

# Nitrogen Form Affects pH and EC of Whole Pine Tree Substrate and Growth of Petunia<sup>1</sup>

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## Abstract

Wood-based substrates are potential alternatives or amendments to traditional peat-based and pine bark substrates. Undesirable changes in substrate pH may result from the application of supplemental fertilizer required by some crops grown in wood-based substrates. Experiments were conducted to evaluate petunia growth and substrate pH in response to nitrogen (N) treatments applied as a nutrient solution to whole pine tree (WPT) and peat-lite (PL) substrates. Nitrogen treatments were applied as 100% ammonium ( $\text{NH}_4^+$  N), 100% nitrate ( $\text{NO}_3^-$  N), or a combination of both in various proportions. The pH range of WPT substrate widened considerably over time among the N treatments, while a change in substrate pH was minimal for PL substrate during the same period. Generally, 100%  $\text{NO}_3^-$  N and 100%  $\text{NH}_4^+$  N resulted in the highest and lowest substrate pH, respectively, regardless of substrate. Greater shoot dry mass was obtained in PL substrates compared with WPT substrates. Maximum shoot dry mass and flower count with 'Celebrity Rose' petunia were obtained with the mixed N-form treatments in both substrates. Greater substrate air space and total porosity was associated with WPT substrates compared with PL substrates, the latter having greater container capacity.

**Index words:** growing media, peatmoss, *Pinus taeda*, ammonium, nitrate, plant nutrition, alternative substrate, *WholeTree*.

**Species used in this study:** 'Wave Purple' and 'Celebrity Rose' petunia (*Petunia* × *hybrida* Hort. ex E.Vilm.).

## Significance to the Nursery Industry

Wood-based substrates produced from pine trees have been identified as supplements to traditional container substrates. Several investigators have demonstrated the effectiveness of wood-based substrates for production of a variety of crops, with some crops requiring additional fertilizer for growth comparable to those produced in peat-based substrates. Wood-based materials have an inherently higher pH and reduced buffering capacity compared with pine bark and peatmoss, thus information regarding pH change over time would be beneficial to growers. Petunia growth and substrate pH was evaluated in response to nitrogen form in various proportions. In both substrates, an increase or decrease in pH was associated with increasing  $\text{NO}_3^-$  N or  $\text{NH}_4^+$  N proportions, respectively. Nitrogen form proportion had a more pronounced effect on substrate pH in WPT resulting in a wider pH range compared with PL over a 34-day period. Higher quality plants resulted from mixed N-forms in both substrates, so growers using high  $\text{NO}_3^-$  N or  $\text{NH}_4^+$  N fertilizers would need to closely monitor WPT substrate pH to minimize any negative crop responses due to high or low substrate pH. Additional research is required to identify methods for maximizing the buffering capacity of WPT substrates.

## Introduction

The wholesale value of the floriculture industry increased 35% from 1998 to 2004, yet has since remained stable (27). Reduced profitability, due in part to increased input costs, has forced producers to search for more affordable alternative materials, including container substrates. For over 30 years, peatmoss has been the predominant component of container substrates utilized for floriculture crop production. Canadian sphagnum peatmoss accounts for over 98% of the total peatmoss consumed by horticultural industries in the United States (28). In recent years, fuel prices have dramatically affected the cost of peatmoss, especially for producers in the Southeastern U.S. The Canadian Sphagnum Peat Moss Association indicated peatmoss shortages were likely in 2008 due to extremely rainy conditions during the spring harvest season (25). Converting to container substrates composed of a sustainable, regionally available material could alleviate a number of these issues. In order to compete with peatmoss, alternative materials should be cost competitive, be readily available, and have physical and chemical properties adequate to support plant growth. Acceptance and commercial utilization of alternative substrates will be influenced by results gathered from research of comparisons with peatmoss substrates.

Composted organic waste materials can be used in container substrates to attain ideal physical properties and as a source of organic matter and supplemental mineral nutrients (4, 26). Various comparative studies with traditional substrates demonstrated similar plant growth occurred in substrates composed of materials such as cotton gin compost, spent mushroom compost, and composted green wastes. Although composted materials work well as a substrate component, commonly substrates composed of > 50% composted material had undesirable physical properties or excessive soluble salt concentrations (8, 9). Additionally, many of these alternative materials are not widespread and growers have concerns about inconsistent quality and long-term availability of such materials (21).

