while SWC values varied from 15% to 22% with the lower value being from compost that had not been stabilised sufficiently. However, compost with the lower stability as evidenced by AT4 did not have the highest level of humic acid (Results not presented here).

## 3.6 LIGNIN CONTENT (ASH FREE)

Lignin also plays a significant role in the carbon cycle sequestering of atmospheric carbon within the living tissues of woody perennial vegetation. Lignin is one of the slowest decomposing components of dead vegetation, contributing a major fraction of the material that becomes humus as it decomposes. Other components are cellulose and hemi cellulose. Previous research has shown that lignin can be a predictor of the release of nitrogen from composts. The correlation is negative, meaning that the higher the lignin level the lower the nitrogen release from composts and subsequent N-uptake by plants (Griffin & Hutchenson, 2007).

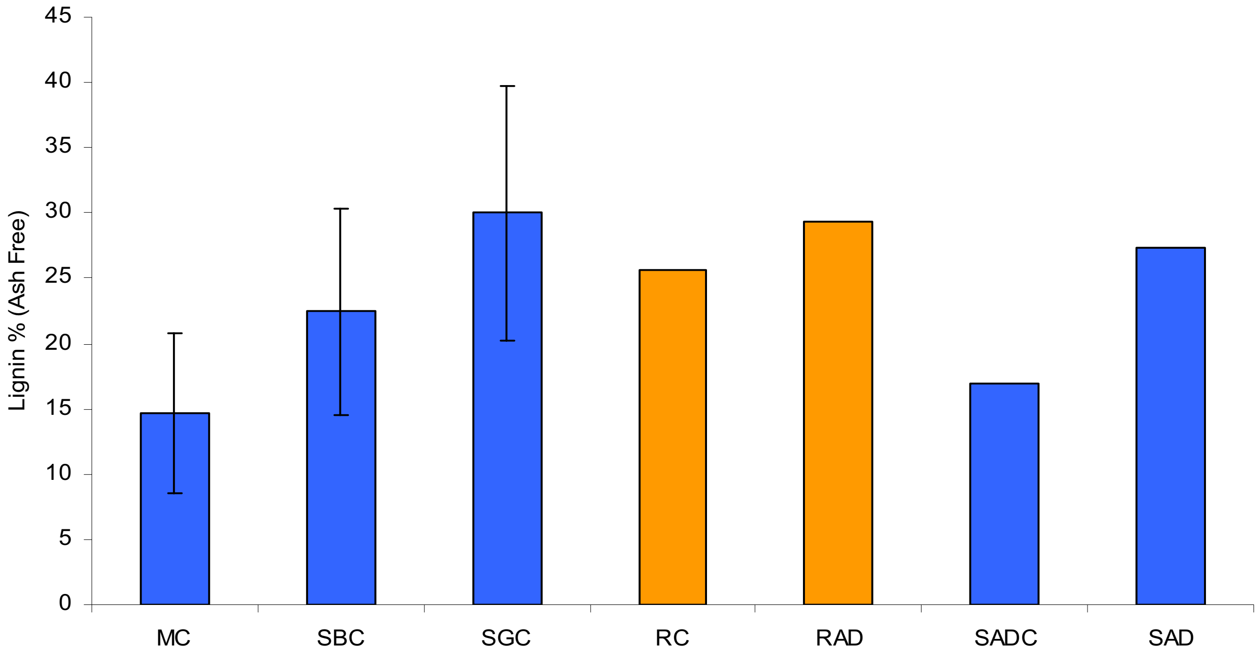


**Figure 7: Comparative Lignin (Ash Free) content of composts and digestate fibre[1].**

Lignin levels were lowest in MC (Fig 7). The higher levels of lignin were found in SGC, SAD and RAD but the differences between them were small. Lowest levels were found in MC and SADC indicating that they could release nitrogen at a faster rate than the other materials.

Lignin content varied from 11.7 to 30.9% in a study conducted in the UK on 12 bio waste composts (Dimambro *et al.* 2007). They state that compost containing vegetable waste had lignin content of between 10 - 17% and higher levels of lignin were found where wood was part of the original feedstock. (Since Lignin is one of the factors that control decomposition, lower values would result in quicker breakdown of the compost in the soil, thus releasing available nitrogen).

## 3.7 TOTAL KJELDAHL NITROGEN

Total nitrogen gives an indication of potential nitrogen availability. This availability could be over one season or over a number of seasons. It is therefore not a very important compost parameter for farmers. Be that as it may, the degree of compost stability and total nitrogen content has always been considered important for agronomic use and almost invariably defined in compost (and AD) specification.

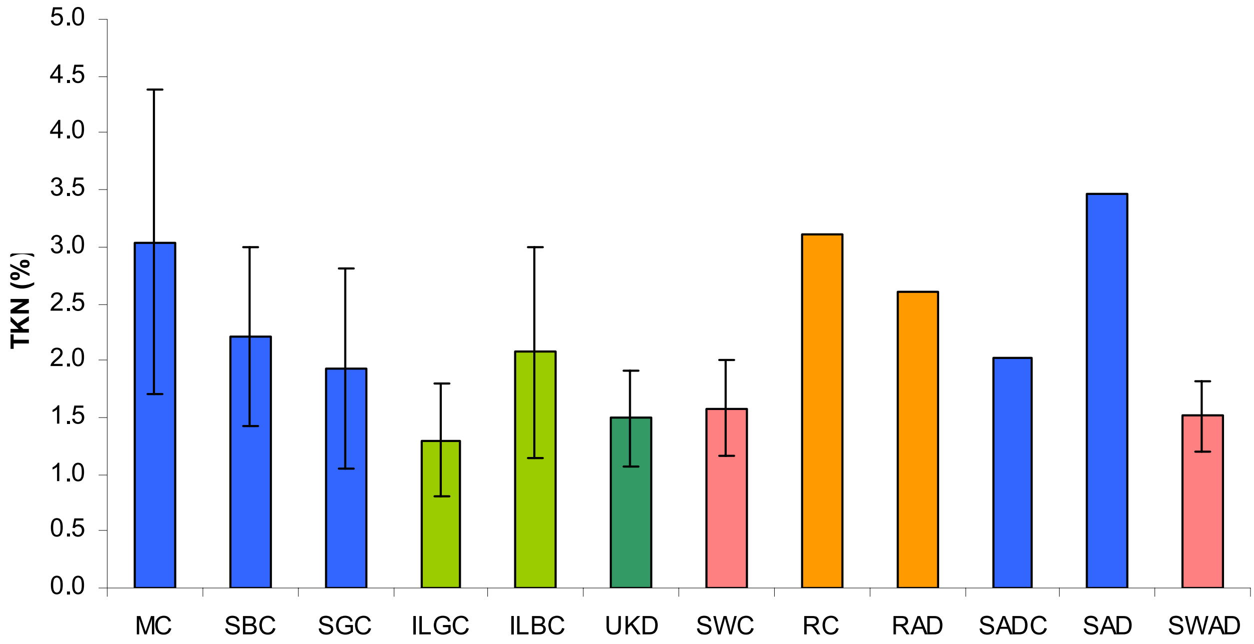


**Figure 8: Total Nitrogen content of a number of compost and digestate fibres[1].**

Total Nitrogen was particularly high in the SAD, RAD and RC samples. SGC had inorganic nitrogen added in one of the composts during processing (composting) hence it brought the average total nitrogen content higher. MC had high nitrogen content. SWAD however did not have values as high as SAD and RAD. In general most of the composts had nitrogen values below 2%. The UK composts, the Swiss composts, the ILCG had particularly low nitrogen content in marked contrast to RC. These results are in marked contrast to some total nitrogen values in digestate materials from other sources where nitrogen values as high as 17% have been recorded with nitrogen values around 6% very common, (Fig. 30) the probable reason for this will be covered in the Discussion section.

## 3.8 AMMONIUM NITROGEN

In the literature, ammonium nitrogen levels are particularly high in anaerobic digestion materials including both whole digestate and separated digestate, in some instances ammonium nitrogen as high as 80% of total N has been reported but can be low in Swiss, German (ECN source) and of course our data samples (Fig. 9). In a report prepared by ADAS and SAC (UK) they report ammonium as a percentage of total nitrogen of 67 to 71 % for whole digestate and 75% to 81% for separated digestate (ADAS, 2007), This is in complete contrast to RAD and SAD data where the ammonium nitrogen levels are below < 0.03% to < 0.25%. Although the anaerobic digestion process is an anaerobic process, these samples were received after they had been stored outdoors for a time, which may have caused it to nitrify (nitrate nitrogen levels were up to 500 ppm) or much of the ammonium nitrogen volatilized. Results from Italy (Tamboni *et al*.., 2010) had ammonium nitrogen levels as a percentage of total N up to 63% but after composting, these levels fell to 11%. The levels of total nitrogen almost halved as a result of composting. This aspect will be further elucidated in the Discussion section (p x).

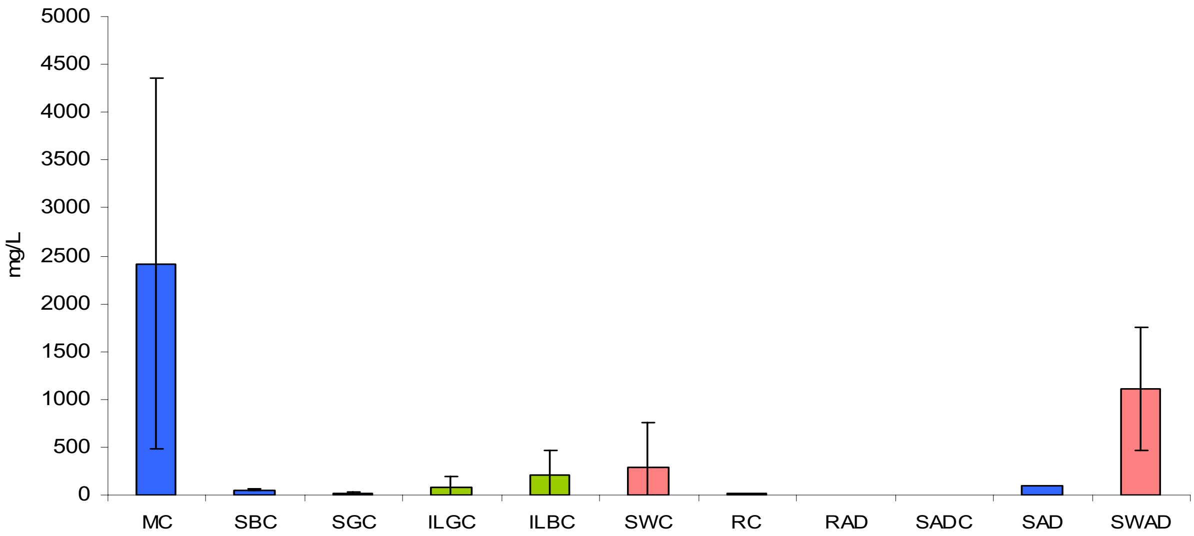


**Figure 9: Ammonium nitrogen content of a number of compost and digestate fibres.**

The low value of total nitrogen and ammonium nitrogen measured in the composts was expected as the aerobic treatment would cause ammonia losses due to the drying step that occurred at the end of the process. It should be noted that in the case of the Italian data, the feedstock came from two municipal waste water treatment plants. Data from this study and others (Fouda2011, Chambers & Smith 1992) would indicate that ammonium nitrogen levels as a percentage of the total nitrogen gives a very good indication of the fertilising value of the digests particularly over the short term.

