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Organomineral Fertilisers: Nitrogen Dynamics and Evaluation of Agronomic Characteristics

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Abstract. *The production of sewage-sludge in the UK is set to increase due to population growth and stringent requirements for the treatment of effluents. Recycling to agricultural land is regarded as the best practicable environmental option and currently represents the main disposal route. A novel method recently developed by United Utilities-plc, allows organomineral fertilisers to be produced by blending mineral fertilisers with biosolids thereby improving the N:P:K biosolids' ratios. Using this method, two OMFs with different N concentrations have been formulated: OMF_{10} (10%N) and OMF_{15} (15%N). The purpose of this study was to identify the effects of the use of OMFs on agricultural crops and grassland. To achieve this aim, a number of interconnected experiments using two soil types (sandy loam and clay loam), two OMFs, urea, and digested cake (3%N) as a base for comparison, have been set up. The experiments included the use of small plots (field) with winter wheat (Triticum aestivum L.), pots (greenhouse) with rye-grass (Lolium perenne L.), and an incubation experiment (laboratory). Results from the plot trial indicated that the use of OMFs produced similar ($p=0.690$) crop yields as urea (10516 and 10325 kg ha^{-1} respectively) and that the most economic rates of N (MERN) were 287, 222, and 207 kg [N] ha^{-1} for OMF_{10}, OMF_{15}, and urea respectively. The pot trial showed significant differences ($p<0.001$) in yield between the control and the treatments with respect to the fertiliser type. After three cuts, grass yield was found to increase with the N content in the fertiliser and specifically with the concentration of readily available N. Similarly, increased application rate of N and concentration of readily available N in the fertiliser were found to have a significant effect ($p<0.001$) upon the N content of harvested plant material measured on average after three cuts.*

Keywords. Organomineral fertilisers (OMF), biosolids, wheat, grassland, MERN, N-mineralisation

Introduction

The water industry is under increasing pressure resulting from rigorous legislation both at UK and EC levels, regarding the production and disposal of sewage-sludge. The UK produces approximately 1.4 million tonnes (dry solid basis) of sewage-sludge per annum (Defra, 2007*a*). This level of production is set to increase in response to population growth and stringent requirements for the treatment of effluents (Defra, 2007*b*). Recycling to agricultural land is regarded by the UK Government as 'the best practicable environmental option' and represents the main disposal route (65%) followed by incineration (20%) and landfill (< 10%) (Defra, 2007*a*). Although a cost advantage of recycling with respect to incineration and landfill has been acknowledged (Le, 2007), increasing current levels of sewage-sludge up-take by farmers is usually restricted by a number of problems, among these are spreading, transport, and handling of bulky materials. The use of sludges in agriculture has been also restricted due to their variable chemical composition (Sommers *et al.*, 1976) and the fact that the amount of N available following land application is poorly understood (Bowden and Hann, 1997). Low N:P ratios of biosolids can lead to rapid build up of soil-P increasing the risk of P losses when recommendations are carried out on the basis of plant available N. The combination of these factors determines a highly variable agronomic performance. A novel method, recently developed by United Utilities plc, allows producing organomineral fertilisers by blending mineral fertilisers (e.g. urea) with biosolids thereby improving the N:P:K ratios in the raw material. It is believed that this development would significantly contribute to address some of the problems highlighted above.

The aim of this work was to determine the effects of the use of OMFs in agriculture and to identify the most advantageous OMFs' formulations for selected crops and soil types. This paper explains the methodological approach used to fulfil the aim of this research through a series of interconnected studies conducted under controlled conditions and field-scale trials and shows preliminary results obtained during the first year of this investigation.

Methodology

Two OMFs with different N concentrations were formulated. These formulations given in % as N:P:K are: 15:4:4 (OMF_{15}) and 10:4:4 (OMF_{10}) with P and K expressed in % as P_2O_5 and K_2O respectively. The rationale behind the chosen formulations are explained in detail by Antille *et al*. (2008*a*) and a description of the physical characteristics is given by Antille *et al*. (2008*b*). The effects of the use of OMFs on selected crop and grassland are determined in two experiments: ***a.*** a plot trial (field) with winter wheat (*Triticum aestivum L.*) and ***b.*** a pot trial (greenhouse) with rye-grass (*Lolium perenne L.*). In addition, an incubation trial has been set up to determine the N release characteristics.

The purpose of these experiments was to quantify the OMFs' agronomic value and identify the most appropriate application rates strategies; this will also provide a valuable feedback on the proposed OMF's formulations. A statistical analysis was undertaken using GenStat Release 10.1 (2007) and involved analysis of variance (ANOVA) and least significant differences (LSD) to compare means. A 5% probability level was used ($p < 0.05$).

Experiment 1: Plot trial

The aim of this trial was to identify the responses of winter wheat to increasing N-application rates to be able to determine the optimum N-rate for a number of fertiliser materials. The trial was conducted at Silsoe Farm at Cranfield University at Silsoe (CU@S) on a sandy loam soil (*Cottenham series*; King, 1969). A total of 60 plots having 2 m by 5 m (**Figure 1**) were marked out in the field with N-application rates ranging from 0 (control) to 350 kg [N] ha^{-1} at regular intervals of 50 kg [N] ha^{-1}. The plots were harvested mechanically using a DF-M660 plot combine-harvester. A total of 4 different fertiliser materials were used: OMF_{15} (15% N), OMF_{10} (10% N), urea (46% N), and digested cake (3% N). Fertiliser application was carried out manually.