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Substrates containing non-composted wood-based materials have been commercially available in Europe for many years. European wood-based materials contain > 50% wood, are made from various coniferous species, and are obtained from forestry operations or as waste from wood product manufacturing (24). In the United States, pine trees have been identified as an excellent source for wood-based materials for use in container substrates (11, 33). The raw material required for processing substrates can be readily obtained from harvesting operations at pine tree plantations throughout the Southeastern United States.

Processed whole pine trees contain about 80% wood, while processed pine logs may contain 90 to 100% wood. The effectiveness of processed whole pine trees as a container substrate for marigold (*Tagetes erecta* L.), petunia (*Petunia ×hybrida* Hort. ex E.Vilm), annual vinca (*Catharanthus roseus* (L.) G. Don), and Boston fern (*Nephrolepis exaltata* (L.) Schott 'Massii') production has been demonstrated (10, 11, 30). Container substrates derived from chipped pine logs have been successfully used for marigold, holly (*Ilex crenata* Thunb. 'Compacta'), and azalea (*Rhododendron indicum* (L.) Sweet) production (15, 32).

Some crops grown in wood-based substrates require supplemental fertilizer for optimum growth compared with plants grown in a PL or PB substrate. A nutrient starter charge of fertilizer was required to achieve similar petunia growth in a 100% whole pine tree (WPT) substrate compared with a PL substrate (11). In the same study, similar petunia growth was achieved in a 75% WPT substrate, compared with a PL substrate, when a starter charge (7N-1.3P-8.3K) of at least 2.37 kg·m<sup>-3</sup> (4 lbs·yd<sup>-3</sup>) was used. Similar growth of holly and azalea was obtained in chipped pine log (CPL) and PB substrates when a 29% (holly) to 40% (azalea) greater rate of fertilizer was applied to CPL (15). An additional 100 ppm N from a soluble fertilizer (20N-4.4P-16.6K) was required to achieve similar growth of chrysanthemum in a CPL substrate compared with a PL substrate (33).

Increased fertilizer application rates/concentrations can affect substrate pH over time and subsequently affect plant growth. Nitrogen (N), the predominant nutrient in commercial fertilizers, is supplied in various forms including ammonium (NH<sub>4</sub><sup>+</sup> N), nitrate (NO<sub>3</sub><sup>-</sup> N), and urea. Generally, a high NH<sub>4</sub><sup>+</sup> N fertilizer will cause substrate pH to decrease over time while a high NO<sub>3</sub><sup>-</sup> N fertilizer will cause substrate pH to increase over time (1). Other factors can affect substrate pH including fertilizer type, irrigation water alkalinity, lime type and application rate, substrate buffering capacity, and plant species being grown (1, 3). Growers can modify substrate pH by applying a different type of fertilizer, although the degree of change will be affected by the aforementioned factors. As a result, a better understanding of the relationship between N-form and wood-based substrate pH would be beneficial.

Growers considering a wood-based substrate should know whether switching substrates will require a dramatic change in fertilizer management practices. The objective of this study was to evaluate the effect of N-form proportion on substrate pH and electrical conductivity (EC), and growth of petunia in PL and WPT substrates.

## Materials and Methods

Experiments were conducted at the USDA-ARS Southern Horticultural Laboratory in Poplarville, MS. In January

