



Nitrogen and Phosphorus availability from various composted wastes for use in Irish agriculture and horticulture

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Abstract

Current environmental EU legislation promotes recycling and recovery from organic waste products. Compost has been identified as an alternative to inorganic fertilisers and animal slurries as a nutrient source for crop plants. This study aimed to investigate nitrogen (N) and phosphorus (P) availability from various composted waste through detailed characterisations, complemented by short term lab incubations and long term plant growth experiments.

Twenty-five composts were selected and classified by their groups. The composts were characterised by multiple different analytical techniques. Two incubation studies were conducted. One investigating N and P mineralisation potential of the composts and the second on the effects of soil type on P mineralisation. Two large glasshouse based pot experiments were then conducted. A subsequent stability study of two separate methods on mechanical biological treated waste was also investigated for a potential relationship.

Characterisation of the composts highlighted the difference between compost feedstocks with the manure waste being distinctly separate from the other groups. The biowaste groups identified as either food waste or brown bin waste. The incubation experiment highlighted that N mineralisation was more predictable than P. From the pot experiment only manure waste mineralised N above 10%. All of the other groups mineralised minute amounts. Prediction of N mineralisation was found to be more accurate from lignin and neutral detergent fibre content over the more traditional C/N ratio. Mineralisation of small amounts of organic N occurred in summer months. There was a distinct lack of a relationship between the P incubation and pot experiment. Plant uptake

of P was higher than expected for all treatments. The manure waste composts were higher in cumulative P uptake than inorganic fertiliser. Stability in composts was found not to affect mineralisation or induce immobilisation. The effects of soil type on composts were most pronounced in composts lower in fulvic acid. The composts with higher humic acid were not found to significantly mineralise a higher amount of P. The stability study investigating oxygen uptake rate (OUR) and respiration index (AT_4) on the mechanical biological treated waste showed a high correlation between the two methods where AT_4 was below $40 \text{ mg O}_2.\text{g DM}^{-1}$.

The findings point to a possible reassessment of compost quality guidelines for composts. The availability of P is far greater and therefore should be considered the primary nutrient available from compost. The stability parameter for manure waste compost may also need assessing as it is unachievable in reasonable composting time frame. The biowaste compost has proven to be high in P. There is also the potential to develop quite specifically produced composts based on their feedstock and composting length for particular agronomic or environmental needs. Compost application is a feasible source of nutrients and organic matter due to escalating fertiliser prices and more stringent regulations surrounding fertilisers and slurries.

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List of Abbreviations

AD	Anaerobic digestate
Al	Aluminium
ASP	Aerated static pile
BMW	Biodegradable municipal waste
BW	Biowaste
C	Carbon
Ca	Calcium
CaCl ₂	DTPA Calcium chloride Diethylene triamine pentaacetic acid
CAN	Calcium ammonium nitrate
Cd	Cadmium
CEC	Cation exchange capacity
CEN	Comité Européen de Normalisation
C/N	Carbon/nitrogen
CO ₂	Carbon dioxide
Cr	Chromium
Cu	Copper
EAS	Enclosed aerated system
EU	European Union
EC	Electrical conductivity
Fe	Iron
FTIR	Fourier transform infrared technology
GDP	Gross domestic product
GW	Green waste
HA	Humic acid
HCA	Hierarchical cluster analysis
HCl	Hydrochloric acid
Hg	Mercury
HNO ₃ /HClO ₄	Aqua regia
H ₂ O	Water
HR	High rate
HS	Humic substances
IAT	In-vessel aerated tunnel
ICP-AES	Inductively coupled plasma-atomic emission spectrum
IEW	Indoor enclosed windrow
IOW	Industrial organic waste
IR	Infrared
IS	Irish standard
ISP	Indoor static pile
IV	In-vessel
IVS	In-vessel static
K	Potassium
KCl	Potassium chloride

LR	Low rate
MBT	Mechanical biological treatment
MC	Moisture content
MW	Manure waste
MR	Medium rate
N	Nitrogen
NaHCO ₃	Sodium bicarbonate
NaOH	Sodium hydroxide
NDF	Neutral detergent fibre
NO ₂	Nitrite
NO ₃	Nitrate
NH ₃	Ammonia
NH ₄	Ammonium
NSAI	National Standards Association of Ireland
OM	Organic matter
OUR	Oxygen uptake rate
P	Phosphorus
Pb	Lead
PCA	Principal component analysis
PCI	Pile composted indoor
S	Sulphur
SP	Static-pile
SSP	Single superphosphate
TKN	Total Kjeldahl Nitrogen
W	Windrow
WHO	World Health Organisation
Zn	Zinc

Chapter 1

Introduction and literature review

1.1 General introduction and project background

The National Strategy on Biodegradable Waste published by the Department of Environment in 2006, points to the large gap between the projected Biodegradable Municipal Waste (BMW) production and the maximum amount of landfill permitted for BMW under the EU Landfill Directive. This gap represents the capacity which must be provided for alternative treatment methods. In 2004, about 630,000 tonnes of BMW were diverted from landfill (mainly in favour of recycling and recovery). This must increase to approximately 1.41 million tonnes in 2010, rising to about 1.73 million tonnes in 2013 and an estimated 1.82 million tonnes by 2016. This represents a huge challenge to the Irish waste industry.

Organic material such as food and garden waste – also referred to as ‘biowaste’ - comprises some 40% of biodegradable municipal waste and represents a major constituent of BMW. Ambitious recycling rates for food and garden waste will have to be pursued to help meet the overall landfill diversion targets for BMW. The amount of municipal food and garden waste generated in 2004 was 780,460 tonnes. The target is to provide a combination of home composting and centralised biological treatment

facilities to divert approximately 35% of organic waste to biological treatment of source-separated material by 2010 rising to 50% by 2016. This figure was met in 2010 (860,000 tonnes diverted) but is currently slightly off target for 2016. Total biological treatment capacity in operation in 2004 was approximately 100,000 tonnes per annum, but this included treatment of sewage sludge and industrial waste. Performance has improved since 2004 with capacity now at 550,000 tonnes per annum and significant additional capacity is in planning and/or under development. This capacity must increase to a minimum level of 250,000 tonnes in 2010 rising to 320,000 tonnes in 2016.

Defining Application Rates and Codes of Practice for compost use (as per municipal biosolids) while taking into consideration provisions of the EU Nitrates Directive (91/676/EEC) and the Water Framework Directive (2000/60/EC) along with other Statutory Instruments relevant to land application and environmental protection are essential for the commercial compost producing industry.

In order to define application rates and codes of practice for using composted waste 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. Accurate information supplied will enable the crop producer to develop management plans to allow for maximum uptake of plant nutrients whilst adhering to national and European policy.

A Market Development Plan (2007-2011) was launched by the Department of the Environment in April 2007 with the objective to increase the use of compost products in agriculture and horticulture by demonstrating and quantifying the beneficial and environmental impacts of applying compost products to crops.

1.2 Marketability of compost

As stated above the EU has outlined target figures to be met by each individual EU member state in relation to waste management. Estimated figures show that Ireland produced 2.8 Mt of municipal solid waste in 2010. Under the EU waste policy framework disposal of waste to landfill is seen as the least favourable option. Alternate practices for the disposal or treatment of waste have now become more important than ever before. Composting has become an important resource in waste management. Composting is a technique that is used to convert organic waste into useful agricultural and horticultural products (D'Imporzano *et al.*, 2008). Compost and composting has been shown to have many beneficial facets which include: waste management (i.e. an alternative to landfill), a soil improver and conditioner, recycling of organic matter back into soil and the reuse of important macro & micro-nutrients (organic fertiliser).

Recyclability of essential macronutrients such as N and P are of extreme importance in the current industry. One reason is the escalating costs of conventional inorganic fertilisers and the expense associated with the disposal of different waste streams. Compost has been found to improve soil structure and organic matter content and also

provide an N supply to plants and thus may reduce the input of mineral N fertilizers in conventional agriculture and provide a useful nutrient source in organic farming, respectively (Erhart *et al.*, 2005). Studies have shown that the composting process immobilizes N in litter and produces humus, a source of organic materials and slow release-nutrients (Paul, 1996). Today phosphorus for crop production is sourced almost entirely from non-renewable sources i.e. rock phosphate (Van Vuuren *et al.*, 2010). Increasing world population growth increases the demand of food production. By 2050 we will need to increase food and animal feed to 3 billion tonnes from today's 2.1 billion tonnes (WHO 2009). There is now an increasing need for renewable sources of phosphorus. The agriculture industry is of huge importance to the Irish economy. The industry accounts for 2.5% of GDP with the wider agri-food sector accounting for 8.5% of Irish exports (Gov., 2011). All of the aforementioned benefits of compost usage contribute to an overall financial saving to be made by both commercial and domestic growers.

1.3 Environmental impact of compost

Phosphorus and nitrogen enrichment of subsurface groundwater is a particular environmental concern. In countries all over the world soil N and P levels are insufficient to sustain plant growth. Therefore excesses of N and P based inorganic fertilisers are added to land each year. In some cases up to 500 - 600 kg N ha⁻¹ is applied to land (Xing and Zhu, 2002). Inorganic fertilisers have readily available N and

P which is required for plant growth with maximum efficacy. The negative aspect of this is the imminent loss of N and P to subsurface groundwater. This load of N and P along with poor management practices and cultivation and rotation has seen farm runoff be accountable for up to 50% of eutrophication in lakes and 60% in rivers (Parry, 1998). Deterioration of Irish waters due to excessive algal growth has been of major environmental concern in the last 15 years. Land which undergoes intensive farming practices such as intensive vegetable rotation have been found to be high in soil P levels due to the over application of fertiliser and manure (Withers *et al.*, 2001) This is also the case for N. Over application is not just of concern for groundwater quality. Soil quality benefits from the application of composts. When applied in sufficient amounts it serves as a sufficient organic source of N and P as well as providing humic substances, lignin, soil organic matter and sequestration of carbon – making it an excellent soil conditioner. Compost has been shown to be a slow release organic material for both N and P. Understanding the dynamics and plant available N and P is essential. This greater knowledge of how composts behave can ultimately minimise the threat to the environment. There is a great significance on sustaining the agriculture industry at its current rate whilst continuing to minimise the environmental impact.

1.4 Literature review

The literature review aims to compile a thorough overview of the main aspects of composts, the science behind composting and relevant research which has been conducted which relate to the experimental investigations that will be explored in the

chapters ahead. The areas of research specific to the compost industry that will be reviewed include: (1) the characterisation of compost groups according to feedstock including the various methods investigated to quantify specific parameters of composts; (2) incubation studies conducted to investigate both N and P dynamics and mineralisation of composts applied to soil under controlled conditions; (3) plant uptake and growth response (pertaining solely to N and P) which are observed in trials conducted with various composts.

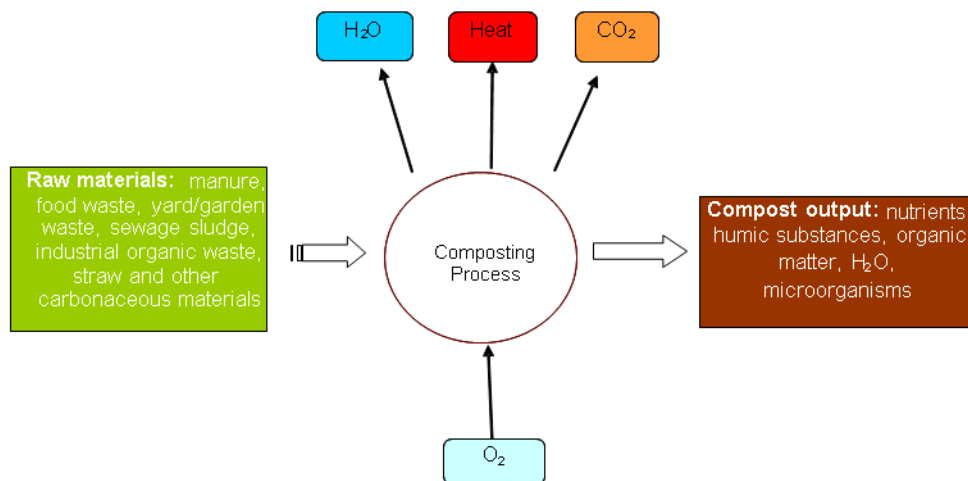


Figure 1.1. Composting process schematic diagram

1.4.1 Compost sources and waste feedstocks

There are numerous compost types available and sub categories of these types. Waste is defined in Section 4 (1) of the Waste Management Acts 1996 and 2001. The definitions provided refer to the European Waste Catalogue and the European Hazardous Waste list. It states that any substance or object belonging to a category of waste specified in the First Schedule of the Act, or included in the European Waste Catalogue, which the holder discards or intends or is required to discard, and anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste until the contrary is proved.

In general there are the following groups of waste feedstocks for compost:

(1) Food processings/waste residue (biowaste), (2) Manure and agricultural waste, (3) Forestry waste and residuals (green waste), (4) Sewage sludge (biosolids), (5) Leaves, grass, bush and yard trimmings (green waste) and (6) Source separated organic waste (biowaste (municipal solid waste/brown bin waste/green waste)).

1. Food processings/residue (biowaste). Potentially compostable material remaining after fruit, vegetables, wheat grain, meat, fish and dairy are processed for consumption. Sources include catering industry, food processing plants and the food retail sector. Biowaste which has high fruit content has been shown to have lower pH values in the initial stages of composting, creating conditions which favour fungal growth (Choi and Park, 1998).

- 2. Manure and agricultural waste.** This is the waste generally generated on farms of both a domestic and commercial scale. The composting of this group is important as they are high in nutrients which are beneficial but also in microbe and pathogens. Generally these groups will have a green waste added to reduce C/N ratio (Bernal *et al.*, 2009).
- 3. Forestry waste and residuals (green waste).** Barks are a common additive to be used as compost substrate. Others include paper mill pulp and saw dust. These are used as a carbon source and rarely used solely due to their low mineral content. There are also barks which are high in conductivity (EC) and are phytotoxic to plants (Cunha-Queda *et al.*, 2007).
- 4. Sewage sludge (biosolids).** This refers to the solid cake-like material produced during the active biological treatment of sewage at a wastewater treatment facility. Composting sewage sludge is a viable option for the utilization of the material as it offers an alternative to land filling. Land application of sewage sludge is restricted due to heavy metals, pathogens, and persistent organic pollutants in the sludge (Wei *et al.*, 2001) and it must be limed before application to sterilise it.
- 5. Green waste** which comprises leaves, grass, bush and yard trimmings. These feedstocks generally originate from parks and gardens and can be high in macro nutrients and humic substances (Keeling *et al.*, 2003). These are generally composted for use as a soil conditioner. One issue that may arise with these types of wastes is the presence of pesticides and organophosphates at a residual level which are potentially dangerous (Fogarty and Tuovinen, 1991).

6. Source separated organic waste. This group can comprise of up to 40% of the municipal solid waste stream (Erhart *et al.*, 2005). This group collectively known as biowaste can include all forms of source separated organic waste. Biowaste has the potential to be a very good source of nutrients for plants. However the main problems confronting this material are the source and the separation after collection. Much of this waste is highly heterogeneous and therefore reliant on the provider of the waste to adhere to the disposal guidelines (Bardos, 2004). Other factors which may influence the end product can be anaerobic conditions at the source in the brown bin.

1.4.2 Introduction to aerobic composting and its processes

A practical definition of composting is the biological decomposition and stabilisation of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can beneficially applied to plants (Haug, 1993). For a material to be considered a compost it must undergo or be involved in the following: 1) Involve a heterogeneous organic substrate in a solid state in the presence of oxygen; 2) Evolve by passing through a thermophilic stage and a temporary release of phytotoxin and 3) Lead to the production of carbon dioxide, water, minerals and a stabilised organic matter. This process must also be controlled by means of temperature, moisture, substratum composition and oxygenation (Zucconi and de Bertoldi, 1987).

The Irish Standard *I.S. 441:2011*, 'Quality requirements for a compost manufactured from source segregated, separately collected, biodegradable materials' defines compost as solid particulate organic matter, that has been sanitised through the action of micro and macro-organisms, resulting from the composting of biodegradable material including biowaste, that has undergone predominantly aerobic decomposition.

During the composting process the organic material undergoes numerous different processes and phases. The composting process can be broken down into four separate stages. These stages are:

1. The mesophilic stage
2. The thermophilic stage
3. The cooling phase/curing stage
4. The maturation/stabilisation stage.

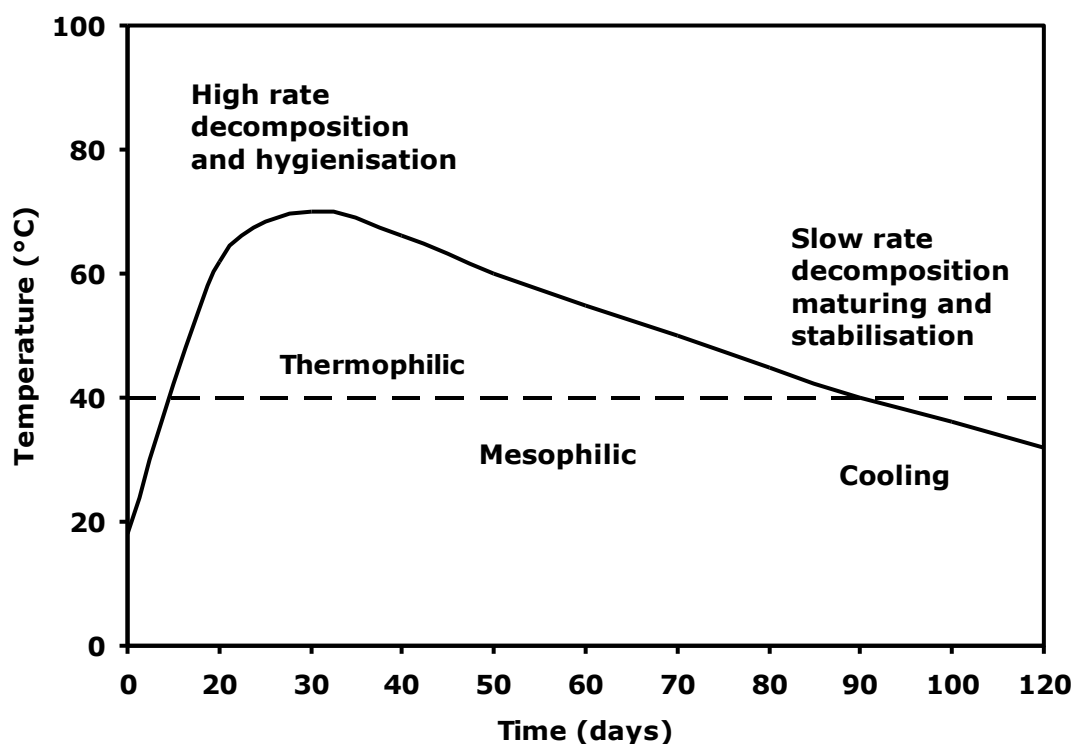


Figure 1.2. The stages of an idealised composting process (Anon, 2012)

These processes are classified by the microbial activity taking place during these stages. The mesophilic stage is the first process which takes place between 20 – 40°C. During the mesophilic stage the microbial species present in the fresh waste feedstock begin colonising the compost at a rapid rate due to the high availability of easily degradable nutrients (Day and Shaw, 2001). This process involves the oxidation of proteins, sugars and starch. During this stage there is an initial drop in pH due to the formation of organic acids (Hellmann *et al.*, 1997b).

From here a temperature increase causes the development of thermophiles and this is the initiation of the thermophilic stage. This process can reach up to 70°C. However,

such a high temperature as this may be considered undesirable. The optimum temperature for degradation to take place is 55 - 60°C (Stentiford, 1996). During this phase many constituents (mainly organic) are broken down by hydrolysis and oxidation reactions (Déportes *et al.*, 1995). Much of the organic matter (OM) is converted to CO₂ and H₂O (Wiley, 1962). Reaching these temperatures is essential to reduce the volume by 90%, kill any pathogens, weed seed, and more recalcitrant compounds (Boulter *et al.*, 2000). Thermophilic bacterial and fungal species are responsible for the activities which take place during the occurrence of the high temperatures. However there are results that suggest in food waste that yeast species are active during this period, especially when the feedstock is high in rice and vegetables (Choi and Park, 1998).

After this stage there is a cooling phase. During this phase, the microorganisms that were replaced by the thermophiles migrate back into the compost and digest the more resistant organic materials. Fungi and macroorganisms such as earthworms and sow bugs that break the coarser elements down into humus also move begin to reinhabit (Jenkins, 1999).

The final stage is the curing or maturation stage. This is the longest stage in the composting process. In this stage much of the organic material is converted to humic substances (Chen and Inbar, 1993). Also during this stage if the compost process remains aerobic there is a re-colonisation by nitrifying bacteria and ammonium is oxidised to NO₂⁻ and NO₃⁻ (Catton, 1983). It is also essential that a compost is fully stable by the end of this process as a more stable compost will have less water soluble P

(WSP) which is the main cause of leaching of P to ground water (Prasad and Foster, 2006a). There is also an increase in maturity at this stage. Increasing maturity in compost increases the stable organic matter such as lignin, cellulose and hydrophobic compounds (Spaccini and Piccolo, 2008). The consequence to this is the nutrient transformations that accompany this process. Usually after four weeks of the composting process the ammonia concentration declines significantly until the maturity stage. The decrease in NH_4 is due to the increased humification process which occurs during this phase (Wu *et al.*, 2010).

1.4.3 Composting processes used industrially

1.4.3.1 Windrow composting

One of the most widely used industrial processes is windrow composting. This involves forming long narrow piles or windrows which are turned and re-mixed on a regular basis. Special turning machines are used to turn the windrow which can be up to 3.5 metres in height and between 1.5 and 6 metres in width. This process depends on a good supply of oxygen throughout the windrow. Turning of the material allows for a uniform mixing of the compost and releases gases and water vapour. It helps keep the temperature regulated which is of paramount importance during the process.



Figure 1.3 Windrow compost pile

1.4.3.2 Static Pile (aerated)

This process involves a stationary pile (hence the name) which undergoes no turning and uses a blow system to supply air to the pile. Generally the pile has air pushed up through it from a set of pipes beneath the pile which contain apertures to allow air to escape up through the pile. This system generally breaks down the material in roughly 3 – 5 weeks. This system is more akin to the traditional method of composting where the organic material was left in heaps to break down. The other type of aeration used is a passive aeration system in which pipes are embedded into the pile and air constantly flows through the pile with cold air flowing in – in exchange for hot air and gases which exit the pile through the piping network (Misra *et al.*, 2003)



Figure 1.4. Aerated static pile compost

1.4.3.3 In – vessel composting

The system involves using an isolated reactor in which the temperature, moisture and air flow are monitored and regulated (Commission, 2001). This method allows for a more rapid composting process due to the tight control of the system. Some of the processes utilised include; contained, horizontal, mechanically agitated, vertical and rotating drum systems (Bardos, 2004)



Figure 1.5. A large scale in – vessel composting plant

1.4.4 Parameters affecting composting

There are numerous different factors which can be used to characterise composts. These factors include physical, chemical and biological characteristics. Some of these include the feedstock material, the process type and length and the influence of microbial community on some of the physical and chemical components of the material. As mentioned previously the feedstock is the most important parameter. This is because some feedstock materials will require less composting lengths than others and may require different processes. The most important parameters which need to be controlled during the composting process include; temperature, aeration, pH, moisture and C/N ratio.

Temperature: This is of high importance during the composting process in order for it to be successful as temperature is commonly used to measure the level of microbial activity within the compost (Fogarty and Tuovinen, 1991). The ideal temperature is 55 – 60°C.

Aeration: Composting is a biological oxidation process in which aeration is central to its successful completion. The importance of aeration is threefold as 1) it supports aerobic metabolism 2) it regulates the temperature and 3) it removes moisture as well as CO₂ and other gases formed (Fogarty and Tuovinen, 1991).

Moisture: The moisture content has an integral role in microbial activity. Under dry conditions the activity decreases and under water-logged conditions the microbial activity decreases due to lack of air supply (Epstein, 1997). A major issue with the composting process is the loss of water through evaporation (Stentiford, 1996).

pH: The pH is initially alkaline within the compost pile. This however drops due to the formation of organic acids during the degradation process (Hellmann *et al.*, 1997a). Optimal pH levels for composting are between pH 5.5 to pH 8.0 (Fogarty and Tuovinen, 1991). Organic acid volatilisation and the accumulation of N compounds such NH_3 cause a subsequent rise in pH. A final drop again is observed due to the formation of humic substances within the material (Fogarty and Tuovinen, 1991). The effect of pH is not as critical on the N dynamics and availability from compost as it is on P. The occurrence of high pH in composts may restrict P mobility by causing it to sorb to Ca (Terman *et al.*, 1973) and Mg in the form of apatites and octocalcium (Frossard *et al.*, 2002).

C/N ratio: The importance of C/N ratio has been researched, written about and debated at length. Poincelot (1972) reported that the C/N ratio is the most important parameter of composting in relation to microbial decomposition. The general consensus is that the C/N ratio at the start of a composting process should be 25 – 35. Having a low C/N ratio can cause excess NH_3 production which in turn increase the pH and thus loss of the NH_3 (Fogarty and Tuovinen, 1991). A high C/N ratio can become N depleted and lower the pH which limits the amount of microbial activity and thus slows the process (Fogarty and Tuovinen, 1991).

1.4.5 Maturity and stability of compost

Two of the most important parameters for compost quality are the stability and maturity of compost. The term "compost stability" should not be confused with "compost maturity". Compost maturity is often assessed through sensory activity or by its potential for plant growth whereas stability refers to the microbial activity of the material (Iannotti *et al.*, 1993). There has also been suggestions of other methods to assess maturity like using dissolved organic carbon due to the anomalies that lie with using growth tests (Zmora-Nahum *et al.*, 2005). Stability can be assessed by more than one method. Some of the methods used include the solvita test (Brinton *et al.*; Brinton *et al.*, 1995) or humic formation as an indicator of the duration of the degradation process (Adani and Spagnol, 2008). One of the more modern techniques used has been to monitor the oxygen uptake rate (O.U.R.). This method has been utilised in a number of studies recently (Gea *et al.*, 2004), (Miyatake and Iwabuchi, 2006) (Puyuelo *et al.*, 2010). This method has become more popular due to its close links with microbiological activity (Miyatake and Iwabuchi, 2006). A popular method for this is using the OxiTop system. This device measures the pressure drop of a gas phase in a closed system. The aerobic activity in the sample is measured within the system. During the activity oxygen from the gas phase is consumed and CO₂ produced. The evolved CO₂ is then absorbed by soda lime present in the head space sensor. The oxygen consumption is related directly to the pressure drop and so the microbial activity can

be measured accurately (Veeken *et al.*, 2003). Work has been done on composted waste materials to qualify the use of OUR (and SOUR) as a means to evaluate compost stability (Chica *et al.*, 2003). Physical and chemical methods are limited due to the fact that they fail to take into account the biological activity within a compost (Chica *et al.*, 2003). It is for this reason that the OUR measurement is seen as an accurate predictor of compost stability. The suitability of OUR has been further researched and compared with other respiration methods (Gea *et al.*, 2004). Their conclusions stated that the OUR method was the most suitable for determining the microbiological activity in the compost.



Figure 1.6. An oxitop pressure head sensor with sample in Duran bottle

1.4.6 Anaerobic digestion and mechanical biological treatment

In more recent times two more methods have become widely used in the waste industry. These two new industrial methods are called anaerobic digestion (AD) and mechanical biological treatment (MBT). AD is a biological process in which organic matter is degraded to methane under anaerobic conditions. Methane can then be used for energy

to replace fossil fuels and thereby to reduce carbon dioxide emissions (Salminen and Rintala, 2002). AD was developed during the 1980's and has grown to be one of the major waste management practices for biowaste and the organic fraction of municipal solid waste (MSW) (De Baere, 2000). AD is essentially a controlled and accelerated decomposition process using the same types of micro-organisms that produce methane in landfills. AD produces both a liquid and solid fraction (digestate). The digestate is used as a compost-like product but usually after a maturation stage (Smith *et al.*, 2001).



Figure 1.7. Anaerobic digestion plant

MBT has evolved from the simple combination of mechanical preparation, material separation and composting to an integrated system with three or more waste fractions which can be recycled, composted from which energy can be recovered via digestion and subsequent combustion (Heermann, 2003). Countries such as France and Austria have invested in state of the art facilities which can maximise the amount of waste

recycled through intricate separation systems. They use materials suitable for energy recovery with excellent efficacy ensuring a largely organic fraction for biological treatment and therefore lowering the quantity of waste land filled. The aim of MBT is to minimise biogas and leachate production, reduce odours during waste deposit, reduce landfill settlement and to minimise the duration of the landfill site after treatment (Scheelhaase and Bidlingmaier, 1997). MBT of residual MSW include: (i) mechanical pre-processing stages to sort out recyclable materials such as paper, metals and plastics, and (ii) biological stages to reduce and stabilize the biodegradable organic matter under controlled anaerobic and/or aerobic conditions (Bayard *et al.*, 2010). MBT had become a favourable option for the treatment of waste in Ireland in the last five years. This in part due to the government policy of promoting MBT as a waste treatment practice but also due to public concern over the use of other methods such as incineration. The first such of these plants was built at Beuparc, Navan in County Meath.



Figure 1.8. An MBT plant

1.4.7 Characterisation of composts

The characterisation of composts is an important issue as it holds many benefits. The most important aspect is to understand the nature of the compost i.e. stability, maturity, moisture content, organic matter content, pH, EC and available nutrients. Furthermore to understand the compost more thoroughly, analysis for more complex parameters may be conducted including; humic substances, lignin content, cation exchange capacity (CEC) and neutral detergent fibre (NDF) reflux. NDF measures the structural component of plant cells which includes lignin, cellulose and hemicellulose. As the composting industry has grown so to have the variability of feedstocks and so other parameters such as heavy metals, metals and organic pollutants have been determined and are legislated in the NSAI *I.S. 441:2011* on compost quality.

1.4.8 Chemical and spectral characterisation

Composts are heterogeneous by their nature but are becoming increasingly more diverse which makes it more difficult to characterise and produce specific guidelines for the production and safe usage of composts (Zmora-Nahum *et al.*, 2007). In their study the authors investigated the relationship between different chemical characterisations and their primary source materials. They highlighted the patterns that emerged based on the primary source material. However other authors (Brewer and Sullivan, 2003) have suggested the problems which may arise are intraspecific to a group such as yard waste (green waste) where the composition may vary seasonally and with the type of material

contained. Other authors also highlight the difference between yard waste composts and other (mixed) composts on the basis of mineral composition, N content and CEC (Zaccheo *et al.*, 2002).

There has been extensive work conducted to identify and characterise different compost groups using spectral methods. FTIR (fourier transform infrared) spectroscopy has been used as a technique to not only identify composts from different feedstock groups but also to evaluate the compost's stage of maturity. The basis for identification of composts at the varying stage of degradation is that different metabolic compounds are produced at different stages of decomposition. These in turn can be identified by absorption bands in the IR spectrum (Smidt and Meissl, 2007). In a similar study by the same authors the potential of FTIR is discussed extensively in which its application in identifying different compost groups through fingerprint regions in the FTIR spectrum is described (Smidt *et al.*, 2002). Here the spectral characteristics of different wastes are presented and discussed. This includes the identification of sewage sludge, biowastes and municipal solid wastes. Another aspect of the study is the identification of compounds such as the presence of lignin in plant or woody material by identifying specific bands within the spectrum. In many of the studies presented, FTIR is seen as a fast and easy method for process monitoring, compost identification and as a complimentary determination of stability. In the Irish standards for compost quality and end-of-waste criteria no specific guidelines are set out for the use of FTIR. This fact would encourage the use of FTIR solely as a complementary method or as a guideline for compost analysis. Oxygen uptake rate (OUR) which is used to measure compost

stability is a means of analysis that would complement FTIR excellently. Oxygen uptake rate has been previously discussed in section 1.4.5.

The study of humic substances (and acids) in composts and their effects on soil and plants has been researched extensively. Some of the effects that humic substances (HS) can have in soil/plant systems include: increased root growth (Vaughan, 1985) which increases the likelihood of nutrient uptake, an extensive buffering capacity in wide pH range (Ceppi *et al.*, 1999; Campitelli *et al.*, 2003), stimulation of NO_3^- uptake (Vaughan, 1985) and stimulation of phosphate uptake (Ayuso *et al.*, 1996). There has also been extensive work conducted to investigate the effects of HS on plant metabolism, hormone activity (Nardi *et al.*, 2002) and the ability of humic substances to remediate contaminated sites of organic pollutants (Rebhun *et al.*, 1996). Although there has been a vast amount of research conducted on humic substances, their beneficial effects and their molecular structures there has been less extensive work conducted to quantify the levels of humic substances in composts and the varying levels of humic substances according to feedstock material.

The nature of the nutrients in compost has not been used traditionally to characterise compost but as studies have shown, it can give an insight into how the compost will behave or its capacity to release nutrients when utilised as a fertiliser. Recent studies have been conducted to evaluate the forms of P in composts (Frossard *et al.*, 2002) and further work has been carried out to characterise P into different forms of available and unavailable P in biowastes (García-Albacete *et al.*, 2012).

1.4.9 Nitrogen in compost: dynamics and availability

Application of compost with the intended use as a fertiliser must be done in order to maximise plant uptake whilst minimising the loss of N to subsurface groundwater and the surrounding environment. The availability of N from mineral based fertiliser is well established along with the influences on N on growth (Gutser *et al.*, 2005). Although in recent years there has been a large amount of research conducted into understanding N availability from compost, there is still some work to be done to maximise the potential of N availability from compost.

Nitrogen availability and its dynamics in soil have been studied in great detail over the last 20 years. N availability from compost is considered to be low due to the fact that upwards of 90% of the N in compost is bound to the organic N pool (Amlinger *et al.*, 2003). This leaves approximately 10% that is considered readily available to plants. The organic N is not considered totally unavailable as mineralisation can take place which converts the organic N to inorganic N i.e. NO_3^- or NH_4^+ . There are numerous factors of compost that affect the mineralisation of N including total N content and C/N ratio (Hartl *et al.*, 2003) of the compost. Soil condition also has an important role to play including moisture content, temperature (Wang *et al.*, 2006), O_2 concentration and pH (Gil *et al.*, 2011). The organic N fraction can undergo many processes including mineralisation (which makes it plant-available), immobilisation, denitrification, volatilisation, fixation through clay materials and/or leaching (Kokkara, 2008). *Figure*

1.9 is a schematic diagram indicating the processes that take place when compost is incorporated into soil in relation to N dynamics (Amlinger *et al.*, 2003).

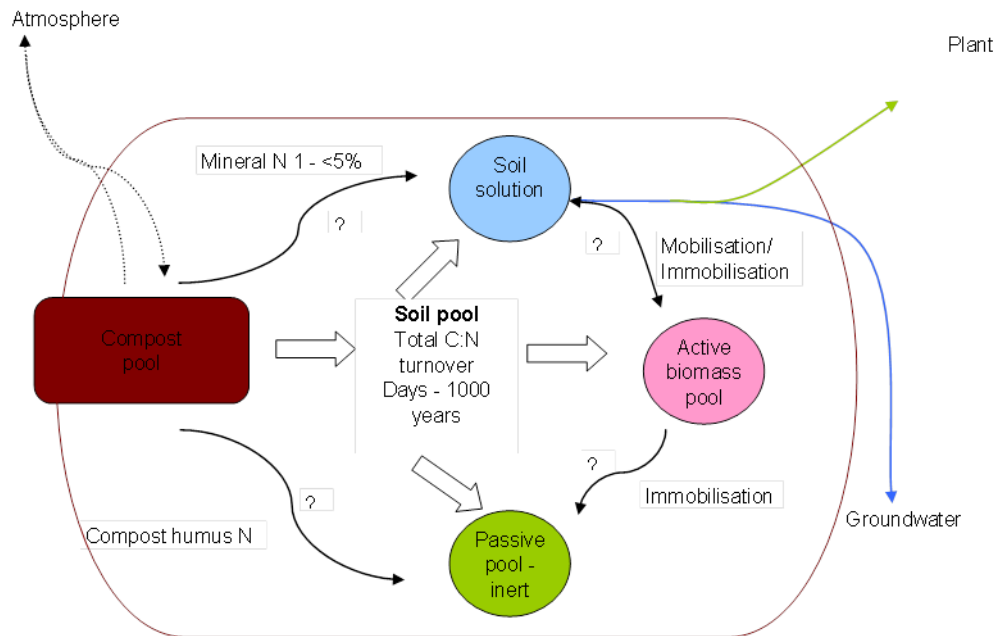


Figure 1.9 A schematic diagram indicating how little is known about the fate of N in compost (Amlinger *et al.*, 2003)

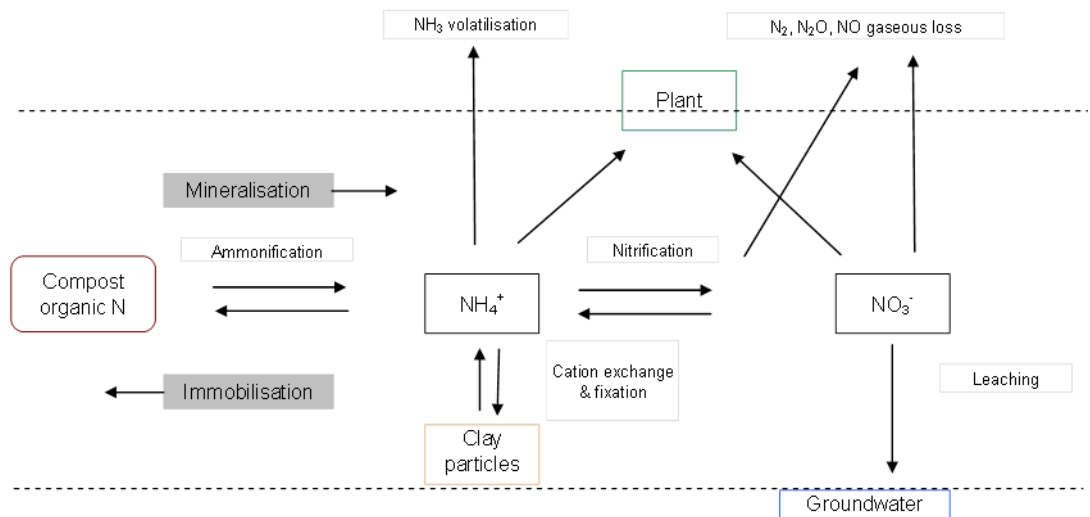


Figure 1.10 Schematic diagram of the main organic compost N transformations in soil (Kokkara, 2008)

1.4.9.1 Mineralisation and immobilisation

As has been previously mentioned up to 90% of the N in the compost/soil system is in the organic form. For organic N to become plant available it must first be converted to inorganic N through a process known as mineralisation. The reverse of this process is known as immobilisation. During decomposition of plant and animal residues a certain fraction of inorganic nitrogen is converted to organic nitrogen (Brady, 1974). The processes involved in mineralisation are ammonification and nitrification. Ammonification involves the hydrolysing of organic N to NH_4^+ . The second stage of this is the oxidation of NH_4^+ to NO_3^- via the production of the intermediate NO_2^- which is brought about by bacteria namely *Nitrosomonas* and *Nitrobacter* (Alexander, 1965; Brady, 1974). Both mineralisation and immobilisation take place at the same time. Soil biomass assimilates inorganic N during microbial metabolism and growth (Prasad and Foster, 2006a) which leads to immobilisation.

Many authors report the importance of C/N ratio as a predictor of N availability and mineralisation rate. It must be noted that this is an approximate factor and that other edaphic factors must be considered i.e moisture content, temperature, pH, salinity and soil type (Prasad and Foster, 2006a). Prasad and Foster (2006a) also highlights that the C/N ratio is very much dependent on the type of carbon which must be considered. A C/N ratio of 25 is typically seen as where both release and immobilisation are in balance (Prasad and Foster, 2006a). It is commonly known that a C/N ratio above this will result in net N immobilisation. Lower C/N ratios will generally result in net mineralisation.

Some studies have shown that a C/N ratio below 12 can mineralise large amounts of organic N (Iglesias-Jimenez and Alvarez, 1993).

The amount of mineralisation of organic N that takes place in compost has been reported to be negative (i.e. immobilisation) for all composts to 18% for cattle manure compost (Gagnon and Simard, 1999; Eghball *et al.*, 2002); for composted sewage sludge 8% (Adegbidi and Briggs, 2003) and 12% (Parker and Sommers, 1983); for composted horse manure 1.8% and 8.9% for composted vegetable waste (Gagnon and Simard, 1999). When mineralisation rates of compost are compared to that of conventional organic amendments i.e. manure or sewage sludge, there is a distinct lack of N release from the composts. However the apparent lower net mineralisation from compost may serve to be beneficial as high initial N release can lead to leaching. Up to 32% gross mineralisation of N has been reported from composted poultry manure with 57% from sewage sludge in the same study (Adegbidi and Briggs, 2003). However it is also suggested by Adegbidi and Briggs (2003) that up to 20% (Beauchamp *et al.*, 1978) of the N from the sewage sludge is volatilised during decomposition after amendment to soil.

As mentioned previously in this section the mineralisation of N is also dependent on many factors. Both increasing temperature and moisture content have been shown to increase N release (Agehara and Warncke, 2005). Agehara and Warncke (2005) showed that increased temperature directly increased the rate of NO_3^- release from composted

chicken manure and increased moisture content increased nitrification of NH_4^+ to NO_3^- . Clay materials have the capacity to “fix” NH_4^+ ions. Vermiculite is said to have the strongest sorbing capacity for NH_4^+ ions (Brady, 1974). Consistent watering has been seen to be more beneficial to mineralisation (over drying and rewetting) of N but the soil type showed less of an effect and was more effective in carbon mineralisation (Kruse *et al.*, 2004). The organic matter may also play an important role in the availability of N in the final product. It is thus important to start the initial composting process with a suitable bulking agent for the feedstock material as it may enhance N organisation and increase its availability in the final product (Doublet *et al.*, 2011).

1.4.9.2 Nitrogen incubation studies

Currently there is no rapid or easy test for mineralisable N in composts; be it chemical or biological (Antil *et al.*, 2011). Incubation tests can be used to predict possible mineralisable N in the longer term. Incubation studies have been used extensively to understand N dynamics in relation to compost. Some of the earliest of these types of trials were conducted on a large number of composts being amended to soil under controlled conditions (Mattingly, 1956). Antil *et al.* (2011) showed in their experiment (168 day incubation) that the percentage N recovery from anaerobically digested sewage sludge was 32 – 52% compared to 16 – 18% from composted sewage sludge, 11 – 15% from composted hen & cattle manure and 4 – 5% from composted cattle manure. In their paper they highlight that the composted cattle manure recorded the highest

organic matter and was less decomposable, therefore restricting the availability of inorganic N. Generally the composting of any waste product reduces the availability of N. However there are some studies in which increased N availability is seen. Gale *et al.* (2006) showed how composting decreased plant available N from composted yard waste (25 – 5%) and composted rabbit manure (42 – 19%) but increased the available N in composted dairy solids. The fresh dairy solids induced a net immobilisation which was a net mineralisation for the composted amendment. Also in this study dry stacked broiler litter (which is sold as compost) showed significant difference in less plant available N when compared to fresh broiler litter.

There are other studies published which detail the importance of the composting time on the availability of N when used as a soil amendment. A negative correlation was seen between the length of composting and the available N in the early stages of the incubation period (Griffin and Hutchinson, 2007). The authors highlighted the trend of increasing N availability with a shorter composting period in the early incubation stages. This trend became less apparent in the residual stages of the experiment.

The effect of soil type on compost mineralisation of N has also been studied under incubated conditions. Hébert *et al.* (1991) studied the effects of composted manure on two different soil types; a sandy soil and a silty loam at three different rates. In their study they found a significant effect of soil type on composted cow manure and composted sheep manure. The silty soil significantly reduced N mineralisation in composted sheep manure and immature composted cow manure. They also report a rate

effect in some treatments where the high application of compost to soil was causing anaerobic conditions and thus restricting N mineralisation. Chèneby *et al.* (1994) incubated composted farm manure with two soil types and showed that soil type had an effect on compost mineralisation. The sandy soil mineralised 34% of the labile N fraction with 25% from the loamy soil. Hades and Portnoy (1997) presented results in which an incubation of composted municipal solid waste (biowaste) mineralised 22% of N added in the form of the compost.

1.4.9.3 Nitrogen pot trial studies and plant uptake

Nitrogen is an essential macronutrient required for sustainable growth which has a quick and pronounced effect by the presence of leaves of deep green colour (Brady, 1974). N compounds are absorbed into the plant roots and translocated throughout the plant before being formed into proteins. A plant depleted in N is very easily detected due to the symptoms of N deficiency which manifests itself in the form of yellowing of the leaves (Fordham and Biggs, 1985).



Figure 1.11. Yellowing of nitrogen deficient plants

Understanding the behaviour of N and its mineralisation from compost can be studied via incubation studies discussed in section 2.3.2 or by conducting larger scale pot or field trials. The latter trials are generally conducted in glasshouses in which conditions can be controlled more precisely in terms of temperature and watering. Field trials develop a more real understanding of the dynamics of the compost behaviour as it is subjected to more extreme and changeable conditions of the seasons.

From the literature studied the results can be varied and disparate. However the trends are quite significant in many studies cited. N supplied by composts specifically from composted municipal solid wastes and biowaste ranged from a negative figure to 21% of total N applied (Gagnon *et al.*, 1997; Gale *et al.*, 2006; Erhart *et al.*, 2005; Kusunwiriawong *et al.*, 2005; Chalhoub *et al.*, 2013). Similar studies that have been conducted on composted manure wastes have shown N uptake in range of <1% to 48%

(Cooperband *et al.*, 2002; Gagnon *et al.*, 1997; Gale *et al.*, 2006; Eghball and Power, 1999b; Takahashi *et al.*, 2004).

Many of the composted wastes studied are used as a soil conditioner due to the relative unavailable N from the compost. Keeling *et al.* (2003) applied a mature and immature green waste compost to a sandy loam with ammonium nitrate fertiliser to study the effects of N uptake in wheat and oilseed rape. From their study they concluded that the green waste compost released 2% of its total N content to the crop. These results would suggest that green waste compost is more suited to being used to add organic matter and improve soil quality rather than supply N for plant growth. Bowden *et al.* (2007) conducted a trial on four composts. Two of the composts were a mixture of poultry waste and green waste and two were sewage sludge composts. Essentially all of the composts induced net N immobilisation. One of the composted sewage sludges with added wood chips had a nitrogen fertiliser equivalent value (NFEQ) of 30% due to the high inorganic N content. Consequently it had a mineralisation rate of <1% which was akin to the rest of the composts in the study.

Sullivan *et al.* (2003) studied N availability from composted food waste seven years after application to soil. Tall fescue seeds were planted and harvested forty times over seven years. Apparent N recovery was reported as 15 – 20%. Gabrielle *et al.* (2005) also conducted a long scale trial over four years to evaluate N availability from “urban waste” composts and applying a mathematical model to their results to predict N

availability. They reported total N uptake at 8 – 25% with 3 – 8% mineralisation of organic N.

Eghball and Power (1999b) conducted a trial to study the effects of both composted and non-composted cattle manure on N uptake and yield of maize. This was a four year study conducted under two tillage systems. The availability of N from composted manure in year one was 20% with an apparent N use efficiency of 12% during the four year period. This is much less than manure which exhibited N availability of 38% in year one and N use efficiency of 17% for the duration of the trial. Cooperband *et al.* (2002) studied the effect of poultry manure and composted poultry manure on both N and P levels in soil and subsequent corn uptake of the available nutrients. In their study they highlight the lack of N availability from the composted poultry manure in the first year of application i.e. immobilisation. Compost released N at a rate 3 – 4 times less than that of the manure and showed no statistical difference from the unfertilised control. They reported a pulse in NO_3^- release from the compost which was statistically different from the control in year two.

1.4.10 Phosphorus in compost: dynamics, availability and mineralisation

Phosphorus (P) is the main macro nutrient (after N) that is critical for plant growth. A lack of P in soil and available to plants can also be detrimental as it may hinder the uptake of other nutrients. Phosphorus plays an important role in the growth of legumes (Brady, 1974). It is also a naturally occurring element in soil through the weathering of

rocks which release mineral and apatite P into the environment (Troeh and Thompson, 2005). Phosphorus also has an organic source in soils in that it is added organically from manures and crop residues recycled back into the soil system.

Phosphorus in soils is considered to be low in availability as much of the P is insoluble or is bound to or adsorbed on to metals within the soil particle surfaces (Suthiphasilp, 2009; Iyamuremye, 1996; Iyamuremye *et al.*, 1996). The rest of the P is in the organic form and therefore considered unavailable. Phosphorus is a very chemically active element and can be categorised into three forms within the soil system. They are soluble P, labile P and non-labile P (Prasad and Foster, 2006b). Generally the inorganic P can be grouped into those that are contained in calcium and those contained in aluminium and iron (Brady, 1974). The effect of these metals and their ability to form phosphate complexes is pH dependent. In alkaline soils calcium compounds affect phosphate solubility by reacting with phosphate rendering it insoluble (Brady, 1974). Calcium and calcium carbonates are in plentiful supply in alkaline soils so therefore are quite effective at restricting P solubility. A similar sequence of events occurs at low pH where the P reacts with aluminium and iron forming insoluble compounds (Brady, 1974).

To improve soil P traditionally organic manure and more recently mineral fertiliser (single superphosphate) have been added to soils to increase their P load. The main issue with this is the addition of organic amendments has been largely on the basis of N requirements. This presents a problem as N and P are not required by plants and crops

in the same ratio. Phosphorus had been identified as the main limiting nutrient in eutrophication of ground waters in Ireland (McGarrigle, 2001). The loss of P occurs as a result of the accumulation of P in soils from application of inorganic and organic sources of P to land i.e. fertiliser, manure or compost (Hart *et al.*, 2004). The N:P ratio in more conventional organic amendments such as manure is typically 2:1 to 6:1 but the crop uptake ratio is much different; generally around 7:1 to 11:1 which lends to more P being added to the soil than is needed (Gburek *et al.*, 2000; Sharpley *et al.*, 1996). It is reported in some countries that P application is in excess of P uptake by between 300 – 500% (Sims *et al.*, 1998). Over-application of inorganic fertilisers and poor management practices in agriculture has led to a build of P in soils. However in a climate like Ireland's where heavy rainfall can occur frequently much of the P can be lost as run-off to groundwater.

Composts are considered a slow release fertiliser and may be beneficial as an organic amendment for releasing sufficient P but also for the purpose of groundwater protection. There are many reports showing that application of organic amendments in the form of composts improves P uptake and the availability of P (Bhatti, 1998; Hue, 1992; Iyamuremye *et al.*, 1996). Some of the earlier work conducted highlighted the beneficial uses of composts as a soil improver but were more concerned about their potential hazardous environmental impact (Lionello and Francesco, 1989).

Another factor that is driving the popularity of composts and the composting industry in Ireland is economics. Phosphorus used in mineral fertilisers comes in the form of rock phosphate. This is a mined material which has exhaustible stocks. There are literature studies available which give conflicting theories as to when peak rock phosphate mining will occur (Cordell *et al.*, 2009). However as rock phosphate is exhaustible the cost of the mining process will continue to increase. There are suggestions that the production costs could increase by a factor of 3 – 5 within this century (Van Vuuren *et al.*, 2010). This has led to increased awareness of the beneficial effects of compost on the basis of its ability to supply P to crops.

The extent of research conducted into compost and the availability of P is somewhat less than that of N. As the research into compost and its potential use as a fertiliser grew, a greater data set of results was developed. With much of the research conducted with composts specifically investigating N there are quite definite trends. Phosphorus presented a different challenge due to the nature of P in composts, the lack of literature available and the wide variation in results that was available (Cabrera *et al.*, 1991; Murillo and Cabrera, 1997). Understanding and interpreting the results can be difficult due to the limited information of the forms and types of P in the added compost amendment (Sinaj *et al.*, 2002). Work has been conducted to understand the different forms of P in compost and their exchangeability and reactivity (Frossard *et al.*, 2002; García-Albacete *et al.*, 2012). Frossard *et al.* (2002) showed from their fractionation of P and measurement of the amount of isotopically exchangeable-P that composted organic waste contained between 2 – 16% of total-P as rapidly exchangeable inorganic

P. They showed that between 41% and 77% was not exchanged over the three month trial period and possibly bound to calcium as apatites or octocalcites. Other studies have been conducted similar to this to analyse the transformation of the P fractions throughout the composting process (Eneji *et al.*, 2003). In their work they found water soluble (plant available) P to be between 29 – 39% of total P in the first 42 days of composting. The HCl extracted-P (calcium bound) ranged from 18 – 36% of total P. After 63 days of composting this fraction became the more dominant fraction. The NaHCO₃ (plant-available) extracted-P was between 15 – 19%. The NaOH extracted P (aluminium and iron bound inorganic-P) ranged from 9 – 19% of total P.

1.4.10.1 Phosphorus incubation studies

Incubation studies on P release and mineralisation are less abundant than N studies but have seen an increase in the last 10 – 15 years. Gagnon and Simard (1999) investigated nutrient release from twenty three different composted materials ranging from different farm manure composts to mixed food waste and yard waste composts. Composts were applied at 200 mg N kg⁻¹ to an Arago sandy loam for thirteen weeks and incubated in glass jars at 35°C. At the end of the incubation the Mehlich – 3 extracted P results varied from 11% of total P for the mixed industrial composts to 38% for the composted poultry litter. They highlighted that effective composting process, length and management contributed significantly to reducing P immobilisation. They also highlighted how composts with higher humic substances resulted in higher P mineralisation. Gagnon *et al.* (2012) selected seven different composted wastes and

characterised them on the basis of their P fractions. They found that between 73 – 96% of the total P was in the inorganic form in their studies. Each of their selected composts was then incubated with three soils to study the behaviour of the composts when mixed with soil. The compost/soil mixture was extracted at two weeks and sixteen weeks. A sequential extraction was performed on the mixture and the different P fractions were analysed for. All of the composts except for the dairy manure compost reported the same amount of labile P (51 – 58%) and total inorganic P (61 – 98%) in soils. From their study the authors reported an influence of soil type on compost P availability. The alkaline soil showed a higher P availability than the two acidic soils. Leytem *et al.* (2004) conducted a similar study on various organic amendments. They found in their work that composted dairy/beef cattle manure had 30 – 58% Mehlich – 3 P relative to the soil amended with mineral fertiliser. There was also an increased amount of P in equilibrium and soluble P in the soil. Jalali and Ranjbar (2009) conducted an investigation to study various different organic amendments and their rate of decomposition and P release. From their study they highlighted that 84% of P in composted fruit waste was released after 12 weeks of incubation. However they also note that some of this P may not have been mineralised as the extracting reagent was sulphuric acid. Adler and Sikora (2003) examined the effects of composted poultry manure at different maturity stages on the levels of available P in two different soils. This allowed them to study the effects of biological activity on extractable P levels in two soils; clay and a loam. They showed that compost maturity effect was most

pronounced in the initial extraction. Their results also show the loam soils may increase the potential loss of P to ground water when immature compost is applied to soil.

1.4.10.2 Effect of soil type on phosphorus availability

When P is added to soils it reacts with minerals such as Al, Ca and Fe and becomes insoluble. In alkaline (calcerous) soils phosphate is sorbed on calcium (CaCO_3) and in acidic soils P is sorbed on Al and Fe oxides (Thomas and Peaslee, 1973). The maximum amount of P that a soil can adsorb is calculated or determined using the Langmuir adsorption isotherm (Olsen and Watanabe, 1957). Organic amendments have been applied to soils to increase P availability (Iyamuremye *et al.*, 1996; Guppy *et al.*, 2005). Iyamuremye *et al.* (1996) conducted an incubation study of the effects of different organic amendments on P dynamics, exchangeable aluminium and pH when added to soil. They used inorganic amendments such as calcium carbonate as the control. They reported positive effects of the composted manure treatment on the pH, the exchangeable aluminium and P levels within the soil. The compost affected the soil by increasing pH and thus lowering the effect of aluminium to sorb P. Yu *et al.* (2013) added poultry manure compost and organic fertiliser to different soils and observed the effects on soil P. The compost was found to decrease the strength of P adsorption in the soils. The organic fertiliser was not as effective and in some soils served to increase soil P adsorption. Other studies have shown no direct evidence of compost reducing P sorption (Erich *et al.*, 2002). The authors found a link between P sorption and C

desorption. This has also been reported previously but also suggests that fast and slow P retention is not directly linked to organic C but is to pH changes (Beck *et al.*, 1999)

1.4.10.3 Phosphorus pot trial studies and plant uptake

This section will cover both glasshouse and field trials in the literature conducted to evaluate the effects of compost application to soil and the subsequent availability and uptake of P. Cooperband *et al.* (2002) studied available-P from poultry litter compost and its uptake by corn crops. In their study they compared three composts of different ages with a mineral fertiliser and raw poultry manure. After a two year study the authors reported that the 15-month old compost exhibited the highest soil P levels. Both the 1 month and 4-month old composts immobilised P in the first year. This was confirmed by the nutrient uptake in the corn crop. The raw poultry litter showed a 15% uptake of P based on total-P added whereas the 15 month old compost showed 4.5 – 7% uptake. This also indicated that control of soil P was sufficient for growth and that nutrient uptake in excess does not occur in corn crops. Hanč *et al.* (2008) conducted a study to evaluate the availability of P from two composts (green waste compost and poultry/sewage sludge compost) and the P uptake by an oat crop over a three-year period. In their experiment they included a mineral fertiliser and manure as comparison to the composts. The soil P content after the amendment application was lower in both composts when compared to the mineral fertiliser and the manure. The poultry/sewage sludge was found to have the lowest soil P after application and was significantly different from the mineral fertiliser and manure. However when the uptake of nutrients

was studied the poultry/sewage sludge compost had uptake figures higher than the manure and other compost. This would suggest a greater mineralisation of P within the compost. Mkhabela and Warman (2005) studied the release of P from MSW compost and uptake in two crops (potato and sweet corn). They also included a treatment that was a mixture 1:1 of mineral fertiliser and MSW compost. Their results showed that the mineral fertiliser and the mixture produced greater yields from both crops in comparison to the MSW composts. However they also conclude that the MSW increased the pH of the soil and released P similar to the mineral fertiliser. They also state that there was no pH increase from the mineral fertiliser. Erich *et al.* (2002) studied the effects of organic amendments on P chemistry in a potato crop rotation. In their experiment the authors added manure in the first year and compost in the second year to one cropping rotation plot and mineral fertiliser to the other. They found that plant available P and desorbable P was higher in the amended soil than the unamended soil in both years. The water – soluble P was significantly higher in the amended plots over the two years at 8 of the 10 sampling dates. The degree of phosphorus saturation of the soils ranged from 31 – 37%. As mentioned this is considered to be an environmental risk in some countries. This also highlights the trend between P sorption and C release. They noted that the soils released C as P was sorbed suggesting that P displaced organic ligands from the adsorption sites. They also concluded that if the P sorption mechanism was reversible with higher C levels then organic materials may be applied to increase P solubility and hence P availability. Wen *et al.* (1997) examined phosphorus availability and uptake from a different organic amendments including composted manure and composted sewage

sludge. The study was a two year trial in which the amendments were applied to soil at five rates in which lettuce and petunia were planted simultaneously to half plots (half lettuce and half petunia). Snap bean was planted in the lettuce plot after harvest. Only the composted manure exhibited an increasing P uptake with increasing rate. None of the other treatment exhibited this trend. There was a lack of a rate effect in the other harvests conducted in which the crops were harvested at the mature stage of growth. They cite that P tends to be re – translocated from older leaves to younger leaves when P deficient (Ozanne, 1980). This is a consistent trend that has been reported by a number of authors (McCoy *et al.*, 1986; Hinesly *et al.*, 1977). Wen *et al.* (1997) also report the positive trend in extractable soil P from the composted manure application with P uptake indicating that extractable soil P is a good test for available P. Zvomuya *et al.* (2006) conducted a controlled growth experiment on composted and non–composted cattle manures. The amendments were applied to soil (clay loam) and were placed in a growth chamber for 363 days. Canola plants were grown in the compost/soil mixture and the plant yield and P uptake was analysed. In the early stages of growth no significant difference was seen among the treatments. There were ten harvests conducted in the experiment. Up until the sixth harvest they reported no significant difference between the organic and inorganic amendments. In the subsequent harvests after this the inorganic treatment was significantly lower in both cumulative and individual harvest yields. No significant difference was reported between the composted and non – composted manure. The trend was similar for the cumulative uptake of P. Both the composted and non–composted manure exhibited the highest uptake of P. The

P recovery for the composted manure was 24% and 33% for the manure. This is due to the composted manure having a greater load of P added. In a study conducted by Kraus and Warren (2000) they analysed the performance of turkey litter compost amended to a pine bark substrate on *Rudbeckia* and *Cotoneaster* growth. They used two irrigation volumes to study their effects. Osmocote was applied at five different rates as a top dressing to supply N. The control contained a sand substrate amended with dolomite limestone and Micromax (nutrient solution) before being top dressed with osmocote. Their results showed that the turkey litter compost released P in greater amounts than the fertiliser control. The authors also suggest the possible use of compost as a P source to replace conventional fertilisers like dolomitic limestone from the evidence in their results and previous literature. Preusch *et al.* (2002) also studied the effects of composted poultry litter and raw poultry litter on strawberry plants in three different soil types. From their results presented, the P uptake was higher in the compost than the poultry manure in all three soil types. Plant growth was higher in the manure and mineral fertilised plants as was N uptake. The authors highlight the significance that applying compost on an N basis can be potentially harmful to the environment due to the readily and possibly excessively available P.

1.4.11 Overview and objectives

As mentioned in this chapter there are multiple reasons for using compost in the agriculture and horticulture industries. The beneficial uses are well known. Quantifying these beneficial uses is an important aspect of furthering the growth of this industry.

Understanding the behaviour of each type of compost and most beneficial uses is an objective of this research that could not only benefit the users and consumers but also the producers, policy makers and the general public.

The project involved procurement of 25 composts from both national and international sources. A wide variety of feedstock materials and compost types were used in the project. The objectives of the project were to:

- Characterise each of the composts using various physical, chemical, spectral and biological methods.
- Conduct a short duration incubation trial for both N and P in which each of the composts are incubated at equivalent rates to mineral nitrogen and phosphorus to determine short – term available N and P from the various composts.
- Conduct a large scale pot trial using information from the characterisations and incubation trials to determine which materials are best suited to the trial. Two trials are conducted independent of each other assessing plant available N and P over a two year (approximately) period.
- Employ regressive statistical methodology to interpret the multivariate trials.
- Apply literature based models to describe N and P availability.
- Develop new models, where necessary to predict N and P availability

Investigating the nutrient content of each material and its behaviour at different application rates to soil is imperative for agronomic and environmental parameters. The

information and results ascertained from the points mentioned will enable the classification of composts into potential organic fertiliser or soil conditioner, quantify medium-term availability of N and P and more long-term availability through compost nutrient availability prediction models. Integrating the agronomic benefits and environmental risks are essential to aid the growth of this industry. A secondary objective from the research is to aid the development of an industry-led standard for compost quality. Much of the other work involving composts involve the researchers developing their own compost piles and extracting samples at different times to study their effects and characterisations. It must also be noted that the composts used were procured from commercial sources and therefore were composts which have undergone a variety of different processes, for different lengths of time and with many different feedstocks. Therefore identifying correlations and trends within the treatments and compost groups may be more difficult than in much of the preceding literature. This aspect alone makes this a very novel study, which to date has not been replicated in Europe.