## 3.9 NITRATE – N

Nitrate levels are very high in both RC and RAD indicating that they have gone through an aerobic process. This could be due to the samples being handled/stored in a manner that allowed them to become aerobic. This is also evident from SAD and SADC – where in the latter, the levels are higher, probably due to the composting step. ILGC had high levels of nitrate indicating that they were well stabilised. ILGC and ILBC have rather low nitrate values.

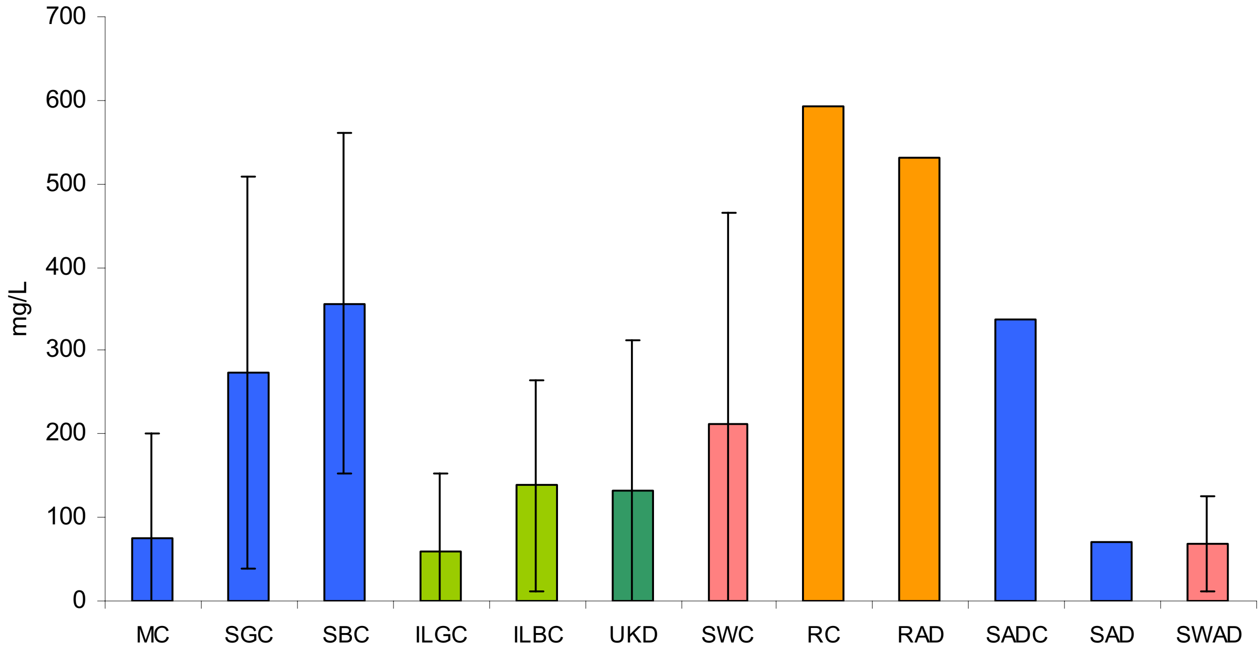


**Figure 10: Nitrate nitrogen content of a number of compost and digestate fibres.**

Much of the compost analysed to generate the ILGC and ILBC samples were taken in the early days of composting in Ireland and probably at that stage much of the composts may have been produced without proper stabilisation. MC compost also has low levels of nitrate indicating that it was not probably well stabilised.

## 3.10 TOTAL PHOSPHORUS

Total phosphorus gives an indication of potential phosphorus availability. It may not be an important parameter for farmers as they would like to know the availability over one or two seasons. It is often stated that the degradation process during anaerobic digestion will improve phosphorus availability but anaerobic digestion may have the opposite influence on crop availability due to raising of pH coupled with an increase in concentration of iron, calcium and magnesium which would tend to bind to phosphorus.

Total phosphorus was very high in RAD while RC also had relatively high levels of phosphorus (Fig. 12). There is no obvious explanation why RAD had such a high phosphorus value. Generally the levels of phosphorus of most materials studied were around 0.5% or below. The MC compost also had very high levels of total P. The plant available phosphorus (Mehlich 3) generally followed the same pattern as total phosphorus except that SBC had similar availability to SGC even though total phosphorus was higher in SBC (Fig. 13). The easily extractable phosphorus based on $CaCl_2$ /DTPA extraction also followed the same pattern as total phosphorus and plant available P (Fig. 14). The extractable values are based on a volume basis but total phosphorus is based on dry weight basis. This should be noted.

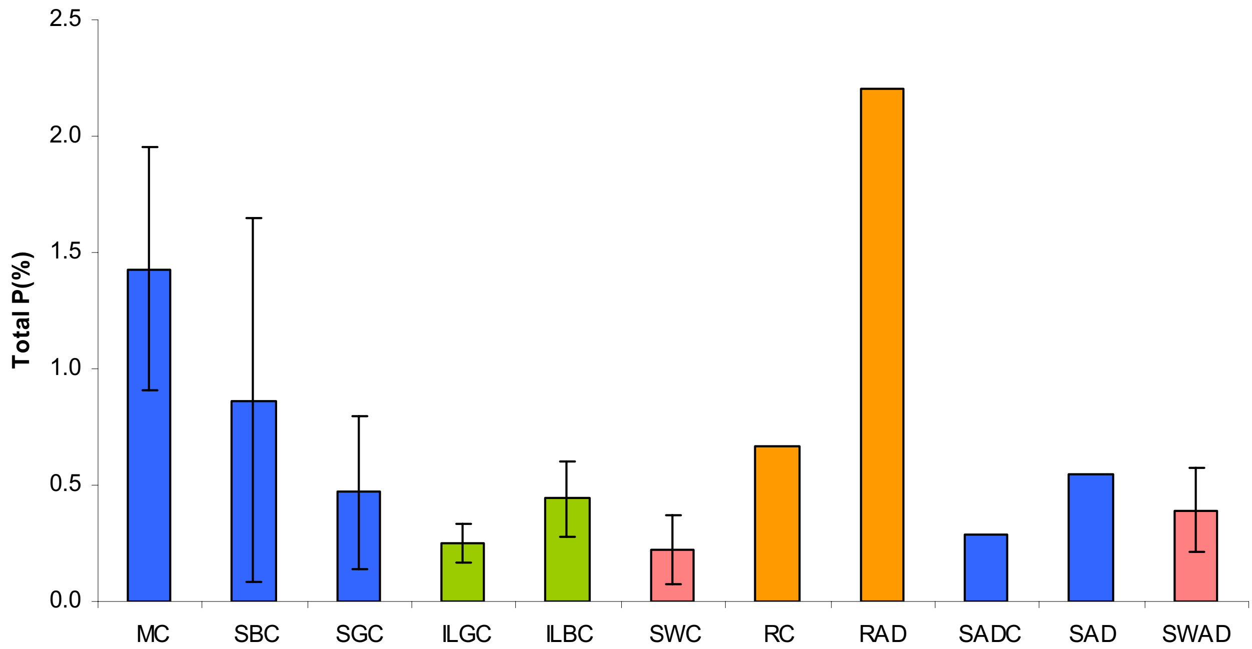


**Figure 11: Total Phosphorus content (%) for the compost and digestate fibres[1].**

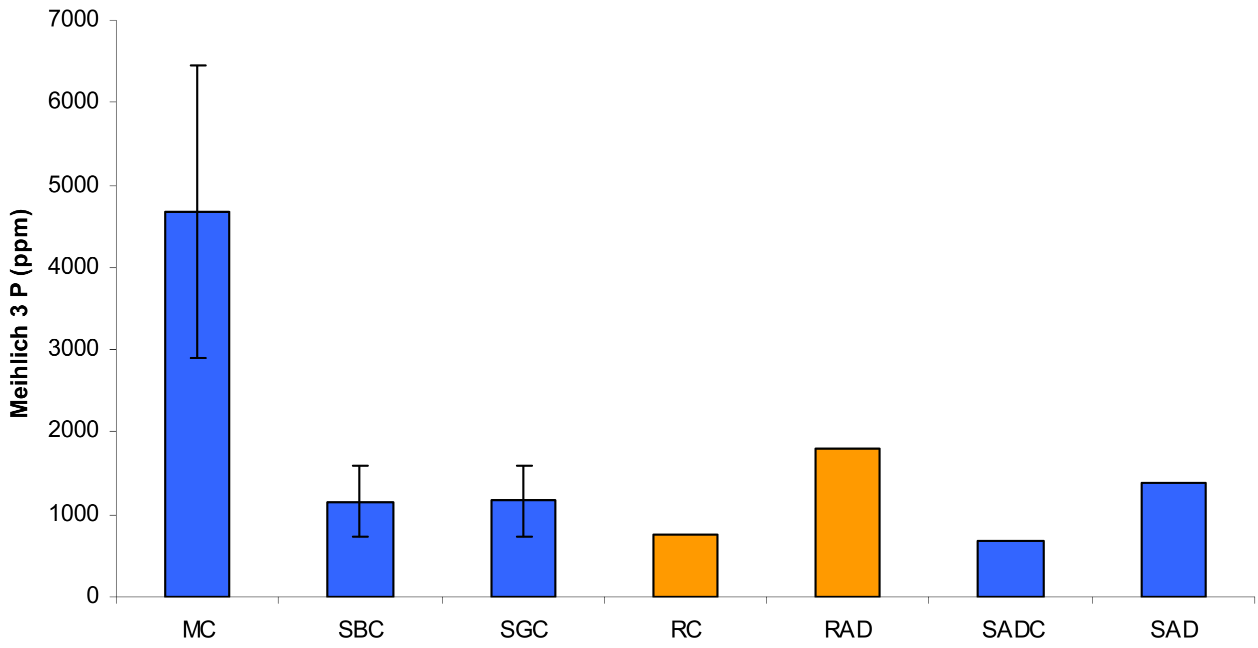


**Figure 12: Plant Available Phosphorus (Mehlich 3)) content (ppm) for the compost and digestate fibres in the study[1].**

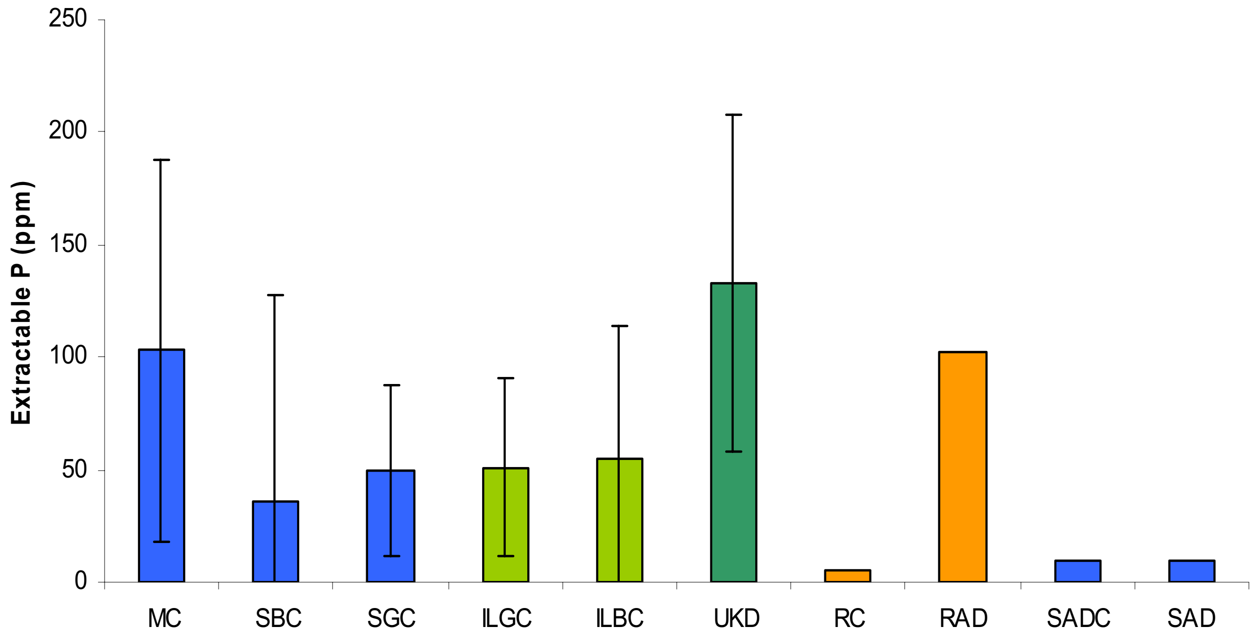


**Figure 13: Extractable Phosphorus ($CaCl_2$/DTPA)) content (ppm) for the compost and digestate fibres in the study[1].**

The easily available phosphorus (Extractable P) and plant available phosphorus (Mehlich 3) are important agronomic properties. The easily available phosphorus is important when crops are grown in spring under cool conditions when high concentrations of soluble phosphorus are required. Information on plant available phosphorus in digestate materials is very scanty and thus this information is very important.

