Trolove, S., Wijeyekoon, S. and Tan,Y., 2019. Effect of temperature on the rate of nitrogen release from a controlled release fertiliser. In *Nutrient loss mitigations for compliance in agriculture.* (Eds. L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html Occasional Report No. 32. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

EFFECT OF TEMPERATURE ON THE RATE OF NITROGEN RELEASE FROM A CONTROLLED RELEASE FERTILISER

Stephen Trolove[1], Suren Wijeyekoon[2], Yong Tan[1]

[1] The New Zealand Institute for Plant and Food Research Ltd, Private Bag 1401, Havelock North 4157, New Zealand
[2] Scion, Private Bag 3020, Rotorua 3046, New Zealand
Email: Stephen.Trolove@plantandfood.co.nz

Abstract

Large applications of highly soluble nitrogen (N) fertilisers to crops can increase the risk of nitrate (NO_3) leaching, which results in the pollution of waterways. The use of controlled release N fertilisers may better match crop demands for N and reduce the risk of NO_3 leaching. However, one of the reasons why growers are reluctant to use controlled release fertilisers (CRFs) is that the timing of nutrient release has often been difficult for growers to predict. Websites often contain insufficient information for growers to estimate N release rates, and published papers contain complicated mathematical models that are not easy to use. This paper describes a soil incubation trial and a pot trial to determine the rate of N release from a CRF.

For the incubation trial, Smartfert® (a commercially available CRF) and urea treatments were applied to a low-N subsoil at 75 kg N/ha with an unfertilised treatment as a control. The fertilisers were incubated at three temperatures: 10, 20 and 25°C, at 80% of field capacity for 105 days. Soil mineral N concentrations were measured at regular intervals. A separate pot trial was conducted at 20±1°C using the same soil and fertiliser rate as the incubation study. One treatment was fertilised with Smartfert and there was an unfertilised control. Perennial ryegrass was used as the test crop. There were three harvests at 31, 61 and 91 days after fertiliser addition.

The rate of release of N from the CRF (measured as mineral N in the soil) was 4% of the N applied every 100 degree days for the first 1800 degree days. This accounted for three quarters of the N applied. By 2100 degree days the incubation trial showed a slowing in N release rate. There was good agreement between the N release rate measured in the incubation trial and in the ryegrass pot trial.

Introduction

Large applications of highly soluble nitrogen (N) fertilisers to crops can increase the risk of nitrate (NO_3) leaching, which results in the pollution of waterways. The use of controlled release fertilisers (CRFs) to better match crop demands for N may reduce this risk. Controlled release fertilisers may also reduce N fertiliser application costs, enabling fewer larger applications of N fertiliser as opposed to the strategy of many smaller applications of soluble fertiliser to reduce N leaching risk. Controlled release fertilisers also have the advantage of being able to provide N to crops for later in the season from a single application at the start of

the season, whereas soluble N fertilisers may be difficult to apply later in the season for various reasons, e.g. the crop is too tall or the canopy has spread and would be damaged by vehicles.

There are a number of CRF products on the market. One of the key reasons given by growers for their reluctance to use a CRF as a N source is that they find it difficult to predict the rate of N release from these fertilisers. Smartfert® is a polymer-coated urea CRF, which, according to the manufacturers, releases N in response to only one factor – soil temperature, and therefore releases nutrient at a more predictable rate. Many websites mention that the rate of nutrient release from CRFs is affected by temperature, but no specific information is provided on what proportion of N is released at a given temperature. Mathematical relationships of nutrient release rates, based on first order kinetics and requiring the fitting of three or more parameters, have been described in the scientific literature (e.g. Ishibashi et al. 1992; Fujinuma et al. 2009), but these are unlikely to be used by growers. There is a need for data to describe the relationship between N release and temperature, and to investigate whether a simple relationship may be found that would be easy for growers to use. This paper provides data that describes the rate of N release following the application of Smartfert under a range of temperatures.