1.4.12 References

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Chapter 2

Characterisation of composted wastes from multiple feedstocks: using multivariate data analysis to assess the influence of feedstock on end use of compost

2.1 Introduction

Composting is the biological decomposition and stabilisation of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to plants (Haug, 1993). In many EU countries, such as Austria and Germany, composting has long been used as a waste management procedure to produce a material rich in organic matter and plant nutrients. The Irish market is somewhat less developed but in more recent times has seen a considerable expansion. Investigating composts on the basis of feedstock and establishing the characteristics responsible for influencing nutrient availability will allow composts to be marketed for a specific use while reducing the need for excessive chemical and physical analysis. The Irish legal definition and standard (*I.S. 441:2011*) was published in June 2011 detailing specific criteria for compost quality and standards for compost produced from source segregated, separately collected, biodegradable materials including biodegradable municipal waste. Compost quality has often been defined by maturity and stability. Immature composts which are considered unstable (Oxygen Uptake Rate (O.U.R) – Ireland ≥ 13 , Netherlands ≥ 15 , Belgium ≥ 15 mmol

O₂/KgOS/h) can be potentially damaging to the environment due to the release of heavy metals (Tam and Tiquia, 1994) and restrict plant growth and development (Morel *et al.*, 1985). In this study we aim to evaluate a large number of composts using parameters that pertain to compost quality and its potential end use. The aims of this research were to assess the characteristics of various composted wastes, identify the feedstock characteristic differences with an aim to potentially predict the ideal use of the compost, such as a soil conditioner or organic fertiliser. Multivariate data analysis was applied to the results to establish relationships among the composts and to potentially classify the composts.

2.2 Materials and methods

The characterisation of the composts was divided into three categories. The first section included the physico-chemical characterisations conducted. The second section included biological characterisations conducted and the third section consisted of all chemical characterisations.

2.2.1 Composted wastes procured for research

Twenty five composts from Ireland and a number of EU member states were obtained from commercial composting facilities and were considered market ready (Table 2.1). The composts were grouped in terms of feedstock into five categories; anaerobic digested compost (ADC), biowaste (BW), composted manure waste (MW), green waste (GW) and industrial organic waste (IOW). Further details of the composts used

and their feedstock materials, country of origin, composting process and process length are presented in Table 2.1.

Table 2.1 Composted wastes included in study, detailing their origin, feedstock component, country of origin, composting process and length

Code	Feedstock materials	Country	Composting process	Length (Weeks)
BW 1	Fish/shell fish & tree bark	Ire	IV + SP	52
BW 2	Biowaste & yard waste	Aus	IV + W	40
BW 3	Biowaste	Ger	EAS	7
BW 4	Seafood & BW	Ire	IEW	20
BW 5	Food Waste	Ire	ASP	8 & 2 maturing
BW 6	Food Waste	Ire	ASP	6
BW 7	Catering Waste	Ire	IAT	14
BW 8	Biowaste & Greenwaste	Bel	W	16
BW 9	Greenwaste & Dairy Sludge	Ire	W	14
BW 10	Greenwaste & Brewery Waste	Ire	W	14
BW 11	Sludge Compost	Ire	ISP	3 & 1 maturing
BW 12	Brown Bin Compost	Ire	ISP	3 & 1 maturing
BW 13	Seafood & biowaste mulch	Ire	W	8
MW 1	Horse Manure	Ire	W	8
MW 2	Chicken Manure & Seaweed	Ire	PCI	25
MW 3	Pullet Manure	Ire	PCI	18
MW 4	Chicken Manure (sweepings, feathers)	Ire	PCI	21
MW 5	Manure Compost (mix)	Bel	Tunnel	2
GW 1	Greenwaste	Ire	W	13
GW 2	Greenwaste	Ger	W	6
GW 3	Greewaste	Ire	Windrow	14
IOW 1	Industrial Org. Waste	Ire	IVS	2
IOW 2	Industrial Org. Waste	Ire	IVS	6
ADC 1	Composted AD	Ire	AD	6 & 2 maturing
ADC 2	Anaerobic Digest	Ire	AD	2 maturing

IV – in-vessel; SP – static pile; EAS – enclosed aerated system; IEW – indoor enclosed windrow; ASP – aerated static pile; IAT – in vessel aerated tunnel; ISP – indoor static pile; PCI – pile composted indoors; IVS – in-vessel static; AD – anaerobically digested; W - Windrow

2.2.2 Characterisation of composts

2.2.2.1 Physico - chemical analyses

Compost samples were analysed for pH and electrical conductivity (EC) (Eutech PC 700) as described by EN 13037: 1999. Dry matter content (Mettler oven) of the samples was conducted as described by EN 13040, 1999. Following this the organic matter content was determined by loss – on – ignition at 550°C (Carbolite furnace) for 8 hours (EN 13039, 1999).

2.2.2.2 Biological analysis

Oxygen uptake rate (OUR) was conducted on the samples using the WTW Oxitop^{OC} 110 controller as described by CEN method prEN 16087-1. Two grams of O.M. of each compost sample was mixed with 180 ml of distilled water, 10 ml of a nutrient solution, 10 ml of pH buffer and 2.5 ml of a nitrification inhibitor (allylthiourea) in 1L Duran bottles. Each sample was performed in triplicate. The bottles were placed on an orbital shaking incubator (IKA KS 400i control) at $30 \pm 3^\circ\text{C}$ for four hours. This was to allow the temperature and pH to adjust within the samples. After four hours the pH was measured (Eutech PC 700) to ensure it was between 6.5 and 7.5. Soda lime pellets, were placed in the headspace of the controller and the controller was attached to the bottle. These were used to remove carbon dioxide (CO_2) by absorption, instigating a pressure change within the vessel. The pressure change is then recorded by the pressure sensing data recording heads.

2.2.2.3 Chemical analyses

Determination of humic substances was conducted by using a sodium hydroxide:tetrasodium pyrophosphate (NaOH:Na₄P₂O₇) extractant. The method was adapted from two existing methods for soil humic substances measurements (Gerzabek M.H. *et al.*, 1993; Rump, 1999) hence a detailed description of the method is given here. A 0.5g compost sample was weighed out and extracted for 5 hours in 50 mL of a 1:1 mixture of 0.5M NaOH: 0.5M Na₄P₂O₇.

Once the extraction was completed the extract was taken and centrifuged for 15 minutes at 4000 rpm. The supernatant was decanted and the solid was extracted a second time in the same manner. The exact same process was conducted for the second extract. At the end of the second extract the sample was discarded. The decanted supernatant (initial extract) was analysed for humic substances via UV spectrophotometry (Jenway 6305 spectrophotometer) at 472nm and 664nm. An aliquot 20ml of the initial extract was reserved. The pH was adjusted to 1 using concentrated hydrochloric acid (HCl). The sample stood overnight to allow precipitation of the humic acid, leaving fulvic acid within the liquid fraction. The solution was centrifuged for 10 minutes at 4000 rpm. The liquid fraction containing fulvic acid was then decanted off and dilute HCl was added as a washing step. The solution was further centrifuged for 10 minutes at 4000 rpm. The HCl was decanted off and the remaining humic acid was dried overnight at 50°C. Once dried the solidified humic acid was dissolved in the NaOH: Na₄P₂O₇ and made up to 50mL. The absorbance of the solution was measured at 472nm and 664nm.

Total Kjeldahl nitrogen (TKN) was analysed for using the Kjeldahl digestion method (EN 13654-1, 2001). After HNO₃/HClO₄ digestion, total P (conducted by Teagasc, Johnstown Castle, Ire) was analysed (EN 13650:2001) by measurement by ICP–AES as were the heavy metals (Cr, Cu, Ni, Cd, Hg, Pb, conducted by NRM, UK). Total K (conducted by Bord na Mona, Newbridge, Ire), CaCl₂ DTPA (conducted by NRM, UK) extractable nutrients (including all N (NO₃⁻ N & NH₄⁻N), P and K) were determined in accordance with the standard CEN method (EN 13651:2001). Calcium (Ca) and sulphur (S) (conducted by Penn State University, US) were extracted with Mehlich-3 and determined using ICP (Faithfull, 2002). For each compost treatment Olsens extractable P and Mehlich–3 P (conducted by Penn State University, US) were conducted by the standard procedure described by Olsen *et al.* (1954) and Mehlich (1984) and were analysed via UV spectrophotometer using the complex colourimetric method (Murphy and Riley, 1962). Cation Exchange Capacity (CEC, conducted by Penn State University, US) was determined by summation of the cations using Mehlich 3 extract. The high levels of Ca indicate probable soluble Ca; therefore the CEC's were calculated using maximum exchangeable of 15 mEq 100 g⁻¹. Both lignin and NDF (conducted by University of Southern California, US) were determined by the method previously described by Van Soest *et al.* (1991).

2.2.3 Statistical analysis

The statistical analysis was conducted using SAS version 9.3. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) was conducted on the composts. All characterisation results were inputted into SAS to produce dendrograms

in which composts that were similar were linked within the dendrograms. The lower the Euclidian distance in the dendrogram the more closely related the composts were. The same was done for compost on the basis of their N release characteristics (total and DTPA N, C/N ratio, lignin content and NDF) and their P release characteristics (total P, Olsens and Mehlich P, DTPA P and humic substances). PCA was conducted by inputting all the characteristics to which had the most influence on the groupings for the composts by feedstock.

2.3 Results

2.3.1 Physico-chemical analyses

The physico-chemical results (pH, EC, moisture content and organic matter), the biological results (O.U.R.) and the physico-chemical results pertaining to the organic macromolecules humic substances (HS), humic acid (HA), lignin and cellulose are outlined in Table 2.2. The pH of the composts in this study ranged from 5.30 – 8.28. There is no specific guideline for compost electrical conductivity (EC) for field application but when used as a growing medium a composted waste must be below the CEN specification for EC of 0.8 mS cm^{-1} . The range for the EC was $0.83 - 9.60 \text{ mS cm}^{-1}$. The moisture content (M.C.) and organic matter (O.M.) content was determined together. The range for M.C. was 12– 69%. The results from this study display a wide variance of O.M. figures ranging from 27.6% (GW 2) to 82.8% (MW 4). It is important to note that under the NSAI guidelines composts in Ireland must have a minimum organic matter content of 20% of dry weight.

Table 2.2 Physico–chemical and biological characteristics of compost wastes

		pH	EC mS cm ⁻¹	MC %	OM %	OUR mmol O ₂ /kgOS/h	HS g kg ⁻¹	HA g kg ⁻¹	Lignin %	NDF - Reflux
BW <i>n</i> = 13	Mean	6.9	3.8	45.6	56.1	6.1	194.0	118.0	44.8	61.1
	Range	8.1	8.6	68.2	88.0	23.9	363.6	252.4	64.5	73.9
		5.4	0.2	15.0	28.9	2.6	83.7	21.5	27.9	41.3
MW <i>n</i> = 5	Mean	6.4	6.2	45.6	76.7	31.3	90.5	66.4	17.8	41.9
	Range	8.3	9.6	69.6	82.9	55.7	163.3	139.2	31.2	58.9
		5.3	2.5	21.2	64.6	6.3	55.3	8.2	12.3	34.7
GW <i>n</i> = 3	Mean	7.0	3.2	44.2	50.1	7.0	229.6	145.7	61.7	69.6
	Range	7.7	4.6	68.9	74.6	9.5	326.0	146.3	74.4	73.6
		6.3	1.8	12.9	27.6	4.8	178.2	144.9	53.0	66.7
IOW <i>n</i> = 2	Mean	6.0	5.3	45.2	81.0	5.9	87.7	41.7	38.3	63.5
	Range	6.1	7.5	45.9	81.5	6.0	117.1	48.1	38.8	66.1
		5.9	3.2	44.5	80.4	5.8	58.3	35.3	37.7	60.9
ADC <i>n</i> = 2	Mean	6.6	8.0	44.8	42.3	5.7	216.9	196.5	51.6	60.6
	Range	6.7	8.4	51.0	53.6	6.3	250.2	246.1	51.9	64.8
		6.4	7.5	38.5	31.0	5.0	183.6	147.0	51.2	56.3

Individual compost data available in Appendix A 1.

2.3.2 Biological characterisation

The stability measurement using the oxygen uptake rate (O.U.R.) ranged from 2.6 – 55.7 mmol O₂/kgOS/h. The NSAI standard sets 13 mmol O₂/kgOS/h as the upper limit for a composted waste to be considered microbiologically stable. Five of the composts (mostly manure based feedstock) were above this limit.

2.3.3 Quantification of Humic Substances, lignin and neutral detergent fibre

Quantification of humic substances was conducted, as was the determination of the percentage content of lignin and neutral detergent fibre (NDF). Within this study HS

content ranged from 55 – 363 g kg⁻¹. The manure waste composts (90.5 g kg⁻¹) were generally lower in humic content than the green wastes (229.6 g kg⁻¹) and the biowaste (194 g kg⁻¹) composts. The lignin content ranged from 12.3 – 74.4%. The manure feedstock composts were the lowest in lignin content (14.4%) with the green waste composts the highest (61.7%). NDF percentage content also followed a similar trend with the manure waste composts generally below 45% and the other composts above 55%.

2.3.4 Macro nutrient analyses, CaCl₂ DTPA extractible nutrients and extractible phosphorus

The analyses for the macronutrients N, P, K and C are presented in Table 2.3. The range for total nitrogen was 7 – 49 g kg⁻¹. This figure does not give an indication of available N as much (>90%) of the N in stable composts is an organic form. A similar range was observed for the total P content with 0.4 – 28 g kg⁻¹ observed. As with the N results this does not give a clear indication of available P. The range for the total K being 3.20 – 35.70 g kg⁻¹ with the MW composts being the highest.

Table 2.3 Macro nutrient analysis results of the composted wastes

Code		Carbon g kg⁻¹	C:N Ratio	Total N g kg⁻¹	Total P g kg⁻¹	Total K g kg⁻¹
BW <i>n = 13</i>	AVG	311.4	13.1	21.5	7.9	8.3
	Range	489.0	19.3	37.3	28.0	13.0
		160.4	8.5	13.4	2.4	3.2
MW <i>n = 5</i>	AVG	426.1	11.6	30.4	14.3	31.4
	Range	460.3	15.0	44.1	19.8	35.7
		358.8	10.0	10.3	6.3	27.1
GW <i>n = 3</i>	AVG	278.1	14.9	20.9	2.8	8.3
	Range	414.2	21.9	34.5	4.3	16.1
		153.5	10.1	8.2	0.5	4.1
IOW <i>n = 2</i>	AVG	449.9	13.7	16.3	8.6	5.2
	Range	453.0	13.8	18.2	9.2	5.2
		446.7	13.7	14.4	8.0	5.2
ADC <i>n = 2</i>	AVG	235.1	8.6	27.4	4.2	8.5
	Range	298.0	8.6	34.6	5.5	9.5
		172.1	8.5	20.2	2.9	7.5

Note: Total carbon was calculated out as a coefficient of organic matter and not directly measured
Individual figure are located in Appendix A.1

Results for CaCl₂ DTPA extractions presented in Table 2.4 were conducted to give an indication of the immediately available nutrients. CaCl₂ DTPA results are more applicable to the availability of N rather than P. Nitrogen containing compounds are water soluble and are therefore more readily extractable. Phosphorus containing compounds are not 100% soluble and require a stronger extractant to give a figure for plant available P. Generally Olsen's, Morgan's or Mehlich - 3 extractable P is used as a predictor of plant available P. Olsen's is used for neutral to alkaline pH's, Morgan's for slightly acidic pH's and Mehlich - 3 on high CEC acidic soils. Olsen's is best suited

to compost as composts are expected to have a relatively neutral to alkaline pH. The results for $\text{NO}_3^- - \text{N}$ and $\text{NH}_4^+ - \text{N}$ show that N can take many forms across many different composts although it is generally stated that only a very small fraction of N is considered plant available.

Table 2.4. CaCl_2 DTPA extractable nutrients and plant available P

Code		DTPA Extractable nutrients mg L^{-1}					mg L^{-1}	
		$\text{NH}_4 - \text{N}$	$\text{NO}_3 - \text{N}$	N	P	K	Mehlich 3 P	Olsen's P
BW <i>n</i> = 13	Mean	19	321	340	40	1404	1109	483
	Range	167 0	588 66	755 66	313 2	2856 312	1647 550	903 268
MW <i>n</i> = 5	Mean	2418	74	2492	103	7378	4672	2458
	Range	4681 2	300 10	4691 302	230 18	10850 5740	6206 1781	3885 746
GW <i>n</i> = 3	Mean	3	107	110	35	1290	773	398
	Range	6 1	237 3	237 9	88 7	2634 544	950 519	539 265
IOW <i>n</i> = 2	Mean	38	555	593	48	988	2026	491
	Range	55 20	601 509	621 564	53 42	1074 901	2349 1703	503 479
ADC <i>n</i> = 2	Mean	51	204	255	9	1154	1024	453
	Range	99 2	338 70	340 169	9 9	1264 1044	1374 674	602 304

Individual figure are located in Appendix A.1

2.3.5 Heavy metal analysis

The results for heavy metal analysis are presented in Table 2.5. Upper limits for the maximum permissible levels for seven heavy metals have been detailed. These are as

follows: Cadmium (Cd) 1.3 mg kg⁻¹ dry weight (all figures are expressed on these bases), chromium (Cr) 92, copper (Cu) 149, mercury (Hg) 0.4, nickel (Ni) 56, lead (Pb) 149 and zinc (Zn) 397. Both Cu and Zn were the two most abundant metals recovered in the composts, both of which are agronomically important elements. A number of the biowaste compost group samples were above the threshold limits for Cu and Zn. In particular BW 13 which reported over 12,000 mg kg⁻¹ Cu. A possible source of the Cu in the aquatic/marine ecosystem is anti-fouling paint which is applied to the hull of boats.

All of the manure waste composts were also above the limit for Zn. BW 5 was the only compost above the limit for lead (Pb).

Table 2.5 Heavy metal content of composted wastes included in study

		All heavy metals in mg kg ⁻¹ dm						
		Cd	Cr	Cu	Hg	Ni	Pb	Zn
BW n = 13	Mean	0.7	18.6	1010.0	0.2	15.2	63.1	268.4
	Range	1.3	42.8	12020.0	0.4	30.3	160.0	558.0
		0.3	1.6	15.9	0.1	1.7	2.9	75.2
MW n = 5	Mean	0.4	5.1	90.5	<0.05	6.1	4.8	452.2
	Range	0.6	8.8	123.0	<0.05	7.3	12.1	566.0
		0.3	2.3	70.1	<0.05	4.6	1.4	186.0
GW n = 3	Mean	0.7	10.0	44.8	0.1	11.9	30.0	162.5
	Range	1.0	11.7	55.8	0.1	15.1	32.5	180.0
		0.5	8.2	33.7	0.1	8.6	27.5	145.0
IOW n = 2	Mean	0.5	17.1	451.5	0.3	11.0	70.5	282.0
	Range	0.5	21.1	687.0	0.4	11.2	101.0	305.0
		0.5	13.0	216.0	0.3	10.7	40.0	259.0
ADC n = 2	Mean	0.4	22.3	72.5	0.1	13.0	22.4	155.5
	Range	0.4	28.6	76.8	0.1	15.6	23.5	176.0
		0.4	16.0	68.1	0.1	10.3	21.3	135.0

Individual figure are located in Appendix A.1

2.3.6 Extractable calcium, sulphur and cation exchange capacity

Extractable sulphur indicated (Table 2.6) the highest levels were found in the MW composts with two of the BW composts reporting high figures (BW 4 >3000 and BW 7 >5000 mg L⁻¹). The lowest levels were found in the GW composts (GW3 <65 mg L⁻¹) and some of the other composts with a GW component (BW 9 & 10 <85 mg L⁻¹ and MW1 <205 mg L⁻¹).

For the extractable calcium (Ca) the highest levels were found in biowastes with a seafood component (BW1 >31,000 mg L⁻¹, BW 6 >14,500 mg L⁻¹ and BW 13 >11,000 mg L⁻¹). Also GW 1 presented a high figure for Ca which was above 10,000 mg L⁻¹. The lowest levels of Ca were found in some of the MW composts (MW 4 <3,000 mg L⁻¹).

The highest cation exchange capacities (CEC) were seen in the MW composts with both MW 2 (92.9) and MW5 (91.8) reporting figures above 90 meq 100 g⁻¹. BW 1 (44.5) and 2 (42.2) and GW 1 (49.9) showed slightly more elevated CEC's over some of the other compost within their respective groups. The lowest CEC's were seen in BW 11 (24.2), 12 (24.4) and 13 (28.4) and GW 2 (25.8).

Table 2.6. Extractable calcium, sulphur and cation exchange capacity (CEC)

Code		Calcium mg L⁻¹	Sulphur mg L⁻¹	C.E.C. meq 100g⁻¹
BW <i>n = 13</i>	Mean	10575.6	1088.8	35.1
	Range	4019.0 31284.0	75.6 5290.1	24.2 44.5
MW <i>n = 5</i>	Mean	5287	2645.6	78.2
	Range	2997.0 10434.0	203.6 5968.5	57.4 92.9
GW <i>n = 3</i>	Mean	7900	161.9	35.9
	Range	6575.0 10484.0	63.7 285.9	25.8 49.9
IOW <i>n = 2</i>	Mean	5157	1164.5	34.2
	Range	4924.0 5390.0	1164.5 1164.5	31.9 36.4
ADC <i>n = 2</i>	Mean	9386	37.4	37.4
	Range	8937.0 9834.0	36.5 38.2	36.5 38.2

Individual figure are located in Appendix A.1

2.3.7 Hierarchical cluster analysis and principal component analysis

Hierarchical cluster analysis (HCA) was applied to the data to investigate if the feedstock material or its classification group was critical. The dendrogram displayed in Fig. 2.1 shows the composts which are comparable (similar) and non-comparable (non-similar) based on the full analysis of the 27 established characteristics of the materials. Samples that are related or similar are contained within clusters. The lower the Euclidian distances between the samples the more similar the samples are (Zbytniewski and Buszewski, 2005; Bustamante *et al.*, 2010). From the dendrogram in Fig. 2.1 three main clusters were identified: A, B and C. Not included in these three clusters were

BW1 and BW 13. Both of these composts were seafood waste composts and this most probably accounted for them being unclustered. Possibly the ratio and differing types of seafood waste accounted for them not clustering together. As can be identified in Fig 2.1 – Cluster A encompasses all MW 2 – MW 5. Cluster B encompasses all composts from BW 6 to BW 8. Cluster C includes all composts from BW 7 to BW 2. MW 5 was included although it has a slightly larger Euclidian distance from the main cluster Euclidian distances.

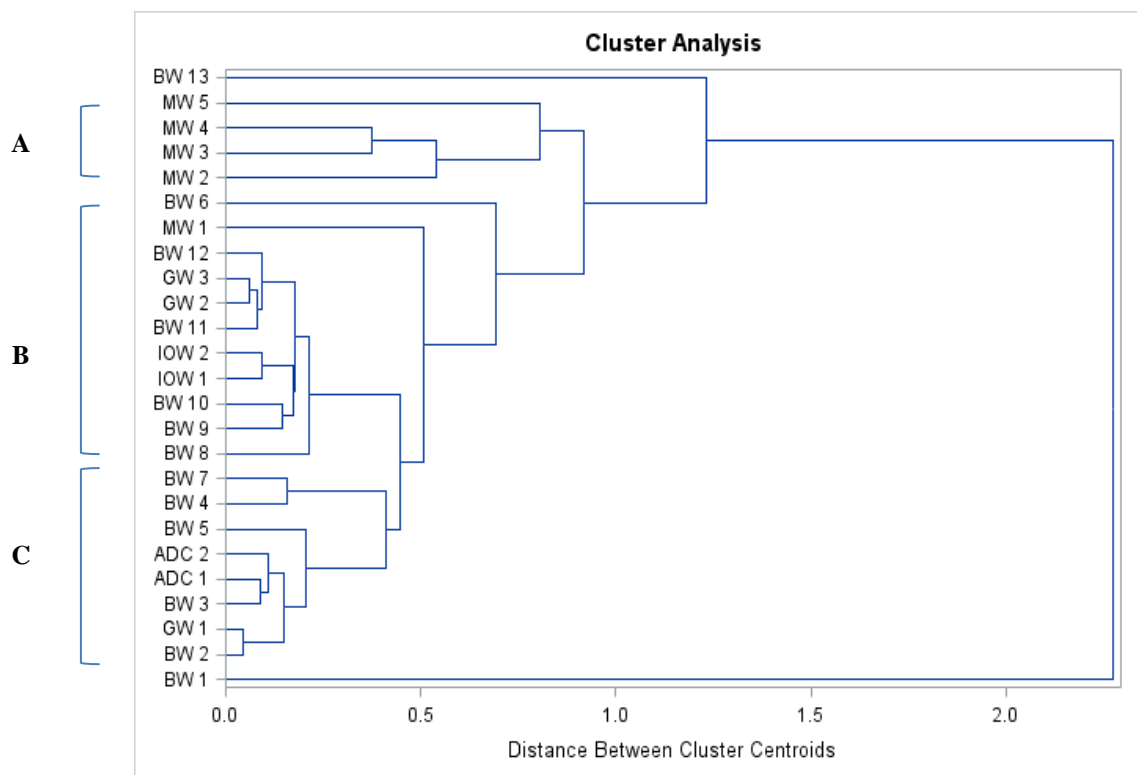


Figure. 2.1 Dendrogram of the HCA conducted on the total characterisations comprising the physico – chemical, biological and spectral characterisations

The composts were then analysed by a set of characteristics pertaining to nitrogen and phosphorus availability (Fig. 2.2 and 2.3). This resulted in a closer clustering, with

smaller Euclidian distances. The characteristics that affect nitrogen (N) release are displayed in Fig. 2.2 For this the characteristics used included total N, C/N ratio, lignin, NDF reflux, CaCl₂ DTPA extractable N and organic matter. From the dendrogram in Fig. 2.2 there is one main cluster (B) which extends from ADC 2 to BW 1. The second cluster (A) is small and only contains MW 2, MW 3 and 5. Although MW 4 is clustered to cluster B it has a large Euclidian distance from that cluster and so therefore is considered to be too dissimilar.

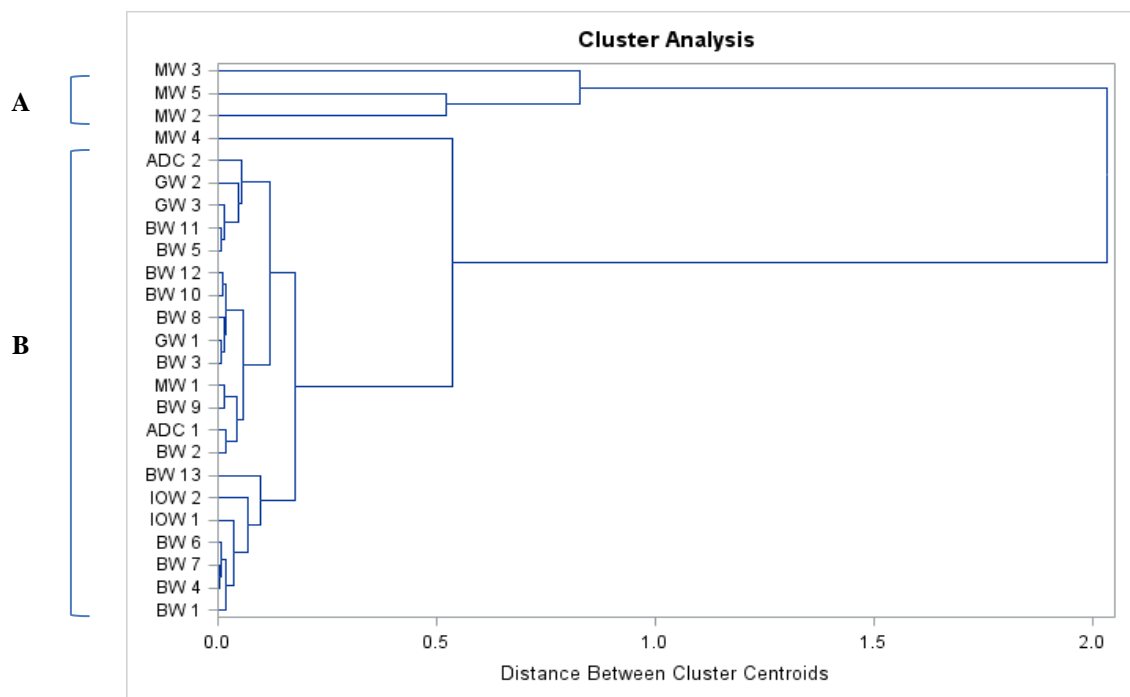


Figure. 2.2 Dendrogram of the HCA conducted on the characterisations potentially related to nitrogen availability from composts

The characteristics that impact on phosphorus (P) release are displayed in Fig. 2.3 The characteristics used to cluster the composts were; total P, Olsen’s P, Mehlich–3 P, CaCl₂ DTPA extractable P, humic substances and organic matter. Two main clusters came from the composts (A and B). The main cluster (B) contains everything from IOW

1 to BW 1 could be subclustered into two smaller clusters but the Euclidian distances are so small between the subclusters that there is no need for this. Cluster A contains the composts MW 2 - MW 5. Both MW 3 and MW 4 are slightly separated from the other two composts due to the higher Euclidian distances. Both of these graphs highlight the manure waste composts standing out from all other feedstocks.

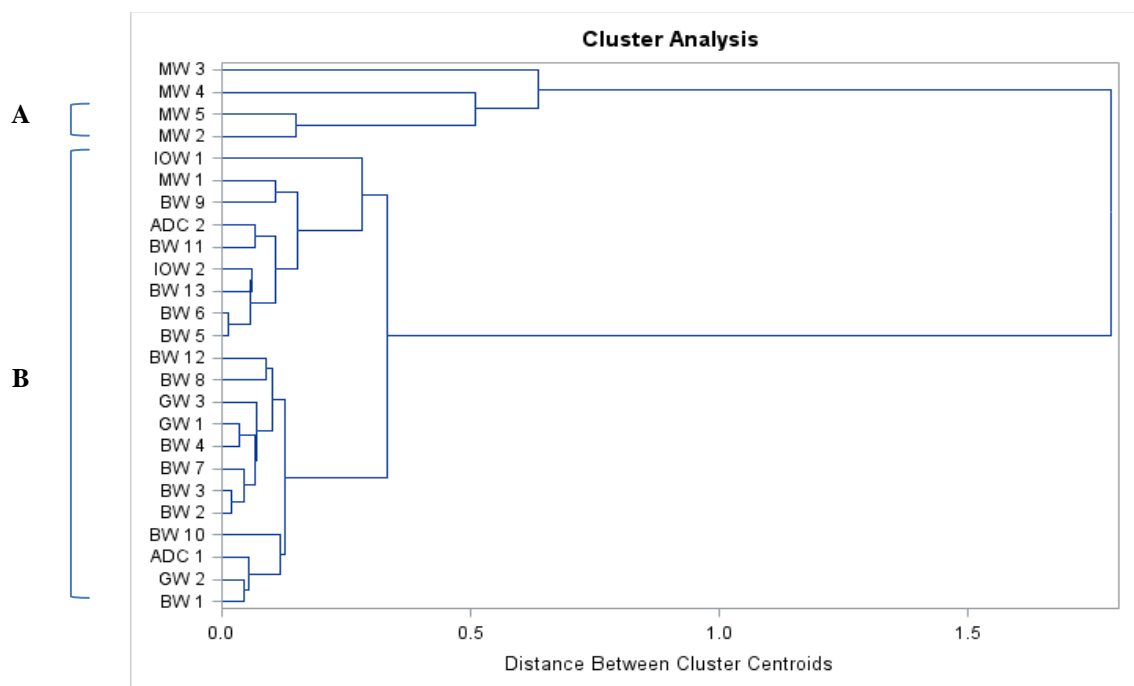


Figure. 2.3 Dendrogram of the HCA conducted on the phosphorus releasing characterisations of the composts

Principal component analyses conducted to evaluate the loadings of the characterisations that lead to the clusters are presented in Fig 2.4 (a and b) and 2.5. The loadings are plotted to give an indication of the characteristics most influential on the compost groups emerging. The components closer to 1.0 are the more influential loadings. The loadings in component 1 show that CEC, Olsen’s and Mehlich P and

lignin (negatively) are the most influential characterisations. In component 2 the heavy metals, CaCl₂ DTPA P and total carbon appear to have the most influence. Finally in component 3 total HS, total HA and the heavy metals are the most influential loadings.

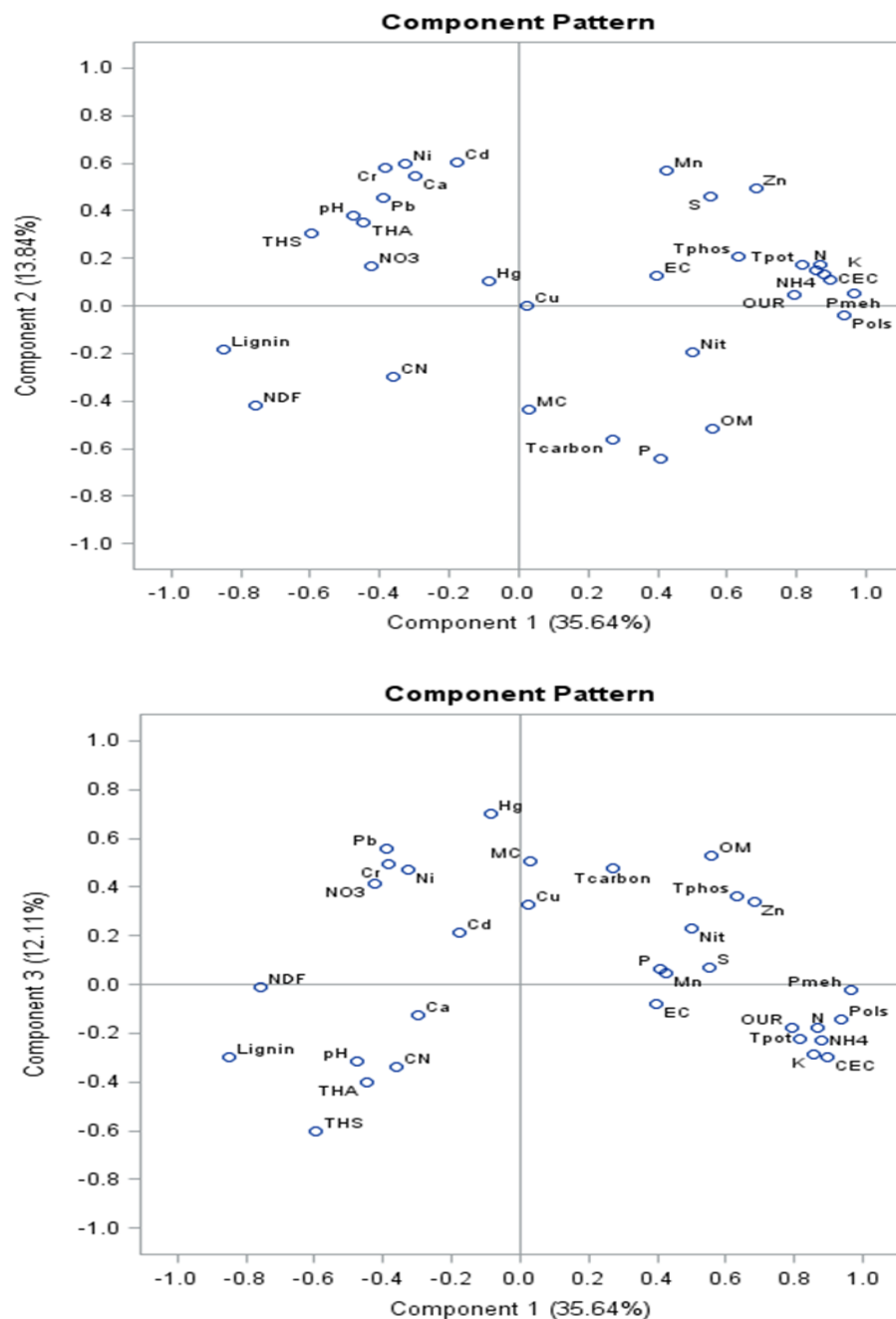


Figure. 2.4a and b. PCA loadings plot highlighting the components affecting the outcome of the compost clusters

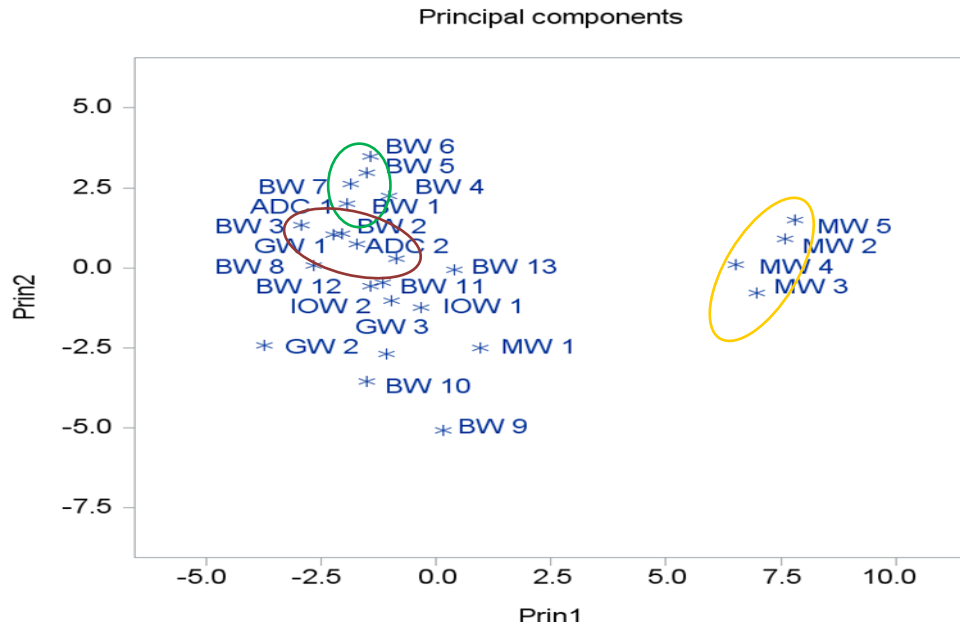


Figure. 2.5 PCA score plot highlighting the grouping of composts based on the Prin 1 and 2

The PCA score plot when studied in conjunction with the loadings allows you to identify between variables and samples and the relationships that exist. The scree plot in Fig. 2.5 highlights the differences between the MW compost and the rest of the other groups. The three main groups are highlighted in coloured ovals. This further shows the importance of feedstock and among the BW and GW composts that the largest feedstock component is paramount to determining the compost and its characteristics.

2.4 Discussion

2.4.1 Physico – chemical analyses.

Physical characterisations are important parameters to be measured when assessing compost quality. This information can give an early indication as to the degree of composting which the material has been subjected to and the possible availability of nutrients.

The pH of the composts in this study ranged from 5.30 – 8.28. These figures are in line with the optimum pH levels for composts which may range from 4.4 – 9.4 (Tang *et al.*, 2003). Soils of low pH may require a compost that will act as a liming agent (Eghball, 1999) or to offset the acidification of soils after fertiliser application (Stamatiadis *et al.*, 1999).

There is no specific guideline for compost electrical conductivity (EC) for field application but when used as a growing medium a composted waste must be below the CEN specification for EC of 0.8 mS cm^{-1} . Many of these materials have an EC value that are above 0.8 mS cm^{-1} (growth test for soil improvers: CEN BS EN 16086-1) and cannot be directly utilised as a growing media. The EC of compost is an important characteristic as EC levels dictate the appropriate use of the compost, specifically being used as a growing medium. The range for the EC was $0.83 - 9.60 \text{ mS cm}^{-1}$. When compost is applied as a soil conditioner or growing media it may be significantly diluted with soil or peat, more so in the case of field application. In situations like this the EC

becomes less important. In a high salinity medium plants are found to have a lower osmotic potential (Leone *et al.*, 2000) which can affect crop growth detrimentally (Brady and Weil, 1996), as can often be seen when unsuitable composts are used as peat dilutants in growth media. The EC range for the composts studied is large (0.83 – 9.60 mS cm⁻¹) mainly due to the array of different feedstocks, with MW composts having the highest and the BW and GW composts the lowest.

The moisture content (M.C.) and organic matter (O.M.) content was determined together. The range for M.C. was 12 – 69%. The NSAI guideline is that compost can have a minimum O.M. of 20% (NSAI, 2011) on a dry weight basis (Saveyn and Eder, 2014) with a EU minimum of 15% of dry weight (Saveyn and Eder, 2014). All of the composts presented OM content above the lower limit. These figures compare with a range of 21 – 61% for GW compost (n = 37) and 27 – 75% for BW (n = 114) in an earlier study in Ireland (Prasad and Foster, 2009). The organic matter (O.M.) fraction of composted organic waste positively affects crop agronomy and improves soil fertility as an amendment (Sequi, 1996). Some of the other compost samples with similar feedstocks had higher O.M. values. However both GW 2 and BW 2 had high levels of H.S. This suggest they may have undergone a longer curing phase during which humification takes place (Chen and Inbar, 1993; Castaldi *et al.*, 2005). The GW composts displayed a wide variety of O.M. values due to the percentage of green waste feedstock in the compost.

Previous studies have been conducted to investigate the potential of the O.M. in compost to increase the P availability in soils (Hue, 1990). The theory proposed suggests that organic amendments react with P binding metals such as iron and aluminium and release P from these sites (Hoyt and Turner, 1975; Singh and Jones, 1976) and demonstrated in a more recent paper by Iyamuremye et al. (1996), which demonstrated the positive effect of addition of organic amendments on increasing P availability from four different soils. These studies suggest it is desirable for a compost to have a large percentage of O.M. when being applied to soil. The results from this study display a wide variance of O.M. figures ranging from 27.6% (GW 2) to 82.8% (MW 4). It is important to note that under the NSAI guidelines, composts in Ireland must have a minimum organic matter content of 20% of dry weight.

2.4.2 Biological characterisation

For a compost to be considered stable it must have an Oxygen Uptake Rate (O.U.R) of less than 13 mmol O₂/kg organic solids/h. The current EU document (EN 26425) on compost quality states 15 mmol O₂/kg organic solids/h as the EU standard for stability (Saveyn and Eder, 2014). From the results presented in Table 2.1 it shows that five of the composts are considered unstable under national guidelines (NSAI, 2011). Four of these composts contain a high proportion of animal manure in their feedstock. This compares to a range of 8.8 – 15.5 mmol O₂/kg organic solids/h in a previous study in Ireland (Prasad and Foster, 2009). The other compost is a BW composed purely of brown bin waste (BW 12). The composts MW 3 and MW 4 were both chicken manure and were composted for 18 and 21 weeks respectively. Reaching the figure of 13 mmol

O₂/KgOS/h units for an OUR test may require the MW compost to be composted for a longer period and in a more active fashion than might be more routinely used for a biowaste or green waste compost given that some of the MW composts were composted for up to six months. Composting for this length of time will drastically reduce any available nutrients as they become bound in the organic pools of N and P (Amlinger *et al.*, 2003), which may be preferable for field application when the compost is being utilised as a soil conditioner and a longer term source of nutrients. It is also suggested that unstable composts (or less mature) will potentially immobilise nutrients (Amlinger *et al.*, 2003). However in the case of the MW composts this was not an issue in a subsequent pot trial, indicating that OUR figures of higher than 30 would be needed to see such an effect.

2.4.3 Quantification of Humic Substances, lignin and neutral detergent fibre

Humic substances were quantified, as was the determination of the percentage content of lignin and neutral detergent fibre (NDF). Both lignin and cellulose are seen as important contributing factors to the formation of humic substances in compost. The formation of humic substances and their agronomic benefits is an area of research that has been studied extensively over the last 25 years (Chen and Aviad, 1990; MacCarthy, 2001; Nardi *et al.*, 2002). More recently the importance of humified organic matter has been discussed with respect to the potential for humic substances to sequester carbon in soils and thus reduce CO₂ emissions (Spaccini *et al.*, 2002). The level of HA in the composts is also an important parameter to consider due to the potential for HA's to bind metals in solution (Chang Chien *et al.*, 2006; Vinkler *et al.*, 1976; Piccolo and

Stevenson, 1982). Within this study, humic substances content ranged from 55 – 363 g kg⁻¹. The manure waste composts (90.5 g kg⁻¹) were generally lower in humic content than the green wastes (229.6 g kg⁻¹) and the biowaste (194 g kg⁻¹) composts. This compares to a range of 377 – 710 g kg⁻¹ from a previous study on composted cattle manure (Inbar *et al.*, 1990) and HA levels in composted pig manure of 205 – 379 g kg⁻¹ (Huang *et al.*, 2006). Four of the compost samples with the highest HS (BW 2 and BW 3, GW 2 and ADC 1) all contained a green or yard waste component. These data suggest that a well-balanced input of mixtures of different biowaste and green waste is important to maximise humic substance content. Aerobic conditions favour humification but an over – aeration can lead to mineralisation of organic matter (Smidt *et al.*, 2008b). The results presented by Meissl *et al.* (2007) describing 33 Austrian compost samples showed that the humic acid content ranged from approx. 7 to 45% and it also showed clearly that the sewage sludge compost had much lower values from approx. 7 – 25% while biowaste compost ranged from approx. 22 – 45%. The input material (Feedstock) is therefore an important factor in the humic acid content. Our results are in agreement with their findings. Smidt *et al.* (2008b) discuss extensively the importance of the type of input material and the composting process, on HA formation, while also indicating a correlation between yard waste as a component of the overall feed stock and elevated HA formation. They also concluded that adequate aeration at the beginning of the composting process and a moderate aeration after that produced the highest levels of humification. Therefore HA formation seems to be heavily related to feedstock and composting process.

The benefits of HS and HA to plant development are well documented (Vaughan, 1985; Ayuso *et al.*, 1996; Eyheraguibel *et al.*, 2008). More recent studies have shown that fulvic acids have the potential to increase phosphate solubility and availability (Gu *et al.*, 2011). Knowing quantitatively the levels of humic and fulvic acids and the benefits of both could help influence the potential use for the composts. The ratio between HA and FA has been proposed to be a good indicator of stability (Zaccheo *et al.*, 2002). However when data from this study were used to determine the ratio between HA and FA, no relationship with stability was identified ($R^2 = 0.029$, $P > 0.05$). The O.M. content of compost (Table 2.2) for this study has correlated well with HS levels (Table 2.3) ($R^2 = -0.6697$, $P > 0.01$). This is an inverse correlation which indicates that as HS levels increase O.M. levels decrease. This indicates that organic matter is directly linked to humic substance formation. The nitrogen (N) content of the feedstock materials plays an important role in humic substances formation (Burdon, 2001). The samples which contain the highest HA content generally had a mixture of feedstock materials that were balanced sources of C and N. From the results there is evidence to support the fact that humification can take place quite readily but requires a number of parameters to be met; namely aeration and suitable feedstock (Smidt *et al.*, 2008a).

The lignin content ranged from 12.3 – 74.4% across all feedstocks. The manure feedstock composts were the lowest in lignin content (14.4%) with the green waste composts the highest (61.7%). UK data based mostly on municipal waste composts reported a range of 11 – 31% (Dimambro *et al.*, 2007). NDF content also followed a

similar trend with the manure waste composts generally below 45% and the other composts above 55%. Lignin is an important contributor to the formation of humic substances in compost (Smidt *et al.*, 2008a). A significant correlation ($R^2 = 0.71$; $P < 0.01$) was observed between lignin content and humic substances. This correlation may indicate that lignin plays a role in humic substance production during composting. NDF gives an indication of the fibrous composition of compost mainly cellulose, hemicellulose and lignin (Griffin and Hutchinson, 2007). NDF was not correlated ($R^2 = 0.1345$) with humic substances indicating that lignin and not cellulose plays a role in humic substance formation

2.4.4 Macro nutrient analyses, CaCl₂ DTPA extractible nutrients and extractible phosphorus

Macronutrient content, including nitrogen (N), phosphorus (P), potassium (K) and carbon (C) are presented in Table 2.3. The range for total nitrogen was 7 – 49 g kg⁻¹. This figure does not give an indication of available N as much (>90%) of the N in stable composts is in an organic form and therefore not readily available (Amlinger *et al.*, 2003). The protein content in the original feedstock plays a major role in the final N figure for the composts (Dimambro *et al.*, 2007). The MW composts presented the highest N content as a group. Among the other groups all the higher N containing composts had some food waste component: BW 9 (37.9 g kg⁻¹) had a dairy waste feedstock while BW 13 (35.0 g kg⁻¹) had a seafood waste feedstock. Both of these feedstocks are high in protein content leading to a high N content. A similar range was observed for the total P content with 0.4 – 28 g kg⁻¹ observed. As with the N results this

does not give a clear indication of available P. Results for CaCl₂ DTPA extractions presented in Table 2.4 were conducted to give an indication of the immediately available nutrients which may be lost through leaching, through rainfall or over watering (Prasad and Foster, 2006b). This information could be used in the protection of ground water when field applying composted wastes. For example if a crop was to succeed in a compost/soil mixture, to calculate the amount of additional mineral N, P and K to be added, it would be reasonable to estimate the contribution from composts from the CaCl₂ DTPA extractable results. Other forms of the nutrients are more dependent on moisture and temperature (e.g. Olsen's P and KCl N) with regard to mineralisation and therefore need more careful considerations when assessing potential availability. CaCl₂ DTPA results are more applicable to the availability of N rather than P.

Claassen and Carey (2004) demonstrated in their incubation study that GW compost was associated with low levels of N mineralisation. This supports the argument that GW compost would be better suited to being used as a soil conditioner/improver. The O.M. of GW compost is therefore an important parameter of GW compost quality. Saviozzi *et al.* (2006) reported a higher O.M. in soil when amended with GW compost in comparison to cattle manure.

Nitrogen containing compounds are water soluble and are therefore more readily extractable. Phosphorus containing compounds are not 100% soluble and require a

stronger extractant to give a figure for plant available P. Generally Olsen's or Morgan's extractable-P is used as a predictor of plant-available P. The MW composts presented highest levels (2400 – 3800 ppm) of available P (Olsen's). The BW composts presented a range of approximately 270 – 900 ppm of available P. The upper end of the range being composts which had a GW portion added before composting. A significant result to note is the high level of CaCl₂ DTPA P in BW 9 (313 mg L⁻¹), as this material is classified as a biowaste with a feedstock of green waste and dairy processing waste. However a high figure for P is not unusual in dairy waste with reports of a level of P ranging from 35 – 640 mg l⁻¹ P in cheese processing waste and whey respectively (Watkinsa and Nash, 2010). There was one significantly high total P result for a biowaste (BW 13, 28 g kg⁻¹) which had a major feedstock component of seafood waste. However much of this is in the unavailable form of organic P when contrasted with the Olsen's P results (607 mg L⁻¹). This material was slightly acidic (pH 6.4) which could account for the low available P. In pH neutral or acidic environments the Fe and Al present can adsorb or bind the inorganic P (available P) (Kuo *et al.*, 1999). The bioaccumulation of Fe and Al in fish has been reported in many studies and their solubility at lower pH's (Oberholster *et al.*, 2012; Coetzee *et al.*, 2002). The availability of P can also be largely influenced by metals such as calcium (Ca). Frossard (2002) detailed the capabilities of phosphorus to be bound to calcium in the form of apatite and octocalcium phosphates and be slowly available or unavailable.

C/N ratio of compost has previously been suggested as a predictor of compost maturity (Huang *et al.*, 2004; Guo *et al.*, 2012). The initial C/N ratio of feedstocks is a very important factor influencing the quality of the compost (Michel Jr *et al.*, 1996). Therefore C/N ratio could be used as a guideline to assess compost maturity and/or possibly net N mineralisation (Loecke *et al.*, 2012) i.e. an initial C/N ratio of 25 – 30 being suggested as ideal (Kumar *et al.*, 2010). A final C/N ratio of <12 is more desirable as it has been shown to result in net N mineralisation (Iglesias-Jimenez and Alvarez, 1993). As mentioned, carbon type is also critical (lignin, cellulose, hemi cellulose or humic acid) when considering C/N ratio. The contrast in C/N ratio and the initial feedstock can be seen in the results presented in Table 2.3. Both BW 3 (brown bin) and GW 2 (green waste) have C/N ratios of 19.27 and 21.92 respectively. These materials were the two highest recorded C/N ratios in the study of the total group. The higher C/N ratio would commonly be attributed to the C content of the feedstock materials. Contrast this with the manure waste composts which had lower C/N ratios ranging from \approx 9 – 14. The manure based feedstocks have a very high N content typically between 3 – 4% N. This has the effect of lowering the C/N ratio. All of the manure composts had a carbon based material added as a bulking agent to aid the composting process, including wood shavings, biowaste and seaweed.

The CaCl₂ DTPA extractable showed very high levels of NH₄-N for MW compost with rather lower levels in GW and BW (Table 2.4). All composts had some proportion of nitrate N indicating that nitrification had taken place during composting although it

could have occurred during storage. The highest levels were in IOW and BW and lowest in MW and GW. P levels were highest in MW and lowest in ADC. The range of P levels reported in BW, MW and GW were very large but this may be simply due to greater number of samples in these categories. Extremely high levels of K were recorded in MW while others had more moderate levels. Levels of extractable K must be considered critically as this may cause toxicity in some plants when used as a growing media. Spiers and Fietje (2000) highlight that toxicity may be an issue with GW being used in growing media due to high EC and water extractable K. One of the only BW composts that didn't contain a GW component in its feedstock had a low level of extractable K (BW 5). This compost had a feedstock of brown bin waste and waste water sludge. Low levels of K are common in waste water (Mosquera *et al.*, 2006).

2.4.5 Heavy metal analysis

Heavy metal analysis is a specific criterion that must be determined under all European national guidelines, including Irish national guidelines (NSAI). Both Cu and Zn were the two most abundant metals recovered in the composts. A number of the biowaste compost group samples were above the threshold limits for Cu and Zn. Compost samples BW 5 (201 & 558 mg kg⁻¹), BW 6 (305 & 402 mg kg⁻¹) and BW 13 (12020 & 305 mg kg⁻¹) were above the threshold limit for copper and zinc stipulated in the Irish national guidelines. All of the manure waste composts were also above the stipulated limit for zinc. IOW 1 (687 mg kg⁻¹) and IOW 2 (216 mg kg⁻¹) were also over the copper limit. However, the current provisions of the NSAI guidelines have considered increasing the permissible levels for Cu and Zn in compost as has been mentioned in

EN 26425. BW 5 was the only compost above the limit for lead (Pb). This was due to the waste water sludge that was added to the feedstock at the start which is known for elevated levels of Pb (Younos, 1987). None of the compost contained elevated levels of Cd. Cadmium content is also an important parameter in Ireland in terms of field application of composted wastes as there is upward of 15% of Irish soils above the maximum threshold limit for Cd (Fay *et al.*, 2007).

2.4.6 Extractable calcium, sulphur and cation exchange capacity

Extractable sulphur listed in Table 2.6 indicated that the highest levels were found in the MW composts with two of the BW composts reporting high figures (BW 4 >3000 and BW 7 >5000 mg L⁻¹). The lowest levels were found in the GW composts (GW3 <65 mg L⁻¹) and some of the other composts with a GW component (BW 9 & 10 <85 mg L⁻¹ and MW1 <205 mg L⁻¹). In relation to S both BW 4 (5290 mg L⁻¹) and BW 7 (3837 mg L⁻¹) presented relatively high figures for S. However this can be expected as the BW 4 and BW 7 are composed of seafood and catering waste respectively which can be high in S content due to the presence of seafood or green vegetables (Clark, 2008).

For extractable calcium (Ca) the highest levels were found in biowastes in composts with a seafood component (BW1 >31000 mg L⁻¹, BW 6 >14500 mg L⁻¹ and BW 13 >11000 mg L⁻¹). Also GW 1 presented a high figure for Ca which was above 10,000 mg L⁻¹. The lowest levels of Ca were found in some of the MW composts (MW 4 <3,000 mg L⁻¹). Many of the BW composts and GW 1 that presented high levels of Ca which

can have a restricting effect on P availability to plants but a positive effect on the potential environmental risk (García-Albacete *et al.*, 2012).

The highest cation exchange capacities (CEC) were seen in the MW composts. Previous studies have reported a correlation between compost maturity and CEC (Harada and Inoko, 1980) BW 1 (44.5 meq 100g⁻¹) and BW 2 (42.2 meq 100g⁻¹) and GW 1 (49.9 meq 100g⁻¹) showed slightly more elevated CEC's over some of the other compost within their respective groups (Table 2.6). The lowest CEC's were seen in BW 11 (24.2 meq 100g⁻¹), BW 12 (24.4 meq 100g⁻¹) and BW 13 (28.4 meq 100g⁻¹) and GW 2 (25.8 meq 100g⁻¹). The cation exchange capacity (CEC) has been postulated as a good predictor of maturity in a compost as direct correlations have been presented in a previous study. (Harada and Inoko, 1980). Results from the current study suggest a linear relationship with a good correlation $R^2 = 0.69$ ($P = 0.01$) is observed between the CEC and OUR. The manure waste composts had a high CEC compared to all of the other feedstocks. This is the expected result due to the high levels of nutrients and ions within these materials

2.4.7 Hierarchical cluster analysis and principal component analysis

The data in Fig. 2.1 gives a good indication as to the heterogeneity of the composts and the range of variation in the composts. The data in Fig. 2.1 shows the emergence of three main clusters. Cluster A includes everything from MW 2 – MW 5. This cluster contained three composts of which are poultry manure based feedstocks. MW 1 was not within this cluster. This was an expected result given some of the characterisation

results as MW 1 was a mixture of both cattle and horse bedding with hedge clippings. Cluster B is the biggest cluster with all composts from BW 6 to BW 8 and generally contained brown bin wastes. The argument could be made to include all of the composts within clusters B and C (mainly food waste composts) together as one cluster and then further subcluster the composts. The rest of the composts can be considered unclustered due to the high Euclidean distance between them and other composts.

In Fig. 2.5 an obvious and somewhat expected trend emerges highlighting the difference between the manure waste composts and the rest. However within the main cluster of composts there are groups. The first group circled includes the composts ranging from BW 4 – BW 7. All of these composts are primarily and predominantly composed of food waste. The next group containing BW 2, BW 3, GW 1 and ADC 2 again all share a component of their feedstock which is green or yard waste. There are also two further groups which are not highlighted. These groups contain the two IOW composts and the other has BW 11 and BW 12. Both of these composts contain brown bin waste. Using HCA and PCA can be a useful technique when dealing with a large population of samples that are very heterogeneous to group them into composts for specific uses. This technique has also identified differences between pure food waste, brown bin waste and composts classed as biowaste with a component of green waste.

2.5 Conclusion

The highest levels of total nutrients and available nutrients were all to be found in the MW composts. These results were expected due to the nature of the feedstocks. The MW composts were generally low in other parameters such as humic substances, lignin content and NDF. The MW composts potentially can supply sufficient amounts of N and P to sustain growth in plants and crops. Many of the other materials may not supply a sufficient amount of nutrients to ensure sustainable crop growth based on their characterisations. However, given the levels of humic substances, organic matter and the low salinity levels; some of the green waste composts and biowastes compost would be ideal to be used as a soil additive and conditioner. There is an argument that any manure based compost requires a separate stability threshold, as achieving a level of 13 mmol O₂/kg organic solids/h may be unnecessary and costly for its intended and appropriate use. The current Irish standard of an OUR of 13 mmol O₂/kg organic solids/h or lower is realistically unachievable in a reasonable time and possibly not necessary.

The use of HCA to group the materials that were similar gave distinct patterns which generally showed the manure waste composts to be different to the other groups. The application of PCA also showed how composts fitted into groups where feedstock was the common denominator within the group. Generally the diversity of feedstock within a group (i.e. biowastes) tended not to affect the characterisation results and the subsequent multivariate data analysis conducted. Further grouping of the composts such

as the green wastes, biowastes and anaerobic digestates may require further and more analytical experiments such as an incubation trial to investigate N and P availability over time.

2.6 References

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Chapter 3

Predicting nitrogen and phosphorus availability from composted wastes: An incubation study

3.1 Introduction

In 2012 approximately 160,000 tonnes of biodegradable municipal waste was composted in Ireland (McCoole *et al.*, 2012) . This figure is set to rise with the ensuing European waste directive protocols (2008/98/EC). Although there is a large biowaste compost stream available it has not seen its market value potential being realised. One issue arising from this is the lack of knowledge in understanding the fertilising and soil conditioning potential of Irish composted wastes. The Nitrates Directive (part of Water Framework Directive (2000/60/EC) has redressed the availability of N from composted manures. Spent mushroom compost is now considered to have 20% availability for N and 50% availability for P. This has greatly increased the volume of compost which may be applied to land per annum. These guidelines are based on total N and P content and not on plant available N and P.

Evaluating the immediate plant availability of nitrogen (N) and phosphorus (P) plays a key role when developing application rates for composts which can be done through incubation experiments (Gil *et al.*, 2011). The aim of this chapter was to improve

knowledge of release rates of both N and P from biowastes and other composted wastes. Compost management for the benefit of agriculture and horticulture must consider strategies to meet crop nutrient requirement while also protecting the environment (Hartl *et al.*, 2003). Understanding N dynamics is important for crop nutrition in terms of application rates as the availability of N to plants is low, with the majority of compost N (>90%) bound to the organic N – pool (Amlinger *et al.*, 2003). Commercial crops largely require a high level of N for optimum growth. Applying an appropriate amount of compost is significant to delivering sufficient N to the plant whilst minimising loss to the environment.

Some composts (spent mushroom) are considered to have P release that is 100% of the total P; that it is equivalent to the content in chemical fertilizer e.g. Superphosphate. However a literature study carried out has indicated that phosphorus availability from composts can vary depending on feedstock (Prasad, 2008). Accurate prediction of P availability and plant P recovery will help tailor compost applications to plant needs and minimise the over application of bioavailable P which can contribute to eutrophication of sensitive water courses (Magette, 2007). This gives an opportunity to investigate alternatives to glasshouse and field trials to yield information on nutrient availability from composts.

The aim of this chapter was to investigate the nutrient (N and P) mineralisation potential of the various composted wastes applied to soil when subjected to controlled moisture,

temperature and aeration. Understanding net mineralisation or immobilisation is of key importance to determining the potential usage of the composted waste material.

3.2 Materials and methods

The twenty five composts that were sourced both nationally and internationally have been detailed in Table 2.1 (Chapter 2) along with their feedstock, country of origin, composting process they underwent and the length of the process.

3.2.1 Compost groups

Each of the 25 composts has been grouped into a select group based on their feedstock as follows.

Table 3.2 The classification composts groups, group code and the groups size

Compost group	Code	Group size
Biowaste	BW	n =13
Manure waste	MW	5
Green waste	GW	3
Industrial organic waste	IOW	2
Anaerobic digestate compost	ADC	2

3.2.2 Nutrient analyses of the composts

Total kjeldahl nitrogen (TKN) was analysed for using the Kjeldahl digestion method (EN 13654-1, 2001). After HNO₃/HClO₄ digestion, total P was analysed (EN 13650:2001) by measurement by ICP –AES. CaCl₂ DTPA extractable nutrients (including all N (NO₃ – N & NH₄ – N), P and K) were determined in accordance with the standard CEN method (EN 13651:2001). For each compost treatment Olsen’s extractable P and Mehlich – 3 P were conducted by the standard procedure described

Olsen *et al.* (1954) and Mehlich (1984) and were analysed via UV spectrophotometer using the complex colourimetric method (Murphy and Riley, 1962). All acknowledgments for analysis conducted are given in Chapter 2.

