# Slow release and conventional N fertilizers for nutrition of bell pepper

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**ABSTRACT**

Bell pepper (*Capsicum annuum* L.) high-quality and yield implies the management of N nutrition. Field and pot experiments with bell pepper and Italian ryegrass were carried out during 2009 and 2010. The experimental design included three N delaying fertilizers (Sulfammo Meta 46-5-0, controlled-release fertilizer; Nitrophoska Gold 15-9-15, slow-release fertilizer; Entec 26 26-0-0, stabilized fertilizer), two conventional N fertilizers, urea and calcium nitrate and one N-unfertilized control. The fertilizer's rate was 150 kg N/ha. A pot experiment with bell pepper followed by ryegrass with the same fertilizers treatments was carried out in 2009. Dry matter (DM) yield, plant N concentration, plant N recovery and fruit mineral concentration were measured. Calcium nitrate and urea produced statistically higher DM in both field and pots. Sulfammo Meta produced always lower yields. In the field plants recovered a minimum of 18% and a maximum of 82% of the N applied, respectively, in Sulfammo Meta and calcium nitrate. In the pot experiment, bell pepper + ryegrass recovered only 32.5% of N applied with Sulfammo Meta and nearly 100% of N applied in the other fertilized pots. None of the slow-release N materials provided clear advantages over conventional fertilizers to be used in this crop.

**Keywords**: slow-release fertilizers; controlled-release fertilizers; stabilized fertilizers; urea; calcium nitrate

In the Mediterranean region bell pepper is one of the main crops for open field and greenhouse cultivation, and in Italy it is cultivated over 11 420 ha (Istat 2010) with a production of 296.253 t. High-quality and high yield are an essential prerequisite for its economical success which consequently implies high N-fertilization rates (Olsen et al. 1993).

With this respect, farmers increase application of N fertilizers to their land year by year (Wang et al. 2000), without considering the response of different species to N rate and forms. Indeed, while adequate supply of N can promote plant growth and yield, excessive and inappropriate use of chemical N fertilizers causes accumulation in the edible products of compounds harmful to humans (Stagnari et al. 2007) and environmental pollution.

Although few large-scale vegetable producers rely upon fertigation to supply N, the majority of the small-scale or low-input growers apply N fertilizer as a preplant application, with risks of significant N losses through leaching and volatilization. To minimize such losses, slow-release N fertilizers were proposed (Mao et al. 2005).

Several studies showed beneficial effects of the use of slow and controlled-release fertilizers, stabilized fertilizers and/or nitrification and urease inhibitors to enhance crop productivity. It is the case of rice (Carreres et al. 2003), or containerized nursery tree plants (Girardi et al. 2005), and other irrigated field crops. In other studies, however, positive results were not obtained (Diez et al. 1997, Guertal 2000).

Inconsistencies in results may appear since nutrient-release rates could vary depending on fertilizers characteristics, soil properties and/or climatic conditions.

Limited research was conducted on the use of slow N fertilizers in vegetable production systems, although the leaching potential of these fertilizers was examined.

Therefore, the objective of this work was to study the effect of three fertilizers with different mechanisms of delaying N in bell pepper fertilization. The effect on crop growth, yield and quality and the time and rate of N availability were evaluated in field experiments. Furthermore, with the aim to obtain additional data on the N release pattern in conditions of reduced risks of nitrate leaching and denitrification and to monitor soil nitrate levels over time, a pot experiment with bell pepper followed by ryegrass was also carried out.

## MATERIAL AND METHODS

**Experimental design**. All the experiments were conducted at the experimental field of University of Teramo (altitude of 0 m a.s.l., 42°52'N, 13°55'E) which is located in the area characterized by a typical Mediterranean climate with a mean annual temperature of 10.7°C and precipitation of 630 mm.

One experiment consisted of cultivation of pepper, cv. Sienor, in the field and it was carried out in 2009 and repeated in 2010, while one pot experiment was conducted in 2010 and it consisted of pepper followed by ryegrass (*Lolium multiflorium*).