2007, 12-year-old loblolly pine (*Pinus taeda* L.) trees were fed through a portable heavy-duty horizontal grinder with 10.19 cm (4 in) screens (Peterson 4700B; Peterson Pacific Corp. Eugene, OR) and the resulting material was stored outside in full sun. In April 2007, the material was further processed through a hammer mill (C.S. Bell No. 30, Tiffin, OH) fitted with a 0.47 cm (0.19 in) screen and stored in 1.8 m<sup>3</sup> (2.4 yd<sup>3</sup>) polypropylene bulk bags placed under a canopy. Two experiments were conducted to compare the resulting WPT substrate to an industry standard PL substrate of fine professional sphagnum peatmoss:coarse horticultural perlite:fine vermiculite (8:1:1, by vol). The two experiments were conducted in a similar manner, but differing in the time of year, cultivar used, and storage duration of the WPT material. While mixing, all substrates were treated with a surfactant at 77.8 mL·m<sup>-3</sup> (2 oz·yd<sup>-3</sup>) (Aqua-Gro L, The Scotts Co., Marysville, OH) and amended with 2.97 kg·m<sup>-3</sup> (5 lbs·yd<sup>-3</sup>) pulverized dolomitic limestone, 0.59 kg·m<sup>-3</sup> (1 lb·yd<sup>-3</sup>) gypsum and 0.89 kg·m<sup>-3</sup> (1.5 lbs·yd<sup>-3</sup>) Micromax (The Scotts Co.). On May 7, 2007 (Expt. 1), substrates were mixed and 1.21-liter containers (05.50AZ TRAD CX; Dillen Products, Middlefield, OH) were uniformly filled to the lip with substrate and each planted with three 'Wave Purple' petunia plugs grown in 288-cell flats (PLG2880; ITML Horticultural Products Inc.). On October 11, 2007 (Expt. 2), substrates were mixed and 1.22-liter containers (SP-525; East Jordan Plastics Inc., East Jordan, MI) were uniformly filled to the lip with substrate and each planted with two 'Celebrity Rose' petunia plugs grown in 288-cell flats. Containers were placed on elevated benches inside a polycarbonate-covered greenhouse. 'Wave Purple' petunia has a spreading growth habit, thus 'Celebrity Rose' (compact, upright growth habit) petunia was chosen for Expt. 2 to reduce the required bench space.

Plants were hand irrigated with municipal water (pH = 6.64; alkalinity = 33 mg·liter<sup>-1</sup>) as needed by supplying small amounts of water over multiple applications to maintain adequate moisture (based on container weight) and minimize runoff. Nutrient solutions contained N, phosphorus (P), and potassium (K) at 300, 150 and 300 ppm, respectively. The 300 ppm N concentration was chosen to achieve maximum plant growth in WPT, based on previously published reports for wood-based substrates (14, 33). Five N treatments were supplied as different proportions of ammonium (NH<sub>4</sub><sup>+</sup> N) and nitrate (NO<sub>3</sub><sup>-</sup> N) obtained from (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub>, and NH<sub>4</sub>NO<sub>3</sub>. The N treatments were 100% NH<sub>4</sub><sup>+</sup> N (100NH<sub>4</sub>), 75% NH<sub>4</sub><sup>+</sup> N:25% NO<sub>3</sub><sup>-</sup> N (75NH<sub>4</sub>:25NO<sub>3</sub>), 50% NH<sub>4</sub><sup>+</sup> N:50% NO<sub>3</sub><sup>-</sup> N (50NH<sub>4</sub>:50NO<sub>3</sub>), 25% NH<sub>4</sub><sup>+</sup> N:75% NO<sub>3</sub><sup>-</sup> N (25NH<sub>4</sub>:75NO<sub>3</sub>), and 100% NO<sub>3</sub><sup>-</sup> N (100NO<sub>3</sub>). In each nutrient solution, P and K (obtained from KH<sub>2</sub>PO<sub>4</sub> and KCl) concentrations were the same. Five stock solutions were prepared, diluted at a 1:50 ratio and applied to individual containers every 2-3 d (18 total applications for each experiment) in volumes of 100 mL (3.4 oz) [1-16 d after planting (DAP), Expt. 1; 1-27 (DAP), Expt. 2] or 130 mL (4.4 oz) [17-31 DAP, Expt. 1; 28-35 DAP, Expt. 2]. Nutrient solution was applied to moist substrates to maximize absorption. Moisture content of each container (container weight) was determined 2 h prior to nutrient solution application. Nutrient solution volume was increased to reflect plant growth and increased water absorption.

In each experiment, initial substrate pH and EC were measured (Accumet Excel XL50; Fisher Scientific, Pittsburgh,



PA) from samples collected from empty containers using the pour-through method (31). Subsequent pH and EC analyses were conducted at 8, 15, 22, 29, and 34 (Expt. 1) or 36 DAP (Expt. 2). At 34 (Expt. 1) or 39 DAP (Expt. 2), flower count (flowers and buds showing color) and leaf chlorophyll content (SPAD 502 Chlorophyll Meter; Minolta Camera Co., Ramsey, NJ) were recorded. Substrate shrinkage was measured (in centimeters) at a single location from the top lip of the container to the upper surface of the substrate. Visual root ratings of roots covering the outer surface of the container substrate were recorded on a scale of 0 (no visible roots) to 5 (roots visible over the entire area). Plant shoots were harvested at the upper surface of the substrate, oven-dried at 65C (149F) for 72 h and weighed. Petunia foliar samples were analyzed for N, P, K, Ca, Mg, S, B, Fe, Mn, Cu, Zn, and Al (data not shown). Substrate air space (AS), container capacity (CC), total porosity (TP), and bulk density (BD) were determined using the North Carolina State University porometer method (12), from substrate samples collected prior to planting.

