Effect of Micronutrient Rate on the Growth of Containerized *Quercus palustris* Seedlings in Pine Bark

by

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(ABSTRACT)

The objectives for this research were to determine: 1) the rate of Micromax which will produce maximum growth of pin oak (*Quercus palustris* Münchh.), a landscape tree which has shown a previous growth response to the addition of Micromax at the manufacturer's recommended rate, 2) which micronutrient(s) are most associated with maximum growth, and 3) the rate of Fe, Mn, Zn, and Cu required to produce maximum growth of *Q. palustris*. *Q. palustris* seedlings were container-grown in pine bark amended with the following rates of Micromax: 0, 0.15, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$ in 2000, 2001, and 2002. For all three years, the maximum growth was obtained at rates near the manufacturer's recommended rate of 0.9 $kg \cdot m^{-3}$. A micronutrient mix was

formulated by increasing the levels of Zn, Mn, Fe, and Cu individually while holding the other micronutrients constant based on the grams of each micronutrient that would be added at the 0.9 $kg \cdot m^{-3}$ rate of Micromax. The increasing rates of Zn, Mn, Fe, and Cu were based on the grams of each micronutrient contained in Micromax at 0, 0.15, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$ for 2001 and 0, 0.45, 0.9, or 1.8 $kg \cdot m^{-3}$ for 2002. In addition, Cu, Fe, Mn, and Zn were also applied alone to pine bark at rates of 0, 0.45, 0.9, or 1.8 $kg \cdot m^{-3}$ without the addition of any other micronutrients. Holding all other micronutrients constant and increasing the rate of one micronutrient did not increase growth. However, when Cu, Fe, Mn, or Zn was added to pine bark alone at increasing rates, growth increased. For Cu and Zn, the growth increase was linear suggesting that a higher rate of Cu and Zn than that provided by Micromax at the manufacturer's recommended rate might be advantageous.

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INTRODUCTION

Micronutrients are commonly added to organic substrate for the production of containerized nursery crops. Several studies have shown the addition of micronutrients to be beneficial to plant growth (Reavis et al, 1980; Whitcomb, 1979a, 1979b; Wright et al, 1999a, 1999b). However, some researchers have found micronutrients to have no effect on growth, or to be detrimental to plant growth (Leda, 1986; Wright and Hinesley, 1991). Although adding micronutrients to organic substrate does not always increase growth, micronutrients are essential for plant growth.

The following are functions of select micronutrients used in this study. Iron is a component of enzyme systems which aid electron transport, chlorophyll formation, and the terminal oxidation step in respiration. In addition, iron is required for NADP production, NO_3 and SO_4 reduction, and N_2 assimilation. Manganese plays a role in the oxidation-reduction processes in electron transport and is essential for photolysis in photosystem II. Similarly, copper also plays an important role in photosynthesis. It is part of the electron transport system which links photosystem I and photosystem II and is a constituent of plastocyanin, a protein in the chloroplast. Copper is also involved in carbohydrate and protein metabolism and N fixation (Jones 1998). Zinc activates the enzyme carbonic anhydrase in the chloroplast, which is responsible for hydrolysis and hydration reactions of carbonyl groups (Mengel and Kirkby, 1987). Lastly, boron plays a

role in the synthesis of uracil in RNA and is also involved with cell division, differentiation, growth, and respiration (Jones, 1998).

Micronutrients can be supplied to a plant as a liquid or soluble granular fertilizer, a slow release fertilizer, or as a foliar spray. Since most woody ornamental nurseries use soilless media such as pine bark, micronutrients supplied by the substrate may not be available in sufficient amounts for maximum plant growth. Therefore, several fertilizer companies have manufactured micronutrient fertilizers. Broschat and Donselman (1985) found levels of micronutrients supplied by several micronutrient fertilizers, including Micromax (O.M. Scott, Marysville, Ohio), to be relatively constant in the substrate over an 18 month period.

