Interactions of High Temperature and Exposure Time Influence Nitrification in a Pine Bark Medium

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Abstract. Pine bark-filled containers periodically fertilized with NH4-N were heated from 21°C to 28, 34, 40, 46, or 52°C for daily exposures of 1, 2, 4, 6, or 24 hours over 20 days. Concentrations of NH4-N and NO3-N in medium solution extracts were determined every 5 days. Medium solution NH4-N concentration was highest at constant (24 hours) exposure to 40°C than at lower temperatures or exposure times. There was a similar increase in NH4-N concentration for a 2-hour-day–1 exposure to 46°C, with further increases in NH4-N for longer exposure times. By day 10, NH4-N concentration was highest after 1 hour-day–1 exposure to 52°C. Decreases in medium solution NO3-N concentration generally coincided with the increases in NH4-N. These results indicate that container medium thermal periods, similar to those observed in nurseries of the southern United States, may inhibit nitrification, thereby influencing NH4-N : NO3-N ratios in the medium solution of plants fertilized with predominantly ammoniacal N sources.

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Growth and quality of container-grown plants in southern U.S. nurseries can be limited by the supraoptimal medium temperatures that result from heat gain due to solar radiation on the sidewalls of dark containers (Ingram, 1981; Keever and Cobb, 1984; Laiche, 1985). Daily medium temperatures can be >40°C for ≤6 h and 50°C for ≤2 h (Ingram, 1981; Martin and Ingram, 1988). Temperatures this high may inhibit nitrification (Beck, 1983), potentially increasing the NH4-N : NO3-N ratio in the medium solution when plants are fertilized with ammoniacal N. Heat-induced NH4 toxicity may be one factor contributing to summer heat stress of container-grown plants (Walden et al., 1989).

In a pine bark medium at constant temperature, 20 or 30°C promoted rapid nitrification, but nitrification was inhibited at 40°C (Niemiera and Wright, 1987). This inhibition increased the NH4-N concentration relative to that of NO3-N in the medium solution extracts. The NH4-N concentrations in leachates from a container nursery was higher during August than the cooler month of September (Walden et al., 1989). This information suggests that the container medium may reach temperatures sufficiently high for an adequate period to inhibit nitrification. Our objective was to determine the temperatures and the daily exposure durations that inhibit nitrification in a pine bark medium. Knowledge of this interaction would help producers of container-grown plants adjust cultural practices for plants that may be sensitive to elevated NH4-N levels in the medium solution.

Materials and Methods

Preincubation procedure. One-liter polyethylene containers were filled with a milled pine bark medium amended with 6 kg dolomitic limestone/m3. To stimulate nitrification, each container received a twice weekly irrigation with 200 ml of a solution containing 200 mg N/liter as (NH4)2SO4, H3PO4, and KCl. The containers were held in a room with a 28°C day/20°C night cycle and were allowed to equilibrate to room temperature. This sequence was repeated every 24 h using the same five containers, randomly placed in a chamber, for each temperature–exposure time combination. Four containers remained in each chamber for continuous (24 h/day–1) exposure to the chamber temperature.

The medium attained the chamber temperature within 4 h of placing into a chamber in all five chambers, with little variation in temperature during the exposure time (Fig. 1). Following removal from a chamber, the containers equilibrated to room temperature in <5 h. The gradual heating and cooling of the medium each day was intended to simulate temperature patterns observed in southern U.S. nurseries during summer months (Ingram, 1981; Martin and Ingram, 1988).

Before their initial placement into the chambers, containers were irrigated with 200 ml of a nutrient solution that contained (in mg-liter–1): 200 N–0–25 K as (NH4)2SO4, H3PO4, and KCl, respectively. After a 2-h drainage, an initial weight was recorded for each container. All containers were brought back to this initial weight by adding distilled water at the start of each 24-h period; this procedure was intended to keep medium moisture levels above that which might inhibit nitrification.