Containers were arranged in a randomized complete block design, with four replications containing three subsamples per treatment. Quadratic, cubic, and interaction terms were selected for inclusion in linear models modeling substrate pH and EC, SPAD Index, shoot dry mass, root ratings, substrate shrinkage, and flower count using stepwise, forward, and backward selection procedures with the REG procedure of SAS (Version 9.1.3; SAS Institute, Inc., Cary, NC). Final data analyses for these response variables were conducted using linear mixed models with the MIXED procedure of SAS; the results are shown as projected means. Two-sample pooled t-tests were conducted to determine whether AS, CC, TP, and BD were different for WPT and PL.

## Results and Discussion

Substrate pH at 0 DAP in Expt. 1 was 5.2 and 6.6, respectively, for PL and WPT. Non-amended substrates in Expt. 2 had a pH of 4.4 (PL) and 5.8 (WPT), while 0 DAP substrate pH was 5.0 (PL) and 6.3 (WPT). In Expt. 1, the overall pH range increased (for each substrate) between 8 and 34 DAP (Fig. 1A). The WPT substrate pH ranged from 5.4 to 6.9 and 5.6 to 7.6 at 8 and 34 DAP, respectively; while the PL substrate pH ranged from 4.8 to 5.0 and 4.7 to 5.1 at 8 and 34 DAP, respectively. In Expt. 2, the substrate pH range at 36 DAP (Fig. 1B) was much broader than at 8 DAP for both substrates. The WPT substrate pH ranged from 5.9 to 6.2 and 5.2 to 7.7 at 8 and 36 DAP, respectively. The PL substrate pH ranged from 5.1 to 5.2 and 5.0 to 5.9 at 8 and 36 DAP, respectively. At project termination, 100NO<sub>3</sub> resulted in the highest substrate pH for WPT and PL in both experiments. The lowest substrate pH at project termination resulted from 75NH<sub>4</sub>:25NO<sub>3</sub> for both substrates in Expt. 1, while 100NH<sub>4</sub> resulted in the lowest substrate pH for both substrates in Expt. 2.

A substrate pH of 5.4 to 6.0 is recommended for petunia production (3, 18). The PL substrate pH (among all N-form treatments) remained below or within this range throughout both experiments, while WPT substrate pH (among all N-form treatments) remained within or above this range in both experiments. Wood-based substrates have a greater inherent pH compared with peat-based substrates (14, 16, 33). Therefore, a dolomitic limestone amendment may not be required for certain crops grown in WPT.

Predicted means were included to provide a clear illustration for pH response to N-form over time. The increase or decrease in substrate pH over time was primarily a result of the N-form treatment applied and was consistent with previously published research (2, 7). Hydrogen ions are released into the substrate solution during NH<sub>4</sub><sup>+</sup> N absorption into plant roots, and from nitrification of ammonium to nitrate, causing a decrease in substrate pH. Hydroxyl ions are released into the substrate solution during NO<sub>3</sub><sup>-</sup> N absorption in plant roots, causing an increase in substrate pH. In both experiments, petunia plants were most likely able to absorb NH<sub>4</sub><sup>+</sup> N and NO<sub>3</sub><sup>-</sup> N, regardless of substrate.

The PL substrate exhibited a greater buffering capacity, compared with WPT, by maintaining a narrower gap between the least and greatest substrate pH at corresponding sampling dates throughout both experiments. Broader pH ranges of wood-based substrates compared with peat- or pine bark-based substrates have been reported when various fertilizer rates/concentrations were administered (11, 14, 15, 16), yet a detailed account of changes in pH over multiple (> 3) sampling dates has not been previously presented. The data obtained from our experiments was used to provide a more detailed representation of PL and WPT substrate pH range over time. Changes in substrate pH due to N-form treatment occurred more quickly and to a greater degree in WPT compared with PL in both experiments.