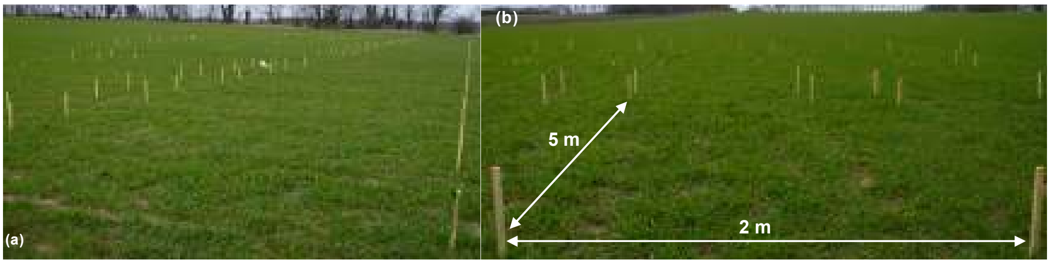

Figure 1: Overview of plot experiment in Avenue Field – CU@S **(a)**; and **(b)** close-up plot.

All treatments were replicated three times except those plots receiving 350 kg [N] ha^{-1} which were replicated only twice to allow all the plots to fit in the designated experimental area. The most economic rate of nitrogen (MERN) was calculated following the procedure proposed by James and Godwin (2003).

Experiment 2: Pot trial

The purpose of this experiment was similar to that of ***experiment 1*** but uses rye-grass which is grown in pots under controlled environmental conditions; i.e. glasshouse. Dry matter (DM) and N-concentration in oven-dried harvested plant material were determined to identify the responses of the grass to increasing rates of N application. The trial comprises two soil types, a sandy loam (*Cottenham series*; King, 1969) and a clay loam (*Holdenby series*; King, 1969). Pots of 10 litres capacity containing 8 kg of air-dried soil were used in this experiment. A layer of 25 mm of gravel was placed at the bottom to allow free drainage as shown in **Figure 2**.

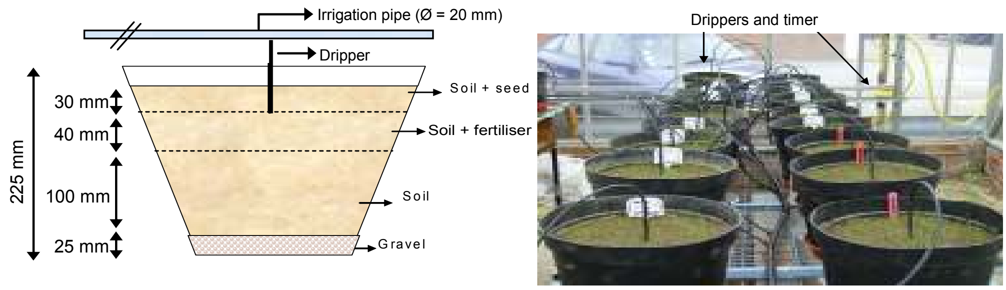

Figure 2: Diagram of a pot (left) and pots with established grass and irrigation system (right).

The experiment used the same fertiliser materials as those described for ***experiment 1*** and three level of N fertilization: 0 (control), 150, and 300 kg [N] ha^{-1} respectively. As a result of this experimental design a total of 54 pots were used. Three replicates per treatment were needed to undertake the statistical analysis. A total of three cuts were carried out throughout the growing season (April – September) without any further fertiliser application. The experiment will continue for three years and the pots will receive new fertiliser applications each year in early spring; i.e. before middle April.

Experiment 3: Incubation trial

The purpose of this experiment was to quantify the release of N from the OMF in comparison with urea and determine whether the mineralised OMF-N matched crop N requirements at any given time. This would help to develop appropriate application rates strategies and timing of application. The experiment was conducted under controlled laboratory conditions and uses the same soil types as those described for ***experiment 2***. Pots of 0.25 litres capacity were filled with 200 g of air-dried soil sieved to 2 mm, mixed with fertiliser, and wetted-up to reach field capacity. Subsequently, they were placed in an incubator and maintained at 25 degrees Celsius at around field capacity throughout the experiment. Moisture losses were regularly replenished by adding de-ionised water to the incubation pots on a mass basis as suggested by Smernik *et al.,* (2004). This experiment used the same N-rates as those indicated for ***experiment 2*** but with four replicates for each treatment. With this experimental design, a total of 20 pots for each soil type were needed. Soil samples for analysis of plant available N were taken on a monthly basis and for a period of four months.

Results and discussion

Results of soil analyses are shown in **Table 1**. Soil samples were taken before fertiliser application and soil analyses were carried out following the procedures described in MAFF (1985).

Table 1: Soil analysis.