## *3.11 CARBON / PHOSPHORUS RATIO*

The addition of composts resulting in initial immobilisation or initial mineralisation of soil phosphorus has been shown to depend on the C: P ratio of the organic material added. Immobilisation is likely to occur with a carbon: phosphorus ratio of >200. (Hannapel *et al*. 1964).

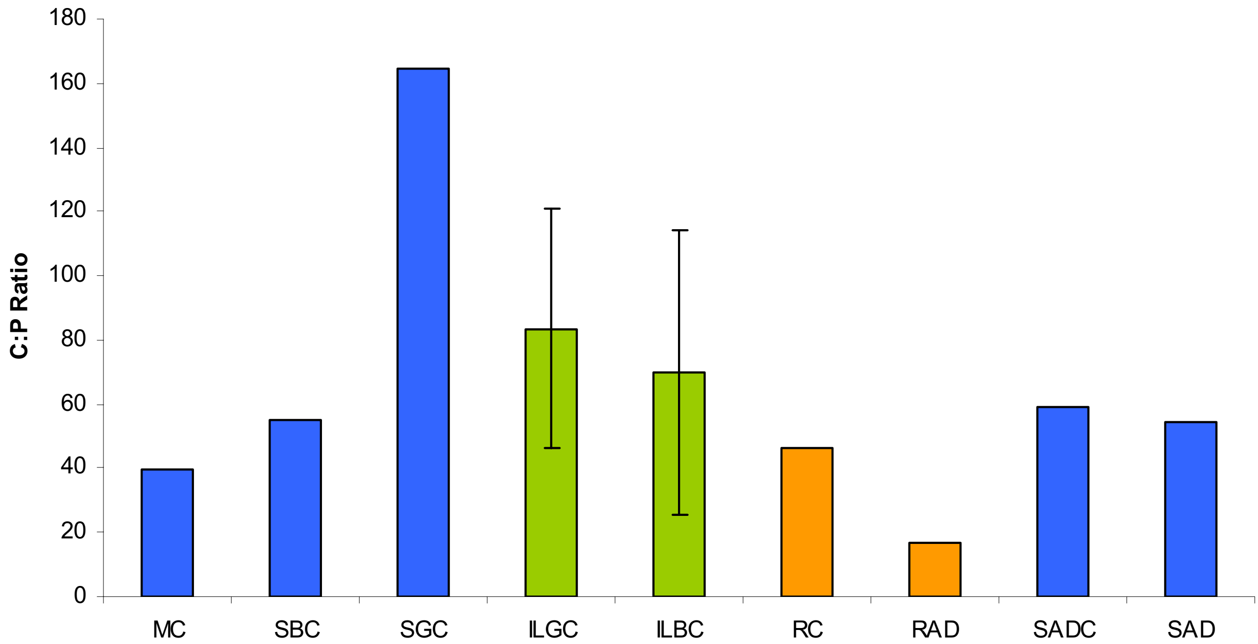


**Figure 14: Carbon Phosphorus ratio for the compost and digestate fibres in the study[1].**

On the basis of this none of the compost samples would immobilise phosphorus but would rather release phosphorus. On this basis maximum phosphorus availability is likely to be from RAD, RC and MC. Less availability is likely to be from SGC, ILGC and ILBC in that order.

## 3.12 POTASSIUM

Total potassium gives a good indication of plant availability in contrast to total nitrogen or even phosphorous as potassium is not bound into the structural part of the plants and occurs in the plant sap. Highest levels of potassium occurred in MC. RAD and SAD have slightly higher potassium values than RC and/or SADC.

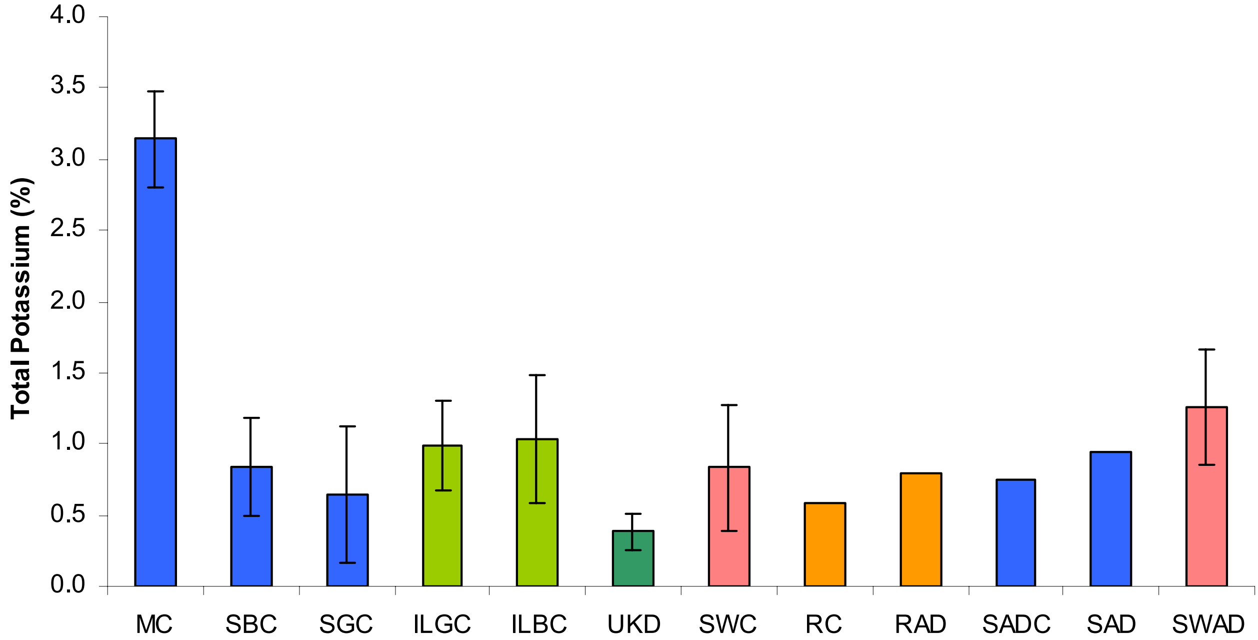


**Figure 15: Total Potassium for the compost and digestate fibres in the study[1].**

## 3.13 PLANT AVAILABLE POTASSIUM

Generally plant available K (Mehlich 3) values generally follow the same pattern as total K (Fig. 17). The extractable values are based on volume basis but total K is based on dry weight basis. This should be noted.

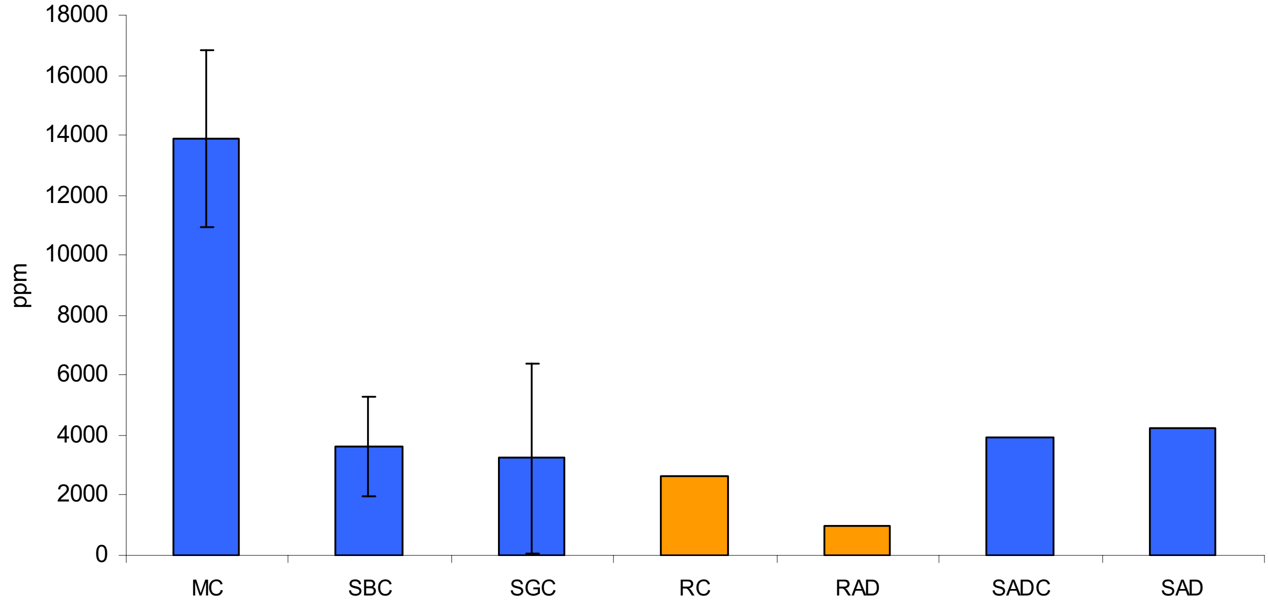


**Figure 16: Plant available Potassium (Mehlich 3) for the compost and digestate fibres in the study[1].**

## *3.14 PLANT AVAILABLE MAGNESIUM*

Plant available magnesium (Mehlich 3) in RAD are much higher than RC. The SAD from Germany has very similar values, although the SADC values are slightly lower (Fig 18).

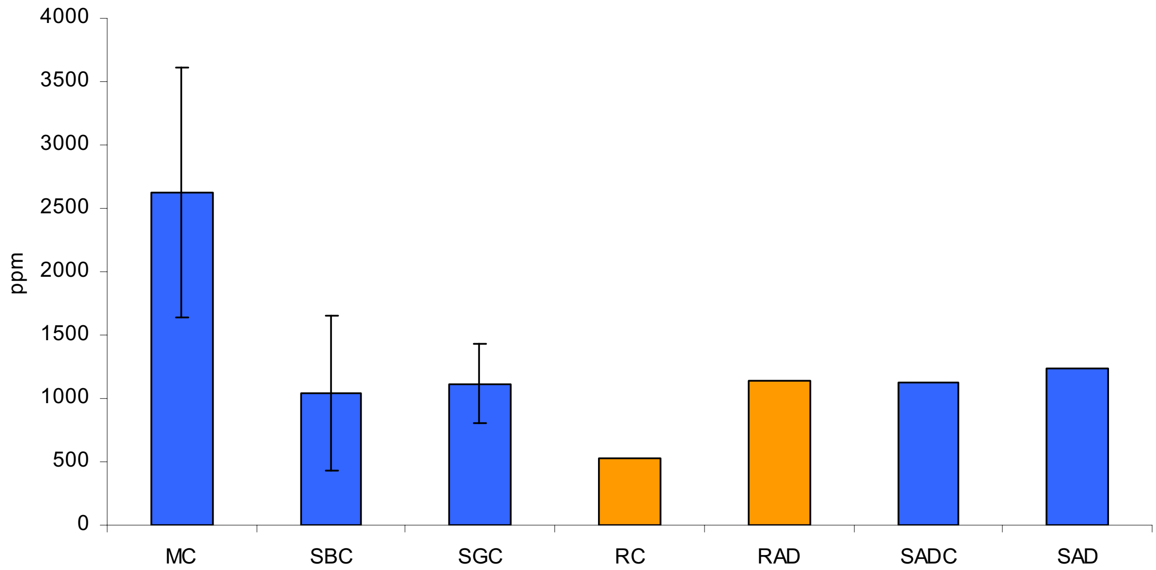


**Figure 17: Plant available Magnesium (Mehlich 3) for the compost and digestate fibres in the study[1].**

## *3.15 PLANT AVAILABLE SULPHUR*

Plant available sulphur (Mehlich 3) levels are much higher in RAD than SAD. The composting in SAD, as expected, leads to lower levels of plant available sulphur. RC has very high levels of sulphur, higher even than MC. SGC has slightly higher value than SBC. Total Sulphur was 0.41% and 0.63% in RC and RAD, respectively.