Materials and Methods

Soil

The soil used for the incubation trial was an Ohakune silt loam subsoil. The soil was leached with 840 mm of water to remove existing NO_3, as indicated by the low value in Table 1.

Table 1. Characteristics of the Ohakune subsoil used for the experiment. The pH was measured in water. Mineral nitrate (NO_3^-) and ammonium (NH_4^+) were extracted in 2 M KCl, Olsen P in 0.5 M $NaHCO_3$ (Blakemore et al. 1987). Mineralisable N was determined after a 7-day anaerobic incubation (Sparling & Searle 1993). Total N and C were determined by dry combustion (Skjemstad & Baldock 2008).

pH_{H2O}	NO_3^- (mg N kg^{-1})	NH_4^+ (mg N kg^{-1})	Mineralisable N (mg kg^{-1})	Total N (%)	Total C (%)	C:N	Olsen P (mg L^{-1})
5.7	4.0	2.6	21	0.26	3.3	13.1	2

Incubation experiment

The incubation experiment had a two factor design with three replicates. There were three fertiliser treatments – CRF (Smartfert), urea and an unfertilised control. Each fertiliser treatment was incubated at three temperatures: 10, 20 and 25 °C.

One kg of air-dried Ohakune silt loam soil was weighed into a 2 L plastic container and 150 mg of N fertiliser added (equates to 75 kg N/ha mixed into the top 5.5 cm of soil). The soil was also fertilised with 3.1 g superphosphate and 0.9 g of potassium chloride per pot to maintain consistency with the pot trial (see below). Water was added to bring the soil water content to 0.36 g water/g dry of oven dry soil, which equated to 80% of field capacity. The soil was thoroughly mixed and then a lid (not air tight) was pressed on to reduce water loss.

The fertilised soil was incubated at each of the three treatment temperatures (see above). The containers were weighed every 7–10 days and any water lost replaced with deionised water.

Soil samples were taken at 7, 21, 42, 63, 84 and 105 days after fertiliser addition (105 days is a common time-span for a crop growth cycle). At sampling, the soil was thoroughly mixed then a 20-g sample of field moist soil shaken with 200 mL of 2 M KCl to extract mineral N (NH_4 and NO_3) according to the method of Blakemore et al. (1987) and analysed by spectroscopy. Note: the CRF was extracted in duplicate, because there was expected to be more variation in soil N content around larger granules. Total soil N in each treatment was measured at each harvest.

Pot trial

A pot trial was undertaken in a climate-controlled growth room to assess the rate of release of fertiliser N to plants. Perennial ryegrass (*Lolium perenne* L. 'Nui') was grown in the same Ohakune Silt Loam subsoil used for the incubation study. Plants were grown indoors at 20±1°C under LED growth lights to avoid N leaching losses from rainfall, and to avoid the extremes of heat found in pots in a glasshouse over summer. The design used was modified from the method of Stanford & DeMent (1957) for assessing plant-available nutrients over short time periods.

The pot trial consisted of two phases:

Phase 1 was the plant establishment phase, where a sward of perennial ryegrass was grown for 30 days with minimal N to develop a mat of roots.

Phase 2 was the fertiliser evaluation phase, where the root mat established in Phase 1 was placed on top of soil treated with the fertiliser to be tested. The roots quickly spread through the soil, taking up plant-available nutrients. The pot trial was designed so that there was sufficient plant growth within each 30–day time period to take up any N released.

Treatments

There were two treatments – CRF (Smartfert) and a no fertiliser control, each replicated four times This gave 2 treatments × 4 replicates × 3 time periods plus 4 at time zero, which was a total of 28 pots.

Pot trial detail

Phase 1

Perennial ryegrass (*Lolium perenne* L. 'Nui') seeds (5 g/pot) were sown in a saucer filled with Ohakune silt loam subsoil. After 11 days the ryegrass had formed a mat of roots at the base of the saucer.

