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Soil and crop responses following application of biosolids-derived organomineral fertilisers to ryegrass (Lolium perenne L.) grown in pots

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Abstract. *Biosolids-derived organomineral fertilisers (OMF) were produced using a novel technique reported in earlier studies. This technique enables addition of N and potash to biosolids granules to form a balanced NPK fertiliser. Two fertiliser products; OMF_{10} (10:4:4) and OMF_{15} (15:4:4), were formulated and tested in a glasshouse facility on pot-grown ryegrass in comparison with urea and biosolids granules at N application rates ranging from 0 to 300 kg ha^{-1}. The aim of this research was to contribute to the understanding of nutrients management and dynamics in grass crops fertilised with OMF. The study focused upon dry matter yield (DMY) and crop responses to applied fertiliser, nitrogen use efficiency (NUE) and fertilisers' effect on soil fertility. Results indicated that ryegrass responds linearly to application of OMF increasing DMY by about 2% to 27% compared with biosolids but to a lesser extent than urea (range: 17% to 55%). NUE was related to the concentration of readily available N in the fertiliser; urea and OMF showed significantly greater ($P<0.05$) N recoveries than biosolids (26% to 75%, and 19% to 29%, respectively). Total nitrogen in soil and SOM increased ($P<0.05$) depending on the concentration of organic-N in the fertiliser applied. DMY was lower but more sustained overtime in biosolids-treated pots. OMF application did not result in significant changes in soil extractable-P levels whereas for urea, it decreased significantly while it showed a significant increase in biosolids-treated pots, where soil-P Index changed from 5 to 6. In OMF-treated soil, soil P Index remained close to constant overtime thereby supporting the purpose of the formulations tested.*

Keywords. Biosolids granules, Dry matter yield, Organomineral fertilisers (OMF), Ryegrass, Soil nutrient dynamics, Soil P Index.

Introduction

This paper summarises the work reported by the authors in Antille et al. (2014a), which supports findings from previous studies (Antille et al., 2012, 2014b-c) conducted at the laboratory-scale. In England and Wales, the disposal of sewage sludge (biosolids) follows a number of routes which include, most importantly, recycling to farmland (72%), incineration (18%), land reclamation and restoration (6%), and landfill (1%) with a total production (dry solids basis) estimated at 1.6 million tonnes per year (DEFRA, 2011). This is set to increase in response to population growth, the adoption of cleaner technology for the treatment of effluents and stringent legislation which restricts the opportunities for disposal. In most circumstances, the disposal route to farmland is the least expensive available option, and it is widely accepted in Europe that recycling of organic materials, including biosolids, to land is the best practicable environmental practice (Edge, 1999). Recycling aims to complete the natural nutrients and carbon cycles (Taylor et al., 2009) while it mitigates the demand for finite resources such as rock phosphate (Weikard and Seyhan, 2009). A novel technique was employed to produce of organomineral fertilisers (OMF) from biosolids granules, which adds additional nitrogen and potash to the biosolids' nutrients to form a balanced NPK fertiliser (Antille, 2011; Antille et al., 2013). This new product concept would appear to be a sustainable approach to recycling biosolids to land; it has the potential to contribute significantly to overcome some of the problems commonly faced by land managers with regards to the use of organic materials in crop production; e.g. nutrients availability, concentration, fertiliser value, handling and storage, and, to some extent, issues associated with their field-spreading. The proposed technique was used to produce two OMF formulations; namely, 15:4:4 (OMF_{15}) and 10:4:4 (OMF_{10}) (Antille, 2011; Antille et al., 2013). The aim of the work reported in this paper was to provide a better understanding of nutrients management and dynamics when OMF are applied in grass crops. The specific objectives of this work were to investigate dry matter yield and responses of rye grass (*Lolium perenne* L.) to the application of OMF in comparison with urea (46% N) and biosolids granules (range 4.0% to 5.5% N) under semi-controlled environmental conditions in a glasshouse. The effects of continuous application of OMF, urea, and biosolids granules on the fertility status of the soil were quantified to monitor changes (build-up or run-down) in total soil N and soil extractable P. It was hypothesised that the OMF formulation, when applied at the rates used in this study, should not induce significant changes soil-P index.