The physical-chemical characteristics of the soil are: sand 48%, silt 29% and clay 23%, soil organic carbon (Walkley-Black) 14.0 g/kg; pH (soil/water, 1:2.5) 7.2; extractable P and K (Egner-Rhiem) 43 and 450 mg/kg, respectively; exchangeable Ca and Mg 1000 and 40 mg/kg; soluble B (boiling-water and azomethine-H procedure) 0.46 mg/kg (34 ± 0.62%), total N 1.0 g/kg.

In the field, on a completely randomized design with three replicates (plots of 17.5 $m^2$), pepper was subjected to six fertilizer treatments: urea; calcium nitrate; Sulfammo Meta 46-5-0 (controlled-release fertilizer, double membrane calcium salt and MPPA polyphenols activated molecules); Nitrophoska Gold 15-9-15 (slow-release fertilizer, containing 5% N as IBDU); Entec 26 26-0-0 (stabilized fertilizer, with 3,4 DMPP as nitrification inhibitor); and a zero N control. All these fertilizers were applied at transplanting at a rate of 150 kg N/ha.

Phosphorus and potassium rates were balanced using singular-granular superphosphate and potassium chloride.

Plants were transplanted on 17 May 2009 and 22 May 2010 at a density of 3 plant/$m^2$. The crop was irrigated when needed to maintain the soil water content at field capacity.

One month from transplanting and at harvesting, plant dry matter and total N were measured. Ten fruits per plot were randomly collected at four different growing stages to determine the content in some macronutrients, yield and total N.

In the pot experiment, pepper plants were transplanted on 2 April 2010, in pots filled with 35 kg of air dried soil containing the same fertilizers described for the field experiments. The treatments were applied at a rate of 10 g N/pot. The pots were arranged on a randomized block design with five replicates (five pots) and only a single plant was grown in each pot.

The plants were grown in a well-aerated wire netting structure 4 m high, and protected from the rainfall with a corrugated PVC sheet, limiting the nitrate leaching and denitrification. Pepper plants were irrigated with distilled water and weeds were manually removed.

At harvest (27 July) plants were separated into stems, leaves and fruits, then dried (75°C), weighed and analyzed for total N.

The soil was then kept moist to maintain high microbial activity and seeded with Italian ryegrass. During the growing season, the soil was maintained at a moisture status that allowed for adequate crop development. Dishes under the pots prevented water losses and nitrate leaching. Two cuts were carried out to measure dry matter and N concentration. Nitrogen released from fertilizers was monitored by recovering the $NO_3^-$ adsorbed in 1 cm × 2 cm strips of an anion exchange membrane (AEM) inserted directly into the soil with the help of a thin spatula (Rodrigues et al. 2006).

**Laboratory analysis**. Dry matter content was determined after oven drying at 70°C, while nitrogen concentration was determined by steam distillation and acid titration in a Kjeltec Autoanalyser 1030 (Foss Tecator, Höganäs, Sweden). Nitrate ions adsorbed in the anion exchange membranes (AEM) were eluted with 20 mL of 0.5 mol/L HCl and analyzed in the extracts by UV/Vis spectrophotometry (Perkin Elmer, Waltham, Massachusetts, USA). Anion and cations concentration in the fruits was assessed by ion chromatography.

**Data analysis**. Data were subjected to ANOVA using the Statistica package (Stat Soft, Inc. Tulsa, USA). The means with significant differences were separated by the Duncan's test. Standard errors of the differences were reported in the graphs.

## RESULTS

**Field experiments**. In 2009 the unconventional fertilizers, principally Sulfammo Meta, induced low values of early accumulation in plant dry matter (TDM), N concentration (PNC), N recovery (PNR)

Table 1. Bell pepper plant dry matter (TDM), N concentration (PNC), N recovery in biomass (PNR) and apparent N recovery (ANR) at the first sampling in 2009

| Treatment | TDM (g/plant) | PNC (g N/kg) | PNR (kg N/ha) | ANR (%) |
|---|---|---|---|---|
| Urea | 60.8$^{B1}$ | 28.6$^{A}$ | 52.1$^{B}$ | 23.6$^{B}$ |
| Calcium nitrate | 71.1$^{A}$ | 29.0$^{A}$ | 61.7$^{A}$ | 30.0$^{A}$ |
| Sulfammo Meta | 40.6$^{D}$ | 23.5$^{C}$ | 28.6$^{D}$ | 7.9$^{D}$ |
| Nitrophoska Gold | 56.4$^{BC}$ | 26.4$^{B}$ | 44.7$^{C}$ | 18.7$^{C}$ |
| Entec 26 | 57.8$^{BC}$ | 26.5$^{B}$ | 45.9$^{C}$ | 19.5$^{C}$ |
| Control | 29.3$^{E}$ | 19.0$^{D}$ | 16.7$^{E}$ | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

