PAPER II

Effects of temperature on nutrient release from slow-release fertilizers. II. Emulsion-forming N and NPK fertilizers

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Key words: emulsion, nitrogen release, slow-release fertilizer, temperature

Abstract

Recent research has shown that addition of hydrophilic polymers to fertilizer solutions (gels) can control the nutrient release rates in different plant systems under various soil conditions. A micro-lysimeter experiment was conducted in a growth chamber to evaluate non commercial N and NPK emulsions (nutrient-in-oil solutions) as potential slow-release fertilizer products, similar to that reported from gel products. Weekly measurements of mineral-N in the leachates at 4, 12 and 21°C were made for a 42 day period. The NPK (8-1-6) emulsions released 79 to 93% of the applied N as mineral-N during the experimental period at the three different temperatures. These rates of release were similar to that of calcium ammonium nitrate (CAN) but somewhat higher than that measured for the urea ammonium nitrate (UAN) emulsion (57-69%) and the NPK (18-2-3) emulsion (57-85%). The N release was not affected by an increase in temperature from 4 to 21°C. For all the emulsions examined, the N release was too rapid the first two to three weeks after application in the sphagnum peat medium, suggesting that these products may not be alternatives to the slow-release fertilizers available in the market.

Introduction

In the last thirty years, many slow-release fertilizers (SRF) have been investigated under laboratory, greenhouse and field conditions for their chemistry and use in various ornamental and agricultural cropping systems (Reddy and Menary, 1989; Jarrell et al., 1983; Swanson, 1982; Hummel and Waddington, 1981; Wiedenfeld, 1980; Cox and Addiscott, 1976). The results have shown a wide variation in plant growth and yield due to differences in the nitrogen (N) release rates from the products. Granule size, type of coating, coating thickness, soil temperature, moisture content, microbial activity and pH affect the N release. In addition, Kochba et al. (1994) found significant differences in nutrient release from each individual granule in a fertilizer population. This performance makes it difficult to get an even and controlled nutrient supply to high-value crops, and environmentally sound fertilization practices. The need for improved and more efficient SRF may be of great importance for minimizing the potentially negative impacts from these fertilizers on the environment, since the SRF's generally have decreased leaching of N as compared to conventional water-soluble N carriers (Waddington, 1990; Hauck, 1985; Allen, 1984).

Hydrophilic polymers mixed with fertilizer solutions (described as gels) may control fertilizer release under various soil conditions, and are a new and interesting tool to improve the management of fertilizers (Mikkelsen, 1994; Mortvedt et al., 1992; Smith and Harrison, 1991). The use of hydrophilic polymers in controlling the release rate of certain medicines have been going on in pharmaceutical industry for several years (Ratner and Hoffman, 1976). The polymer act as a semi-permeable membrane, allowing small nutrient molecules to diffuse into soil solution more slowly (Johnson and Veltkamp, 1985). The effectness of slowed release is related to the chemistry of each polymer (Mikkelsen, 1994; Smith and Harrison, 1991).

In two experiments conducted with a sandy soil, Mikkelsen et al. (1993) found 0-45% reduction in N losses within the first four weeks of application if the polymers were added to urea ammonium nitrate (UAN) solution, compared to UAN alone. They reported that after a month, the N loss from the polymer-amended fertilizers was identical to the N lost from UAN alone. Smith and Harrison (1991) found when mixing different polymers with different N solutions, that polyacrylate retained higher N concentrations than the vinyl-alcohol polymer. In their tests most of the gels released a large portion of the N within only a few days in a loamy sand soil.

The polymer type, the viscosity as related to the polymer concentration of the gel, and the fertilizer type, can affect the N release. Mikkelsen et al. (1993) observed slightly less N loss by increasing the gel viscosity from 5000 to 15000 cpoise, while Smith and Harrison (1991) reported that urea gels showed greater loss of N than ammonium sulphate and potassium nitrate gels with increased viscosity. Only polymers containing supersaturated concentrations of potassium nitrate sustained high N concentration for up to four weeks.