Materials and Methods

The studies were conducted in a glasshouse facility between 2007 and 2009; two different soil types were used: a sandy loam (67% sand, 13% clay, 20% silt), and a clay loam (46% sand, 25% clay, 29% silt) classified as Arenosol and Cambisol, respectively. The experiment used pots of 10 litres capacity filled with 8 kg of air-dried soil previously ground to pass a 2 mm sieve. The fertilisers were mixed with the soil during the preparation of the pots to conform a layer of 50 mm beneath the rye grass seeds (*Lolium perenne* L.) to avoid their direct contact with the fertiliser. The seeds were spread on the soil surface at a rate equivalent to 4 g m^{-2}. A drip irrigation system was installed and irrigation was adjusted to prevent water leaching. The following experimental design was used: two soil types (sandy loam and clay loam), four fertiliser materials (biosolids granules, OMF_{10}, OMF_{15} and urea), and two N-application rates (150 and 300 kg [N] ha^{-1}). A completely randomised design was used; all treatments were replicated three times and there were three control pots (zero-fertiliser) for each soil type. In 2008 and 2009, the fertilisers were surface-applied by hand at a single dressing. A total of three cuts were performed annually throughout the main growing season (April-October). The soils were sampled prior to the start of the experiment to determine the baseline level. Routine analyses on both crop and soil were conducted thereafter by means of standard laboratory techniques (MAFF, 1986) for determination of total N in soil, soil mineral N, soil extractable-P, soil pH, SOM, total above-the-ground biomass, total-N and total-P in harvested plant material. The grass was cut at 20 mm above the soil surface and the harvested plant material was subsequently oven-dried for determination of total above-the-ground biomass, which is reported as dry matter yield expressed in kg [DM] ha^{-1}. Nitrogen use efficiency (NUE) was estimated by means of the apparent recovery of applied N, that is, the difference in N uptake between fertilised and unfertilised (control) crops divided by the N application rate (Baligar et al., 2001). The statistical analyses included ANOVA, the least significant differences to compare the means using a 5% probability level ($LSD_{[5\% \text{ level}]}$), and repeated measurement of analysis of variance (used to compare annual yield data as well as that of individual cuts both within- and between-years). The same technique was applied to the data corresponding to the measured soil properties. Grass responses to N-fertiliser application were investigated using generalised linear models. The analyses were conducted using the statistical package GenStat 10.1 (2007).

Results and Discussion

Dry matter yield

Figure 1 shows the mean values of DM yield obtained between 2007 and 2009 for unfertilised control pots and the treatments on the two soil types. In 2007, the fertilisers were incorporated during the preparation of the pots whereas in the following two years the fertilisers were surface-applied. It was of interest to determine if there was a residual effect of the fertiliser applied in previous years by comparing DM yield in the first cut in subsequent years, prior to the fertiliser dressing. The differences in DM yield between treatments, as recorded in the first cuts in 2008 and 2009, were not significant ($P>0.05$). Therefore, a distinctive residual effect of the fertiliser type on DM yield could not be observed up to the first cut. The regression analyses conducted indicated that increments in DM yield for every additional unit of N added (kg [DM] ha^{-1} per kg of additional N) were in the range of 7 to 12 (biosolids), 8 to 16 (OMF_{10}), 8 to 20 (OMF_{15}) and 6.5 to 26 (urea), depending on soil type and year. These increments, as well as differences observed between treatments, were smaller in years two and three of the experiment compared with the year of establishment; possibly due to surface-application of fertiliser. In the first year (2007), DM yield was consistently higher in clay loam soil compared with sandy loam soil (by about 1000 kg ha^{-1} – field equivalent) whereas in the second and third years, DMY was similar ($P>0.05$) in both soil types (5800 and 5100 kg [DM] ha^{-1} for 2008 and 2009, respectively).