Soil analysis (March 3rd 2007)			
Determination	**Sandy loam**	**Clay loam**	**Observations**
pH	6.96	6.6	-
SOM (%)	3.6	5.1	-
C/N ratio	11.4	10.6	-
Total-C (% w w^{-1})	1.59	1.80	-
Extractable-P (mg l^{-1})	67.2	65	[Olsen]
P-index	4	4	[MAFF, 2000]
Extractable-K (mg l^{-1})	215	334	-
K-index	2+	3	[MAFF, 2000]
Extractable-Mg (mg l^{-1})	86	97	-
Mg-index	2	2	[MAFF, 2000]
Total-N (% w w^{-1})	0.14	0.17	-
Total-P (mg kg^{-1})	1070	1326	-
Total-K (mg kg^{-1})	2173	3063	-

Experiment 1: Plot trial

Figure 3 shows the yield responses of winter wheat to applied N for 2006/7 at Silsoe Farm at CU@S. The statistical analysis revealed that there were significant differences in grain yield between the control (no fertiliser added) and the treatments ($p < 0.001$). Mean yields for the controls and the treatments were 6049 kg ha^{-1} and 10464 kg ha^{-1} respectively.

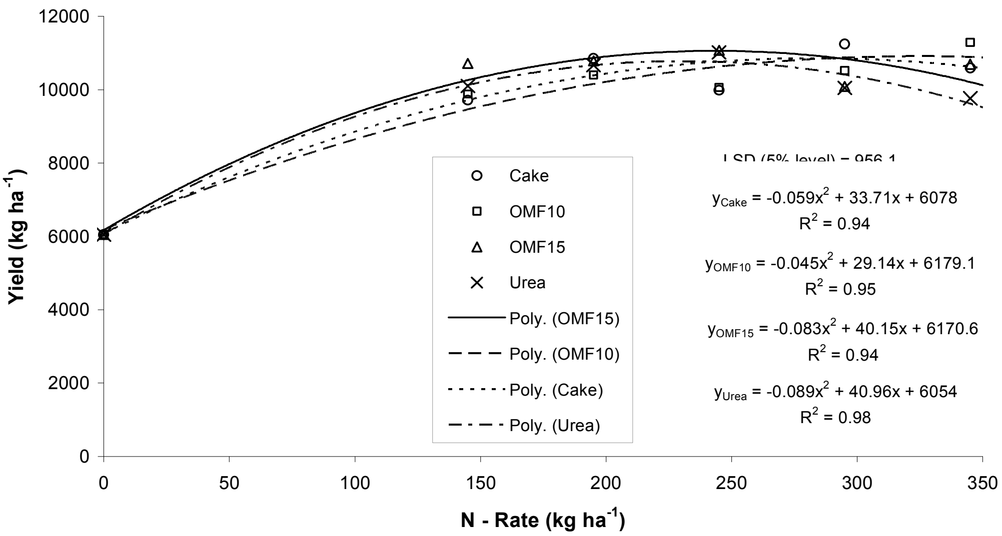

Figure 3: Yield responses to applied N for winter wheat for the crop season 2006/7 at Silsoe Farm at CU@S.

As can be seen in **Figure 3**, crop responses to increasing rates of N were statistically similar ($p = 0.614$); this means that apart from the control, all N rates produced similar yields (LSD [5% level] = 956). In addition, no significant differences were found between fertiliser types ($p = 0.690$); i.e. on average all fertilisers produced similar yields (LSD [5% level] = 939). The interaction between fertiliser type and rate showed also no significant differences ($p = 0.365$) indicating that all fertilisers produced similar responses or yields at any given rate of N (LSD [5% level] = 1434).

It is important to note that all plots, except the controls, received a base N application on March 27th 2007 at growth stage 24; i.e. main shoot and 4 tillers (Tottman and Broad, 1987), equivalent to 100 kg [N] ha^{-1} using UAN (urea-ammonium nitrate; 28-30% N). The application of OMF, cake, and urea to the plots was not carried out until May 17th 2007 with the crop at growth stage 36-37; i.e. between 6th node and flag leaf just visible (Tottman and Broad, 1987). Therefore, it may be argued that this second application of N may have only had a very small effect on yield and instead this second dressing should have been done at growth stage 30-31; i.e. early stem extension (Tottman and Broad, 1987) or approximately two weeks after the first dressing so as to have a larger effect on yield. In addition, chemical analyses of the OMFs were carried out to verify that the N content in the product was consistent with the declared N content. The chemical analysis indicated that the OMFs (OMF_{15} and OMF_{10}) were not made to specification and that both products had similar N concentrations (9.83% and 8.13% [w w^{-1}] total-N respectively). This resulted in the amount of OMF-N applied being under dosed. Thus, a decision was made to carry out a third fertiliser application to make up the balance of N. This took place on June 6th 2007 with the crop at growth stage 41; i.e. flag leaf sheath extending (Tottman and Broad, 1987). These two late applications of N might have had an effect on grain protein, particularly the third dressing; however, this statement cannot be supported as analytical data were not available at the time this report was written. The weight of 1000 grains showed no significant differences between the controls and the treatments with respect to N rate ($p = 0.125$), fertiliser type ($p = 0.194$), and the interaction between rate and fertiliser type ($p = 0.144$). The mean weights for the controls and the treatments were 46.82 and 46.77 g [1000] $grains^{-1}$ respectively with an LSD value (5% level) of 1.330. Although it is not statistically significant ($p = 0.194$), it appears that N concentration in the fertiliser had some effect upon the weight of 1000 grains with urea (46% N) producing a higher grain weight (47.18 g [1000] $grains^{-1}$) than OMF_{15} and OMF_{10} (46.38 and 46.40 g [1000] $grains^{-1}$ respectively). However, this cannot be fully supported as the cake (3% N) gave a higher value (47.10 g [1000] $grains^{-1}$) compared with the two OMFs.