Incorporation of hydrophilic polymers to nutrient solutions other than nitrogen may also be of importance. Mortvedt et al. (1992) reported that some gel-forming polymers were effective carriers of $FeSO_4$, and Mikkelsen (1995) doubled the Mn uptake by soybeans adding a polymer to $MnSO_4$ and $MnCl_2$ showing that these compounds may have significant benefits for plant growth and nutrient uptake.

The first part of this study described the nutrient release of commercial and experimental slow-release and slowly mineralized fertilizers at different temperatures (Engelsjord et al., 1997). Since gelled-fertilizer solutions have shown benefits for plant growth, it was interesting to examine other products based on similar technology. In this study, different emulsions (nutrient-in-oil solutions) have been examined for their slow-release characteristics in a sphagnum peat medium. The purpose of the experiment was to determine whether ammonium-N and nitrate-N were retained within the fertilizer solution. All the emulsions were made from materials and technology developed by Norsk Hydro, and the fertilizers tested were intended to be used for nursery plants and on lawns and sports turf.

Materials and Methods

A micro-lysimeter experiment to determine N release from different fertilizer products was conducted in a growth chamber. All the fertilizer products were prepared according to technology developed by Norsk Hydro, and they all formed viscous fertilizer mixtures (emulsions), consisting of nutrient solution in 4% white oil and 1% of an emulgator. The fertilizer solutions were included 10% of water. Polypropylene vials (volume of 300 cm^3) were placed on specially constructed stands. From the outlet opening there was a tube connected to a collecter can. The lysimeters were filled with Huminal® sphagnum peat and fertilizer solutions, and incubated at 4, 12 or 21°C. The peat medium was little to medium decomposed

(H2 to H4 on von Post's scale; Sveistrup, 1984) with a bulk density of 0.07 kg dm^{-3} and a pH value of 4.0. Prior to fertilizer incubation, the peat was limed with 2 gram dolomitic limestone per liter, similar to the practice followed in nurseries. The initial and final pHs in the peat were not measured. The emulsions were injected into the peat medium as a clump and buried beneath the peat surface to prevent rapid degradation. Both inlet and outlet openings were covered between every sampling to minimize potential N losses. All the treatments were replicated twice. The fertilizer compositions and rates are presented in Table 1.

The lysimeters were leached once a week for six weeks, starting one week after fertilizer application, by gently adding 150 ml of tap water to each micro-lysimeter. Following a complete drainage, the volumes of the leachates were measured and samples for chemical analysis were collected. The NH_4- and NO_3-N concentrations were measured using Flow Injection Analysis (Tecator Application Note, ASN 151-02/1992 and ASN 62-02/1983. Measurements of electrical conductivity of leachates (EC_w) were done with a Philips PW 9529 Conductivity Meter. The data on N release, EC_w and pH from the fertilizer treatments were statistically evaluated using an analysis of variance procedure. A Ryan-Einot-Gabriel-Welsch Multiple Range test (REGWQ) was used with a significance level of $p=0.05$ using the GLM procedure of SAS (SAS Institute Inc., 1987).

Results and Discussion

The six fertilizer solutions tested varied considerably for all the variables examined. Both nitrogen release as well as pH and electrical conductivity of the leachate were significantly different between the emulsions. Increasing the temperature from 4 to 21°C did not have any significant effect on neither the cumulative N release nor the EC_w for most of the fertilizer solutions, while the leachate pH showed significant variations. A significant decrease in the mineral-N release throughout the experiment corresponded with a decrease in the EC_w and an increase in the leachate pH.