When comparing controls versus treatments, the sandy loam soil showed a higher overall increase in DMY (from 2278 to 6495 kg [DM] ha^{-1}) than the clay loam soil (from 3713 to 7390 kg [DM] ha^{-1}), which reflected a higher response to the fertiliser applied in the former soil. This enhanced response was expected given the lower overall fertility status compared with the clay loam soil. Significant differences in DM yield were also found with respect to fertiliser type, N application rate and the interaction N-rate × fertiliser type (P-values <0.001). In 2007, on average over the entire experiment, OMF_{10} and OMF_{15} increased DM yield by about 12% and 27%, respectively, compared with biosolids whereas urea increased DM yield by about 55%. In 2007, DM yield was found to increase with the concentration of N in the fertiliser applied, particularly, the concentration of readily available N in the fertiliser. These observations help explain the significant interaction fertiliser type × N-rate indicated above.

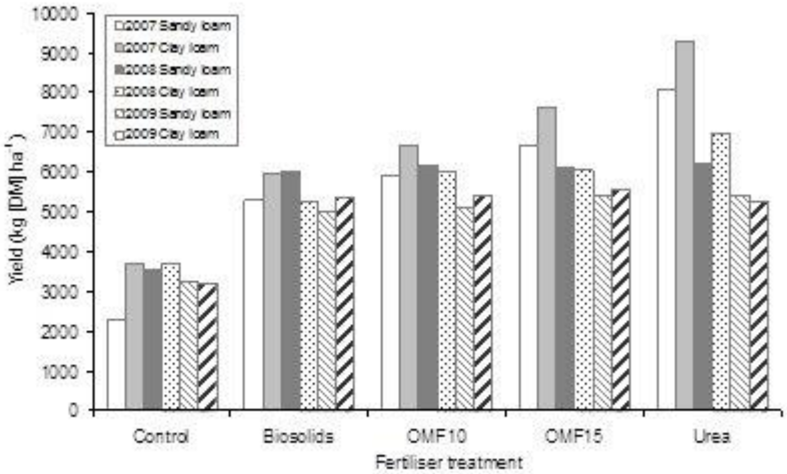

Figure 1: Mean dry matter yield of rye grass (field equivalent) in controls (zero-fertiliser) and treatments obtained in sandy loam and clay loam soils between 2007 and 2009 for the two N rates used (n=6, except controls n=3). ***2007***: LSD-values [5% level]: 361 (min. rep.), 312 (max-min. rep.), 255 (max. rep.); P-value: 0.02. ***2008***: LSD-values [5% level]: 908 (min. rep.), 786 (max-min. rep.), 642 (max. rep.); P-value: 0.02. ***2009***: LSD-values [5% level]: 753 (min. rep.), 652 (max-min. rep.), 532 (max. rep.); P-value: 0.57.

In 2008, there was no soil type effect (P=0.82) on DM yield. However, there was a significant difference (P<0.001) in DM yield between unfertilised controls and treatments where the application of fertiliser increased DM yield by about 2500 kg ha^{-1} (field equivalent) compared with controls. Overall, in 2008, significant differences in DM yield were found with respect to fertiliser type (P=0.002) and N-application rate (P<0.001) but the interaction between the two factors was nonsignificant (P=0.14). Differences in DM yield encountered as a result of fertiliser type were observed in both soils (P=0.02) but this effect was mainly due to the use of urea on the clay loam soil at 150 kg [N] ha^{-1}, which showed a relatively improved performance compared with the other fertilisers materials. On average, the use of OMF$_{10}$ and OMF$_{15}$ in 2008 increased DM yield by about 8%, respectively, compared with biosolids granules whereas for urea this increase was about 17%. These differences in DM yield were substantially smaller than those obtained in 2007 for all treatments. Similarly, in 2009, differences in DM yield between soil types were nonsignificant (P=0.32) but there was an overall effect of treatments compared with controls (P<0.001). There was, as expected, a significant effect of the N-rate on grass yield (P<0.001), which was not observed for the fertiliser type (P=0.41). There was a progressive decline in DM yield overtime (*c*.15% year on year), across the entire experiment. This could be due to a relatively small reduction in the plants' population in the pots, which was noticed in the periphery of the pots and in the proximity of the inner wall (˜20 mm). The repeated measurement analysis of variance indicated that there were significant differences (P<0.001) in DM yield with respect to fertiliser type, and the same was observed when factoring in the time (P=0.045). There was an overall decline in the production of DM overtime and the differences encountered between fertiliser types became progressively smaller from the start of the experiment. In 2009, all fertiliser treatments exhibited similar DM yield levels (mean values across the whole experiment were in the range of 5178 to 5483 kg [DM] ha^{-1}; LSD$_{[5\% \text{ level}]}$ =367). In biosolids-treated pots, however, DM yield remained relatively stable ranging from 5613 to 5178 kg [DM] ha^{-1} between 2007 and 2009.