3.2.3 Nitrogen incubation experiment

The incubation experiment was prepared using 175 mL plastic pots (Alpack Ltd.) to hold the compost/soil bioassay during the experiment. The soil used was a clay loam with pH of 7.2. Each pot had sufficient amount of aeration through four pierced holes on the side wall the pots. The 25 compost samples were prepared by ensuring each sample was at the desired moisture content. All composted samples were adjusted to 50% moisture. This required either adding additional water or careful drying of the individual samples to make the adjustment. A total of 150 soil lots were prepared (100g). Soil was sieved through a 4mm sieve and 15ml of distilled water was added in 3 x 5ml aliquots to each lot. After each addition the soil and water added were mixed thoroughly. This allowed for a uniform distribution of the moisture throughout the soil. The 25 compost samples were then added to the soil at two rates; a high rate (40mg N/100g soil) and a low rate (20mg N/100g soil) with three replicates of each. Application on this basis meant that each of the composts was being applied at an equivalent rate of total N. The chemical control used was calcium ammonium nitrate (CAN). CAN was used as this is the most commonly used N fertiliser and also enabled the agronomic comparison of the composts with the chemical fertiliser. The chemical controls were added at the same rates as the composts. There was also an untreated control of soil. The samples were incubated at 25°C for four weeks. This temperature

was selected after consultation with previous literature (Griffin *et al.*, 2005). The moisture levels were monitored (and adjusted) on alternating days to ensure the levels were stable throughout the incubation and also allowing aeration through agitation of the soil. Sampling was conducted at 0, 7, 14, and 28 days. A 12.5 g stratified sample was extracted from each pot and was extracted for thirty minutes in 50 mL 1M KCl. Samples were filtered through Whatmann 2V filter paper and placed in plastic centrifuge tubes. All extracts were analysed via a KONELAB discrete auto-analyser.

3.2.4 Phosphorus Incubation Experiment

For this experiment 25 composted waste samples were moisture adjusted in the manner as explained in section 3.2.1. The 25 compost samples were then added at two rates to the soil; a high rate (10 mg P/100g soil) a low rate (5 mg P/100g soil) with three replicates of each. Application on this basis meant that each of the composts was being applied at an equivalent rate of total P. There was a chemical control of single superphosphate (SPP: 8% P) added. The chemical control was added at the same rates as the composts. There was also an untreated control of soil. The samples were incubated at 30°C for four weeks. This temperature was selected after consultation with previous literature (Khan and Joergensen, 2009). The moisture levels were continuously monitored to ensure the levels were stable throughout the incubation. The samples were also aerated every two days as previously described. Sampling was conducted at 0, 14, and 28 days. A 5g stratified sample was extracted from each pot and was shaken for thirty minutes in 100mL of 0.5M sodium hydrogen carbonate (Olsens reagent). Samples were filtered through Whatmann 2V filter paper and placed in 50ml plastic centrifuge

tubes. All extracts were analysed using a Perkin Elmer UV spectrophotometer probe at 880nm using the ammonium molybdate colour complex reaction (Murphy and Riley, 1962). The Olsen test is best suited to neutral or alkaline soils. The Mehlich – 3 test can extract more nutrients along with P and is more suited to a wider pH range (Sawyer and Mallarino, 1999). The Morgan’s test is the standard agronomic test for P used in Ireland (Daly and Casey, 2005).

3.2.5 Statistical analysis

The statistical analyses for the experiments were conducted using the SAS 9.3 program. (SAS Version 13). A linear mixed model ANOVA was conducted to evaluate the statistical significance between compost treatments and groups at the different rates and extraction time points. Comparisons were made between each treatment, their respective group for each rate and at each extraction time point. The model analysed all possible interactions and compared treatments and groups. The compost treatments and groups were determined to be normally distributed from the statistically analysis.

3.3 Results

3.3.1 Nitrogen and phosphorus characteristics of composts

The results presented in Table 3.3 display all the analyses for N and P performed on each compost treatment. The highest results for total N and P were all from the MW group. There were some other high results for total N: namely BW 13, GW 3 and ADC

2. The highest total P was found in BW 13, BW 6 and the MW group composts. The lowest levels were found in BW 3 (2.4 g kg⁻¹) and GW 2 (0.5 g kg⁻¹).

Table 3.3 Total nitrogen and phosphorus, CaCl₂ DTPA extractable nitrogen and phosphorus and extractable phosphorus

Code	C:N Ratio	Total N g kg ⁻¹	Total P g kg ⁻¹	DTPA Extractable nutrients mg L ⁻¹					Olsen's P mg L ⁻¹
				NH ₄ - N	NO ₃ - N	N	P	K	
BW 1	13.2	20.6	8.2	30	476	505	2	1017	268
BW 2	10.2	13.4	3.9	1	366	367	6	2317	378
BW 3	19.3	14.5	2.4	1	231	232	10	1909	390
BW 4	10.1	20.4	3.3	5	477	482	15	2407	372
BW 5	10.8	23.8	11.4	0	66	66	4	312	453
BW 6	12.4	18.5	17.1	3	469	472	4	1906	428
BW 7	10.0	25.0	3.2	2	473	475	11	1905	414
BW 8	16.4	16.1	3.9	23	227	250	22	2856	620
BW 9	9.9	37.3	6.1	1	304	305	313	498	903
BW 10	17.8	20.3	2.4	2	207	209	98	420	554
BW 11	16.4	17.0	7.0	3	68	71	8	680	459
BW 12	15.8	17.4	5.3	6	221	227	10	1158	432
BW 13	8.5	35.0	28.0	167	588	755	15	862	607
MW 1	15.0	24.0	6.3	2	300	302	107	5874	746
MW 2	11.1	38.2	13.8	3740	28	3768	127	10850	2653
MW 3	12.2	35.4	19.8	2722	13	2735	230	6890	3885
MW 4	10.0	44.1	13.4	945	19	964	33	5740	2588
MW 5	10.0	10.3	18.1	4681	10	4691	18	7537	2416
GW 1	12.6	19.9	3.6	1	237	237	10	2634	391
GW 2	21.9	8.2	0.5	6	3	9	7	693	265
GW 3	10.1	34.5	4.3	1	82	83	88	544	539
IOW 1	13.7	18.2	9.2	55	509	564	53	1074	503
IOW 2	13.8	14.4	8.0	20	601	621	42	901	479
ADC 1	8.5	20.2	2.9	2	338	340	9	1264	304
ADC 2	8.6	34.6	5.5	99	70	169	9	1044	602

The data displayed in Table 3.4 show the total mineralisable N ($\text{NO}_2^- + \text{NO}_3^- + \text{NH}_4^+$). Apart from the manure waste composts and the chemical control which had high level of $\text{NH}_4 - \text{N}$ the other composted wastes had trace amounts of $\text{NH}_4 - \text{N}$ detected during the incubation trial. A significant increase in mineralisation of N was only observed with the manure waste composts. Each of the other groups exhibited no increase in N availability over the course of the incubation. The chemical control of CAN exhibited a percentage recovery of approximately 90%. The soil control has been subtracted from the compost results to indicate mineralisation of N from the composts only. It is evident that in the case of the other groups (apart from the MW group) that the effect of adding compost to the soil is net immobilisation during the course of the incubation. The range of recovery for the MW was from 20 – 40% at both rates. Some of the individual treatments in the BW group exhibited a recovery of between 7 and 8% whereas the IOW were approximately 3 – 4%. Two of the GW composts showed no N release and hence immobilisation. The same can be said for BW with the mineralisation of N being negligible and the two anaerobic digested composts (ADC) materials.

3.3.2 Nitrogen mineralisation

Table 3.4 Nitrogen mineralisation data (mg L^{-1}) for the compost treatments applied to soil at rates of 20 mg and 40 mg N/100g of soil

Code	Rate	Days				Code	Rate	Days			
	40 mg	0	7	14	28		20 mg	0	7	14	28
BW <i>n</i> = 13	Mean	30.26	29.56	28.15	28.71	BW <i>n</i> = 13	Mean	25.61	25.31	24.46	24.59
	Range	16.70	16.99	16.71	17.81		Range	34.82	34.26	34.38	31.98
		46.73	44.51	42.53	43.11			18.43	19.35	17.65	18.30
MW <i>n</i> = 5	Mean	102.67	112.41	121.75	120.68	MW <i>n</i> = 5	Mean	62.90	69.41	70.78	66.72
	Range	145.63	176.40	194.63	186.49		Range	91.14	100.20	93.04	90.70
		100.84	106.29	123.80	122.80			59.88	71.18	71.91	68.03
GW <i>n</i> = 3	Mean	21.26	23.14	22.46	22.18	GW <i>n</i> = 3	Mean	20.77	22.40	21.35	21.42
	Range	24.90	28.87	26.48	26.99		Range	22.78	25.22	23.46	23.12
		16.52	18.47	18.19	18.08			16.90	19.07	17.50	18.14
IOW <i>n</i> = 2	Mean	31.13	30.45	42.88	29.64	IOW <i>n</i> = 2	Mean	25.86	24.82	23.53	24.09
	Range	31.30	31.96	55.44	30.81		Range	27.95	25.78	24.03	25.12
		30.95	28.94	30.31	28.47			23.76	23.86	23.04	23.07
ADC <i>n</i> = 2	Mean	23.39	23.23	21.39	21.55	ADC <i>n</i> = 2	Mean	19.27	21.68	19.19	19.74
	Range	23.54	23.80	21.40	22.19		Range	19.38	22.12	19.38	20.27
		23.23	22.65	21.37	20.91			19.16	21.24	19.00	19.20
CAN <i>n</i> = 1	Mean	382.64	356.54	341.80	364.92	CAN <i>n</i> = 1	Mean	195.96	185.51	177.52	167.47
	Range	382.64	357.00	343.55	364.92		Range	195.96	188.33	177.52	167.47
		377.21	352.56	339.65	360.87			190.25	185.51	174.51	160.74
Soil <i>n</i> = 1	Mean	18.68	21.75	22.65	22.79	Soil <i>n</i> = 1	Mean	18.68	21.75	22.65	22.79
	Range	19.98	22.54	24.83	23.35		Range	19.98	22.54	24.83	23.35
		16.67	20.57	21.28	22.35			16.67	20.57	21.28	22.35

Individual mineralisation figures are presented in Appendix A.2

Table 3.5 Fixed effects and observed significance for the Nitrogen incubation

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Treat	23	96	557.83	<.0001
Level	1	96	1347.57	<.0001
Treat*Level	23	96	58.78	<.0001
time	3	288	10.55	<.0001
Treat*time	69	288	5.98	<.0001
Level*time	3	288	4.5	0.0042
Treat*Level*time	69	288	1.93	0.0001

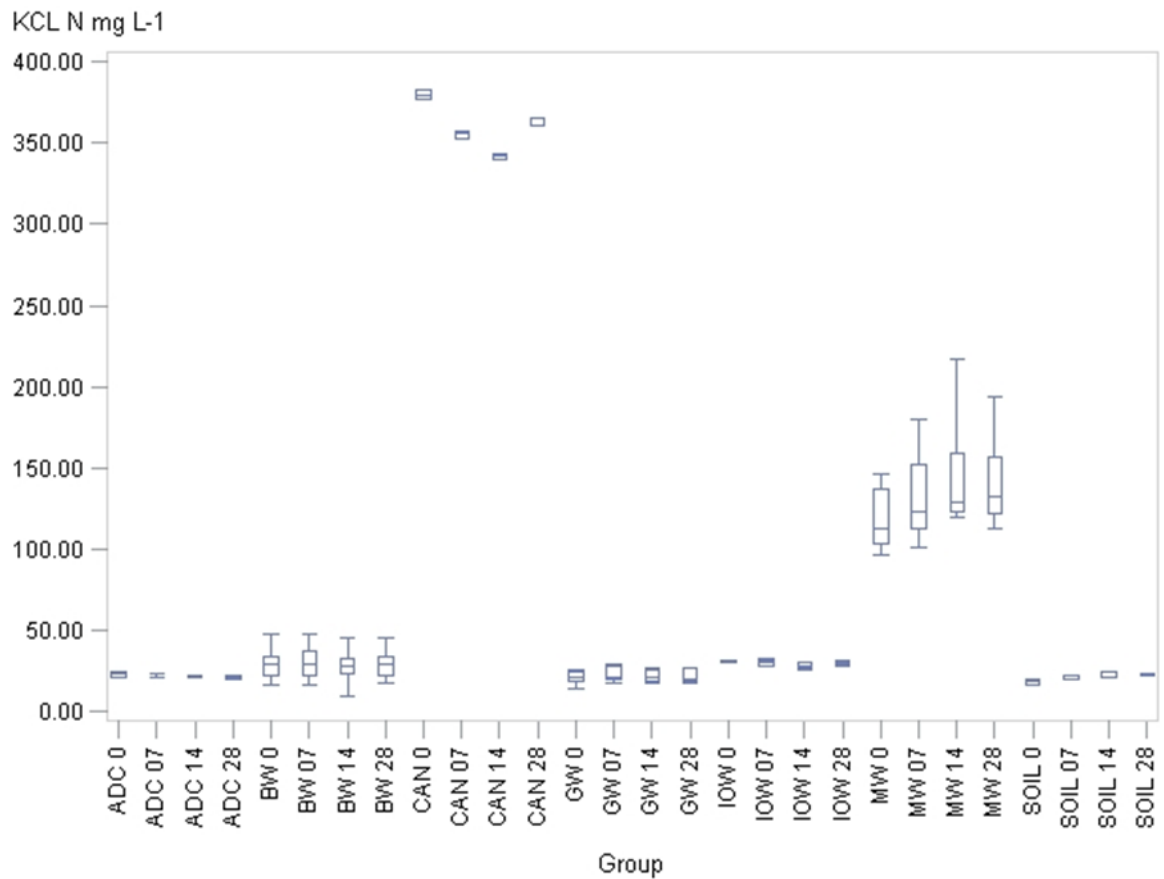


Figure 3.1. Total KCl extractable N (mg L^{-1}) data as box and whisker plots for the compost groups applied at 40 mg per 100g of soil

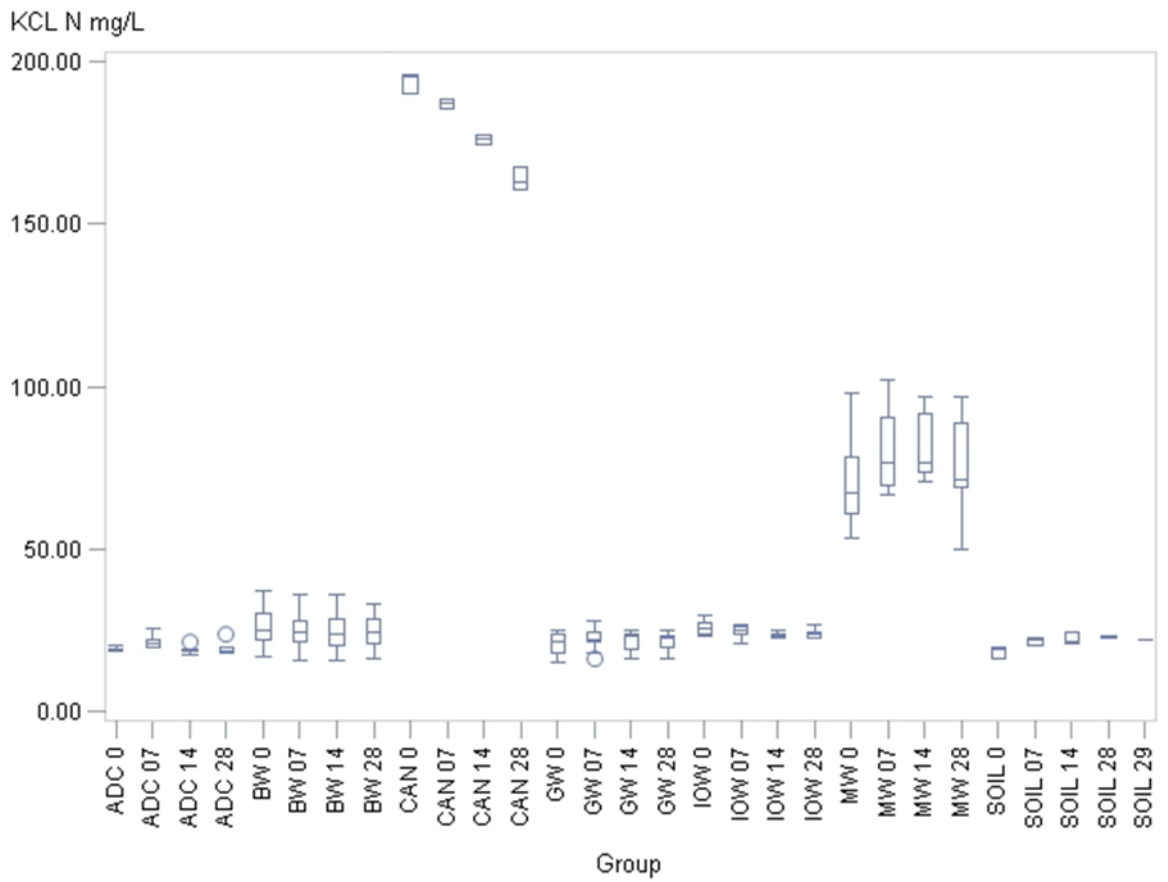


Figure 3.2. Total KCl extractable N (mg L^{-1}) data as box and whisker plots for the compost groups applied at 20 mg per 100g of soil

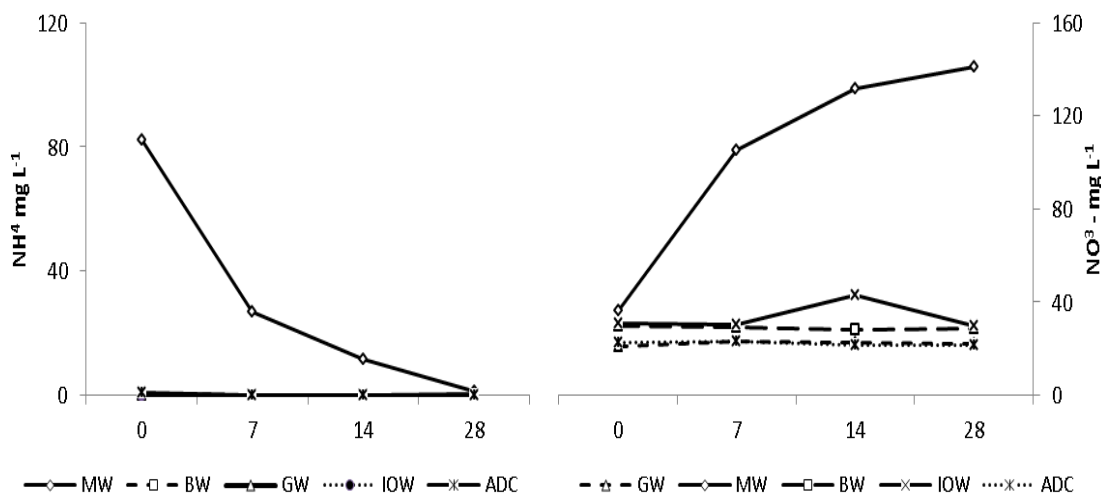


Figure 3.3. (a and b). Graphical representation indicating nitrification taking place in the MWC group and not in any other group. Figure 3.3a showing the decrease in NH_4^+ and Figure 3.3b showing the decrease in NO_3^-

3.3.3 P mineralisation

The results from the P incubation present much different results from the N incubation. Almost all of the groups exhibit a release of P during the experiment. The treatments where the lowest P release was exhibited were from the composts composed mainly of food waste i.e. BW 5 and BW 6. The most significant result was from the MW group where some of the individual treatments were higher in available P than the chemical control of SSP. The availability of P from SSP was 49.95 mg L^{-1} (10 mg rate) initially decreasing to 27.55 mg L^{-1} . The broiler manure compost MW 4 (10 mg rate) had an initial P of 69.64 mg L^{-1} which decreased to 38.27 mg L^{-1} . Both the IOW and the ADC show an increase in P availability at the second extraction with a decrease for the final extraction. This is contrast to the MW which exhibited and steady decline in P

availability over the three extractions. The trends for both applications of compost are shown numerically in Table 3.6.

Table 3.6 Phosphorus mineralisation data (mg L^{-1}) for the compost treatments applied to soil at rates of 5 mg and 10 mg P/100g of soil

Code	Rate		Days			Code	Rate		Days		
	10 mg	0	14	28	5 mg		0	14	28		
BW <i>n = 13</i>	Mean	17.31	17.62	18.45		BW <i>n = 13</i>	Mean	13.64	12.71	13.81	
	Range	24.61 9.23	28.83 8.28	27.16 11.15			Range	24.67 7.06	18.35 6.33	20.62 8.65	
MW <i>n = 5</i>	Mean	42.61	28.54	21.33		MW <i>n = 5</i>	Mean	22.96	19.13	13.26	
	Range	69.64 24.22	37.24 21.74	38.27 14.06			Range	33.07 16.27	24.93 14.61	25.09 8.66	
GW <i>n = 3</i>	Mean	14.44	14.56	13.24		GW <i>n = 3</i>	Mean	10.45	9.35	9.00	
	Range	15.32 13.67	19.97 11.44	16.88 11.35			Range	11.55 8.47	11.85 7.43	10.95 7.81	
IOW <i>n = 2</i>	Mean	26.19	27.60	17.26		IOW <i>n = 2</i>	Mean	14.35	22.02	14.97	
	Range	33.60 18.77	29.24 25.95	17.85 16.67			Range	14.95 13.76	22.89 21.15	15.20 14.74	
ADC <i>n = 2</i>	Mean	16.95	29.92	18.65		ADC <i>n = 2</i>	Mean	13.50	21.62	15.75	
	Range	18.73 15.17	33.48 26.36	18.91 18.39			Range	13.95 13.06	24.15 19.09	17.06 14.44	
SSP <i>n = 1</i>	Mean	49.95	36.74	27.55		SSP <i>n = 1</i>	Mean	31.66	28.27	14.87	
	Range	58.72 43.26	41.60 32.66	28.49 25.93			Range	36.20 27.95	31.36 26.34	14.99 14.77	
Soil <i>n = 1</i>	Mean	5.84	7.72	6.86		Soil <i>n = 1</i>	Mean	5.84	7.72	6.86	
	Range	8.08 1.86	8.61 6.12	7.16 6.55			Range	8.08 1.86	8.61 6.12	7.16 6.55	

Individual mineralisation figures are presented in Appendix A.2

Table 3.7 Fixed effects and observed significance for the phosphorus incubation

Type 3 Tests of Fixed Effects				
<i>Effect</i>	<i>Num DF</i>	<i>Den DF</i>	<i>F Value</i>	<i>Pr > F</i>
Treat	23	96	45.89	<.0001
Level	1	96	258.38	<.0001
Treat*Level	23	96	5.66	<.0001
Time	2	238	14.53	<.0001
Treat*time	46	238	14.15	<.0001
Level*time	2	238	0.51	0.6005

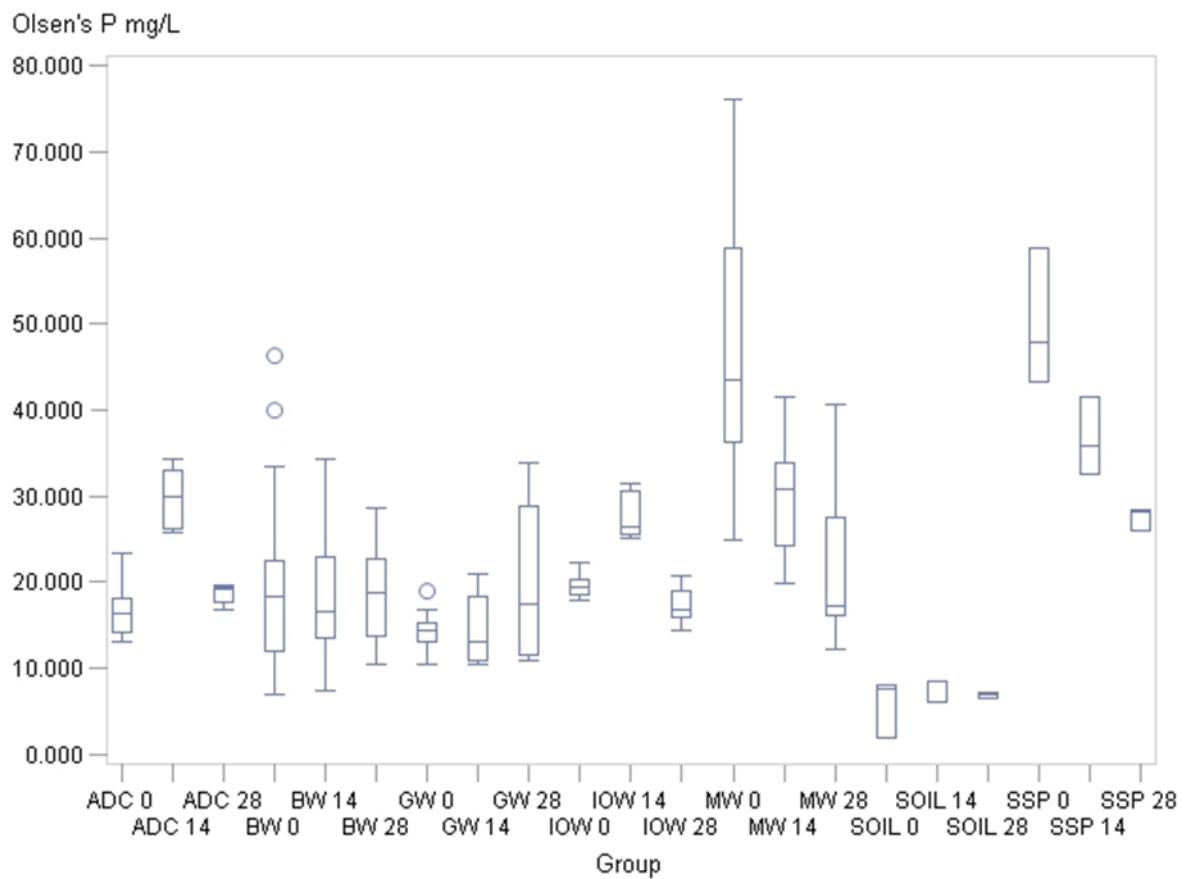


Figure 3.4 Total Olsen's extractable P (mg L^{-1}) data as box and whisker plots for the compost groups applied at 10 mg per 100g of soil

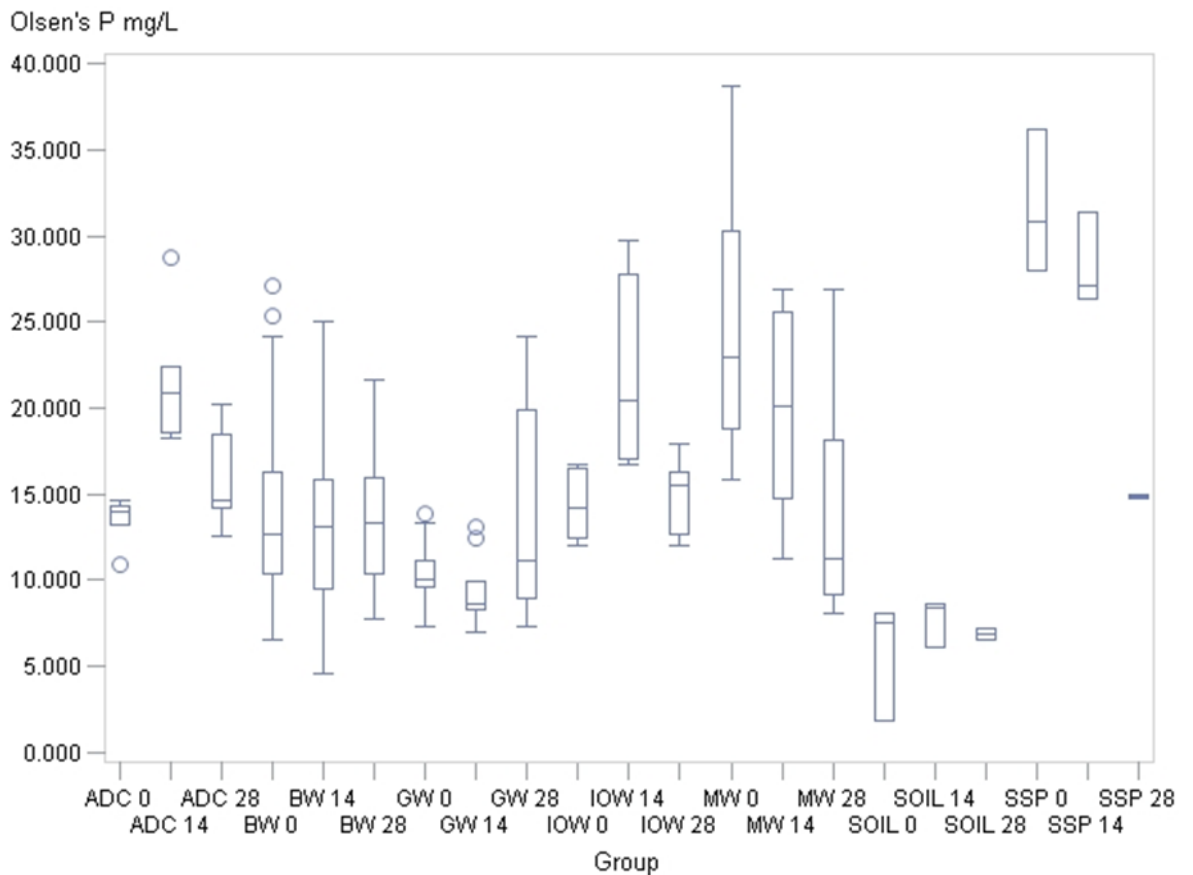


Figure 3.5 Total Olsen's extractable P (mg L^{-1}) data as box and whisker plots for the compost groups applied at 5 mg per 100g of soil

3.4 Discussion

3.4.1 Nitrogen mineralisation

Investigations into understanding N dynamics in compost when incorporated into soil under controlled conditions have been reported in multiple studies (Preusch *et al.*, 2002; Gale *et al.*, 2006). Incubation experiments help to understand the mineralisation kinetics of organic materials added to soil and provide information over the short and medium term (Barral *et al.*, 2009). From the results presented, only the MW group mineralised a

sufficient amount of N for plant growth. MW 4 had the highest available N over the four extractions presented in Table 3.3. At the first extraction the N recovery was 31% (20 mg rate) and 36% (40mg rate). These final extraction figures (recovery) were 40% and 33% respectively. The recovery figures for the entire MW group were above 20% and ranged from 20% to 40%. Treatments MW 2, MW 3 and MW 4 had chicken manure as a major component of their feedstock. However when their N mineralisation figures are examined there is a large variance in the results. Both MW 2 and MW 3 had almost identical percentage recovery figures during the course of the experiment. Both MW 2 and MW 3 were composted for 25 weeks whereas MW 4 was composted for 21 weeks. The importance of compost maturity on N dynamics have been discussed (Helgason *et al.*, 2007). From our results the stability appears to have an impact on N mineralisation dynamics. This is evident in the OUR results recorded with MW 4 significantly higher than the other compost treatments at 55 mmol O₂/kgOS/h. MW 4 is significantly different from MW 5 (P<0.05) and highly significantly different from MW 2 and MW 3 (P<0.01). MW 2 is unique in that this material was mixed 1:1 with seaweed. Seaweed has been known to be a carbon fixation source (Muraoka, 2004) and carbon mineralisation has an impact on the N availability (Chèneby *et al.*, 1994). The addition of the seaweed may have reduced the C/N ratio but may have also acted to reduce the available nutrients within the compost. All of the MW group treatments initially had a high level of NH₄⁺. This gradually declined to near zero by day 14 (MW 2, MW 3 and MW 5) and day 28 (MW 4) at the 40 mg rate. This contradicts results presented by Mallory and Griffin (2007) in a similar incubation experiment conducted

on a freeze dried manure (not a composted manure) applied to two soils at rates based on organic N content. In their experiment an initial flush of NO_3^- is noted followed by a sharp decrease to day 28 and confirmed in a subsequent paper (Griffin *et al.*, 2005). Mallory and Griffin (2007) suggest that microbial immobilisation is responsible for the drop in NO_3^- concentration. From our experiment an increase in NO_3^- is observed over the course of the incubation displayed in Fig. 3.5 (a and b). This would suggest a strong nitrification process occurring. This demonstrates how compost might be a more suitable material to be co applied with mineral N as it gives a controlled release of N and therefore is less likely to immobilise or denitrify N. The likely result of the latter processes is loss of N to the environment. Nitrification taking place within the compost gives an indication of the maturity of the compost (Bernai *et al.*, 1998). When a drop in NH_4^+ occurs and there is an appearance of NO_3^- , the compost is said to be ready for land application (Finstein and Miller, 1985). The other groups i.e. BW, GW, IOW and ADC in the experiment exhibit little or no nitrification taking place. This is confirmed by the absence of NH_4^+ from the results when the analyses of the extracts were conducted. This indicates that all the nitrification has taken place during the composting process and the only form of available N is NO_3^- - N. Similar results for composted broiler litter have previously been presented (Gale *et al.*, 2006). Their study also showed little difference between the availability of N from composted and fresh broiler manure. However the broiler manure was dry stacked and sold as “composts”. The average recovery for the broiler manure was $\approx 31\%$ compared with 30% for our incubation.

The MW group are considered unstable and not suitable for land application under the specifications Irish compost standard (NSAI IS: 441), which does not currently cover composted wastes with an animal manure component. However these results further enhance the need to consider a separate stability limit for composts with a manure feedstock. Use of an unstable green waste or biowaste may restrict nutrient availability by competing for available nutrients (Bernal *et al.*, 1998) but this may not be the case with manure composts as no net immobilisation was reported from the MW composts.

The other compost groups exhibited a release of N (mineralisation) considerably less than the MW group. The average accumulated recovery for the BW group was 8%. The maximum recovery came from composts BW 6 (16%) and BW 7 (22%) which compare to a study by Hadas and Portnoy (1997) who reported 22% recovery after a 33 week incubation.. A study to investigate the differences between N mineralisation in fresh and mature municipal solid waste composts reported recovery of 14.3% from mature compost (Chodak *et al.*, 2001). The lowest N mineralisation came from BW 3, BW 5, BW 11 and BW 12. BW 12 was composted for the shortest time at only three weeks and left to mature for one week. The instability of this material is confirmed with the OUR reading of 23.9 O₂/kgOS/h. Although BW 11 is a stable material; it does present very low levels of extractable NO₃⁻ (3 mg L⁻¹) and NH₄⁺ (68 mg L⁻¹). This suggests that the N content of this material is largely in the organic form and therefore unavailable. BW 5 is a unique material in this experiment in that it contains a predominant mixture of waste water sludge and brown bin waste. The low level of N mineralisation from this

treatment may come from the slightly elevated levels of copper (Cu) in the compost. The feedstock of waste water sludge may also be a source for heavy metals which may inhibit N availability as previously suggested (Chang and Broadbent, 1982). The composts BW 6, BW 13, IOW 1 and IOW 2 were also above the NSAI upper limit for Cu (149 mg kg^{-1}). BW 13, IOW 1 and IOW 2 all had high levels of total N but presented low available N figures for incubation. This could be attributed to the levels of Cu by inhibiting mineralisation (Kostov and Van Cleemput, 2001) but equally due to the high organic N content. Consequently all of the composts that reported less than 10% recovery contained a portion of green/yard waste in the feedstock. Both the ADC and GW immobilised N showing no significant difference from the untreated control ($P>0.05$). The low NH_4 concentrations (and low O.U.R.) suggest that the composts are at full maturity (Bernai *et al.*, 1998). Similar results have been presented for a short duration incubation on N mineralisation from GW composts (Vaughan *et al.*, 2011). In their paper the authors highlight the immobilisation effect of GW compost on available soil N and that GW composts would be better suited to controlling N losses to the environment.

3.4.2 Predicting nitrogen availability from nitrogen compost parameters

The use of C/N ratio has been used previously to predict N availability from compost or more specifically whether mineralisation or immobilisation will take place in the early stages of decomposition (Cambardella *et al.*, 2003). From the N incubation results a poor correlation between the available N and C/N ratio was seen. However Table 3.8

shows the strong correlation of available N with. A similar result has been reported in another study but these findings are not widespread (Griffin and Hutchinson, 2007). Cambardella (2003) found no significant relationship between the C/N ratio of the compost (and soil post amendment) and net N mineralisation. Griffin and Hutchinson (2007) note that the decomposition of the N pool (more recalcitrant) could be controlled by compounds such as lignin.

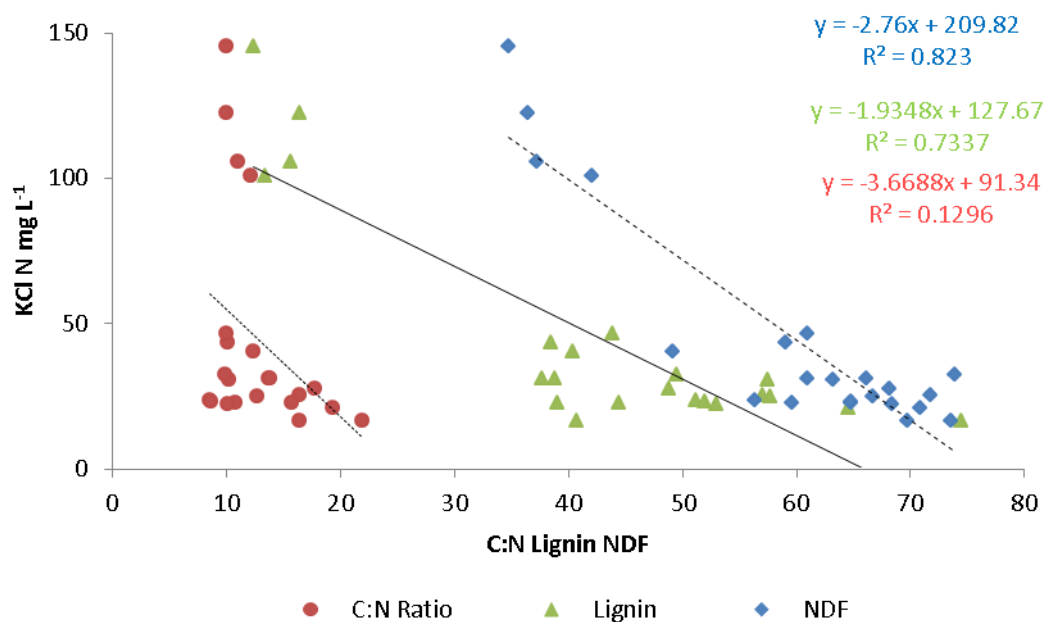


Figure. 3.6 Graphical representation highlighting the relationship between KCl N with NDF (%), lignin (%) and C/N ratio. Line equation and R² values are in descending order.

Table 3.8 Pearson's correlation coefficients of incubated soil test N with NDF, lignin and C/N ratio

Day	NDF		Lignin		C/N Ratio	
	R ²	P value	R ²	P value	R ²	P value
0	-0.78442	<.0001	-0.79154	<.0001	-0.33085	<0.05
7	-0.7786	<.0001	-0.7685	<.0001	-0.31299	<0.05
14	-0.75392	<.0001	-0.76769	<.0001	-0.28109	<0.05
28	-0.7683	<.0001	-0.77015	<.0001	-0.29348	<0.05

This could be a significant step in formulating more accurate predictive characterisation parameters for net N mineralisation from compost.

3.4.3 Phosphorus mineralisation

In contrast to the a significant body of work done on the dynamics and availability of N when composted materials are incorporated into soil, there is a smaller volume of available research conducted on P dynamics and availability (Prasad, 2008). This may be due to the Good Agricultural Practice established within the action programme of the Nitrates Directive with the aim of controlling diffuse and direct water pollution (Bomans *et al.*, 2005). The results from the P incubation study appear initially to be less consistent within feedstock groupings. With the N incubation the trends among the compost groups and the controls were as expected for N availability. The same cannot be said of the P incubation. Most of the groups produced a significant level of P capable of sustained growth of commercial crops. The mineralisation rate of P was higher for the groups over the incubation period when compared to N mineralisation rates. The MW group exhibited a high P mineralisation not significantly different from the chemical control (SSP). When the individual treatments results are analysed; one

treatment (MW 4) showed an initial extraction P recovery of 68%. This compared to 39% and 33% for MW 2 and MW 3 respectively. Gagnon and Simard (1999) report a 38% recovery for composted poultry litter in an incubation experiment. At the high rate MW 4 showed a significant difference from SSP ($P < 0.05$). No significant difference between MW 4 and SSP was seen at the low rate. This material had a lower extractable P than both MW 3 and MW 5; both of which presented higher figures for Morgan's extractable P and Mehlich – 3 P. Both of these treatments were lower in available P when incorporated into soil. One possible explanation for this may be the high levels of Ca and Mg that were present (Ca: 4261 and 10434 mg L⁻¹ and Mg: 2984 and 5620 mg L⁻¹ for MW 3 and MW 5 respectively). Contrast this with the level of Ca (2997 mg L⁻¹) in MW 4. This agrees with a previous study by Cooperband and Ward Good (2002) that suggests that the mineral phase of Ca and Mg controls the solubility and hence the availability of P. This has been further supported by other studies conducted investigating the forms of P in composts (Frossard *et al.*, 2002) which suggests that P can be bound to Ca in the form of apatites or octocalcites. This is an interesting finding as both MW 3 and MW 4 are almost identical in feedstock but differ in their composting process length. MW 5 is a different material as it contains a mixture of poultry and pig manure and composted biowaste.

Table 3.9 Percentage recoveries of compost groups for nitrogen (40 mg rate) and phosphorus (10 mg rate)

N %	0	7	14	28	P%	0	7	14
MW	24.99	27.63	30.27	29.92	MW	42.35	32.68	19.00
BW	2.89	1.95	1.37	1.48	BW	17.53	19.22	17.01
GW	0.64	0.35	0.00	0.00	GW	11.78	14.49	9.60
IOW	3.11	2.17	5.06	1.71	IOW	21.56	33.68	17.58
ADC	0.77	0.03	0.00	0.31	ADC	16.09	34.44	19.05

The BW group gave very differing results among the different composts. The group exhibiting the lowest P mineralisation rate was BW 6 which showed a significant difference ($P < 0.01$) to BW 10 which had the highest mineralisation rate. As with the MW composts BW 6 had a level of Ca that was approximately three times higher than BW 10. BW 6 was brown bin waste compost. The high levels of calcium may have been from particular foods present in the feedstock known to be high in calcium. This again adds further to the results indicating that the level of Ca in compost has an effect on the availability of P. Furthermore BW 10 with a feedstock of brewery waste is likely to contain yeast. Yeast is known to produce phosphate mineralising bacteria in the form of phosphatases (Vogel and Hinnen, 1990). The activity of such bacteria and their benefits have been reported although not as extensively as N mineralising bacteria (McKercher and Tollefson, 1978; Chauhan *et al.*, 1979). The biowaste group may be considered a low to medium nutrient compost in terms of P but it is indicating a longer mineralisation of P than the MW group. The range of percentage recovery was quite large within the biowaste group. It ranged from 3% (BW 6 10 mg rate) to 37% (BW 10 5mg) from the first extraction to 4% (BW 13 10mg) and 22% (BW 10 5mg) for the final

extraction. It is also interesting that the rate has an effect ($P>0.05$) on the P concentration in the extractions. More importantly the percentage recovery was higher from the lower rate than the higher rate. With all of the other groups the high rate yielded a higher percentage recovery. The MW group was approximately double in terms of the difference between the two rates. The BW group was the only group in which the recovery of P was higher at the lower rate than at the higher rate. The lower recovery may have been due to the larger amount of compost being added to the soil. The higher compost content may have increased the liming effect of the compost on the soil and therefore ultimately caused more of the P to be bound to Ca within the soil/compost system (Terman *et al.*, 1973). Many of the biowastes exhibited a significant mineralisation of P.

The IOW group consisted of feedstocks of organic waste from pharmaceutical extraction processes. This group behaved in a similar way to the ADC group in so far that there was an increase in P mineralisation at the second extraction. This occurrence was seen in both the rates in this experiment. There were two treatments in this group: IOW 1 and IOW 2. The only major difference between these two composts was the duration of composting which the materials underwent. IOW 1 recorded a higher level of Olsen's and Mehlich – 3 P which accounted for the higher uptake figures. Both of the groups were significantly different from MW in P mineralisation for the first extraction ($P < 0.01$). However by the second and third extractions there was no significant difference between the groups. This would indicate a steadier rate of mineralisation of P

which may be beneficial in long term application of composts. Both of these groups are similar to the biowaste group in that there was an appreciable level of mineralisation of P but little or no mineralisation of N. The mineralisation of P from the GW compost was the lowest of the groups. Typically it was less than 10%.

3.5 Conclusion

The results from the N incubation are in general agreement with much of the literature cited. From the results presented it is obvious that for the intended use of the compost treatment its feedstock is critical to its correct usage and application. Understanding the nature of the feedstock is essential. For example; using a green waste or biowaste compost for crop growth alone is not ideal considering the results presented on the basis of N mineralisation. This is due to the fact that both net N mineralisation and immobilisation is a possibility from both of these types of materials. On the other hand using MW compost as a soil conditioner or improver may also be an incorrect use of the material as it has a high level of available nutrients. The MW group would serve as an ideal organic amendment or fertiliser due to the levels of available N and P. Typically N mineralisation for the groups (excluding MW) was low. The GW composts immobilised N. This was also confirmed by the relatively low available N from the other composts that contained green waste as part of the feedstock. This would suggest the primary use of these materials is for soil conditioning/improvement or as a P fertiliser. Any N requirement would require supplementation with a mineral fertiliser.

Predicting N availability from composted wastes has been shown to be better correlated to NDF and lignin content. There was a distinct lack of any relationship between C/N ratio and available N. This has not been widely reported in literature but it does give an opportunity to potential further research as C/N ratio is currently used as method for plant available N in Irish legislation.

The results from the P incubation indicate that available P is higher from all of the materials than N. The MW group had a sufficient amount of P available to ensure a sufficient amount of growth. However, the trend suggests that longer predictions of mineralisation of P maybe more difficult due to the unknown rate of mineralisation of organic P and some of the irregular patterns emerging regarding P mineralisation. The other groups have lower available P but a similar issue with the unknown long term effects. One issue with incubation studies is that they are a closed system and therefore estimating or predicting the amount of N or P that can leached is difficult to achieve.

The MW group have shown to be efficient in N and P availability although may require additional N to be added for optimal crop growth. The BW, IOW and ADC groups all mineralise P but certainly require additional N to be used for crop growth. These groups would suffice to be used as a soil improver/conditioner. The GW group has shown from the results their potential end use is a soil improver/conditioner or for use as an amendment after crop harvest (Vaughan *et al.*, 2011). Planning the usage of the

compost and crop requirement can facilitate management of the compost and possible mineral fertiliser with maximum agronomic, economic and environmental efficacy.

3.6 References

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Chapter 4

The effect of three biowaste composts on phosphorus availability when applied to various Irish soil types: An incubation study

4.1 Introduction

Phosphate adsorption by soils plays a crucial role in phosphate availability and retention with approximately two-thirds of inorganic phosphorus (P) and one third of organic P unavailable (Jiao *et al.*, 2008; Yu *et al.*, 2013). Ireland has a diverse range of soils; especially soils that are primarily used for agriculture and horticulture. From a nutrient management perspective it is important to understand how various soils interact with phosphorus after compost application. Organic matter (OM) has the potential to react with soils by various methods thus influencing the P sorption reactions (Saunders, 1965). The methods are complex as many edaphic factors must be considered namely: pH; soluble aluminium (Al), calcium (Ca), iron (Fe) and their minerals; decomposition of OM and microbial activity (Brady and Weil, 1996).

Crop use of P during growth is low as phosphates are fixed by Al, Ca and Fe in soils (McBeath *et al.*, 2005; Yu *et al.*, 2013). Organic amendments are commonly used in agriculture and horticulture to supply plant available P. Studies have shown crops utilised P more efficiently when applied with organic amendments (Hue, 1990). The

application of compost is thought to reduce P adsorption by soils through a number of mechanisms. These include: organic acids produced after application to soil competing with P fixation sites (Bumaya and Naylor, 1988; Hue, 1992); humic acids reduce P sorption by chelating the ions that sorb P (1994; Lobartini *et al.*, 1998) and partial substitution of Ca binding sites by sulphur compounds (Tan, 2010). It is generally accepted that the application of compost increases P solubility and uptake through the actions of its organic matter. Extensive research has been conducted on the P fixing capabilities of soils (Lopez-Hernandez *et al.*, 1979; Mc Kercher and Anderson, 1989; Ohno and Crannell, 1996; Hunt and He, 2015) and recently the emphasis has been placed on the interaction and benefits of organic amendments in soil (Gu *et al.*, 2011; Yu *et al.*, 2013).

To understand the dynamics and actions of soils in terms of P binding P sorption isotherms have been determined (Bache and Williams, 1971) and applied to the Langmuir Isotherm (Olsen and Watanabe, 1957). The objective of this chapter was to characterise and evaluate soils on their P binding capacity and investigate if the application of three commercially available biowaste composts were influenced by the soils and their potential to sorb P.

4.2 Materials and Methods

4.2.1 Characterisation of the soils

For the incubation experiment 10 soils were sourced from various locations in Ireland. The soils selected were done so on the basis of local knowledge, previous research

conducted and their known characteristics. These soils were then characterised chemically and physically. Three soils were then selected on the basis of their characteristics. The soils were selected that would be most likely to give a contrast in their capacity to sorb P. Soils that were assumed to be low P sorbing and high P sorbing were selected. The textural class of the soils was conducted as per the method described by Miller and Schaetzl (2012) (conducted by NRM, UK). The pH, EC and moisture contents were determined as outlined by Van Reeuwijk (2006). Organic matter was determined by loss – on – ignition (Davies, 1974). The bulk density of the soil was measured using a known volume (McKenzie *et al.*, 2002). Phosphorus retention capacity of the soils was measured at 20°C shaking for 24 hours (Blakemore *et al.*, 1987). Phosphorus adsorption isotherms and sorption maxima using the Langmuir equation was conducted. One gram of ground soil was added to a 50 ml centrifuge tube. 20 ml of 0.01 M KCl solution containing 0, 0.1, 0.5, 1, 5, 10, 50 and 100 mg l⁻¹, KH₂PO₄ (Dunne *et al.*, 2005). Active or amorphous aluminium (Al) and iron (Fe) were extracted by the acid oxalate method (Reeuwijk, 2006). Organically-bound Al and Fe was extracted using sodium pyrophosphate (Reeuwijk, 2006). Both measurements were made using atomic absorption spectrometer (Al – 309.3 nm and Fe – 248.3 nm). Plant-available P was measured by extracting in 0.5 M sodium bicarbonate and measurement using the Murphy – Riley UV spectrophotometry method (Murphy and Riley, 1962).

4.2.2 Phosphorus adsorption calculations

The total amount of P adsorbed including surface adsorption maximum (S_{max}), bond energy constant (k) and the phosphorus equilibrium buffering capacity (PEBC) was

calculated from the following equation (Reddy *et al.*, 1998; Rhue and Harris, 1999; Graetz and Nair, 2009).

$$C/S = 1/kS_{\max} + C/S_{\max}$$

where C is solution P concentration (mg l^{-1}), S is the amount of P sorbed (mg kg^{-1}), S_{\max} is the adsorption maximum (mg kg^{-1}), and k is a constant related to bonding energy (l mg^{-1}).

Phosphorus not recovered in solution was assumed retained by soil (Reddy *et al.*, 1998):

$$[(C_o * V)-(C_t * V)]/M = S'$$

where C_o = concentration of P initially added to extracting solution, mg l^{-1} ; V = volume of extracting solution l; C_t = concentration of P in filtered extracted solution after 24 hours of equilibration, mg l^{-1} M = mass of dry soil used, kg S' = phosphorus sorbed by soil, mg kg^{-1} (Dunne *et al.*, 2005)

The values for P adsorbed are fitted to the Langmuir Equation using the first equation. Both the S_{\max} and K constant are calculated from this. At low P concentrations the relationship between P in solution (C) and P sorbed (S) is described by a simple linear equation. The slope (K) is equal to PEBC. PEBC refers to the capacity of the soil to sorb additional P from solution (Hongthanat, 2010). The PEBC was calculated by taking two points at lower concentrations and calculating the slope between the two points. The soils were also fitted to the Freundlich equation but the soils did not correlate of fit the equation to produce any discernible results.

4.2.3 Incubation

A preliminary incubation was conducted on all ten soils and controls (untreated and chemical – single superphosphate). The composts were added to the soils at 10 mg and 5 mg of total P content per 100 g of soil. Extractions took place at 0 and 7 days. The preliminary test ensured that the soils would produce results that were contrasting and show various effects of the soils on the amendments. From this the three soils were selected. The fourth soil was the soil used in the first incubation (Chapter 3) and the pot experiments (Chapters 5 & 6). The soils were selected largely on the basis of these characterisations. The preliminary incubation did not produce any unusual or unexpected results. The experiment served to confirm the previous suppositions about the soils and that a difference in P availability would occur. The set – up for the incubation involved preparation of the four soil samples and additions of the composts and single superphosphate (SSP) as per Chapter 3. The only difference being that 200 g of soil was used (in 400 mL pots) as the incubation would be running for 12 weeks with extractions taken at 2-week time points. Each sample was prepared in quadruplicate. Four apertures to allow air diffusion were pierced in each pot. The moisture content of the soils was monitored every two days and any moisture losses were replenished with distilled water. At each extraction time point the step by step procedure was followed as per Chapter 3 to extract the sample for orthophosphate. Analysis of the sample was conducted via flow injection UV spectrophotometry method (Lachat quikchem 8500 series 2 autoanalyser).

4.2.4 Statistical analysis

To compare the soil and compost interactions ANOVA through LS means was conducted using SAS 9.3 programme. Slices were added to the LS means to observe the potential four way interactions. Table 4.4 gives all interactions and their significance (Type III effects).

4.3 Results

4.3.1 Chemical characterisation of the soils

The results presented in Table 4.1 show the physical and chemical characteristics of the soils used in the incubation experiment. All soils were considered to be a clay soil for the textural class analysis. Soils SS1, SS2 and SS4 were clay loams with SS3 considered a clay soil. The pH range was from 5.8 – 7.5 showing that the soils were generally neutral. All of the soils exhibited a high P retention capacity typically above 75% in all of the soils. The range of amorphous Al was 82.91 (SS3) – 156.49 mg L⁻¹ (SS1) with the range for Fe being 212.36 (SS2) – 1271.35 mg L⁻¹. A large variance for Calcium was recorded ranging from 2489 (SS3) – 27040 mg L⁻¹ (SS2). These characteristic figures formed a large part of the selection process for the soils used in the incubation. The results presented in Table 4.2 show the phosphorus characteristics for the composts used in the incubation. They also show the organic matter and humic substances results due to the potential for both to release P from the metal binding sites in soils. The organic matter content ranged from 40.23 (BW 3) – 77.74% (BW 10) and the HS content ranged from 143.23 (BW 10) – 352.97 g kg⁻¹ (BW 3).

Table 4.1. Physical and chemical characteristics of soils used in the incubation experiment

Soil	pH	MC %	OM %	Sand %	Silt %	Clay %	Textural Class	P Retention %
SS1	6.8	39.53	16.10	42	22	36	Clay	77.88
SS2	7.5	29.52	8.64	39	25	36	Clay	83.14
SS3	6.4	19.62	5.87	33	22	45	Clay	69.24
SS4	7.2	12.66	4.36	38	24	38	Clay	84.50

	Organic mg L ⁻¹		Amorphous mg L ⁻¹		Ca mg kg ⁻¹	mg L ⁻¹		
	Al	Fe	Al	Fe		Olsens P	Available K	Available Mg
SS1	29.79	151.97	156.49	1271.35	8081	8	48.9	159
SS2	4.28	18.88	100.08	212.36	27040	18.2	70.1	49.5
SS3	10.76	54.31	82.91	385.86	2489	12.2	222	245
SS4	14.52	61.95	79.33	262.45	3934	12.6	83.3	90.3

4.3.2 Phosphorus adsorption capacities of the soils

The soils maximum sorption capacity (S_{max}), bond energy constant (K) and PEBC are presented in Table 4.2. These figures give an indication of the soil's potential to bind P. The range for S_{max} was quite large at 500 – 1250 mg kg⁻¹ with SS3 having the highest adsorption maximum. The bond energy constant gives an index for potential P loss ranged from 0.4 – 1.36 L kg⁻¹ and was within the expected range for neutral to alkaline soils. The PEBC gives the capacity for soil to buffer additional P in water

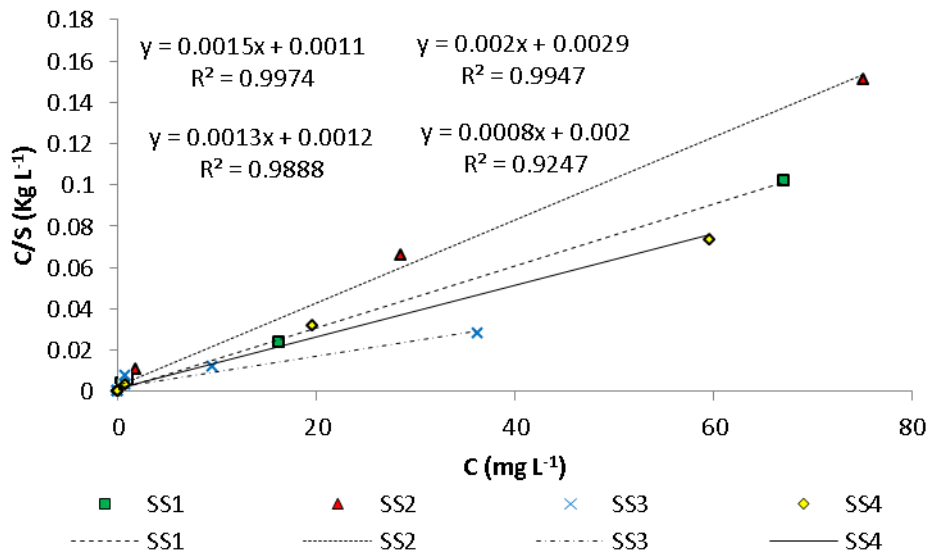


Figure 4.1. Linear fit plot of the Langmuir isotherm for the soils. Equations of the line are orders clockwise from top left SS1 – SS4.

The R^2 figures show an excellent correlation for three of the soils. SS3 had a slightly lower coefficient ($R^2 = 0.9247$). The Langmuir method that was applied based on the specific soil parameters is one of the most commonly applied and was applied on this basis from the other three that may also be used (Zhang *et al.*, 2015).

Table 4.2. Maximum phosphorus sorption capacity (S_{\max}), bond energy constant (K) and the phosphorus equilibrium buffering capacity (PEBC) of the soils used in the incubation

	S_{\max} mg kg^{-1}	K L kg^{-1}	PEBC L kg^{-1}
SS1	667	1.36	128
SS2	500	0.68	70
SS3	1250	0.40	74
SS4	833	1.00	108

Table 4.3. Chemical characteristics of composts used in the incubation experiment

Treatment	pH	Total P g kg ⁻¹	mg L ⁻¹			Organic Matter	HS g kg ⁻¹	Ca mg L ⁻¹
			DTPA P	Mehlich 3	Olsen			
BW 3	7.7	2.4	10	836	390	40.23	352.97	9239
BW 4	6.5	3.3	15	857	372	55.29	159.27	10819
BW 10	5.8	2.4	98	561	554	77.74	143.23	4959

The characteristics for the composts presented in Table 4.3 show the total P and plant available P. Four different methods for extracting plant available P were conducted on the composts. The composts also had a large variance for both organic matter and humic substances. This was a big factor in selecting the compost as these two parameters are the main mechanisms by which P can be released from soil binding sites. These were also selected due to their commercial availability of other types of compost.

4.3.3 Incubation results

The results in Fig. 4.1 – 4.4 exhibit Olsen extractable P for compost treatment and the chemical control (SSP) at each extraction point from 0 – 12 weeks. The left hand side graph shows compost added at 10 mg /100g soil with the graph on the right showing the lower rate of 5 mg/100g of soil. Fig. 4.5 shows the untreated soils (soil only) during the same time period. The highest available P was from the SSP treatment. This was expected given the lower availability from the biowaste composts in the first incubation in chapter 3. The effects of soil type are more pronounced on both BW 10 and SSP. The effects are less pronounced on BW 3 and BW 4. The effect of the soil type indicates that SS3 had the most effect on the composts and SSP. This might have been expected due to the high S_{max} recorded. The SSP displayed quite a steadily decreasing

unavailability of P. From the graphs in Fig. 4.4 it is clear that the initial high available P that was present had significantly decreased by the conclusion of the experiment. All of the soils had a more uniform effect on the availability of P whereas the composts tended to give more unpredictable response. It is not known how much effect the agitation of the samples had as they were routinely agitated when the moisture levels were adjusted.