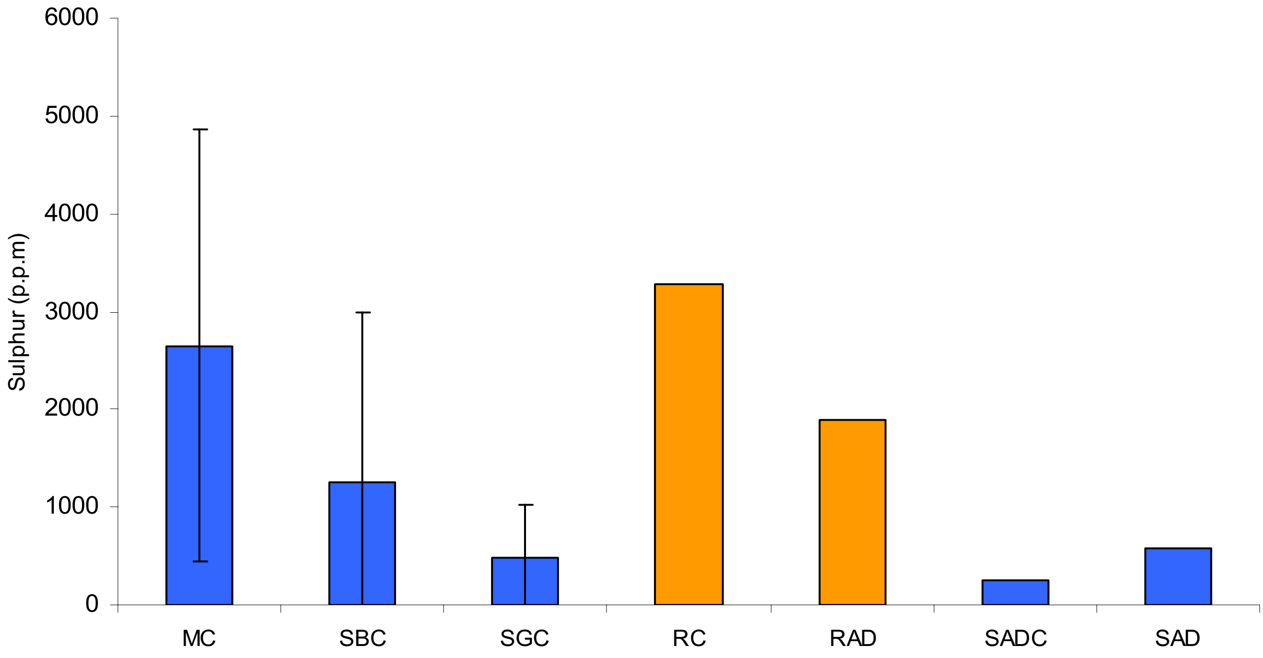


**Figure 18: Plant available sulphur content (Mehlich 3) for the compost and digestate fibres in the study[1].**

## *3.16 PLANT AVAILABLE COPPER*

Plant available copper (Mehlich 3) levels are higher than in RAD (Fig. 20). The other materials have similar values, less than 10ppm. Total Copper in contrast was 183 ppm and 40 ppm in RC and RAD, respectively

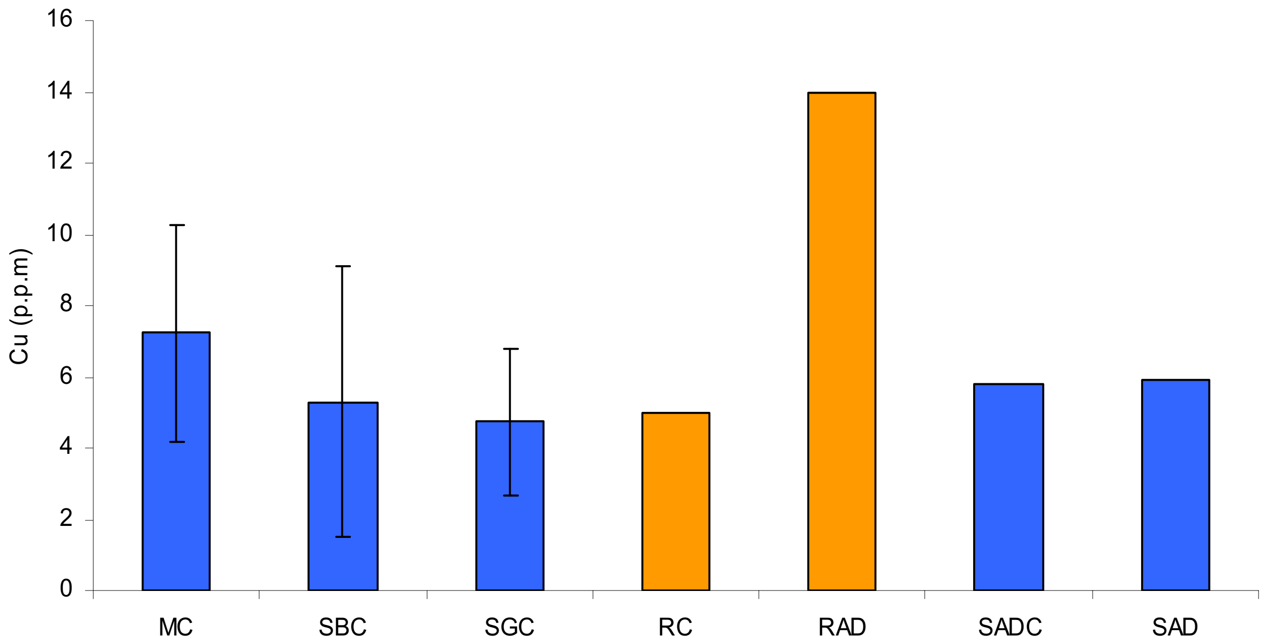


**Figure 19: Copper content for the compost and digestate fibres in the study[1].**

## 3.17 PLANT AVAILABLE ZINC

Plant available zinc (Mehlich 3) values in RAD are lower than SAD (Fig. 21). SADC, RC and SBC have similar values. The highest values are in MC. Total Zinc was 331 ppm and 127 ppm in RC and RAD, respectively

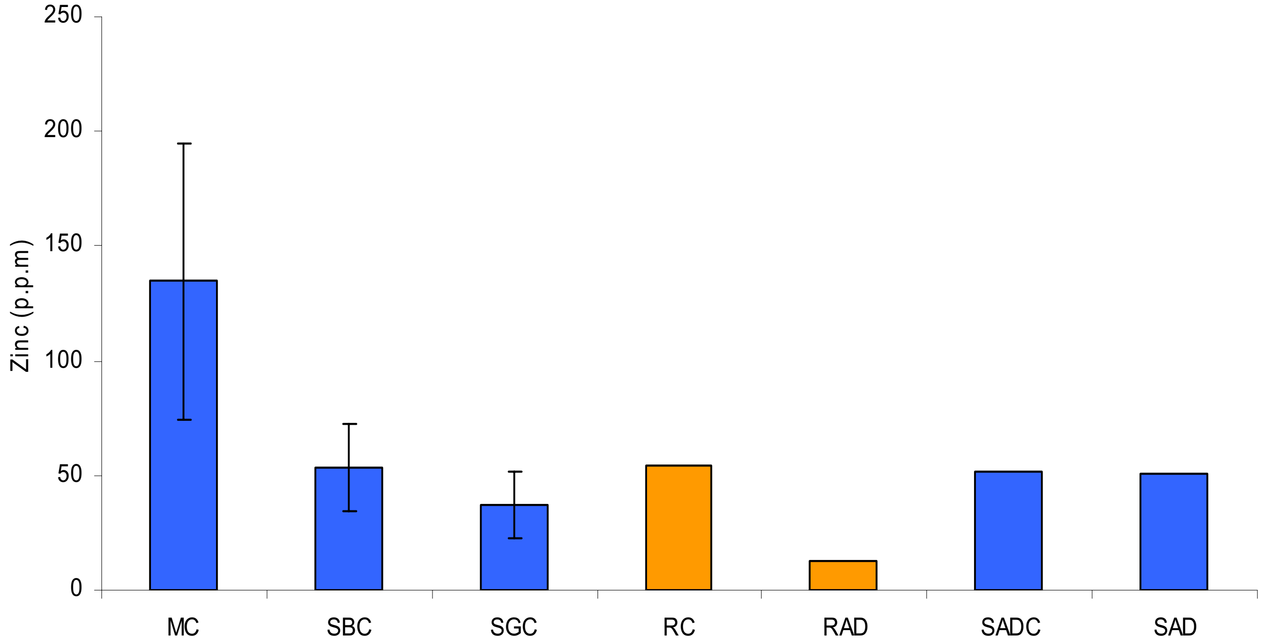


**Figure 20: Zinc content for the compost and digestate fibres in the study[1].**

# 4 Nitrogen Incubation

The results showed that the release of nitrogen from RC and RAD was minimal over 8 weeks (Fig. 22 & 23). However there was no immobilisation of nitrogen. This is expected as both materials were stable as evidenced by other parameters such as oxygen uptake rate, and C:N ratio. The addition of digestate liquor to RC did not appear to have any additional effect on the release of nitrogen over and above that of liquor itself. The digestate liquor showed similar trend to CAN except at first sampling the release of nitrogen was much less. There is no obvious explanation for this. Results from incubation tests done within the STRIVE project indicated that when the incubation is done for only 4 weeks, they also showed minimal release of N. This was also the case with SGC and SBC where there was a minimal release. Only the MC, which was mostly comprised of unstable composts showed significant release of nitrogen from time zero.

