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Nitrogen uptake and growth of two citrus rootstock seedlings in a sandy soil receiving different controlled-release fertilizer sources

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Abstract Understanding the fate of different forms of nitrogen (N) fertilizers applied to soils is an important step in enhancing N use efficiency and minimizing N losses. The growth and N uptake of two citrus rootstocks, Swingle citrumelo (SC), and Cleopatra mandarin (CM), seedlings were evaluated in a pot experiment using a Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamments) without N application or with 400 mg N kg^{-1} applied as urea or controlled-release fertilizers (CRF; either as Meister, Osmocote, or Poly-S). Meister and Osmocote are polyolefin resin-coated urea with longevity of N release for 270 days (at 25°C). Poly-S is a polymer and sulfur-coated urea with release duration considerably shorter than that of either Meister or Osmocote. The concentrations of 2 M KCl extractable nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) in the soil sampled 180 days and 300 days after planting were greater in the soil with SC than with CM rootstock seedlings. In most cases, the extractable NH_4^+ and NO_3^- concentrations were greater for the Osmocote treatment compared to the other N sources. For the SC rootstock seedlings, dry weight was greater with Meister or Poly-S compared with either Osmocote or urea. At the end of the experiment, ranking of the various N sources, with respect to total N uptake by the seedlings, was: Meister = Osmocote > Poly-S > Urea > no N for CM rootstock, and Meister = Poly-S = Osmocote > Urea > no N for SC rootstock. The study demonstrated that for a given rate of N application the total N uptake by seedlings was greater for the CRF compared to urea treatment. This suggests that various N losses were lower from the CRF source as compared to those from soluble fertilizers.

Key words Urea · Coated fertilizers · Ammonium nitrogen · Nitrate nitrogen · Nitrogen uptake

Introduction

Nutrition programs for a number of crops are currently being reevaluated in an effort to maximize nitrogen (N) use efficiency, and minimize nitrate (NO_3^-) contamination of groundwater. There is also some concern with respect to the gaseous emission of N from fertilizers and its effects on the environment (Mengel 1992). Losses from N fertilizers are dependent on its form and other management factors (Mengel and Kirkby 1987).

During the last three decades, many coated fertilizers have been developed for agricultural and horticultural crops. These products are generally referred to as controlled-release fertilizers (CRF) due to their unique characteristics of nutrient release over an extended period. Nutrient uptake efficiency is greater and leaching losses are lower for CRF products as compared to readily available forms of fertilizers (Shoji and Gandeza 1992). During the early 1970s and 1980s a group of products, including urea formaldehyde, isobutylidene diurea (IBDU), crotonylidene diurea, and sulfur-coated urea (SCU), and sulfur-coated ammonium nitrate were extensively studied for their release characteristics and longevity of nutrient availability (Mengel and Kirkby 1987). The availability of N from the above products was primarily influenced by their physicochemical properties and by soil microbial activity. Generally, two major coatings are used to delay nutrient release from fertilizer prills. Sulfur is used mainly as a surface coating on urea, because of its low cost and its value as a plant nutrient. More recently, resin coating technology has been widely adapted to produce CRF. Osmocote and Meister are resin-coated soluble N forms. The rate of N release

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and longevity of release are controlled by thickness as well as multiple coating (Brown et al. 1966; Sharma 1979). The N release from CRF is usually independent of soil pH, but increases with soil temperature (Sharma 1979; Maeda 1990).

During recent years, considerable progress has been made in fertilizer production technology by adapting polymer coating to modify the rate and longevity of nutrient release. CRF products could have some potential for use in agricultural and horticultural industries by minimizing NO_3^- leaching losses and contamination of groundwater. Alva and Tucker (1993) reported a significant reduction in NO_3^--N leaching below the rooting depth of Pineapple orange trees (on Swingle citrumelo rootstock) grown in a Candler fine sand, which received CRF sources as compared to dry soluble granular fertilizer. However, Marler et al. (1987) reported no differences in growth of 1- and 2-year-old Hamlin orange trees fertilized with CRF or dry soluble granular fertilizer. The objective of this study was to evaluate the effects of commercially available CRF sources on the growth and foliar N concentrations of two citrus rootstock seedlings.