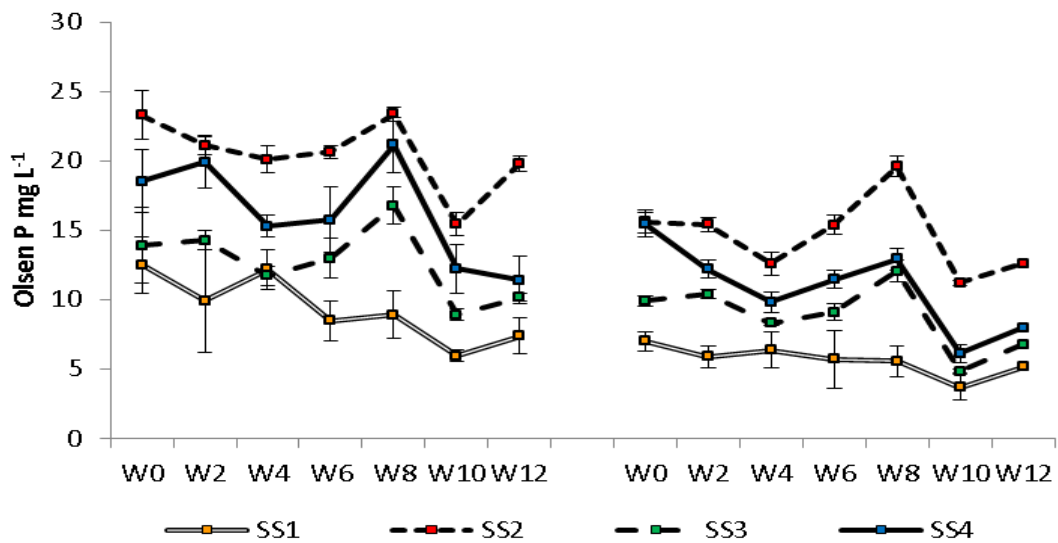


Figure 4.2a and b. Olsen extractable P of BW 3 at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at each extraction time point from week 0 to week 12. Error bars indicate standard deviation. Individual results can be found in Appendix A.3

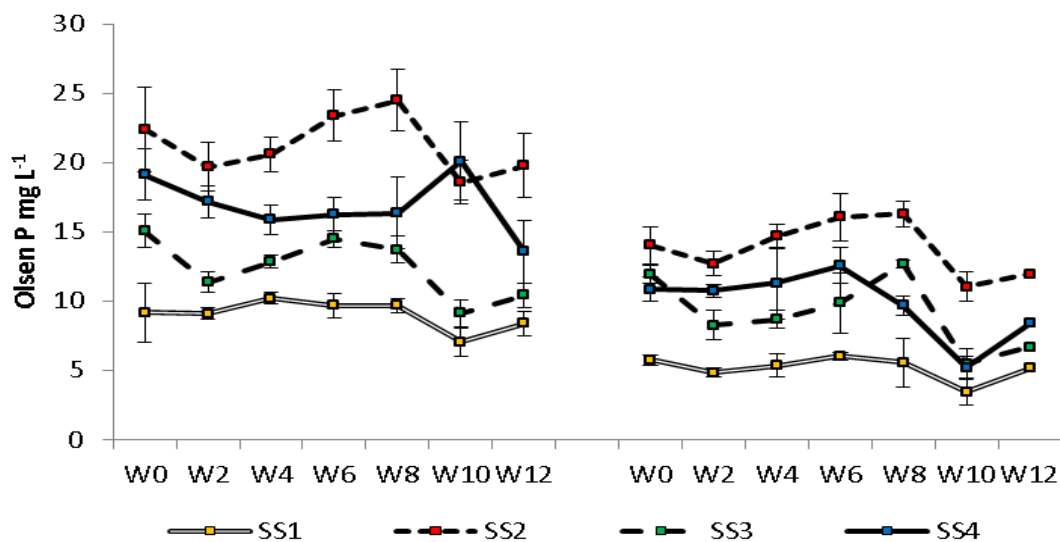


Figure 4.3a and b. Olsen extractable P of BW 4 at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at each extraction time point from week 0 – week 12. Error bars indicate standard deviation

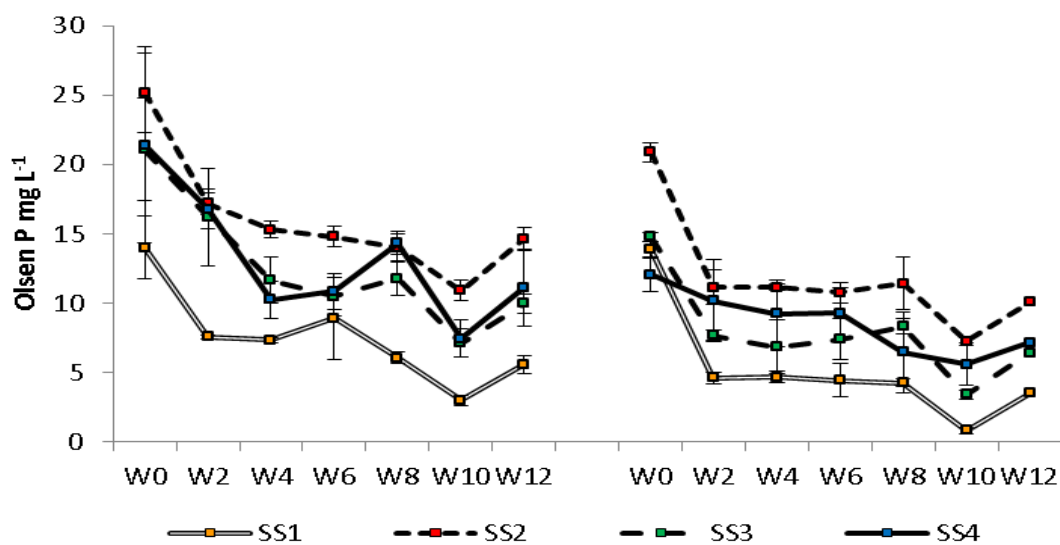


Figure 4.4a and b. Olsen extractable P of BW 10 at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at each extraction time point from week 0 – week 12. Error bars indicate standard deviation

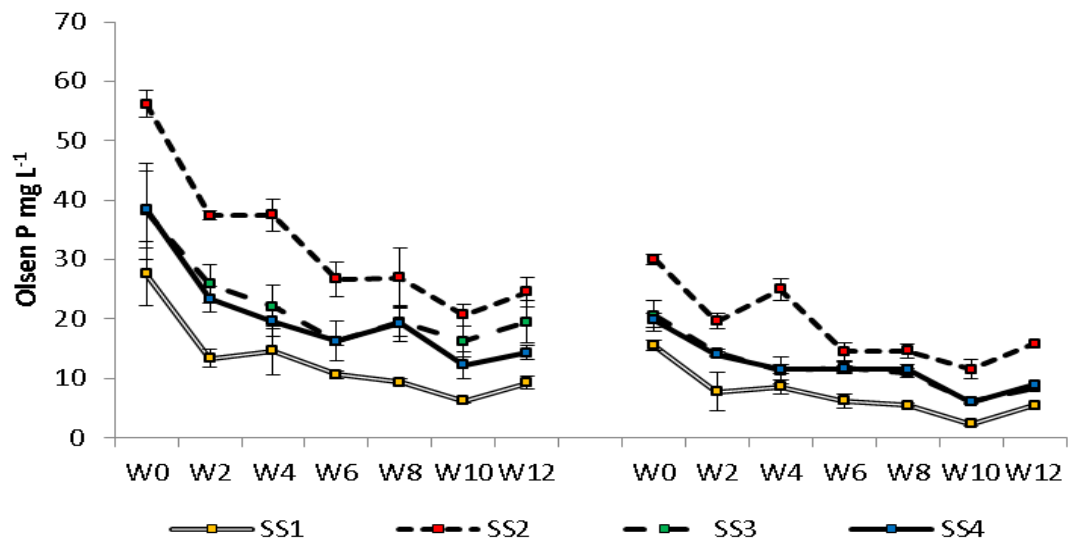


Figure 4.5a and b. Olsen extractable P of SSP at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at each extraction time point from week 0 – week 12. Error bars indicate standard deviation

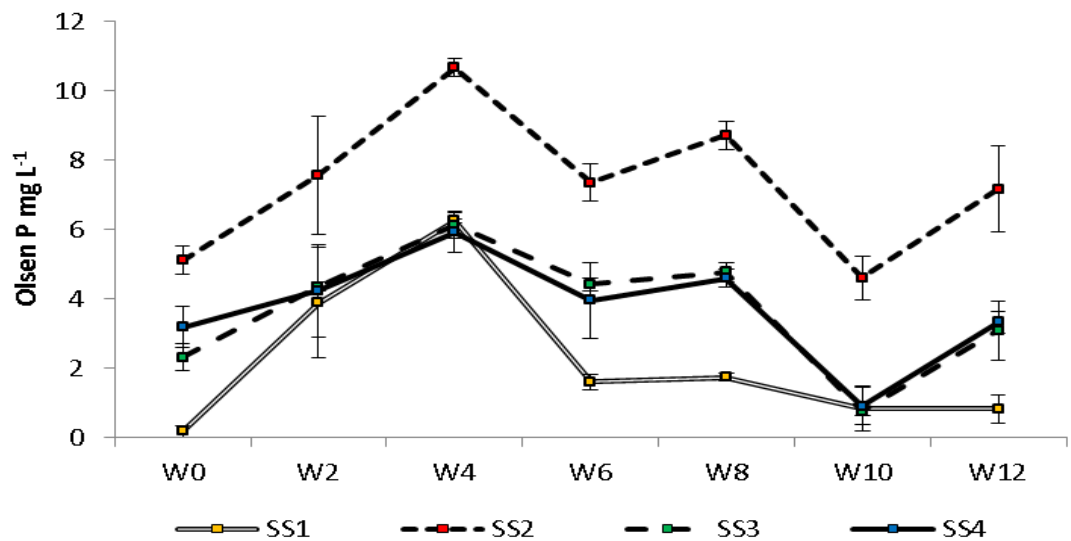


Figure 4.6. Olsen's extractable P of untreated controls (soils) at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at each extraction time point from week 0 – week 12. Error bars indicate standard deviation

The untreated controls (soils only) presented in Figure 4.6 show that SS2 had the highest available P levels. This was expected as it also had the highest Olsen P. There

was quite an uneven availability of P from the other three soil samples. SS1 had the lowest level of Olsen P and generally was lower than the other soils. The relatively high standard deviation at some of the extractions may be attributed to the high variable nature of the soils from one sample to the next.

Table 4.4. Type III test effects examining the significance of each effect within the model

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	109	1091.41	<.0001
Rate	1	109	1542.12	<.0001
Treatment*Rate	3	109	8.36	<.0001
Soil_type	3	109	1071.2	<.0001
Treatment*Soil_type	11	109	10.39	<.0001
Rate*Soil_type	3	109	3.49	0.0182
Treatme*Rate*Soil_type	9	109	1.81	0.0749
Time	6	701	300.23	<.0001
Treatment*Time	24	701	36.93	<.0001
Rate*Time	6	701	6.44	<.0001
Treatment*Rate*Time	18	701	0.85	0.6404
Soil_type*Time	18	701	6.73	<.0001
Treatme*Soil_type*Time	66	701	2.91	<.0001
Rate*Soil_type*Time	18	701	2.11	0.0047

4.4 Discussion

The results presented highlight that the composts were less affected by soil type than the SSP. From the first extraction at W0 to the final extraction at W12 both the SSP and BW 10 displayed a decrease in P availability while both BW 3 and BW 4 had fluctuating P availability. This is seen in the general increase in P availability from W0

to W8 before a drop in P was observed. This is further emphasised by the percentage difference in P available from the first extraction to the final extraction. The average percentage differences across the four soils for the treatments were; BW 3 (30%), BW 4 (20%), BW 10 (51%), SSP (59%). For the compost BW 3 an average reduction of 30% was observed whereas the SSP exhibited an average 59% reduction in P availability. This highlights the significantly greater effect the soils had on SSP. This confirms the previous results presented by Hue (1990) and the mechanisms proposed in literature suggesting that organic matter complexes P binding sites such as Al and Fe (Iyamuremye *et al.*, 1996).

The interactions between compost and soil are presented in Table 4.4. All of the interactions were seen as significant ($P < 0.01$). Unfortunately all of these are strongly significant. This gives very little insight as to what is happening. Due to the four-way interaction or soil*compost*rate*time there are a huge amount of permutations. Interpreting the results from a statistical viewpoint is more challenging and therefore is better served to be interpreted from the results and the current literature available.

A recent study also reported a significant decrease in S_{max} of soil after compost application during an incubation experiment (Qayyum *et al.*, 2015). The authors also contribute this reduction to organic acids being sorbed to the metal binding sites. The fact that BW 10 had a far higher level of organic matter than BW 3 and BW 4 would suggest that the humic content of the compost was responsible for reducing the amount

of P sorbed. However, it is unclear as to whether the humic or fulvic content is responsible, a topic of debate which has yielded very different results previously. This is due to the fact that both HA and FA are soluble in optimum agronomic conditions (Guppy *et al.*, 2005). Sibanda and Young (1989) found FA's to be more effective in reducing P sorption when added to highly weathered soils. Wang *et al.* (1995) found that addition of humic acids with fertiliser increased P uptake by 25% in wheat. Both BW 3 and BW 4 have a far higher FA levels with BW 10 having higher HA levels. This would suggest the FA's are more active in replacing sorbed P at the activation sites. It has been suggested that FA's and HA's can act as P sorbing surfaces (Perrott, 1978). It has also been suggested that in weathered soils FA's and HA's that bind P may slowly mineralise the P to become plant available (Pushparajah, 1998). This is also evident in the phosphorus pot experiment where P from the BW and GW composts was being slowly mineralised throughout the experiment. This suggests that the compost bind the P through the FA's and HA's before making it slowly plant available.

The effect of BW compost addition also added an excess of carbon which will have activated the microbes within the sample matrix (García-Gil *et al.*, 2000). This initial flush of microbial activity may have served to immobilise the inorganic P added from the compost - previously discussed (Khan and Joergensen, 2009; Liptzin and Silver, 2009). Liptzin and Silver discuss the relationship between the reduction of Fe and release of P before being immobilised by microbes. This would further enhance our results that show FA's were active in releasing P to become plant available. During the

initial stages the control samples displayed an increase in Olsen P (W0 – W4) whereas the compost/soil samples displayed a decrease, also demonstrating the effect the compost had in stimulating microbial activity within the compost/soil matrix. This effect was more pronounced in the lower compost additions. The 5 mg rate for BW 3, BW 4 and BW 10 all show a large decrease in Olsen P (strictly compost Olsen P i.e. soil subtracted) from W0 – W4. Furthermore, a decrease in P was observed from W8 – W10 across all of the control samples. This drop was also observed in the compost samples. However, as with the other P fluctuations the drop in P was least in BW 4. The decrease was more pronounced than was seen in the 10 mg rate displayed in Fig. 4.6.

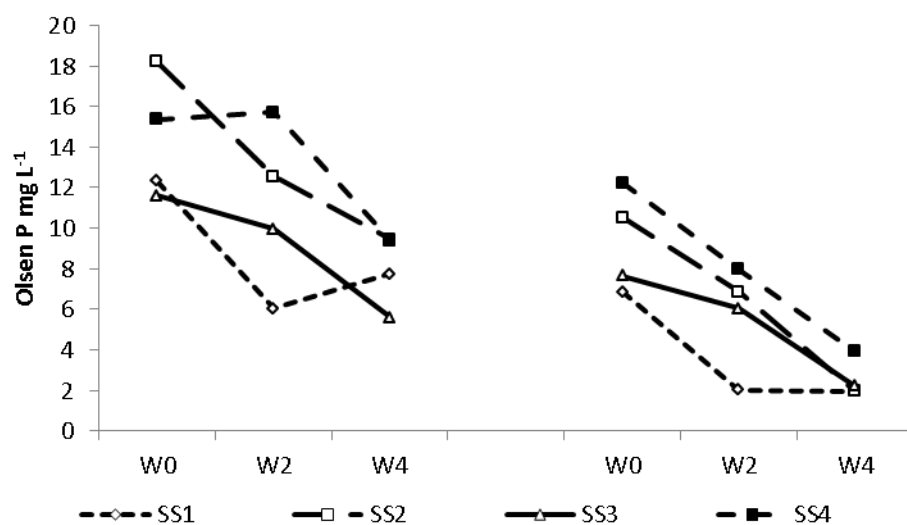


Figure 4.7. Olsen's extractable P of BW 3 at rates 10 mg 100g⁻¹ soil and 5 mg 100g⁻¹ soil at extraction time point W0 – W4 highlighting the microbial immobilisation of P

The least pronounced affect is on BW 4. This compost is quite similar to BW 3 but has half the level of FA's of BW 3. However, it is high in sulphur (S) content; quite significantly higher by as much as five times higher than BW 3. Studies have been

conducted to investigate the effect sulphur has on phosphorus uptake (Taalab *et al.*, 2008). The authors' results showed an increase in P availability and uptake when elemental sulphur was applied together with mineral fertiliser P. This result was only seen for SS1 and SS2 at the higher rate where P was cumulatively higher in BW 3 compared to BW 4.

The microbial effect of immobilising P was also observed in the P pot experiment (chapter 5). At every second harvest a reduction in P uptake was observed bar one harvest. This meant that after replanting the next crop, the uptake was generally lower than the preceding harvest. This would suggest that the agitation of the compost/soil matrix reactivated the microbes which may have temporarily immobilised P causing a lower uptake in the succeeding harvest.

The effect of soil is not so apparent on viewing the graph. However, there are some significant differences between the soils. Relating to the compost samples alone SS2 appears to have a strong effect on BW 10 but not on the other composts. There is a significantly lower cumulative P uptake for BW 10 compared to BW 3 and BW 4 ($P < 0.05$). SS2 had the highest total Ca levels and a pH of 7.5. The addition of the BW 10 to this soil at its pH would suggest that Ca was quite active in binding P. The binding of P by calcium is most active in the alkaline pH range (Hopkins and Ellsworth, 2005). SS4 had an effect on BW 10 in reducing P availability. SS4 had the highest P retention capacity but this was not reflected in any other parameters. BW 10 had the highest

Olsen and CaCl_2 DTPA P figures (554 and 98 mg L^{-1} respectively) and would therefore be expected to have a higher available P. SS1 had a slightly acidic pH and the highest levels of Fe. This would suggest that Fe was active in binding P as it is most active at lower pH's (Jackman and Black, 1951). However, there was no significant effect on any of the composts. From W8 – W10 SS2, SS3 and SS4 display a large fall in P which is mirrored in the subsequent drop in P of BW 3 (both rates) and BW 4 (5 mg). BW 4 (10 mg) does not display as large a decrease in available P. This indicates that the physical volume and rate was significant regarding BW 4.

The chemical control (SSP) was significantly affected by SS4 similar to BW 10. It can also be said that all of the soils reduce the available P. The composts show fluctuations in their available P whereas the SSP only decreased in time. All four of the soils decreased the level of P from the start of the incubation to the end. Generally no increases were observed during the experiment.

The net percentage recoveries were in general quite low. The highest recovery was approximately 20% at W0 for SS2 amended with BW 10 at the high rate. These figures are akin to the first incubation experiment. However, these results did not translate to the pot experiment. This suggests that there is a significant interaction between the plant roots and the soil nutrients which is not apparent from an incubation experiment. This is due to a higher concentration of plant available nutrients in the vicinity of the plant roots (Barber, 1962). Plant roots also play a role in mineralising organic P during the

latter stages of growth (Sinaj *et al.*, 2002). This process was observed by Sinaj *et al.* on a sandy soil and not on the clay soil used in the experiment.

The S_{\max} , K and PEBC values for each of the soils showed that SS2 had lowest binding capacity for P. From the incubation experiment it shows that the Langmuir equations fitted the soils. However, the caveat with the equation is that it is known to underestimate adsorption by as much as 30% (Holford, 1997) and therefore the more accurate “2 surface” equation is required to give more accurate results (Holford *et al.*, 1974). The use of this equation was not used here due to its complexities and the lack of necessary computational software. Also the Langmuir equation is widely used under the pretence that the 30% underestimate is taken into consideration. The highest S_{\max} value was SS3 (1250 mg kg⁻¹). This may have been due to the higher clay content (Khan *et al.*, 2010). However, the clay content may not have been significantly higher to cause such a high S_{\max} value. SS3 was a coarse soil with quite a high amount of mineral material. The expected high P sorbing capacity may not have been achievable due to the low surface area which the compost P may not have bound to easily. Three of the composts were highly correlated to the equation ($R^2 > 0.98$). Only SS3 was less than this value ($R^2 = 0.9247$). This was an unusual result as this soil series had been expected to be high P sorbing.

4.5 Conclusion

The application of the composts produced numerous interactions of which all were significant ($P < 0.01$). There was an effect of compost type, soil type and rate. All of the composts used were similar in their feedstock and total and available P. Therefore it can be concluded that there was other characteristics of the composts that produced the different results during the incubation experiment. As has been discussed there is a strong possibility that the fulvic content of the compost had a major effect on releasing P from the soil binding sites. This is evident in the results for BW 3 and BW 4 when compared to BW 10 (very low FA). Soil samples SS1 and SS2 had a pronounced effect on reducing P availability from BW 10.

The capabilities of the soils to bind P were quite difficult to evaluate from the soil characteristics. This was primarily due to the nature of the results. The variation in the P retention capacity was quite low. However, a wide variation was reported for their amorphous metals (Al and Fe) and their P binding capacities. The P retention test may serve a purpose but was found to be less accurate in the current experiment.

The use of the incubation experiment is quite time consuming and lengthy. From the two incubation experiments conducted the results are not sufficient to give accurate predictions of P availability. The P pot experiment has shown that biowaste composts have a far higher than expected P availability during a two year growing season than the incubation results predicted. The effect of plant roots in the compost/soil matrix is

major component of P mineralisation mechanism and must be considered when assessing compost P availability.

4.6 References

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Chapter 5

Effect of compost and co – application of compost and fertiliser nitrogen on plant nitrogen uptake:

A glasshouse study

5.1 Introduction

Over and under-application of Nitrogen (N) is a problem associated with both inorganic and organic amendments in agriculture. Understanding the availability of N and the uptake of available N by plants in agriculture is of critical importance to the sector. Typically in agriculture, inorganic fertilisers in the forms of calcium ammonium nitrate, urea or sulphate of ammonia are added to soil to improve N availability to plants. One problem encountered with this practice is the high level of nitrate and its solubility. The EPA literature study on nitrogen availability from compost indicated that N availability is affected by feedstock (Prasad and Foster, 2006a). The instant availability of N and its solubility in water quite often leads to N being lost to subsurface groundwater through leaching. As mentioned in Chapter 1 this can lead to rapid algal growth in water systems which is ultimately detrimental to water quality and can cause irreparable damage to local aquatic ecosystems. High levels of nitrate in drinking water are detrimental to human and animal health and have been documented by the WHO (Speijers and Fawell, 2011).

The introduction to the thesis broadly outlines the need for compost to be used in agriculture and horticulture. For compost to be implemented successfully in these Irish industries the behaviour of the composts must be investigated. A pot based growing trial was conducted where the composted waste materials are applied at varying rates to soil – based on their total N content. Typically soils are low in available N. Contrastingly plant N requirements in relation to other nutrients is high and has a major impact on crop yield (Prasad and Foster, 2006a). Therefore addition of different composted wastes was applied at varying rates with an aim to quantifying the uptake of N by cabbage plants over multiple harvests. The application of the composted wastes at different rates allows for the evaluation of uptake of N with the aim of quantifying the maximum amount of N available.

Due to the high and immediate availability of N it is more ideal to supplement composts with an inorganic form of N. Three different composted wastes were also co – applied with CAN to soil to evaluate the response of crops to compost and mineral N simultaneously. Finally after the experiment is completed the pots were left fallow for six months before replanting of cabbage plants. This was done to investigate the potential for composts to mineralise organic N during a fallow period or during a crop rotation.



Figure 5.1. Nitrogen and phosphorus growing experiments mid harvest

5.2 Materials and methods

Data in relation to available N was obtained from the incubation experiment conducted in Chapter 3. Composts for the pot study were selected on the basis of available N, compost characterisations as defined in Chapter 2 and on the basis of feedstock. On the basis of the Incubation study each of the composted wastes within the larger study was assigned a ‘nitrogen release profile’ (Table 5.1). This was done so as to ensure a good mixture of nitrogen release rates and different feedstock materials. Consultation on the selection on the composts was extended to the representatives of the composting sector, regulatory agencies and third level institutes.

Table 5.1 Composted wastes selected for the growing trial including the treatment label, classification group and the feedstock material and N release profile

Treatment	Group	Feedstock material	Release Profile
CAN	Control	Calcium ammonium nitrate	N/A
BW 2	Biowaste	Brown bin & green waste	Medium
BW 4	Biowaste	Mixed (Seafood) waste	Medium
BW 7*	Biowaste	Catering Waste	Medium
BW 11	Biowaste	Brown Bin Compost	Medium
BW 12	Biowaste	Brown Bin Compost	Medium
MW 3	Manure waste	Chicken Manure	High
MW 4*	Manure waste	Broiler Manure	High
MW 5	Manure waste	Poultry & pig manure	High
GW 3*	Green waste	Green Waste	Low
ADC 1	AD compost	AD & green waste	Low
Soil	Untreated	Clay loam soil	N/A

Table 5.2 Selected nitrogen characteristics and mineralisation parameters of the compost treatments

Treatment	Total N g kg⁻¹	NH₄ - N mg L⁻¹	NO₃ - N mg L⁻¹	Organic Matter %	Lignin %	Reflux %	C:N Ratio
BW 2	13.4	1	366	28.88	57.5	63.2	10.2
BW 4	20.4	5	477	55.29	38.5	59.0	10.1
BW 7*	25.0	2	473	51.57	43.8	60.9	10.0
BW 11	17.0	3	68	65.70	40.7	69.7	16.4
BW 12	17.4	6	221	62.37	44.4	64.8	15.8
MW 3	35.4	2722	13	78.61	13.4	42.1	12.2
MW 4*	44.1	945	19	82.86	12.3	34.7	10.0
MW 5	10.3	4681	10	64.59	16.4	36.4	10.0
GW 3*	34.5	1	82	74.56	53.0	68.4	10.1
ADC 1	20.2	2	338	30.97	51.2	56.3	8.5

*Composts with an asterisk were also used in the extra CAN trial

5.2.1 The growing trial – plant nitrogen uptake from composts applied to soil

The experiment was designed in a 12 x 3 factorial design. There were three absolute control treatments. This gave a total of 42 treatments. Each plot consisted of one 2 L pot. The experiment contained six replicates. This gave a total of 252 pots. Surrounding the trial pots was a guard row layer of pots to mitigate the edge effect. The pot based experiment was set up first by sieving the soil to 10mm through a sieve and air dried for two weeks. The soil was then adjusted to approximately 15% moisture. For each individual treatment and rate 12 litres of soil was required. The soil for the experiment was sourced from a farm in Navan, Co. Meath. The soil characteristics are listed in Table 5.3. Both nitrogen and phosphorus levels for the soil were categorised as Index 1 (Teagasc Green Book). Forty two lots of 12 L of soil were weighed out. Superphosphate (50 kg/ha P) and sulphate of potash (100 kg/ha K) were added to each.

Table 5.3 Selected soil chemical characteristics used in the pot trial

pH	Available mg L ⁻¹			Total mg kg ⁻¹	Textural % w/w		
	P	K	Mg	Ca	Sand	Silt	clay
7.2	12.6	83.3	90.3	3934	38	24	38

Each lot was mixed thoroughly using the ‘Kinsealy method’. The Kinsealy method involves heaping one pile of the compost/soil mixture on a bench. The pile is then taken one handful at a time from the top of the pile and a new pile is created adjacent to the original pile. This is repeated four times to give a complete mixture of the compost and soil. The composts selected for the trial were applied at three rates. There was a low

rate (LR) of 150 kg N/ha (100 mg N/L), a medium rate (MR) of 300 kg N/ha (200 mg N/L) and a high rate (HR) of 450 kg N/ha (300 mg N/L). The rates were decided upon based on appropriate agronomic application rates and also consideration was given to fact that the experiment was planned to run over 24 months. For each rate the amount of compost to be weighed out to be added to 12 L of soil was calculated based on the total N content of the compost and the dry matter. The composts were sieved to 10mm as total N content was based on this particle size. Each treatment was added to a 12 L lot of soil using the 'Kinsealy method'. The compost/soil mixture was then filled into an each individual pot and placed into its block in a randomised order. Each pot was placed on a saucer to prevent leaching of N from the system due to excessive watering. Once all the treatments were in place, a light watering was applied to moisten the treatments. Three cabbage ('hispi' variety) plants were then planted into each pot. The cabbage plants were grown for two weeks in peat compost (seedling substrate – Bord na Móna) in a heated glasshouse until the second cotyledon growth stage.



Figure 5.2 Planting of the cabbage plant at the second cotyledon growth stage
The guard row pots were done in the exact same manner except for these pots contained A 50:50 mixture of soil and peat compost (Nursery Grade). The cabbage plants were allowed to grow until the physiological stage where the leaves of neighbouring plants began to overshadow each other. The plants were monitored on a daily basis with sufficient water being applied daily. Once the plants reached the stage of where they began to overshadow each other in the best treatments – a harvest was conducted. Each pot was harvested individually with the plants being cut from just above the top layer of soil. The three plants from each pot were put in to a labelled bag and weighed. The samples were then dried overnight at 70°C in a fan assisted oven (Memmert). A dry weight of the plant was taken and the sample was then ground up through a mechanical mill (IKA MF 10.2 grinding mill) through a 2 mm screen for nutrient analysis.

5.2.1.1 Plant nitrogen uptake from composts co – applied with nitrogen fertiliser

Three composts from the nitrogen trial were selected to be co – applied with CAN to the same soil. A biowaste, green waste and manure waste compost were all selected and applied at the three rates previously stated. The chemical control CAN was applied with the compost at 60 kg ha⁻¹. This trial was incorporated into the nitrogen pot trial. A repeated application of CAN at the same rate was continued throughout the harvests until completion.

5.2.1.2 Plant nitrogen uptake after six month fallow period

After the end of the last harvest the pots were then left for a six month fallow period. At the end of the six months cabbage plants were replanted and grown until the second cotyledon stage. From there the same procedure was followed as per the other harvests and analysis.

5.2.2 The digestion procedure and analysis

The digestion (Foss Tecator 2020 digestor) procedure for the plant analysis was conducted by weighing out 0.2g of the ground plant sample and digesting it in 6 mL of concentrated H₂SO₄ (containing 5% selenium) at 380°C for 2.5 hours. Once the digestion was complete the samples were allowed to cool. Upon cooling 10 mL of DI H₂O was added to each sample. This step was conducted to stop the formation of calcium sulphate. The samples were left overnight to degas. The samples were then placed in a 50 mL centrifuge tube and placed in cold storage (Sahrawat *et al.*, 2002).

The analysis of the plant tissue digests was completed using an automated UV spectrophotometry method at 640nm (Lachat quikchem 8500 series 2 autoanalyser).

The limit of detection was 0.025 mg/L. Each of the samples were analysed for ammonia (NH₃) concentration. Each sample was prepared by diluting to 50mL with DI H₂O. Standards were prepared for each of the samples within the specific range that the samples were expected to fall (0 – 10 mg L⁻¹).

5.2.3 Statistical analysis

Statistical analysis of the results (One – way ANOVA with Tukey pairwise comparison) was conducted with SAS 9.2 with all significant differences identified at $P < 0.05$.

5.3 Results

5.3.1 Pot experiment

The fresh and dry weight figures for the eight harvests are presented in Fig. 5.1 a – g. In general the plant weights followed the trend with the highest rate of application producing the large plant size. This is most pronounced at the first harvest where the largest uptake of N was recorded. This became less pronounced throughout the trial as the rate of N uptake was significantly less. The effect of light and temperature can be seen in the plant weights in harvest 4 – 6 and there is a gradual increase in plant weights. These harvests took place during the transition from winter months to summer months.

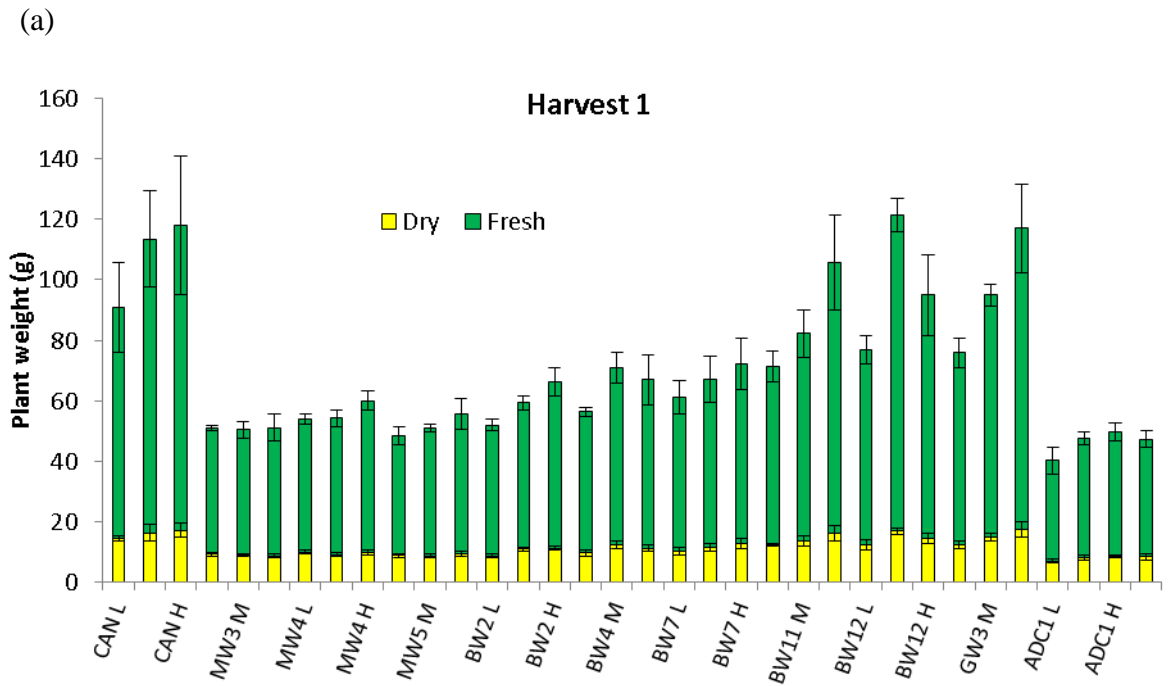
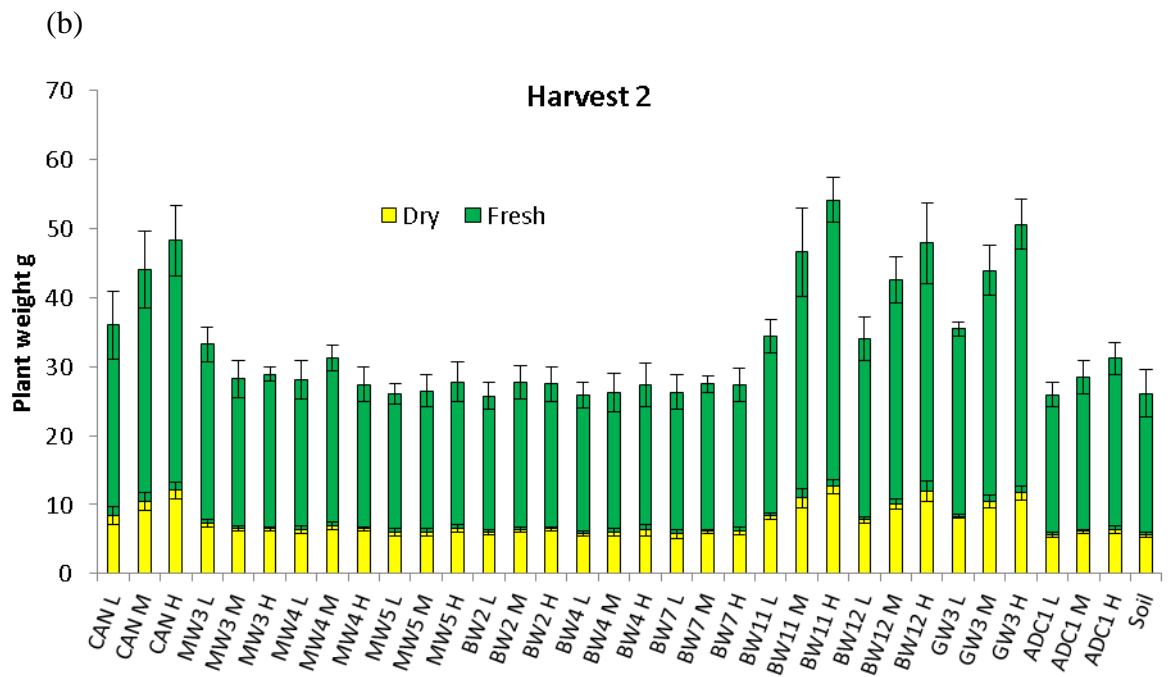
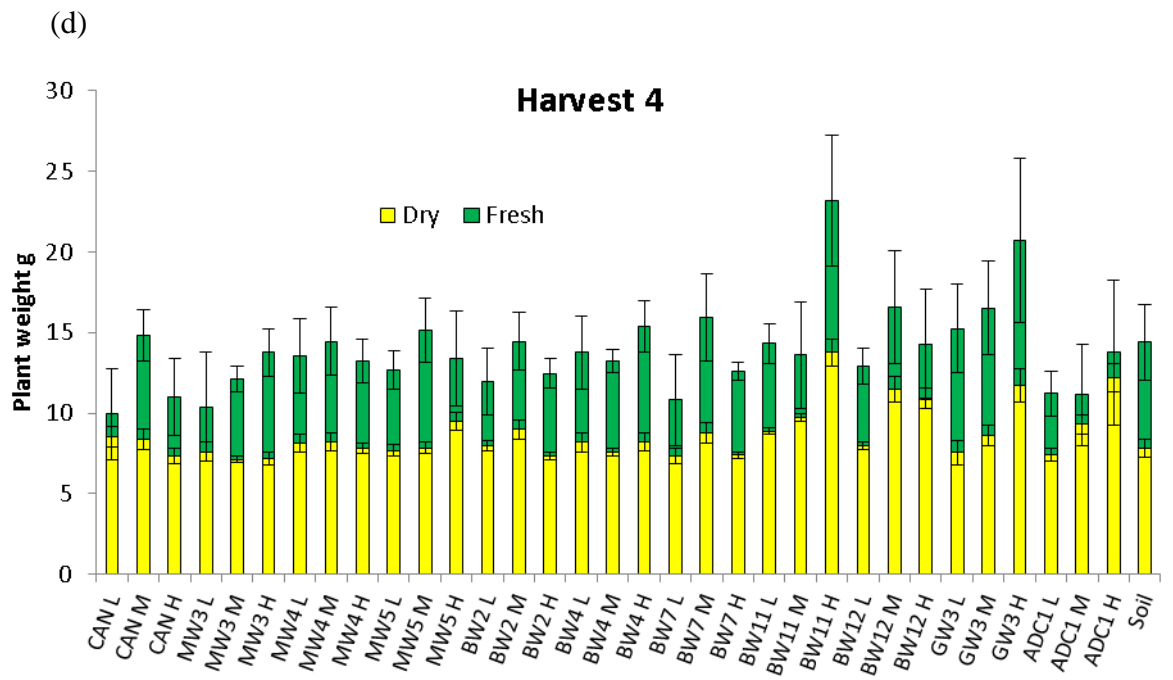
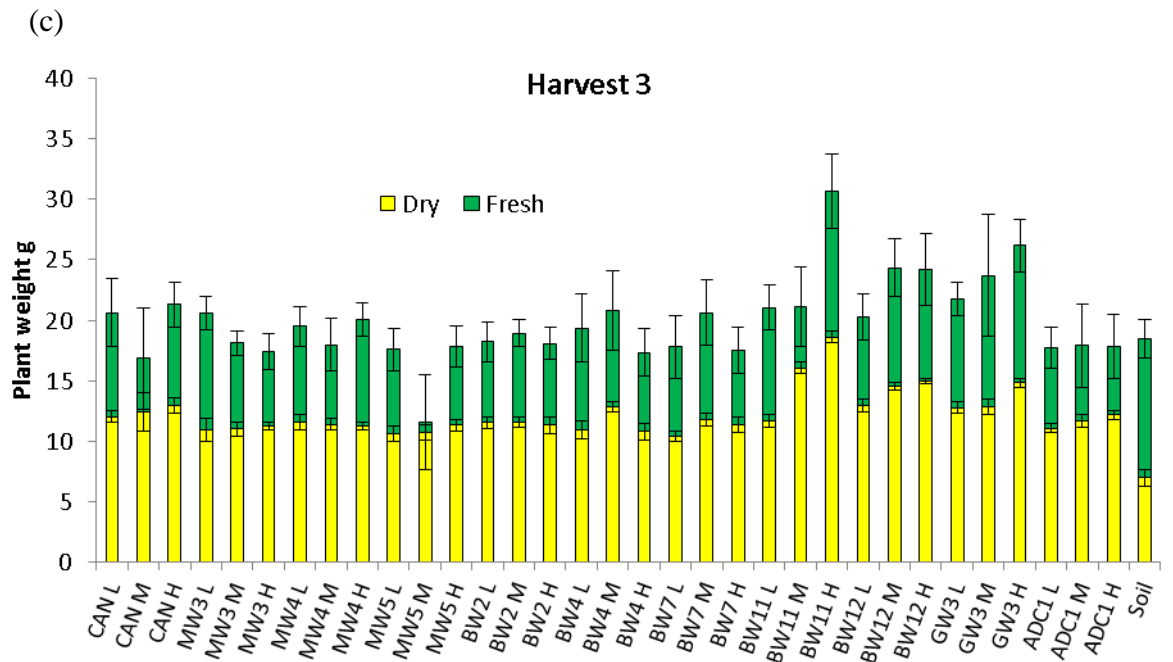
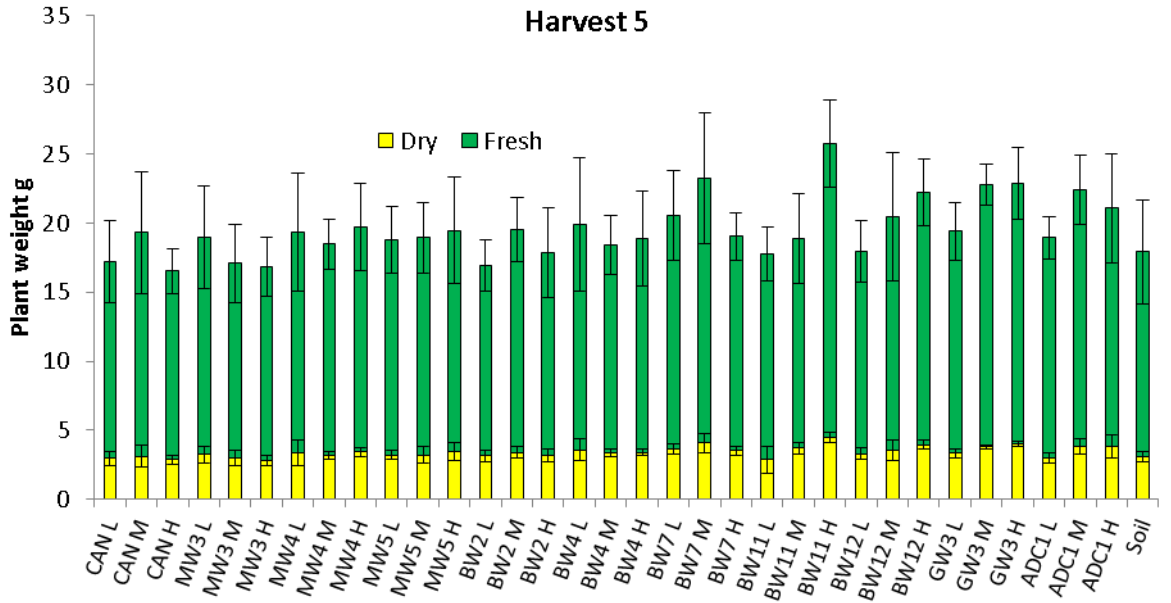


Figure. 5.3 a – h. Fresh and dry weights of all compost treatments and controls used in the pot experiment. The bars show the fresh weight overlapped on dry weight

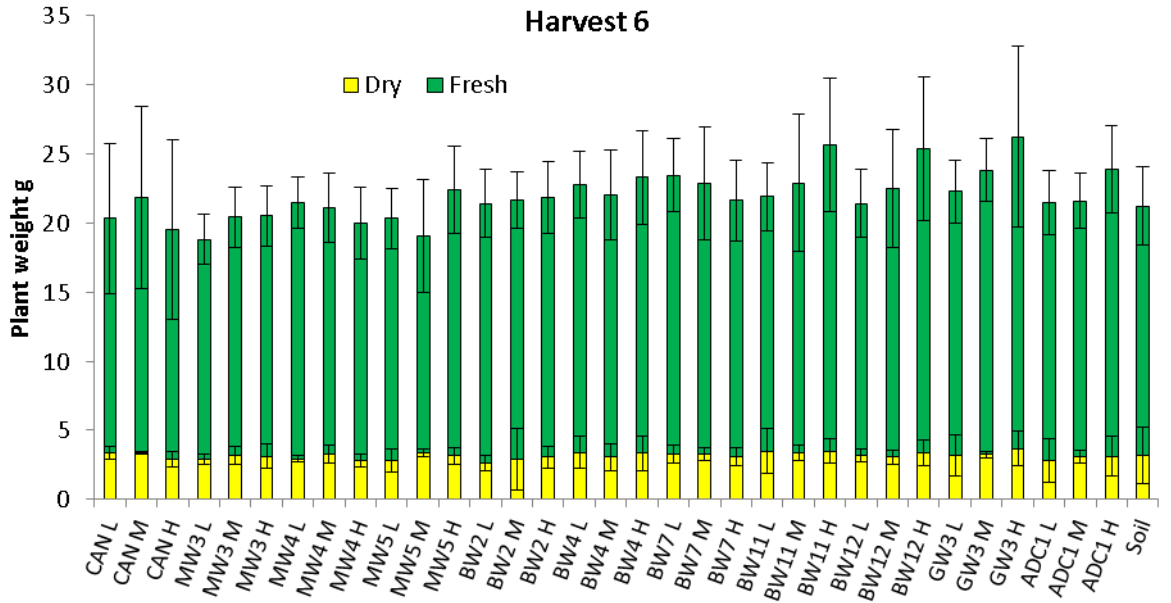


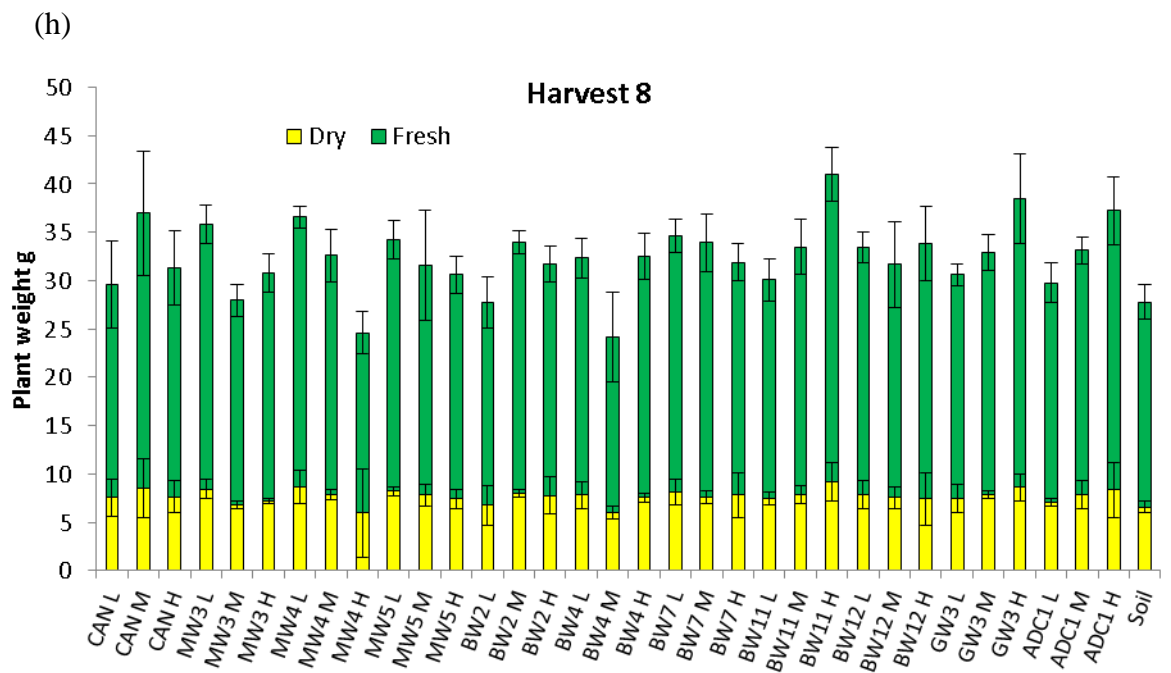
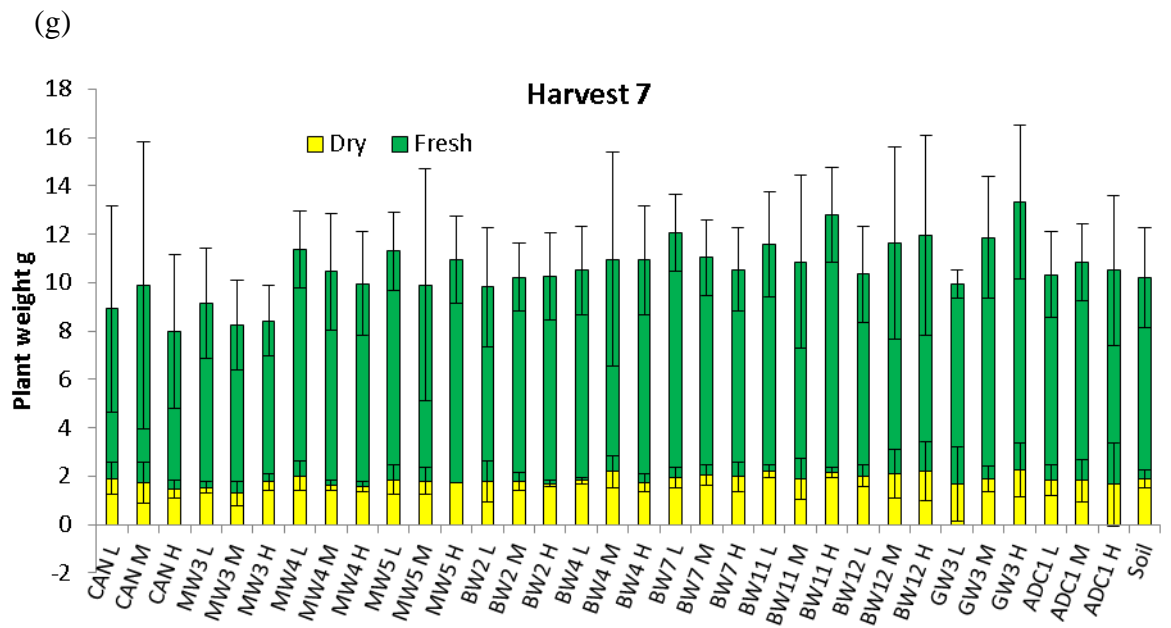


(e)



(f)





CAN figures were highest with an initial uptake of 205.1 (LR), 321.27 (MR) and 465.93 (HR) mg N dw⁻¹ for their respective rates. There was a rapid decrease in N uptake by

the plants; as by the fourth harvest the N uptake was 16.78, 21.65 and 14.30 mg N dw⁻¹ respectively. The uptake data for the untreated control read as 65.74 mg N dw⁻¹ for the first harvest decreasing to 17.78 mg N dw⁻¹ for the fourth harvest. Figures for the soil were taken as an average of three replicates. This trend continued until the final harvest where an increase in N uptake was observed in all the treatments. MW 5 (composted poultry/pig manure waste) exhibited the highest available N for the compost treatments with uptake data of plant uptake of N. The lowest performing MW compost was MW 3. This was most likely due to the higher NH₄ content and higher OUR figure (P<0.05). The biowastes were the largest group in the trial with a sample size of five. These ranged from food/catering waste composts to brown bin waste compost and sludge compost. Both BW 4 and BW 7 (catering/food wastes) performed stronger than the other three biowastes in the first harvest. BW 11 and BW 12 (both brown bin waste) were the lowest performing biowastes. Both BW 4 and BW 7 were significantly different from BW 12 (P>0.05). After the first harvest the uptake of N was relatively uniform across all treatments within the biowastes group. Both the BW and MW compost groups exhibited a minor increase in N uptake from harvest four to harvest six. This was again observed at harvest 8. The increase was much greater at harvest 8 and was significant (P <0.01 both groups). This is quite possible due to the prolonged period or warm weather before the 8th harvest.

In this experiment there was only one green waste (GW 3) as greenwastes on their own are unlikely to be available for land application and will most likely be used as a carbon

source for co – composting with other materials. The middle rate of application (300 kg ha⁻¹) was the highest uptake result for the first harvest. The three figures for harvest one were 77.25 (LR), 95.34 (MR) and 79.60 (HR) mg N dw⁻¹. The low uptake at the HR was possibly caused by microbial biomass immobilisation of N instigated by the large quantity of carbon added from the composts (Török *et al.*, 2000). The compost ADC 1 was the only composted anaerobic digestate material used in the experiment. The N uptake for harvest one from ADC 1 were 68.93 (LR), 77.59 (MR) and 83.12 (HR) mg N dw⁻¹. Both of these treatments exhibited the lowest uptake of N over the course of the trial. As with the other treatments an increase in N was observed at harvest 8.

The N uptake for the compost groups at the application rate 150 kg ha⁻¹ are presented in Fig 5.2. The chemical control exhibited the highest uptake of N. Uptake figures for the MW group was highest among the compost treatments. For the first harvest the CAN treatment is significantly different from the MW ($P < 0.01$). However for the three subsequent harvests; the MW exhibits a higher uptake of N than the control; with no significant difference between the two ($P > 0.05$ respectively). The BW group, the GW group and the ADC group were all significantly lower in uptake of N than the CAN and the MW group. This trend continued for the entire experiment. However by the fourth harvest there is no significant difference recorded between any of the groups. The BW, GW and ADC also show no significant difference with the untreated control ($P > 0.05$). The increase in N at harvest 5 and 8 is shown below potentially indicating mineralisation of organic N.

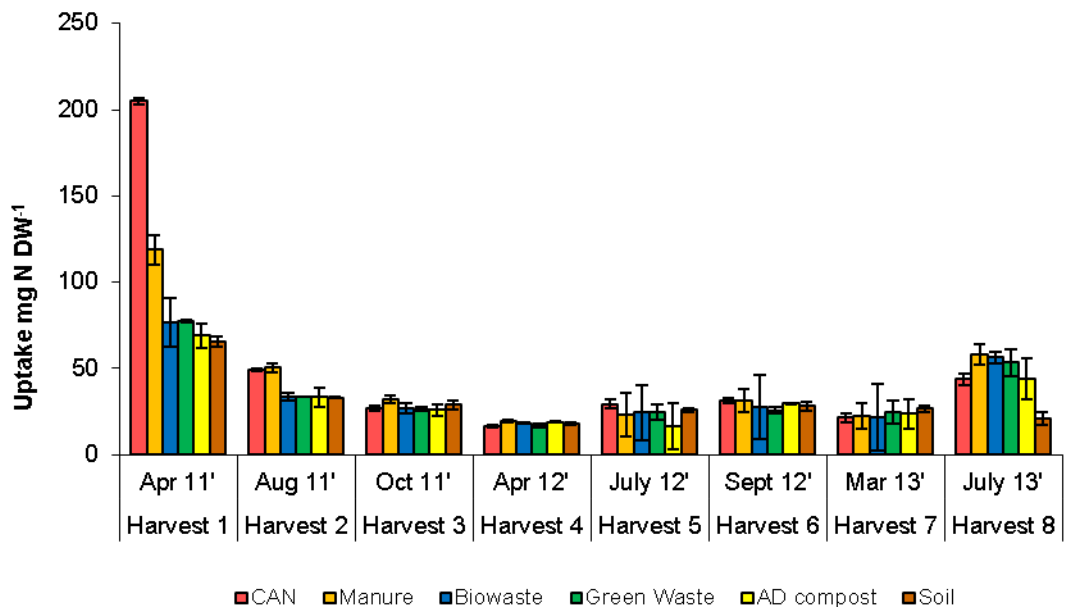


Figure 5.4 Plant nitrogen uptake of compost groups at application rate 150 kg ha⁻¹. Plant nitrogen uptake is measured in mg N dw⁻¹. Errors bars denote standard deviation.

Figure 5.3 presents the compost groups and controls at the medium application rate of 300 kg ha⁻¹. As with the previous graph CAN is again exhibiting the highest uptake of N. The MW group is the highest in available N when compared to the other compost groups. Over the course of the trial CAN is significantly different to the rest of the compost treatments. Both the MW and CAN show a significant difference with all other compost groups ($P < 0.01$). By the third harvest only the MW shows a significant difference from the untreated control ($P < 0.05$). At this stage only the MW group is still mineralising N for plant uptake. Between all other groups there are no significant figures to present.

Considering sample variance this suggests there may be a limited amount of N still available from the MW group. As with the previous rate the potential mineralisation of

organic N is noted by the increase in N uptake at harvests 5 and 8. This is seen as significant for BW ($P<0.01$) but not for MW ($P>0.05$).

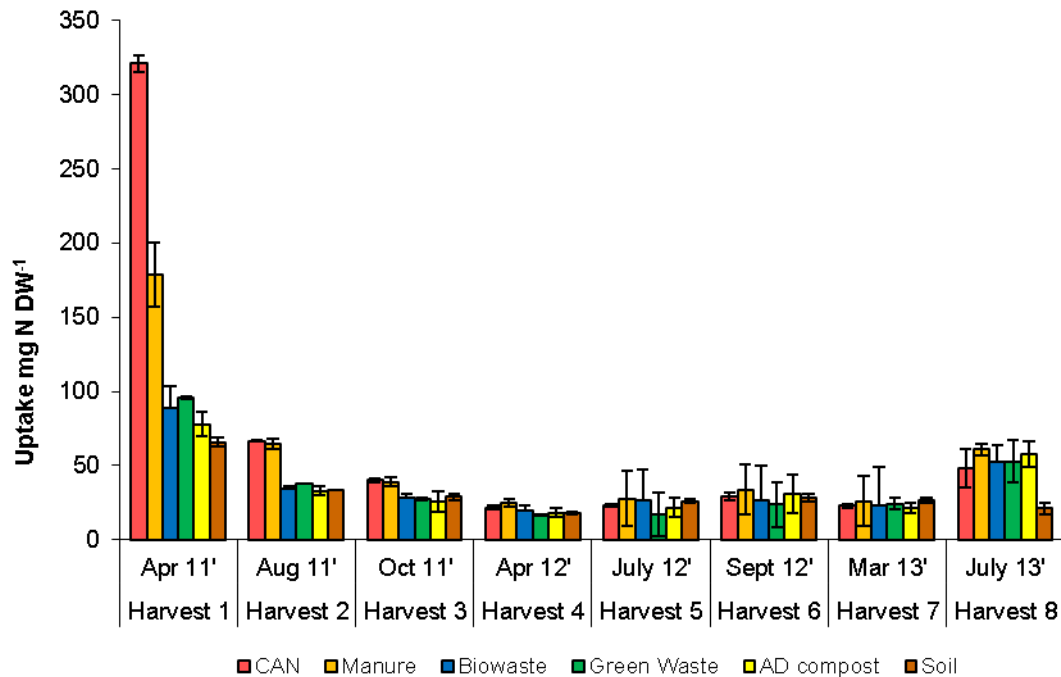


Figure 5.5 Plant N uptake of compost groups at application rate 300 kg ha⁻¹. Plant N uptake is measured in mg N dw⁻¹. Errors bars denote standard deviation.

For the highest rate of application the CAN had the highest uptake figures. As with the previous rates the uptake figures for the MW group was the highest among the compost treatments. There is a significant increase in the uptake from BW composts relative to the other two reduced rates. However there was a decrease in uptake with regard to the GW in comparison to the medium rate. The ADC also showed a very small increase in available N from the medium rate. As with the trend in the other rates there is significant difference between CAN and the other treatments for the first harvest (all groups $P<0.01$). The results for the second harvest show that there is no significant

difference between CAN and MW ($P>0.05$). By the third harvest the uptake figures have almost reversed for CAN and the MW group ($P>0.05$) but there is no noticeable biological difference (i.e. plant size). The uptake by the MW group is greater than that of CAN. Both the GW and ADC show no significant difference from soil ($P>0.05$). The BW group shows a significant difference from soil at the first harvest ($P<0.01$). However, for the succeeding harvests there is no significant difference ($P>0.05$ for each harvest).

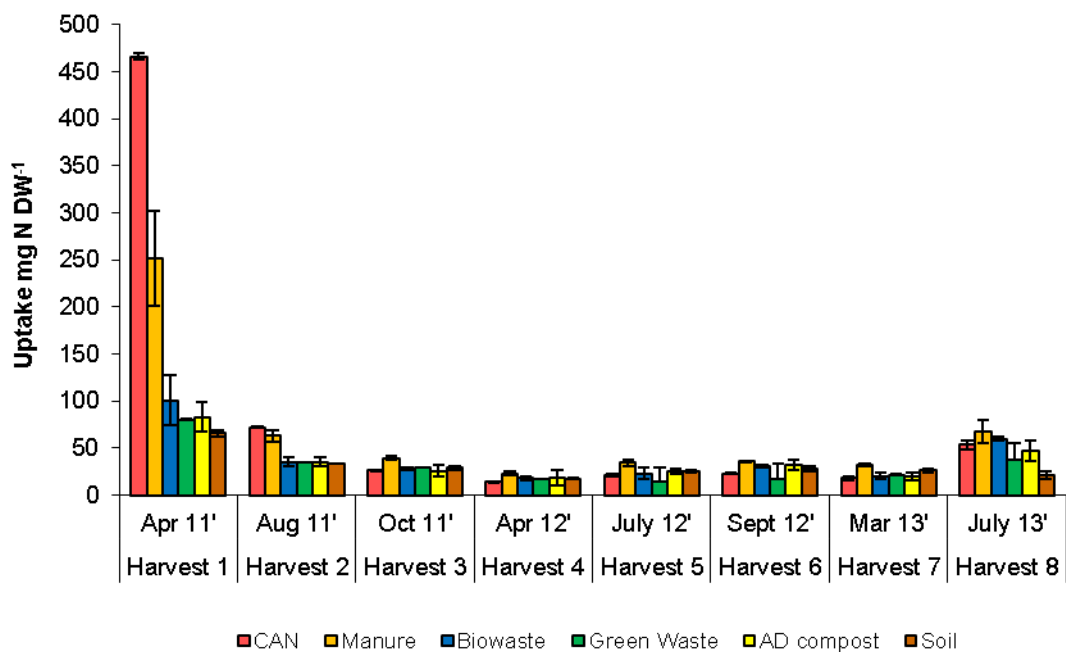


Figure 5.6 Plant N uptake of compost groups at application rate 450 kg ha^{-1} . Plant N uptake is measured in mg N dw^{-1} . Errors bars denote standard deviation.

Table 5.4 LS means of overall comparisons of controls vs compost groups. A plus sign indicates no significant difference

Groupings	H1	H2	H3	H4	H5	H6	H7	H8
CAN vs MW	**	+	+	+	+	+	+	+
CAN vs BW	***	***	+	+	+	+	+	+
MW vs BW	***	***	+	+	+	+	+	+
BW vs GW	+	+	+	+	+	+	+	+
CAN vs Soil	***	*	+	+	+	+	+	+
MW vs Soil	***	***	+	+	+	+	+	*
BW vs Soil	+	+	+	+	+	+	+	+

P <0.01 *; P <0.001 **; P <0.0001 ***; P >0.05⁺

The cumulative uptake for each treatment is presented in Figure 5.7 (450 kg N ha⁻¹). This indicates the total amount of N mineralised and uptake from each compost group for the pot experiment. The trend follows the uptake figures presented above. However, if the first harvest was excluded the MW group would have a higher cumulative uptake than CAN. This highlights the greater slow release N from the MW group after the initial harvest.