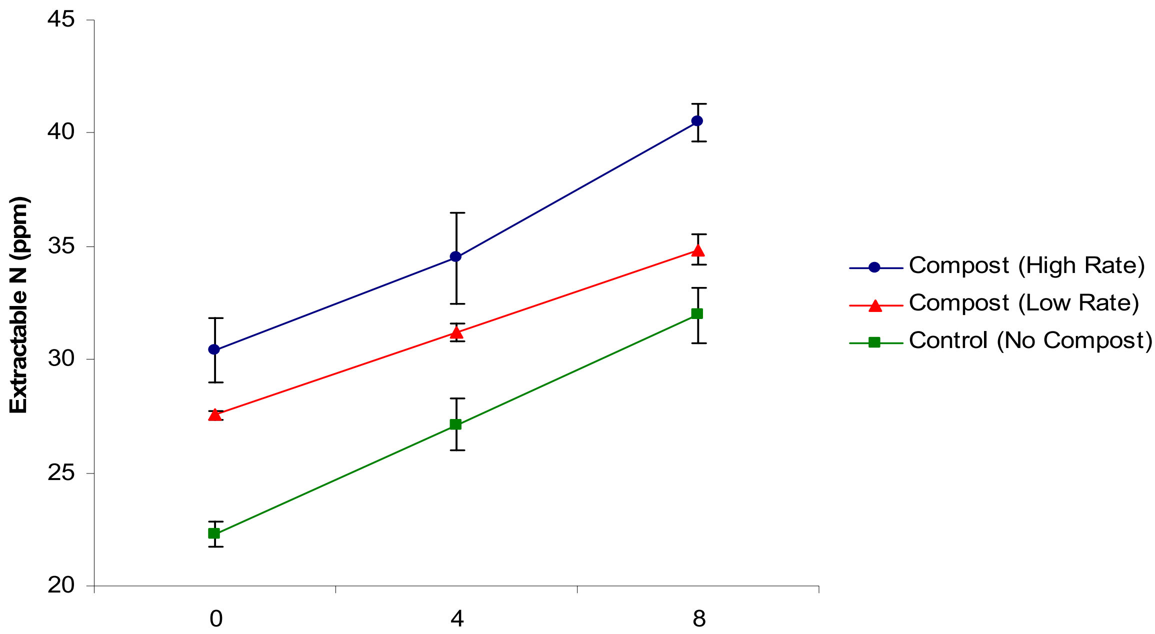


**Figure 21: Extractable nitrogen from the compost (RADC) samples at two rates.**

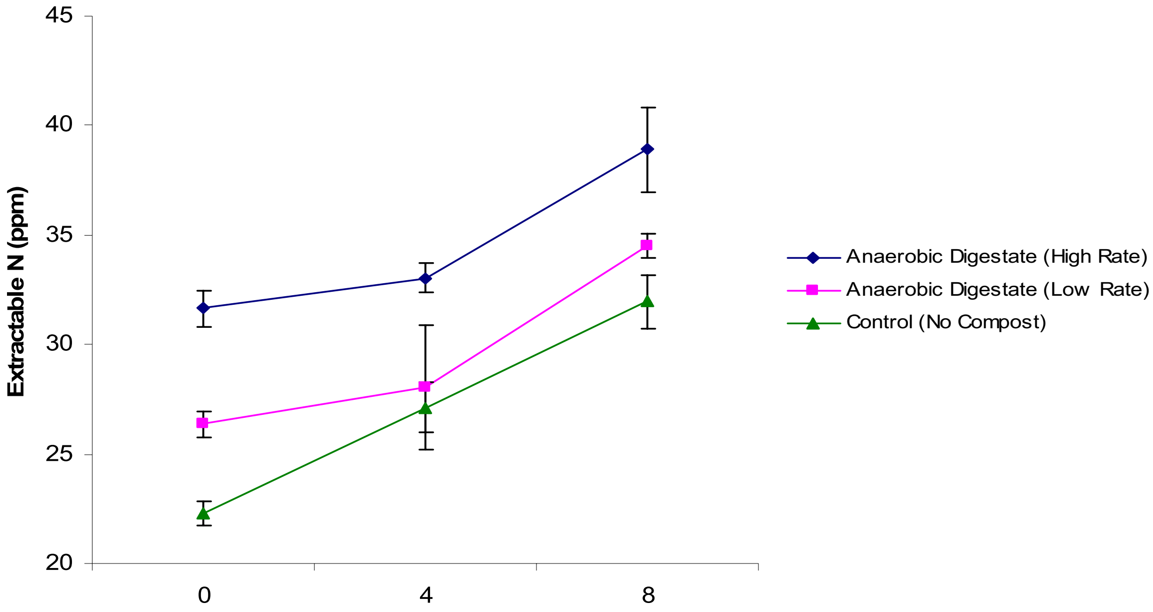


**Figure 22: Extractable nitrogen from the digestate fibre (RAD) sample at two rates**

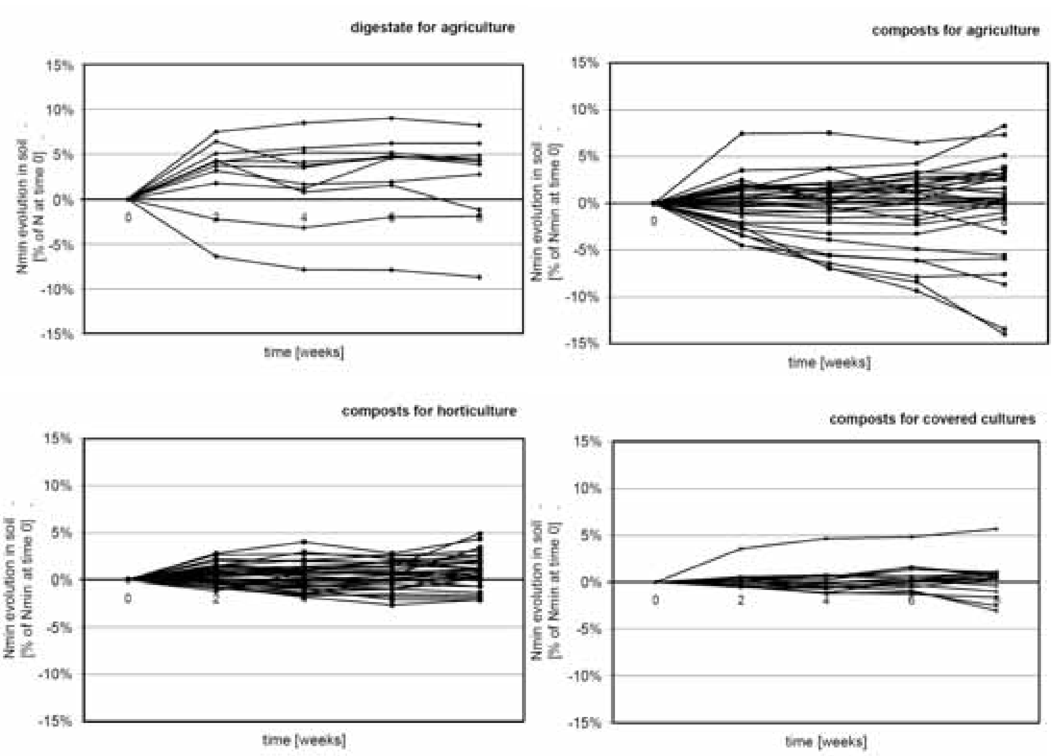


**Figure 24: Influence of the addition of different composts to soil on the evolution of its mineralised content.**

For each compost in Figure 24, the mineralised nitrogen after 2, 4, 6 and 8 weeks are compared to the mineralised nitrogen present in the soil immediately after compost addition. The data illustrated from this study (Ref) indicates the effect of stability on its mineralised nitrogen content. (Digestates for Agriculture = Unstable, Composts of Agriculture = least stable, Composts for Horticulture = moderately stable, Composts for covered cultures = stable).

These results are in agreement with the findings from a number of other countries. This is illustrated in the figures above. Swiss data (Fuchs *et al*., 2007) showed clearly that as composts become more stable the release of nitrogen decreases. At lower stability there was a tendency for more release of nitrogen but also an increased chance of nitrogen immobilization. According to the authors (Fuchs *et al*., 2007) they report that two of the 11 digest materials showed nitrogen immobilisation. Normally digestate fibre contain high amount of mineralised nitrogen mainly as ammonia and they contain relatively low quantities of lignin rich materials. Therefore nitrogen immobilisation is not expected. The reason for the immobilisation of nitrogen by some digestates is that these products were not used fresh, but after an inadequate subsequent treatment step during which the digestates get aerated and/or dried and lose most of the ammonia. The mainly young composts are rich in non-degraded lignin. The degradation of these woody substances in soil leads to temporary immobilisation of available N. When the composts are more mature, the risk is decreased.

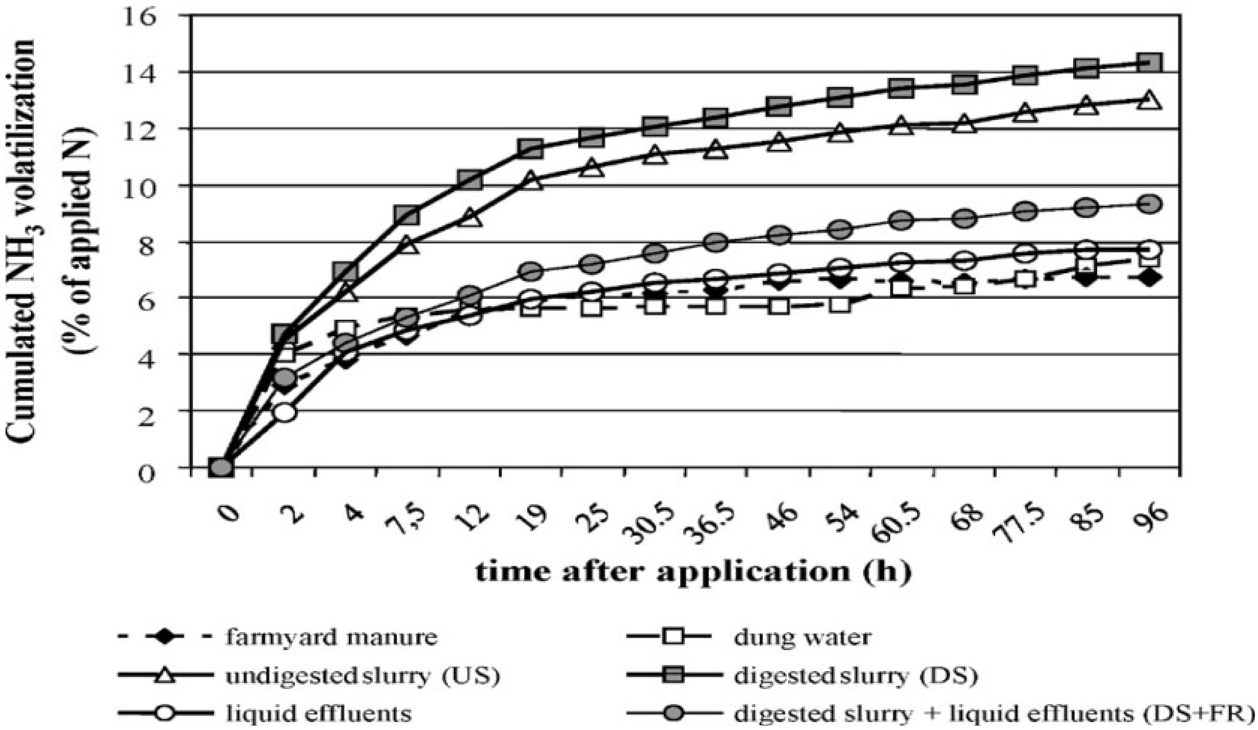


**Figure 23: NH4-N volatilization kinetics from digestate fibre and other materials when applied to soil (Moller & Strinner 2009)**

# 5 Pot Trial

Two growing trials were carried out to evaluate the release of nitrogen and phosphorus from RC and RAD using perennial rye grass as a test crop. Some combinations of RC and RAD with CAN and/or digestate liquor treatments were also evaluated. The total rate applied was, however, the same (equivalent to 218kg/ha N). The grass was harvested 5 times over 3 to 4 months. Fresh and dry weights were taken. The samples were dried, ground and analysed for nutrients. We then calculated nitrogen uptake for different treatments at each harvest. More details of the treatments as are given in Appendix 1.