and apparent N recovery (ANR). Conversely, calcium nitrate registered the highest values (Table 1). At maturity (Table 2) Sulfammo Meta confirmed the lowest total plant dry matter (TDM) while the highest was observed for urea. The application of calcium nitrate stimulated the highest N concentration in stems, leaves (SLNC) and fruits (FNC), while Sulfammo Meta produced very low values. Hence, PNR was highest in calcium nitrate plots, followed by urea, Entec 26 (statistically similar values) and Nitrophoska Gold. Consequently, calcium nitrate induced the highest ANR (79.0%), followed by urea (75.0%), and Entec 26 (73.4%) with values statistically higher than Nitrophoska Gold (70.3%) and Sulfammo Meta (18.2%).

In 2010, the rank of the bell pepper responses to the different fertilizer treatments in term of DM, PNC, PNR was confirmed (Table 3). Consequently ANR% ranged from 19.0% of Sulfammo Meta to 81.9% of calcium nitrate with urea and Entec 26 inducing values (77.8% and 76.5%) higher than Nitrophoska Gold (70.8%) (Table 4).

Table 3. Bell pepper total plant dry matter (TDM), N concentration (PNC), N recovery in the above-ground biomass (PNR) and apparent N recovery (ANR) at the first sampling in 2010

| Treatment | TDM (g/plant) | PNC (g N/kg) | PNR | ANR (%) |
|---|---|---|---|---|
| Urea | 41.7$^{B1}$ | 31.8$^{A}$ | 39.8$^{B}$ | 17.1$^{B}$ |
| Calcium nitrate | 47.7$^{A}$ | 30.8$^{A}$ | 44.1$^{A}$ | 20.0$^{A}$ |
| Sulfammo Meta | 30.5$^{C}$ | 22.8$^{B}$ | 20.9$^{D}$ | 4.5$^{D}$ |
| Nitrophoska Gold | 40.6$^{B}$ | 30.6$^{A}$ | 37.3$^{C}$ | 15.4$^{C}$ |
| Entec 26 | 41.2$^{B}$ | 29.3$^{A}$ | 36.2$^{C}$ | 14.7$^{C}$ |
| Control | 25.2$^{D}$ | 18.7$^{C}$ | 14.1$^{E}$ | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

The influence of the N fertilization on fruit mineral accumulation was noticeable. The conventional fertilizers induced the highest K concentration at maturity (2900 mg/kg FW) while the control was the lowest (2400 mg/kg FW); Sulfammo Meta registered lower K accumulation than Entec 26 and Nitrophoska Gold (Figure 1A).

Mg accumulation in fruits was particularly favored by calcium nitrate, urea and Entec 26, while Sulfammo Meta and Nitrophoska Gold induced a scarce store (Figure 1B).

Conversely, the Ca concentration in fruits was increased by all fertilizers (Figure 1C), although calcium nitrate, urea and Sulfammo Meta induced the significantly highest accumulation values (99.7, 85.5, 85.7 mg/kg FW).

Table 2. Bell pepper dry matter of stems and leaves (SLDM), fruit dry matter (FMY) at first and second harvest, total plant dry matter (TDM), N concentration in stems and leaves (SLNC), N concentration in fruits (FNC), plant N recovery in the above-ground biomass (PNR) and apparent N recovery (ANR) at harvest in 2009