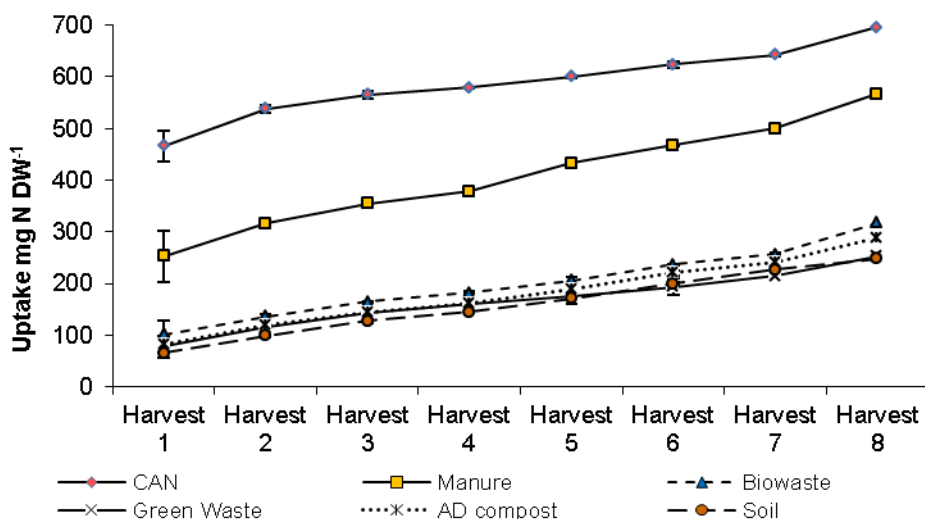


Figure 5.7 Cumulative nitrogen uptake (450 kg ha⁻¹) for the composted waste treatments and CAN over the eight harvests. Error bars denote standard deviation

5.2.1 Co –application of compost and nitrogen fertiliser

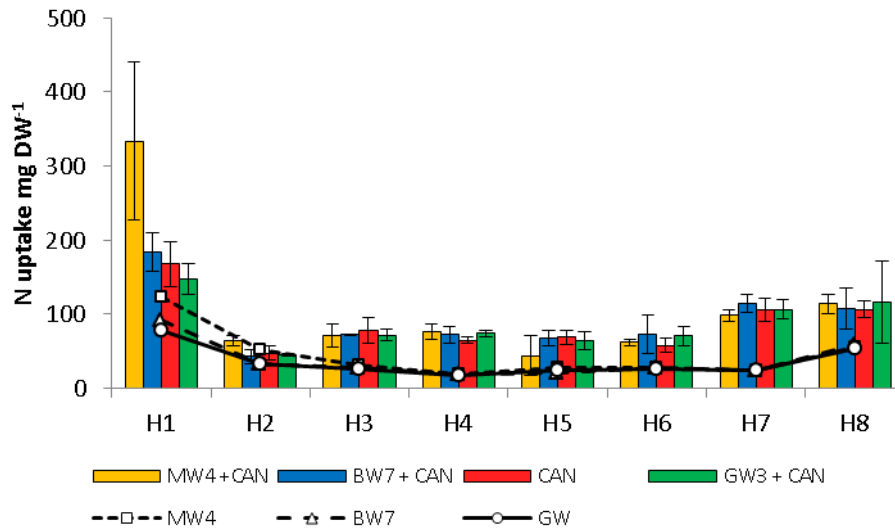


Figure 5.8 Plant nitrogen uptake of composts + CAN co - applied at application rate 150 kg ha⁻¹. Plant N uptake is measured in mg N dw⁻¹. Line graph values are of just compost application. Errors bars denote standard deviation

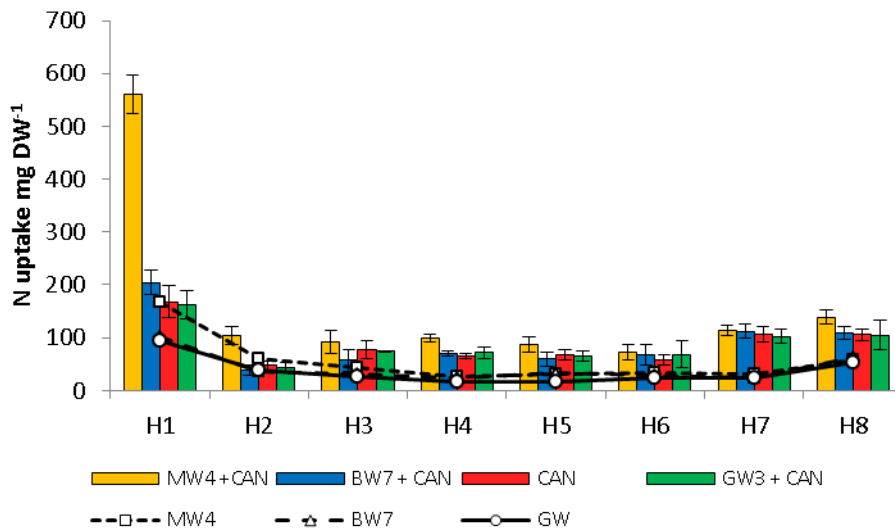


Figure 5.9 Plant nitrogen uptake of composts + CAN co - applied at application rate 300 kg ha⁻¹. Plant N uptake is measured in mg N dw⁻¹. Line graph values are of just compost application. Errors bars denote standard deviation.

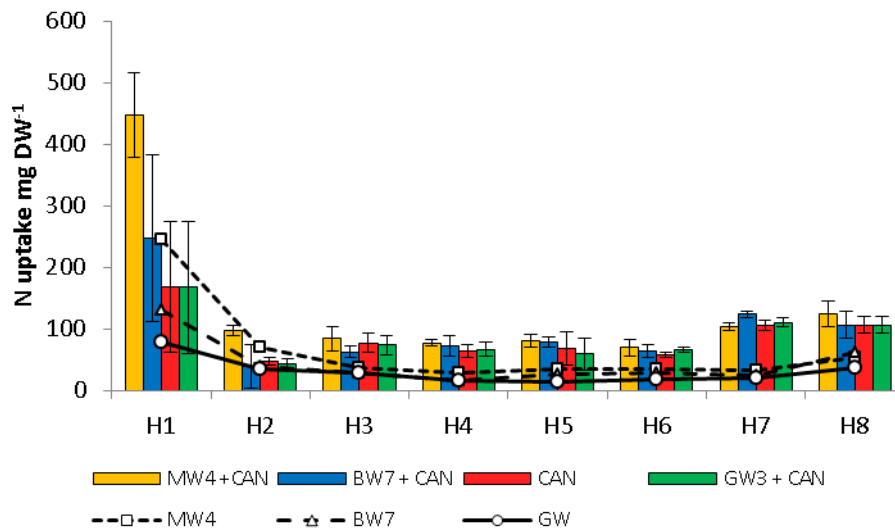


Figure 5.10 Plant nitrogen uptake of composts + CAN co - applied at application rate 450 kg ha^{-1} . Plant N uptake is measured in mg N dw^{-1} . Line graph values are of just compost application. Errors bars denote standard deviation.

The co - application of CAN and composts are presented in Figures 5.6 – 5.8. There was a large deviation present in the first harvest for the three composts. However, this did not alter the results which showed that a significant increase in uptake was seen in the composts at the first harvest. The addition of CAN with the BW, GW and MW compost yielded a significant increase. The N uptake from the composts alone was significantly different than when co - applied with CAN. The MW compost was significantly different from the chemical control. However, the BW and GW + CAN were not significantly different from the chemical control. In the case of the GW, the uptake of N was lower than the chemical control.

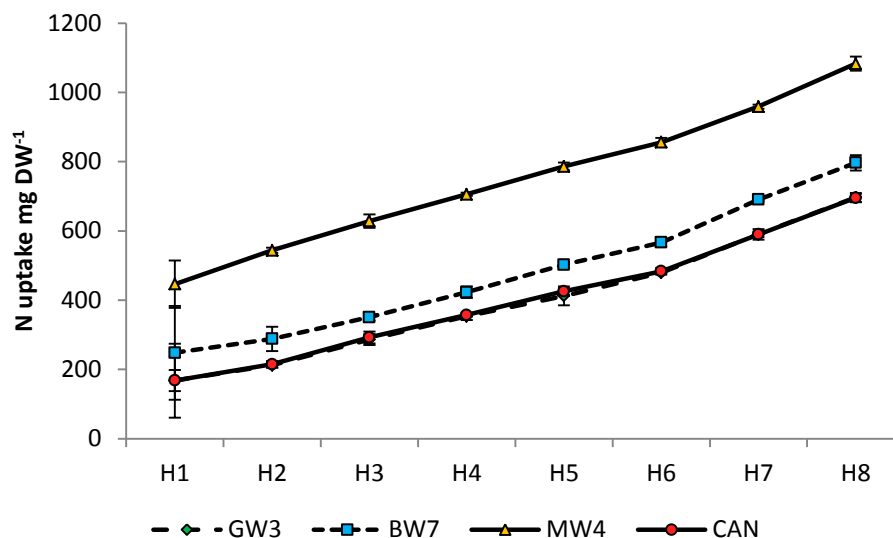


Figure 5.11 Cumulative plant nitrogen uptake of composts + CAN co - applied at application rate 450 kg ha⁻¹. Plant N uptake is measured in mg N dw⁻¹. Errors bars denote standard deviation.

5.4 Discussion

5.4.1 Nitrogen uptake from composts applied to soil

N uptake from the MW was the highest of all the compost groups. Within the MW group there was significant differences recorded between the treatments. MW 3 (HR) and MW 5 (HR) show a significant difference ($P < 0.05$). MW 4 (HR) shows no significant difference to MW 5 (HR) ($P > 0.05$). MW 5 had the highest levels on N and was expected to be higher in N uptake. Both MW 3 and MW 4 were almost identical composts and expected to behave quite similarly. MW 4 had a higher uptake of N. This compost was far more unstable than MW 3 which accounts for its higher uptake. The unstable compost is more likely to release N rapidly than a more stable compost. The

final harvest yielded an increase in N uptake from the MW composts. This increase was biologically and statistically significant ($P < 0.05$). This harvest took place approximately two years after the first harvest. Mineralisation of organic N can be suggested to have taken place here, as this has been previously reported to happen approximately two years after compost application (Cooperband *et al.*, 2002). Within the MW group MW 5 had the highest uptake of N. This was a mix of manure wastes which had been composted in vessel. This came from an optimised process which had been in use for a long period. Both MW 3 and MW 4 were from feedstocks of both chicken and broiler manure which were pile composted indoors. MW 5 had the highest CaCl_2 DTPA extractable N (≈ 4600 ppm). This high level of available N (inorganic N) would suggest a greater uptake of N as described above. MW 5 was composted for the shortest length of time among the MW group. Griffin and Hutchinson (2007) showed that materials that underwent a longer composting process were significantly lower in available N. MW 5 also has the lowest $\text{NO}_3 - \text{N}$ levels (CaCl_2 DTPA extraction) which would suggest a more immature compost than other two MW composts. This is confirmed with the oxygen uptake rate (O.U.R) of $55 \text{ mmol O}_2/\text{kgOS/h}$. Unstable composts are more likely to release N sporadically and rapidly hence MW 5 having the highest N uptake for the first two harvests. MW 3 had the lowest uptake figures for the MW group. The decrease in uptake of N from harvests one to harvest two for MW 3 was 38% for HR. The subsequent average decrease for the other two MWs was approximately 27%. This suggests a more stable release rate of N from MW 3. MW 3 had an O.U.R. of $21 \text{ mmol O}_2/\text{kgOS/h}$ and a high level of $\text{NO}_3 - \text{N}$ (CaCl_2 DTPA

extraction). These figures would imply that MW 3 was the most stable of the MW group. Preusch et al. (2002) reported that the longer the composting the less availability of N from composted poultry manure. Both MW 3 and MW 4 were composted for longer periods of time than MW 5. At 25 and 18 weeks respectively compared to just 4 weeks for MW 5. There is quite a large difference and the evidence of this lies within these figures. The cumulative uptake results for the trial are presented in Fig. 5.5. The average recovery of N from the MW group was 69% (of application rate). These are high for composted manures. Eghball and Power (1999b) reported a recovery of 23% over a two year study for composted cattle manure. Gale *et al.* (2006) reported an average of 40% plant available N for composted broiler litter. These values are more comparable to non-composted manures. The three MW composts used are considered unstable due to the OUR values being above the maximum threshold of 13 mmol O₂/kg OS/hr. This is a possible explanation for the high levels of N recovery. The composts are potentially behaving more like manure. The long duration of the trial is another factor that may have accounted for the higher recovery

The 'hispi' cabbage plant has an extensive root network which has been shown to be able to access N which would be considered unavailable to other crops (Thorup-Kristensen, 1999). This along with the fact that cabbage plants are high N requiring plants may have allowed for an increase in N uptake where available.

The overall comparison between CAN and MW group shows a significant difference between the groups at comparable application rates. This is distorted by the figures for

the uptake from CAN for the first harvest. The individual uptake figures for the second and third harvests and so on show no significant difference between CAN and the MW ($P>0.05$). The immediately available N from CAN is released and assimilated by the plant during the course of the first harvest. This leaves a vast drop in plant available N for uptake for subsequent harvests. It is understood that composted materials can release nutrients slowly. The MW has a greater uptake of N from the second harvest to the final harvest when compared to CAN. By the fourth harvest there is a significant difference between MW and CAN ($P<0.01$) at the higher rate (450 kg N /Ha), although the cumulative figures for the two groups show a greater uptake of CAN. These results show that compost has a slower release of N over time compared to CAN.

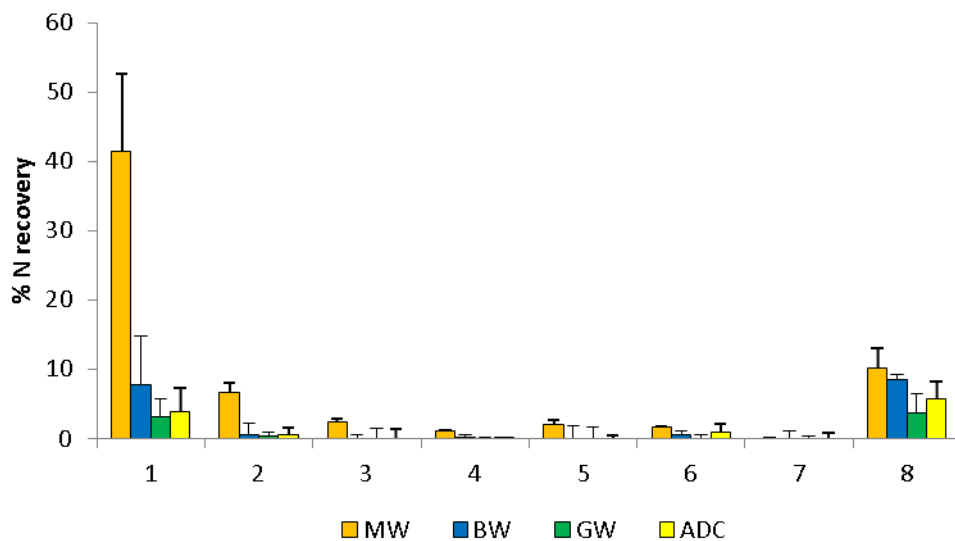


Figure 5.12 Net nitrogen percentage recovery for the compost groups over eight harvests for the high rate of compost application (450 kg ha^{-1}). Errors bars indicate standard deviation within the group

Within the biowastes group there was much less effect of rate on the uptake of N from the treatments. In many cases there was no significant difference between the treatments

and at the individual rates. At the LR and MR there is no significant difference between the treatments ($P>0.05$). However there is a slight separation in the uptake with BW 2, BW 4 and BW 7 being at the upper level of N uptake and BW 11 and BW 12 being at the lower level. This trend becomes increasingly more significant at the HR. BW 7 and BW 12 are significantly different at harvest 1 ($P=0.039$). Composts BW 11 and BW 12 were static pile composted. Static pile composting can lead to many issues with the end product. Temperature control can be quite difficult which often leads to problems with the system such as areas of the pile becoming anaerobic.

Nitrogen uptake from the BW group was significantly lower than that of the MW group. The net N recovery for the first harvest was averaged at 8%. This compares to an 8% increase in crop yield by Erhart *et al.* (2005) after biowaste application at 8 t ha⁻¹. Chalhoub *et al.* (2013) reported a 9.3% crop recovery through increased soil organic N after five applications to maize and wheat. This increased to 27% after the last application. A similar study on a household waste compost also reported a 10% N availability after the first year of application (Scherer *et al.*, 1996) From our experiment the last harvest yielded a 23% recovery from the BW group. No increase in the untreated control was observed suggesting that all increases were caused by the composts ($P<0.001$)

C/N ratio has often been suggested as a good index and indeed indicator of N availability from composts. Composts BW 2, BW 4 and BW 7 have C/N ratios in the

range of 9 – 11 whereas BW 11 and BW 12 are higher at 15 – 16. Amlinger et al. (2003) reported that a C/N ratio greater than 14 will result in distinct N - binding. A C/N ratio in the range of 9 – 11 exhibits a balanced mobilisation of N. The initial uptake for BW 11 and BW 12 was lower than that of the other three BW composts – although not significantly different ($P > 0.05$). From the second harvest these two composts exhibit an uptake of N not significantly less than the other three composts with lower C/N ratios. BW 11 and BW 12 presented the lowest CaCl_2 DTPA extractable N figures which may suggest the initial lower N uptake. A study conducted on a larger population scale may have yielded a significant difference.

Studies have also been conducted to investigate the effect humic substances have on nutrient uptake and in particular sources of N. Vaughan (1985) suggested that humic substances stimulate N uptake by promoting the expression of nitrate carrier proteins. BW 4 and BW 7 show quite a large fraction of CaCl_2 DTPA extractable $\text{NO}_3 - \text{N}$. However, of these treatments BW 4 had relatively low humic substance content (159 g kg^{-1}) whereas BW 7 had higher content (245 g kg^{-1}). This may account for the difference in N uptake between the two treatments, although that difference was not significant ($P > 1.0$). It could also be suggested that the ratio of organic N to inorganic N was quite high. BW 4 had a total N value of 3.04%. However, BW 4 had a low value for CaCl_2 DTPA extractable N relative to its total N figure. Amlinger et al. (2003) suggested that in biowastes more than 90% of the N pool is organic and therefore unavailable for mineralisation.

The GW group (GW 3) was the only GW in the trial. There was no significant difference between the three different rates for this treatment. GW 3 was quite stable with a low O.U.R. of 6.86 mmol O₂/kgOS/h and C/N ratio of 10.04. GW 3 also had a high total N content above 4%. However a very large fraction of this was organic. This is confirmed by the extremely low N present in the CaCl₂ DTPA extract. This suggests that there was a low amount of plant available N throughout the trial. At the LR and HR there appears to be no significant difference between these treatments and the untreated control. The slightly higher uptake in the GW, similar to BW 11 and BW 12, may be attributed to a priming effect by the treatment when incorporated into the soil (Lohnis, 1926). A well composted and stable material would suggest a low availability of nutrients over a short term with a more prolonged and consistent release of nutrients over a longer period of time (Griffin and Hutchinson, 2007).

The GW averaged 6% N recovery from the first harvest but subsequently immobilised N until the final harvest where a large portion of N was mineralised as with the other groups. A previous study reported a 2% recovery of total N applied (Keeling *et al.*, 2003). Berner *et al.* (1995) demonstrated that on average, 2% of total N was mineralised by composted yard waste – the highest results being 8%. These results contrast the N incubation which identified GW composts as N immobilising. However, given the range of results presented by other authors who show N mineralisation, this could be expected. As there was no appreciable rate affect or minimal linear response to rate the mineralised N may have been a result of the ‘priming effect’ (Lohnis, 1926; Kuzyakov,

2010). This is where the additive i.e. compost acts as a stimulus for microbial activity which increases nutrient uptake. Finally at the eighth harvest an increase in N uptake was seen with a recovery of 21% of total N applied. The anaerobic digested compost (ADC) group consisted of only one treatment (ADC 1). This material also showed no significant application rate effect and also showed no significant difference to the untreated soil treatment ($P=1$).

Within the biowaste group, only BW 7 at the higher application rate was significantly different from the ADC. Reasons for the low N availability can possibly be attributed to the composting and digestion process. During the AD process organic matter (OM) mineralisation can lead to the transformation of the organic N to ammonia (NH_3) (Pognani *et al.*, 2009). Much of this NH_3 may be lost during the extra composting stage due to the volatility of NH_3 and the temperatures achieved during composting. This is evident in the very low level of $\text{NH}_4 - \text{N}$ found in ADC 1 (2 mg/L). ADC 1 also has a very stable O.U.R. reading of 4.98 mmol $\text{O}_2/\text{kgOS}/\text{h}$ with a C/N ratio of 8.52. Composts like these of such stability would have a relatively low immediate availability of nutrients. This material was also diluted with a green waste after the AD process. The addition of the green waste may have attributed to the low plant available N. As with the other groups a significant increase in N uptake was seen at the eighth harvest.

Using characteristics such as NDF, lignin and C/N ratio to predict N uptake are presented in table 5.3. Both NDF and lignin show a strong correlation with plant uptake

over the first three harvests. However this is not sustained after the third harvest, most likely due to the limited N available for uptake. The use of these two parameters has not been used widely but has previously been related to mineralisation of N (Griffin and Hutchinson, 2007). Lignin/N ratio and lignin + polyphenol/N ratio has been previously reported to be correlated to mineralised N (Fox *et al.*, 1990; Vigil and Kissel, 1991). Immobilisation of N has been cited to be induced by a compost with a C/N ratio above 30 (Sims, 1990; Shiralipour *et al.*, 1992) after the first year of application. In this study there were no composts used with a C/N ratio above 16. This may have given rise to the lack of relationship between C/N ratio and N mineralisation. However, this also poses the question about the use of C/N ratio as many modern composting processes are producing finished materials with a C/N ratio of less than 20 after composting.

Table 5.5 Nitrogen uptake results correlated with NDF, lignin and C/N ratio for the eight harvests

	NDF		Lignin		C/N Ratio	
	R ²	p Value	R ²	p Value	R ²	p Value
Harvest 1	0.8067	<0.01	0.7396	<0.01	0.1663	>0.05
Harvest 2	0.8294	<0.01	0.9135	<0.01	0.0061	>0.05
Harvest 3	0.6363	<0.01	0.7872	<0.01	0.0202	>0.05
Harvest 4	0.4284	<0.05	0.3078	>0.05	0.0205	>0.05
Harvest 5	0.0199	>0.05	0.0155	>0.05	0.1516	>0.05
Harvest 6	0.1973	>0.05	0.2631	>0.05	0.0176	>0.05
Harvest 7	0.0170	>0.05	0.0015	>0.05	0.0504	>0.05
Harvest 8	0.0042	>0.05	0.0021	>0.05	0.0076	>0.05

Comparison of the N incubation study with the N pot trial gave an excellent correlation between the two. The incubation experiment (Chapter 3) was conducted over four

weeks with an extraction taking place at 0, 7, 14 and 28 days. The mineralised N figures for the extraction dates W0 and W4 were then correlated with harvests 1, and 8 from the growing experiment presented in Figure 5.13. This indicates the effectiveness of an incubation experiment to predict N availability over a short period. The correlation for the first harvest with the initial extraction is strong but this correlation does not extend throughout the experiments. Thus suggesting it may be more reasonable to use the initial extraction to predict potential N uptake in a short time frame.

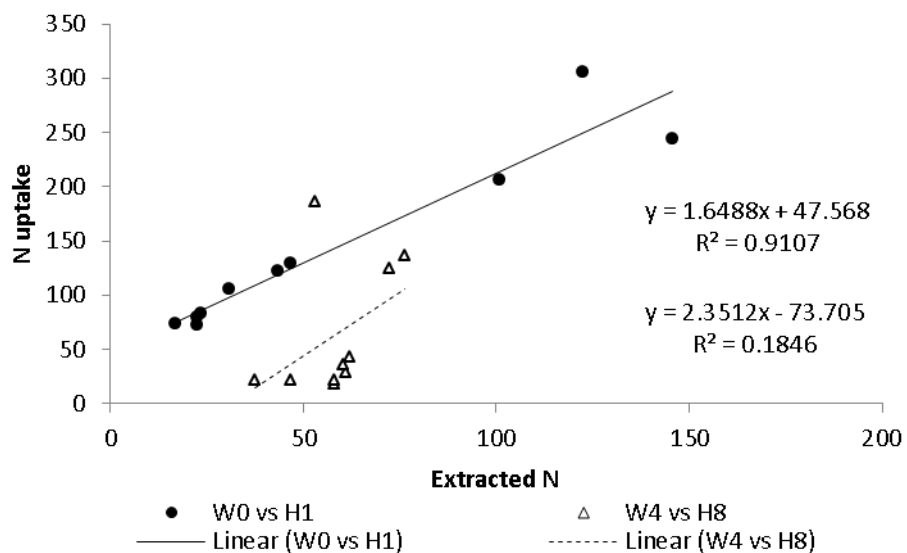


Figure 5.13. Correlation of nitrogen extracted at W0 (incubation) with nitrogen uptake at H1 compared to correlation of nitrogen extracted at W4 (incubation) with nitrogen uptake at H8

5.4.2 Nitrogen uptake from co-application of composts and nitrogen fertiliser

The results for the co-application of composts with CAN show a significant increase in N uptake at the first harvest for MW but not for BW and GW. After the first harvest the

MW and BW composts promoted an increase in N uptake by the plants. This is similar to results presented on a crop rotation of winter wheat with composted municipal solid waste (MSW) and inorganic N (Montemurro, 2009). Gagnon *et al.* (1997) found that the addition of dairy manure compost with inorganic fertiliser did not significantly increase yields of wheat growth. Another study by Montemurro (2005) found that MSW compost increased crop N uptake by 6.4% and when co – applied with inorganic N by 11.1%. A lack of linear response has been reported after increasing rates of application of composted manure (Kirchmann, 1985). The co – application of MW compost and inorganic N would have resulted in a flush of NH_4^+ . The clay loam soil used in the pot trial has the capacity to fix the NH_4^+ by its clay minerals (Gagnon *et al.*, 1997), although this effect was not seen in the pot experiment. An increase in N uptake is exhibited by the GW + CAN. However, the uptake is lower than the chemical control, highlighting the immobilising effect of GW compost (Vaughan *et al.*, 2011)

5.4.3 Plant nitrogen uptake after six month fallow period

At the culmination of the growing experiment, the experimental pots were left fallow for a six month period before being replanted with cabbage and grown for one more harvest period. After harvest eight there was a significant increase in N uptake with all of the composts – suggesting mineralisation of organic N. However, after the six month fallow period there was a distinct drop in N uptake. The N uptake from the control remained unchanged which suggests that the microbial activity may have ceased in the compost/soil matrix. The drop in N uptake may have been due to ammonification

(Brady and Weil, 1996) to NO_2^- or NO_3^- of the native N and then further denitrification of the NO_2^- or NO_3^- (Fillery and Vlek, 1982). This gives a good indication that soils in crop rotation or fallow periods are subject to gaseous N losses. Reactivating the matrix or understanding its reactivation is important due to the large quantities of organic N that the composts contain. It is unclear what methods be it chemical, physical or biological may serve to activate the system.

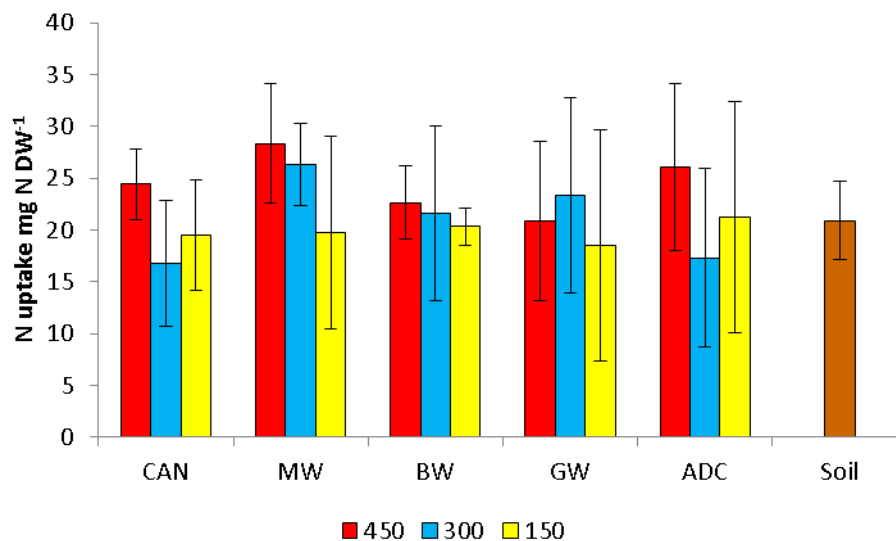


Figure. 5.14 Nitrogen uptake from compost groups after fallow period of six months. Rates of application are indicated as 450, 300 and 150 kg N ha⁻¹. Error bars denote standard deviation

5.5 Conclusion

The data presented within this chapter suggests a separation in the classification of the treatments or groups in terms of N availability. The MW group may be classed as being high in available N with the BW, GW and ADC composts being low in available N.

One of the major issues with the aforementioned groups of composted waste is N immobilisation which has been widely discussed. The major challenge regarding application of composts to soils is short term immobilisation of N, and the possibility of longer term N mineralisation due to changes in the physical, chemical and biological parameters in the soil. The uptake from the MW waste group was immediate due to the comparatively high levels of ammonia. This may also be detrimental to the surrounding environment in so far that plant available N may also be lost to subsurface groundwater through leaching. Again, this further highlights the importance of planning and application rates as this is a concern to environmental groups (EPA, other state agencies and the agroecological community as a whole). From the results presented the MW group have the capacity to release N at a more stable rate than a conventional inorganic fertiliser but not at comparable N levels. The other three compost groups within the study exhibited a low availability of N but were more consistent and predictable in their release of N when compared to the MW and inorganic N treatment. This would suggest their usefulness in growing low N requiring plants or for use as a soil conditioner rather than an organic source of N or as a growing media constituent. The compost treatments have shown that mineralisation of organic N takes place but was two years after application.

The co – application yielded an increase in N from the MW that was significant. However, this was not the case with BW and GW. An increase in N uptake was exhibited but not significantly different than the chemical control at the same rate.

Leaving compost/soil plots fallow has shown to cause N losses mostly likely in the gaseous form. This evidence suggests that soils in a crop rotation or fallow period may require watering or physical agitation.

It may also be necessary to adopt feedstock prediction for N as compost with similar C/N ratio but different feedstock will not behave in the same manner concerning N mineralisation and availability. The nitrates directive currently states that composts with a C/N ratio of <10 have a 25% availability of nitrogen and 17.5% for composts with a C/N ratio of 12.5. The results presented show that C/N may not accurately predict N availability. Using lignin or NDF content was more accurate.

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Chapter 6

Effect of compost application to soil on plant phosphorus uptake: A glasshouse study

6.1 Introduction

Phosphorus has been identified as the main limiting nutrient in eutrophication of ground waters in Ireland (McGarrigle, 2001). As mentioned in the previous chapter the application rate of nitrogen in the form of organic and inorganic amendments can be problematic. This concern also extends to phosphorus (P) in both the inorganic and organic forms however P is more troublesome when considering the potential detrimental effect it has on the environment. The loss of P occurs as a result of the accumulation of P in soils from application of inorganic and organic sources of P to land i.e. fertiliser, manure or compost (Hart *et al.*, 2004). The N:P ratio in more conventional organic amendments such as manure is typically 2:1 to 6:1 but the crop uptake ratio is much different; generally around 7:1 to 11:1 which lends to more P being added to the soil than is needed (Sharpley *et al.*, 1994; Gburek *et al.*, 2000) . It is reported in some countries that P application is in excess of P uptake by between 300 – 500% (Sims *et al.*, 1998). Tegasc have reported that 55% of soils have a low to very low P status and that soils considered P Index I have increased from 14 – 27% since 2007. Over application of inorganic fertilisers and poor management practices in agriculture has led to a build of P in soils. In a climate like Ireland's where heavy

rainfall can occur frequently much of the P can be leached or lost as run – off to groundwater and hence cause eutrophication in water courses.

Phosphorus has a tendency to interact with soil in a more complex manner than most other macronutrients. When P is applied to soil in the form of inorganic fertiliser (superphosphate) or as an organic amendment (compost) it can take multiple different forms within the soil it is applied to. It also can strongly bind to inorganic and organic complexes within the soil system. This ultimately limits the availability of P to plants. Phosphorus used in mineral fertilisers comes in the form of rock phosphate. This is a mined material which has exhaustible stocks. There are literature studies available which give conflicting theories as to when peak rock phosphate mining will occur (Van Kauwenbergh, 2010). However, as rock phosphate is exhaustible the cost of the mining process will continue to increase. There are suggestions that the production costs could increase by a factor of 3 – 5 within this century (Van Vuuren *et al.*, 2010).

Phosphorus along with nitrogen and potassium are the main macronutrients required by plants for sustainable growth. Phosphorus plays a key role in many plant processes including but not limited to; the accumulation and release of energy associated with cellular metabolism, seed and root formation, maturation of crops (especially cereals), crop quality and strength of straw in cereals (Prasad and Foster, 2006c).

Accessing readily available P for growth is a common problem faced by many plants. Phosphorus forms in soil come in many different varieties and complexes and this factor affects the growth of plants in soils where the unavailable P is found in the organic form. This is due to the highly reactive nature of P. Traditionally, inorganic fertilisers are used to supply P for plant growth. However, when incorporated into soil much of the P from the fertiliser can be immobilised by being converted to organic P by the native microorganisms. Forms of organic P are not completely unavailable to the plant but there are uncertainties as to when and how much of it will become available. There are many reports where results are presented showing that application of organic amendments in the form of composts improves P availability and uptake (de Bertoldi *et al.*, 1983; Hue, 1992; Bhatti *et al.*, 1998). The objective of this experiment was to apply different composted wastes at various rates (based on nitrates directive limits) to an Index I soil in which cabbage plants were grown. The growth response was measured by fresh weight, dry weight and P uptake in the plants at each harvest conducted.

6.2 Material and methods

The experiment was designed in a 13 x 3 factorial design. There were three absolute control treatments. This gave a total of 42 treatments. Each plot consisted of one 2 L pot. The experiment contained four replicates. This gave a total of 126 pots. Surrounding the trial pots was a guard row layer of pots.

Table 6.1 Composted wastes selected for the growing trial including the treatment label, classification group and the feedstock material and P release profile

Treatment	Group	Feedstock	Release Profile
SSP	SSP	Single superphosphate	High
MW 4	Manure waste	Chicken waste	High
MW 5	Manure waste	Poultry/pig manure	High
BW 2	Biowaste	Brown bin waste	Medium
BW 3	Biowaste	Brown bin waste	Medium
BW 4	Biowaste	Food waste	Medium
BW 8	Biowaste	Food waste	Medium
BW 9	Biowaste	Dairy sludge & green waste	Medium
BW 12	Biowaste	Brown bin waste	Medium
GW 1	Green waste	Green waste	Low
GW 2	Green waste	Green waste	Low
ADC 2	Anaerobic digestate	AD fibre	Low
Soil	Untreated control	Clay loam soil	N/A
Rates	60 kg P ha ⁻¹	150	240

The growing experiment was set up initially by sieving the soil to 10mm and air dried for two weeks. The soil was then adjusted to 15% moisture. For each individual treatment and rate 12 litres of soil was required. Bulk density measurements were taken of each lot prepared. Forty two lots of 12 L of soil were weighed out. Calcium ammonium nitrate (150 kg/ha N) and sulphate of potash (100 kg/ha K) were added to each. Each lot was mixed thoroughly using the ‘Kinsealy method’, which is described in Chapter 5. The composts selected for the trial were applied at three rates as shown in Table 6.1. Composts were categorised as low, medium or high releasers akin to the nitrogen experiment. For each rate the amount of compost to be weighed out to be added to 12 L of soil was calculated based on the total P content of the compost and the

dry matter. The composts were sieved to 10mm. Each treatment was added to a 12 L lot of soil using the ‘Kinsealy method’. The characteristics of the soil are listed in Table 6.2. The compost/soil mixture was then filled into each individual pot and placed into its block in a randomised order. Each pot was placed on a saucer to prevent leaching of nutrients from the system. Once all the treatments were in place, a light watering was applied to moisten the treatments. Three cabbage plants were then planted into each pot. The guard row pots were done in the exact same manner except for these pots contained a 50:50 mixture of soil and peat seedling substrate – Bord na Móna. The cabbage plants were allowed to grow until the stage where the leaves of neighbouring plants began to overshadow each other. The plants were monitored on a daily basis with sufficient water being applied daily. Once the plants reached the stage of where they began to overshadow each other – a harvest was conducted (Figure 6.1).



Figure 6.1 Cabbage plants photographed before harvest

Each pot was harvested individually with the plants being cut from just above the top layer of soil. The three plants from each pot were put in to a labelled bag and weighed. The samples were then dried overnight at 70°C in a fan assisted oven (Memmert). A dry

weight of the plant was taken and the sample was then ground up through a mechanical mill (IKA MF 10.2 grinding mill).

Table 6.2 Selected chemical properties of the soil used for the growing trial

pH	Available mg L ⁻¹			Total mg kg ⁻¹	Textural % w/w		
	P	K	Mg	Ca	Sand	Silt	clay
7.2	12.6	83.3	90.3	3934	38	24	38

6.2.2 The digestion procedure and analysis

The digestion (Foss Tecator 2020 digester) procedure for the plant analysis was conducted by weighing out 0.2g of the ground plant sample and digesting it in 6 mL of concentrated H₂SO₄ (containing 5% selenium) at 370°C for 3 hours.. Once the digestion was complete the samples were allowed to cool. Upon cooling 10 mL of DI H₂O was added to each sample. This step was conducted to stop the formation of calcium sulphate. The samples were left overnight. The samples were then placed in a 50 mL storage tube and placed in cold storage (Sahrawat *et al.*, 2002).

The analysis of the plant tissue digests was completed using an automated UV spectrophotometry method (Lachat quikchem 8500 series 2 autoanalyser). Each of the samples were analysed for P concentration. Standards were prepared for each of the samples within the specific range that the samples were expected to fall.

Table 6.3 Selected phosphorus characteristics and mineralisation parameters of the compost treatments

Treatment	Total P	Mehlich 3			Organic			Ca mg L ⁻¹
	g kg ⁻¹	DTPA P	P mg L ⁻¹	Olsen's P	Morgan's P	Matter %	HS g kg ⁻¹	
BW 2	3.9	6	786	378	581	28.88	363.65	10409
BW 3	2.4	10	836	390	791	40.23	352.97	9239
BW 4	3.3	15	857	372	530	55.29	159.27	10819
BW 8	3.9	22	1088	620	1040	42.77	258.99	6182
BW 9	6.1	313	1641	903	1180	88.02	88.05	4019
BW 12	5.3	10	1081	432	554	62.37	108.83	5888
MW 4	13.4	33	4199	2588	3600	82.86	74.04	2997
MW 5	18.1	18	5732	2416	6290	64.59	62.82	10434
GW 1	3.6	10	950	391	766	47.97	184.75	10484
GW 2	0.5	7	519	265	258	27.63	325.96	6641
ADC 2	5.5	9	1374	602	N/A	53.64	183.56	8937

6.2.3 Statistical Analysis

Statistical analysis of the P uptake results (ANOVA with Tukey pairwise comparison) was conducted with SAS (version 9.2). A mixed model by LS – means was created to compare treatment with significant differences identified at P<0.05. The untreated control (soil) was nested to the model at rate = 0. The Tukey test compared all means with each other simultaneously. This lowered the possibility of Type I error due to the multiples of comparisons being made.

6.3 Results

The results for the fresh and dry weights are presented in Figures 6.2 a – h. Generally the plant weights showed a linear response to compost application rate. However, many times the plant fresh weight was not a direct linear response to plant uptake. Some of the BW composts had a higher plant fresh weight than the MW composts but did not

have a higher uptake of P. A seasonal effect on the plant weights was less pronounced and generally not evident during the trial.

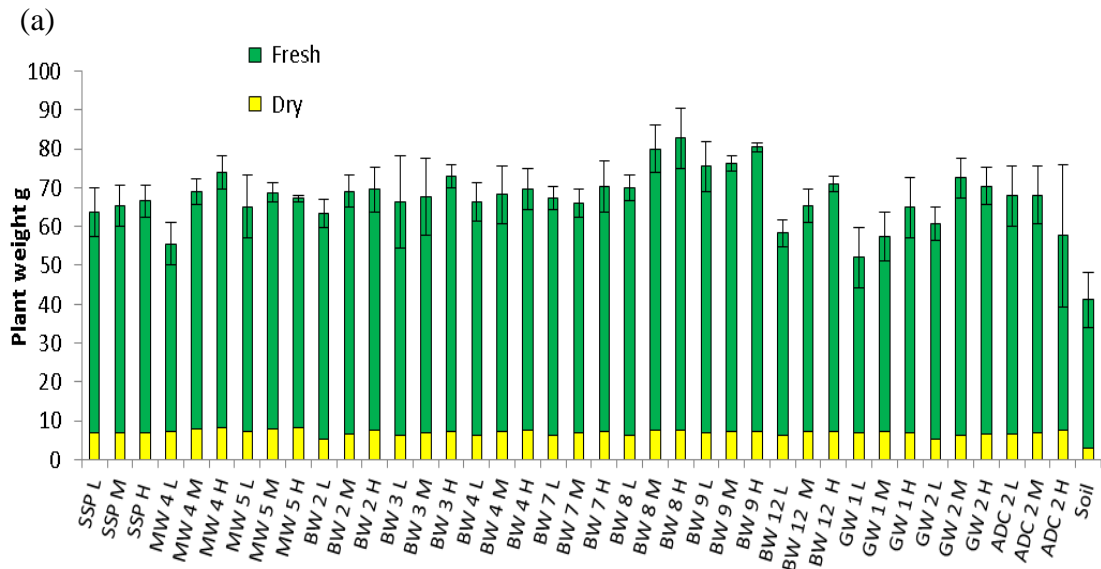
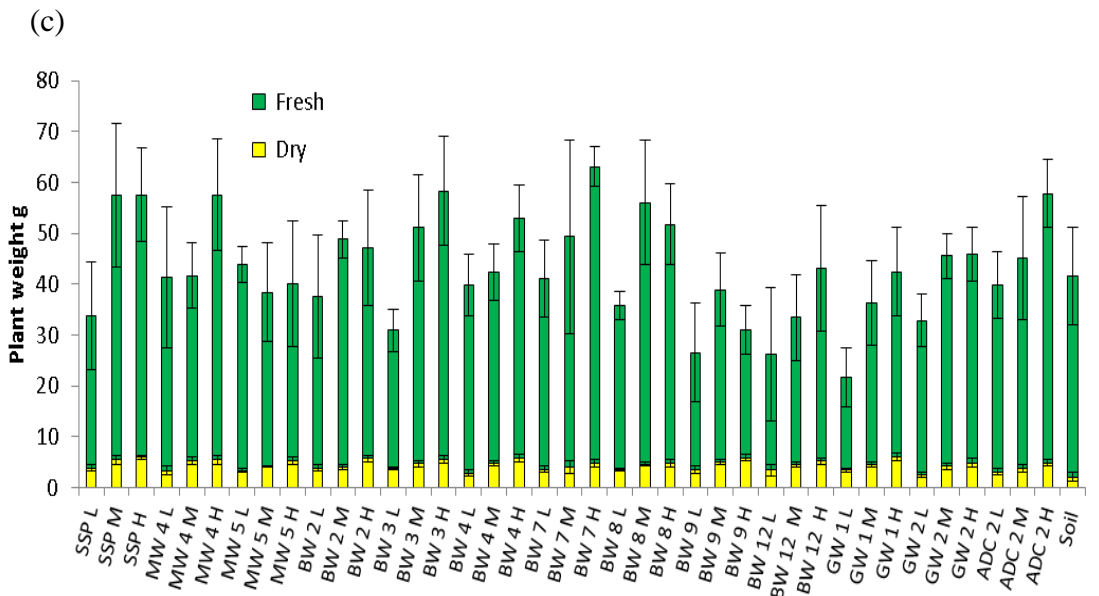
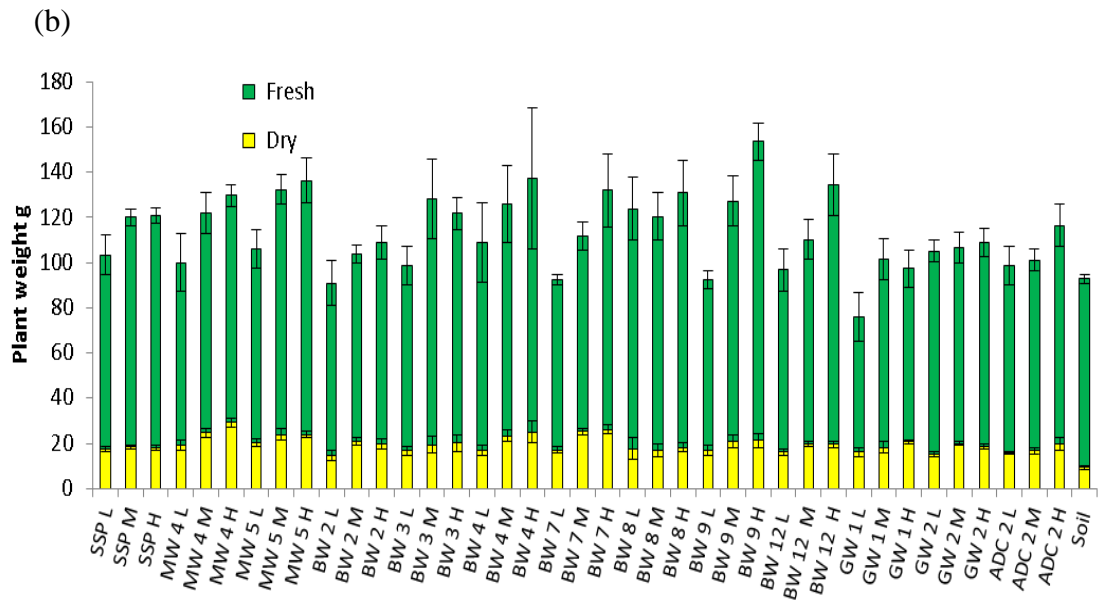
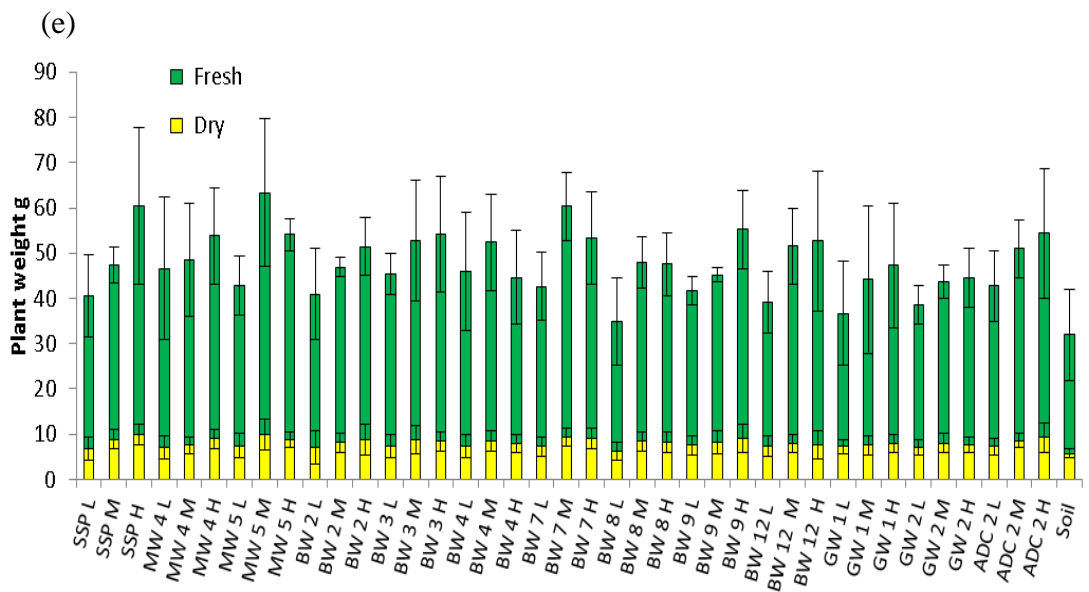
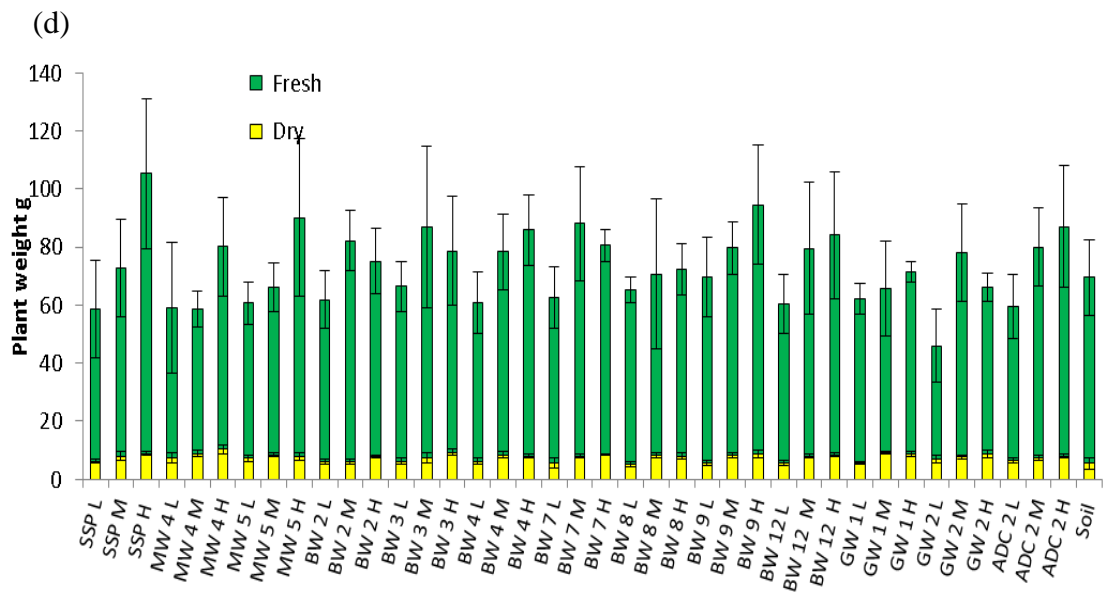
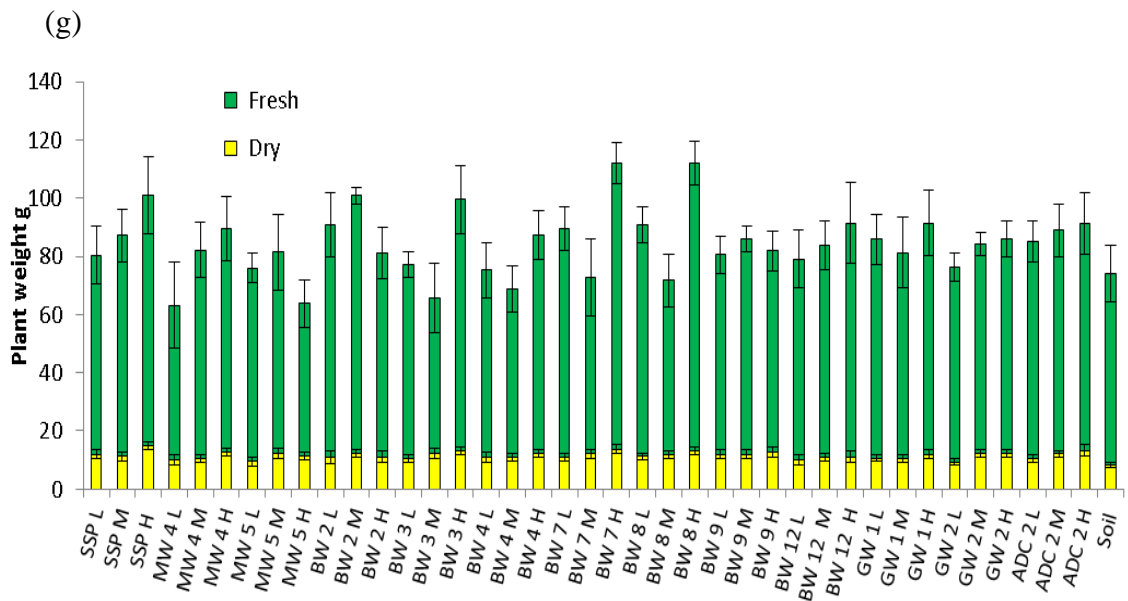
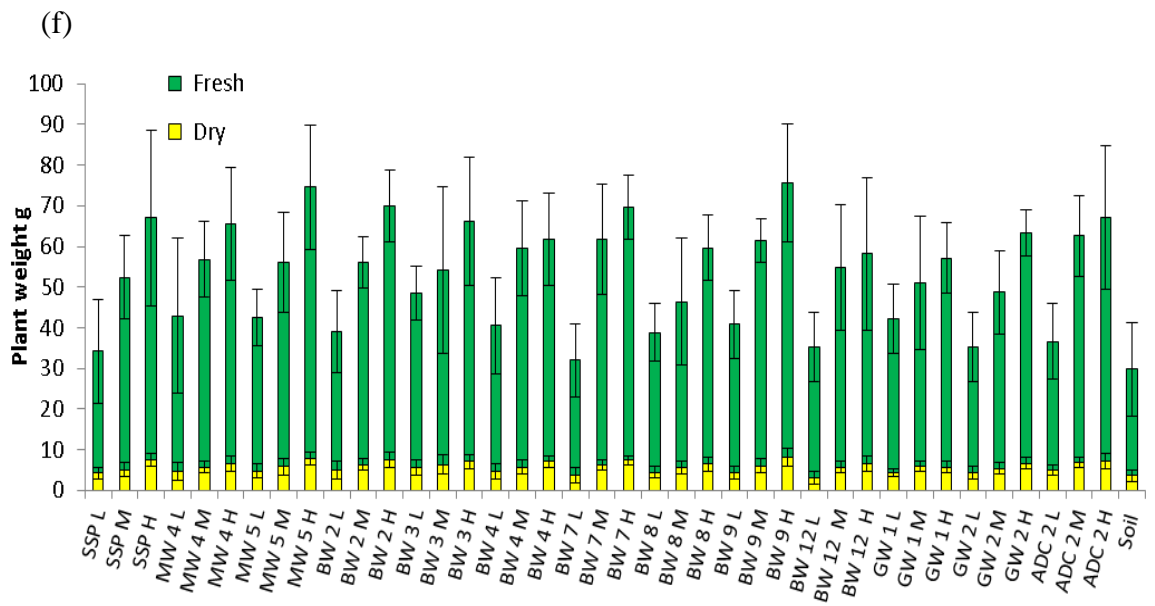
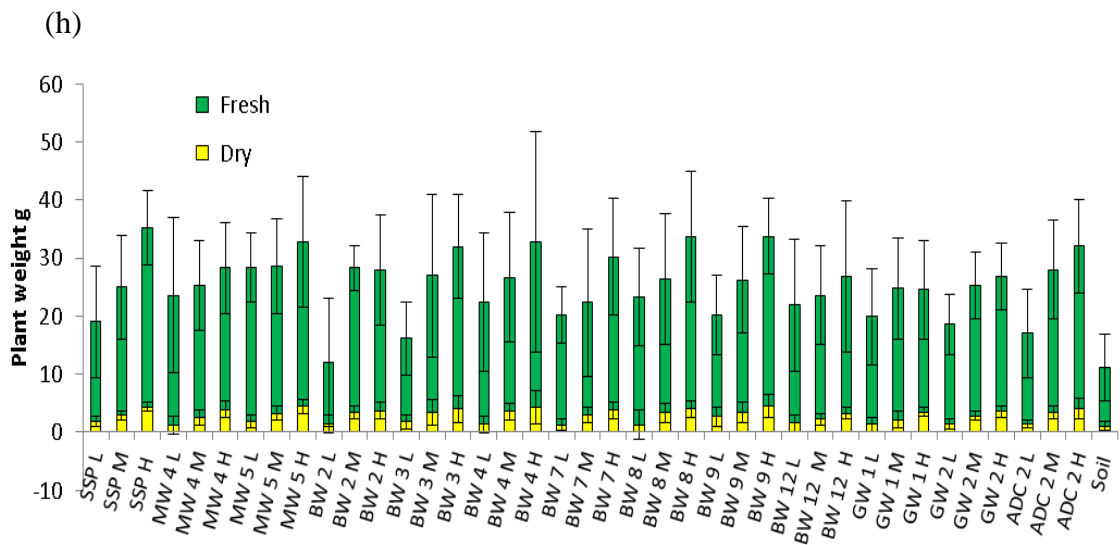


Figure. 6.2 a – h. Fresh (green) and dry (yellow) weights of all compost treatments and controls used in the pot experiment. Harvest 1 is Figure 6.2a running up to Harvest 8 at 6.2h. The bars show the fresh weight overlapped on dry weight.









Phosphorus uptake figures for the manure waste composts (MW) were the highest of all the treatments. There was a steady uptake of P throughout the harvests. Increasing application resulted in increased uptake. Within the group there were two composts used; MW 4 and MW 5. The uptake figures for the individual compost displays an effect of rate and a seasonal effect on uptake of P. MW 4 exhibits a greater availability and uptake of P over the course of the harvests.

There was quite an extensive number of biowastes (BW) used within the experiment. A total of seven BW were investigated for P uptake in the experiment. Similar to with the MW's, the uptake of P was similar for the BW's in the trends exhibited over the eight harvests. The uptake of P was relatively low in variance across the group – considering there were seven different treatments used. At the high rate (HR) the group shows a

separation in the uptake of P with three treatments (BW 3, BW 4, BW 7 and BW 12) forming an upper level with the other four treatments (BW 2, BW 8 and BW 9) at a lower level. These composts contained a green waste portion in their feedstock. There is no clear evidence to suggest that green waste has an immobilising effect on P.

GW 1 and GW 2 and the anaerobic digestate – ADC 2 as with the other groups the uptake trends for the GW and ADC groups are the same. Cumulatively GW 1 exhibited the highest uptake of the GW composts. At the lowest rate (LR) the cumulative uptake for the two GW was similar with uptake figures of 346.6 mg P dw⁻¹ (GW 1) and 308.4 mg P dw⁻¹ (GW 2). For the other two rates (MR and HR) there was a greater uptake in GW 1 than in GW 2. ADC 2 was the only AD used in this trial. This material exhibited the lowest uptake figures at all three rates.

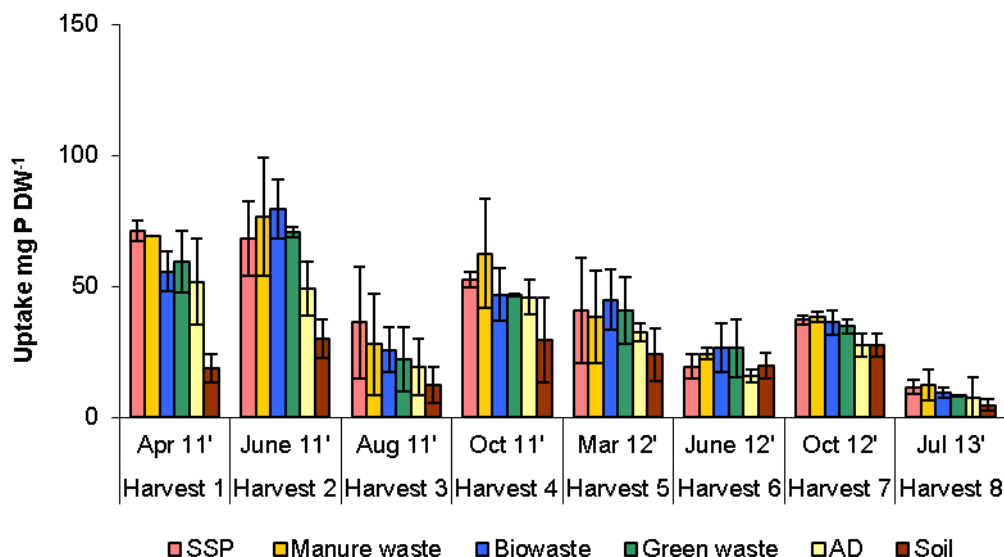


Figure 6.3. Plant phosphorus uptake of compost groups over eight harvests at application rate 60 kg ha⁻¹. Plant phosphorus uptake is measured in mg P dw⁻¹

The figure for the uptake of P at the low rate (LR – 60 kg ha⁻¹) shows MW with the highest uptake of P (Figure 6.3). Both the BW group and the GW group exhibit a high uptake of P relative to the SSP control and the MW. The ADC had the lowest uptake of the groups over the harvests. This however, did not prove to be statistically significant when compared with the uptake with the all other groups ($P < 0.05$). When compared to the untreated control (soil) there is no significant difference in the uptake of P for the ADC ($P > 0.05$). The visual aspect of the plant growth suggests there is an effect of some significance of compost addition. The uptake from the MW was possibly not as high as expected. Uptake data for harvest three show the SSP with the highest uptake of P, but for the other harvests there is more variability. This would suggest a slower mineralisation rate for the compost treatments as harvest three was the shortest in duration. This was a summer harvest which suggests the higher temperatures were influential.

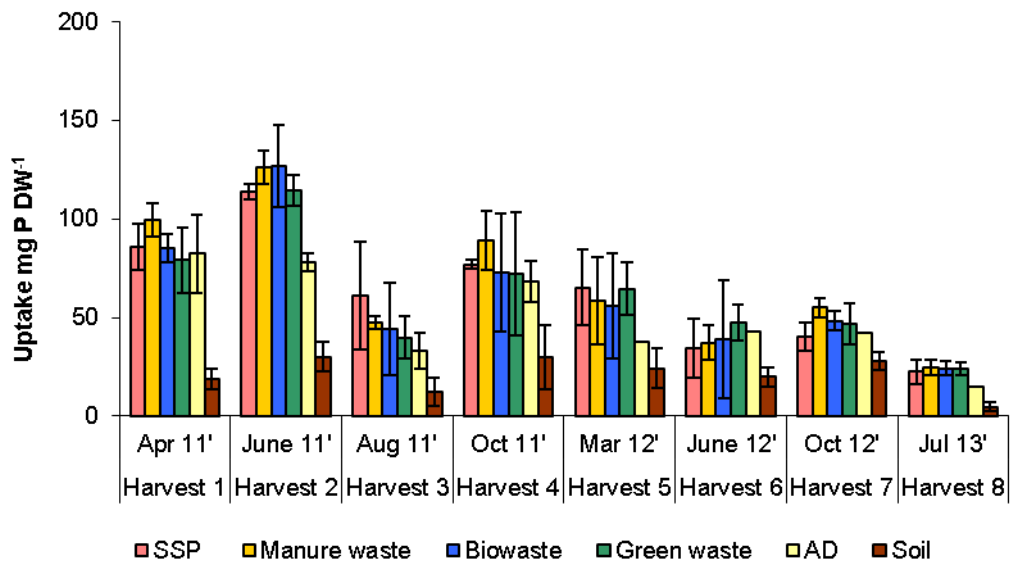


Figure 6.4. Plant phosphorus uptake of compost groups over eight harvests at application rate 150 kg ha^{-1} . Plant phosphorus uptake is measured in mg P dw^{-1}

The MW group displayed the highest uptake of P (Figure 6.4). The control of SSP had the second highest uptake with both the BW and the GW groups have almost equal cumulative P. There was a lower uptake from the ADC with a cumulative P uptake. Similar to the trend in the low rate (LR) the mineralisation rate (a precursor to uptake) for SSP is higher than the compost treatments. At harvest three the uptake for the compost treatments is lower than the SSP which was the shortest harvest. Due to the low figure for soil it shows that there is still a significant amount of P being mineralised from the composts at each harvest and thus demonstrating slower nutrient release.

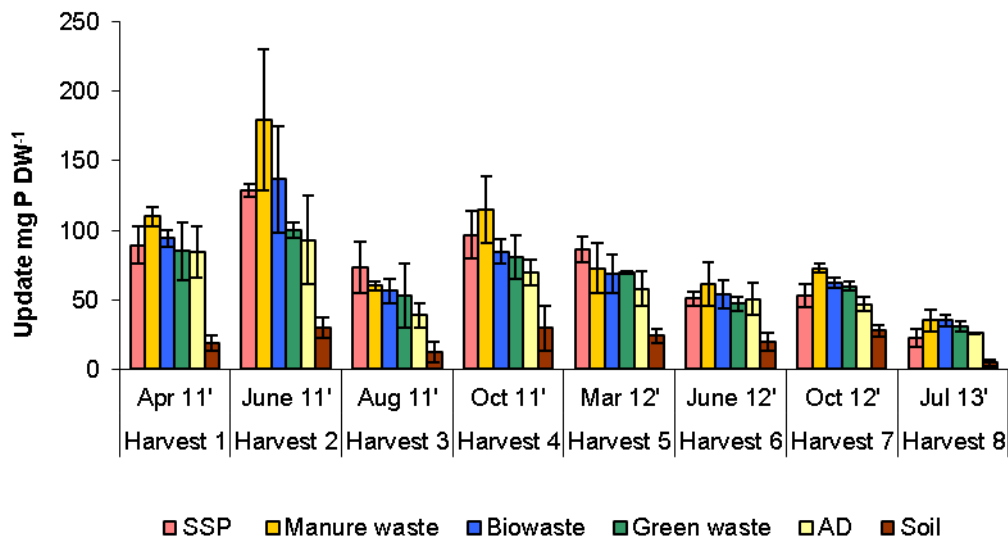


Figure 6.5. Plant phosphorus uptake of compost groups over eight harvests at application rate 240 kg ha^{-1} . Plant phosphorus uptake is measured in mg P dw^{-1}

Uptake figures for the high rate (HR) again show the MW group with the highest uptake of P. The HR application was 240 kg P ha^{-1} . There was also a high uptake of P from both the BW and the GW groups. As with the other rates during the shorter harvests there was a more rapid mineralisation from the SSP. The second harvest which ran for the longest duration shows a much higher uptake of P from the MW and the BW groups. The MW group also shows a significant difference ($P < 0.01$) to all the other compost groups.