Phase 2

The ryegrass with the mat of developed roots was placed on top of a 2.5-L pot containing Ohakune silt loam subsoil treated with the fertiliser to be tested. The soil was fertilised with 3.1 g superphosphate and 0.9 g of potassium chloride per pot to ensure that the only nutrient limiting growth was N. The amount of N fertiliser was 150 mg N/pot (150 mg N/kg), which was sufficient to supply maximum growth of ryegrass for 30 days, if all the N were immediately plant-available. The fertiliser was placed in the top 5.5 cm of soil. Pots were watered by weight

three times per week using deionised water to 80% of field capacity. The pots were placed in saucers to ensure no N was leached from the bottom of the pots.

At intervals of 31, 61 and 91 days, the pots were destructively harvested for determination of plant dry weight and tissue N content. One-third of the pots were destructively harvested at each time period; soil was collected for total N, NH_4 and NO_3 analysis. Soil was washed from the roots and total plant N (shoot plus root) was determined by dry combustion (Leco Corporation 2005). After each 30-day period the remaining pots (i.e. those for the 61- and 91-day harvests) were harvested to a grazing height of 3.5 cm above the soil surface and the biomass stored for later analysis. An additional 0.3 g of P per pot as monocalcium phosphate was added during the second growth period to ensure there was no P deficiency arising from the high phosphate fixation capacity of this soil. An additional 0.17 g of S per pot as magnesium sulphate was also added during the second growth period.

Calculations and statistics

Fertiliser N taken up by plants during each time period was calculated by subtracting N uptake from the previous time period as well as N taken up by plants in the Control (no fertiliser) treatment over that time period (to account for N released from the soil). The amount of plant-available N released from the different fertilisers was compared with mineral N release data from the soil incubation study, to see whether a soil incubation gives a true indication of the rate of release of N in the presence of plants.

The linear regression function in Excel was used to fit a linear relationship between the percentage of N released and growing degree days. The number of growing degrees accumulated per day was calculated as the (maximum + minimum temperature/2) - base temperature. The base temperature was set at zero, so the number of growing degrees accumulated per day equated to daily average temperature. Analysis of variance was conducted using Genstat® (VSN International 2015) to identify differences between treatments in the pot trial.

Results

Incubation trial

Urea was completely converted to mineral N within the first 7 days of incubation (Figure 1). Note that the mean percentage of urea mineral N measured was greater than 100% in the first 7 days as a result of sampling variation with high amounts of mineral N being measured where a granule had recently dissolved and the mineral N had not yet diffused through the soil. The percentage of mineral N measured in the CRF treatment steadily increased up to an average of 62% over the 105-day incubation period (Figure 1). The release of N (measured as mineral N) from the CRF increased as temperature increased (Figure 2).