Both calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN) emulsions showed a rapid N release (Figure 1). During the first week of study the N release was significantly lower than the following week. However, the UAN solution released significantly less N than the CAN. The major reason for this is the lower fraction of nitrate found in leachate from UAN pots, as compared to the very similar ammonium amounts measured for the two emulsions. Within 21 days 67 to 80% of the N applied was found as mineral-N in the CAN leachates, whereas 45 to 50% of the applied N was recovered in leachate from UAN lysimeters during the same period of time. The cumulative curves for both N emulsions increased slightly from 21 to 42 days after incubation, indicating minor N release within this time. The mean total mineral-N recoveries in the leachates at the end of the experiment for three different temperatures were 84% for CAN and 64% for UAN, which are similar to the total N release of 53-86% from gels reported by Mikkelsen et al. (1993).

While CAN and UAN showed the highest release rates from 7 to 21 DAI, the NPK (8-1-6) released > 47% of applied N within seven days and > 70% after 14 days (Figure 1). After 28 days the release rates dropped to < 2%, which is very similar to the release patterns reported by Smith and Harrison (1991). These authors found that most of the gels released a large portion of the N within few days, while some gels showed acceptable results up to 28 days. Totally, between 80% and 93% of the N applied as NPK (8-1-6), was recovered as mineral-N in the leachate after 42 days in the present study. Increasing the viscosity of the emulsion slightly decreased the N leaching, in contrast to gel-findings by Mikkelsen et al. (1993).

The NPK (18-2-3) emulsion showed a slow N release shortly after incubation, especially at the lowest temperature (Figure 1). Eleven percent of the N applied was collected within 21 days at 4°C, whereas the percentage increased to 57 after 42 days. Significantly higher mineral-N amounts were measured in the leachate at 12°C and 21°C. After 21 days of incubation, 42 and 77% of the N applied were recovered at 12°C and 21°C, respectively. Corresponding values after 42 days were 82 and 85%, similar to the results found for NPK (8-1-6).

Overall, the N and NPK emulsions examined in this study did not control N release as long as many slow-release carriers. Between 57 and 93% of the N applied was leached as mineral-N within 42 days. This is significantly higher than data found for typically slow-release N carriers like urea formaldehydes and sulphur coated ureas, and slow-release NPK products like Osmocote® (Engelsjord et al., 1997).

Figure 1 shows a slightly higher N release rate for NPK (8-1-6) than for NPK (18-2-3). These findings are quite different from those reported in gel-studies by Smith and Harrison (1991), showing higher release rates with increasing presence of soluble salts mixed with the polymer. The use of different emulgators more than the differences in nutrient concentrations, is likely to explain the variations in N release among the NPK emulsions tested in the present study.

One of the reasons for the overall lack of slow release, seems to be a rapid degradation of the emulsion following application to the peat medium. This is also reported in gel-studies by Mikkelsen et al. (1993) and Smith and Harrison (1991), where polymer degradation was likely to occur.

The salt concentration in the leachates varied with the N release, giving highest EC_w values shortly after fertilizer incubation (Figure 2). In the NPK (8-1-6) treated lysimeters the salt concentration varied from 8 to 12 mS at 7 DAI. The EC_w values decreased to approximately 4 mS at 14 DAI and < 2 mS at 21 DAI and almost zero at 42 DAI. No differences in leachate EC_w were observed among the three NPK (8-1-6) solutions during the sampling period. The salt concentrations in leachate from N emulsion treatments were lower than for the NPK (8-1-6), but higher than for NPK (18-2-3). These variations are due to different N release rates and fertilizer compositions.

Higher concentrations of salts in the leachate generally resulted in lower pH values (Table 2). The leachate pH was significantly lower for NPK (18-2-3) than for NPK (8-1-6) in the present study. Both NPK types, as well as CAN, gave significantly more acid leachates than the UAN. A similar tendency was also observed between coated calcium nitrate and urea-based slow-release carriers (Engelsjord et al., 1997), where leachate pH was significantly higher for the latter products. One reason may be that the exchangeable cation status of organic soils (peat) is difficult to describe, since different cations are complexed to various degrees by organic matter. Divalent cations are, for example, retained more strongly than monovalent cations. Generally, calcium may effectively replace H^+ at the humus colloids under moist peat conditions, displacing H-ions into the soil solution, causing lower leachate pH.