Nitrogen in plant material

Total N in plant (TN_{plant}) was significantly lower (P=0.01) in control compared with treated-pots (mean values of TN_{plant} were 1.81% and 2.04% [w w^{-1}] for control and treatments, respectively, $LSD_{[5\% \text{ level}]}$ =0.06). There were effects (P<0.001) of fertiliser type, N-application rate, and the interaction between the two factors. Total N in plant increased with increasing concentration of readily available N in the fertiliser applied; biosolids showed consistently lower TN_{plant} levels than the other fertilisers materials. OMF_{10} and OMF_{15} resulted in intermediate levels of TN_{plant} between biosolids and urea (mean values of TN_{plant} were 1.97%, 2.01% and 2.15% [w w^{-1}] for biosolids, OMF_{10} and OMF_{15}, and urea, respectively, $LSD_{[5\% \text{ level}]}$ =0.06). The effect of the interaction between the N-rate and the fertiliser type was due to high TN_{plant} in urea-treated grass at 300 kg [N] ha^{-1}. The differences recorded between OMF_{10} and OMF_{15} were, on average, nonsignificant over the range of N application rates and soil types (mean values of 2.01% [w w^{-1}]; $LSD_{[5\% \text{ level}]}$ =0.05). Both OMF products resulted in significantly higher levels of TN_{plant} than biosolids at the two N-rates used (mean value for biosolids was 1.97% [w w^{-1}]). The fertiliser type also showed a significant effect (P<0.001) with respect to controls when factoring in the time; this implied that the various fertiliser types used resulted in different N concentrations in plant at different times of the year, which explains differences in the ability of the fertiliser to release N.

Nitrogen uptake

In 2007, significant differences in total N uptake (TN_{uptake}) were found between the two soil types, the control and the treatments, fertiliser types, N-application rates, and the interaction between fertiliser type and N-rate (P-values <0.001). With respect to fertiliser type, N uptake was related to the concentration of available N in the fertiliser. In both soil types, urea-treated grass showed the highest N uptake (232 kg [N] ha^{-1} – mean value of TN_{uptake} for the two soil types). The values of TN_{uptake} obtained for OMF_{10} and OMF_{15} ranged from 148 to 170 kg [N] ha^{-1} (mean value for the two soil types) which were, approximately, 20% to 40% higher than that of the biosolids-treated grass respectively. With regards to the N-application rate, regression analyses conducted for 2007's data showed that TN_{uptake} was significantly correlated (P<0.001) with the level of N-fertilisation and the effect was observed in all fertiliser treatments. The slope of the regression line was steeper in urea-treated grass compared with the rest of the treatments. Total N uptake was significantly higher (by about 12% to 15%) in OMF_{15} compared with OMF_{10} despite of the small difference in their N contents. Similarly, in 2008, significant differences in TN_{uptake} were found between control and treatments (P<0.001), fertiliser types (P=0.017) and N application rates (P<0.001). Both OMF products showed, on average, intermediate levels of TN_{uptake} (range: from 110 to 135 kg [N] ha^{-1}) between biosolids (range: 97 to 128 kg [N] ha^{-1}) and urea (range: 126 to 140 kg [N] ha^{-1}). TN_{uptake} by the crop increased markedly shortly after fertiliser application. The majority of the N was taken up between the date of fertiliser application and the subsequent cut. However, for biosolids, N uptake between the second and third cuts represented a larger proportion of total uptake compared with the other fertiliser treatments. It is suggested that the release of N from the biosolids required more time; hence, it progressed to a further extent into the season compared with the other fertilisers. The percentage of the TN_{uptake} taken up in the 3rd cut represented, on average, 18.3% for biosolids (range: 12.9 to 23.6%), 14.5% for OMF_{10} (range: 12.5 to 16.4%), and 12.9% for OMF_{15} and urea (range: 10.5 to 15.3%). In 2008, N uptake recorded for all treatments up to the 1st cut (including controls) was approximately the same (range: 36 to 43 kg [N] ha^{-1}). Regression analyses indicated that the expected increment in TN_{uptake} for every additional unit of N-applied (kg [TN_{uptake}] kg^{-1}) is higher in the products carrying a larger proportion of readily available nitrogen in its composition, ranging from 0.24 to 0.82 (urea), 0.20 to 0.48 (OMF_{10} and OMF_{15}), and 0.21 to 0.28 (biosolids granules).