Substrate EC was greater overall for the PL substrate (among all N-form treatments) compared with the WPT substrate during the first two weeks of both experiments (Fig. 1C and D). Final EC was lower than initial EC among all N-form treatments in both experiments, except for 100NH<sub>4</sub> and 75NH<sub>4</sub>:25NO<sub>3</sub>. For 100NH<sub>4</sub>, final EC was equal or slightly higher than the initial EC for both substrates, except WPT in Expt. 1. For 75NH<sub>4</sub>:25NO<sub>3</sub>, final EC was slightly higher than the initial EC for PL. Predicted means were used to more clearly illustrate changes in substrate EC among N-form treatments over time.

A substrate EC between 2.0 and 3.5 dS·m<sup>-1</sup> is recommended for a greenhouse petunia crop (6). In Expt. 1 from 8 to 22 DAP, PL substrate EC (among all N-form treatments) was within or above this range while WPT substrate EC (among all N-form treatments) was within or below this range. In Expt. 2, all N-form treatments were within or above the recommended range throughout the experiment, except for the mixed N-form treatments at 29 and 36 DAP. Substrate EC fluctuated among all N-form treatments throughout the experiment, yet initial and final EC were similar for 100NH<sub>4</sub> (within each substrate) in both experiments. A lower EC in wood-based substrates when compared with peat-based substrates has been previously reported, the higher EC associated with PL commonly was attributed to a greater CEC and CC (11, 14, 16, 33).

In both experiments, leaf chlorophyll content (SPAD index) was greatest for 75NH<sub>4</sub>:25NO<sub>3</sub> in WPT substrate and 100NH<sub>4</sub> in PL substrate (Fig. 2A and B). In Expt. 1, mixed N-form treatments resulted in greater SPAD index for plants grown in WPT substrate compared with those grown in PL substrate, while the opposite was true for 100NH<sub>4</sub> and 100NO<sub>3</sub>. SPAD index was overall greater for plants grown in PL substrate in Expt. 2. Generally, SPAD index increased with the NH<sub>4</sub><sup>+</sup> N proportion for both substrates in the two experiments. Limited data is available for how chlorophyll content is affected by N-form, but darker green leaves and a