None of the emulsions in this experiment showed satisfactory slow-release patterns, even though the UAN released less mineral-N at 4°C. These results may also indicate that not all of the N released was detected as mineral-N in the leachate. Some of the applied N may have been immobilized in the organic matter fraction and/or may have been lost as urea-N in the leachate.

Conclusions

This experiment indicates that the emulsions (nutrient-in-oil solutions) released most of their nitrogen within 21 days. After 42 days, the mean mineral-N recovery in CAN leachate was 84% of the total N applied. Corresponding values for UAN and NPK (18-2-3) were 64% and 75%. NPK (8-1-6), with three different viscosities, released 82%, 87% and 92% of N applied as mineral-N, respectively. Neither temperature nor viscosity had significant effect on N release from NPK (8-1-6). The results presented show that the emulsions are not an alternative to typically slow-release fertilzers available on the market.

Acknowledgements

The authors wish to thank the Research Council of Norway and Norsk Hydro for awarding a fellowship to the senior author and for financial support to carry out this research. The technical assistance of Karl Martin Kalfjøs (deceased), Ann-Helen Kalfjøs, Ellen Zakariassen and Sissel Alvestad is gratefully acknowledged.

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Table 1. Fertilizer emulsion types, nutrient composition and the rate applied to each treatment.

Fertilizer	N	P	K	Rate
		(%)		(g l^{-1})
N fertilizer				
Calcium ammonium nitrate (CAN)	25			9.0
Urea ammonium nitrate (UAN)	31			7.2
NPK fertilizer				
NPK, low viscosity	8	1	6	28.3
NPK, medium viscosity	8	1	6	28.3
NPK, high viscosity	8	1	6	28.3
NPK (18-2-3)	18	2	3	12.5

Table 2. Leachate pH from emulsion-forming fertilizers (average for three temperatures, 4, 12 and 21 °C).

Fertilizer	Incubation period (days)					
	7	14	21	28	35	42
CAN	4.53c ±0.27[1]	4.25c ±0.23	4.42c ±0.15	4.92c ±0.21	5.25c ±0.08	5.57c ±0.31
UAN	7.98a ±0.29	8.10a ±0.17	7.88a ±0.40	7.48a ±0.58	7.55a ±0.49	7.72a ±0.25
NPK (8-1-6) LV	4.58c ±0.42	5.40b ±0.50	6.02b ±0.35	6.43b ±0.23	6.52b ±0.28	6.60b ±0.20
NPK (8-1-6) MV	4.72bc ±0.21	5.42b ±0.25	6.12b ±0.33	6.52b ±0.21	6.60b ±0.06	6.62b ±0.17
NPK (8-1-6) HV	4.78bc ±0.40	5.47b ±0.48	6.27b ±0.39	6.50b ±0.25	6.67b ±0.15	6.50b ±0.39
NPK (18-2-3)	5.47b ±0.93	4.55c ±0.72	4.63c ±0.38	4.88c ±0.46	5.12c ±0.55	5.25c ±0.38

[1] Mean ± standard deviation. Mean values followed by the same letter within a coloumn are not significantly different at p=0.05.