6.4 Discussion

Uptake figures for the compost treatments for the P growing trial exhibited much more variety than the N trial (Chapter 5). The MW groups exhibited the highest uptake of P over the trial. Within the MW group the two treatments showed indifferent

results at the different rates. For the LR MW 5 exhibited the highest cumulative uptake. However for the following two rates MW 4 exhibited a higher cumulative uptake. In each of these cases the overall cumulative uptake shows no significant difference between the two treatments ($P > 0.05$). The difference in the cumulative uptake by the treatments at the individual rates could be attributed to pH and the levels of metals. Phosphorus availability can be affected by the levels of iron (Fe) and aluminium (Al) (Axt and Walbridge, 1999). These two metals form complexes with phosphate ions which have less solubility and thus are unavailable to plants. The same process takes place when soils have a basic pH (> 7.5) when phosphorus binds to calcium (Ca) in a similar process (Faulkner and Richardson, 1989) to Fe and Al.

The compost addition to the soil at the LR would have seen the smallest volume of compost added. At this low rate of addition the soil may dictate the overall pH (7.2) of the system within the pot. MW 5 exhibited a higher uptake of P at the LR but also had significantly higher levels of Ca (10434 mg L^{-1}) and Mg (5620 mg L^{-1}) over MW 4 (Ca 2997 mg L^{-1} & Mg 2857 mg L^{-1}) respectively. At the MR and HR the amount of compost and level of P added was greater. The addition of CAN to the system may have also decreased the pH at the LR and therefore the binding action of Ca would be decreased. Ammonium compounds have the potential to be acidified by bacteria in the soil. The decrease may have been caused by nitrification of fertiliser taking place in the soil/compost matrix (Yan *et al.*, 1996). At the higher rates the compost may have dictated the pH and pushed it higher which would activate the binding sites of Ca.

It is widely reported that maturity of composts can have an impact on the availability of nutrients. There is a significant difference in the composting process length concerning both MW 4 (21 weeks) and MW 5 (2 weeks). Alder and Sikora (2003) state that a less mature compost is more likely to displace sorbed P from sites within the soil due to high levels of organic acids. There does not appear to be any evidence of this. However a study by Bhatti *et al* (1998) described how oxalate and soil organic matter (SOM) affected the P in soil by decreasing phosphate sorption. There is evidence for this with MW 4 and MW 5. MW 4 had organic matter at 828.6 g kg⁻¹ and MW 5 was 645.9 g kg⁻¹ thus allowing a greater potential to release P from the metal binding sites. De Bertoldi (1983) presented results where increasing organic residues reduced the concentration of exchangeable Al. Hue (1992) reported that an increase in soil pH after application increased P availability. This may be attributed to the mineralisation of C and production of OH⁻ ions by ligand exchange and the introduction of Ca and Mg (Hue, 1992; Iyamuremye *et al.*, 1996).

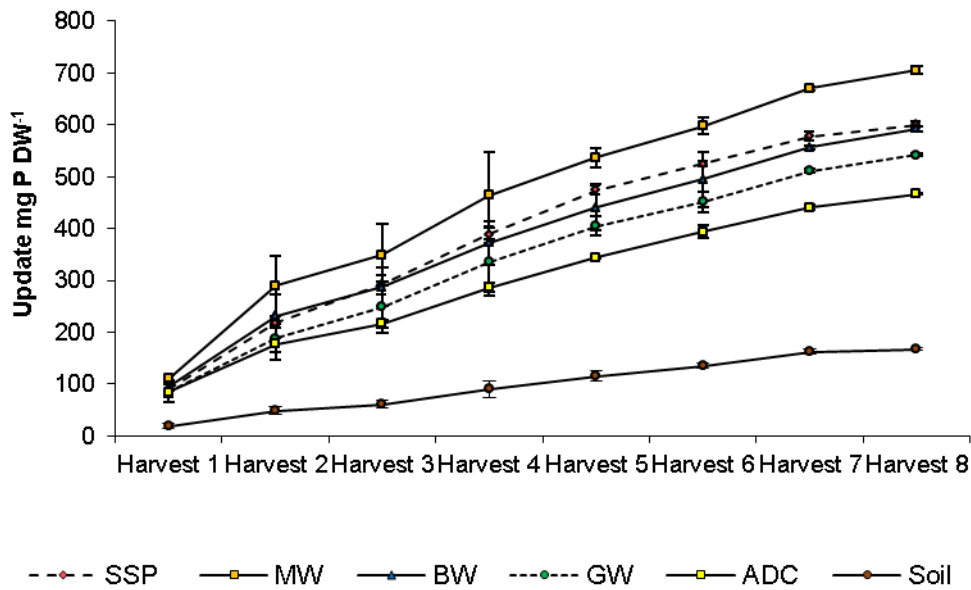


Figure 6.6. Cumulative plant phosphorus uptake of compost groups over eight harvests at application rate 240 kg ha^{-1} . Plant phosphorus uptake is measured in mg P dw^{-1}

The BW group shows less uniform results. All of the treatments show a significant uptake of P. A higher uptake of P was seen than expected. All treatments at their respective rates showed no significant difference in uptake of P ($P > 0.05$ for all treatments). This also applies for the chemical control. Contrast these results with HR where a significant difference is observed between some treatments. At the HR, BW 12 shows a significant difference in uptake of P when compared with BW 2 over the eight harvests ($P < 0.01$). Both of these treatments contain the same feedstock (brown bin waste). However, BW 2 contains a small portion of yard waste which may account for the difference. BW 2 was composted for a total of thirty eight weeks whereas BW 12 underwent a considerably shorter process of three weeks (In vessel) with one week maturing. These results suggest that the treatment process and the length of the treatment process are of significant importance. It must also be noted that BW 12 had

organic matter of 623.7 g kg^{-1} and BW 2 had 288.8 g kg^{-1} . Organic matter figures such as the figures presented confirm the theory proposed by Bhatti *et al.* (1998) which indicated that SOM may decrease phosphate adsorption. Kang *et al.* (2009) also describes how organic matter can influence P uptake by its capacity to sorb P. Another point of interest in relation to BW 12 is that it is the only treatment within the BW group that is classified as unstable as it has an oxygen uptake rate (O.U.R.) of $23.9 \text{ mmol O}_2/\text{kg organic solids/h}$, and perhaps this instability affected P uptake BW 7 had the second highest uptake of P at the HR and showed no significant difference in uptake of P when compared with BW 12 ($P>0.05$). BW 7 would be considered stable as it had an O.U.R. figure of $3.64 \text{ mmol O}_2/\text{kg organic solids/h}$. BW 7 underwent a longer composting process of twelve weeks. As stated by Eghball and Power (1999a) composting can decrease the N availability of compost by approximately 40 – 60%. However this is not the case with P. Composting does not have as pronounced an effect on P loss or conversion to the unavailable form during the composting process. As can be seen by the results presented a longer composting process will yield statistically the same amount of P uptake and will generate a stable compost.

The GW group of GW 1 and GW 2 were both 100% green waste. Over the course of the harvests there is no significant difference in uptake at all three rates. GW 2 had a lower cumulative uptake at the HR then at MR. This was the only treatment in which rate effect was not linear on uptake. There is a suggestion by Ayuso *et al.* (1996) that humic substances may increase P uptake. This could be attributed to the formation of

phosphohumate which are readily absorbed by the plant. The authors mention that the humic substances have a phytohormonal effect on the plant and above a certain level would be phytotoxic. GW 2 had a total humic substances concentration of 325.9 g kg^{-1} which is three times that of GW 1 (110.7 g kg^{-1}).

Unlike nitrogen dynamics when compost is added to soil – rate has an effect. There is some evidence that the rate of P addition is less effective. Catton (Catton, 1983) presented results in which a consistent lack of P response is observed in lettuce when harvested at advanced stages of maturity. There is evidence of this with all treatments used in this experiment of this P response. Observation of the percentage recovery would suggest that there was no linear response to the P applied i.e. the amount of compost. The rate effect was seen as significant in terms of P uptake throughout the harvests ($P > 0.05$). However, the percentage recoveries show a different result. In general no linear response in P recovery was seen from P applied. This is probably due to such large rates of compost being applied at the start and hence there was more P available than the plant required for growth. The large application rates were to ensure that the trial ran for the two year duration and wasn't exhausted of P prior to this. In every treatment used the LR had the highest percentage recovery. In some cases it is three times higher than the HR. There are previous literature publications which suggest similar results where P uptake is not directly affected by rate or treatment type (McCoy *et al.*, 1986; Ozanne, 1980). There was a visual difference in plants at different rates which is shown in the appendix (Figure A.6.1) There is also evidence that availability of

P may be restricted to more long term availability by the tendency of inorganic P to bind to low soluble Ca – P compounds such as apatites or octacalcium phosphates in more basic/alkaline environment (Frossard *et al.*, 2002) and similarly in soils (Bertrand *et al.*, 2003). This has been previously suggested for low pH soils and the tendency to bind to Al and Fe (Khan and Joergensen, 2009).

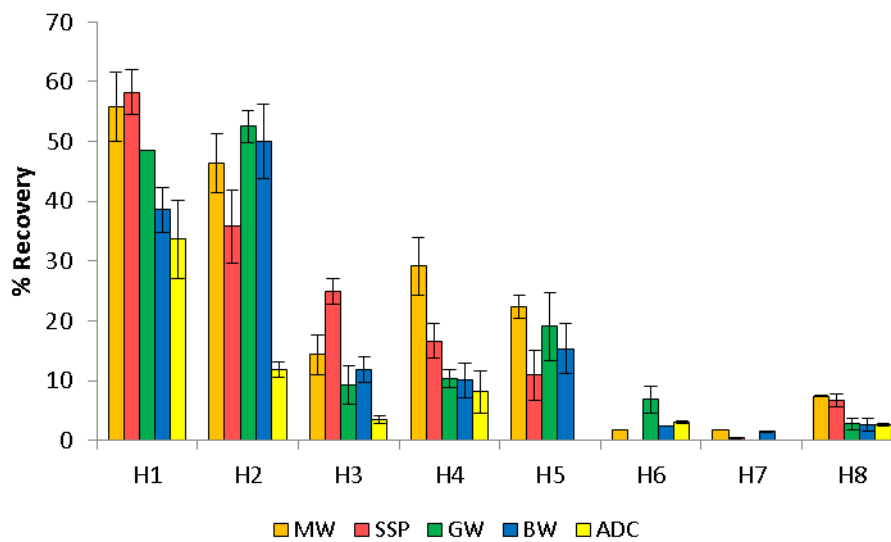


Figure 6.7. Net P percentage recovery for the compost groups over eight harvests for the high rate of compost application (60 kg ha^{-1}). Errors bars indicate standard deviation within the group

The concentration of P that was up taken by the plants was not significantly different across the individual rates. The limitation of the experiment lies with the high application rates as it limits understanding and quantification of exact P requirement of the plants.

There are suggestions that the availability, mobility and movement of P when incorporated into soil (to be accessed by plants) is more complex than just how much P is applied and the consideration of some other characteristics of the soil and the organic amendment applied. Schachtman *et al.* (1998) reviewed the mechanism of P uptake from soil into the plant cell. Results presented in this work show that the uptake and the mechanism of uptake is influenced by the genetic properties of the plant. There is also a suggestion of different P transporters being expressed at times of low and high P.

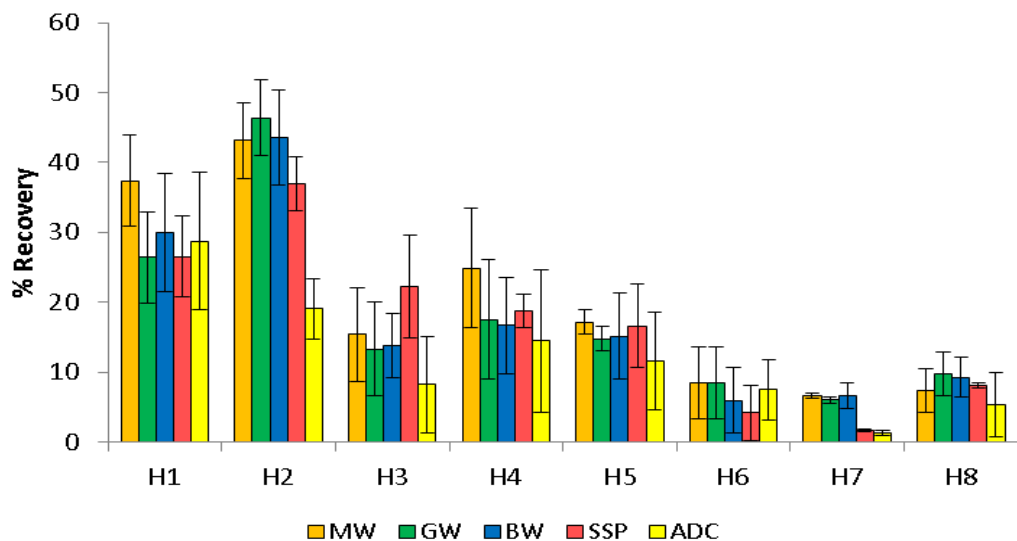


Figure 6.8. Net P percentage recovery for the compost groups over eight harvests for the high rate of compost application (150 kg ha^{-1}). Errors bars indicate standard deviation within the group

The apparent net percentage recoveries of P are shown in Fig. 6.6 – 6.8. The recoveries were higher for all treatments at the lowest rate. This shows that the application rate of 60 kg Ha^{-1} mineralised a significant amount of P for plant uptake. However, not growing the cabbages to full maturation may have been an issue as at the LR the rate of

growth would have slowed closer to the harvest at full maturation. A previous study on cabbage growth by Adhikari and Chen (2011) reported a recovery of 18 – 20% for swine manure compost. This is much lower than the recoveries reported in this study. The authors do mention a quite significant loss of P through forms of leaching from the soil/compost matrix. In our trial we used a closed system which virtually ensured all P was kept within the matrix and potentially plant available. Up to 63% of total P applied from cattle manure was leached from soil in a previous study (Idowu *et al.*, 2008). Our results coupled with previous work on P losses (Tunney *et al.*, 1997) from soils make effective and diligent nutrient management planning more and more important.

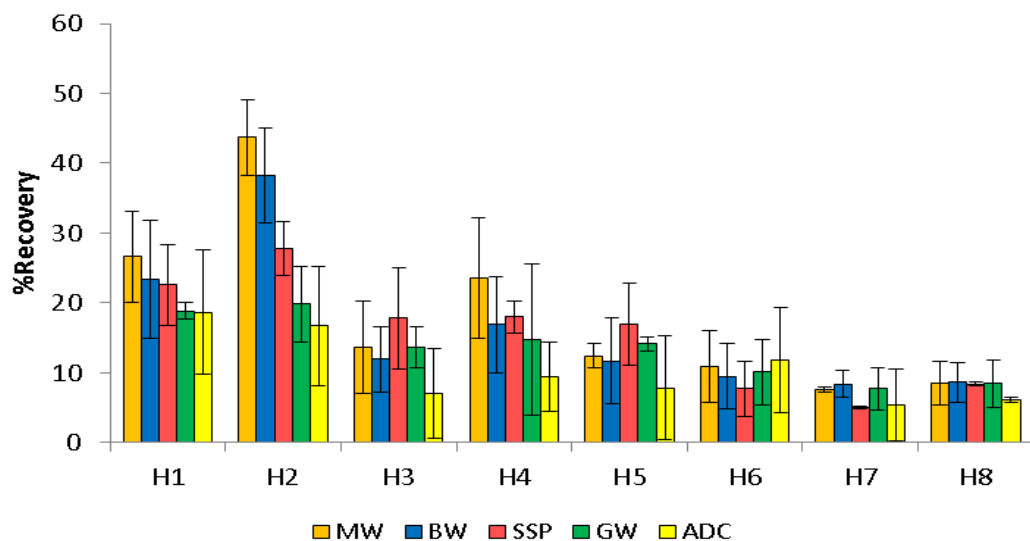


Figure 6.9. Net P percentage recovery for the compost groups over eight harvests for the high rate of compost application (240 kg ha^{-1}). Errors bars indicate standard deviation within the group

The high uptake of P suggests that composted manure, biowaste and green waste may be as effective as mineral P fertiliser in crop growth. Our results confirm the results

Cooperaband *et al.* (2002) and Mkhabela and Warman (2005). Composts have the ability to stimulate mineralising bacteria for both inorganic and organic P (Perucci, 1990; Ancheng and Xi, 1994). The details of how this affects P availability and uptake are well documented (Khan *et al.*, 2009). In some cases very high volumes of compost were added to the soil. From the results presented it is also unclear how much of the soil and compost organic P was mineralised by the addition of the composts. This action is facilitated by the presence of low molecular weight organic acids in the rhizosphere (Bar-Yosef, 1996) and the amount of root – derived carbon flow through the rhizosphere (Helal and Sauerbeck, 1989). Additions of compost would increase the amount of carbon and organic acids and thus increase mineralisation of native organic P. This action has been identified by Zhao *et al.* (2010). However, their study was specifically to investigate the rhizosphere effects on soil N and P transformations. There were no organic additions made i.e. compost. Previous studies have shown compost to mineralise P that equates to 60% mineral fertiliser P (Sinaj *et al.*, 2002; Olson *et al.*, 2010). From the results presented in the current experiment there is a higher P mineralisation and plant uptake from composts over mineral P – generally. This would give an indication as to the importance of soil type on P availability and also the type of crop grown. From the results presented the cabbage crop has shown a strong capability of mineralising compost organic P.

6.5 Conclusion

The findings from the experimental pot study indicate a significant uptake of P from the composts. In general the uptake and P recovery was higher than expected. There was a lack of a linear relationship between application rate and recovery. However, this is more than likely due to the amount of P being applied was more than required. The treatments also showed minimal differences although effect of treatment was significant. The MW group exhibited the highest uptake of P. The other treatments exhibited no significant difference when compared to the SSP control. The positive result is that the other treatments also supplied sufficient P for growth when equated to SSP throughout the trial. The uptake of P showed no discernible pattern when individual treatments were considered on the basis of feedstock and characterisation. This may be attributed to the complex nature of the behaviour and interaction of P in soil and plants. Understanding these interactions and the ultimate fate of P is essential if organic amendments are to become a possible replacement or part supplement for P based fertilisers. Both plant available (Olsen's) and total P remains important parameters for compost P availability. Olsen's P gives an accurate figure for readily available plant P. The total P figure will allow for prudent planning in terms of the potential amount of mineralisable P. The higher than expected uptake highlights the potential for nutrient management from composts to be done on the basis of P availability.

6.6 References

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Chapter 7

A study investigating the relationship between two stability measurements on Mechanical Biological Treated waste

7.1 Introduction

Pre-treatment of municipal solid waste (MSW) before landfilling in Ireland with efforts to segregate and recycle waste has become increasingly more significant in the last decade. This has led to an increase in the use of mechanical biological treatment (MBT) of MSW. The EPA in Ireland define MBT as “partially processed mixed household waste by mechanically removing some parts of the waste and biologically treating others, so that the residual fraction is smaller and more suitable for a number of possible uses” (Anon, 2008; Archer *et al.*, 2005). Pre-treatment of waste is carried out to with the objectives of recovering materials from waste, producing energy and/or minimising the amount of waste to be landfilled (Komilis *et al.*, 1999). In Ireland the majority of the MBT waste is composted and then sent to landfill. This minimises the amount of potential pathogenic waste entering the ground and reduces the greenhouse gas emissions. Before landfilling of MBT waste it is important to assess the stability of the material. Unstable materials sent to landfill may ferment under anaerobic conditions (Carey *et al.*, 2000) producing greenhouse gases. The purpose of this study was to

investigate a potential relationship between two independently conducted stability tests methods; namely Oxygen Uptake Rate (OUR) and AT_4 on a population of MBT samples.

7.2 Materials and methods

A total of 29 samples were used in this study. Samples were procured from Austria, Germany and Ireland. The samples used were taken from MBT pilot plants at different stages of the treatment processes. The samples ranged in age from two weeks to six months. This gave a variation and heterogeneity to the physical composition of the samples. The samples were sieved to <10mm before analysis was conducted.

7.2.1 Oxitop O.U.R. Measurements

Before the analysis was completed the moisture content and organic matter (OM) were determined by drying at 105°C for 24 hours (Mettler oven) and by loss on ignition at 550°C for 16 hours (Carbolite furnace). These figures are required in order to calculate the amount of sample that is needed, that is equivalent to 2g of OM. This is the specified amount for the OUR test. The OUR test was conducted using a pressure transducer system (System OxiTop® Control^{OC}110, WTW GmbH, Weilheim, Germany). The procedure has been outlined in detail with the specific calculations required by Nolan (2011). Two grams of OM of each MBT sample were mixed with 180 ml of distilled water, 10 ml of a nutrient solution, 10 ml of pH buffer and 2.5 ml of a nitrification inhibitor (allylthiourea) detailed in I.S. EN 16087-1:2011.

in 1L Duran bottles. Each sample was performed in triplicate. The bottles were placed - unsealed - on an orbital shaking incubated at 30 ± 2 °C for four hours. This was to allow the temperature and pH to adjust within the samples. After four hours the pH was measured (Eutech PC 700) to ensure it was between 6.5 and 7.5. Soda lime pellets, were placed in the headspace of the controller. These were used to remove carbon dioxide (CO_2) by absorption.

Pressure transducer heads were then attached to the bottles and the samples returned to the incubator for 5 days. During this period, the rate at which oxygen was consumed by the inherent micro- organisms was estimated by measuring the pressure drop in the headspace above the water phase.

7.3 Results

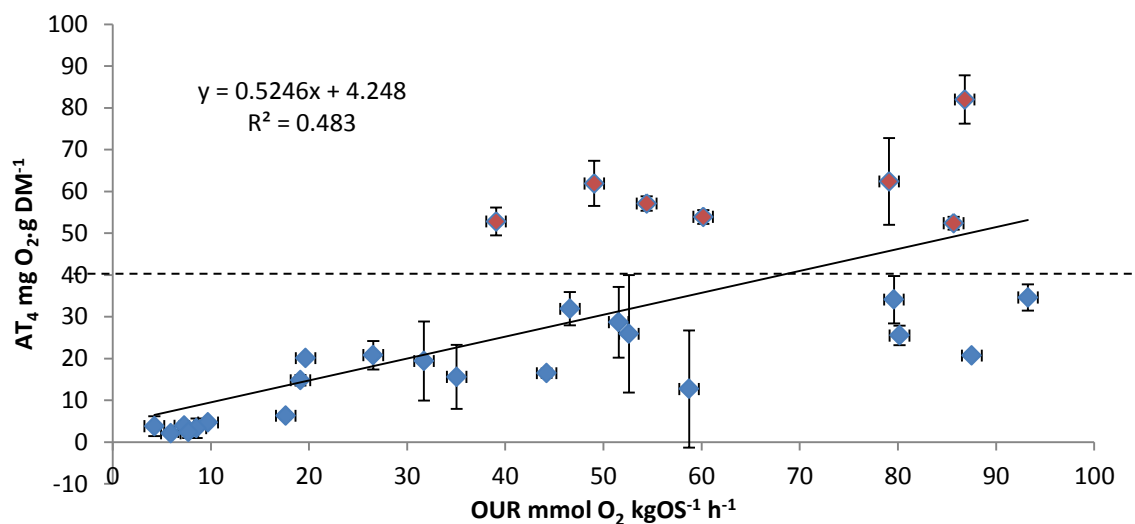


Figure 7.1 OUR measurements for MBT wastes correlated with AT₄ measurements for the same wastes. Values highlighted in red are above an AT₄ reading of 40 mg O₂.g DM⁻¹. For goodness of fit the line axis is not passed through zero as the results do not suggest that both OUR and AT₄ have the same figure at zero

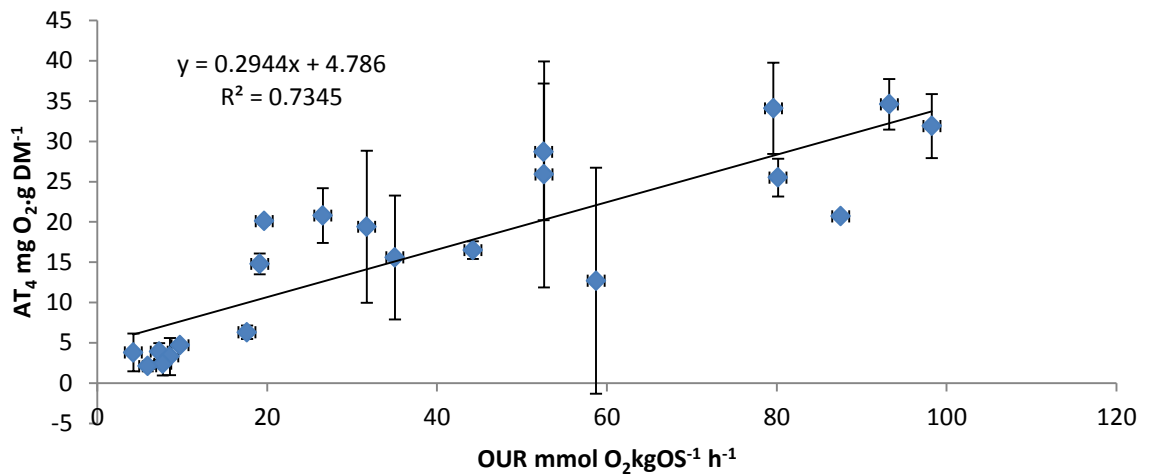


Figure 7.2 OUR measurements for MBT wastes correlated with AT₄ measurements for the same wastes with the AT₄ values above 40 mg O₂.g DM⁻¹ removed. For goodness of fit the line is not passed through zero as the results do not suggest that both OUR and AT₄ have the same figure at 0

All three sets of data were correlated individually before being correlated as a group. A correlation with the Irish samples yielded $R^2 = 0.8794$, for the German samples $R^2 = 0.7343$ and for the Austrian samples $R^2 = 0.7462$.

7.4 Discussion

These set of experiments were conducted to investigate if there was a relationship between two independent stability test methods. From the results presented there is not an overall strong correlation between the total numbers of samples which is not significant ($P > 0.05$). However, removal of all samples that have an AT₄ reading above 40 mg O₂.g DM⁻¹ resulted a strong correlation ($R^2 = 0.7345$) that is significant being ($P < 0.05$). Some of the samples report a high standard deviation which could be attributed to the heterogeneity of the samples. The nature of the materials are quite heterogeneous especially samples from the early stages of the treatment process. This could have led to

potential discrepancies in sampling or an introduction of human error as the highly heterogeneous material make reproducible sampling more difficult.

Removing the samples that had a reading above 40 for AT₄ was done to highlight the trend between both OUR and AT₄ at readings below 40. Disregarding the samples above 40 was essentially done as a sample at 50 or 60 O₂.g DM⁻¹ has no influence on its potential landfilling. It is considered completely unstable and therefore not suitable to be landfilled. The Austrian standard for MBT waste to be considered stable is 7 mg O₂.g DM⁻¹. These are strict standards due to the fact that the material must be strictly inert and so not to ferment or produce greenhouse gases under anaerobic conditions. Conducting these tests on such unstable materials may be used for process monitoring as this could be used to give an indication as to how treatment process is progressing. From examining the results as an overall population there are many trends that can be observed. One trend that tends to emerge within the three population groups (Austrian, German and Irish samples) is that at lower figures there is a definite correlation between the two methods. At some of the larger values i.e. above AT₄ of 40 or OUR of 50 – the correlations are non-significant.

A previous study by Binner et al. (2012) highlighted the significant relationship between conducting AT₄ measurements by OxiTop and Sapromat. In their paper the authors detail that the systems operation are essentially what gives a lower reading for AT₄ by OxiTop over Sapromat. In our study the experiments were conducted

independently of each other and therefore would have increased the chance of error due to different sampling preparation techniques. It must be noted that this was a trial experiment to assess the potential of using the two methods separately.

Böhm et al. (2010) discuss the relationship between FT-IR and respiration techniques conducted on MBT samples. The authors display the limitations of conducting respiration tests on MBT samples and that failure is more likely due to the sensitivity of the test methods. They also recommend that in countries where acceptance criteria have not been developed that FT-IR could be used to prove the stability of MBT waste. In Ireland the OxiTop OUR method has been accepted as a national standard for assessing compost stability and therefore would be more applicable to MBT waste. There is also the expense. Although both methods require a capital investment the OxiTop system is cheaper by roughly half which for many laboratories is a significant saving.

7.5 Conclusion

Although the study conducted was not holistic and extensive in its approach; the results appear promising. This might warrant a further study that is more in-depth and extensive. The preliminary results show that there is a correlation between the two test methods. Across Europe many countries use different methods to measure stability in MBT waste – and compost for that matter. Developing the methods so that the sample preparation is similar and studying a larger population of samples could lead to a possible universal stability value for MBT.

7.6 References

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Chapter 8

Conclusion and future research

8.1 Introduction

The research undertaken in this project encompasses three key areas including: increasing biodegradable municipal waste that must be diverted from landfill to be composted, defining application rates and codes of practice for compost use through understanding nitrogen (N) and phosphorus (P) dynamics and mineralisation rates with the goal of maximising crop efficacy and protection of ground waters. While in mainland Europe and other parts of the world compost research has expanded exponentially since the 1980's Ireland has not seen the same research being conducted. However, in the last decade there has been a surge in the organic waste recycling industry and subsequently compost use in both horticulture and agriculture. This has seen the industry rapidly expand. Regulating the industry was an important step that was achieved in 2011 with the launch of the national standard for compost quality (*IS:441*). A minimum set of criteria is now in place for a compost to adhere to before being considered 'market ready'. One of the issues that accompany this is that there is a standard for composts during the composting stage. There is however, the problem in what to do with the composts at the end of their composting phase. This is where this project aimed to bridge the gap between the composting and the end usage of composts.

Throughout Europe much of the research conducted has been to improve the composting techniques and the quality of the finished product. The other main area of research has been to investigate the potential of compost as a fertiliser through its N or P mineralisation potential. Generally this type of research focussed on one nutrient and studied it in depth. This project differed from many other previous research studies as it investigated the compost type and characteristics through 27 different physico-chemical, spectral and biological characterisations; N and P availability over a short duration after application at equivalent rates and over a medium duration through two separate pot experiments conducted in a glasshouse.

8.2 Overview and synopsis of experimental chapters

Chapter 2

- Biowaste (BW) and green waste (GW) composts had characteristics that were similar.
- Within the BW composts there was a separation between brown bin waste and pure food waste feedstock.
- Composted manure wastes (MW), given the high nutrient availability demonstrated their potential as organic fertilisers.

Chapter 3

- The MW group would serve as an ideal organic fertiliser due to the levels of available N and P.

- Typically N mineralisation for the groups (excluding MW) was low. The GW composts immobilised N.
- Predicting N availability from composted wastes has been shown to be better correlated to NDF and lignin content. There was a distinct lack of any relationship between C/N ratio and available N.
- The results from the P incubation indicate that available P is higher from all of the materials than N.
- Irregular mineralisation patterns made longer term predictions difficult

Chapter 4

- The application of the composts to the different soils produced numerous interactions of which all were significant
- Fulvic acid (FA) content of the composts had an effect on P availability.
- The capabilities of the soils to bind P were quite difficult to evaluate from the soil characteristics due to the inconsistent nature of the results.

Chapter 5

- The results from the N pot experiments further highlighted the poor mineralisation rates of N from compost.
- The MW group may be classed as being high in available N with the BW, GW and ADC composts being low in available N.
- From the results presented the MW group have the capacity to release N at a more stable rate than a conventional inorganic fertiliser.

- The co – application yielded an increase in N from the MW that was significant. However, this was not the case with BW and GW.

Chapter 6

- The findings from the P growing trial indicate a high uptake of P from the composts. In general the uptake and P recovery was higher than expected.
- The MW group exhibited the highest uptake of P. The other treatments exhibited no significant difference when compared to the SSP control.
- The uptake of P showed no discernible pattern when individual treatments were considered on the basis of feedstock and characterisation.

Chapter 7

- Primary results indicate relationship between the two methods where the reading for AT₄ was below 40.

8.3 Economic appraisal of compost vs inorganic fertiliser

Protecting the environment was a major component highlighted under ‘Agriculture’ in the National Development Plan. All farmers receiving payments under the Common Agricultural Policy (CAP) must conduct their farming practices whilst complying with the minimum national and EU environmental protection requirements. This creates a gap in the market for compost to exploit. Approximately 1.25m ha of land is used for agricultural purposes in Ireland. Land used for crop production was seen as the most viable land for compost application. This amounted to approximately 400,500 ha. The EPA report estimated that around 250,000 tonnes of compost could be applied to

agricultural land used for crop production. An economic appraisal was included in the final discussion chapter as it brings into focus the economics of the research. The experimental work covered the potential agronomic, edaphic and environmental impacts compost can have. However, it is imperative that the monetary value of compost is also examined.

The international fertiliser market is in itself quite volatile due to the commodities market which can often dictate prices. This is due to the fact that gas in the form of methane is used as an integral part of ammonia production (Haber – Bosch process). Some of the issues that influence the phosphorus fertiliser market are the mining costs and production associated with rock phosphate. In the last two decades the price of calcium ammonium nitrate (CAN) has doubled. In the last twelve months alone gas prices have fallen by 30%, yet no significant fluctuation in N fertiliser prices was noted for this same time period. This trend alone would suggest that fertiliser prices are on an upward curve which doesn't look like it will change in the near future. However, one cannot make assumptions this will not change. The supply and demand economic model now appears to outrank the cost and margin model. This is reflected in the profits being reported by the big fertiliser producers. Yara, one of the world's biggest N producers have reported a 50% increase in revenue for Q1 in 2015 which equates to €676 million. Both the agriculture and horticulture sectors in Ireland have been slow to adopt composts as a fertiliser as the horticulture sector has traditionally used compost to improve soil condition. There are two issues with instigating a shift towards using

compost or at least supplementing composts with inorganic fertilisers. The first issue is the economic value of composts.

8.3.1 Assessment of compost and fertiliser

In order for farmers and growers to adopt composts as fertilisers they must first be made aware of the fertiliser value of composts and how they compare to conventional fertilisers such as CAN and SSP. The second aspect which needs to be addressed is the benefits of using compost and how they release nutrients once applied to soil.

Table 8.1 Nitrogen, phosphorus and potassium fertiliser equivalents for a food/green waste blend (Anon, 2012)

Green/Food waste compost	N	P	K	Total
Fertiliser equivalent (kg/tonne compost)	11	3.8	8	22.8
Financial value of nutrients in compost (€/tonne compost)	€8.24	€3.19	€4.61	€16.04

The figures in Table 8.1 (Anon, 2012) show the amount of nutrient per tonne of compost and the financial value of the nutrients in €/tonne if compared to a fertiliser.

Table 8.2 Comparative inorganic N and P fertiliser prices and nutrient cost per kg

CAN 27.5%	€350/ t	SSP 16%	€410/ t
Fertiliser value	13.7 kg N	Fertiliser value	8.0 kg P
Nutrient cost/kg	€1.27 kg N	Nutrient cost/kg	€2.56 kg P

Composts can be purchased for a little as €30/t unbagged. The comparative figures show that composts have a large quantity of N, P and K. The issue with using them when compared to inorganic fertilisers is their relative rate of mineralisation of these

nutrients. Although the compost listed is stated as having 11 kg N content, this is largely unavailable as has been frequently discussed throughout the thesis. The availability of N from the compost varies but is approximately 8% in year one. The net N uptake for the final harvest at the end of year 2 was 23%. This is a significant increase in mineralisation of organic N from year on year. This was a far greater result than expected. This highlights the unpredictable nature of composts but does allow for effective nutrient management plans to be implemented. The phosphorus availability is far greater than N and from the results in chapter 6 show that organic P mineralisation takes place quite readily and frequently. Based on these results composts should be used as an organic P fertiliser with limited N availability.

There are problems that come with using composts as a P fertiliser rather than an N fertiliser. Nitrogen is the nutrient that is required in the highest amounts by crops. This means that growers base their rate of application on the nitrogen requirements.

Table 8.3 Rates and amounts of P added of compost based on nitrogen application applied during the nitrogen pot experiment.

	Biowaste compost		Manure waste compost	
	N content	P content	N content	P content
Biowaste compost	30.4 g/kg	3.30 g/kg	46.2 g/kg	13.4 g/kg
Available	482 mg/L	372 mg/L	964 mg/L	2588 mg/L
Addition of compost	189.58 g	644.89 g	180.34 g	229.57 g
P addition	450 kg/ha N = 70.4 kg/ha P		450 kg/ha N = 188 kg/ha P	

8.4 Conclusion

The figures in Table 8.3 show how much P is applied when application is based on N requirements. In the case of biowaste compost approximately 70 kg of P per hectare is applied. There is an even bigger amount when manure waste compost is considered. This is a large quantity of P to be applied and may not be fully required by crops. This leaves an alternative fate for P other than plant uptake. The most likely source is loss of P to the environment and local water courses. An application based on P requirements is both agronomically and environmentally practical as the N requirement by crops is far in excess of the amount of available N from compost.

The figures presented combined with the results from the pot experiments certainly show that composts have the potential to be P organic fertilisers. The financial savings to be made are not just from available nutrients as there is no metric to how important composts are in improving soil health by adding organic matter, priming soil to release nutrients, releasing P from binding sites, carbon sequestration and reducing greenhouse gas emissions. These are all added benefits which chemical fertilisers will not add due to their more destructive nature to soils.

8.7 References

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Final conclusion and future research

The research has produced a large amount of data sets. Therefore, it is more reasonable to select the major findings that will warrant further research in the near future.

- 1.** The results for the OUR test and the subsequent pot experiments suggests that unstable MW composts are not likely to immobilise nutrients or cause phytotoxicity. Further work is required to investigate using unstable MW composts in greater detail but also investigations into the microbiological effects are required.
- 2.** Both lignin and NDF have shown to be better predictors of N availability when compared to C/N ratio. There is definite cause to investigate how this relationship holds when applied to field scale. The rate of organic N mineralisation also requires further research. This would also require investigation at a field scale.
- 3.** The results from the P experiments indicate that far more considerations must be made when investigating or predicting potential P mineralisation and release. The results from the characterisation and the incubation experiments did not correlate highly with the pot experiment. The levels of available P from the composts did not translate directly to plant uptake.

4. Lysimeter experiments may also be necessary as the rate at which N and P are lost from the soil matrix is unknown due to the fact these experiments were closed systems.
5. There is also the potential to develop tailor-made or 'designer' composts. An example of such compost is a short duration composted manure that would be a compost but behave like a manure. Identification of specific feedstocks and composts for a target use i.e fertiliser, biostimulant, nitrogen inhibitor or compost to alleviate P-fixing soils.
6. The potential for brown bin waste as a compost fertiliser needs addressing. With incineration back on the agenda in Ireland a market gap has been created for compost over black bin waste.

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Appendices

A.1 Characterisation of composts

The individual characterisation results for each compost used are presented in table A1.1 – A1.4. All tables contain the compost code and their respective results.

Table A.1.1 Physico - chemical characteristics of all composts samples

	pH	EC mS cm ⁻¹	Moisture Content %	Organic Matter %	OUR mmol O ₂ /kgOS/h	Total HS g kg ⁻¹	Total HA g kg ⁻¹	Total FA g kg ⁻¹	Lignin %	NDF - Reflux
BW 1	7.49	4.48	15.01	49.09	3.46	214.87	190.49	24.39	30.2	41.6
BW 2	7.40	2.35	36.04	28.88	8.43	363.65	75.01	288.64	57.5	63.2
BW 3	7.66	7.30	35.63	40.23	2.80	352.97	126.64	226.33	64.5	70.9
BW 4	6.45	4.96	31.79	55.29	7.95	159.27	59.11	100.16	38.5	59.0
BW 5	7.64	2.27	49.16	59.70	2.93	191.06	159.65	31.41	39.0	59.6
BW 6	6.98	4.12	44.51	42.85	2.66	180.64	138.56	42.07	40.4	49.1
BW 7	7.02	4.65	38.53	51.57	3.64	245.37	201.37	44.00	43.8	60.9
BW 8	8.05	1.40	48.20	42.77	5.27	258.99	252.36	6.63	57.0	71.8
BW 9	5.35	4.26	67.86	88.02	2.83	88.05	21.52	66.53	49.5	73.9
BW 10	5.81	3.37	68.20	77.74	7.42	143.23	123.38	19.85	48.8	68.2
BW 11	6.50	8.64	63.83	65.70	5.11	83.71	55.69	28.03	40.7	69.7
BW 12	7.19	0.83	44.55	62.37	23.90	108.83	30.49	78.33	44.4	64.8
BW 13	6.45	0.18	49.06	64.47	2.63	131.25	99.18	32.07	27.9	41.3
MW 1	8.28	2.51	69.59	81.49	6.33	96.99	92.33	4.66	31.2	58.9
MW 2	6.31	7.02	41.33	75.96	25.98	163.29	139.24	24.05	15.6	37.2
MW 3	6.25	6.82	21.18	78.61	20.47	55.32	8.24	47.08	13.4	42.1
MW 4	5.30	5.03	40.44	82.86	55.72	74.04	49.84	24.20	12.3	34.7
MW 5	6.02	9.60	55.50	64.59	48.12	62.82	42.43	20.39	16.4	36.4
GW 1	7.72	1.84	50.80	47.97	4.76	184.75	146.34	38.41	57.7	66.7
GW 2	6.94	n/d	12.92	27.63	9.49	325.96	144.89	181.07	74.4	73.6
GW 3	6.25	4.56	68.89	74.56	6.84	178.23	145.73	32.50	53.0	68.4
IOW 1	6.10	7.47	44.53	80.40	5.97	117.05	35.32	81.74	38.8	66.1
IOW 2	5.90	3.15	45.91	81.54	5.78	58.25	48.05	10.20	37.7	60.9
ADC 1	6.70	8.41	38.51	30.97	4.98	250.24	246.05	4.19	51.2	56.3
ADC 2	6.40	7.53	51.00	53.64	6.34	183.56	146.99	36.57	51.9	64.8

Table A.1.2 Nutrient content of all composts used. Data shows total and available nutrients

Code	Carbon mg kg ⁻¹	C:N Ratio	Total N mg kg ⁻¹	DTPA Extractable nutrients mg L ⁻¹							Mehlich 3 P	Olsen's P	Morgan' s P
				Total P	Total K	NH ₄ - N	NO ₃ - N	N	P	K			
BW 1	272.7	13.2	20.6	8.2	4.4	30	476	505	2	1017	550	268	433
BW 2	160.4	10.2	13.4	3.9	13.0	1	366	367	6	2317	786	378	581
BW 3	223.5	19.3	14.5	2.4	9.0	1	231	232	10	1909	836	390	791
BW 4	307.2	10.1	20.4	3.3	11.0	5	477	482	15	2407	857	372	530
BW 5	331.7	10.8	23.8	11.4	12.6	0	66	66	4	312	1622	453	460
BW 6	238.1	12.4	18.5	17.1	10.3	3	469	472	4	1906	1614	428	451
BW 7	286.5	10.0	25.0	3.2	10.4	2	473	475	11	1905	784	414	435
BW 8	237.6	16.4	16.1	3.9	12.5	23	227	250	22	2856	1088	620	1040
BW 9	489.0	9.9	37.3	6.1	3.5	1	304	305	313	498	1641	903	1180
BW 10	431.9	17.8	20.3	2.4	3.2	2	207	209	98	420	561	554	546
BW 11	365.0	16.4	17.0	7.0	5.8	3	68	71	8	680	1345	459	551
BW 12	346.5	15.8	17.4	5.3	7.4	6	221	227	10	1158	1081	432	554
BW 13	358.2	8.5	35.0	28.0	4.8	167	588	755	15	862	1647	607	1010
MW 1	452.7	15.0	24.0	6.3	31.0	2	300	302	107	5874	1781	746	2180
MW 2	422.0	11.1	38.2	13.8	35.7	3740	28	3768	127	10850	5441	2653	N/A
MW 3	436.7	12.2	35.4	19.8	29.6	2722	13	2735	230	6890	6206	3885	5270
MW 4	460.3	10.0	44.1	13.4	33.6	945	19	964	33	5740	4199	2588	3600
MW 5	358.8	10.0	10.3	18.1	27.1	4681	10	4691	18	7537	5732	2416	6290
GW 1	266.5	12.6	19.9	3.6	16.1	1	237	237	10	2634	950	391	766
GW 2	153.5	21.9	8.2	0.5	4.8	6	3	9	7	693	519	265	258
GW 3	414.2	10.1	34.5	4.3	4.1	1	82	83	88	544	851	539	786
IOW 1	446.7	13.7	18.2	9.2	5.2	55	509	564	53	1074	2349	503	N/A
IOW 2	453.0	13.8	14.4	8.0	5.2	20	601	621	42	901	1703	479	N/A
ADC 1	172.1	8.5	20.2	2.9	7.5	2	338	340	9	1264	674	304	N/A
ADC 2	298.0	8.6	34.6	5.5	9.5	99	70	169	9	1044	1374	602	N/A

Table A.1.3 Heavy metal content of individual compost used

Code	All heavy metals in mg kg ⁻¹ dm							
	Cd - 1.3	Cr - 92	Cu - 149	Hg 0.4	Mn	Ni - 56	Pb - 149	Zn - 397
BW 1	1.3	1.6	15.9	0.1	257.0	1.7	2.9	88.1
BW 2	0.3	17.2	47.3	0.1	494.0	14.2	29.0	222.0
BW 3	0.6	20.3	69.6	0.1	526.0	18.2	53.9	249.0
BW 4	0.6	28.1	70.2	0.1	386.0	20.2	119.0	286.0
BW 5	0.9	26.4	201.0	0.2	480.0	25.0	160.0	558.0
BW 6	0.9	42.8	305.0	0.3	418.0	30.3	63.0	402.0
BW 7	0.9	26.3	86.8	0.1	373.0	20.1	118.0	355.0
BW 8	0.6	14.7	42.6	0.1	258.0	8.9	53.4	206.0
BW 9	0.3	4.8	26.4	<0.05	146.0	4.3	14.4	110.0
BW 10	0.3	5.9	30.0	<0.05	185.0	5.7	20.0	75.2
BW 11	0.7	25.6	125.0	0.4	398.0	22.1	68.6	386.0
BW 12	0.5	18.7	89.7	0.1	354.0	21.0	51.9	247.0
BW 13	0.4	9.8	12020.0	0.1	417.0	5.7	66.7	305.0
MW 1	0.5	5.3	70.7	<0.05	292.0	5.3	12.1	186.0
MW 2	0.6	2.3	76.8	<0.05	570.0	6.5	1.5	546.0
MW 3	0.4	4.1	70.1	<0.05	419.0	4.6	1.4	472.0
MW 4	0.5	5.1	112.0	<0.05	727.0	6.9	1.8	566.0
MW 5	0.3	8.8	123.0	<0.05	481.0	7.3	7.0	491.0
GW 1	1.0	11.7	55.8	0.1	578.0	15.1	32.5	180.0
GW 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GW 3	0.5	8.2	33.7	0.1	305.0	8.6	27.5	145.0
IOW 1	0.5	13.0	687.0	0.4	244.0	10.7	40.0	305.0
IOW 2	0.5	21.1	216.0	0.3	198.0	11.2	101.0	259.0
ADC 1	0.4	16.0	68.1	0.1	481.0	10.3	23.5	135.0
ADC 2	0.4	28.6	76.8	0.1	602.0	15.6	21.3	176.0

Table A.1.4 Extractable sulphur, calcium and cation exchange capacity of compost used

Code	Sulfur mg L⁻¹	Calcium mg L⁻¹	meq 100g⁻¹
BW 1	221.7	31284	44.5
BW 2	281.4	10409	42.2
BW 3	254.4	9239	39.3
BW 4	5290.1	10819	34.2
BW 5	685.3	10995	35.4
BW 6	1880.9	14765	34.5
BW 7	3837.4	10339	31.3
BW 8	233.3	6182	40.0
BW 9	75.6	4019	38.9
BW 10	83.4	4959	37.4
BW 11	311.1	6624	24.2
BW 12	265.2	5888	26.4
BW 13	734.4	11961	28.4
MW 1	203.6	5274	57.4
MW 2	3575.9	3469	92.9
MW 3	1741.2	4261	68.2
MW 4	1738.9	2997	80.6
MW 5	5968.5	10434	91.8
GW 1	285.9	10484	49.9
GW 2	136.2	6641	25.8
GW 3	63.7	6575	32.1
IOW 1	1164.5	5390	36.4
IOW 2	1164.5	4924	31.9
ADC 1	249.1	9834	36.5
ADC 2	570.3	8937	38.2

A.2 Incubation results

The graphs A2.1 and A2.2 present all nitrogen data for the incubation experiment on one soil for both nitrogen and phosphorus. Standard deviation is indicated in red.

Table A.2.1 Nitrogen results for all composts used in the incubation experiment at the high rate (40mg N)

Rate	Time (days)							
	0 (mg L ⁻¹)	<i>SD</i>	7	<i>SD</i>	14	<i>SD</i>	28	<i>SD</i>
BW 1	33.05	<i>0.84</i>	37.67	<i>0.32</i>	33.51	<i>1.05</i>	34.18	<i>0.56</i>
BW 2	30.78	<i>1.57</i>	31.45	<i>2.73</i>	28.12	<i>0.29</i>	29.36	<i>0.49</i>
BW 3	21.15	<i>2.35</i>	22.06	<i>2.48</i>	23.07	<i>0.38</i>	22.41	<i>1.61</i>
BW 4	43.56	<i>3.39</i>	37.90	<i>2.11</i>	35.94	<i>2.54</i>	35.74	<i>1.85</i>
BW 5	22.72	<i>1.10</i>	22.05	<i>0.87</i>	18.04	<i>6.93</i>	21.28	<i>0.79</i>
BW 6	40.61	<i>2.39</i>	37.99	<i>1.63</i>	36.12	<i>1.41</i>	36.94	<i>2.64</i>
BW 7	46.73	<i>1.82</i>	44.51	<i>3.03</i>	42.53	<i>2.83</i>	43.11	<i>1.82</i>
BW 8	25.24	<i>0.49</i>	25.08	<i>0.48</i>	25.98	<i>0.88</i>	25.23	<i>0.30</i>
BW 9	32.38	<i>2.05</i>	29.68	<i>1.71</i>	30.99	<i>1.59</i>	29.75	<i>2.32</i>
BW 10	27.49	<i>1.54</i>	24.53	<i>0.81</i>	24.96	<i>1.16</i>	25.35	<i>0.53</i>
BW 11	16.70	<i>0.55</i>	16.99	<i>1.22</i>	16.71	<i>0.45</i>	17.81	<i>0.22</i>
BW 12	22.66	<i>4.33</i>	23.06	<i>2.36</i>	21.32	<i>2.81</i>	22.02	<i>2.68</i>
BW 13	30.36	<i>1.21</i>	31.28	<i>1.04</i>	28.60	<i>1.48</i>	30.02	<i>1.19</i>
MW 1	38.71	<i>2.68</i>	32.88	<i>0.28</i>	33.90	<i>0.59</i>	33.48	<i>1.18</i>
MW 2	105.62	<i>2.74</i>	118.08	<i>2.52</i>	123.80	<i>3.35</i>	122.80	<i>10.76</i>
MW 3	100.84	<i>4.49</i>	106.29	<i>4.06</i>	124.12	<i>6.24</i>	124.52	<i>5.06</i>
MW 4	145.63	<i>1.72</i>	176.40	<i>2.93</i>	194.63	<i>19.79</i>	186.49	<i>12.05</i>
MW 5	122.57	<i>7.11</i>	128.37	<i>2.21</i>	132.31	<i>4.48</i>	136.11	<i>5.63</i>
GW 1	24.90	<i>0.25</i>	28.87	<i>0.78</i>	26.48	<i>0.16</i>	26.99	<i>0.42</i>
GW 2	16.52	<i>1.88</i>	18.47	<i>0.98</i>	18.19	<i>1.10</i>	18.08	<i>0.85</i>
GW 3	22.35	<i>3.61</i>	22.10	<i>2.63</i>	22.72	<i>2.68</i>	21.47	<i>3.52</i>
IOW 1	30.95	<i>0.32</i>	31.96	<i>0.72</i>	30.31	<i>0.63</i>	30.81	<i>0.86</i>
IOW 2	31.30	<i>0.83</i>	28.94	<i>0.90</i>	55.44	<i>0.80</i>	28.47	<i>0.23</i>
ADC 1	23.54	<i>1.58</i>	23.80	<i>0.30</i>	21.40	<i>0.61</i>	22.19	<i>0.41</i>
ADC 2	23.23	<i>1.65</i>	22.65	<i>1.16</i>	21.37	<i>0.57</i>	20.91	<i>0.88</i>
CAN	382.64	<i>3.67</i>	356.54	<i>2.32</i>	341.80	<i>3.66</i>	364.92	<i>3.97</i>
Soil	18.68	<i>1.77</i>	21.75	<i>1.04</i>	22.65	<i>1.91</i>	22.79	<i>0.51</i>



Figure A.2.1 Compost and soil in pot used in the incubation experiment

Table A.2.2 Nitrogen results for all composts used in the incubation experiment at the high rate (20mg N)

Rate 20 mg	Time (days)							
	0	<i>SD</i>	7	<i>SD</i>	14	<i>SD</i>	28	<i>SD</i>
BW 1	27.90	<i>0.50</i>	31.96	<i>1.26</i>	29.61	<i>0.19</i>	29.36	<i>0.59</i>
BW 2	24.94	<i>2.07</i>	27.37	<i>1.12</i>	24.83	<i>2.35</i>	25.82	<i>2.94</i>
BW 3	18.82	<i>1.85</i>	19.86	<i>1.98</i>	18.97	<i>1.47</i>	19.36	<i>1.04</i>
BW 4	29.90	<i>0.33</i>	27.79	<i>0.21</i>	26.82	<i>1.24</i>	26.74	<i>0.69</i>
BW 5	21.85	<i>1.03</i>	21.10	<i>1.35</i>	21.18	<i>1.75</i>	20.63	<i>0.83</i>
BW 6	33.44	<i>0.93</i>	30.51	<i>0.72</i>	29.77	<i>0.89</i>	30.62	<i>0.36</i>
BW 7	34.82	<i>2.28</i>	34.26	<i>1.64</i>	34.38	<i>1.78</i>	31.98	<i>1.10</i>
BW 8	26.59	<i>1.19</i>	24.04	<i>0.64</i>	24.41	<i>0.44</i>	24.32	<i>0.86</i>
BW 9	28.31	<i>4.67</i>	26.12	<i>0.79</i>	27.41	<i>3.29</i>	26.86	<i>1.37</i>
BW 10	23.87	<i>0.07</i>	22.47	<i>1.55</i>	21.82	<i>0.32</i>	22.79	<i>0.47</i>
BW 11	19.33	<i>3.48</i>	19.65	<i>3.06</i>	17.65	<i>2.61</i>	18.30	<i>2.36</i>
BW 12	18.43	<i>0.66</i>	19.35	<i>1.19</i>	17.91	<i>0.92</i>	18.74	<i>0.86</i>
BW 13	24.68	<i>1.03</i>	24.61	<i>0.88</i>	23.23	<i>0.78</i>	24.16	<i>0.81</i>
MW 1	29.78	<i>1.47</i>	26.96	<i>0.59</i>	28.01	<i>0.30</i>	26.98	<i>0.85</i>
MW 2	59.88	<i>2.11</i>	71.18	<i>4.77</i>	71.91	<i>2.09</i>	78.03	<i>16.57</i>
MW 3	60.48	<i>5.84</i>	73.22	<i>5.34</i>	75.25	<i>2.23</i>	69.87	<i>1.20</i>
MW 4	91.14	<i>9.56</i>	100.20	<i>1.65</i>	93.04	<i>2.85</i>	90.70	<i>3.71</i>
MW 5	73.23	<i>2.61</i>	75.50	<i>7.90</i>	85.68	<i>10.84</i>	68.03	<i>16.54</i>
GW 1	22.78	<i>3.41</i>	25.22	<i>3.16</i>	23.08	<i>3.47</i>	23.12	<i>2.90</i>
GW 2	16.90	<i>1.66</i>	19.07	<i>3.29</i>	17.50	<i>1.79</i>	18.14	<i>2.36</i>
GW 3	22.64	<i>1.08</i>	22.90	<i>1.56</i>	23.46	<i>0.30</i>	22.99	<i>0.32</i>
IOW 1	27.95	<i>1.47</i>	25.78	<i>0.86</i>	24.03	<i>0.95</i>	25.12	<i>1.37</i>
IOW 2	23.76	<i>0.59</i>	23.86	<i>2.59</i>	23.04	<i>0.19</i>	23.07	<i>0.52</i>
ADC 1	19.16	<i>0.30</i>	21.24	<i>1.18</i>	19.00	<i>0.45</i>	19.20	<i>0.48</i>
ADC 2	19.38	<i>0.85</i>	22.12	<i>3.04</i>	19.38	<i>2.10</i>	20.27	<i>3.12</i>
CAN	195.96	<i>3.22</i>	185.51	<i>1.41</i>	177.52	<i>1.51</i>	167.47	<i>3.43</i>
Soil	18.68	<i>1.77</i>	21.75	<i>1.04</i>	22.65	<i>1.91</i>	22.79	<i>0.51</i>

Table A.2.3 Group comparisons data by LS – means for the nitrogen incubation experiment

Effect	group	time	Differences of Least Squares Means				DF	t Value	Pr > t
			_group	_time	Estimate	Standard Error			
group*time	ADC	1	BW	1	-6.6065	0.8611	402	-7.67	<.0001
group*time	ADC	1	GW	1	0.3128	0.9895	402	0.32	0.7521
group*time	ADC	1	IOW	1	-7.165	0.626	402	-11.45	<.0001
group*time	ADC	1	MW	1	-73.595	4.1724	402	-17.64	<.0001
group*time	ADC	2	BW	2	-4.9817	0.8611	402	-5.79	<.0001
group*time	ADC	2	GW	2	-0.3172	0.9895	402	-0.32	0.7487
group*time	ADC	2	IOW	2	-5.1792	0.626	402	-8.27	<.0001
group*time	ADC	2	MW	2	-83.7017	4.1724	402	-20.06	<.0001
group*time	ADC	3	BW	3	-6.0167	0.8611	402	-6.99	<.0001
group*time	ADC	3	GW	3	-1.6172	0.9895	402	-1.63	0.103
group*time	ADC	3	IOW	3	-5.7825	0.626	402	-9.24	<.0001
group*time	ADC	3	MW	3	-92.3067	4.1724	402	-22.12	<.0001
group*time	ADC	4	BW	4	-6.0041	0.8611	402	-6.97	<.0001
group*time	ADC	4	GW	4	-1.1522	0.9895	402	-1.16	0.245
group*time	ADC	4	IOW	4	-6.2217	0.626	402	-9.94	<.0001
group*time	ADC	4	MW	4	-88.9217	4.1724	402	-21.31	<.0001
group*time	BW	1	GW	1	6.9193	1.184	402	5.84	<.0001
group*time	BW	1	IOW	1	-0.5585	0.9025	402	-0.62	0.5364
group*time	BW	1	MW	1	-66.9885	4.2227	402	-15.86	<.0001
group*time	BW	2	GW	2	4.6644	1.184	402	3.94	<.0001
group*time	BW	2	IOW	2	-0.1975	0.9025	402	-0.22	0.8269
group*time	BW	2	MW	2	-78.72	4.2227	402	-18.64	<.0001
group*time	BW	3	GW	3	4.3994	1.184	402	3.72	0.0002
group*time	BW	3	IOW	3	0.2342	0.9025	402	0.26	0.7954
group*time	BW	3	MW	3	-86.29	4.2227	402	-20.43	<.0001
group*time	BW	4	GW	4	4.8519	1.184	402	4.1	<.0001
group*time	BW	4	IOW	4	-0.2176	0.9025	402	-0.24	0.8096
group*time	BW	4	MW	4	-82.9176	4.2227	402	-19.64	<.0001
group*time	GW	1	IOW	1	-7.4778	1.0258	402	-7.29	<.0001
group*time	GW	1	MW	1	-73.9078	4.2508	402	-17.39	<.0001
group*time	GW	2	IOW	2	-4.8619	1.0258	402	-4.74	<.0001
group*time	GW	2	MW	2	-83.3844	4.2508	402	-19.62	<.0001
group*time	GW	3	IOW	3	-4.1653	1.0258	402	-4.06	<.0001
group*time	GW	3	MW	3	-90.6894	4.2508	402	-21.33	<.0001
group*time	GW	4	IOW	4	-5.0694	1.0258	402	-4.94	<.0001
group*time	GW	4	MW	4	-87.7694	4.2508	402	-20.65	<.0001
group*time	IOW	1	MW	1	-66.43	4.1811	402	-15.89	<.0001
group*time	IOW	2	MW	2	-78.5225	4.1811	402	-18.78	<.0001
group*time	IOW	3	MW	3	-86.5242	4.1811	402	-20.69	<.0001
group*time	IOW	4	MW	4	-82.7	4.1811	402	-19.78	<.0001

The control (CAN) was excluded from the table due to it being significantly different from the other groups.