| Treatment | SLDM (g/plant) | FMY I harvest (g/plant) | FMY II | TDM (g/plant) | SLNC (g N/kg) | FNC | PNR (kg N/ha) | ANR (%) |
|---|---|---|---|---|---|---|---|---|
| Urea | 90.8$^{A1}$ | 69.6$^{A}$ | 58.6$^{A}$ | 219.1$^{A}$ | 23.8$^{B}$ | 23.2$^{A}$ | 153.6$^{B}$ | 75.0$^{B}$ |
| Calcium nitrate | 89.8$^{A}$ | 66.0$^{B}$ | 58.1$^{A}$ | 213.9$^{B}$ | 25.8$^{A}$ | 24.3$^{A}$ | 159.6$^{A}$ | 79.0$^{A}$ |
| Sulfammo Meta | 62.0$^{C}$ | 31.8$^{C}$ | 30.3$^{C}$ | 124.0$^{C}$ | 18.6$^{C}$ | 18.2$^{B}$ | 68.4$^{D}$ | 18.2$^{D}$ |
| Nitrophoska Gold | 91.7$^{A}$ | 64.8$^{B}$ | 56.3$^{B}$ | 214.8$^{B}$ | 22.7$^{B}$ | 23.6$^{A}$ | 146.6$^{C}$ | 70.3$^{C}$ |
| Entec 26 | 85.6$^{B}$ | 66.4$^{B}$ | 60.8$^{A}$ | 212.9$^{B}$ | 23.9$^{B}$ | 23.6$^{A}$ | 151.2$^{B}$ | 73.4$^{B}$ |
| Control | 52.4$^{D}$ | 15.2$^{D}$ | 17.6$^{D}$ | 85.2$^{D}$ | 14.4$^{D}$ | 18.0$^{B}$ | 41.1$^{E}$ | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

Table 4. Bell pepper dry matter of stems and leaves (SLDM), fruit dry matter (FDM) at first and second harvest, total plant dry matter (TDM), N concentration in stems and leaves (SLNC), N concentration in fruits (FNC), plant N recovery in the above-ground biomass (PNR) and apparent N recovery (ANR) at harvest in 2010

| Treatment | SLDM (g/plant) | FDM I | FDM II | TDM (g/plant) | SLNC | FNC | PNR (kg N/ha ) | ANR (%) |
|---|---|---|---|---|---|---|---|---|
| | | harvest (g/plant) | | | (g N/kg) | | | |
| Urea | 62.6$^{C1}$ | 82.7$^{A}$ | 75.4$^{A}$ | 220.7$^{A}$ | 23.4$^{B}$ | 22.2$^{A}$ | 149.4$^{B}$ | 77.8$^{B}$ |
| Calcium nitrate | 71.2$^{A}$ | 79.9$^{A}$ | 70.7$^{B}$ | 221.8$^{A}$ | 25.2$^{A}$ | 22.5$^{A}$ | 155.5$^{A}$ | 81.9$^{A}$ |
| Sulfammo Meta | 48.3$^{D}$ | 33.0$^{C}$ | 30.3$^{C}$ | 111.6$^{D}$ | 18.6$^{D}$ | 18.0$^{B}$ | 61.2$^{D}$ | 19.0$^{D}$ |
| Nitrophoska Gold | 62.7$^{C}$ | 76.9$^{B}$ | 73.4$^{A}$ | 213.1$^{C}$ | 20.5$^{C}$ | 22.2$^{A}$ | 138.9$^{C}$ | 70.8$^{C}$ |
| Entec 26 | 65.4$^{B}$ | 78.5$^{AB}$ | 74.3$^{A}$ | 218.2$^{AB}$ | 23.5$^{B}$ | 22.1$^{A}$ | 147.4$^{B}$ | 76.5$^{B}$ |
| Control | 41.0$^{E}$ | 18.8$^{D}$ | 18.5$^{D}$ | 78.3$^{E}$ | 14.4$^{E}$ | 13.4$^{C}$ | 32.7$^{E}$ | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

The dynamic of $SO_4^{2-}$ accumulation in bell pepper fruits as response to N fertilization was pretty unclear (Figure 1D).