Materials and methods

A Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamments) was sampled at a depth of 15–30 cm from a citrus grove near Lake Alfred, Polk County, Fla. The characteristics of soil used are shown in Table 1. The soil was air-dried, ground, passed through a 2-mm sieve, and 2.5 kg soil was used per pot. CRFs used in this study included Meister (Helena Chemical Co., Tampa, Fla.), Osmocote and Poly-S (Scotts, Marysville, Ohio). Meister and Osmocote are polyolefin resin-coated urea granules with release duration of about 270 days. Poly-S is a polymer and SCU with a very thin coating and a release duration shorter than that of Meister or Osmocote. The treatments included: no N (control) or 1 g N pot^{-1} (equivalent to 400 mg N kg^{-1} soil) as either urea or the CRF sources, i.e., Meister, Osmocote, Poly-S. All pots received 100 mg P kg^{-1} as KH_2PO_4, and 500 mg K kg^{-1} as a combination of K_2SO_4 and KH_2PO_4. The N, P, and K sources were mixed throughly with 2.5 kg dry soil and transferred to the pots. Six-month-old uniform seedlings of Cleopatra mandarin (CM; *Citrus reticulata* Blanco) and Swingle citrumelo (SC; *Citrus paradisi* × *Poncirus trifoliata*) rootstocks were planted, one seedling per pot. Each treatment was replicated five times with a single pot as one replicate. The experiment was conducted in a partially temperature-controlled greenhouse at 28°/22°C (day/night). The pots were weighed every day to determine moisture depletion, and watered at 30% depletion of available soil moisture capacity. Soil samples (approximately 20 g per pot) were taken 180 days and 300 days after the experiment began. Two grams moist soil was weighed into a 50-ml centrifuge tube, 20 ml of 2 M KCl was added, and the tubes were shaken for 30 min. The suspension was settled for 30 min and filtered through a Whatman no. 42 filter paper. The concentrations of NH_4^+ (method A303-S020) and NO_3^- (method A303-S170) were measured using a Rapid Flow Analyzer (RFA; Alpkem 1986, 1989). The experiment was terminated on the 300th day. Leaves, stems, and roots of each plant were separated, rinsed several times in distilled water, dried at 70°C for 72 h, and dry weights were recorded. The concentration of N was measured using an elemental analyzer (CNS Analyzer, NA 1500, Fisons Instruments, Dearborn, Mich.), and total N contents in different plant parts were calculated. Analysis of variance was carried out to test the significance among the treatments using the SAS Program (1991), and mean N uptake or dry weight among different treatments were analyzed by least significant differences (LSD).

Table 1 Selected physico-chemical characteristics of the soil used. *N* Nitrogen, NO_3^--*N* nitrate nitrogen, NH_4^+-*N* ammonium nitrogen, *P* phosphorus, *K* potassium, *Ca* calcium, *Mg* magnesium

pH (soil:water 1:1 ratio)	6.9
	– mg kg^{-1}–
Total N (Kjedahl-N)	300.0
NO_3^--N[a]	3.1
NH_4^+-N[a]	4.1
P[b]	80.0
K[b]	20.0
Ca[b]	500.0
Mg[b]	52.0
	– % (wt. basis) –
Organic matter	1.3
Clay	1.5
Silt	4.1
Sand	94.4

[a] 2 M KCl extraction at 1:10 (soil:extractant)

[b] Mehlich 3 extraction (Mehlich 1984)

Results and discussion

In the soil with SC seedlings, the concentrations of 2 M KCl extractable NO_3^--N and NH_4^+-N were greater in the CRF treatments compared to those in the urea treatment (Fig. 1). The Osmocote-treated soil had the highest concentrations of NO_3^--N and NH_4^+-N among the CRF treatments, and concentrations of NO_3^--N were 3- to 5-fold greater than that of NH_4^+-N. The concentrations of soil NO_3^--N were lower in the pots with CM as compared to SC seedlings. At both sampling dates for both rootstocks, the soil concentrations of exchangeable NH_4^+-N were lower than those of NO_3^--N. A parallel study, using the Candler find sand amended with organic residues, also showed similar trends with regard to soil NO_3^--N and NH_4^+-N concentrations (Dou and Alva 1998). This is an indication of rapid transformation of NH_4^+ into NO_3^- due to favorable soil conditions (Mengel and Kirkby 1987). The concentration of NH_4^+-N in the soil was in the range of 5–50 mg kg^{-1} depending on the N product used and time of sampling. The source of N in all the CRF products used in this study was urea. The intermediate product of urea hydrolysis is NH_4^+-N.