Using the quadratic equations given in **Figure 3** and following the procedure described by James and Godwin (2003), the N fertiliser rate at which the maximum yield is obtained can be calculated by equating the first order differential to zero.

Given for example for the OMF_{15},

$$Y_{OMF15} = -0.083x^2 + 40.15x + 6170.6 \quad \textbf{[1]}$$

Then,

$$\frac{dy}{dx} = 40.15 - 2 * 0.083x' = 0 \quad \textbf{[2]}$$

Therefore,

$$x' = \frac{40.15}{2*0.083} = 241.8 \text{ kg [N] ha}^{-1} \quad \textbf{[3]}$$

Where,

x' = 241.8 kg [N] ha^{-1} is the N-fertiliser rate at which the maximum yield is obtained when using OMF_{15}.

Then, solving equation [**1**] to find the correspondent yield at this level of N-fertilisation it gives 11026 kg [grain] ha^{-1} which is the maximum crop yield obtained with OMF_{15}. The most economic rate of N (MERN) can be calculated when equation [**2**] is equated to the price ratio (R_p) (James and Godwin, 2003). R_p is defined as the price of N-fertiliser (P_n) in £ t^{-1} divided by the price of the crop (P_c) in £ t^{-1} (Kachanoski *et al.*, 1996) as shown in equation [**4**].

Thus,

$$40.15 - 2*0.083x' = Rp = \frac{Pn}{Pc} \quad \textbf{[4]}$$

Where,

Rp is the price ratio,

Pn is price of the N-fertiliser, and

Pc is the price of the crop.

Then,

$$MERN = \frac{40.15 - Rp}{2*0.083} \quad \textbf{[5]}$$

Where,

MERN is the most economic rate of N

The total-N contained in the OMF is made up of biosolid-N and urea-N which are 20% and 80% for the OMF_{15} and 30% and 70% for the OMF_{10} respectively. Taking for instance the OMF_{15}, 100 kg of product would provide the equivalent to 12 kg of urea-N and 3 kg of biosolid-N.

As biosolids are normally given free of charge to farmers, it can be assumed that the biosolid-N is free and therefore the price of 15 kg of OMF-N are equivalent to the price of 12 kg of urea-N; i.e. a farmer would have to pay for the OMF-N only 80% of the price of urea-N. Taking a price of urea-N of 0.70 £ kg^{-1} or 320 £ t^{-1} of urea (46% N), then the price of OMF-N can be inferred (0.70 £ kg^{-1} [N] *x* 80% = 0.56 £ kg^{-1} [OMF-N]). Given this assumption and taking a price of wheat of 170 £ t^{-1}, the price ratio (R_p) can now be calculated by solving equation [**4**] which gives an R_p of 3.29. Solving equation [**5**], the MERN for the OMF_{15} can be calculated as follow:

$$MERN = \frac{40.15 - 3.29}{2 * 0.083} \qquad [\mathbf{6}]$$

$$MERN = 222 \text{ kg [N] ha}^{-1}$$

The price ratio (R_p) is simply the break even ratio (B/E) and indicates the extra return of the produce that just covers the extra unit of N added. At this point, the economic return from the applied N is maximised. Lower N rates than MERN would result in economic losses whereas higher rates would provide the opportunity for N-losses; e.g. N-leaching, as above this point the efficiency of N up-take starts falling. If the B/E ratio increased, for example as a result of increased fertiliser price, then the MERN would be lower to allow the same rate of economic return from the fertiliser. The same exercise can be done for any fertiliser material as long as the response curve and the cost of applied N are known. The calculated MERNs for urea and OMF_{10} were 207 and 287 kg [N] ha^{-1} respectively. From this, it can be stated that without significantly compromising crop yield, when the readily available N content in the fertiliser increases, the MERN decreases. This could have environmental implications as smaller N-inputs are required therefore reducing the scope for N-losses. However, in the long term, continuous use of OMFs may result in build-up of soil organic-N. This N, providing mineralises relatively fast during the crop growing season, can potentially reduce the reliance on mineral-N fertilisers which are going up in price.

Experiment 2: Pot trial

Figure 4 shows yield responses of rye grass to applied-N and N concentration in harvested plant material. A total of three cuts were carried out throughout the growing season (April to September 2007). For the first cut, significant differences in grass yield were observed between the controls and the treatments in both soils types ($p = 0.001$). In addition, significant differences were found for each soil type ($p < 0.001$) with the clay loam producing consistently higher yields than the sandy loam (mean values of 3070 and 2581 kg [DM] ha^{-1} respectively and LSD (5% level) = 84.6). This may be attributable to higher mineralization of soil organic N due to higher level of soil organic matter (SOM) as shown in **Table 1**. The effect of the soil alone is shown when comparing the yields produced by the controls (1804 and 907 kg [DM] ha^{-1} for the clay loam and the sandy loam respectively). There were also significant differences between the control and the treatments with respect to N application rates ($p < 0.001$) and fertiliser type ($p < 0.001$). Yield increases were obtained when N application rates were increased from 150 to 300 kg [N] ha^{-1} and also when the fertiliser applied had a higher N content. For both soil types, both OMF_{10} and OMF_{15} produced statistically similar yield responses ($p = 0.101$) although there was a clear effect of the N-fertiliser content.