**Figure 24: Grass plant growth trials at Teagasc, Kinsealy**

## *5.1 N TRIAL RESULTS*

The dry weight and nitrogen uptake results showed that at the first harvest all treatments performed well including the untreated control and although the untreated control (no nitrogen added) performed the poorest, the differences were small. Presumably the reason why the untreated control did well was because the soil contained some residual soluble nitrogen from the field. After the first harvest, the CAN treatment (chemical control) gave the highest dry weight and N-uptake values and the differences between the treatments became greater and greater as the trial proceeded. By the third harvest, dry weight and uptake of N from the RC and RAD treatments where still significantly better than the untreated control. When CAN was applied as a top dress after each harvest, it resulted in improved dry weight and nitrogen uptake of the RC and RAD treatment.

Although the RC and RAD did not show the big differences, such as between the chemical control (CAN) and untreated control, they still performed significantly better as regards dry weight and nitrogen uptake than the untreated control. They also showed a very steady and consistent nitrogen release (see N-uptake data in Fig 25 & 26 at fourth and fifth harvest). Digestate liquor on its own and in combination with RC performed somewhat poorly in relation to its ammonium nitrogen content. This was because the application of liquor (at the required rate) caused burning of the foliage when applied. The fact that both dry weight and N-uptake followed each other at each harvest showed that the treatments were effective and the response of grass as evidenced by dry weight was due to nitrogen and not to some other extraneous factor. The growth trial results are in agreement with the results from the incubation which showed little or no release of nitrogen from RC and RAD (Fig 21 and 22). These results are also in agreement with other publication which has shown that nitrogen release from compost is in the range of 0 – 20% (and even N-immobilisation). (Prasad 2009b Amlinger & Dreher. 2003). However in relation to our results on RAD, superficially it appears that the results are contradictory to results from other sources which have shown that digestate supplies significant amount of nitrogen. For instance, comparisons of digestate application with mineral nitrogen fertiliser based on equivalent amounts of total nitrogen have shown lower nitrogen values than mineral nitrogen fertiliser (Quakernack *et al., 2011*). For the year of application the fraction of plant available nitrogen is associated with NH4-N fraction. However, if the application was only based on equivalent amounts of $NH_4$ - N fraction of the digestate fibre, comparable apparent nitrogen recoveries of digestate and mineral nitrogen fertiliser are reported (Chambers & Smith, 1992; van Kessel *et al.*, 2000 Gutser *et al.,* 2005). In our trial the RAD had insignificant amount of ammonium nitrogen, so the release was from organic nitrogen. Gunnerson *et al*. (2010) found that nitrogen release from bio digested material was only 12% over a six month period. This is in complete agreement with our findings on RAD assuming that the NH4-N fraction had volatized.

A major problem with digestate fibre, which cannot be overemphasised, is that a great amount of the nitrogen initially present when digestate fibre comes from the anaerobic digestion facility mainly consists of $NH_4$ - N as a high percentage of the total nitrogen and is very labile and can be lost by volatilisation. In fact it is often recommended to have a suitable covering to eliminate ammonium losses from stored digestate. We have been unable to find information on how quickly the ammonium nitrogen will volatilise when stored. We have been able to find data on ammonium nitrogen losses when digestate fibre is applied to the soil. These losses show that about 12% of the ammonium nitrogen value is lost in the first 24 hours (Moller & Strinner 2009). This rapid initial release slows down (Fig 23). This is an "average value" Obviously, an average value would is just that and factors such as storage would greatly change the average value.

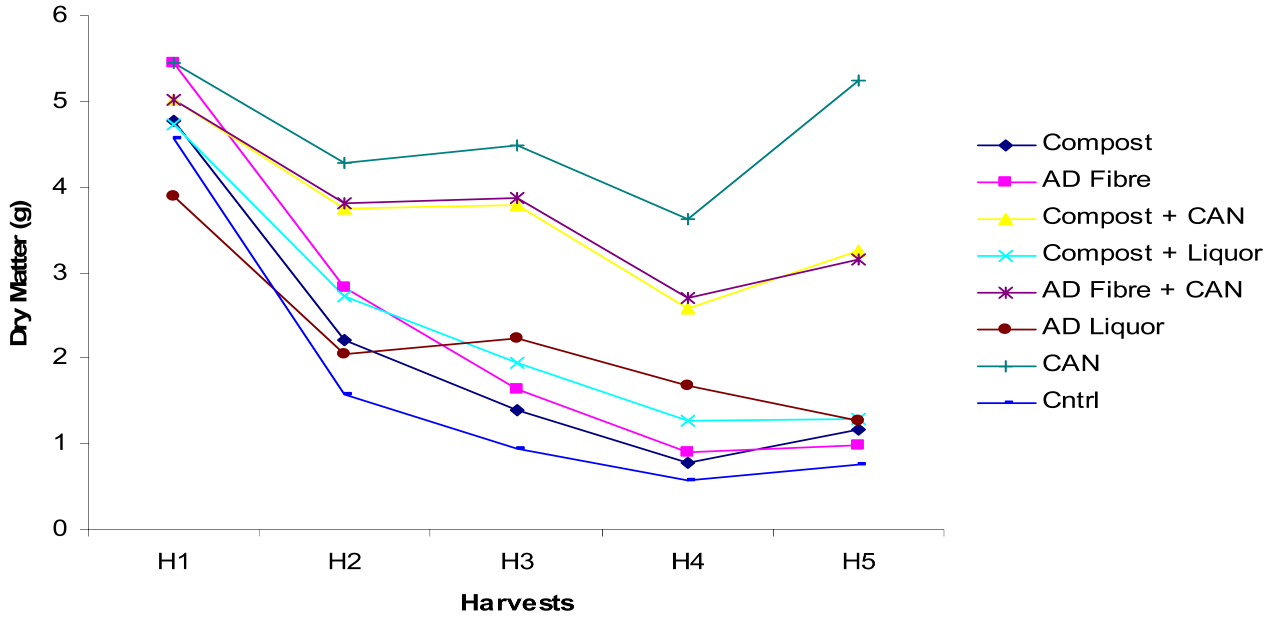


**Figure 25: Effects of Compost, digestate fibre and digestate liquor on dry matter yield of grass over 5 harvests. (H = Harvest)**

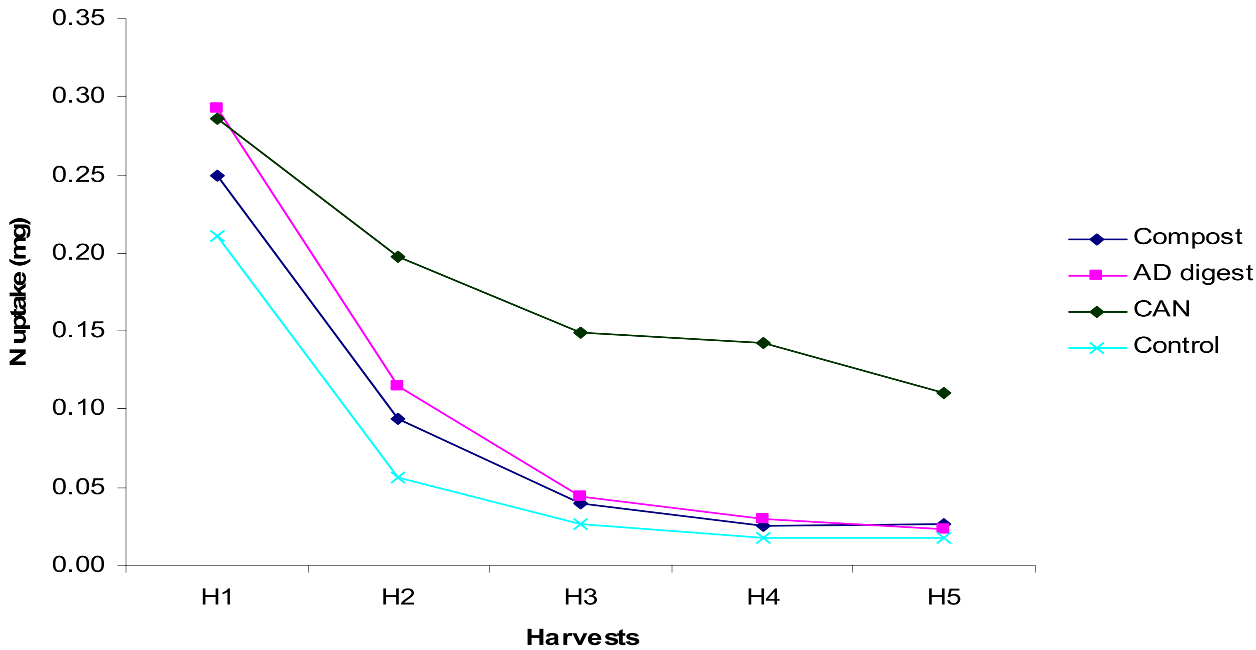


**Figure 26: Nitrogen uptake by grass from CAN, Compost and digestate fibre addition to the soil.**

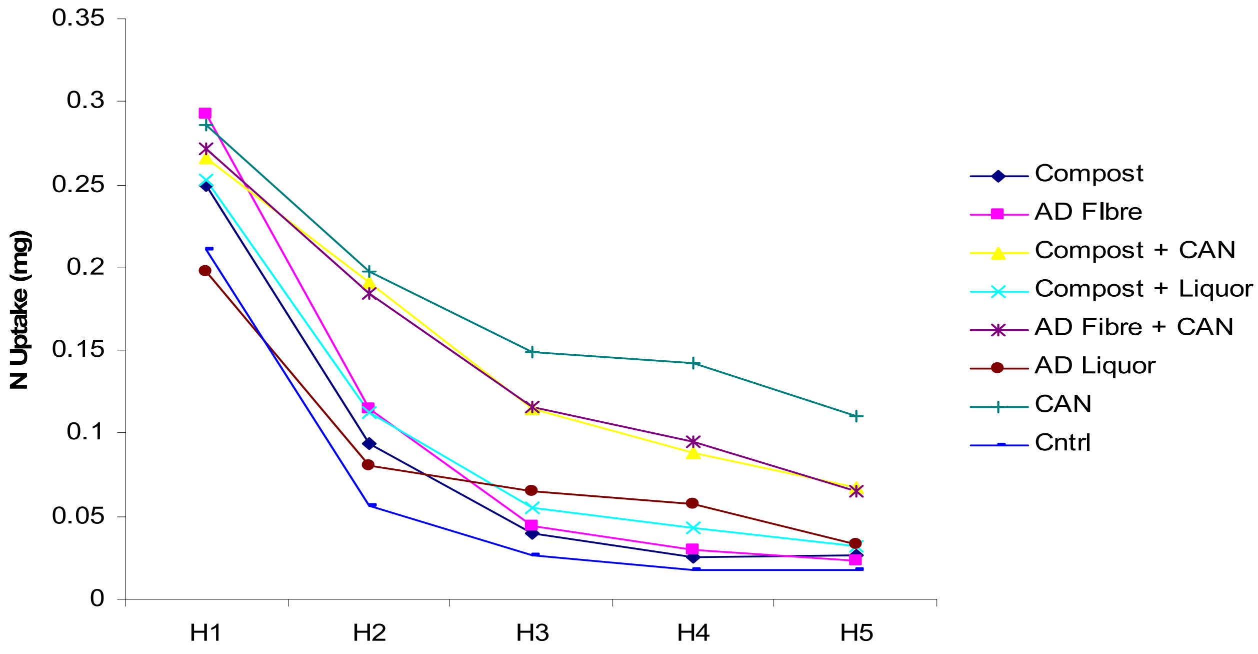


**Figure 27: Nitrogen Uptake from all treatments.**

## *5.2 P TRIAL RESULTS*

The dry weights of RC and RAD usually gave dry weight yields that were approximately of 70% of the Superphosphate. However in some cases the RAD performed marginally better than Superphosphate (i.e. at 3rd and 5th harvest) (Fig. 27). Phosphorus uptake data from grass from various treatments follows the same pattern as dry weight yield. Phosphorus uptake data follows the same pattern as the dry weight data and phosphorus efficiency of RC and RAD in relation to superphosphate is between 70 to 100 % (Fig 28). It appears that the release from RP and to a greater extent RAD shows a slight tendency of increasing release of phosphorus in relation to control as the number of harvests increases. Data from the EPA STRIVE project follows similar trend as regards dry weight of cabbage. In relation to the EPA STRIVE project, the efficiency of digestate from Germany (SAD) in relation to superphosphate was 75% to 95% as regards dry weight yield. Data on phosphorus uptake is not yet available. However it should be remembered that the STRIVE Project has been conducted on a different crop (cabbage), a different application rates and the growing period is much longer (2 years). The results from RC are similar to published work on composts which has shown phosphorus availability of composts in relation to Superphosphate as 60- 100% (Prasad, 2009a).