Nitrogen use efficiency

Nitrogen use efficiency (NUE), determined as apparent recovery of applied N, was higher (P=0.007) in sandy loam compared with clay loam soils (mean N recoveries were 38.7% and 35.5%, respectively; $LSD_{[5\% \text{ level}]}$ =2.23), which suggests relatively larger soil mineral N (SMN) supply in the latter soil. There were significant differences in N recovery with respect to fertiliser type, which were observed in both soil types (P-values <0.05). Overall, there was no N-rate or N-rate × fertiliser type effects (P-values >0.05) on N recovery. Differences in N recovery recorded between-years were significant (P<0.001); mean values encountered in 2007 and 2008 were 49% and 25.2%, respectively. Overall, OMF reported intermediate levels of N recoveries (mean values in the range of 33.4% to 37.4%) between those encountered for biosolids- and urea-treated grass (mean values of 24.5% and 53.2%, respectively; $LSD_{[5\% \text{ level}]}$ =3.16). The relatively lower recoveries observed in 2008 compared with 2007 are due to the surface application of fertiliser in the second year of the experiment, and N losses due to volatilization of ammonia from urea-containing fertilisers under the prevailing experimental conditions; in urea-treated pots N recovery decreased from about 75% in 2007 to 31% in 2008 whereas for biosolids-treated pots the decrease was from about 29% in 2007 to 20% in 2008. N recovery in OMF-treated grass decreased from about 41% to 26% for OMF_{10}, and from about 51% to 25% for OMF_{15} in 2007 and 2008, respectively. Nitrogen recovery decreased proportionally to the N application rate and the content of urea-N in the fertiliser.

Soil analyses

Total soil nitrogen

Overall, total N in soil (TN_{soil}) levels were significantly higher (P<0.001) in clay loam compared with sandy loam soils, which was observed across all fertiliser treatments (mean values of TN_{soil} were 0.21% and 0.17%, [w w^{-1}] for clay loam and sandy loam soils, respectively). There were significant differences in TN_{soil} between control and treatments (P=0.001), and with respect to the fertiliser type used (P<0.001), which was observed in both soil types (P=0.02). Differences with respect to N-application rate were nonsignificant (P=0.46) but there was an effect fertiliser type × N application rate (P=0.02) on TN_{soil}. In addition, significant changes (increases) in TN_{soil} were observed overtime (P<0.001), which were also encountered with respect to the fertiliser type used (P<0.001). At the end of the experiment, the pots amended with biosolids, OMF_{10} and OMF_{15} reported approximately the same TN_{soil} levels (range: 0.20% to 0.22% [w w^{-1}]), which were statistically higher than that recorded for urea (<0.18% [w w^{-1}]) for an $LSD_{[5\% \text{ level}]}$ value <0.01. Similar TN_{soil} levels recorded in the final year of the experiment helps explain the small differences in DM yield encountered in 2009 between treatments, which suggests similar N mineralisation rates from these treatments. C:N ratios were not affected by fertiliser type (P=0.75); however, pots treated with OMF_{10} and OMF_{15} reported intermediate TN_{soil} levels between urea and biosolids.