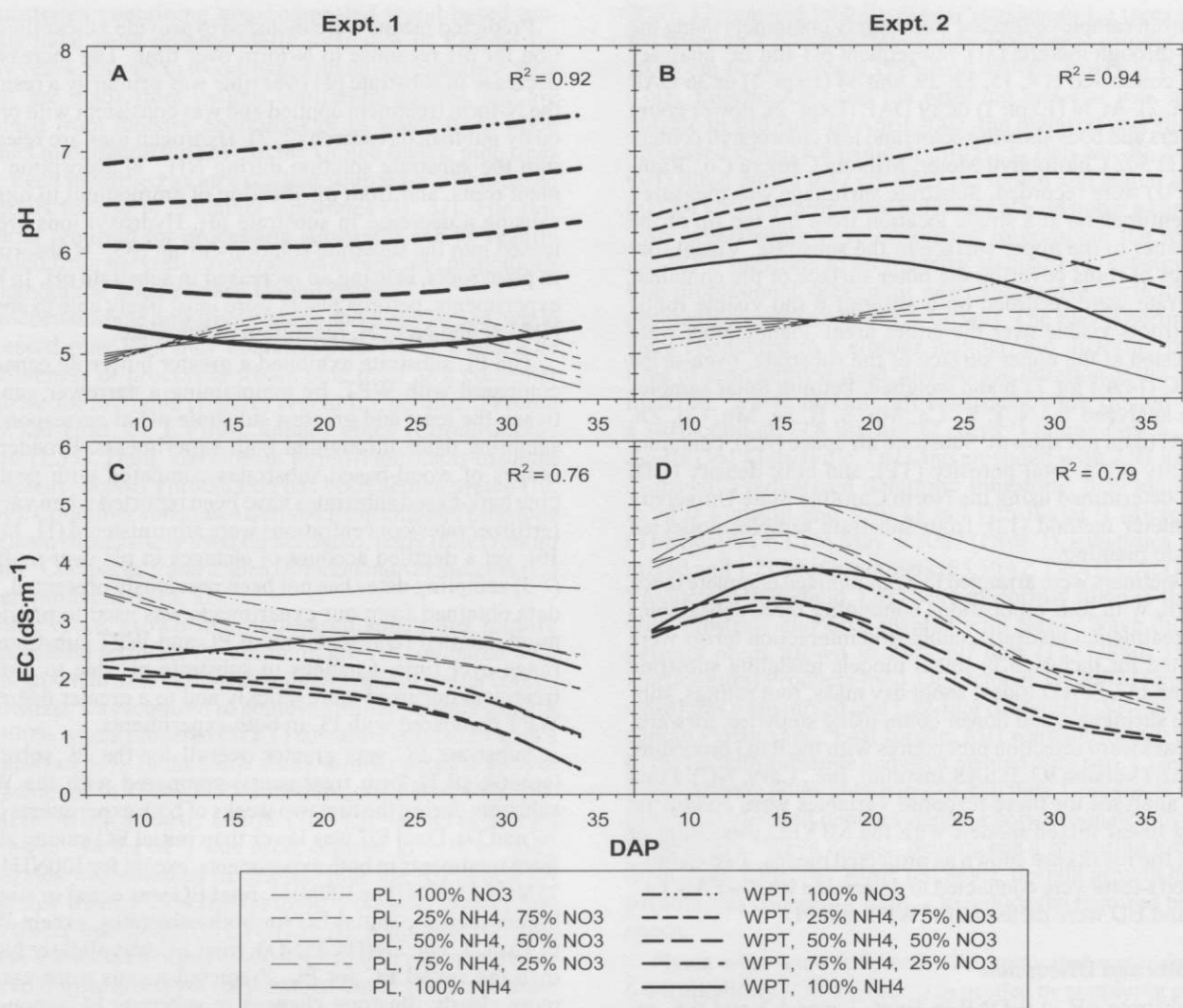


Fig. 1. Predicted means for substrate pH and electrical conductivity (EC) as affected over time (DAP = days after planting) by nitrogen form [ammonium ( $\text{NH}_4^+$  N) and nitrate ( $\text{NO}_3^-$  N)] proportions in a peat-lite (PL) or whole pine tree (WPT) substrate. Substrate pH was analyzed from leachate obtained weekly for each treatment ( $n = 4$ ) using the pour-through method. 'Wave Purple' petunia was used in Expt. 1, which began on May 7, 2007. 'Celebrity Rose' petunia was used in Expt. 2, which began on October 11, 2007.

greater SPAD index have been reported for tomato (*Solanum lycopersicum* L.) and pecan (*Carya illinoensis* Wangenh. K. Koch) plants grown under greater  $\text{NH}_4^+$  N: $\text{NO}_3^-$  N ratios (19, 23).

Shoot dry mass was greater (within individual N-form treatments) for PL substrate compared with WPT substrate in both experiments (Fig. 2C and D). Similarly, PL substrate resulted in higher root ratings compared with WPT substrate for each N-form treatment (Fig. 2E and F). Shoot dry mass decreased slightly with increasing  $\text{NH}_4^+$  N proportion for both substrates in Expt. 1, while the mixed N-form treatments produced the greatest shoot dry mass for both substrates in Expt. 2. Maximum predicted mean shoot dry mass occurred at 55 and 43%  $\text{NH}_4^+$  N for WPT and PL, respectively, in Expt. 2. Root ratings followed the same trend as shoot dry mass in respective experiments. In Expt. 2, maximum predicted mean root rating for both substrates was between 35 and 48%  $\text{NH}_4^+$  N. The greater shoot dry mass observed for the PL substrate, compared with the WPT substrate, is similar to results of previous evaluations of wood-based substrates

involving various fertilizer rates applied as a nutrient starter charge or water-soluble fertilizer (11, 33).

Many plants have the ability to absorb multiple forms of nitrogen, yet the N-form required for optimum plant growth and development varies by plant species (13, 19, 29). Jeong and Lee (17) reported petunia and several other bedding plant species grew best when fertilized with equal proportions of  $\text{NH}_4^+$  N and  $\text{NO}_3^-$  N. In the same study, 100%  $\text{NH}_4^+$  N fertilization resulted in the greatest growth of ageratum (*Ageratum houstonianum* Mill.) while celosia (*Celosia* sp.) grew best under 100%  $\text{NO}_3^-$  N fertilization. In our study, foliar N content was below the recommended range (20) for all plants sampled in Expt. 1, but within the recommended range for those sampled in Expt. 2 (data not shown). Increased foliar N content did not necessarily result in greater shoot dry mass or leaf chlorophyll content, yet petunia plants had the ability to acquire N regardless of the N-form applied.