**Figure 28: Cabbage plant growth trials at Teagasc, Kinsealy**

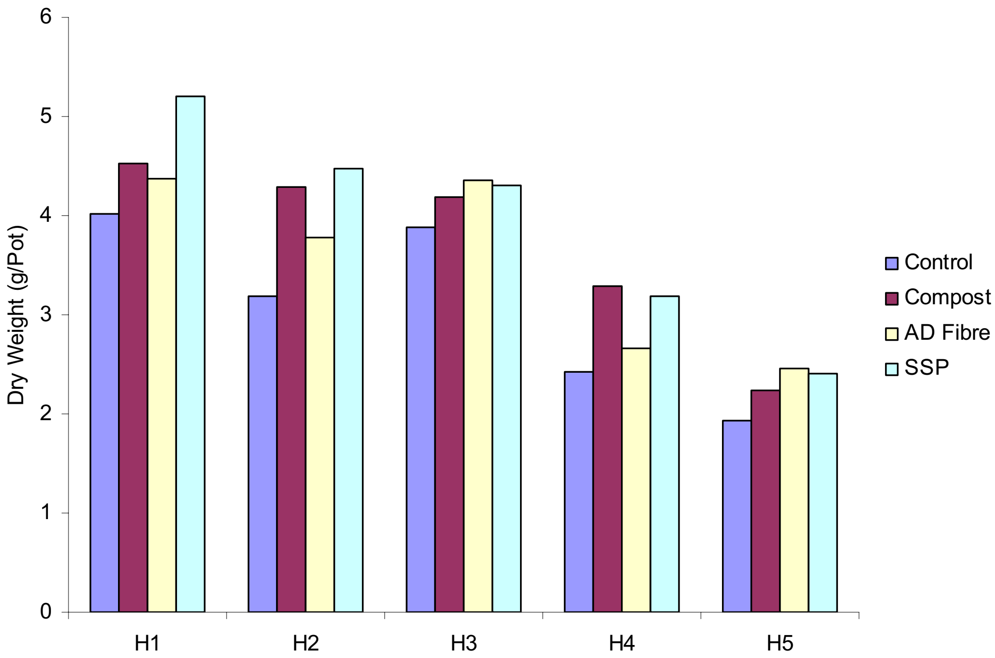


**Figure 29: Effect of Compost and digestate fibre addition on the dry weight of Grass compared to Single Super Phosphate.**

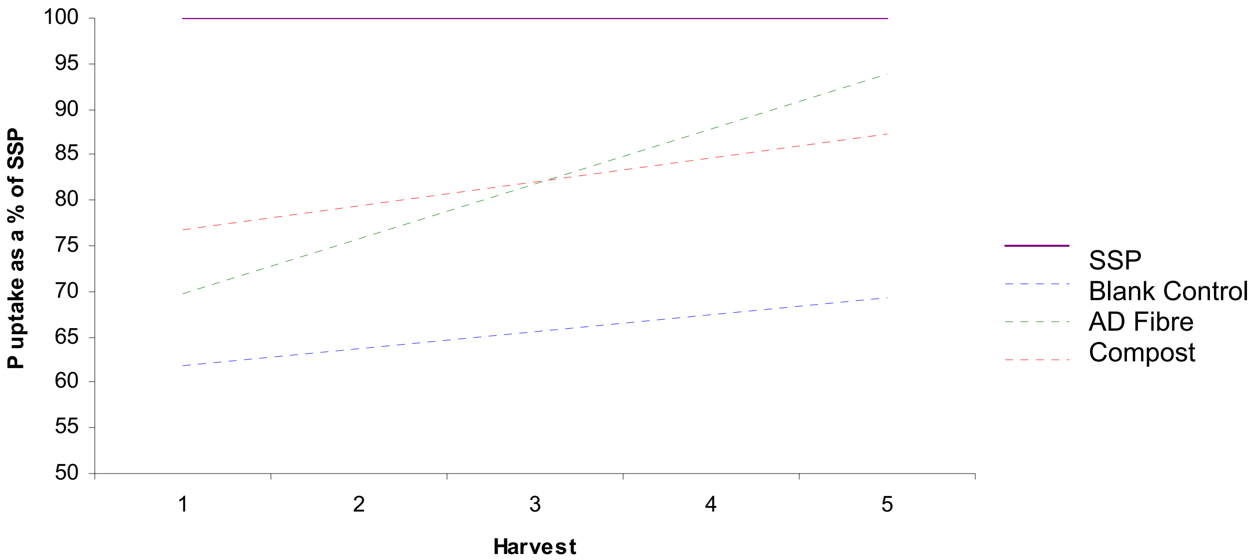


**Figure 30: Phosphorus Uptake over 5 harvests compared with superphosphate**

It has been reported that anaerobic digestion can sometimes increase phosphorus plant availability (Masse *et al*. 2011) or it can have an opposite influence on crop phosphorus availability as pH can strongly influence the solubility of phosphorus and micronutrients (Chambers & Smith, 1992, van Kessel *et al*., 2000, Gutser *et al* 2005). On the whole it is accepted that in most cases there is no change in availability as a result of anaerobic digestion (Bachmann *et al*., 2011). The exact amount of phosphorus availability whether 70% or over 100% of superphosphate equivalent will depend strongly on the feedstock and, to a lesser extent, the anaerobic digestion process. In our experience from the EPA STRIVE project, for composts, we can say that compost based predominantly on green waste feedstock had slightly lower phosphorus availability as expressed on dry weight response, in relation to superphosphate, than compost based on poultry manure where in relation to superphosphate equivalent it gave a higher response.

## *5.3 DISCUSSION*

The main finding from the characterization study was that both materials were stable with the RAD slightly less stable. The parameters that gave an indication of stability were oxygen uptake rate, humic acid, C: N ratio and lignin content. Total Phosphorus was very high for RAD. Plant available phosphorus and easily extractable phosphorus followed the same pattern as total phosphorus. This fraction is important for phosphorus supply to the plant. These materials also supply various amounts of plant available secondary nutrients such as Magnesium and Sulphur and important micronutrients such as Copper and Zinc. More research work needs to be done in this area before definitive conclusion can be drawn regarding the availability of these nutrients for plants from the digestates.

Nitrogen release from both RAD and RC were similar. These findings were based on N- incubation and pot trial using grass as a test crop. Both these materials had very low release rate (<20%) compared to the mineral fertiliser CAN. These findings are apparently in contradiction to other findings where the RAD gave N-efficiency similar to mineral fertilization. This apparent contradiction can be explained on the basis that our RAD test material had lost all the NH4 –N most probably due to ammonium nitrogen volatilization. The organic nitrogen left over has been found by others to have a low nitrogen release rate. This finding and explanation is one of the critical factors as regards N-efficiency from digestate fibre. The NH4-N is very labile and therefore the way digestate fibre is stored and the period of storage can be very critical on its use as nitrogen source in Agriculture.

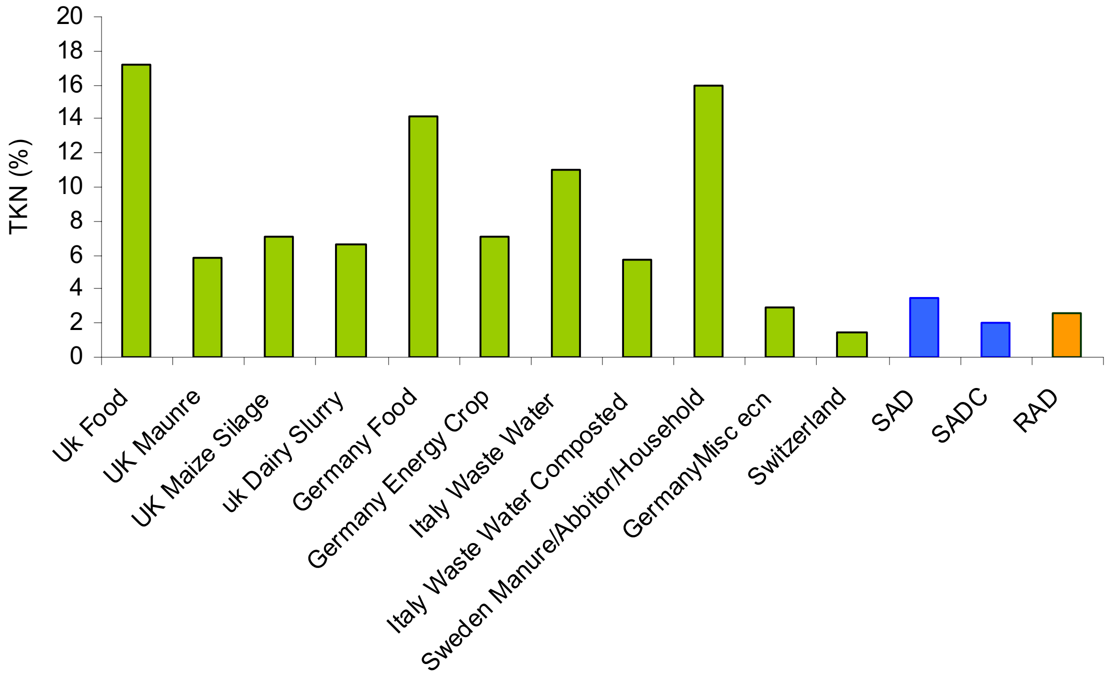


**Figure 31: Total nitrogen from digestate fibre from various countries and feedstock**

It is important to bear in mind that nitrogen availability will increase incrementally in year 2 and subsequent years if compost/digestate is applied annually. This because the nitrogen from year 1 compost application will still be releasing at a steady incremental rate in year 2 while the year 2 compost applied will also be releasing. In year 3 the release of nitrogen of year 1 and 2 will still be present, and so on. Compost and digestate applications could continue and it could reach a point where nitrogen release may equal crop nitrogen demand depending on whether the crop concerned has a low or high nitrogen demand. At this point artificial nitrogen fertiliser use could be greatly reduced.