Mean leachate pH of the control was: 4.78 ±0.46

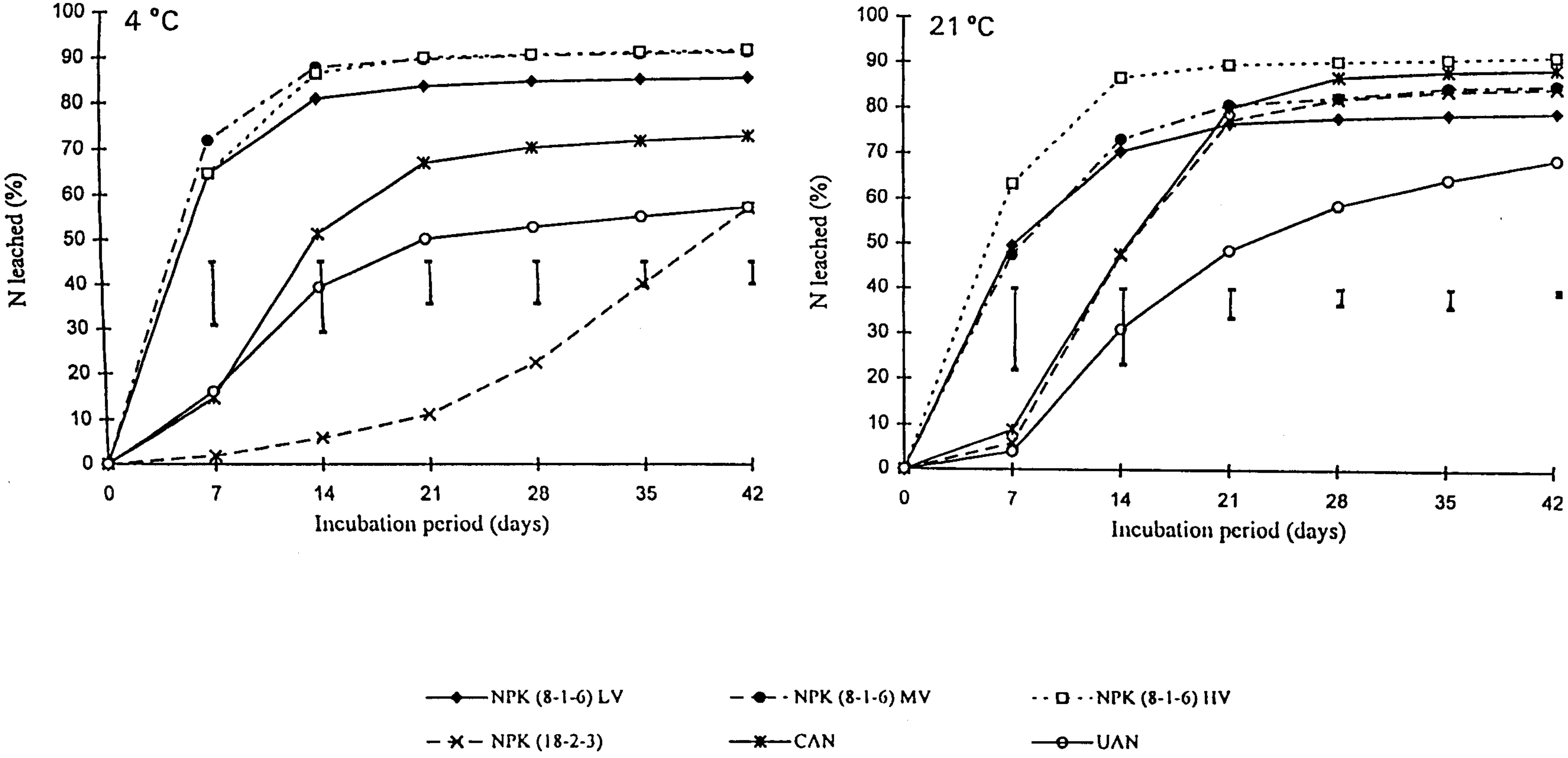

Figure 1. Effect of temperature on cumulative mineral-N release from emulsion-forming N and NPK fertilizers at 4 °C (left) and 21 °C (right). Critical range value for $REGWQ_{0.05}$ at each date is calculated for the amounts released and not for the cumulative values.