The interaction between fertiliser type and N-rate for a particular soil type showed significant differences with respect to the control ($p = 0.001$). Therefore, it can be stated that the choice of a particular fertiliser will depend upon the soil type and the required rate of N as this will have a significant effect upon the yield; e.g. urea at 300 kg [N] ha^{-1} applied on the clay loam soil produced the highest yield in the first and second cuts (4414 and 4885 kg [DM] ha^{-1} respectively).

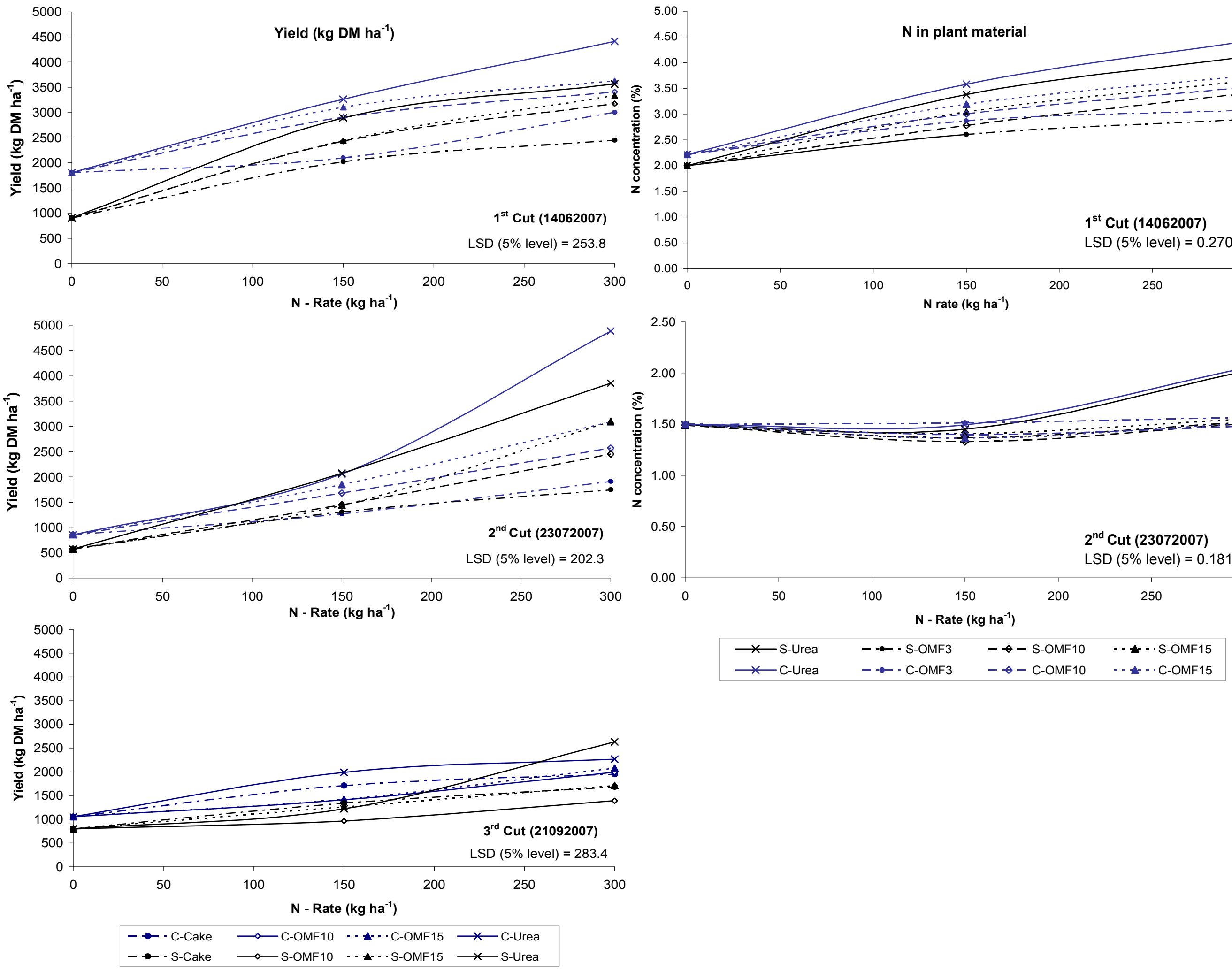

Figure 4: Yield responses to applied N in rye-grass (left) and N concentration in harvested plant material (right) in 2007. [C – clay loam; and S – sandy loam. N concentration is expressed in % (w w^{-1})].

It is important to highlight that emergence was recorded on May 6th 2007 which gives 38 days till the first cut (June 14th 2007) and there were also 38 days between the first and the second cut which was carried out on July 23rd 2007.