For both rootstock seedlings, the dry weights of total and respective plant parts (leaves and stems) were significantly lower in unamended soil as compared to that in N-amended soils (Table 2). For the duration of this study, the total and individual dry weights of CM seedlings were very similar when N was applied either as CRF or urea. In the case of SC seedlings, however, leaf weight was significantly greater in the Meister treatment as compared to the other treatments. The reason for this difference between the two rootstock seedlings is not clearly understood, and field studies are necessary to evaluate the different responses of rootstock seedlings to sources of N.

The N concentrations in plant parts were significantly greater in both types of rootstock seedlings grown in N-amended soil as compared to unamended soil (Table 3).

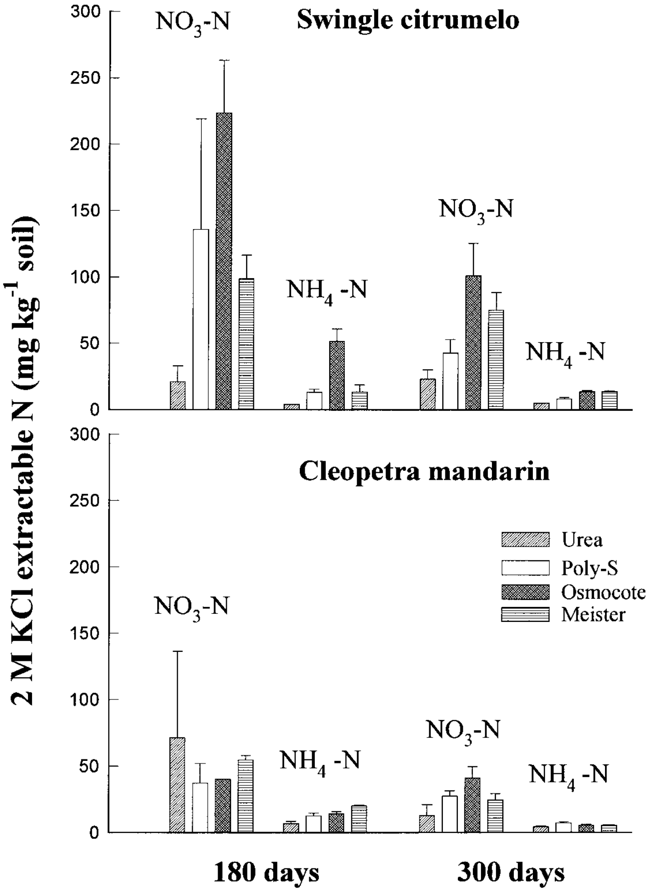

Fig. 1 Concentrations of 2 M KCl extractable ammonium nitrogen (*NH_4^+-N*) and nitrate nitrogen (*NO_3^--N*) in soil samples taken 180 days and 300 days after planting Swingle citrumelo and Cleopatra mandarin seedlings in a Candler fine sand which received different forms of N. The concentrations of respective forms of nitrogen (N) in the unamended soil were subtracted from those in N-amended soil. The standard deviation of the mean is shown on the top of each histogram

Table 2 Dry weight of citrus seedlings grown in a Candler fine sand with no nitrogen (N) applied or N applied as urea or different sources of controlled-release fertilizers. *LSD* Least significant difference

	Dry weight (g seedling^{-1})			
Treatments	Leaf	Stem	Root	Total
Swingle citrumelo				
No N applied	1.0	1.9	2.5	5.4
Urea	1.9	2.7	2.3	6.9
Poly-S	2.2	3.4	3.0	8.6
Osmocote	2.1	3.0	2.7	8.0
Meister	2.7	3.3	2.7	8.7
LSD (*P* = 5%)	0.5	1.3	1.2	1.1
Cleopatra mandarin				
No N applied	2.7	3.4	4.2	10.3
Urea	5.0	6.3	5.4	16.7
Poly-S	4.7	6.5	4.0	15.2
Osmocote	4.4	6.7	3.7	14.8
Meister	5.3	6.4	4.9	16.6
LSD (*P* = 5%)	1.1	2.1	2.2	1.7

Table 3 Concentration of N in citrus seedling parts grown in a Candler fine sand with no N applied or N applied either as urea or as different sources of controlled-release fertilizers. For abbreviations, see Table 2

	mg g^{-1}		
Treatments	Leaf	Stem	Root
Swingle citrumelo			
No N applied	17	7	14
Urea	31	19	32
Poly-S	36	22	33
Osmocote	34	26	33
Meister	39	25	40
LSD (*P*=5%)	5	6	7
Cleopatra mandarin			
No N applied	11	6	12
Urea	22	11	22
Poly-S	31	21	31
Osmocote	36	31	36
Meister	35	25	31
LSD (*P*=5%)	5	3	5

The N concentrations were largely similar in leaf and root, which were greater than that in stem for both types of rootstock seedlings. In N-amended treatments, total N uptake by CM was 2- to 3-fold greater than that by SC seedlings (Table 4). This, in turn, resulted in lower residual soil N in most treatments with CM than with SC seedlings (Fig. 1). The dry matter weight of seedlings CM was also greater than that of SC seedlings (Table 2).