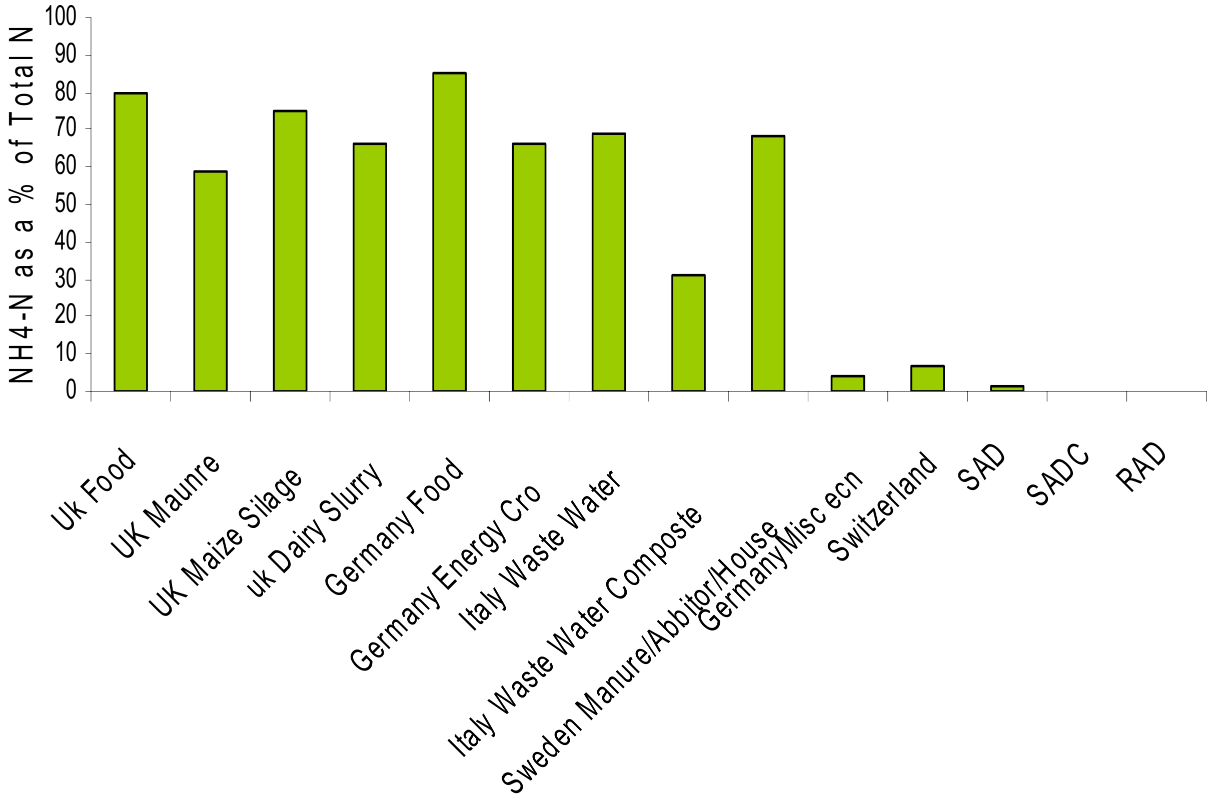


**Figure 30: Ammonium nitrogen as percentage of total nitrogen from digestate from various countries and feedstock**

The release of phosphorus from both RAD and RC showed phosphorus efficiency similar to mineral phosphorus fertiliser (superphosphate). It has been claimed that anaerobic digestion does not change the phosphorus availability of the feedstock. If this is the case, the feedstock used in anaerobic digestion would affect availability. From the other project (EPA STRIVE) we have found that poultry manure compost is much higher than green waste compost and can ever surpass phosphorus efficiency of mineral phosphorus fertiliser.

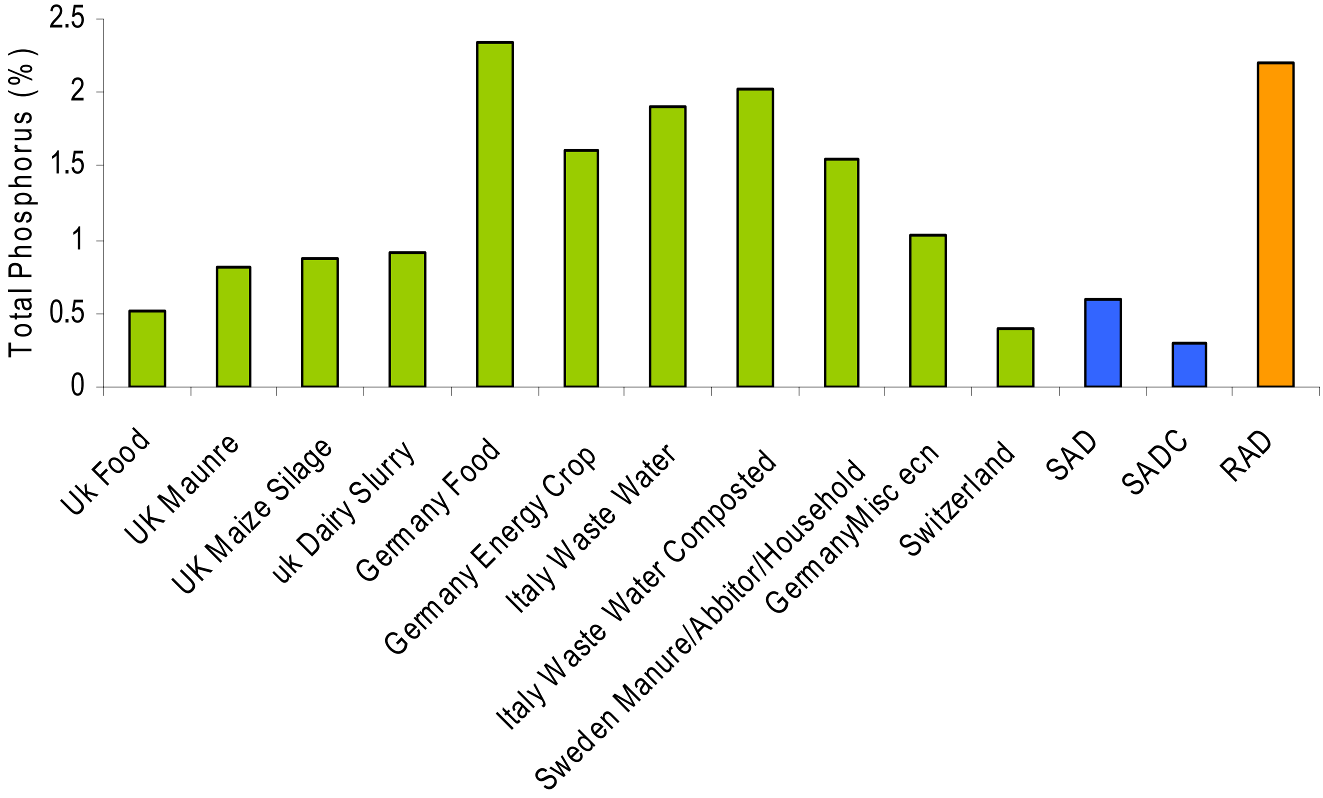


**Figure 32: Total phosphorus from digestate from various countries and primary feedstock**

# 6 Main Conclusions

- From the characterization data it is evident that the compost and digestate fibre were similar in most cases, except for certain stability parameters and certain other plant nutrients. The low nitrogen content and low ammonium content stands out in relation to data from some other countries, but might be explained by storage and handling prior to sampling.

- These results indicate that total nitrogen analysis on digestate fibre has limited value. It is very important to measure the inorganic nitrogen (mostly NH4-N) and express it as a percentage of total nitrogen. This gives a better indication of nitrogen availability. Nitrogen analysis needs to be conducted as close as possible to application in the field

- The nitrogen content of digest can vary a great deal not only due to nitrogen volatilization but also due to feedstock. Manure type of feedstock for e.g. poultry manure would give a higher nitrogen content and presumably higher nitrogen availability per unit of nitrogen than a feedstock based mostly on an energy crop e.g. maize.

- With compost the phosphorus content is often the limiting factor on the volume of compost that can be applied to land as phosphorus availability is much higher than nitrogen availability. Usually the nitrogen availability can be less than 0 (ie the compost immobilises nitrogen) rising to 20%. With fresh digestate fibre with a nitrogen content of 10 - 15% nitrogen and phosphorus content of 1 – 2 %, nitrogen could be a limiting factor for application rate of digestate. However if the nitrogen has been lost as in the case of the digestate used in our investigation, phosphorus would be the limiting factor.

- P availability from digestate fibre and compost is high, 70 – 100% of superphosphate equivalent. Since it is generally agreed that anaerobic digestion does not change the phosphorus availability, and the results from the STRIVE project indicate that a compost based on poultry manure can have similar or higher availability than superphosphate, anaerobic digestion feedstock based in say poultry manure will have higher phosphorus availability. Feedstock is thus a critical factor whether the phosphorus availability would be 100% of superphosphate equivalent or would be slightly less.

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# Appendix A: Definition of Methods

**Referenced methods for compost and digestate testing.**

Parameter Method of Analysis:

Organic matter (dry combustion) I.S. EN 13039:2000 Soil Improvers and Growing Media – Determination of Organic Matter Content and Ash

Electrical conductivity I.S. EN 13038:2000 Soil Improvers and Growing Media – Determination of Electrical Conductivity

I.S. EN 13037:2000 Soil Improvers and Growing Media – Determination of pH

I.S. EN 13650:2001 Soil Improvers and Growing Media – Determination of Aqua Regia Soluble Elements

I.S. EN 13651:2002 Soil Improvers and Growing Media – Extraction of Calcium Chloride/DPTA (CAT) Soluble

CEN 16087 Soil improvers and growing media - Determination of the aerobic biological activity - Oxygen uptake rate

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Humic acid. Extraction and fractionation of humic and fulvic acids (modified method according to Danneberg) ABF-BOKU,Austria, Method for Analysing Humic acid.
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Horneck, Donald A. and Robert O. Miller. 1998. Determination of total nitrogen in plant tissue. In Y.P. Kalra (ed.) Handbook and Reference Methods for Plant Analysis. CRC Press, New York.

P, K, Ca, Mg, Mn, Fe, Cu, Zn Dry Ash. Miller, Robert O. 1998. High-Temperature Oxidation: Dry Ashing. In Y.P. Kalra (ed.) Handbook and Reference Methods for Plant Analysis. CRC Press, New York.

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Pot Study Procedure:

The pot trial was conducted in 15 cm diameter pots containing 5 litres of soil. The test materials were added at the equivalent of 218kg N/ ha of total nitrogen for the N trial and the equivalent of 40 kg P/ha for the phosphorus trial. For the N trial Calcium ammonium nitrate was added as a mineral fertiliser (Treated Control) and for the P trail Superphosphate at an equivalent rate as a mineral fertiliser, respectively for comparative purpose. Both trials had blank control treatments which had phosphorus and potassium added for nitrogen trial and nitrogen and potassium for the phosphorus trial. Phosphorus and potassium were added to the Nitrogen treatments and nitrogen and potassium for the phosphorus trials, in order to ensure that these nutrients were not limiting factors in the respective trials.

(A) NITROGEN TRIAL Treatments:

(1) Compost at equivalent of 218 kg N/ha
(2) Digestate fibre at equivalent of 218Kg N/ha
(3) Compost at equivalent of 109 kg N/ha + 109kg N as CAN in 5 increments at the start and after each harvest (5 times)
(4) Digestate fibre at equivalent of 109 kg N/ha+ 109kg N as CAN in 5 increments at the start and after each harvest (5 times)
(5) Digestate liquor applied at 218kg N /ha in 5 increments at the start and after each harvest (5 times)
(6) CAN 218kg/ N in 5 increments at the start and after each harvest (5 times)
(7) Blank Control

There were 4 replicates in a randomised block design.

(B) PHOSPHORUS

(1) Compost at equivalent of 40 kgP/ha
(2) Digestate fibre at equivalent of 40 kgP/ha
(3) Superphosphate 40 kgP/ha
(4) Control(only N and K)

Grass was sown at 5 gram per pot.Five harvests were taken when the plants reached approx 20cm in height in the “best” treatment. Fresh and dry weight (after drying at 70oC) of grass and plant nutrients were analyzed.