Between the second and the third cut (September 21st 2007) there was a longer growth period (62 days) to allow the grass to produce a reasonable amount of biomass and enable the necessary laboratory analyses to be carried out. In order to allow comparisons between the cuts, it may be assumed that the growth of the grass in the first 38 days after the second cut was linear. Therefore, the growth during this period (kg [DM] ha^{-1}) can be calculated by dividing by 62 days the total [DM] accumulated between the second and the third cuts and then multiplying this value by 38 days. Mean grass yield (kg [DM] ha^{-1}) for a 38 days period between cuts is shown in **Table 2** below.

Table 2: Mean grass production (kg [DM] ha^{-1}) for three cuts following application of OMFs and urea on two different soil types, clay loam and sandy loam assuming a period of 38 days between cuts. [LSD values (5% level) of 219.8; 176.1; and 150.4 for the first, second, and third cuts respectively].

	Mean DM (kg ha^{-1})								
Soil	**1st Cut**			**2nd Cut**			**3rd Cut**		
	OMF_{10}	**OMF_{15}**	**Urea**	**OMF_{10}**	**OMF_{15}**	**Urea**	**OMF_{10}**	**OMF_{15}**	**Urea**
Clay loam	3157	3367	3839	2126	2469	3472	1043	1074	1219
Sandy loam	2802	2891	3230	1952	2269	2964	722	912	1165

Clearly, the production of [DM] decreases markedly over time in both soil types. Although this is typical of grass production because radiation falls therefore potential crop yield, a larger decrease in [DM] in the third cut compared with the other two cuts may be indicating that the majority of the readily available N is taken up by the grass in the first two cuts. A larger production of [DM] observed with urea in the third cut is primarily due to the excess of readily available N applied as urea-N at high rate (300 kg [N] ha^{-1}); i.e. there appears to be a residual effect of urea-N when it is applied at this high rate. This [N] remains in the soil in the available form and is responsible for sustaining a significantly higher yield ($p = 0.031$) late in the season compared with the OMFs. This residual effect of mineral-N does not appear to take place with the OMF_{15} and OMF_{10} since only 80% and 70% of their total-N are, respectively, in the form of urea-N. This smaller proportion of available-N is used during the first two cuts. Therefore, after the second cut, there is less available-N left in the soil and consequently the yields drop to a lower level compared with urea (**Figure 5**). On the other hand, it may also be expected that the organic-N in the OMFs mineralises and therefore becomes progressively available over time. This is true; otherwise, the yields obtained with OMFs late in the season would be comparable to those of the controls in the third cut; i.e. 645 and 490 kg [DM] ha^{-1} for the clay loam and the sandy loam soils respectively assuming a 38 days growth period between cuts. However, these yields suggest that mineralisation rate of the organic-N fraction contained in the OMFs were not large enough to meet the crop requirement and sustain a high yield, for instance, similar to that obtained with urea.

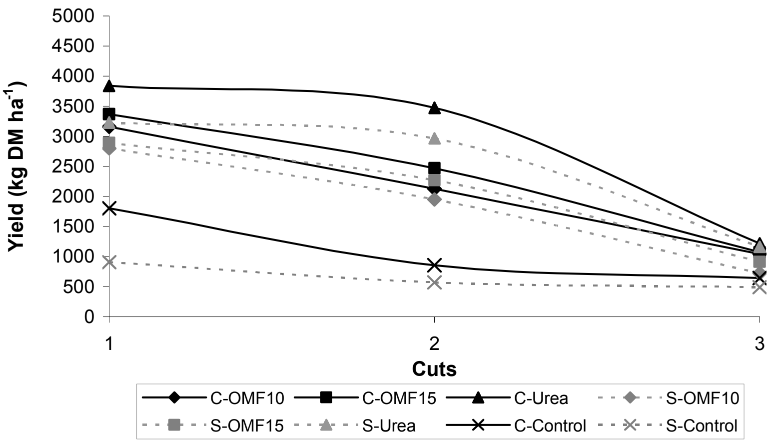

Figure 5: Comparison of [DM] production in three cuts following fertiliser application to rye-grass in two soil types (C – clay loam, and S – sandy loam) for a 38 days period between cuts. [LSD values (5%) level of 219.8, 176.1, and 150.4 for the first, second, and third cuts respectively].

As shown in **Figure 5**, the largest decrease in [DM] was observed between the second and the third cuts for urea, particularly on the clay loam, but the final yields are still higher than those of OMFs reflecting the effect of residual mineral-N. When using OMFs, the decrease observed in yields from the second to the third cuts is less marked compared with urea. Hence, mineralisation from the organic OMF-N, although low, helped to prevent the yields decreasing further. When using urea, yield was not reduced further due to the residual mineral-N in the soil especially when it was applied at a high rate. However, as this N becomes limiting results in larger decrease in [DM] and biomass production needs to rely entirely on mineralisation of soil organic-N whereas for the OMF there would be mineralisation from both the soil and the organic OMF-N. Appropiate application strategies for N would consider adjusting the N required by the crop for the period between cuts. This means splitting N-applications and specifically for the OMFs early application of OMF-N; e.g. early spring, and subsequent applications of mineral-N as and when required by the crop. This would allow enough time for mineralisation of organic OMF-N and improved efficiency of N up-take. Mineralisation of organic OMF-N needs to be accounted for when deciding N application rates as this could reduce the need for mineral N-fertilisers especially in late applications.