The total N content of the CM seedlings grown in soil amended with either Osmocote or Meister was significantly greater than that of the seedlings grown in soil amended with other N sources or in unamended soil (Table 4). Poly-S is a polymer and SCU, and its longevity of N release is considerably shorter than that of Meister or Osmocote (Fujita et al. 1994). A leaching column study also using the Candler fine sand showed faster release of N from Poly-S compared to either Meister or Osmocote (Paramasivam and Alva 1997).

The N availability of Poly-S depends on the physicochemical conditions in the soil (Mengel and Kirkby 1987). In the current experiment, the soil water content was optimal since the pots were irrigated on a daily basis, and this was favorable for optimal release from Poly-S. The N release from resin-coated fertilizers (Meister, Osmocote) is mainly influenced by the soil microbial activity (Moore 1972). The N release from these products follows a first-order reaction. In the case of SC seedlings, the total N content was highest in the Meister treatment; the N uptake was similar in the Poly-S and Osmocote treatment. A number of soil factors, i.e., temperature, moisture, rhizosphere effect, and microbial activity, influence the release of urea from the coated fertilizer and the subsequent transformation of urea into NH_4^+ and NO_3^- forms (Mengel and Kirkby 1987; Alva and Tucker 1993). Soil conditions which stimulate microbiological activity in the soil tend to

Table 4 Total N content in two citrus rootstock seedlings grown in a Candler fine sand with no N applied or N applied either as urea or as different sources of controlled-release fertilizers. For abbreviations, see Table 2

	mg N seedling^{-1}	
	Swingle citrumelo	Cleopatra mandarin
No N applied	65.3	100.5
Urea	183.8	298.1
Poly-S	253.0	406.2
Osmocote	238.5	499.3
Meister	295.8	498.9
LSD (*P* = 5%)	65.7	79.6

enhance N release from resin-coated fertilizers. Sharma (1979) and Maeda (1990) reported that N release from Osmocote was independent of soil pH, but doubled when the temperature increased from 10°C to 20°C. The release of N from Meister was affected by the coating of thermoplastic resin used in its production (Fujita et al. 1994). The resin-coated fertilizer has a longer release period than any SCU (Fujita et al. 1994). This explains the increased growth and greater total N uptake by the seedlings grown in the soil which received resin coated fertilizer as compared to either Poly-S or urea. The lower N uptake and N concentration in both rootstock seedlings in urea-amended soil could be attributed to greater losses of N due to NH_3 volatilization. Losses due to volatilization can account for as much as 30% of the total N applied in urea fertilizer (Dou and Steffens 1995).

This study demonstrated a greater N uptake and seedling growth in CRF-amended soil as compared to urea-amended soil (Tables 2, 3). Using Troyer citrange seedlings, Koo (1988) reported 77% and 29% N recovery from IBDU and ammonium nitrate, respectively, and found that soil N content was greater when applying the former as compared to the latter source. Alva and Tucker (1993) conducted a field study to evaluate the effect of various CRF and soluble N sources on Pineapple orange trees on SC rootstock. They reported significantly a lower NO_3^--N concentration in the leachate below the rhizosphere of the trees which received CRF as compared to soluble N sources. In contrast, a study on non-bearing Hamlin orange trees on sour orange rootstock showed no significant difference in tree growth and N uptake when CRF sources or standard fertilizers were applied (Marler et al. 1987; Ferguson et al. 1988). These different conclusions drawn from various experiments were a consequence of the various release characteristics of the CRF products used in the different studies.

In conclusion, this experiment demonstrated differential growth responses of two seedlings of citrus rootstock to various N sources. The total N content was greater in the seedlings which received CRF sources compared to those in the urea or unamended treatments. For a given source of N, the residual soil N content was greater in the soil with SC seedlings compared to that with CM seedlings, indicating the greater growth and N uptake by the latter rootstock.

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