In a commercial nursery, micronutrients are normally applied in a sulfate or chelate form. Chelates are organic compounds which bind with metals such as Zn, Fe, Mn, and Cu to protect them from precipitation reactions or substrate adsorption, thus increasing their availability to the plant (Brady and Weil, 1996), whereas sulfate forms are more easily adsorbed by soil colloids and organic matter, rendering them unavailable. However, Whitcomb (1983) points out several problems with chelating agents. First, chelating agents are broken down by microorganisms and therefore, micronutrient availability may only last a few months. Secondly, elements in a chelated form may be replaced by another element with a higher degree of affinity. Lastly, chelates are very expensive.

Although micronutrients are essential, research has shown conflicting results in growth from the addition of micronutrients to several different types of soiless substrates. Several studies show that micronutrient additions are beneficial to plant growth. Wright et al. (1999b) showed that the addition of micronutrients to nine landscape species grown in pine bark increased shoot height and dry weight when Micromax was applied at a rate of 0.9 $kg \cdot m^{-3}$. In a second study by Wright et al. (1999a), the shoot dry mass and height of *Koelreuteria paniculata* Laxm. seedlings were 74% and 56% higher, respectively, when grown in pine bark amended with 0.9 $kg \cdot m^{-3}$ of Micromax compared to the unamended control. Applying micronutrients at 0.45 $kg \cdot m^{-3}$, along with 5.3 $kg \cdot m^{-3}$ of Osmocote 18-6-12 to a substrate which consisted of 1:1 peat:perlite increased growth of *Pistacia chinensis* Bunge. and *Pinus thunbergii* Parl. compared to applying 0 or 5.3 $kg \cdot m^{-3}$ of Osmocote and 0, 0.9, or 1.78 $kg \cdot m^{-3}$ of Micromax (Whitcomb, 1979b). Similarly, *Ulmus parvifolia* Jacq., *Platanus acerifolia* Ait., *Acer saccharum* Marshall., *and Pinus thubergii* seedlings grew more rapidly when amendments of 0.59 $kg \cdot m^{-3}$ of Micromax and 5.3 $kg \cdot m^{-3}$ of Osmocote 18-6-12 were applied to a substrate composed of 2:1:1 bark:peat:perlite than treatment combinations of 1.8 or 3.6 $kg \cdot m^{-3}$ of Osmocote and 0 or 1.78 $kg \cdot m^{-3}$ of Micromax (Reavis et al., 1980). In addition to increasing growth, Micromax at rates of 0.59, 1.19, and 1.78 $kg \cdot m^{-3}$, along with 8.3 $kg \cdot m^{-3}$ Osmocote, 4.7 $kg \cdot m^{-3}$ dolomite, and 0.9 $kg \cdot m^{-3}$ 0-46-0, increased the quality and the number of liners with new growth of *Ilex crenata* Thunb., *Juniperus chinensis* 'Hetzi", and *Rhododendron spp.* 'Fashion' grown in a 2:1:1 substrate of pine bark:peat:sand (Whitcomb, 1979a).

Despite the numerous positive effects of applying micronutrients, several studies have shown a negative response from the additions of micronutrients. For example, Wright and Hinesley (1991) found that applications of micronutrients (Micromax at 0, 0.5, 1.0, and 1.5 $kg \cdot m^{-3}$) to 5:1 pine bark:sand reduced shoot growth of *Juniperus virginiana* L. Furthermore, eastern redcedar which did not receive micronutrients, were healthy and had maximum root growth. *Juniperus chinensis procumbens* 'Nana', *Ilex crenata* 'Helleri', and *Ligustrum lucidum* Ait. grown in pine bark amended with 2 $kg \cdot m^{-3}$ of dolomitic lime and 14 g of Osmocote 18-6-12 per pot, were amended with Na_2FeEDTA and Na_2MnEDTA at ratios of Fe:Mn at 0.25:0.125 ppm and 0.125:0.25 ppm at concentrations of 1x, 2x, 6x, 12x, and 24x. However, *Juniperus chinensis procumbens* 'Nana', *Ilex crenata* 'Helleri', and *Ligustrum lucidum* did not respond to different rates and ratios of applied Fe and Mn (Leda, 1986).