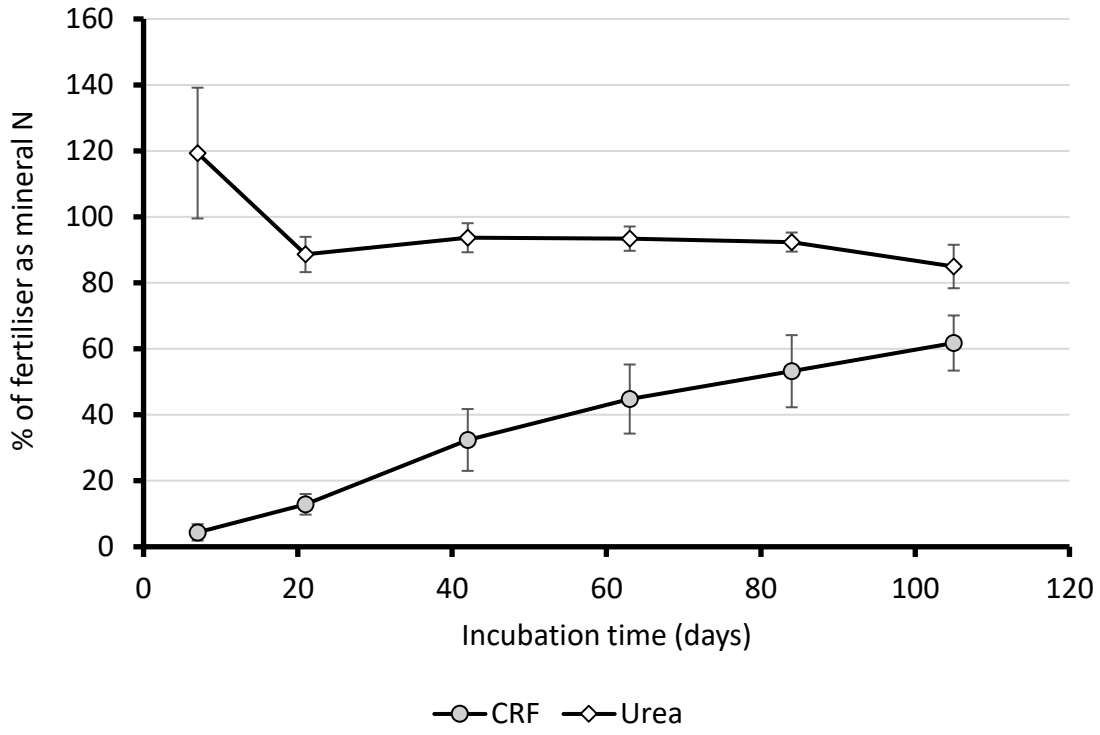

Figure 1. Proportion of fertiliser converted to mineral N (NO3-N + NH4-N) during the incubation. Data are averaged across temperature. Bars are mean ±SE, n=3.

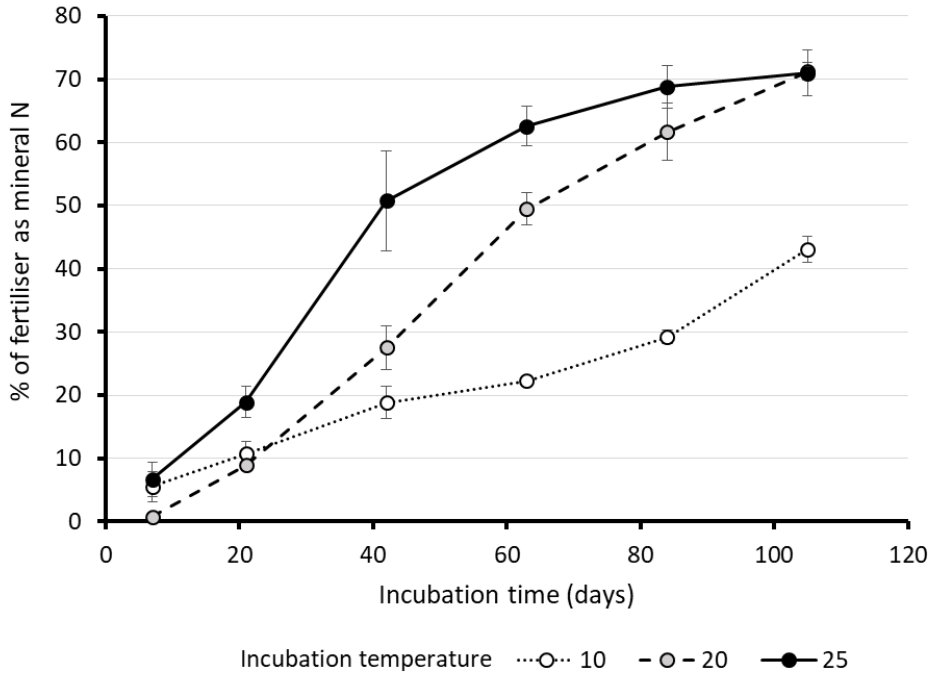

Figure 2. Effect of incubation temperature (°C) on the proportion of fertiliser converted to mineral N (NO_3-N + NH_4-N) during the incubation for the CRF treatment. There was no effect of temperature for the urea treatment. Bars are mean ±SE, n=3.