The analysis of N concentration in harvested plant material (**Figure 4**) for the first cut revealed that there were significant differences between the control and the treatments ($p < 0.001$). In addition, there were significant differences between the control and the treatments with respect to fertiliser rate ($p < 0.001$) and with respect to fertiliser type ($p < 0.001$). The concentration of N in harvested plant material increased with the N rate and also increased with the concentration of plant available N in the fertiliser product. The same effects were observed in the second cut although in this case the differences are mainly due to the effect of urea applied at the highest N rate (300 kg [N] ha^{-1}). Mean values of N concentration obtained with cake, OMF_{10}, and OMF_{15} (1.512; 1.415; and 1.458 [N] % w w^{-1} respectively) were statistically similar for an LSD value (5% level) of 0.1106 whereas for urea this value was 1.721 [N] % w w^{-1}. This means that N concentration in harvested plant material in the second cut was significantly influenced ($p < 0.001$) by the interaction between N-rate and fertiliser type. These results appear to be consistent with those reported for grass yield; when urea is used at the highest N-rate there is a larger amount of plant available N in the soil that is used to produce a higher yield without compromising the N content in the plant.

This was not observed when using OMFs possibly because the readily available N in the soil was mostly taken-up up until the first cut and mineralisation of organic OMF-N was not sufficient to maintain a high N concentration in the plant for instance compared with that of urea in later cuts. Analysis of soil mineral N (SMN) before the cuts would be needed to support this statement.

Experiment 3: Incubation trial

Overall, N-mineralisation in the clay loam soil was significantly higher than the sandy loam soil ($p = 0.001$) which may be attributable to higher level of soil organic matter (SOM) as shown earlier in **Table 1**. Significant differences in total oxides of N (TON) were found between the control soil (no fertiliser added) and the treatments ($p < 0.001$), and also between the two N application rates ($p < 0.001$). When N application rate was increased from 150 to 300 kg [N] ha^{-1}, TON increased on average from 120.2 to 205.2 mg kg^{-1} [soil] (LSD value [5% level] = 15.9). In addition, during the four months incubation trial urea amended soils produced a significantly larger ($p = 0.005$) amount of TON than those amended with OMF_{15}. Mean values of TON were 68.2, 152.6, and 172.9 mg kg^{-1} [soil] (LSD value [5% level] = 15.9) for the control, and OMF_{15} and urea amended soils respectively.

TON in fertilised soils were found to increase progressively during the first three months of the experiment followed by a decrease in the level of TON in the forth month after fertiliser application. The same was observed in the control soil were the level of TON in the soil decreased between the third and the forth month after the start of the experiment (**Figure 6**). The largest increase in TON following fertiliser application was found to occur during the first month; however, this may be attributed to the effect of NH_4^+-N from urea being rapidly converted to NO_3^--N under the prevailing experimental conditions.

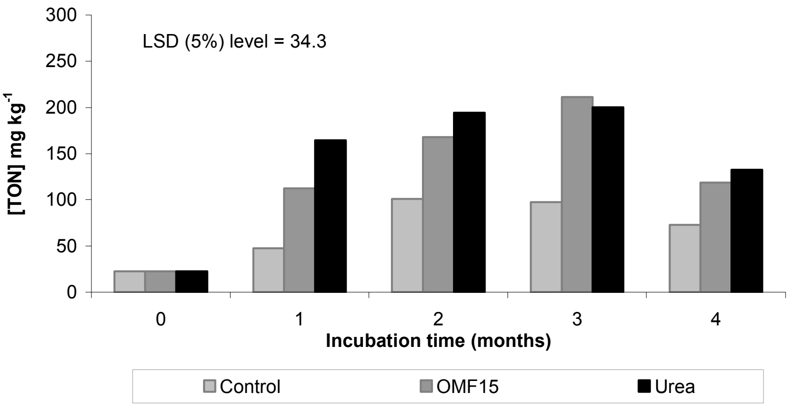

Figure 6: Mean TON (mg kg^{-1} [soil]) produced during the four months incubation trial following application of OMF_{15} and urea to the soil, and the control with no fertiliser added. [Month 0 corresponds to the start of the experiment and indicates the initial level of TON in the soil].

The decrease in the level of TON in the soil observed in month four may be due to N-immobilisation and/or gaseous losses. Significant losses by denitrification may be difficult to justify as anaerobic conditions were avoided.

Rowell (1994) suggested that losses of N by denitrification are minimised when the soil is maintained at 60% of field capacity. The fact that the soil was maintained in the proximity of field capacity may have provided the opportunity for this process to take place when the amount of NO_3^--N in the soil accumulated above a certain level. Immobilization may have also occurred resulting in lower amounts of TON being determined in the forth month compared with the previous months. However, these statements cannot be supported at this stage of the research. Further work is currently being carried out to explain these observations. The amounts of TON (mg kg^{-1} [soil]) produced during the four months incubation trial for all the treatments and the two soil types used in this experiment are shown in **Figure 7** below.