**Pot experiments**. The differences in bell pepper TDM detected in the field were emphasized (Table 5). Sulfammo Meta produced the lowest value (256.4 g/plant) while calcium nitrate the highest (546.9 g/plant). Significant differences in SLNC, FNC and PNR were observed. Sulfammo Meta stimulated poor N accumulation. ANR was

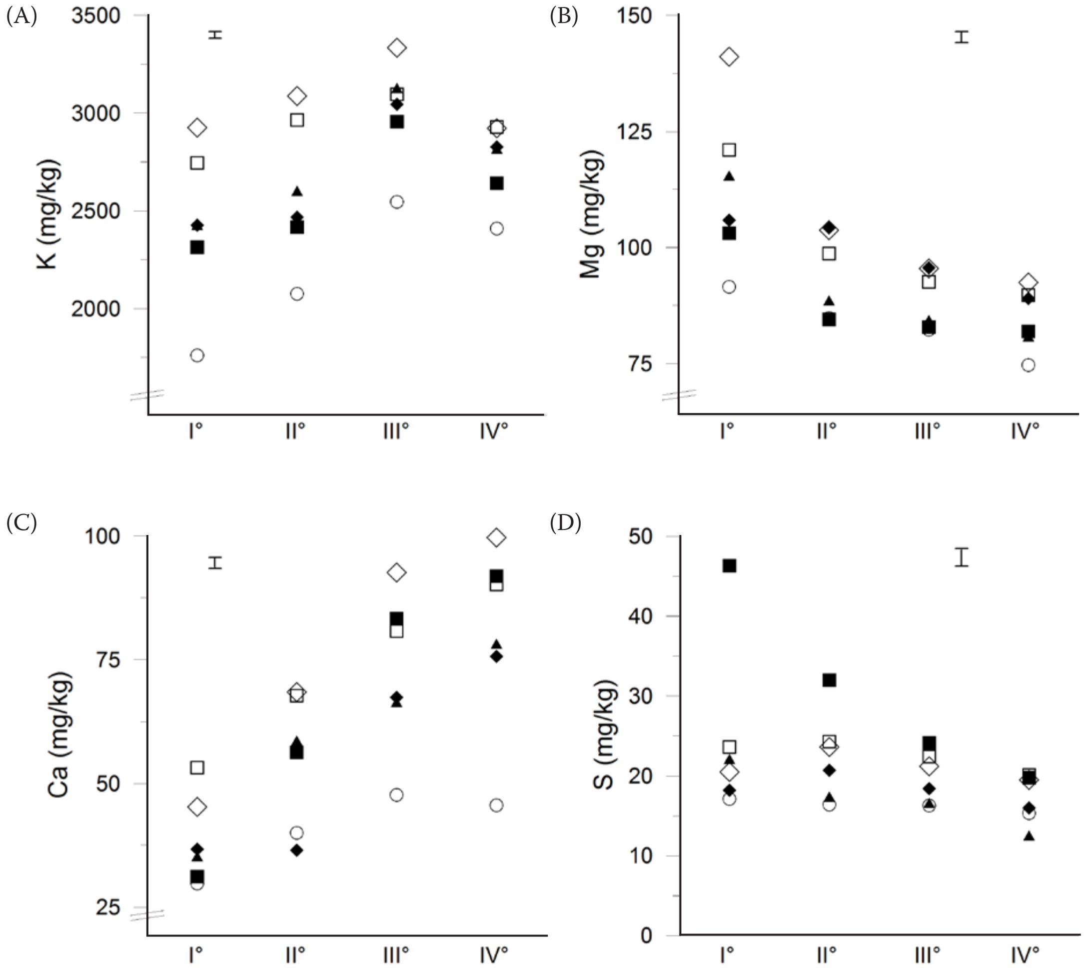


Figure 1. Concentration of $K^+$ (A), $Mg^{2+}$ (B), $Ca^{2+}$ (C), $SO_4^{2-}$ (D) in bell pepper fruits (mg/kg of fresh weight) at four growing stages (vertical bar stands for standard errors). ◊ – calcium nitrate; □ – urea; ■ – Sulfammo Meta; ▲ – Nitrophoska Gold; ♦ – Entec 26; ○ – control (vertical bar stands for standard errors)