Pot trial

Dry matter production

In the first 31 days after fertiliser addition, ryegrass fertilised with CRF produced a similar amount of DM to ryegrass grown without fertiliser. In the second 30-day period after fertiliser addition, there was some evidence (p=0.059) that ryegrass fertilised with CRF produced more DM than unfertilised ryegrass, with differences being highly significant (p<0.001) by the third 30-day period (Figure 3). There were a significant number of dead and brown leaves, particularly in the control treatment, which increased as the plants aged, suggesting plants became extremely N deficient.

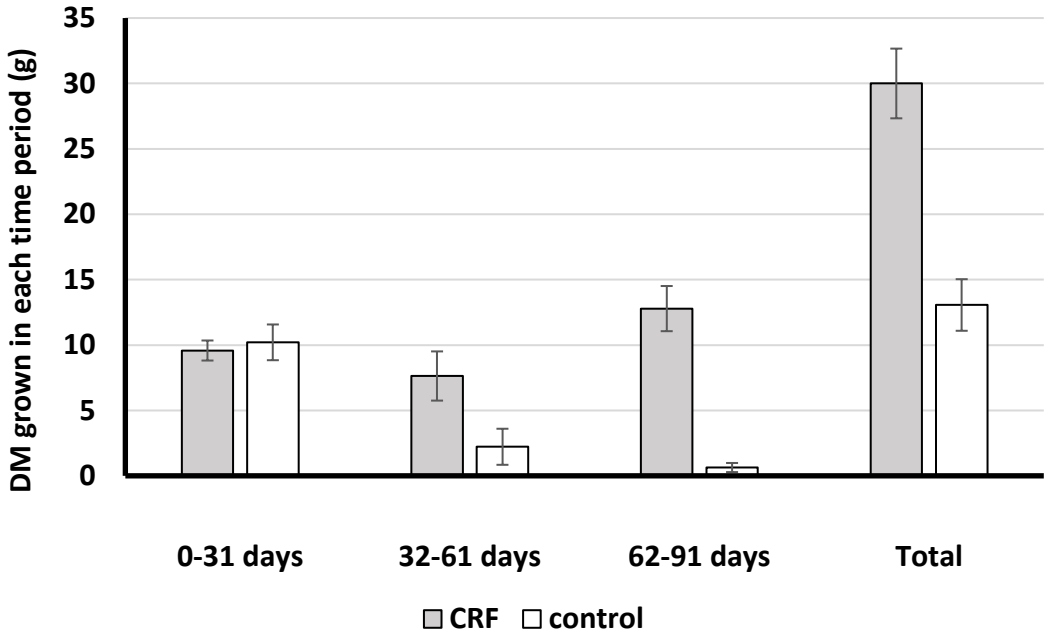

Figure 3. Ryegrass dry matter (DM) grown in each time period after fertiliser addition. Bars are mean ±SE, n=4.

Nitrogen uptake

Soil N

The concentration of NH_4 and NO_3 present in the soil was undetectable (<1 mg kg^{-1} air dry soil) at each harvest time, except for soil NH_4 concentrations at the final harvest, where low concentrations were measured (≤3 mg kg^{-1} air dry soil). There were no significant differences in total soil N among the fertiliser treatments (data not shown).

Plant N

Plant N concentrations (Table 2) were very low, and decreased with plant age. There were no significant differences in plant N concentration among treatments, although there was some evidence (p=0.067) that the N concentration in ryegrass grown with CRF was greater than that in unfertilised ryegrass at the second harvest (Table 2).

Seventy-eight percent of CRF N was taken up by ryegrass over the 91-day period. Twelve percent of added CRF N was taken up in the first harvest period, increasing to 33% for both the second and third harvest periods (Table 2).

Table 2. Total (shoot + root) N concentrations (%) at harvest for ryegrass fertilised with either CRF or no fertiliser (Control). Means are significantly different if $p<0.05$. Nitrogen fertiliser uptake from the CRF treatment (% of total applied) is also shown.