Table A.2.3 Phosphorus results for all composts used in the incubation experiment at the high rate (10 mg P)

Rate 10 mg	Time (days)					
	0 (mg L ⁻¹)	<i>SD</i>	14	<i>SD</i>	28	<i>SD</i>
BW 1	13.02	<i>2.18</i>	12.08	<i>2.77</i>	12.32	<i>1.23</i>
BW 2	11.99	<i>1.70</i>	20.23	<i>6.25</i>	18.40	<i>1.21</i>
BW 3	20.49	<i>1.96</i>	23.48	<i>2.72</i>	21.19	<i>2.23</i>
BW 4	21.94	<i>1.06</i>	16.86	<i>3.43</i>	17.25	<i>2.56</i>
BW 5	11.17	<i>0.67</i>	10.85	<i>1.49</i>	17.78	<i>3.05</i>
BW 6	9.23	<i>1.91</i>	8.28	<i>0.87</i>	11.87	<i>1.60</i>
BW 7	17.06	<i>1.50</i>	18.39	<i>5.21</i>	19.31	<i>0.64</i>
BW 8	23.22	<i>5.22</i>	20.33	<i>3.80</i>	22.12	<i>0.64</i>
BW 9	21.08	<i>2.26</i>	15.40	<i>0.96</i>	13.24	<i>0.85</i>
BW 10	24.61	<i>6.40</i>	28.83	<i>4.81</i>	23.93	<i>1.52</i>
BW 11	18.11	<i>3.16</i>	17.75	<i>2.61</i>	24.15	<i>2.51</i>
BW 12	20.95	<i>3.06</i>	23.58	<i>3.06</i>	27.16	<i>1.63</i>
BW 13	12.14	<i>2.01</i>	12.96	<i>1.18</i>	11.15	<i>0.85</i>
MW 1	24.22	<i>2.46</i>	24.34	<i>2.95</i>	18.59	<i>3.85</i>
MW 2	44.86	<i>8.97</i>	30.75	<i>5.08</i>	17.69	<i>2.54</i>
MW 3	38.84	<i>5.73</i>	28.61	<i>4.73</i>	18.04	<i>1.27</i>
MW 4	69.64	<i>5.72</i>	37.24	<i>5.26</i>	38.27	<i>3.24</i>
MW 5	35.49	<i>9.61</i>	21.74	<i>2.99</i>	14.06	<i>2.23</i>
GW 1	14.32	<i>4.37</i>	19.97	<i>1.47</i>	16.88	<i>1.13</i>
GW 2	13.67	<i>1.33</i>	12.27	<i>1.38</i>	11.49	<i>2.84</i>
GW 3	15.32	<i>1.33</i>	11.44	<i>1.38</i>	11.35	<i>0.39</i>
IOW 1	33.60	<i>1.54</i>	29.24	<i>3.15</i>	17.85	<i>2.48</i>
IOW 2	18.77	<i>0.93</i>	25.95	<i>0.73</i>	16.67	<i>2.26</i>
ADC 1	18.73	<i>4.05</i>	33.48	<i>0.75</i>	18.91	<i>1.13</i>
ADC 2	15.17	<i>2.64</i>	26.36	<i>0.68</i>	18.39	<i>1.42</i>
SSP	49.95	<i>7.94</i>	36.74	<i>4.52</i>	27.55	<i>1.43</i>
Soil	5.84	<i>3.45</i>	7.72	<i>1.39</i>	6.86	<i>0.31</i>

Table A.2.4 Phosphorus results for all composts used in the incubation experiment at the high rate (5 mg P)

Rate 5 mg	Time (days)					
	0	<i>SD</i>	14	<i>SD</i>	28	<i>SD</i>
BW 1	10.64	<i>0.46</i>	8.50	<i>1.84</i>	10.30	<i>1.08</i>
BW 2	8.98	<i>1.82</i>	13.82	<i>2.83</i>	13.14	<i>0.64</i>
BW 3	12.50	<i>1.05</i>	15.50	<i>3.35</i>	14.66	<i>1.25</i>
BW 4	10.84	<i>1.96</i>	11.10	<i>3.61</i>	13.82	<i>0.58</i>
BW 5	9.43	<i>1.91</i>	6.33	<i>1.51</i>	9.00	<i>1.24</i>
BW 6	7.06	<i>0.46</i>	8.51	<i>0.88</i>	11.16	<i>0.90</i>
BW 7	11.58	<i>1.26</i>	10.34	<i>0.71</i>	14.39	<i>0.28</i>
BW 8	20.10	<i>1.39</i>	13.05	<i>1.00</i>	17.38	<i>2.34</i>
BW 9	16.06	<i>2.36</i>	11.51	<i>1.52</i>	8.65	<i>0.42</i>
BW 10	32.68	<i>1.12</i>	17.65	<i>1.96</i>	17.93	<i>2.10</i>
BW 11	18.94	<i>8.56</i>	15.24	<i>0.51</i>	20.62	<i>1.26</i>
BW 12	12.98	<i>0.26</i>	18.35	<i>5.84</i>	17.61	<i>0.51</i>
BW 13	13.54	<i>1.04</i>	15.37	<i>1.96</i>	10.83	<i>0.44</i>
MW 1	16.27	<i>2.81</i>	15.54	<i>3.29</i>	10.27	<i>1.16</i>
MW 2	25.08	<i>9.10</i>	24.93	<i>1.17</i>	12.83	<i>0.29</i>
MW 3	22.61	<i>1.14</i>	14.61	<i>4.22</i>	9.46	<i>0.52</i>
MW 4	33.07	<i>5.33</i>	21.76	<i>3.80</i>	25.09	<i>1.87</i>
MW 5	17.79	<i>1.70</i>	18.81	<i>7.04</i>	8.66	<i>0.78</i>
GW 1	11.55	<i>2.13</i>	11.85	<i>1.68</i>	10.95	<i>0.40</i>
GW 2	8.47	<i>1.39</i>	7.43	<i>0.75</i>	7.81	<i>2.17</i>
GW 3	11.34	<i>1.88</i>	8.77	<i>0.24</i>	8.24	<i>0.88</i>
IOW 1	13.76	<i>2.58</i>	22.89	<i>4.21</i>	14.74	<i>1.84</i>
IOW 2	14.95	<i>1.40</i>	21.15	<i>7.42</i>	15.20	<i>2.99</i>
ADC 1	13.95	<i>0.72</i>	24.15	<i>4.04</i>	17.06	<i>4.03</i>
ADC 2	13.06	<i>1.89</i>	19.09	<i>1.16</i>	14.44	<i>0.29</i>
SSP	31.66	<i>4.18</i>	28.27	<i>2.70</i>	14.87	<i>0.11</i>
Soil	5.84	<i>3.45</i>	7.72	<i>1.39</i>	6.86	<i>0.31</i>

Table A.2.5 Group comparisons data by LS – means with Tukey - Pairwise adjustments for the phosphorus incubation experiment

Differences of time*group Least Squares Means									
Adjustment for Multiple Comparisons: Tukey-Kramer									
group	time	_group	_time	Estimate	Standard Error	DF	t Value	Pr > t	Adj P
ADC	1	BW	1	-0.5077	0.9456	36	-0.54	0.5946	1
ADC	1	CAN	1	-26.3986	1.6275	36	-16.22	<.0001	<.0001
ADC	1	GW	1	1.4633	1.184	36	1.24	0.2245	0.9981
ADC	1	IOW	1	-2.9765	1.402	36	-2.12	0.0407	0.7863
ADC	1	MW	1	-16.3152	1.0663	36	-15.3	<.0001	<.0001
BW	1	CAN	1	-25.8908	1.5167	36	-17.07	<.0001	<.0001
BW	1	GW	1	1.9711	1.0264	36	1.92	0.0628	0.8854
BW	1	IOW	1	-2.4688	1.2717	36	-1.94	0.0601	0.8767
BW	1	MW	1	-15.8074	0.8881	36	-17.8	<.0001	<.0001
CAN	1	GW	1	27.8619	1.6758	36	16.63	<.0001	<.0001
CAN	1	IOW	1	23.422	1.8362	36	12.76	<.0001	<.0001
CAN	1	MW	1	10.0834	1.5948	36	6.32	<.0001	<.0001
GW	1	IOW	1	-4.4398	1.4577	36	-3.05	0.0043	0.2317
GW	1	MW	1	-17.7785	1.1386	36	-15.61	<.0001	<.0001
IOW	1	MW	1	-13.3387	1.3639	36	-9.78	<.0001	<.0001
ADC	2	BW	2	8.9807	0.9456	36	9.5	<.0001	<.0001
ADC	2	CAN	2	-8.9675	1.6275	36	-5.51	<.0001	0.0004
ADC	2	GW	2	8.9117	1.184	36	7.53	<.0001	<.0001
ADC	2	IOW	2	-0.2136	1.402	36	-0.15	0.8798	1
ADC	2	MW	2	1.7167	1.0663	36	1.61	0.1162	0.9713
BW	2	CAN	2	-17.9482	1.5167	36	-11.83	<.0001	<.0001
BW	2	GW	2	-0.069	1.0264	36	-0.07	0.9468	1
BW	2	IOW	2	-9.1943	1.2717	36	-7.23	<.0001	<.0001
BW	2	MW	2	-7.264	0.8881	36	-8.18	<.0001	<.0001
CAN	2	GW	2	17.8792	1.6758	36	10.67	<.0001	<.0001
CAN	2	IOW	2	8.7539	1.8362	36	4.77	<.0001	0.0033
CAN	2	MW	2	10.6843	1.5948	36	6.7	<.0001	<.0001
GW	2	IOW	2	-9.1253	1.4577	36	-6.26	<.0001	<.0001
GW	2	MW	2	-7.195	1.1386	36	-6.32	<.0001	<.0001
IOW	2	MW	2	1.9303	1.3639	36	1.42	0.1656	0.9916
ADC	3	BW	3	0.9052	0.9456	36	0.96	0.3448	0.9999
ADC	3	CAN	3	-4.593	1.6275	36	-2.82	0.0077	0.3431
ADC	3	GW	3	3.0363	1.184	36	2.56	0.0147	0.5018
ADC	3	IOW	3	0.6582	1.402	36	0.47	0.6415	1
ADC	3	MW	3	2.8668	1.0663	36	2.69	0.0108	0.4222
BW	3	CAN	3	-5.4982	1.5167	36	-3.63	0.0009	0.0675
BW	3	GW	3	2.1312	1.0264	36	2.08	0.0451	0.812
BW	3	IOW	3	-0.247	1.2717	36	-0.19	0.8471	1
BW	3	MW	3	1.9616	0.8881	36	2.21	0.0336	0.7358
CAN	3	GW	3	7.6293	1.6758	36	4.55	<.0001	0.0061
CAN	3	IOW	3	5.2512	1.8362	36	2.86	0.007	0.3224
CAN	3	MW	3	7.4598	1.5948	36	4.68	<.0001	0.0043
GW	3	IOW	3	-2.3781	1.4577	36	-1.63	0.1115	0.9677
GW	3	MW	3	-0.1696	1.1386	36	-0.15	0.8825	1
IOW	3	MW	3	2.2086	1.3639	36	1.62	0.1141	0.9698

A.3 Soil phosphorus incubation

All Olsens extractable phosphorus for the second incubation experiment of soil type effects on compost are presented in the table displayed. The seven extraction time points are displayed from W0 – W12.

Table A.3.1

Soil/compost	P Results mg/L						
	W0	W2	W4	W6	W8	W10	W12
SS1 BW 3 HR	12.51	9.92	12.17	8.50	8.93	5.95	7.38
SS2 BW 3 HR	23.30	21.12	20.10	20.66	23.38	15.44	19.80
SS3 BW 3 HR	13.91	14.29	11.71	13.00	16.78	8.91	10.16
SS4 BW 3 HR	18.54	19.93	15.31	15.76	21.14	12.24	11.42
SS1 BW 3 LR	7.03	5.89	6.37	5.72	5.56	3.70	5.16
SS2 BW 3 LR	15.63	15.43	12.59	15.40	19.59	11.20	12.59
SS3 BW 3 LR	9.95	10.38	8.31	9.09	12.07	4.86	6.80
SS4 BW 3 LR	15.42	12.20	9.82	11.47	12.93	6.14	7.99
SS1 BW 4 HR	9.17	9.11	10.22	9.70	9.69	7.07	8.39
SS2 BW 4 HR	22.42	19.70	20.60	23.40	24.51	18.58	19.79
SS3 BW 4 HR	15.07	11.38	12.84	14.49	13.73	9.15	10.45
SS4 BW 4 HR	19.13	17.17	15.88	16.28	17.37	20.08	13.56
SS1 BW 4 LR	5.77	4.85	5.37	6.04	5.56	3.45	5.17
SS2 BW 4 LR	14.03	12.72	14.69	16.09	16.32	11.06	11.94
SS3 BW 4 LR	11.93	8.28	8.68	9.89	12.70	5.51	6.71
SS4 BW 4 LR	10.86	10.77	11.31	13.58	10.68	5.19	8.40
SS1 BW 10 HR	14.01	7.55	7.33	8.89	6.03	2.98	5.59
SS2 BW 10 HR	25.17	17.18	15.30	14.79	14.01	10.90	14.62
SS3 BW 10 HR	21.09	16.20	11.66	10.47	11.76	7.13	9.96
SS4 BW 10 HR	21.39	16.77	10.24	10.83	14.34	7.44	11.13
SS1 BW 10 LR	13.85	4.60	4.65	4.44	4.23	0.83	3.51
SS2 BW 10 LR	20.86	11.13	11.15	10.76	11.41	7.26	10.06
SS3 BW 10 LR	14.76	7.67	6.85	7.40	8.32	3.39	6.42
SS4 BW 10 LR	12.04	10.18	9.22	9.26	6.45	5.56	7.15
SS1 SSP HR	27.61	13.33	14.65	10.60	9.40	6.28	9.24
SS2 SSP HR	56.20	37.37	37.52	26.69	26.91	20.63	24.61
SS3 SSP HR	38.11	25.89	22.06	16.28	19.49	16.29	19.53
SS4 SSP HR	38.43	23.33	19.58	16.31	19.29	12.24	14.30
SS1 SSP LR	15.54	7.76	8.56	6.18	5.48	2.40	5.47
SS2 SSP LR	30.02	19.65	25.01	14.49	14.60	11.48	15.80
SS3 SSP LR	20.57	14.36	11.33	11.76	10.98	6.12	8.36
SS4 SSP LR	19.80	14.05	11.49	11.63	11.49	6.04	8.94
SS1	0.18	3.88	4.43	1.60	1.74	0.83	0.82
SS2	5.10	8.56	10.65	7.34	8.71	4.59	7.16
SS3	2.32	4.35	6.11	4.41	4.77	0.76	3.08
SS4	3.18	4.22	5.91	3.95	4.58	0.90	3.32

A.5 Nitrogen pot experiment

Figures A.5.1 and A.5.2 show the process involved after each harvest of cutting up the old root structure and adding the necessary mineral fertiliser before re – potting.





Figure A.5.1 and A.5.2. Flipping the pots and cutting up the root structure after each harvest before adding mineral fertiliser

All uptake data for the nitrogen pot experiment are presented in Tables A5.1. and A.5.2.

These are the results for the biowaste and manure waste groups. The other groups were not included as all of their data is available within the chapters.

Table A.5.1 Nitrogen uptake of all biowaste waste composts used in the nitrogen pot experiment at their respective rates

Rate	Compost	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
150 kg ha⁻¹	BW 2	76.42	29.83	22.28	18.59	21.21	24.33	18.64	59.76
150	BW 4	86.90	33.77	30.76	18.32	28.62	33.72	21.31	53.83
150	BW 7	92.36	33.33	26.89	18.59	21.37	27.74	24.36	58.52
150	BW 11	71.02	36.74	25.92	17.64	26.03	24.60	18.74	51.61
150	BW 12	56.08	33.50	27.11	18.47	25.28	27.65	25.15	58.44
300	BW 2	92.52	32.68	30.20	19.68	19.63	23.69	22.51	59.48
300	BW 4	102.83	33.78	26.32	19.50	25.59	31.00	25.77	42.00
300	BW 7	101.75	34.95	30.87	24.62	32.93	28.09	22.99	63.07
300	BW 11	73.36	35.03	24.25	14.87	22.74	22.17	16.25	38.17
300	BW 12	71.58	35.74	28.81	18.09	31.38	29.14	26.76	59.19
450	BW 2	106.03	37.06	26.49	16.69	19.97	32.26	20.91	61.14
450	BW 4	122.84	28.01	30.02	19.14	26.41	29.28	16.71	60.37
450	BW 7	129.85	39.18	28.22	17.22	27.06	29.77	24.45	61.89
450	BW 11	73.39	32.31	26.75	17.18	14.59	29.01	18.02	58.00
450	BW 12	72.75	40.29	29.73	20.53	27.74	33.10	22.62	57.93

Table A.5.2 Nitrogen uptake of all manure waste composts used in the nitrogen pot experiment at their respective rates

Rate	Compost	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
150 kg ha⁻¹	MW3	109.15	47.47	30.51	20.09	22.15	38.431	21.52	53.39
150	MW4	122.38	52.23	31.17	18.66	28.22	27.389	23.31	56.12
150	MW5	124.76	51.91	34.48	18.86	19.36	28.380	22.82	64.52
300	MW3	164.11	66.08	36.86	22.92	28.43	35.221	22.30	60.04
300	MW4	168.09	60.87	42.39	27.35	31.26	34.003	31.72	57.29
300	MW5	203.13	67.41	37.35	22.83	23.49	31.997	23.78	65.11
450	MW3	206.18	79.07	41.68	30.03	37.90	36.389	31.74	72.17
450	MW4	244.56	71.08	37.91	28.07	35.35	34.328	33.69	53.08
450	MW5	306.02	82.91	38.05	26.31	31.17	36.179	31.02	76.21

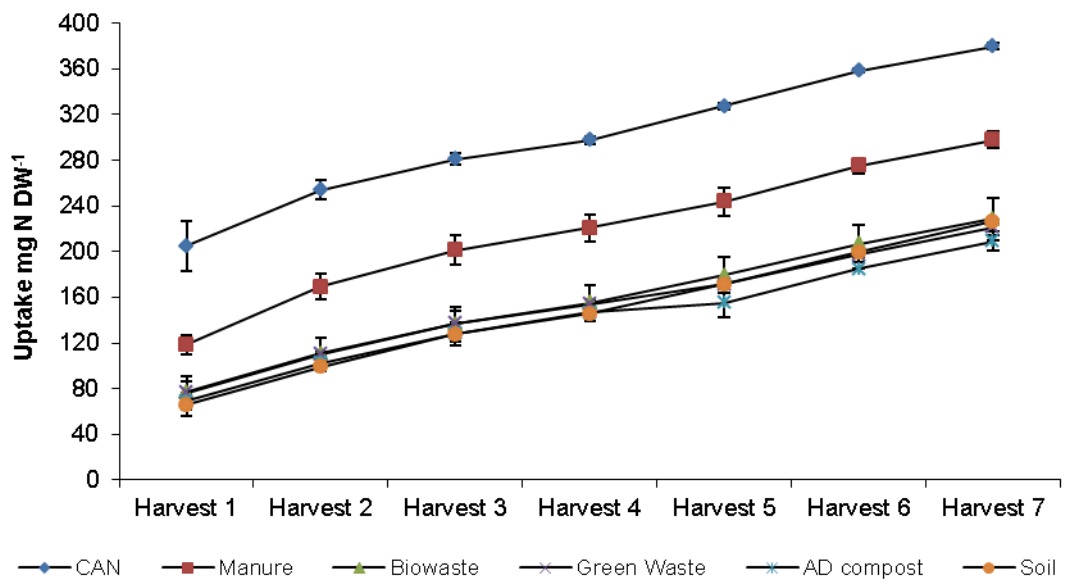


Figure A.5.1 Cumulative nitrogen uptake for the compost groups at 150 kg ha⁻¹

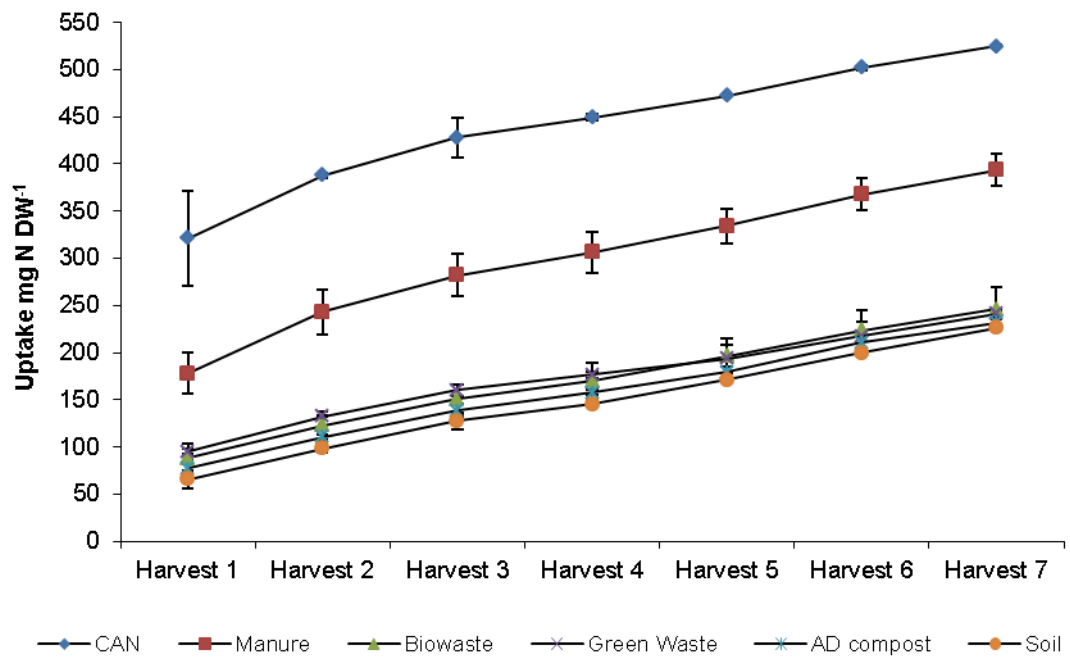


Figure A.5.2 Cumulative nitrogen uptake for the compost groups at 300 kg ha⁻¹

Table A.5.3 Percentage recoveries for all individual treatments in the nitrogen pot experiment. Negative figures indicate a net N immobilisation

Treatment		% Recovery							
		Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
CAN	150	92.91	10.59	-1.36	-0.67	2.37	1.96	-3.38	1.33
CAN	300	85.18	11.16	3.71	1.29	-0.93	0.36	-1.25	-3.33
CAN	450	88.93	8.71	-0.51	-0.77	-1.04	-1.09	-1.92	1.96
MW 3	150	28.94	9.53	1.10	1.53	0.10	-2.42	-5.20	-4.61
MW 3	300	32.79	10.97	2.67	1.71	-1.05	-2.02	-3.43	5.24
MW 3	450	31.21	10.20	2.85	2.72	-2.51	0.17	-1.89	-0.99
MW 4	150	37.76	12.71	1.54	0.58	-0.87	-1.75	-1.40	7.82
MW 4	300	34.12	9.24	4.51	3.19	-3.04	-1.49	-0.75	6.14
MW 4	450	39.74	8.43	2.01	2.29	-2.43	-2.30	-1.18	3.70
MW 5	150	39.35	12.50	3.75	0.72	-6.10	1.04	-1.79	12.55
MW 5	300	45.80	11.41	2.83	1.68	-1.49	0.93	-1.68	7.99
MW 5	450	53.40	11.05	2.04	1.89	-0.11	0.87	-1.50	8.93
BW 2	150	7.12	-2.22	-4.39	0.54	-3.11	-2.60	-5.27	6.50
BW 2	300	8.93	-0.16	0.45	0.63	-2.08	-1.51	-1.34	-7.43
BW 2	450	8.95	0.87	-0.53	-0.24	-1.31	0.90	-1.25	10.84
BW 4	150	14.11	0.40	1.27	0.36	1.82	3.66	-3.49	11.11
BW 4	300	12.36	0.21	-0.85	0.57	-0.10	0.92	-0.26	13.80
BW 4	450	12.69	-1.15	0.26	0.30	0.12	0.23	-2.18	10.60
BW 7	150	17.75	0.11	-1.31	0.54	-3.01	-0.32	-1.45	4.90
BW 7	300	12.00	0.60	0.67	2.28	2.35	-0.05	-1.19	10.98
BW 7	450	14.25	1.34	-0.14	-0.13	0.26	0.34	-0.46	17.94
BW 11	150	3.52	2.38	-1.96	-0.10	-2.49	6.80	-3.35	32.15
BW 11	300	2.54	0.62	-1.54	-0.97	0.85	2.33	-1.42	5.36
BW 11	450	1.70	-0.19	-0.47	-0.13	2.67	1.81	1.15	-15.42
BW 12	150	-6.44	0.23	-1.17	0.46	-4.35	0.10	-2.48	44.00
BW 12	300	1.95	0.86	-0.02	0.10	-0.80	1.26	-0.92	12.55
BW 12	450	1.56	1.58	0.19	0.61	1.18	1.77	0.99	44.77
GW 3	150	7.68	0.34	-1.76	-0.65	1.56	-0.56	-2.16	9.39
GW 3	300	9.87	1.47	-0.55	-0.39	1.79	1.92	1.73	8.83
GW 3	450	3.08	0.40	0.09	-0.20	2.10	1.36	1.59	5.29
ADC 1	150	2.13	0.05	-2.05	0.76	-0.40	-0.38	-0.93	15.80
ADC 1	300	3.95	-0.06	-1.10	0.15	1.83	0.30	0.07	13.67
ADC 1	450	3.86	0.54	-0.64	0.06	0.41	1.08	-0.87	14.76



Figure A.5.3. Cabbage plants at harvest one. Pictured on the extreme right is the chemical control (CAN) with the untreated control (soil) on the extreme left.



Figure A.5.3. Cabbage plants at harvest seven. Pictured on the extreme right is the untreated control (soil) with the chemical control (CAN) on the extreme left.

Figures A.5.3 and A.5.4 show the difference in plant size from harvest one to harvest seven shows little or no growth.

Table A.5.4 LS – means for each compost treatment and rate in the pot experiment

Treat*Rate*Nesting Least Squares Means						
Treat	Rate	Estimate	Standard Error	DF	t Value	Pr > t
CAN	150	53.9292	9.8207	778	5.49	<.0001
CAN	300	70.3663	9.8207	778	7.17	<.0001
CAN	450	87.4492	9.8207	778	8.9	<.0001
MW 3	150	33.1413	9.8207	778	3.37	0.0008
MW 3	300	35.3629	9.8207	778	3.6	0.0003
MW 3	450	39.9725	9.8207	778	4.07	<.0001
MW 4	150	38.99	9.8207	778	3.97	<.0001
MW 4	300	40.9825	9.8207	778	4.17	<.0001
MW 4	450	41.7871	9.8207	778	4.25	<.0001
MW 5	150	37.255	9.8207	778	3.79	0.0002
MW 5	300	42.0325	9.8207	778	4.28	<.0001
MW 5	450	45.9904	9.8207	778	4.68	<.0001
BW 2	150	34.0538	9.8207	778	3.47	0.0006
BW 2	300	38.4767	9.8207	778	3.92	<.0001
BW 2	450	34.6408	9.8207	778	3.53	0.0004
BW 4	150	43.18	9.8207	778	4.4	<.0001
BW 4	300	54.1521	9.8207	778	5.51	<.0001
BW 4	450	64.5092	9.8207	778	6.57	<.0001
BW 7	150	45.2246	9.8207	778	4.61	<.0001
BW 7	300	56.8604	9.8207	778	5.79	<.0001
BW 7	450	67.8658	9.8207	778	6.91	<.0001
BW 11	150	36.5496	9.8207	778	3.72	0.0002
BW 11	300	32.6829	9.8207	778	3.33	0.0009
BW 11	450	31.1013	9.8207	778	3.17	0.0016
BW 12	150	35.8483	9.8207	778	3.65	0.0003
BW 12	300	37.4221	9.8207	778	3.81	0.0001
BW 12	450	41.0263	9.8207	778	4.18	<.0001
GW 3	150	45.6392	9.8207	778	4.65	<.0001
GW 3	300	59.3867	9.8207	778	6.05	<.0001
GW 3	450	78.4829	9.8207	778	7.99	<.0001
ADC 1	150	34.6304	9.8207	778	3.53	0.0004
ADC 1	300	35.9729	9.8207	778	3.66	0.0003
ADC 1	450	37.6546	9.8207	778	3.83	0.0001
Soil	0	103.15	9.8207	778	10.5	<.0001

A.5.5 Group comparisons ANOVA - LS – means with Tukey – Pairwise adjustment

Differences of group*Harves*Nesting Least Squares Means									
group	Harvest	_group	_Harvest	Estimate	Standard Error	DF	t Value	Pr > t	Adj P
ADcompost	1	ADcompost	2	0.795	0.1477	732	5.38	<.0001	0.0001
ADcompost	1	ADcompost	3	1.0696	0.1477	732	7.24	<.0001	<.0001
ADcompost	1	ADcompost	4	1.3807	0.1477	732	9.34	<.0001	<.0001
ADcompost	1	ADcompost	5	1.3767	0.1477	732	9.32	<.0001	<.0001
ADcompost	1	ADcompost	6	0.8977	0.1477	732	6.08	<.0001	<.0001
ADcompost	1	ADcompost	7	1.2406	0.1477	732	8.4	<.0001	<.0001
ADcompost	1	ADcompost	8	0.2845	0.1477	732	1.93	0.0545	0.9994
ADcompost	1	Biowaste	1	-0.1239	0.1144	732	-1.08	0.2795	1
ADcompost	1	Blank control	1	0.1507	0.1477	732	1.02	0.3082	1
ADcompost	1	Control	1	-1.4035	0.1477	732	-9.5	<.0001	<.0001
ADcompost	1	ManureWaste	1	-0.8141	0.1206	732	-6.75	<.0001	<.0001
ADcompost	2	Biowaste	2	-0.0066	0.1144	732	-0.06	0.954	1
ADcompost	2	Blank control	2	0.02	0.1477	732	0.14	0.8924	1
ADcompost	2	Control	2	-0.5897	0.1477	732	-3.99	<.0001	0.05
ADcompost	2	GreenWaste	2	-0.04623	0.1477	732	-0.31	0.7544	1
ADcompost	2	ManureWaste	2	-0.6116	0.1206	732	-5.07	<.0001	0.0005
ADcompost	3	Biowaste	3	-0.06105	0.1144	732	-0.53	0.5939	1
ADcompost	3	Blank control	3	-0.09708	0.1477	732	-0.66	0.5113	1
ADcompost	3	Control	3	-0.1391	0.1477	732	-0.94	0.3466	1
ADcompost	3	GreenWaste	3	-0.05026	0.1477	732	-0.34	0.7338	1
ADcompost	3	ManureWaste	3	-0.344	0.1206	732	-2.85	0.0045	0.7332
ADcompost	4	Biowaste	4	0.004212	0.1144	732	0.04	0.9707	1
ADcompost	4	Blank control	4	0.04927	0.1477	732	0.33	0.7389	1
ADcompost	4	Control	4	0.06137	0.1477	732	0.42	0.678	1
ADcompost	4	GreenWaste	4	0.0951	0.1477	732	0.64	0.52	1
ADcompost	4	ManureWaste	4	-0.2293	0.1206	732	-1.9	0.0577	0.9996
ADcompost	5	Biowaste	5	-0.2499	0.1144	732	-2.18	0.0293	0.9922
ADcompost	5	Blank control	5	-0.313	0.1477	732	-2.12	0.0345	0.9955
ADcompost	5	Control	5	-0.235	0.1477	732	-1.59	0.1122	1
ADcompost	5	GreenWaste	5	-0.2379	0.1477	732	-1.61	0.1078	1
ADcompost	5	ManureWaste	5	-0.3843	0.1206	732	-3.19	0.0015	0.4497
ADcompost	6	Biowaste	6	0.09049	0.1144	732	0.79	0.4294	1
ADcompost	6	Blank control	6	0.0859	0.1477	732	0.58	0.5611	1
ADcompost	6	Control	6	0.1161	0.1477	732	0.79	0.4323	1
ADcompost	6	GreenWaste	6	0.2471	0.1477	732	1.67	0.0949	1
ADcompost	6	ManureWaste	6	-0.0832	0.1206	732	-0.69	0.4906	1
ADcompost	7	Biowaste	7	0.01066	0.1144	732	0.09	0.9258	1
ADcompost	7	Blank control	7	-0.1979	0.1477	732	-1.34	0.1808	1
ADcompost	7	Control	7	0.03131	0.1477	732	0.21	0.8323	1
ADcompost	7	GreenWaste	7	-0.0768	0.1477	732	-0.52	0.6033	1
ADcompost	7	ManureWaste	7	-0.1963	0.1206	732	-1.63	0.1041	1
ADcompost	8	Biowaste	8	0.09102	0.1144	732	0.8	0.4267	1
ADcompost	8	Blank control	8	0.4992	0.1477	732	3.38	0.0008	0.3006
ADcompost	8	Control	8	0.1798	0.1477	732	1.22	0.2241	1
ADcompost	8	GreenWaste	8	0.1622	0.1477	732	1.1	0.2725	1
ADcompost	8	ManureWaste	8	-0.03829	0.1206	732	-0.32	0.751	1

A5.5 continued

Differences of group*Harves*Nesting Least Squares Means									
group	Harvest	_group	_Harvest	Estimate	Standard	DF	t Value	Pr > t	Adj P
Biowaste	1	Blankcontrol	1	0.2745	0.1144	732	2.4	0.0167	0.9631
Biowaste	1	Control	1	-1.2796	0.1144	732	-11.18	<.0001	<.0001
Biowaste	1	GreenWaste	1	0.03084	0.1144	732	0.27	0.7876	1
Biowaste	1	ManureWaste	1	-0.6902	0.0763	732	-9.05	<.0001	<.0001
Biowaste	2	Blankcontrol	2	0.0266	0.1144	732	0.23	0.8163	1
Biowaste	2	Control	2	-0.5831	0.1144	732	-5.09	<.0001	0.0005
Biowaste	2	GreenWaste	2	-0.03963	0.1144	732	-0.35	0.7292	1
Biowaste	2	ManureWaste	2	-0.605	0.0763	732	-7.93	<.0001	<.0001
Biowaste	3	Blankcontrol	3	-0.03603	0.1144	732	-0.31	0.753	1
Biowaste	3	Control	3	-0.0781	0.1144	732	-0.68	0.4952	1
Biowaste	3	GreenWaste	3	0.01079	0.1144	732	0.09	0.9249	1
Biowaste	3	ManureWaste	3	-0.2829	0.0763	732	-3.71	0.0002	0.1253
Biowaste	4	Blankcontrol	4	0.04505	0.1144	732	0.39	0.6939	1
Biowaste	4	Control	4	0.05716	0.1144	732	0.5	0.6176	1
Biowaste	4	GreenWaste	4	0.09089	0.1144	732	0.79	0.4274	1
Biowaste	4	ManureWaste	4	-0.2335	0.0763	732	-3.06	0.0023	0.5567
Biowaste	5	Blankcontrol	5	-0.06315	0.1144	732	-0.55	0.5812	1
Biowaste	5	Control	5	0.01492	0.1144	732	0.13	0.8963	1
Biowaste	5	GreenWaste	5	0.01197	0.1144	732	0.1	0.9168	1
Biowaste	5	ManureWaste	5	-0.1344	0.0763	732	-1.76	0.0785	0.9999
Biowaste	6	Blankcontrol	6	-0.00459	0.1144	732	-0.04	0.968	1
Biowaste	6	Control	6	0.0256	0.1144	732	0.22	0.8231	1
Biowaste	6	GreenWaste	6	0.1566	0.1144	732	1.37	0.1717	1
Biowaste	6	ManureWaste	6	-0.1737	0.0763	732	-2.28	0.0231	0.9837
Biowaste	7	Blankcontrol	7	-0.2086	0.1144	732	-1.82	0.0688	0.9998
Biowaste	7	Control	7	0.02064	0.1144	732	0.18	0.8569	1
Biowaste	7	GreenWaste	7	-0.08747	0.1144	732	-0.76	0.4449	1
Biowaste	7	ManureWaste	7	-0.207	0.0763	732	-2.71	0.0068	0.8311
Biowaste	8	Blankcontrol	8	0.4081	0.1144	732	3.57	0.0004	0.1876
Biowaste	8	Control	8	0.08874	0.1144	732	0.78	0.4383	1
Biowaste	8	GreenWaste	8	0.07122	0.1144	732	0.62	0.5339	1
Biowaste	8	ManureWaste	8	-0.1293	0.0763	732	-1.69	0.0905	1
Blankcontrol	1	Control	1	-1.5542	0.1477	732	-10.52	<.0001	<.0001
Blankcontrol	1	GreenWaste	1	-0.2437	0.1477	732	-1.65	0.0995	1
Blankcontrol	1	ManureWaste	1	-0.9647	0.1206	732	-8	<.0001	<.0001
Blankcontrol	2	Control	2	-0.6097	0.1477	732	-4.13	<.0001	0.0307
Blankcontrol	2	GreenWaste	2	-0.06623	0.1477	732	-0.45	0.6541	1
Blankcontrol	2	ManureWaste	2	-0.6316	0.1206	732	-5.24	<.0001	0.0002
Blankcontrol	3	Control	3	-0.04207	0.1477	732	-0.28	0.7759	1
Blankcontrol	3	GreenWaste	3	0.04682	0.1477	732	0.32	0.7514	1
Blankcontrol	3	ManureWaste	3	-0.2469	0.1206	732	-2.05	0.0411	0.9978
Blankcontrol	4	Control	4	0.0121	0.1477	732	0.08	0.9347	1
Blankcontrol	4	GreenWaste	4	0.04583	0.1477	732	0.31	0.7565	1
Blankcontrol	4	ManureWaste	4	-0.2786	0.1206	732	-2.31	0.0212	0.9794
Blankcontrol	5	Control	5	0.07807	0.1477	732	0.53	0.5974	1
Blankcontrol	5	GreenWaste	5	0.07512	0.1477	732	0.51	0.6113	1
Blankcontrol	5	ManureWaste	5	-0.07126	0.1206	732	-0.59	0.5549	1
Blankcontrol	6	Control	6	0.03019	0.1477	732	0.2	0.8382	1
Blankcontrol	6	GreenWaste	6	0.1612	0.1477	732	1.09	0.2757	1
Blankcontrol	6	ManureWaste	6	-0.1691	0.1206	732	-1.4	0.1614	1
Blankcontrol	7	Control	7	0.2292	0.1477	732	1.55	0.1212	1
Blankcontrol	7	GreenWaste	7	0.1211	0.1477	732	0.82	0.4126	1
Blankcontrol	7	ManureWaste	7	0.001606	0.1206	732	0.01	0.9894	1
Blankcontrol	8	Control	8	-0.3194	0.1477	732	-2.16	0.031	0.9935
Blankcontrol	8	GreenWaste	8	-0.3369	0.1477	732	-2.28	0.0229	0.9833
Blankcontrol	8	ManureWaste	8	-0.5374	0.1206	732	-4.46	<.0001	0.0084

A5.5 continued

Differences of group*Harves*Nesting Least Squares Means									
group	Harvest	_group	_Harvest	Estimate	Standard Error	DF	t Value	Pr > t	Adj P
Control	1	GreenWaste	1	1.3105	0.1477	732	8.87	<.0001	<.0001
Control	1	ManureWaste	1	0.5894	0.1206	732	4.89	<.0001	0.0012
Control	2	GreenWaste	2	0.5434	0.1477	732	3.68	0.0003	0.1368
Control	2	ManureWaste	2	-0.02196	0.1206	732	-0.18	0.8556	1
Control	3	GreenWaste	3	0.08889	0.1477	732	0.6	0.5476	1
Control	3	ManureWaste	3	-0.2048	0.1206	732	-1.7	0.09	1
Control	4	GreenWaste	4	0.03373	0.1477	732	0.23	0.8195	1
Control	4	ManureWaste	4	-0.2907	0.1206	732	-2.41	0.0162	0.9605
Control	5	GreenWaste	5	-0.00296	0.1477	732	-0.02	0.984	1
Control	5	ManureWaste	5	-0.1493	0.1206	732	-1.24	0.2161	1
Control	6	GreenWaste	6	0.131	0.1477	732	0.89	0.3756	1
Control	6	ManureWaste	6	-0.1993	0.1206	732	-1.65	0.099	1
Control	7	GreenWaste	7	-0.1081	0.1477	732	-0.73	0.4646	1
Control	7	ManureWaste	7	-0.2276	0.1206	732	-1.89	0.0596	0.9996
Control	8	GreenWaste	8	-0.01752	0.1477	732	-0.12	0.9056	1
Control	8	ManureWaste	8	-0.218	0.1206	732	-1.81	0.0711	0.9999
GreenWaste	1	ManureWaste	1	-0.721	0.1206	732	-5.98	<.0001	<.0001
GreenWaste	2	ManureWaste	2	-0.5654	0.1206	732	-4.69	<.0001	0.0031
GreenWaste	3	ManureWaste	3	-0.2937	0.1206	732	-2.43	0.0151	0.9543
GreenWaste	4	ManureWaste	4	-0.3244	0.1206	732	-2.69	0.0073	0.8455
GreenWaste	5	ManureWaste	5	-0.1464	0.1206	732	-1.21	0.2254	1
GreenWaste	6	ManureWaste	6	-0.3303	0.1206	732	-2.74	0.0063	0.8151
GreenWaste	7	ManureWaste	7	-0.1195	0.1206	732	-0.99	0.3221	1
GreenWaste	8	ManureWaste	8	-0.2005	0.1206	732	-1.66	0.0969	1

All statistics presented are of comparisons between the compost groups. The comparisons of the individual composts were far too long to include within the appendix. To include the statistics for these treatments would have run to over 150 pages

A.6 Phosphorus pot experiment

Table A.6.1. Phosphorus uptake of all biowaste waste composts used in the phosphorus pot experiment at their respective rates

Treatment	Rate	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
BW 2	60 kg ha ⁻¹	41.10	72.82	31.81	47.19	49.10	34.69	42.09	8.00
BW 3	60	59.30	73.59	32.00	52.09	53.59	24.77	34.86	12.43
BW 4	60	56.74	89.68	18.42	55.44	44.91	25.57	39.82	11.19
BW 7	60	57.89	80.43	28.04	45.78	35.07	31.64	36.02	8.41
BW 8	60	50.73	79.60	23.22	42.63	44.50	29.22	31.61	8.37
BW 9	60	59.25	87.73	15.12	49.23	44.12	21.82	36.07	8.85
BW 12	60	64.56	74.23	31.90	36.48	43.18	21.72	28.86	7.68
BW 2	150	74.04	110.08	41.51	62.05	64.25	38.77	54.24	21.99
BW 3	150	92.28	111.42	42.58	61.27	84.69	36.92	53.35	27.65
BW 4	150	82.19	124.83	46.51	74.97	57.84	33.26	43.06	24.23
BW 7	150	87.20	143.21	43.16	86.94	50.95	50.19	53.48	31.54
BW 8	150	87.34	112.38	35.13	73.52	49.33	32.47	44.03	21.16
BW 9	150	79.98	131.86	54.41	72.60	57.96	39.88	45.21	23.24
BW 12	150	93.85	153.60	45.86	77.99	54.68	37.66	50.41	23.09
BW 2	240	87.13	67.92	65.27	75.26	73.08	39.37	67.70	36.16
BW 3	240	100.32	114.17	68.63	91.86	85.81	57.93	58.04	39.89
BW 4	240	100.26	174.16	46.48	82.68	75.40	59.57	64.23	35.91
BW 7	240	94.50	172.69	50.78	84.28	48.93	53.74	64.33	39.72
BW 8	240	96.56	124.61	46.61	84.95	71.39	56.19	57.38	30.22
BW 9	240	83.52	140.13	58.16	73.86	50.74	42.13	61.84	29.82
BW 12	240	96.34	163.58	59.89	98.56	76.40	67.63	62.79	34.83

Table A.6.2. Phosphorus uptake of all manure waste composts used in the phosphorus pot experiment at their respective rates

Treatment	Rate	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
MW 4	60 kg ha ⁻¹	69.47	60.89	30.33	61.54	50.87	22.85	39.68	16.68
MW 5	60	69.41	92.90	25.75	63.70	39.795	25.92	37.06	8.42
MW 4	150	105.42	148.580	55.57	97.47	74.30	43.48	58.45	27.16
MW 5	150	93.49	137.84	39.11	80.67	65.462	31.11	51.52	21.74
MW 4	240	114.55	215.13	62.27	131.60	85.54	72.10	74.95	40.55
MW 5	240	105.15	181.633	57.87	97.54	90.250	50.05	70.16	29.81

Table A.6.3. Phosphorus uptake of all anaerobic digestate and green waste composts used in the phosphorus pot experiment at their respective rates

	Rate	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6	Harvest 7	Harvest 8
ADC 2	60 kg ha ⁻¹	51.77	49.30	19.30	45.89	48.9375	15.83	27.63	7.69
GW 1	60	71.95	74.77	31.31	39.08	49.99	34.24	36.69	8.56
GW 2	60	55.20	88.75	16.72	55.83	31.80	18.73	33.04	8.29
ADC 2	150	82.29	78.00	33.05	68.26	58.38	43.09	41.99	14.88
GW 1	150	89.33	115.20	56.35	88.93	73.87	53.68	53.77	30.56
GW 2	150	65.97	149.78	29.91	59.82	55.14	41.21	39.44	17.12
ADC 2	240	84.40	93.04	38.70	69.50	57.88	50.34	46.76	26.04
GW 1	240	100.07	107.08	76.30	97.72	82.70	61.06	65.40	35.99
GW 2	240	70.10	99.43	43.93	75.36	56.91	33.00	54.01	25.69

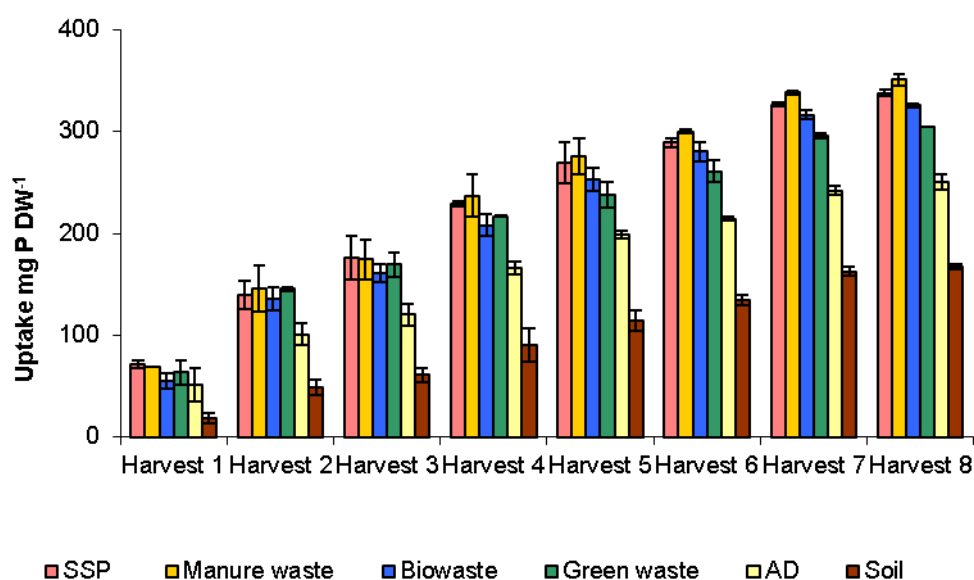


Figure A.6.1 Cumulative phosphorus uptake for the compost groups in the phosphorus pot experiment at 150 kg ha⁻¹ rate.

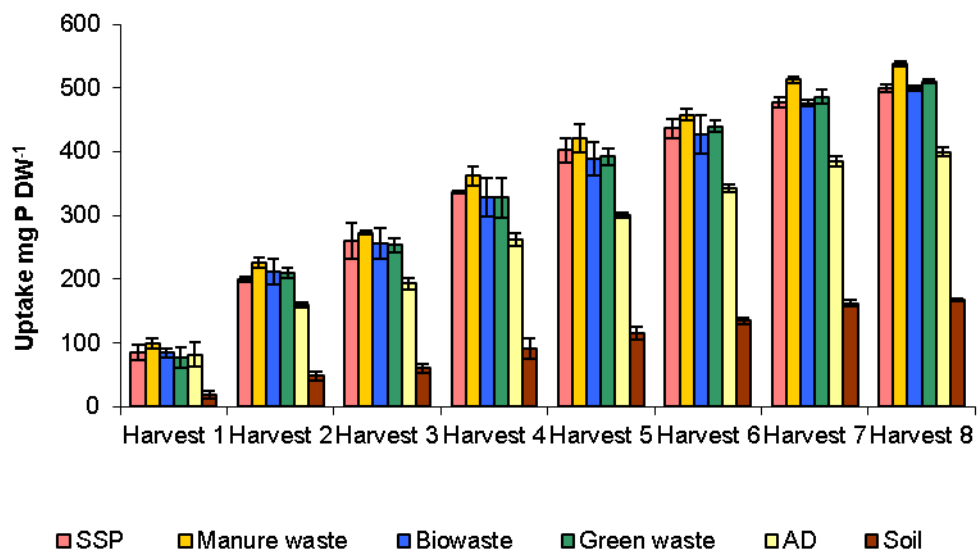


Figure A.6.2 Cumulative phosphorus uptake for the compost groups in the phosphorus pot experiment at 240 kg ha⁻¹ rate.



Figure A.6.1 Healthy cabbages grown in the phosphorus experiment at the third harvest pictured with SSP on the right and untreated soil control on the left.

x	x	x	x	x	x	x	x	x	x	x	x	x
x	39	6	17	49	46	29	37	19	41	34	x	x
x	26	8	4	20	29	17	40	45	14	33	x	x
x	34	19	11	41	13	9	13	18	4	39	x	x
x	1	42	30	40	24	5	20	21	49	10	x	x
x	48	27	31	47	45	8	16	36	6	3	x	x
x	28	33	32	36	22	28	42	47	44	1	x	x
x	43	38	35	10	14	46	11	48	2	7	x	x
x	21	7	37	16	23	24	12	30	22	38	x	x
x	50	12	5	2	15	35	15	32	31	25	x	x
x	44	3	18	9	25	26	43	27	23	51	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x
x	15	32	13	33	21	44	4	14	17	6	x	x
x	10	38	8	4	18	3	40	39	19	31	x	x
x	46	34	30	6	44	8	15	47	21	35	x	x
x	14	47	17	37	26	42	10	33	30	26	x	x
x	7	24	51	39	50	32	36	27	7	41	x	x
x	25	16	3	48	5	49	24	48	9	29	x	x
x	19	20	31	49	11	28	5	25	37	12	x	x
x	22	9	42	28	12	46	1	38	51	43	x	x
x	36	45	41	43	40	45	11	13	20	18	x	x
x	27	1	35	2	29	23	2	16	34	22	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x
x	24	23	44	33	29	6	12	22	21	1	x	x
x	18	34	36	40	41	2	4	10	27	33	x	x
x	22	26	31	37	21	43	41	19	37	30	x	x
x	11	25	15	14	7	32	24	3	35	39	x	x
x	20	1	16	2	27	40	44	23	13	51	x	x
x	12	39	47	32	30	42	31	28	15	8	x	x
x	5	48	46	43	10	29	5	46	20	48	x	x
x	13	8	4	9	17	18	49	38	34	17	x	x
x	38	51	45	49	28	14	9	25	36	11	x	x
x	42	6	35	3	19	16	47	45	26	7	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x

Figure A.6.2 Randomised block design layout of pots used in both experiments in the glasshouse.

Table A.6.4 Net phosphorus percentage recovery for all compost treatments used in the phosphorus pot experiment at their respective rates

Treatment	Rate	Percentage recovery							
		H1	H2	H3	H4	H5	H6	H7	H8
SSP	60	58.18	35.74	24.84	16.64	10.95	0.00	0.39	6.68
SSP	150	26.56	37.01	22.26	18.75	16.65	4.17	1.67	8.14
SSP	240	22.59	27.82	17.81	17.98	16.90	7.68	5.00	8.37
BW 2	60	20.29	41.29	19.10	9.75	21.35	10.51	6.50	2.15
BW 2	150	24.63	35.20	12.50	11.34	16.14	6.25	8.69	7.88
BW 2	240	19.49	8.79	15.26	11.23	12.85	4.10	9.65	9.36
BW 3	60	43.10	42.26	19.34	15.88	26.97	0.00	0.00	0.00
BW 3	150	33.77	35.87	13.04	10.95	26.38	5.33	8.24	10.71
BW 3	240	23.63	23.28	16.31	16.43	16.84	9.91	6.62	10.53
BW 4	60	39.89	62.42	2.32	20.08	13.93	0.00	0.00	1.76
BW 4	150	26.63	42.59	15.01	17.82	11.34	5.70	6.77	8.42
BW 4	240	24.91	42.07	9.37	13.55	13.89	12.95	8.11	8.94
BW 7	60	41.33	50.83	14.37	7.97	16.11	0.00	3.66	6.15
BW 7	150	31.22	51.80	13.33	23.82	12.92	3.49	3.09	9.00
BW 7	240	21.80	41.61	10.72	14.05	13.58	10.42	8.56	9.28
BW 8	60	32.36	49.79	8.34	4.02	3.77	6.69	0.00	2.67
BW 8	150	31.30	36.35	9.30	17.10	9.47	11.98	8.31	12.66
BW 8	240	22.45	26.55	9.41	14.26	5.28	8.60	8.59	10.48
BW 9	60	43.04	59.97	0.00	12.30	15.12	0.00	0.00	3.23
BW 9	150	27.61	46.11	18.97	16.64	12.98	6.81	4.16	8.50
BW 9	240	18.36	31.41	13.03	10.79	5.85	4.96	7.81	7.37
BW 12	60	49.69	43.06	19.21	0.00	9.69	0.00	0.21	2.69
BW 12	150	34.56	57.01	14.68	19.34	16.74	2.41	7.33	7.75
BW 12	240	22.38	38.76	13.57	18.53	18.23	7.44	10.42	7.37
MW 5	60	55.77	66.46	11.50	30.44	23.57	2.35	3.48	13.04
MW 5	150	34.38	49.11	11.30	20.68	21.17	8.61	10.80	10.46
MW 5	240	25.14	32.49	12.94	18.21	16.75	14.35	11.92	10.74
MW 4	60	55.84	26.34	17.24	27.73	21.15	1.11	0.00	1.76
MW 4	150	40.36	37.19	19.55	29.10	13.19	8.42	2.55	4.31
MW 4	240	28.08	54.91	14.32	28.88	8.09	7.53	3.09	6.19
ADC 2	60	33.66	11.82	3.42	8.12	-0.32	3.05	0.00	2.53
ADC 2	150	28.76	19.11	8.26	14.46	11.57	7.47	1.28	5.43
ADC 2	240	18.64	16.66	6.93	9.43	7.78	11.81	5.36	6.08
GW 2	60	37.96	61.26	0.19	20.58	15.59	3.66	0.00	2.62
GW 2	150	20.58	55.09	6.69	10.23	8.66	3.09	3.57	7.46
GW 2	240	14.16	18.66	8.57	11.26	12.32	9.37	6.41	7.50
GW 1	60	58.96	43.73	18.48	0.00	22.47	9.96	0.00	2.86
GW 1	150	32.29	37.76	19.94	24.82	20.96	13.72	8.46	12.17
GW 1	240	23.55	21.06	18.71	18.27	15.87	10.89	8.93	9.31

Table A.6.4 LS – means for each compost treatment and rate in the pot experiment

Treat	Nesting	Rate	Treat*Rate*Nesting Least Squares Means				
			Estimate	Standard Error	DF	t Value	Pr > t
GW 1	Factorial	60	340.26	20.172	82	16.87	<.0001
GW 1	Factorial	150	569.57	20.172	82	28.24	<.0001
GW 1	Factorial	240	608.25	20.172	82	30.15	<.0001
BW 2	Factorial	60	325.93	20.172	82	16.16	<.0001
BW 2	Factorial	150	480.46	20.172	82	23.82	<.0001
BW 2	Factorial	240	505.66	20.172	82	25.07	<.0001
BW 3	Factorial	60	351.21	20.172	82	17.41	<.0001
BW 3	Factorial	150	515.75	20.172	82	25.57	<.0001
BW 3	Factorial	240	625.6	20.172	82	31.01	<.0001
GW 2	Factorial	60	315.75	20.172	82	15.65	<.0001
GW 2	Factorial	150	490.79	20.172	82	24.33	<.0001
GW 2	Factorial	240	482.85	20.172	82	23.94	<.0001
BW 4	Factorial	60	345.63	20.172	82	17.13	<.0001
BW 4	Factorial	150	479.44	20.172	82	23.77	<.0001
BW 4	Factorial	240	648.95	20.172	82	32.17	<.0001
BW 7	Factorial	60	346.48	20.172	82	17.18	<.0001
BW 7	Factorial	150	577.51	20.172	82	28.63	<.0001
BW 7	Factorial	240	639.03	20.172	82	31.68	<.0001
BW 8	Factorial	60	335.56	20.172	82	16.64	<.0001
BW 8	Factorial	150	470.75	20.172	82	23.34	<.0001
BW 8	Factorial	240	565.37	20.172	82	28.03	<.0001
BW 9	Factorial	60	337.07	20.172	82	16.71	<.0001
BW 9	Factorial	150	542.57	20.172	82	26.9	<.0001
BW 9	Factorial	240	541.03	20.172	82	26.82	<.0001
MW 4	Factorial	60	356.84	20.172	82	17.69	<.0001
MW 4	Factorial	150	593.08	20.172	82	29.4	<.0001
MW 4	Factorial	240	819.91	20.172	82	40.65	<.0001
BW 12	Factorial	60	333.13	20.172	82	16.51	<.0001
BW 12	Factorial	150	557.92	20.172	82	27.66	<.0001
BW 12	Factorial	240	670.38	20.172	82	33.23	<.0001
MW 5	Factorial	60	365.63	20.172	82	18.13	<.0001
MW 5	Factorial	150	528.94	20.172	82	26.22	<.0001
MW 5	Factorial	240	687.25	20.172	82	34.07	<.0001
ADC 2	Factorial	60	281.51	20.172	82	13.96	<.0001
ADC 2	Factorial	150	420.61	20.172	82	20.85	<.0001
ADC 2	Factorial	240	456.84	20.172	82	22.65	<.0001
SSP	Factorial	60	342.04	20.172	82	16.96	<.0001
SSP	Factorial	150	493.61	20.172	82	24.47	<.0001
SSP	Factorial	240	622.92	20.172	82	30.88	<.0001
Soil	Blank	0	161.95	11.6463	82	13.91	<.0001

Table A.6.5 Group comparisons ANOVA - LS – means with Tukey – Pairwise adjustment

group	Harvest	_group	_Harvest	Estimate	SE	DF	t Value	Pr > t	Adj P
ADigestate	1	Biowaste	1	-0.0819	0.1197	878	-0.68	0.4939	1
ADigestate	1	Control	1	-0.157	0.1583	878	-0.99	0.3215	1
ADigestate	1	GreenWaste	1	-0.05506	0.1371	878	-0.4	0.688	1
ADigestate	1	ManureWaste	1	-0.2632	0.1371	878	-1.92	0.0552	0.9978
ADigestate	2	Biowaste	2	-0.4135	0.1197	878	-3.46	0.0006	0.1953
ADigestate	2	Control	2	-0.3504	0.1583	878	-2.21	0.0271	0.9759
ADigestate	2	GreenWaste	2	-0.3399	0.1371	878	-2.48	0.0134	0.897
ADigestate	2	ManureWaste	2	-0.4664	0.1371	878	-3.4	0.0007	0.2241
ADigestate	3	Biowaste	3	-0.282	0.1197	878	-2.36	0.0187	0.9435
ADigestate	3	Control	3	-0.6026	0.1583	878	-3.81	0.0002	0.0688
ADigestate	3	GreenWaste	3	-0.2735	0.1371	878	-2	0.0463	0.9955
ADigestate	3	ManureWaste	3	-0.4112	0.1371	878	-3	0.0028	0.5201
ADigestate	4	Biowaste	4	-0.06776	0.1197	878	-0.57	0.5714	1
ADigestate	4	Control	4	-0.1959	0.1583	878	-1.24	0.2162	1
ADigestate	4	GreenWaste	4	-0.0949	0.1371	878	-0.69	0.489	1
ADigestate	4	ManureWaste	4	-0.3522	0.1371	878	-2.57	0.0104	0.8507
ADigestate	5	Biowaste	5	-0.01113	0.1197	878	-0.09	0.9259	1
ADigestate	5	Control	5	-0.07303	0.1583	878	-0.46	0.6446	1
ADigestate	5	GreenWaste	5	0.01396	0.1371	878	0.1	0.9189	1
ADigestate	5	ManureWaste	5	-0.1345	0.1371	878	-0.98	0.3266	1
ADigestate	6	Biowaste	6	-0.1215	0.1197	878	-1.02	0.3101	1
ADigestate	6	Control	6	0.02726	0.1583	878	0.17	0.8633	1
ADigestate	6	GreenWaste	6	-0.09456	0.1371	878	-0.69	0.4905	1
ADigestate	6	ManureWaste	6	-0.1357	0.1371	878	-0.99	0.3225	1
ADigestate	7	Biowaste	7	-0.1995	0.1197	878	-1.67	0.0958	0.9999
ADigestate	7	Control	7	-0.1234	0.1583	878	-0.78	0.4357	1
ADigestate	7	GreenWaste	7	-0.1721	0.1371	878	-1.26	0.2098	1
ADigestate	7	ManureWaste	7	-0.3303	0.1371	878	-2.41	0.0162	0.9256
ADigestate	8	Biowaste	8	-0.3714	0.1197	878	-3.1	0.002	0.4331
ADigestate	8	Control	8	-0.4382	0.1583	878	-2.77	0.0058	0.7137
ADigestate	8	GreenWaste	8	-0.2633	0.1371	878	-1.92	0.0551	0.9978
ADigestate	8	ManureWaste	8	-0.4532	0.1371	878	-3.31	0.001	0.2832
Biowaste	1	Control	1	-0.07513	0.1197	878	-0.63	0.5303	1
Biowaste	1	GreenWaste	1	0.02684	0.08974	878	0.3	0.7649	1
Biowaste	1	ManureWaste	1	-0.1813	0.08974	878	-2.02	0.0437	0.9945
Biowaste	2	Control	2	0.06312	0.1197	878	0.53	0.598	1
Biowaste	2	GreenWaste	2	0.07362	0.08974	878	0.82	0.4122	1
Biowaste	2	ManureWaste	2	-0.05292	0.08974	878	-0.59	0.5556	1
Biowaste	3	Control	3	-0.3206	0.1197	878	-2.68	0.0075	0.78
Biowaste	3	GreenWaste	3	0.008453	0.08974	878	0.09	0.925	1
Biowaste	3	ManureWaste	3	-0.1293	0.08974	878	-1.44	0.1501	1
Biowaste	4	Control	4	-0.1281	0.1197	878	-1.07	0.2845	1
Biowaste	4	GreenWaste	4	-0.02714	0.08974	878	-0.3	0.7624	1
Biowaste	4	ManureWaste	4	-0.2844	0.08974	878	-3.17	0.0016	0.3814
Biowaste	5	Control	5	-0.06191	0.1197	878	-0.52	0.605	1
Biowaste	5	GreenWaste	5	0.02509	0.08974	878	0.28	0.7799	1
Biowaste	5	ManureWaste	5	-0.1234	0.08974	878	-1.38	0.1694	1
Biowaste	6	Control	6	0.1488	0.1197	878	1.24	0.2141	1
Biowaste	6	GreenWaste	6	0.02695	0.08974	878	0.3	0.764	1
Biowaste	6	ManureWaste	6	-0.01417	0.08974	878	-0.16	0.8745	1
Biowaste	7	Control	7	0.0761	0.1197	878	0.64	0.525	1
Biowaste	7	GreenWaste	7	0.02748	0.08974	878	0.31	0.7595	1
Biowaste	7	ManureWaste	7	-0.1308	0.08974	878	-1.46	0.1453	1
Biowaste	8	Control	8	-0.06676	0.1197	878	-0.56	0.577	1
Biowaste	8	GreenWaste	8	0.1081	0.08974	878	1.2	0.2287	1
Biowaste	8	ManureWaste	8	-0.08176	0.08974	878	-0.91	0.3625	1

group	Harvest	group	Harvest	Estimate	SE	DF	t Value	Pr > t 	Adj P
Control	1	GreenWaste	1	0.102	0.1371	878	0.74	0.4572	1
Control	1	ManureWaste	1	-0.1061	0.1371	878	-0.77	0.439	1
Control	2	GreenWaste	2	0.0105	0.1371	878	0.08	0.939	1
Control	2	ManureWaste	2	-0.116	0.1371	878	-0.85	0.3975	1
Control	3	GreenWaste	3	0.3291	0.1371	878	2.4	0.0166	0.929
Control	3	ManureWaste	3	0.1913	0.1371	878	1.4	0.1631	1
Control	4	GreenWaste	4	0.101	0.1371	878	0.74	0.4614	1
Control	4	ManureWaste	4	-0.1563	0.1371	878	-1.14	0.2546	1
Control	5	GreenWaste	5	0.087	0.1371	878	0.63	0.5258	1
Control	5	ManureWaste	5	-0.06151	0.1371	878	-0.45	0.6537	1
Control	6	GreenWaste	6	-0.1218	0.1371	878	-0.89	0.3744	1
Control	6	ManureWaste	6	-0.1629	0.1371	878	-1.19	0.2349	1
Control	7	GreenWaste	7	-0.04862	0.1371	878	-0.35	0.7229	1
Control	7	ManureWaste	7	-0.2069	0.1371	878	-1.51	0.1316	1
Control	8	GreenWaste	8	0.1749	0.1371	878	1.28	0.2024	1
Control	8	ManureWaste	8	-0.01499	0.1371	878	-0.11	0.9129	1
GreenWaste	1	ManureWaste	1	-0.2081	0.1119	878	-1.86	0.0633	0.9988
GreenWaste	2	ManureWaste	2	-0.1265	0.1119	878	-1.13	0.2586	1
GreenWaste	3	ManureWaste	3	-0.1377	0.1119	878	-1.23	0.2189	1
GreenWaste	4	ManureWaste	4	-0.2573	0.1119	878	-2.3	0.0218	0.9591
GreenWaste	5	ManureWaste	5	-0.1485	0.1119	878	-1.33	0.1849	1
GreenWaste	6	ManureWaste	6	-0.04112	0.1119	878	-0.37	0.7134	1
GreenWaste	7	ManureWaste	7	-0.1583	0.1119	878	-1.41	0.1577	1
GreenWaste	8	ManureWaste	8	-0.1899	0.1119	878	-1.7	0.0902	0.9998