Table 5. Bell pepper dry matter of stems and leaves (SLDM), fruit dry matter (FDM), total plant dry matter (TDM), N concentration in stems and leaves (SLNC), N concentration in fruits (FNC), plant N recovery in the above-ground biomass (PNR) and apparent N recovery (ANR) in pot experiments

| Treatment | SLDM | FDM | TDM | SLNC | FNC | PNR (g N/pot) | ANR (%) |
|---|---|---|---|---|---|---|---|
| | (g/plant) | | | (g N/kg) | | | |
| Urea | 286.2[B1] | 206.4[A] | 492.6[B] | 20.7[AB] | 20.0[B] | 10.1[B] | 82.1[B] |
| Calcium nitrate | 318.3[A] | 216.7[A] | 546.9[A] | 22.2[A] | 21.9[A] | 11.7[A] | 99.6[A] |
| Sulfammo Meta | 148.2[D] | 108.2[C] | 256.4[D] | 15.4[C] | 14.8[D] | 3.9[D] | 20.4[D] |
| Nitrophoska Gold | 288.6[B] | 186.7[B] | 488.9[B] | 20.2[B] | 20.8[AB] | 10.0[B] | 81.4[B] |
| Entec 26 | 266.4[C] | 108.2[C] | 453.1[C] | 19.5[B] | 21.1[A] | 9.1[BC] | 72.7[C] |
| Control | 83.0[E] | 54.0[D] | 137.1[E] | 11.2[D] | 15.7[C] | 1.8[E] | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

20.4% for Sulfammo Meta while it reached 99.6% in the calcium nitrate pots, 82.1% in urea and 81.4% in Nitrophoska Gold.

Entec 26 favored the highest ryegrass DMY and PNRt (51.5 g/pot, 42.5 g/pot, and 2.8 g N/pot) while calcium nitrate the lowest (13.7 g/pot, 11.7 g/pots and 0.5 g N/pot) (Table 6). ANR is directly dependent on DMY and PNRt, so we registered values of 23.7% for Entec 26, 16.3% for Nitrophoska Gold, 0.8% for calcium nitrate and 9.0% for urea. ANRt was thus 100.0% for calcium nitrate, 91.1% for urea, 97.7% for Nitrophoska Gold, 96.4% for Entec 26, and only 32.5% for Sulfammo Meta.

Nitrate concentration in soil 21 days after fertilization was the lowest in control pots (Figure 2). The highest values were observed in calcium nitrate and urea. 56 and 91 days after fertilization a significant decrease was observed and on the third sampling no differences were found. At 140 days, soil nitrate levels increased to 325.7, 298.7, 276.1, 245.2, 209.4, and 113.7 mg N/L, respectively in urea, calcium nitrate, Nitrophoska Gold, Entec, Sulfammo Meta and control pots.

## DISCUSSION

In the first development phases of the crop, treatments with Nitrophoska Gold and Entec 26 induced lower TDM, PNC and ANR than urea and calcium nitrate. The differences in TDM disappeared as the crop cycle proceeded, while PNC and FNC equaled those of urea plots. This similarity at harvest indicates that, as in the urea treatment, a fraction of N released from Entec 26 and Nitrophoska Gold was only available later in the season. ANR at crop maturity was very similar between Entec 26 and urea, with Nitrophoska Gold exhibiting lower values.

Nitrogen in Entec 26 is 7.5% $NO_3$-N, 18.5% $NH_4$-N and 0.8% DMPP. Plants can readily absorb $NO_3^-$ and $NH_4^+$, and may be favored by the presence of both forms in soil (Cao and Tibbitts 1993). In well aerated soils, urea is rapidly hydrolyzed to $NH_4^+$ which is thereafter converted in $NO_3^-$ (Rodrigues 2004). Thus, in both Entec 26 and Urea plots, $NH_4^+$ and/or $NO_3^-$ was available for plant uptake. Nevertheless, since calcium nitrate already contains in its formulation the $NO_3^-$ form promptly available for plant uptake, this has probably stimulated an early crop growing and consequently a higher biomass and PNC accumulation. Moreover, part of $NH_4^+$ may be fixed in clay minerals (Gioacchini et al. 2006) reducing N availability to plants with more advantages observed in calcium nitrate application. Consequently, the probable higher persistence of $NH_4^+$ in the plots fertilized with Entec 26, due to the effect of DMPP, had