Harvest	CRF	Control	Significance (*p*)	Fertiliser N uptake (%)
31 days	0.98	0.83	0.102	12
61 days	0.81	0.64	0.067	33
91 days	0.64	0.61	0.604	33

Relationship between N release and growing degree days

A plot of N released from the CRF against growing degree days (with a base temperature of 0°C) showed a linear relationship (Figure 4). This relationship was evident for both the incubation trial and pot trial data. The rate of release of N from the CRF (measured as mineral N in the soil in the incubation trial) was 4% of the CRF N every 100 degree days for the first 1600 degree days (Figure 4). After approximately 1800 degree days the rate of release N from the CRF slowed.

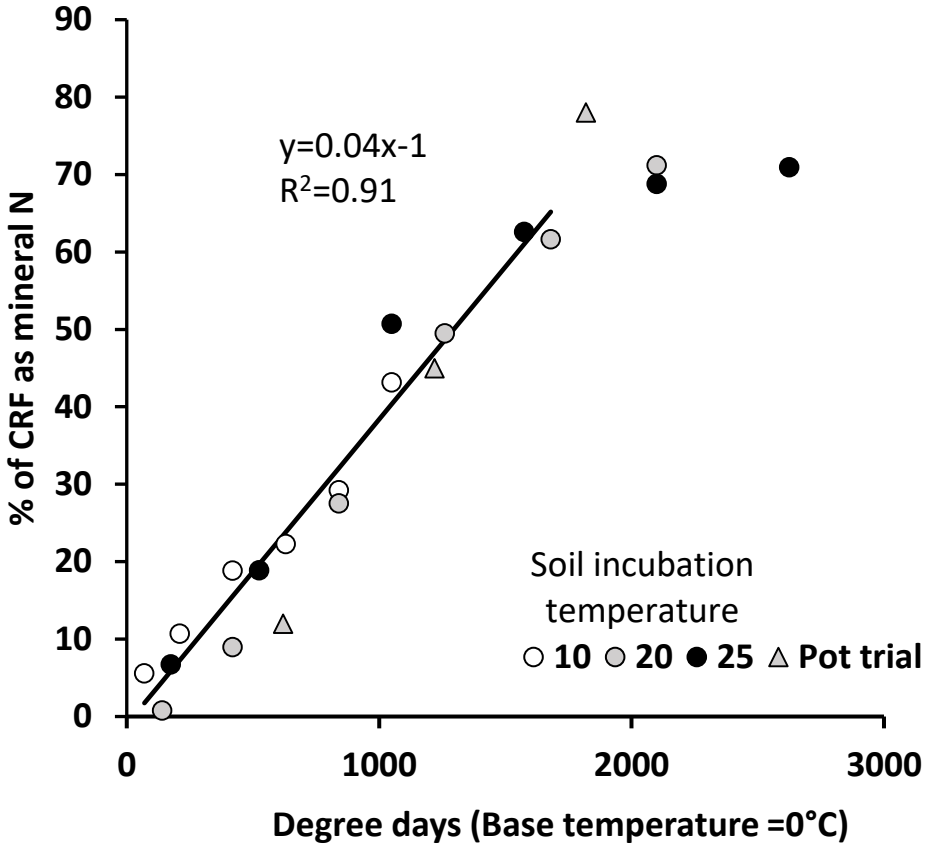

Figure 4. Relationship between the percentage of CRF measured as mineral N in the soil and growing degree days (base temperature =0°C) for the incubation trial. CRF N uptake from the pot trial is also plotted for comparison. Incubation study n=3, pot trial n=4.