Every 5 days, the medium solution of each container was extracted by the pour-through procedure 2 h after the containers had been returned to their initial weight. Then containers were fertilized with 200 ml of the nutrient solution, drained for 1 h, and returned to the temperature-controlled chambers. This procedure was followed for 20 days, resulting in four extraction dates during the experiment. There were five replicate extracts for each temperature–exposure time combination, with the exception of the 24-h exposure, which had only four replications due to space limitations in the chambers. Medium solution extracts were analyzed for NH4-N and NO3-N using ion selective electrodes.

The medium solution pH (±SE) of a sampling from 10 containers was 5.9 ± 0.2. Although the optimum pH range for nitrification is thought to be 7 to 8 (Focht and Verstraete, 1977), nitrification readily occurs in a pine bark medium between pH 5 and 6 (Niemiera and Wright, 1986).

Incubation procedure. On the morning following the preincubation period, 24 containers were placed in each of five temperature-controlled chambers maintained at 28, 34, 40, 46, or 52 ± 0.3°C. The surface of each container was covered by a plastic disk to retard moisture loss from the medium. The containers in each chamber were gradually heated to their respective chamber temperature over = 4 h. Then five containers were selected randomly for removal from each chamber at intervals of 1, 2, 4, and 6 h after the medium attained the chamber temperature. Medium temperatures were monitored with a CR10 data acquisition system (Campbell Scientific, Logan, Utah) by soldered copper constantan thermocouples placed in the center of the medium in the five containers that were the last to be removed from a chamber.

Following removal from a chamber, the containers were held in a room with a 28°C day/22°C night cycle and were allowed to equilibrate to room temperature. This sequence was repeated every 24 h using the same five containers, randomly placed in a chamber, for each temperature–exposure time combination. Four containers remained in each chamber for continuous (24 h/day–1) exposure to the chamber temperature.

The medium attained the chamber temperature within 4 h of placing into a chamber in all five chambers, with little variation in temperature during the exposure time (Fig. 1). Following removal from a chamber, the containers equilibrated to room temperature in <5 h. The gradual heating and cooling of the medium each day was intended to simulate temperature patterns observed in southern U.S. nurseries during summer months (Ingram, 1981; Martin and Ingram, 1988).

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Results and Discussion

Medium solution NH₄-N concentration. The effects of temperature and daily exposure duration on the NH₄-N concentration in medium solution extracts were similar for all four extraction dates (Fig. 2). Medium solution concentrations of NH₄-N were low at 28 and 34°C for all daily exposure times and at 40°C for daily exposures of ≤6 h. The low NH₄-N concentrations in the medium solution, particularly after 15 and 20 days, indicate that, for these treatments, the availability of substrate (NH₄-N) did not exceed the oxidative capacity of the nitrifiers. Nitrification rates decline in mineral soil above the optimum of 26°C (Beck, 1983). In a pine bark medium supplied with NH₄-N, NO₃ accumulation rates were significantly lower at 40°C than at 30°C (Niemiera and Wright, 1987). Presumably in our study, the container medium exposed to 40°C for ≤6 h/day experienced lower, more optimum temperatures for sufficient periods during the five days between extractions to nitrify amounts of applied NH₄-N equivalent to that nitrified at 28 or 34°C. Alternatively, fluctuating medium temperatures may have stimulated nitrification as Campbell et al. (1973) reported in mineral soil.

On all extraction dates, the NH₄-N concentration in medium extracts from the 40°C treatments was higher for the 24-h-day⁻¹ exposure than for shorter exposure times (Fig. 2). This apparent nitrification inhibition (higher medium extract NH₄-N) caused by constant exposure to 40°C agrees with Niemiera and Wright’s (1987) results. On most days, there was a similar increase in NH₄-N for the 2-h-day⁻¹ exposure to 46°C, with greater increases for longer exposures to this temperature. The further nitrification inhibition by temperatures >40°C indicates that nitrification was not completely inhibited at 40°C, even after 20 days of constant exposure to this temperature.