Table 6. Italian ryegrass dry matter yield (DMY) at first and second cut, total plant N recovery (PNRt), apparent N recovery (ANR) and total apparent N recovery (ANRt) in pot experiments

| Treatment | DMY (g/pot) 1st cut | DMY (g/pot) 2nd cut | PNRt (g N/pot) | ANR (%) | ANRt (%) |
|---|---|---|---|---|---|
| Urea | 26.3[C1] | 28.5[B] | 1.4[B] | 9.0[D] | 91.1[B] |
| Calcium nitrate | 13.7[D] | 11.7[C] | 0.5[C] | 0.8[E] | 100.0[A] |
| Sulfammo Meta | 26.5[C] | 29.7[B] | 1.7[B] | 12.1[C] | 32.5[C] |
| Nitrophoska Gold | 39.1[B] | 30.9[B] | 2.1[A] | 16.3[B] | 97.7[A] |
| Entec 26 | 51.5[A] | 42.5[A] | 2.8[A] | 23.7[A] | 96.4[A] |
| Control | 11.9[D] | 11.4[C] | 0.4[C] | – | – |

[1]mean separation within columns by the Duncan's test; $P < 0.05$

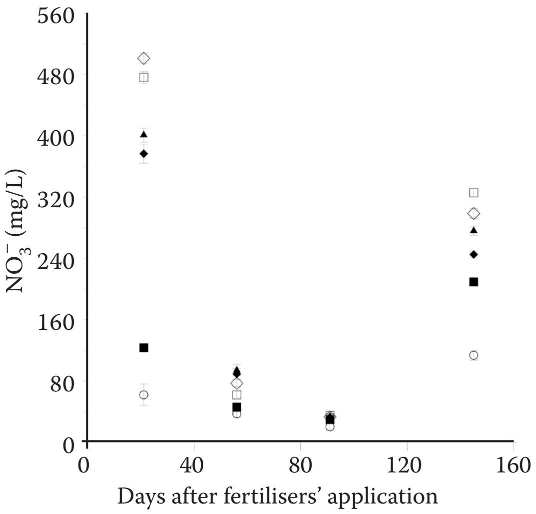


Figure 2. Nitrate concentration (mg/L) in soils of the pot experiment. ◊ – calcium nitrate; □ – urea; ■ – Sulfammo Meta; ▲ – Nitrophoska Gold; ♦ – Entec 26; ○ – control (vertical bar stands for standard errors)

no advantage for crop growth since the weather conditions during the growing seasons did not promote $NO_3^-$ leaching and denitrification; these findings are in accordance with Guertal (2000) who observed that slow-release fertilizers had no consistent advantages over a soluble N source in bell pepper nutrition.

In other studies, however, positive effects of the use of DMPP on yield and quality of several crops were reported (Pasda et al. 2001). DMPP was also indicated as responsible for some positive environmental aspects such as the reduction of nitrate leaching (Roco and Blu 2006) and $N_2O$ emissions (Hatch et al. 2005) from soils.

Nitrophoska Gold contains nitrogen as 2.5% $NO_3$-N, 7.5% $NH_4$-N and 5% ISOBUTILEN DIUREA-N (ISODUR). Probably it is the N from ISODUR that was released later in the growing season than Entec 26, urea and hence calcium nitrate. ISODUR hydrolysis is indeed affected not only by temperature, but also by moisture (Trenkel 2007). Consequently, in June–July, although the temperatures were favorable for ISODUR hydrolysis, the scarcity in soil water postponed N availability from IBDU to the end of the crop cycle.

Sulfammo Meta did not favor bell pepper plant dry matter and yield. In the pot experiment, total ANR from Sulfammo Meta was only 32.5% compared to 100% of the other fertilized treatments. Ryegrass DMY was higher in Sulfammo Meta pots as a result of later N release from the fertilizer after the cut of pepper. These results are to be attributed to its longer life.

Indeed nitrate concentration in the soil was lower in Entec and Nitrophoska Gold than in calcium nitrate and urea pots. Hence DMPP and ISODUR effectively delayed nitrogen plant availability.

There is no evidence of any advantage in the use of delay N fertilizers over urea and calcium nitrate in bell pepper nutrition in the Mediterranean conditions of late spring – summer. Sulfammo Meta showed a very slow release pattern. DMPP delayed $NH_4^+$ nitrification in Entec 26 without advantages for bell pepper plant DM and yield, probably due to $NH_4^+$ and $NO_3^-$ that can be absorbed by the crop. According to the previous literature, one significant advantage of the application of slow release fertilizers is the reduction in greenhouse gaseous emissions, which was not investigated here.

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