Discussion

Shaviv et al. (2003) developed a model to describe the rate of release of nutrients from polymer-coated fertilisers in three phases. In the first phase, or lag phase, there is minimal N release as the fertiliser absorbs water. The second phase is linear, and accounts for approximately 80% of the fertiliser N release, and in the third phase there is a slowing or decay in nutrient release rate. Our data showed that, in the case of Smartfert, the lag phase was negligible, which has also been observed for some other CRFs (Fujinuma et al. 2009). In the second phase, N release was linear with temperature, and our data suggest that 4% of Smartfert N was released for every 100 degree days for the first 1600 degree days in the incubation trial or 1800 degree days if the pot trial data are included. In practical terms, this means that 4% of fertiliser N is released every 10 days at an average temperature of 10°C or 8% of Smartfert N is released as mineral N every 10 days at an average temperature of 20°C. This amount of N released in this phase accounted for 70% of the N fertiliser applied (or 80% if the pot trial data are included). A relationship between N release rate and growing degree days was also observed by Yang et al. (2016), who noted that 50% of N from a polymer-coated urea was released after 2000 degree days in a rice paddy.

In the third phase of the Shaviv model (Shaviv et al. 2003), the solid fertiliser has completely dissolved, the nutrient concentration inside the granule decreases and the rate of release slows. Our incubation data indicate a slowing in N release rate between 1600 and 2100 degree days.

The relationship of 4% of N released per 100 degree days observed in this study is simple to apply, provided that soil temperature data can be obtained. This relationship was observed under conditions where the fertiliser was incorporated and soil was kept moist throughout the study, which may represent many irrigated horticultural uses. The rate of N release from this CRF is likely to be lower under conditions where the fertiliser is surface applied (Sato and Morgan 2008), or if the soil moisture is below 50% (Fujinuma et al. 2009).

Conclusions

The data confirmed that N release from the CRF (Smartfert) is temperature controlled.

In our study, where adequate soil moisture was maintained and the fertiliser was incorporated into the soil, 4% of the CRF (Smartfert) N was released as mineral N (plant available N) every 100 degree days for the first 1800 degree days after application.

References

Blakemore LC, Searle PL, Daly BK. 1987. Methods for Chemical Analysis of Soils. NZ Soil Bureau Scientific Report 80. DSIR, Lower Hutt, New Zealand Pp. 103.

Fujinuma R, Balster RJ, Norman JM. 2009. An improved model of nitrogen release for surface-applied controlled-release fertilizer. Soil Science Society of America Journal 73:2043-2050

Ishibashi E, Konno T, Kimoto H. 1992 Estimation of the nitrogen liquation of coated urea by kinetic method. Japanese Journal of Soil Science and Plant Nutrition 63: 664-668

Leco Corporation 2005. Carbon Hydrogen and Nitrogen in Flour and Plant Tissue, Organic Application Note 203-821-273, Leco Corporation, MI, USA.

Sato S, Morgan KT. 2008. Nitrogen recovery and transformation from a surface or sub-surface application of controlled release-fertiliser on a sandy soil. Journal of Plant Nutrition 31, 2214-2231.

Shaviv A, Raban S, Zaidel E. 2003. Modelling controlled nutrient release from polymer coated fertilizers: diffusion release from single parameters. Environmental Science and Technology. 37: 2251-2256.

Skjemstad JO, Baldock JA 2008. 21.2 Dry Combustion Methods, Carter, M.R., Gregorich, E.G. Eds., Soil Sampling and Methods of Analysis, Second Edition, CRC Press, Boca Raton, Florida, pp. 226-230.

Sparling GP, Searle PL 1993. Dimethyl sulphoxide reduction as a sensitive indicator of microbial activity in soil: The relationship with microbial biomass and mineralization of nitrogen and sulphur. Soil Biology and Biochemistry 25, 251-256.

Stanford G, DeMent JD 1957. A method for measuring short-term nutrient absorption by plants. I. Phosphorus. Soil Science Society of America Proceedings 21: 612-617.

VSN International (2015). Genstat for Windows 18th Edition. VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk

Yang X, Wu LH, Wu SF, Chen JQ. 2016. Nitrogen release characteristic of polymer coated urea in paddy soil and its relationship with cumulative temperature. Transactions of the Chinese Society of Agricultural Engineering 32: 199-204