Overall, WPT substrate had greater shrinkage compared with PL substrate (Fig. 2G and H). The WPT substrate shrinkage increased slightly with increasing  $\text{NH}_4^+$  N propor-

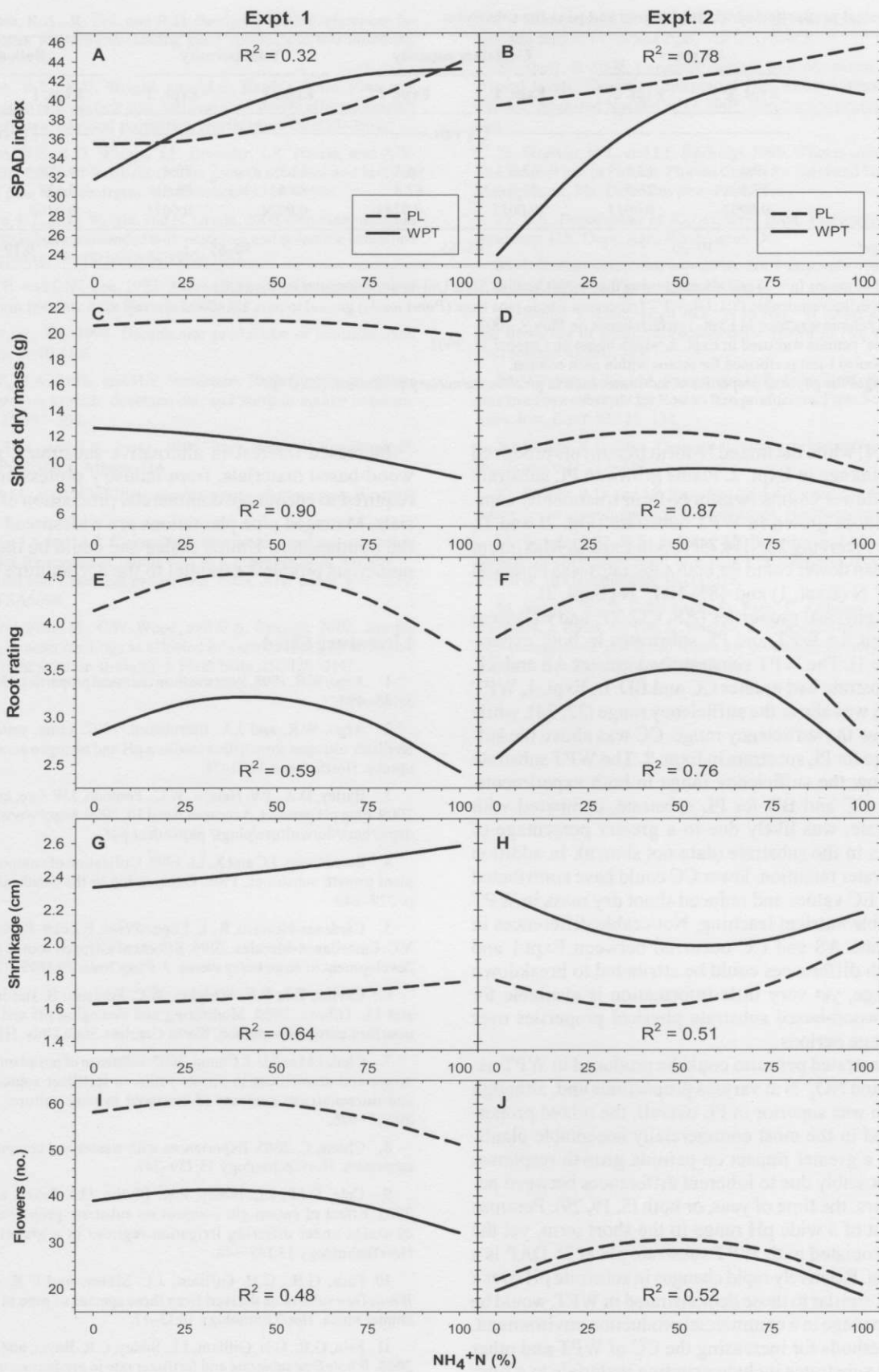


Fig. 2. Predicted means for petunia leaf chlorophyll content (SPAD Index), shoot dry mass, root rating, substrate shrinkage, and flower count at 34 DAP (Expt. 1) and 39 DAP (Expt. 2) as affected by nitrogen form [ammonium ( $\text{NH}_4^+\text{N}$ ) and nitrate ( $\text{NO}_3^-\text{N}$ )] proportions in a peat-lite (PL) or whole pine tree (WPT) substrate. 'Wave Purple' petunia was used in Expt. 1, which began on May 7, 2007. 'Celebrity Rose' petunia was used in Expt. 2, which began on October 11, 2007.