A.7 Temperature and sunlight data for the pot experiments

Table A.7.1 Daily weather data for the pot experiments duration; including max/min daily temperature and hours of sunlight

date	maxtp	mintp	sun	date	maxtp	mintp	sun	date	maxtp	mintp	sun
01-Nov-10	14	3.8	0.3	01-Dec-10	0.9	-2	0	01-Jan-11	7.8	2.4	1.1
02-Nov-10	12.9	9.5	0	02-Dec-10	1.2	-6.2	0.6	02-Jan-11	3.1	0	0
03-Nov-10	14.8	8.4	0	03-Dec-10	2.2	-7.1	0	03-Jan-11	2.7	-0.5	2.5
04-Nov-10	15.9	11.9	0.1	04-Dec-10	1.8	-2.4	1.2	04-Jan-11	5.4	1.7	0
05-Nov-10	12.1	7.9	0	05-Dec-10	-1.7	-3.3	4.1	05-Jan-11	5.8	0.5	4.6
06-Nov-10	8	1.4	1	06-Dec-10	0.9	-7.1	5.5	06-Jan-11	3.5	-6.8	4.2
07-Nov-10	6.7	1.2	3.4	07-Dec-10	2.9	-5.6	0	07-Jan-11	4.6	-6.2	0.3
08-Nov-10	8.5	3.9	2.1	08-Dec-10	-0.6	-7.2	7.1	08-Jan-11	3.8	-1.2	4.6
09-Nov-10	8.8	2.4	1	09-Dec-10	3.2	-3.9	0.2	09-Jan-11	5.2	0.2	5.8
10-Nov-10	8.6	-1.5	6.5	10-Dec-10	5.8	2.5	0.5	10-Jan-11	8.6	3.6	0
11-Nov-10	11.7	7.4	2.3	11-Dec-10	6.4	-1.5	3.7	11-Jan-11	7.2	1.6	4.7
12-Nov-10	9.7	5.9	3.4	12-Dec-10	6.5	-1.3	6.1	12-Jan-11	11.8	5.6	0
13-Nov-10	8.3	4.2	4.5	13-Dec-10	5.8	2.8	0	13-Jan-11	11.8	9	0
14-Nov-10	6.5	-1.2	5.6	14-Dec-10	5.3	-1.7	4.7	14-Jan-11	10.6	6.4	4.8
15-Nov-10	8.5	-2.2	5.5	15-Dec-10	5.2	1.6	0.1	15-Jan-11	12.5	8.6	0.1
16-Nov-10	10	3.5	2.9	16-Dec-10	7.3	-2.2	0.5	16-Jan-11	11.8	5.7	4
17-Nov-10	11	7.9	5.1	17-Dec-10	0.8	-3.5	4.2	17-Jan-11	7.1	1.1	2.5
18-Nov-10	10.9	5.5	3.8	18-Dec-10	-0.3	-8	4.1	18-Jan-11	6.1	-0.2	7.5
19-Nov-10	10.5	-0.3	5.9	19-Dec-10	3.4	-9.8	3.2	19-Jan-11	7.2	-4.6	7.6
20-Nov-10	9	3.3	0	20-Dec-10	0.1	-8.8	0.8	20-Jan-11	6.1	-5.7	7.3
21-Nov-10	7	2.1	1.8	21-Dec-10	0.8	-10.1	0.1	21-Jan-11	3.5	-5.1	5.1
22-Nov-10	7.2	0.9	0.8	22-Dec-10	0.2	-9.8	3.8	22-Jan-11	5.4	-1.2	0
23-Nov-10	7	2.8	5.5	23-Dec-10	0.5	-6.2	0.4	23-Jan-11	4.5	0.1	0
24-Nov-10	5.8	-0.6	4.3	24-Dec-10	-4.7	-11.4	3.8	24-Jan-11	6.3	2.1	0.1
25-Nov-10	3.9	-1.3	5.6	25-Dec-10	-3.3	-12.2	5	25-Jan-11	8.8	5	0
26-Nov-10	3.1	-2	1.6	26-Dec-10	4.9	-9.1	0	26-Jan-11	6.7	4.2	0.1
27-Nov-10	2.7	-2.8	4.3	27-Dec-10	9	4.6	0	27-Jan-11	4.8	1.4	0
28-Nov-10	-1.5	-8.4	5.9	28-Dec-10	11.7	3.3	0.2	28-Jan-11	3.5	-1.9	0
29-Nov-10	3	-8	2	29-Dec-10	9.7	3.5	0.4	29-Jan-11	4.6	-0.9	1.5
30-Nov-10	3.3	-1.5	0.6	30-Dec-10	8.6	7.1	0	30-Jan-11	2.6	-2.4	3.2
				31-Dec-10	7.9	5.2	0	31-Jan-11	8.9	-0.5	1.6
01-Feb-11	10.5	5.9	5.5	01-Mar-11	10.1	-3.2	9.8	01-Apr-11	13.6	11.9	0
02-Feb-11	12.6	3.7	2.5	02-Mar-11	8.8	-4.6	6.5	02-Apr-11	14.6	5.6	8.1
03-Feb-11	9.8	2.7	3	03-Mar-11	7.7	-5.4	5.1	03-Apr-11	12.2	4.4	8.2
04-Feb-11	13.3	7.6	0.2	04-Mar-11	9.6	-2	2.3	04-Apr-11	16.3	3.9	5
05-Feb-11	11.8	6.2	0	05-Mar-11	8.7	4.1	0.1	05-Apr-11	17.7	10.6	1.5
06-Feb-11	11.7	5.7	0	06-Mar-11	8.3	0.9	3.5	06-Apr-11	17.9	11.9	4.9
07-Feb-11	11.2	2.1	5	07-Mar-11	9.7	-2.1	8.7	07-Apr-11	15.6	4.3	4.4
08-Feb-11	9.6	-1.7	4.7	08-Mar-11	9.3	0.8	5.1	08-Apr-11	16.2	1.3	10.7
09-Feb-11	11.6	6.6	0	09-Mar-11	10.7	3.7	6.2	09-Apr-11	17.1	4.2	7.2
10-Feb-11	8.5	3.1	2.4	10-Mar-11	10.2	3.5	6.4	10-Apr-11	20.3	7.1	9.5
11-Feb-11	10.2	4.9	0	11-Mar-11	9.3	2.8	0.1	11-Apr-11	13.8	3.7	9.2
12-Feb-11	8.7	1.7	6.1	12-Mar-11	9.7	1.9	0.7	12-Apr-11	12.4	3.3	8.1
13-Feb-11	9.3	1.6	3.7	13-Mar-11	7.4	-0.2	4.1	13-Apr-11	13.6	4.9	1.2
14-Feb-11	6.7	1.9	5.6	14-Mar-11	8.9	-2.8	4.5	14-Apr-11	12.6	6.2	0
15-Feb-11	7	2.9	0	15-Mar-11	9.3	-2.9	5.5	15-Apr-11	15.3	8	5.7
16-Feb-11	8.7	-0.8	5.4	16-Mar-11	8.3	-3.3	7.4	16-Apr-11	13.4	5.3	2.3
17-Feb-11	7.2	0.9	0	17-Mar-11	10	-0.2	4.6	17-Apr-11	12.7	-0.1	9.1
18-Feb-11	7.5	2.2	0	18-Mar-11	10.9	-2.7	8.5	18-Apr-11	16.4	3	5.7
19-Feb-11	12.1	3	8.1	19-Mar-11	12.5	2.5	6.4	19-Apr-11	16.1	2.6	12.4
20-Feb-11	7.8	5.9	0	20-Mar-11	14.1	6.7	2.7	20-Apr-11	17.7	1.9	11.9
21-Feb-11	10.9	5.1	4.1	21-Mar-11	14.5	6.6	0.7	21-Apr-11	16.8	5.8	12.3
22-Feb-11	10.8	4	0	22-Mar-11	14.9	3.5	3	22-Apr-11	18.4	5.5	7.2
23-Feb-11	13.7	9.4	1.4	23-Mar-11	14.5	0.4	9	23-Apr-11	15.4	4.9	8.2
24-Feb-11	14.7	8.2	5.7	24-Mar-11	13.5	-0.3	10.6	24-Apr-11	16.2	5.9	1.1
25-Feb-11	13.4	8.8	1.5	25-Mar-11	11	0.2	10.9	25-Apr-11	12.2	6	2.6
26-Feb-11	9.4	2.9	8.6	26-Mar-11	9.1	-2.1	1.5	26-Apr-11	12	6.2	0.9
27-Feb-11	10	-0.3	7.7	27-Mar-11	10.6	0.3	9.4	27-Apr-11	14.9	2.4	12
28-Feb-11	9.1	-1.2	9.2	28-Mar-11	10.2	-0.8	7.2	28-Apr-11	15.6	0.2	13.9
				29-Mar-11	11.2	2.8	0.1	29-Apr-11	15.1	1.6	11.2
				30-Mar-11	15	7.2	5.7	30-Apr-11	15.2	8.3	7
				31-Mar-11	15.6	9.1	6.6				

date	maxtp	mintp	sun	date	maxtp	mintp	sun	date	maxtp	mintp	sun
01-Nov-11	12.8	6	7.3	01-Dec-11	6.6	1.2	1.3	01-Jan-12	10	2.7	4.2
02-Nov-11	14.1	11.9	0.1	02-Dec-11	10.3	1.4	0	02-Jan-12	6.9	1.2	5.4
03-Nov-11	14.4	9.8	0.7	03-Dec-11	9.7	5	5.2	03-Jan-12	12.2	2.8	3.1
04-Nov-11	11.9	5.3	4.2	04-Dec-11	5.5	0.7	0.1	04-Jan-12	9.8	3.2	0
05-Nov-11	9.6	0.8	7.5	05-Dec-11	4.6	0.8	4.6	05-Jan-12	10.1	4.2	3.4
06-Nov-11	12.4	-0.6	8.6	06-Dec-11	7.7	1.7	1.2	06-Jan-12	10.4	3.5	0.6
07-Nov-11	10.7	-2	8.6	07-Dec-11	6.2	3.2	6.3	07-Jan-12	8.5	5.7	1.1
08-Nov-11	11.4	10.1	0	08-Dec-11	10.9	1.5	0.4	08-Jan-12	11.2	6.8	0.3
09-Nov-11	14.2	8.3	0.9	09-Dec-11	4.7	-0.3	5.7	09-Jan-12	9.9	6.3	2.1
10-Nov-11	14.5	5.7	6.3	10-Dec-11	8.3	-0.5	0.6	10-Jan-12	11	6.6	1.4
11-Nov-11	13.7	10.8	0.8	11-Dec-11	8.1	2	0.3	11-Jan-12	11.6	9.5	0.1
12-Nov-11	13.3	7.9	4.5	12-Dec-11	10.2	2.5	1.3	12-Jan-12	10.9	1.3	3.5
13-Nov-11	15	11.3	2.1	13-Dec-11	5.9	0.4	4.1	13-Jan-12	8.2	-2.1	6.4
14-Nov-11	13.2	8.8	1.2	14-Dec-11	4.9	0.9	0.8	14-Jan-12	6.9	-3	3.4
15-Nov-11	12.4	5.7	1	15-Dec-11	4.7	-2	1.8	15-Jan-12	6.2	5	0.1
16-Nov-11	11.4	8.8	0	16-Dec-11	3.1	-2.4	1.3	16-Jan-12	7.2	2.1	4
17-Nov-11	13.9	5.7	0.3	17-Dec-11	4.3	-0.2	6.8	17-Jan-12	11.5	3.9	1.5
18-Nov-11	15.1	12.8	0.1	18-Dec-11	3.9	-0.6	4	18-Jan-12	11.6	6.9	0.4
19-Nov-11	13.1	11.6	0	19-Dec-11	9.2	3.3	1.6	19-Jan-12	8	3.7	4.5
20-Nov-11	13.2	9.7	3.4	20-Dec-11	10.6	4.6	0	20-Jan-12	11	4.3	1.3
21-Nov-11	12	5.5	0.2	21-Dec-11	11.8	10.1	0	21-Jan-12	10.6	5.4	2.1
22-Nov-11	9.5	2.1	6.7	22-Dec-11	12.8	9.3	0.5	22-Jan-12	9.4	4.8	3.9
23-Nov-11	12.9	9.2	0	23-Dec-11	11.6	1.9	2	23-Jan-12	8.2	2.6	3.8
24-Nov-11	12.9	6.8	0.1	24-Dec-11	9.8	2	0.2	24-Jan-12	11.6	5.2	0.1
25-Nov-11	8.7	5.1	2.7	25-Dec-11	13.3	9.6	0.1	25-Jan-12	11.3	1.8	0
26-Nov-11	13.5	8.4	0.1	26-Dec-11	13.1	9.4	1.7	26-Jan-12	5.6	1	3.7
27-Nov-11	13.3	3.8	6.2	27-Dec-11	10.3	7.6	0.4	27-Jan-12	6.2	0	4.1
28-Nov-11	13.7	3.8	0.6	28-Dec-11	9.2	3.4	4.9	28-Jan-12	5.6	-1.9	0.2
29-Nov-11	13.2	4	1.7	29-Dec-11	8.3	4	0.1	29-Jan-12	7.6	3.6	0
30-Nov-11	10.6	4	0.2	30-Dec-11	12	4.4	0	30-Jan-12	4.5	3.8	0
				31-Dec-11	12.8	9.6	0	31-Jan-12	4.4	2	0
01-Feb-12	4.2	-3.7	8	01-Mar-12	13.9	4.3	7.5	01-Apr-12	12	-0.8	6.8
02-Feb-12	3.8	-6	4.5	02-Mar-12	11	4.2	4.1	02-Apr-12	10	5.9	0.1
03-Feb-12	5.6	-6.1	4.8	03-Mar-12	11.1	3.7	7.3	03-Apr-12	7.3	1.3	3
04-Feb-12	8.8	1.9	0	04-Mar-12	7.5	-0.4	9.4	04-Apr-12	7.6	1	7.2
05-Feb-12	7.1	2.5	0	05-Mar-12	9.7	0.5	7.7	05-Apr-12	7.9	1.5	11.8
06-Feb-12	8.7	3.2	0.2	06-Mar-12	11.5	1.5	0	06-Apr-12	11.1	2.6	2.2
07-Feb-12	7.3	0.5	4.7	07-Mar-12	11.5	3.5	7.7	07-Apr-12	13.8	7.4	3.1
08-Feb-12	4.4	2.6	0	08-Mar-12	12.5	3.6	2.4	08-Apr-12	11.6	7.4	0.1
09-Feb-12	9.2	3.6	0	09-Mar-12	13.3	8.7	0	09-Apr-12	10.6	3.8	2.2
10-Feb-12	9.2	6.2	0	10-Mar-12	12.5	9.8	1	10-Apr-12	10.4	1.8	10.3
11-Feb-12	7.9	5.8	0	11-Mar-12	10.7	7	0.1	11-Apr-12	12.1	1.1	9.2
12-Feb-12	7.5	4.7	1.1	12-Mar-12	12.8	7.8	1	12-Apr-12	11.5	1.5	8.2
13-Feb-12	8.3	4.3	0	13-Mar-12	9	0.7	0	13-Apr-12	9.6	-0.6	6.1
14-Feb-12	8.8	5.1	1.5	14-Mar-12	10.7	-1.8	0.3	14-Apr-12	8.8	-0.5	9.4
15-Feb-12	10	6.2	0.5	15-Mar-12	11.8	6.1	1.3	15-Apr-12	8.8	-1.5	7
16-Feb-12	10.1	6.5	0.2	16-Mar-12	11.1	6.5	0	16-Apr-12	10.1	2.2	0.5
17-Feb-12	11.4	7.9	0	17-Mar-12	8.5	2.4	1.2	17-Apr-12	10.5	4.5	8.2
18-Feb-12	8.1	0.9	7	18-Mar-12	10.6	1.5	10.2	18-Apr-12	10.4	2.5	7.2
19-Feb-12	6.9	-0.2	5.4	19-Mar-12	12.1	2.4	2.3	19-Apr-12	11.6	1.6	9.1
20-Feb-12	9.1	1.8	0	20-Mar-12	12.4	7.8	1.2	20-Apr-12	12.3	3.5	6.4
21-Feb-12	12.6	8.5	2.3	21-Mar-12	10.9	2.3	0	21-Apr-12	13.6	2.8	10.6
22-Feb-12	14.1	10.2	0.2	22-Mar-12	11.3	-0.1	3	22-Apr-12	12.3	5.1	7.1
23-Feb-12	14.1	11	1.6	23-Mar-12	11.4	7.4	5.2	23-Apr-12	10.2	3.1	5.7
24-Feb-12	11.5	5.2	3.7	24-Mar-12	15.7	4.5	6.8	24-Apr-12	12.6	2	7.8
25-Feb-12	9.7	1.7	6.6	25-Mar-12	18.1	2.4	10.7	25-Apr-12	7.9	5.5	0
26-Feb-12	11.9	6.1	3	26-Mar-12	15.1	1.1	11.3	26-Apr-12	9.1	6.1	0
27-Feb-12	11.3	9.2	0	27-Mar-12	17.8	0.8	11.3	27-Apr-12	9.3	2.1	3.2
28-Feb-12	11.5	9.2	0.2	28-Mar-12	18.7	-0.7	11.1	28-Apr-12	10.5	2	9.8
29-Feb-12	12.3	8.1	7.1	29-Mar-12	17.4	2.4	6.7	29-Apr-12	7.7	4.2	0.1
				30-Mar-12	11.6	7.8	0.3	30-Apr-12	12.3	6.1	2.2
				31-Mar-12	11.8	1.8	5.2				

01-May-11	15.6	7.8	12.8	01-Jun-11	19.7	10.6	4	01-Jul-11	16.4	5.2	7.3
02-May-11	14.4	7.6	13.3	02-Jun-11	19.4	5.5	8	02-Jul-11	18.4	5.8	8.7
03-May-11	12.7	5.8	10.1	03-Jun-11	21.6	4.4	15.6	03-Jul-11	19.4	10	15.3
04-May-11	13.4	8.4	7.2	04-Jun-11	18.2	6.5	9.1	04-Jul-11	21.5	9.7	10
05-May-11	15.3	10	0.9	05-Jun-11	12.7	7.1	2.4	05-Jul-11	20.5	12.2	7.8
06-May-11	17.3	10	4.3	06-Jun-11	14.4	5.1	7	06-Jul-11	16.3	7.2	4.9
07-May-11	15.3	10.6	1.6	07-Jun-11	13.9	7.9	5.5	07-Jul-11	18.9	6.7	2.7
08-May-11	16	10.4	9.2	08-Jun-11	15.3	6.5	3.4	08-Jul-11	16.4	9.9	1.3
09-May-11	16.8	10.9	8.6	09-Jun-11	13.3	4	8.5	09-Jul-11	19.7	9.1	6
10-May-11	17.6	9.5	6.7	10-Jun-11	13.3	3.8	8.9	10-Jul-11	18.5	10.6	2
11-May-11	15.1	8.3	7.6	11-Jun-11	14.3	4.9	5.8	11-Jul-11	16.9	7.3	2.2
12-May-11	15	8.1	9	12-Jun-11	11.6	2.1	0.3	12-Jul-11	17.7	7.6	6.9
13-May-11	12.5	6.5	7.6	13-Jun-11	18.1	4.8	11.4	13-Jul-11	18.6	4.9	15.2
14-May-11	13	6.4	5.9	14-Jun-11	17.2	2.8	10.2	14-Jul-11	21.2	11.4	7.2
15-May-11	15	6.5	0.2	15-Jun-11	19.2	7.6	4.4	15-Jul-11	17.9	10.9	1.3
16-May-11	15.7	10.6	0.1	16-Jun-11	16	6.8	8.1	16-Jul-11	18.4	11.4	4.8
17-May-11	16.3	11.1	0.9	17-Jun-11	16.3	9.1	1.8	17-Jul-11	15.3	10.9	0.4
18-May-11	15.2	6.9	6.9	18-Jun-11	16.8	8.2	4.5	18-Jul-11	16.7	11.8	2
19-May-11	13.8	4.9	5.8	19-Jun-11	16.6	8	7.6	19-Jul-11	15.9	8.8	0.7
20-May-11	15.2	6.5	7.1	20-Jun-11	16.6	5.4	6.6	20-Jul-11	15.7	8.3	0.4
21-May-11	15.9	3.8	0.1	21-Jun-11	18.6	10.3	1.9	21-Jul-11	13.7	7	0
22-May-11	15	7.8	11.1	22-Jun-11	17.9	10.3	1.7	22-Jul-11	17.4	5.3	9.1
23-May-11	14.2	6.5	9.8	23-Jun-11	17.3	7.7	10.2	23-Jul-11	19.9	6.2	13.8
24-May-11	15.3	5.6	13.5	24-Jun-11	14.9	6.7	3.1	24-Jul-11	20.9	10.5	8.5
25-May-11	14.7	8.3	1.1	25-Jun-11	21.2	14.8	4.6	25-Jul-11	20.2	9.1	1.4
26-May-11	13.4	5.8	4.5	26-Jun-11	23.3	14.5	8.8	26-Jul-11	20.9	13.4	3.3
27-May-11	13.4	4.8	3.4	27-Jun-11	16.9	8.4	2.8	27-Jul-11	22.3	9.6	11
28-May-11	15.7	9.7	3.2	28-Jun-11	17.2	6.7	9.9	28-Jul-11	16.9	11.9	0.1
29-May-11	17.2	9.5	6.4	29-Jun-11	16.5	7.3	8.5	29-Jul-11	16.7	11	2.3
30-May-11	14.3	5.7	6.1	30-Jun-11	17.5	6	6.5	30-Jul-11	19.5	9.2	2.6
31-May-11	16.5	4.9	10.7					31-Jul-11	20.1	13.6	0.1
01-Aug-11	18.2	13.8	1.1	01-Sep-11	18.5	3.9	6	01-Oct-11	14.9	13.1	0
02-Aug-11	19.2	8.8	3.3	02-Sep-11	18.6	14.2	0.8	02-Oct-11	18.2	13.2	0
03-Aug-11	19.5	8.1	4.7	03-Sep-11	16.1	9.7	0.7	03-Oct-11	20.4	9.3	3
04-Aug-11	21.8	12	5.3	04-Sep-11	15.4	7.5	3	04-Oct-11	15.5	9.1	0.8
05-Aug-11	18.1	8.6	5.4	05-Sep-11	16.2	8.7	3.8	05-Oct-11	19.5	9.3	0.9
06-Aug-11	16.2	9.6	1.1	06-Sep-11	16.1	11.7	6.3	06-Oct-11	12.5	6.4	6.3
07-Aug-11	17.2	10.3	5.9	07-Sep-11	15	10.7	0.6	07-Oct-11	13.6	7.7	8.8
08-Aug-11	18.5	9.2	7.1	08-Sep-11	17.4	11.1	1.2	08-Oct-11	18.1	8.4	3.5
09-Aug-11	17.3	7.8	5.9	09-Sep-11	21.6	13.7	4.4	09-Oct-11	17.1	15.1	0
10-Aug-11	18.2	13	0.1	10-Sep-11	19.8	12.7	6	10-Oct-11	16.5	14.9	0
11-Aug-11	20.7	14.7	1.6	11-Sep-11	16.5	11.6	0.8	11-Oct-11	16.3	14.2	0
12-Aug-11	20	14.1	0.9	12-Sep-11	17.4	12	5	12-Oct-11	18.1	11.8	3.2
13-Aug-11	18.1	13.1	1.5	13-Sep-11	15.1	9.2	7.6	13-Oct-11	16.6	7.3	6
14-Aug-11	18	11	7.5	14-Sep-11	15.8	8.5	5.8	14-Oct-11	16.1	4.7	0
15-Aug-11	18.1	9.8	6.6	15-Sep-11	16.5	9.3	9.1	15-Oct-11	15.2	9.8	0
16-Aug-11	18.5	7.7	9.1	16-Sep-11	17	11.3	3.7	16-Oct-11	14.3	7.9	8.6
17-Aug-11	16.7	4.8	9.3	17-Sep-11	15.3	10.1	5.3	17-Oct-11	14.6	4.9	1.6
18-Aug-11	16.1	5.9	1.9	18-Sep-11	15	10.2	1	18-Oct-11	11.4	4.7	9.3
19-Aug-11	16.3	9.8	0.1	19-Sep-11	18.1	10.1	0.3	19-Oct-11	9.9	3	7.8
20-Aug-11	18.7	10.7	7.1	20-Sep-11	13.8	8.1	2.8	20-Oct-11	11	3.4	1.3
21-Aug-11	19.5	7.8	5.7	21-Sep-11	15.2	9.7	3.4	21-Oct-11	13.8	10.4	0
22-Aug-11	18.3	4.6	9	22-Sep-11	16	9.2	1.5	22-Oct-11	13	8.5	0
23-Aug-11	18.7	4.6	4	23-Sep-11	17	11.9	0.9	23-Oct-11	14.8	8.7	0
24-Aug-11	17.7	10.6	8.1	24-Sep-11	17.9	11.7	7.8	24-Oct-11	14.7	8	0
25-Aug-11	16.3	7.4	6.3	25-Sep-11	17.7	11.2	1.2	25-Oct-11	12.5	4.8	4.7
26-Aug-11	18.7	6.2	4.4	26-Sep-11	17.1	8.1	4.2	26-Oct-11	11.7	5.4	3.4
27-Aug-11	17.6	9.1	4.4	27-Sep-11	20.3	10.8	9.6	27-Oct-11	12.5	4.7	4.2
28-Aug-11	16.5	7.9	8.4	28-Sep-11	24.1	13.1	10.4	28-Oct-11	13.3	3.8	3.4
29-Aug-11	15.7	5.5	2.6	29-Sep-11	22.4	15	6.4	29-Oct-11	15.9	10.7	1.7
30-Aug-11	14.8	9.7	1.2	30-Sep-11	20	14.4	0.4	30-Oct-11	18.2	10.7	4.4
31-Aug-11	15.2	5.3	0.1					31-Oct-11	16.4	9.6	1.5

01-May-12	10.1	8	0	01-Jun-12	17.7	11	0.3	01-Jul-12	16	9.9	4.5
02-May-12	11.4	6.5	1.6	02-Jun-12	15.7	11.1	3	02-Jul-12	18.9	13.6	1.6
03-May-12	11.2	5.1	5.8	03-Jun-12	11.1	7.8	0	03-Jul-12	16.9	13	0.2
04-May-12	10.3	3.9	0.6	04-Jun-12	13.7	6.1	13.8	04-Jul-12	18.7	11.3	9.7
05-May-12	8.2	-0.6	10.7	05-Jun-12	12.2	7.1	0	05-Jul-12	19.4	9.5	6.8
06-May-12	9.2	-3	5.1	06-Jun-12	18.3	9.4	4	06-Jul-12	16.9	8.1	0
07-May-12	13.8	3.6	4	07-Jun-12	13.6	9.4	0	07-Jul-12	18.5	11.3	12.5
08-May-12	12.2	3.7	2.4	08-Jun-12	13.1	8.5	0	08-Jul-12	14	10.6	0
09-May-12	10.6	0.9	0.2	09-Jun-12	16.7	5.8	4	09-Jul-12	16.7	9.7	1.5
10-May-12	10.7	6.8	0	10-Jun-12	16.9	5.7	6.8	10-Jul-12	18.5	8.9	1.7
11-May-12	11.6	3.2	12	11-Jun-12	16.7	9.7	14.1	11-Jul-12	16.7	8.4	8.2
12-May-12	14.9	2	9.7	12-Jun-12	13.7	9	0.1	12-Jul-12	15	6.6	6.2
13-May-12	14.9	4.7	4.7	13-Jun-12	14	9.7	0.2	13-Jul-12	16.1	10.1	0.7
14-May-12	13.1	3.9	11.7	14-Jun-12	13.7	10.5	0.8	14-Jul-12	14.6	8.4	1.8
15-May-12	12.9	1.7	10.7	15-Jun-12	15.4	10.6	0.2	15-Jul-12	17.6	7.2	7.3
16-May-12	10.9	2	2.6	16-Jun-12	15.9	10	1.2	16-Jul-12	19	12.7	1.1
17-May-12	10.7	6.3	0.2	17-Jun-12	14.2	7.1	4.2	17-Jul-12	23	13.3	4.3
18-May-12	11.5	5.9	0.3	18-Jun-12	16.6	3.8	6.8	18-Jul-12	19.5	12	7.8
19-May-12	10.7	3.9	4.4	19-Jun-12	17	7.7	11.6	19-Jul-12	16.8	9.4	1.7
20-May-12	12.8	3.6	0.1	20-Jun-12	16.7	5	9.3	20-Jul-12	16.5	7	2.2
21-May-12	15.9	5.8	8.3	21-Jun-12	14.8	10.2	0.9	21-Jul-12	18.9	4.9	5.7
22-May-12	19.4	4.4	5.6	22-Jun-12	16.2	10.2	1.2	22-Jul-12	21	12.4	2.2
23-May-12	20.5	8	11.2	23-Jun-12	16.9	10.1	1.5	23-Jul-12	23.7	16.3	4.8
24-May-12	19.6	7.3	15	24-Jun-12	18.7	8.2	10	24-Jul-12	17.9	14.3	0
25-May-12	20.4	8.9	12	25-Jun-12	16.1	6.9	8	25-Jul-12	19.4	8.1	1.2
26-May-12	20.4	11.3	15.1	26-Jun-12	21.9	11.6	1	26-Jul-12	20.9	7	10
27-May-12	19.8	8.9	14.5	27-Jun-12	22.9	15	6.4	27-Jul-12	18.6	9.6	8.6
28-May-12	21	10.1	14.7	28-Jun-12	21.3	13	9.8	28-Jul-12	16.9	8.7	7.2
29-May-12	16.8	9.4	3.5	29-Jun-12	19.1	12.5	5.7	29-Jul-12	16.9	9.1	8.6
30-May-12	19.5	8.4	2.4	30-Jun-12	15.7	10.1	5.9	30-Jul-12	18.1	8.3	9.9
31-May-12	17	11.9	0	01-Sep-12	20	12.8	6.5	31-Jul-12	16.5	10.6	0
01-Aug-12	19.7	12.2	5.6	02-Sep-12	19.5	12.5	7.2	01-Oct-12	14.4	9	3.7
02-Aug-12	20.5	11.4	6.5	03-Sep-12	22.2	11.3	7.4	02-Oct-12	14.7	7.5	4.4
03-Aug-12	18.8	13	3.7	04-Sep-12	18.5	7.7	8.5	03-Oct-12	11.8	6.6	2.5
04-Aug-12	18.3	9.8	5.8	05-Sep-12	17.9	7.3	10.1	04-Oct-12	13.3	5.9	3.7
05-Aug-12	16.8	7.9	0.7	06-Sep-12	20.4	8.9	10.6	05-Oct-12	11.8	5.4	3.5
06-Aug-12	18.2	10.9	2.7	07-Sep-12	20.7	12.6	6.3	06-Oct-12	13.8	3.6	7.6
07-Aug-12	17.8	9.3	1.9	08-Sep-12	21	6.1	9.7	07-Oct-12	12.6	0.8	4.4
08-Aug-12	18.4	8.1	5.8	09-Sep-12	19.9	5.8	1.7	08-Oct-12	11.9	6.4	0
09-Aug-12	21	12	3.7	10-Sep-12	15.5	9.4	0.1	09-Oct-12	12.4	2	4.5
10-Aug-12	21.2	10	14.5	11-Sep-12	13.5	7	9.8	10-Oct-12	14	2.9	0
11-Aug-12	19.8	11.8	4.4	12-Sep-12	16.4	6.4	6	11-Oct-12	13.3	5.5	0
12-Aug-12	18.4	13.9	1.7	13-Sep-12	17.9	6	5.8	12-Oct-12	11.9	3.4	8.4
13-Aug-12	22.1	15	4.4	14-Sep-12	16.9	10.5	7.4	13-Oct-12	11.5	2.1	6.6
14-Aug-12	21.3	14.1	8.3	15-Sep-12	16.3	11.3	0.1	14-Oct-12	10.4	4.9	0
15-Aug-12	17.9	14.3	0.8	16-Sep-12	17.5	9.2	3.6	15-Oct-12	9.8	4.7	1.7
16-Aug-12	20.2	14.2	5	17-Sep-12	14.8	8.7	5.4	16-Oct-12	12.1	4.8	7.2
17-Aug-12	20.8	14.5	2.1	18-Sep-12	13.7	6.4	10.1	17-Oct-12	12.8	6.7	1.1
18-Aug-12	21.8	15.8	9.1	19-Sep-12	15.2	4.6	6.3	18-Oct-12	13.8	5	3.5
19-Aug-12	20.1	12.2	3.1	20-Sep-12	15.2	9.9	0.2	19-Oct-12	12.3	3.3	0.2
20-Aug-12	22.2	12.2	11.8	21-Sep-12	12.7	1.3	7.3	20-Oct-12	14.5	7.3	3.8
21-Aug-12	20.4	12.6	9.5	22-Sep-12	13.3	0.5	7.1	21-Oct-12	13.4	3.5	4.8
22-Aug-12	19.4	12.5	8.5	23-Sep-12	13.7	1.2	0.9	22-Oct-12	13.9	4.6	3.2
23-Aug-12	17.7	11.6	0.4	24-Sep-12	10.4	8.2	0	23-Oct-12	12.2	11	0
24-Aug-12	15.4	11.1	0	25-Sep-12	11	8.2	0	24-Oct-12	12.6	11.1	0
25-Aug-12	18.4	9.9	2.6	26-Sep-12	14.6	7.5	5.8	25-Oct-12	11.9	9	0
26-Aug-12	18.6	8.7	8.4	27-Sep-12	13.6	6.8	1.2	26-Oct-12	9	1.5	2.3
27-Aug-12	18.9	12.4	1	28-Sep-12	14.5	7.2	4.4	27-Oct-12	7.9	-0.6	7.7
28-Aug-12	17.7	10.9	6.5	29-Sep-12	14.4	5.9	6.5	28-Oct-12	8.2	5.8	0
29-Aug-12	18.6	11.3	3.6	30-Sep-12	15.7	10.2	2.1	29-Oct-12	9.8	2.6	1.6
30-Aug-12	16.7	7	9.3					30-Oct-12	9	2.3	0.4

01-Nov-11	12.8	6	7.3	01-Dec-11	6.6	1.2	1.3	01-Jan-12	10	2.7	4.2
02-Nov-11	14.1	11.9	0.1	02-Dec-11	10.3	1.4	0	02-Jan-12	6.9	1.2	5.4
03-Nov-11	14.4	9.8	0.7	03-Dec-11	9.7	5	5.2	03-Jan-12	12.2	2.8	3.1
04-Nov-11	11.9	5.3	4.2	04-Dec-11	5.5	0.7	0.1	04-Jan-12	9.8	3.2	0
05-Nov-11	9.6	0.8	7.5	05-Dec-11	4.6	0.8	4.6	05-Jan-12	10.1	4.2	3.4
06-Nov-11	12.4	-0.6	8.6	06-Dec-11	7.7	1.7	1.2	06-Jan-12	10.4	3.5	0.6
07-Nov-11	10.7	-2	8.6	07-Dec-11	6.2	3.2	6.3	07-Jan-12	8.5	5.7	1.1
08-Nov-11	11.4	10.1	0	08-Dec-11	10.9	1.5	0.4	08-Jan-12	11.2	6.8	0.3
09-Nov-11	14.2	8.3	0.9	09-Dec-11	4.7	-0.3	5.7	09-Jan-12	9.9	6.3	2.1
10-Nov-11	14.5	5.7	6.3	10-Dec-11	8.3	-0.5	0.6	10-Jan-12	11	6.6	1.4
11-Nov-11	13.7	10.8	0.8	11-Dec-11	8.1	2	0.3	11-Jan-12	11.6	9.5	0.1
12-Nov-11	13.3	7.9	4.5	12-Dec-11	10.2	2.5	1.3	12-Jan-12	10.9	1.3	3.5
13-Nov-11	15	11.3	2.1	13-Dec-11	5.9	0.4	4.1	13-Jan-12	8.2	-2.1	6.4
14-Nov-11	13.2	8.8	1.2	14-Dec-11	4.9	0.9	0.8	14-Jan-12	6.9	-3	3.4
15-Nov-11	12.4	5.7	1	15-Dec-11	4.7	-2	1.8	15-Jan-12	6.2	5	0.1
16-Nov-11	11.4	8.8	0	16-Dec-11	3.1	-2.4	1.3	16-Jan-12	7.2	2.1	4
17-Nov-11	13.9	5.7	0.3	17-Dec-11	4.3	-0.2	6.8	17-Jan-12	11.5	3.9	1.5
18-Nov-11	15.1	12.8	0.1	18-Dec-11	3.9	-0.6	4	18-Jan-12	11.6	6.9	0.4
19-Nov-11	13.1	11.6	0	19-Dec-11	9.2	3.3	1.6	19-Jan-12	8	3.7	4.5
20-Nov-11	13.2	9.7	3.4	20-Dec-11	10.6	4.6	0	20-Jan-12	11	4.3	1.3
21-Nov-11	12	5.5	0.2	21-Dec-11	11.8	10.1	0	21-Jan-12	10.6	5.4	2.1
22-Nov-11	9.5	2.1	6.7	22-Dec-11	12.8	9.3	0.5	22-Jan-12	9.4	4.8	3.9
23-Nov-11	12.9	9.2	0	23-Dec-11	11.6	1.9	2	23-Jan-12	8.2	2.6	3.8
24-Nov-11	12.9	6.8	0.1	24-Dec-11	9.8	2	0.2	24-Jan-12	11.6	5.2	0.1
25-Nov-11	8.7	5.1	2.7	25-Dec-11	13.3	9.6	0.1	25-Jan-12	11.3	1.8	0
26-Nov-11	13.5	8.4	0.1	26-Dec-11	13.1	9.4	1.7	26-Jan-12	5.6	1	3.7
27-Nov-11	13.3	3.8	6.2	27-Dec-11	10.3	7.6	0.4	27-Jan-12	6.2	0	4.1
28-Nov-11	13.7	3.8	0.6	28-Dec-11	9.2	3.4	4.9	28-Jan-12	5.6	-1.9	0.2
29-Nov-11	13.2	4	1.7	29-Dec-11	8.3	4	0.1	29-Jan-12	7.6	3.6	0
30-Nov-11	10.6	4	0.2	30-Dec-11	12	4.4	0	30-Jan-12	4.5	3.8	0
				31-Dec-11	12.8	9.6	0	31-Jan-12	4.4	2	0
01-Feb-12	4.2	-3.7	8	01-Mar-12	13.9	4.3	7.5	01-Apr-12	12	-0.8	6.8
02-Feb-12	3.8	-6	4.5	02-Mar-12	11	4.2	4.1	02-Apr-12	10	5.9	0.1
03-Feb-12	5.6	-6.1	4.8	03-Mar-12	11.1	3.7	7.3	03-Apr-12	7.3	1.3	3
04-Feb-12	8.8	1.9	0	04-Mar-12	7.5	-0.4	9.4	04-Apr-12	7.6	1	7.2
05-Feb-12	7.1	2.5	0	05-Mar-12	9.7	0.5	7.7	05-Apr-12	7.9	1.5	11.8
06-Feb-12	8.7	3.2	0.2	06-Mar-12	11.5	1.5	0	06-Apr-12	11.1	2.6	2.2
07-Feb-12	7.3	0.5	4.7	07-Mar-12	11.5	3.5	7.7	07-Apr-12	13.8	7.4	3.1
08-Feb-12	4.4	2.6	0	08-Mar-12	12.5	3.6	2.4	08-Apr-12	11.6	7.4	0.1
09-Feb-12	9.2	3.6	0	09-Mar-12	13.3	8.7	0	09-Apr-12	10.6	3.8	2.2
10-Feb-12	9.2	6.2	0	10-Mar-12	12.5	9.8	1	10-Apr-12	10.4	1.8	10.3
11-Feb-12	7.9	5.8	0	11-Mar-12	10.7	7	0.1	11-Apr-12	12.1	1.1	9.2
12-Feb-12	7.5	4.7	1.1	12-Mar-12	12.8	7.8	1	12-Apr-12	11.5	1.5	8.2
13-Feb-12	8.3	4.3	0	13-Mar-12	9	0.7	0	13-Apr-12	9.6	-0.6	6.1
14-Feb-12	8.8	5.1	1.5	14-Mar-12	10.7	-1.8	0.3	14-Apr-12	8.8	-0.5	9.4
15-Feb-12	10	6.2	0.5	15-Mar-12	11.8	6.1	1.3	15-Apr-12	8.8	-1.5	7
16-Feb-12	10.1	6.5	0.2	16-Mar-12	11.1	6.5	0	16-Apr-12	10.1	2.2	0.5
17-Feb-12	11.4	7.9	0	17-Mar-12	8.5	2.4	1.2	17-Apr-12	10.5	4.5	8.2
18-Feb-12	8.1	0.9	7	18-Mar-12	10.6	1.5	10.2	18-Apr-12	10.4	2.5	7.2
19-Feb-12	6.9	-0.2	5.4	19-Mar-12	12.1	2.4	2.3	19-Apr-12	11.6	1.6	9.1
20-Feb-12	9.1	1.8	0	20-Mar-12	12.4	7.8	1.2	20-Apr-12	12.3	3.5	6.4
21-Feb-12	12.6	8.5	2.3	21-Mar-12	10.9	2.3	0	21-Apr-12	13.6	2.8	10.6
22-Feb-12	14.1	10.2	0.2	22-Mar-12	11.3	-0.1	3	22-Apr-12	12.3	5.1	7.1
23-Feb-12	14.1	11	1.6	23-Mar-12	11.4	7.4	5.2	23-Apr-12	10.2	3.1	5.7
24-Feb-12	11.5	5.2	3.7	24-Mar-12	15.7	4.5	6.8	24-Apr-12	12.6	2	7.8
25-Feb-12	9.7	1.7	6.6	25-Mar-12	18.1	2.4	10.7	25-Apr-12	7.9	5.5	0
26-Feb-12	11.9	6.1	3	26-Mar-12	15.1	1.1	11.3	26-Apr-12	9.1	6.1	0
27-Feb-12	11.3	9.2	0	27-Mar-12	17.8	0.8	11.3	27-Apr-12	9.3	2.1	3.2
28-Feb-12	11.5	9.2	0.2	28-Mar-12	18.7	-0.7	11.1	28-Apr-12	10.5	2	9.8
29-Feb-12	12.3	8.1	7.1	29-Mar-12	17.4	2.4	6.7	29-Apr-12	7.7	4.2	0.1
				30-Mar-12	11.6	7.8	0.3	30-Apr-12	12.3	6.1	2.2
				31-Mar-12	11.8	1.8	5.2				

01-May-12	10.1	8	0	01-Jun-12	17.7	11	0.3	01-Jul-12	16	9.9	4.5
02-May-12	11.4	6.5	1.6	02-Jun-12	15.7	11.1	3	02-Jul-12	18.9	13.6	1.6
03-May-12	11.2	5.1	5.8	03-Jun-12	11.1	7.8	0	03-Jul-12	16.9	13	0.2
04-May-12	10.3	3.9	0.6	04-Jun-12	13.7	6.1	13.8	04-Jul-12	18.7	11.3	9.7
05-May-12	8.2	-0.6	10.7	05-Jun-12	12.2	7.1	0	05-Jul-12	19.4	9.5	6.8
06-May-12	9.2	-3	5.1	06-Jun-12	18.3	9.4	4	06-Jul-12	16.9	8.1	0
07-May-12	13.8	3.6	4	07-Jun-12	13.6	9.4	0	07-Jul-12	18.5	11.3	12.5
08-May-12	12.2	3.7	2.4	08-Jun-12	13.1	8.5	0	08-Jul-12	14	10.6	0
09-May-12	10.6	0.9	0.2	09-Jun-12	16.7	5.8	4	09-Jul-12	16.7	9.7	1.5
10-May-12	10.7	6.8	0	10-Jun-12	16.9	5.7	6.8	10-Jul-12	18.5	8.9	1.7
11-May-12	11.6	3.2	12	11-Jun-12	16.7	9.7	14.1	11-Jul-12	16.7	8.4	8.2
12-May-12	14.9	2	9.7	12-Jun-12	13.7	9	0.1	12-Jul-12	15	6.6	6.2
13-May-12	14.9	4.7	4.7	13-Jun-12	14	9.7	0.2	13-Jul-12	16.1	10.1	0.7
14-May-12	13.1	3.9	11.7	14-Jun-12	13.7	10.5	0.8	14-Jul-12	14.6	8.4	1.8
15-May-12	12.9	1.7	10.7	15-Jun-12	15.4	10.6	0.2	15-Jul-12	17.6	7.2	7.3
16-May-12	10.9	2	2.6	16-Jun-12	15.9	10	1.2	16-Jul-12	19	12.7	1.1
17-May-12	10.7	6.3	0.2	17-Jun-12	14.2	7.1	4.2	17-Jul-12	23	13.3	4.3
18-May-12	11.5	5.9	0.3	18-Jun-12	16.6	3.8	6.8	18-Jul-12	19.5	12	7.8
19-May-12	10.7	3.9	4.4	19-Jun-12	17	7.7	11.6	19-Jul-12	16.8	9.4	1.7
20-May-12	12.8	3.6	0.1	20-Jun-12	16.7	5	9.3	20-Jul-12	16.5	7	2.2
21-May-12	15.9	5.8	8.3	21-Jun-12	14.8	10.2	0.9	21-Jul-12	18.9	4.9	5.7
22-May-12	19.4	4.4	5.6	22-Jun-12	16.2	10.2	1.2	22-Jul-12	21	12.4	2.2
23-May-12	20.5	8	11.2	23-Jun-12	16.9	10.1	1.5	23-Jul-12	23.7	16.3	4.8
24-May-12	19.6	7.3	15	24-Jun-12	18.7	8.2	10	24-Jul-12	17.9	14.3	0
25-May-12	20.4	8.9	12	25-Jun-12	16.1	6.9	8	25-Jul-12	19.4	8.1	1.2
26-May-12	20.4	11.3	15.1	26-Jun-12	21.9	11.6	1	26-Jul-12	20.9	7	10
27-May-12	19.8	8.9	14.5	27-Jun-12	22.9	15	6.4	27-Jul-12	18.6	9.6	8.6
28-May-12	21	10.1	14.7	28-Jun-12	21.3	13	9.8	28-Jul-12	16.9	8.7	7.2
29-May-12	16.8	9.4	3.5	29-Jun-12	19.1	12.5	5.7	29-Jul-12	16.9	9.1	8.6
30-May-12	19.5	8.4	2.4	30-Jun-12	15.7	10.1	5.9	30-Jul-12	18.1	8.3	9.9
31-May-12	17	11.9	0	01-Sep-12	20	12.8	6.5	31-Jul-12	16.5	10.6	0
01-Aug-12	19.7	12.2	5.6	02-Sep-12	19.5	12.5	7.2	01-Oct-12	14.4	9	3.7
02-Aug-12	20.5	11.4	6.5	03-Sep-12	22.2	11.3	7.4	02-Oct-12	14.7	7.5	4.4
03-Aug-12	18.8	13	3.7	04-Sep-12	18.5	7.7	8.5	03-Oct-12	11.8	6.6	2.5
04-Aug-12	18.3	9.8	5.8	05-Sep-12	17.9	7.3	10.1	04-Oct-12	13.3	5.9	3.7
05-Aug-12	16.8	7.9	0.7	06-Sep-12	20.4	8.9	10.6	05-Oct-12	11.8	5.4	3.5
06-Aug-12	18.2	10.9	2.7	07-Sep-12	20.7	12.6	6.3	06-Oct-12	13.8	3.6	7.6
07-Aug-12	17.8	9.3	1.9	08-Sep-12	21	6.1	9.7	07-Oct-12	12.6	0.8	4.4
08-Aug-12	18.4	8.1	5.8	09-Sep-12	19.9	5.8	1.7	08-Oct-12	11.9	6.4	0
09-Aug-12	21	12	3.7	10-Sep-12	15.5	9.4	0.1	09-Oct-12	12.4	2	4.5
10-Aug-12	21.2	10	14.5	11-Sep-12	13.5	7	9.8	10-Oct-12	14	2.9	0
11-Aug-12	19.8	11.8	4.4	12-Sep-12	16.4	6.4	6	11-Oct-12	13.3	5.5	0
12-Aug-12	18.4	13.9	1.7	13-Sep-12	17.9	6	5.8	12-Oct-12	11.9	3.4	8.4
13-Aug-12	22.1	15	4.4	14-Sep-12	16.9	10.5	7.4	13-Oct-12	11.5	2.1	6.6
14-Aug-12	21.3	14.1	8.3	15-Sep-12	16.3	11.3	0.1	14-Oct-12	10.4	4.9	0
15-Aug-12	17.9	14.3	0.8	16-Sep-12	17.5	9.2	3.6	15-Oct-12	9.8	4.7	1.7
16-Aug-12	20.2	14.2	5	17-Sep-12	14.8	8.7	5.4	16-Oct-12	12.1	4.8	7.2
17-Aug-12	20.8	14.5	2.1	18-Sep-12	13.7	6.4	10.1	17-Oct-12	12.8	6.7	1.1
18-Aug-12	21.8	15.8	9.1	19-Sep-12	15.2	4.6	6.3	18-Oct-12	13.8	5	3.5
19-Aug-12	20.1	12.2	3.1	20-Sep-12	15.2	9.9	0.2	19-Oct-12	12.3	3.3	0.2
20-Aug-12	22.2	12.2	11.8	21-Sep-12	12.7	1.3	7.3	20-Oct-12	14.5	7.3	3.8
21-Aug-12	20.4	12.6	9.5	22-Sep-12	13.3	0.5	7.1	21-Oct-12	13.4	3.5	4.8
22-Aug-12	19.4	12.5	8.5	23-Sep-12	13.7	1.2	0.9	22-Oct-12	13.9	4.6	3.2
23-Aug-12	17.7	11.6	0.4	24-Sep-12	10.4	8.2	0	23-Oct-12	12.2	11	0
24-Aug-12	15.4	11.1	0	25-Sep-12	11	8.2	0	24-Oct-12	12.6	11.1	0
25-Aug-12	18.4	9.9	2.6	26-Sep-12	14.6	7.5	5.8	25-Oct-12	11.9	9	0
26-Aug-12	18.6	8.7	8.4	27-Sep-12	13.6	6.8	1.2	26-Oct-12	9	1.5	2.3
27-Aug-12	18.9	12.4	1	28-Sep-12	14.5	7.2	4.4	27-Oct-12	7.9	-0.6	7.7
28-Aug-12	17.7	10.9	6.5	29-Sep-12	14.4	5.9	6.5	28-Oct-12	8.2	5.8	0
29-Aug-12	18.6	11.3	3.6	30-Sep-12	15.7	10.2	2.1	29-Oct-12	9.8	2.6	1.6
30-Aug-12	16.7	7	9.3					30-Oct-12	9	2.3	0.4

01-Nov-12	7.1	0.1	5.4	01-Dec-12	5.5	-0.2	6.6	01-Jan-13	6.1	1.6	2.6
02-Nov-12	8.7	2.6	5.2	02-Dec-12	9.8	-0.4	0.2	02-Jan-13	12	5.4	0
03-Nov-12	7.6	1.2	8.4	03-Dec-12	9.8	2	5.6	03-Jan-13	12.6	10.3	0.1
04-Nov-12	8	5.2	0.1	04-Dec-12	5.9	1.6	2.7	04-Jan-13	10.7	4.4	4.3
05-Nov-12	9.4	0.3	8.2	05-Dec-12	3.9	-1.2	6.5	05-Jan-13	11.8	2.9	0.3
06-Nov-12	11.1	2.2	2.7	06-Dec-12	6.5	0	0	06-Jan-13	10.9	2.4	0
07-Nov-12	10.9	7.7	3.7	07-Dec-12	7.4	0.8	6.6	07-Jan-13	11.6	8.4	0
08-Nov-12	11	6.6	5	08-Dec-12	7.3	-0.2	1.6	08-Jan-13	12.2	1.3	2.5
09-Nov-12	10.2	5.3	0	09-Dec-12	8	-0.4	1.3	09-Jan-13	8.2	-2.6	6.7
10-Nov-12	8.2	1.9	2.3	10-Dec-12	6.1	-2.7	4.4	10-Jan-13	6.8	-2.6	0.1
11-Nov-12	9	1.5	4.3	11-Dec-12	5.5	-3.3	4.5	11-Jan-13	7.4	-1.3	1
12-Nov-12	13.6	6	0.1	12-Dec-12	6.2	0.5	0	12-Jan-13	7.4	1.1	0.2
13-Nov-12	13.6	11.8	0	13-Dec-12	5.2	-0.1	0.9	13-Jan-13	3.1	-2.4	0
14-Nov-12	13.4	7.8	1.1	14-Dec-12	8.1	4.8	0	14-Jan-13	5.7	0.8	3.3
15-Nov-12	12.9	6.2	2.9	15-Dec-12	9.1	5.3	2.3	15-Jan-13	4.2	-1	3.6
16-Nov-12	8.1	2.8	0.1	16-Dec-12	9.8	5.1	3.1	16-Jan-13	5.3	3.6	0
17-Nov-12	7.9	2.8	6.4	17-Dec-12	8.3	4.9	2.2	17-Jan-13	7.8	4.3	0.2
18-Nov-12	11.4	1	0.7	18-Dec-12	7.4	-0.3	2.3	18-Jan-13	5.1	1.4	0
19-Nov-12	14.2	9.5	1.1	19-Dec-12	9.1	6.9	0	19-Jan-13	3.7	1.2	0
20-Nov-12	13.4	6.4	5	20-Dec-12	8.3	5.9	0	20-Jan-13	2.6	1.6	0
21-Nov-12	10.7	4.1	6.3	21-Dec-12	8.5	3.7	0.2	21-Jan-13	2.6	-1.9	0
22-Nov-12	12.4	5.1	0.1	22-Dec-12	13.8	7.7	0	22-Jan-13	2	-5.3	0.4
23-Nov-12	8	2	6.5	23-Dec-12	12.9	6.6	4.8	23-Jan-13	3.9	-1.4	0.1
24-Nov-12	6	-2.4	0	24-Dec-12	9.2	5.7	0.7	24-Jan-13	5.2	1.1	0
25-Nov-12	5.9	0.2	2.2	25-Dec-12	7.3	3.4	3	25-Jan-13	8.2	4.6	0
26-Nov-12	7.4	4.2	2.1	26-Dec-12	8.9	4.4	0.6	26-Jan-13	12	2	0.4
27-Nov-12	6.8	0.2	5.2	27-Dec-12	7	3.1	4.7	27-Jan-13	11.7	2	4.5
28-Nov-12	5.6	-0.7	7.1	28-Dec-12	12.7	5.2	0	28-Jan-13	10.8	2.4	1.1
29-Nov-12	4.7	-1.2	1.4	29-Dec-12	10.1	2	1.8	29-Jan-13	13.8	6.1	0
30-Nov-12	7.7	-0.6	4.3	30-Dec-12	10.8	2	1.5	30-Jan-13	8.9	4.9	1.1
				31-Dec-12	11	2.6	1.3	31-Jan-13	9.8	4.2	4.5
01-Feb-13	6.6	0.3	1.1	01-Mar-13	8.7	-3.1	3.4	01-Apr-13	4.3	1.3	0.1
02-Feb-13	6.1	-1	7.9	02-Mar-13	6.9	-3.8	0.6	02-Apr-13	6.7	-0.3	10.1
03-Feb-13	10.3	4.2	0.2	03-Mar-13	8.6	1.4	3.6	03-Apr-13	7.2	-1.2	11.3
04-Feb-13	9.6	0.5	3.7	04-Mar-13	6.9	-1.7	2	04-Apr-13	7.6	-3.5	10.6
05-Feb-13	6.7	-0.3	2.6	05-Mar-13	8.9	-3.8	5	05-Apr-13	6.7	-3.9	4.6
06-Feb-13	6.1	-0.7	7.9	06-Mar-13	8.4	4.9	0	06-Apr-13	8.6	-5.6	11
07-Feb-13	6.9	-0.2	0	07-Mar-13	7.6	6.4	0	07-Apr-13	7.2	-2.6	0.2
08-Feb-13	7.4	3	0	08-Mar-13	8.5	6.4	0	08-Apr-13	7.8	1.3	1.7
09-Feb-13	9.4	4.5	0.2	09-Mar-13	6.9	3.8	0	09-Apr-13	7	2	2
10-Feb-13	7.2	4	0	10-Mar-13	4.9	0.6	0.4	10-Apr-13	7.9	1.5	0
11-Feb-13	4.5	2.9	0	11-Mar-13	1.9	-3.1	4.6	11-Apr-13	8.7	3.7	0.1
12-Feb-13	4.8	2.7	0	12-Mar-13	4.5	-2.6	4.6	12-Apr-13	11.3	1.6	4.6
13-Feb-13	11.9	4.7	0	13-Mar-13	7.6	-1.7	6.3	13-Apr-13	13.5	0.3	2
14-Feb-13	9.2	3.7	7.1	14-Mar-13	8.5	-2.5	3	14-Apr-13	14.3	9.1	3.1
15-Feb-13	9.8	2.2	4	15-Mar-13	9.9	-1.1	4.7	15-Apr-13	16	8.8	6.3
16-Feb-13	13	2	2.8	16-Mar-13	7.9	-3.4	5.4	16-Apr-13	14.1	7.4	10.9
17-Feb-13	9.2	5.6	3.6	17-Mar-13	4.8	0	0.2	17-Apr-13	14.9	7.5	0.8
18-Feb-13	7	4.2	6.5	18-Mar-13	6.7	0.3	0.7	18-Apr-13	11.6	4.9	6.6
19-Feb-13	7.8	-1.1	8.8	19-Mar-13	3.8	0	0.1	19-Apr-13	13.6	2.6	10.4
20-Feb-13	7.4	-1.7	4.7	20-Mar-13	6.7	-0.2	2	20-Apr-13	13.4	1.7	6.7
21-Feb-13	3.8	1.5	0.4	21-Mar-13	5.6	3.3	0.3	21-Apr-13	13.1	5.9	6.4
22-Feb-13	2.2	0.4	0	22-Mar-13	5	2.6	0	22-Apr-13	16.6	6	2
23-Feb-13	2.4	-0.2	0	23-Mar-13	3.6	1.5	0	23-Apr-13	16.1	7.6	5.7
24-Feb-13	4.6	-2.6	0.6	24-Mar-13	2.1	0.7	0	24-Apr-13	14.1	6.6	0.1
25-Feb-13	6.7	-3.3	8.8	25-Mar-13	4.8	0.7	3	25-Apr-13	12.8	3.7	6.2
26-Feb-13	6.4	-1.3	0.7	26-Mar-13	3.8	-0.3	0.7	26-Apr-13	9.8	1.8	9.2
27-Feb-13	6.7	1.8	0.8	27-Mar-13	3.3	-0.7	0.9	27-Apr-13	10.6	1.8	11.3
28-Feb-13	6.5	1.1	0.1	28-Mar-13	4.2	-1.9	1.5	28-Apr-13	12.6	4.2	2.7
				29-Mar-13	4	0.5	6.2	29-Apr-13	13.3	2.8	11.1
				30-Mar-13	5.8	0.3	5.5	30-Apr-13	11.5	0.2	7.6
				31-Mar-13	5.3	2.7	4.9				

01-May-13	14.7	1.4	7.7	01-Jun-13	15.1	4.4	4.1	01-Jul-13	17.9	9.9	2.3
02-May-13	15.4	-0.4	4.8	02-Jun-13	16.3	6	2.5	02-Jul-13	17.4	11.7	0.1
03-May-13	14	8.3	0.1	03-Jun-13	18.4	7.1	8.3	03-Jul-13	19.5	11.4	1.7
04-May-13	15.1	7	7.5	04-Jun-13	18.4	4.2	15.3	04-Jul-13	18.2	11.4	6.3
05-May-13	17.2	10.4	5	05-Jun-13	17.3	4.7	15.1	05-Jul-13	20.1	9.6	10.6
06-May-13	17	5.5	5.1	06-Jun-13	17	4.9	14.6	06-Jul-13	21.8	10.9	11.7
07-May-13	16.4	4.2	8.6	07-Jun-13	19.1	5.5	15.3	07-Jul-13	21.8	11.5	5.2
08-May-13	16.1	7.6	3.1	08-Jun-13	18.9	4.4	15.5	08-Jul-13	23.2	10.1	13.6
09-May-13	12.1	7.4	1.9	09-Jun-13	19.5	4	15.5	09-Jul-13	26.2	10	14.8
10-May-13	14.4	6.2	6.9	10-Jun-13	18.1	4.8	10.1	10-Jul-13	21.5	9.5	14.2
11-May-13	11.6	5.3	7.4	11-Jun-13	18.4	10.1	0.4	11-Jul-13	22.3	9.5	14.2
12-May-13	13.9	5.1	0.6	12-Jun-13	16.5	11.1	4	12-Jul-13	26	8.7	14.3
13-May-13	10.9	4.9	9.4	13-Jun-13	16.8	7.4	6.8	13-Jul-13	23.5	12.6	10.7
14-May-13	13.5	3.8	9.9	14-Jun-13	16.4	7.5	0.8	14-Jul-13	25.2	10.9	8.1
15-May-13	12.2	3.3	7.2	15-Jun-13	17.7	7.1	14	15-Jul-13	19.2	12.5	2.8
16-May-13	9.8	-0.4	4.8	16-Jun-13	16.9	9.9	1.6	16-Jul-13	22.2	13.6	2.4
17-May-13	12.9	-0.5	9.1	17-Jun-13	15.6	7.6	3.8	17-Jul-13	23.8	13.2	5.4
18-May-13	11	6.5	0.7	18-Jun-13	20.8	5.7	8.8	18-Jul-13	24.5	10.8	14.7
19-May-13	15.8	8.6	9.3	19-Jun-13	19.8	7.8	12.3	19-Jul-13	25.1	12	14.5
20-May-13	15.6	9.2	0.1	20-Jun-13	19.2	7.2	6.4	20-Jul-13	23.4	12.9	13.8
21-May-13	17.2	7.8	5.3	21-Jun-13	19.4	11.4	3.6	21-Jul-13	19.9	11.5	3.1
22-May-13	14.1	6	4.5	22-Jun-13	16.6	11	4.9	22-Jul-13	22.6	13.3	7
23-May-13	10.8	3.9	3.9	23-Jun-13	14.9	9	1.2	23-Jul-13	24.2	15.5	2.6
24-May-13	13.7	2.4	9.5	24-Jun-13	16.8	7.8	5.5	24-Jul-13	21.5	13.9	2.3
25-May-13	14.5	1.2	12.7	25-Jun-13	18.1	8.7	2.3	25-Jul-13	21.7	14	4.9
26-May-13	17.4	9.6	9.8	26-Jun-13	18.6	8.8	7.8	26-Jul-13	21.1	13.4	6.2
27-May-13	13.9	7.1	1.6	27-Jun-13	17.3	8	0.1	27-Jul-13	19.8	8.5	6.3
28-May-13	13.7	5.9	8.7	28-Jun-13	17.9	10.7	2.5	28-Jul-13	21.6	8.9	5.4
29-May-13	18.6	8.8	13.1	29-Jun-13	22.2	10.1	4	29-Jul-13	21	13.7	6.9
30-May-13	19.6	8	13.8	30-Jun-13	17.9	11.3	3.3	30-Jul-13	20.8	11.1	9.5
31-May-13	15.7	5	2.3					31-Jul-13	20.5	12.8	1.4