The maximum level of NH₄-N concentration in medium solution extracts was found generally after 24 h-day⁻¹ exposure to 46°C or after 1 h-day⁻¹ exposure to 52°C, with no significant increases for longer exposures to 52°C. These results indicate that a short-term (1 h) daily exposure of the container medium to 52°C completely inhibited nitrification, but the effect at 46°C varied with the exposure duration. Beck (1983) found that the activity of nitrifying organisms ceased in mineral soil with incubation at 50°C. Ingram (1985) found similar temperature × exposure duration interactions on the root cell membrane thermostability of Pittosporum tobira Thunb. Using an electrolyte leakage model to describe these interactions, direct membrane injury was predicted for a 30-min exposure to 52.2°C or a 5-h exposure to 46.3°C. In our study, 46°C seemed to be a critical temperature for nitrification in a pine bark medium because NH₄-N increased at this temperature in direct proportion to the exposure duration.

Medium solution NO₃-N concentration. Medium solution NO₃-N concentrations decreased over time for all temperature–exposure time combinations (Fig. 2). The largest decreases in NO₃-N concentration generally corresponded to temperature-related increases in NH₄-N concentration, consistent with a nitrification inhibition. This relationship was strongly evident by day 15. At 46°C, the medium solution NO₃-N concentration decreased for exposures >2 h-day⁻¹ compared to that at lower temperature or exposure time. The lowest NO₃-N concentrations were associated with 24 h-day⁻¹ exposure to 46°C or any exposure of the medium to 52°C. Medium solution NO₃-N and NH₄-N concentrations were negatively correlated on day 15 (Fig. 3). By day 20, 1 h-day⁻¹ exposure to 52°C resulted in a medium solution NH₄-N:NO₃-N ratio that was >70 times higher than that which resulted from constant exposure to 28°C (Fig. 2).

Our results indicate that patterns of container medium temperature in southern U.S. nurseries in midsummer often are capable of inhibiting nitrification, thereby influencing the NH₄-N: NO₃-N ratio in the medium solution of plants fertilized with ammoniacal N. Medium temperature and exposure duration must
be considered in defining conditions that are critical for nitrification.

In this experiment, >6 h•day⁻¹ exposure to 40°C was required to inhibit nitrification in pine bark. Previous work has shown that the influence of 6 h•day⁻¹ exposure to 40°C on nitrification in pine bark can depend on the limestone amendment level (Walden, 1993), which encourages nitrification (Niemiera and Wright, 1986). A medium temperature of 46°C had the greatest interaction with exposure time on nitrification, with little inhibition for a short-term exposure (1 h•day⁻¹) and increasing inhibition for longer daily exposure times. Because nursery containers generally are at their maximum temperature for <1 h•day⁻¹ (Ingram, 1981; Young and Hammet, 1980), there likely will be no heat-induced elevation of medium solution NH₄⁻N concentration if maximum container temperatures do not exceed 46°C when ammoniacal N sources are used. Furthermore, when the maximum medium temperature in nursery containers does not exceed 46°C, medium temperature will not exceed 40°C for >6 h (Ingram, 1981; Martin and Ingram, 1992; Walden, 1993).

Southern U.S. nurseries producing plants that might be sensitive to elevated NH₄⁻N : NO₃⁻N ratios in the medium solution should adopt cultural practices that prevent maximum medium temperatures from exceeding 46°C. Alternatively, using fertilizers containing ≤50% NH₄⁻N in midsummer is advised. Additionally, when choosing a target maximum container medium temperature, it would be prudent to consider the many documented cases of negative growth responses of woody plants to root-zone temperatures near 40°C (Harrison et al., 1988; Johnson and Ingram, 1984; Martin et al., 1989; Ruter and Ingram, 1990; Yeager et al., 1991).

**Literature Cited**