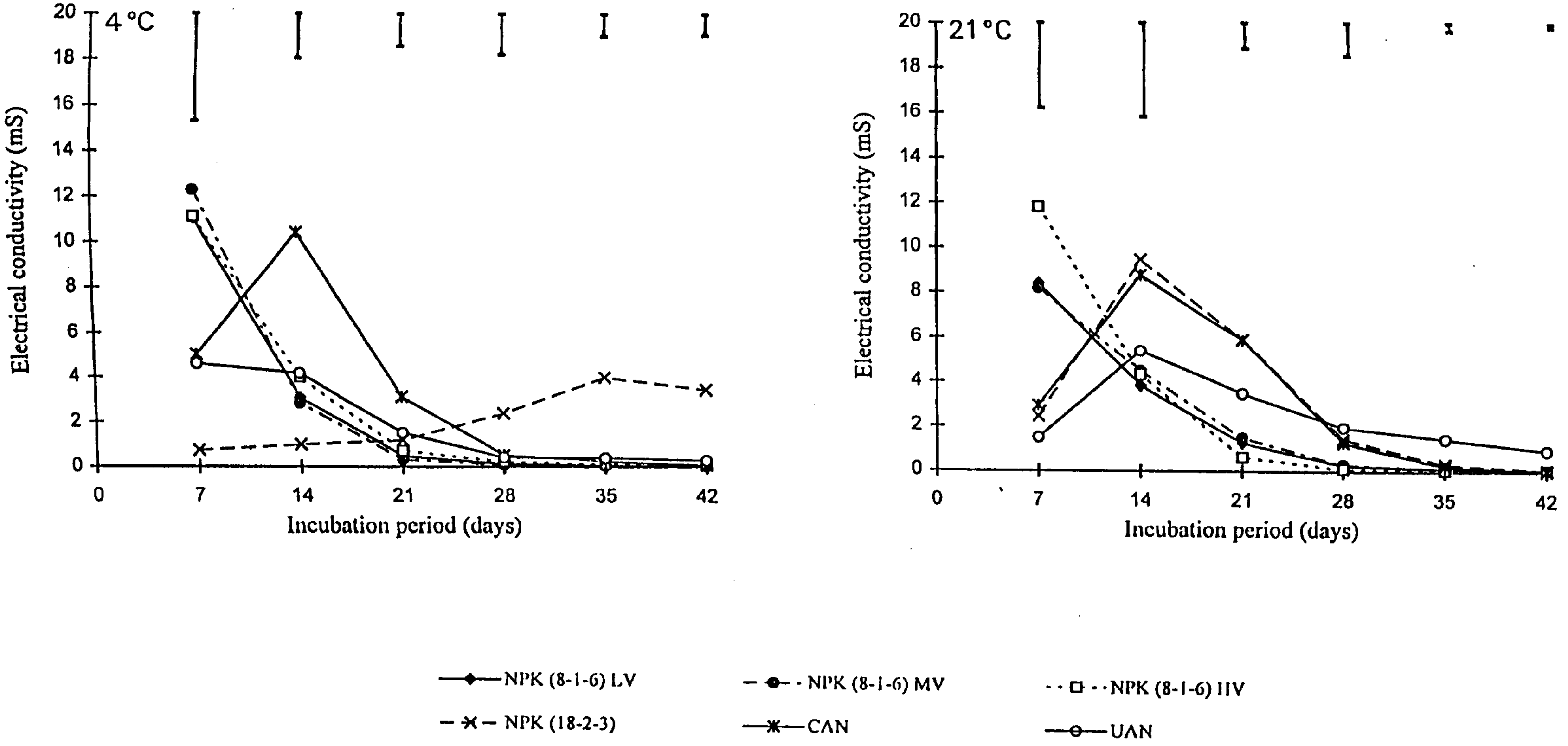

Figure 2. Effect of temperature on electrical conductivity of leachate from emulsion-forming N and NPK fertilizers at 4 °C (left) and 21 °C (right). Critical range value for REGWQ$_{0.05}$ at each date is calculated for the amounts released.