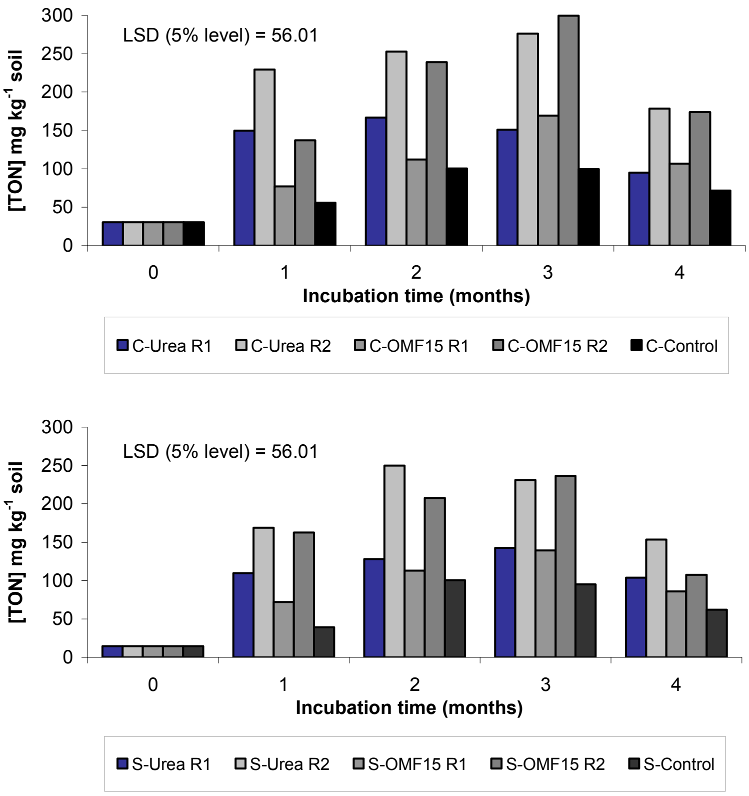

Figure 7: TON (mg kg^{-1} [soil]) produced during the four months incubation trial following application of OMF_{15} and urea, and the control (no fertiliser added) for the two N-rates (R1: 150 kg [N] ha^{-1} and R2: 300 kg [N] ha^{-1}) and soil types (Top: C – clay loam, and bottom: S – sandy loam) used in the experiment. [Month 0 corresponds to the start of the experiment and indicates the initial level of TON in the soil].

It is interesting to note that urea releases the majority of its N approximately between one to two months before the OMF_{15} on both soil types. This has practical implications: it may be advisable to carry out early applications of OMF-N in the spring to allow enough time for mineralisation of organic OMF-N. Crop requirement for N may be subsequently adjusted using an N-fertiliser with a higher content of readily available N; e.g. urea or ammonium nitrate.

Mineralisation of organic OMF-N throughout the season may also help to reduce the need for mineral-N fertilisers later in the season. The information presented in **Figures 6** and **7** appears to be consistent with that shown for the pot experiment with grass. Faster N-release from urea compared with OMF_{15} resulted in the first two cuts producing significantly higher grass yields when using urea compared with OMF_{15}. However, in the fourth month, TON measured in urea amended soils were similar to those of OMF_{15}; i.e. 140.6 and 136.7 mg kg^{-1} [soil] and 128.7 and 96.7 mg kg^{-1} [soil] for the clay loam and the sandy loam soils respectively (LSD value [5%] = 48.5). Similar values of TON; i.e. plant available-N, late in the season helps to explain why grass yields were also more similar in the third cut.

Conclusions

The main conclusions coming from this research are highlighted below:

1. The application of digested cake, OMFs, and urea to winter wheat resulted in significantly different crop responses with respect to the control (no fertiliser added). However, crop yield and weight of 1000 grains were not significantly affected by fertiliser type, N application rate, or the interaction between them. These results may be influenced by an early application of UAN at a rate of 100 kg [N] ha^{-1} to all plots. Therefore, more research is needed to identify crop responses following OMF application only.
2. The calculated MERNs (most economic rate of N) were found to decrease when the concentration of N in the fertiliser increases, and particularly, when the concentration of readily available N increases. The calculated MERNs were 207, 222, and 287 kg [N] ha^{-1} for urea, OMF_{15}, and OMF_{10} respectively. Therefore, using a more concentrated fertiliser material may help to reduce N inputs in the short term. However, in the long term, continuous application of OMFs may result in increased soil organic-N which may lead to a reduction in the reliance on mineral-N fertilisers providing N-mineralisation from the soil is significant during the crop growing season.
3. The application of digested cake, OMFs and urea to rye grass resulted in significantly higher grass production (kg [DM] ha^{-1}) with respect to the control (no fertiliser added). Overall, DM production and N concentration in harvested plant material were significantly affected by fertiliser type, N application rate, and the interaction between them. Increased N application rate and increased concentration of readily available N in the fertiliser resulted in significantly higher DM and N content in harvested plant material.
4. Application of urea-N at high rate (300 kg [N] ha^{-1}) resulted in residual mineral-N which is thought to be responsible for sustaining a marginally higher grass yield in the third cut compared to OMFs when used at the same N-rate. However, mineralisation of organic OMF-N between the second and the third cuts contributed to significantly reduce the differences in grass yield between urea and OMFs amended soils late in the season.
5. TON increased progressively during the first three months following fertiliser application and decreased in the fourth month after the start of the experiment. Further research is needed to clarify whether mineral-N undergoes immobilisation or whether gaseous losses or both take place.
6. Faster N release from urea compared with OMFs results in significantly larger amounts of plant available N which results in enhanced N up-take and increased grass yield as observed for the first two cuts in the pot experiment.

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