Soil mineral nitrogen

Values of soil mineral N (SMN) recorded throughout the experiment were consistently very low (=2.4 and =1.6 mg [N] kg^{-1} for clay loam and sandy loam soils, respectively, field equivalent: =5.9 and =4.3 kg [N] ha^{-1}, respectively); except at the start of the experiment (field equivalent: 57.8 and 35.2 kg [N] ha^{-1} for clay loam and sandy loam soils, respectively). Differences recorded between control and treatments, and with respect to fertiliser type were not significant (P-values >0.05, respectively). There was, however, a significant N application rate effect (P=0.02), which was observed in the treatments that received a field equivalent rate of 300 kg [N] ha^{-1}.

Soil extractable phosphorus

There was a small increase (P=0.01) in soil extractable-P levels overtime, from an initial value of 77.7 to 79.3 mg [P] kg^{-1} at the end of the experiment, which was observed in both soil types (P=0.01). There were no significant differences between control and treatments (P=0.74) in none of the two soil types (P=0.18) but there was a significant fertiliser type effect (P<0.001), which was due to the increase recorded in soil extractable-P levels in biosolids-treated pots and to a small decrease in urea-treated pots (mean values were 78.8, 83.4, and 75.3 mg [P] kg^{-1} for controls, biosolids- and urea-treated pots, respectively; $LSD_{[5\% level]}$ =2.34). The fertiliser type effect was also significant when factoring in the time (P<0.001); i.e. changes recorded in biosolids- and urea-treated pots were significant with respect to initial values recorded at the start of the experiment. The changes recorded in soil extractable-P levels were of similar magnitude in both soil types. A small increase in soil extractable P levels was recorded for control soils (from 99.1 to 102 mg [P] l^{-1}), which induced a change in soil-P index in unfertilized control soils from 5 to 6 (MAFF, 2000), possibly due to reduced P uptake in the absence of N fertilisation.

Application of OMF_{10}, OMF_{15}, and urea did not induce significant changes in soil-P index but they were all significantly different from the value encountered in biosolids-treated pots. The decrease in soil extractable-P observed in urea-treated pots was not sufficient to modify P-index.

Soil organic matter

Soil organic matter (SOM) increased significantly at the end of the three year's trial from 4.4% to 5.2% on average. Overall, there were significant effects of fertiliser type and N application rate (P-values <0.001) on SOM. SOM increased by approximately 3.2% and 5.9% for the treatments fertilised with 150 and 300 kg [N] ha^{-1}, respectively, at the end of the three years' trial compared with initial levels recorded in 2007. The largest increase in SOM was recorded in pots treated with biosolids (7%) compared with urea and OMF, which showed increases in SOM between 2.3% to 4.8%, respectively. The fertiliser type on SOM effect was similar in both soil types (P>0.05).

Summary

Grass responded linearly to application of biosolids, OMF_{10}, OMF_{15} and urea in the range of N rates used in this study (0 to 300 kg [N] ha^{-1}). Application of OMF increased DM yield by about 2% to 27% compared with biosolids but differences between the two fertiliser materials became progressively smaller as a result of: (1) surface application of fertiliser and possible losses of N by volatilisation of ammonia from the fraction carrying urea, (2) enhanced SMN supply in biosolids-treated pots that resulted from build-up of total soil N, and (3) timing of the fertiliser application in relation to the maximum growth rate of grass. Nitrogen use efficiency was related to the concentration of readily available-N in the fertiliser; urea and OMF showed consistently higher N recoveries than biosolids granules (range: 26% to 75%, and 19% to 29%, respectively). Total N in soil showed a slight build-up, which was also related to the concentration of organic-N in the fertiliser (biosolids>OMF>urea). This effect, and the recorded increase in SOM, supports the fact that DM yield was more sustained overtime in biosolids-treated pots compared with the other fertiliser treatments. Application of OMF to the soil in the pots did not induce a significant change in soil extractable-P levels whereas in urea-treated soil, it decreased significantly while it showed a significant increase in biosolids-treated soil. In the soil treated with biosolids, soil-P index changed (+1 level); whereas the changes recorded in urea-treated pots were not sufficient to modify the index despite the significant decrease recorded in soil-P levels. In OMF-treated soil, soil P index remained close to constant overtime; hence, supporting the purpose of the proposed formulations. The use of OMF in grass crops appears to be a sustainable approach to recycling biosolids to agricultural land.

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