**Table 1. Physical properties<sup>a</sup> of whole pine tree and peat-lite substrates.**

Substrate <sup>b</sup>	Air space		Container capacity		Total porosity		Bulk density	
	Expt. 1 <sup>c</sup>	Expt. 2 <sup>d</sup>	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
	(% vol)				(g·cm <sup>-3</sup> )			
PL	19.4	13.5	62.9	66.8	82.3	80.4	0.188	0.202
WPT	47.5	26.0	42.0	62.8	89.4	88.8	0.128	0.158
<i>P</i> values <sup>e</sup>	0.0002	0.0015	0.0015	0.0263	0.0024	0.0011	0.0100	0.0041
Sufficiency range <sup>u</sup>	10–30		45–65		50–85		0.19–0.70	

<sup>a</sup>Data presented as means (n = 3) and obtained using the North Carolina State University porometer method (12).

<sup>b</sup>PL [peatmoss:perlite:vermiculite (8:1:1)]; WPT [processed whole pine trees (*Pinus taeda*) ground to pass a 0.47-cm screen].

<sup>c</sup>Wave Purple<sup>®</sup> petunia was used in Expt. 1, which began on May 7, 2007.

<sup>d</sup>Celebrity Rose<sup>®</sup> petunia was used in Expt. 2, which began on October 11, 2007.

<sup>e</sup>Two sample, pooled t-test performed for means within each column.

<sup>u</sup>Sufficiency ranges for physical properties of substrates used in greenhouse/nursery production (22, 34).

tion in Expt. 1, while the mixed N-form treatments produced the least shrinkage in Expt. 2. Plants grown in PL substrate had greater flower counts (within N-form treatments) compared with those grown in WPT substrate (Fig. 2I and J), except those receiving 25NH<sub>4</sub>:75NO<sub>3</sub> in Expt. 2. Maximum projected mean flower count for both substrates was observed at 33% NH<sub>4</sub><sup>+</sup> N (Expt. 1) and 48% NH<sub>4</sub><sup>+</sup> N (Expt. 2).

Substrate physical properties (AS, CC, TP, and BD) were each different for WPT and PL substrates in both experiments (Table 1). The WPT substrate had greater AS and TP, while PL substrate had greater CC and BD. In Expt. 1, WPT substrate AS was above the sufficiency range (22, 34), while CC was below the sufficiency range. CC was above the sufficiency range for PL substrate in Expt. 2. The WPT substrate BD was below the sufficiency range in both experiments. The greater CC and BD for PL substrate, compared with WPT substrate, was likely due to a greater percentage of fine particles in the substrate (data not shown). In addition to reduced water retention, lower CC could have contributed to the lower EC values and reduced shoot dry mass in WPT due to possible nutrient leaching. Noticeable differences in WPT substrate AS and CC occurred between Expt.1 and Expt. 2. Such differences could be attributed to breakdown during storage, yet very little information is available for changes to wood-based substrate physical properties over various storage periods.

We demonstrated petunias could be produced in WPT using NH<sub>4</sub><sup>+</sup> N and NO<sub>3</sub><sup>-</sup> N at various proportions and, although plant growth was superior in PL overall, the mixed proportions resulted in the most commercially acceptable plants. N-form had a greater impact on petunia growth responses in Expt. 2, possibly due to inherent differences between petunia cultivars, the time of year, or both (5, 19, 29). Petunias were tolerant of a wide pH range in the short term, yet the disparity associated with WPT substrate pH at 35 DAP is a valid concern. Relatively rapid changes in substrate pH over a short period, similar to those demonstrated in WPT, would be difficult to manage in a commercial production environment. Proposed methods for increasing the CC of WPT and other wood-based substrates include grinding materials to a finer particle size, blending of different sizes, or amending with peatmoss (11, 33). Developing WPT with improved buffering capacity and a greater CC would help alleviate undesirable changes in substrate pH, while improving water and nutrient retention properties.

Increased interest in alternative substrates, specifically wood-based materials, from industry professionals will be required to encourage commercial production of such materials. Managed pine plantations are widespread throughout the Southeastern United States and could be the source for numerous products essential to the horticulture industry.

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