In addition to increases in growth, additions of micronutrients have been found to increase substrate solution concentrations of micronutrients. Wright et al. (1999b) noted that additions of micronutrients without amending the substrate with limestone increased Fe, Mn, Cu, and Zn concentrations in pine bark. For instance, copper solution concentration was 400% higher in pine bark amended with 0.9 $kg \cdot m^{-3}$ Micromax compared to the unamended control. Furthermore, Fe solution concentrations were 165% higher with additions of Micromax compared to the unamended control. In contrast, Wright and Hinesley (1991) noted that adding micronutrients to 5:1 pine bark:sand substrate mix did not influence Fe levels in the substrate solution, but did however

increase Mn levels. A study by Niemiera (1992) found that Fe and Zn concentrations in pine bark (*Pinus taeda* L.) was similar to the concentration of extracted bark solution amended with Micromax. The author concluded that pine bark supplies sufficient amounts of micronutrients for growth. Likewise, Leda (1986) concluded that pine bark supplies sufficient amounts of Fe and Mn for proper plant growth.

The addition of micronutrients to the substrate has also been shown to increase concentrations of micronutrients in leaf and shoot tissue. Additions of micronutrients increased Zn and Cu concentrations in leaf tissue of *Prosopis grandulosa* Torr. by 15 ppm Zn and 8 ppm Cu compared to the unamended control (Cline et al., 1986). In addition, Leda (1986) found shoot tissue Fe concentrations in *Juniperus chinensis procumbens* 'Nana' treated with 24 times more micronutrients than the control, to be 14.7-20 ppm higher. *Ilex crenata* 'Helleri' treated with 24 times more micronutrients than the control had shoot levels which were 53-56 ppm of Fe and 35-39 ppm of Mn higher than the control.

Different rates and ratios of micronutrients have also been studied to increase plant growth. Oonk and Whitcomb (1980) found that *Juniperus procumbens* Miq. grown in 3:1:1 bark:peat:sand, had maximum growth at high rates of Cu, low rates of B, and high rates of Fe. *Ilex crenata* 'Hetzi' and *Rhododendron* x 'Festive' obtained maximum growth at intermediate rates of Fe and high rates of Cu and Mn. Whitcomb et al. (1981) found the fresh top weight of *Pyracantha spp.* 'Watereri' grown in 1:1 Canadian peat:sand increased significantly with high rates of Fe, B, and Cu and low rates of Mn.

The authors concluded that Zn had little to do with increasing growth. In all cases, maximum plant growth was achieved only when Mn was applied at a low rate. However, as mentioned before, *Juniperus chinensis procumbens* 'Nana', *Ilex crenata* 'Helleri', and *Ligustrum lucidum* grown in pine bark did not respond to amendments of Na_2FeEDTA and Na_2MnEDTA at ratios of Fe:Mn at 0.25:0.125 ppm and 0.125:0.25 ppm at concentrations of 1x, 2x, 6x, 12x, and 24x (Leda, 1986).

Much of the research previously mentioned tries to optimize growth by supplying the manufacturer's recommended rate of proprietary micronutrient products to the substrate (Wright et al, 1999a, 1999b; Whitcomb, 1979b). However, there are few studies which investigate applying various rates of these products on plants that have shown a growth response to these products. In addition, there is a lack of information on individual micronutrient application rates to maximize growth. Therefore, the objectives for this research were to determine: 1) the rate of Micromax which will produce optimal growth of *Quercus palustris*, a landscape tree which has shown previous growth response to the additions of Micromax at the manufacturer's recommended rate 2) which micronutrient(s) are most associated with maximum growth and 3) which rates of Fe, Mn, Zn, and Cu will produce maximum plant growth.

MATERIALS AND METHODS

Micromax

Experiment 1. Pin oak (*Quercus palustris* Münchh.) was grown in pine bark (*Pinus taeda*, Summit Bark Plant, Waverly, VA), with an initial pH of 5.1. Pine bark was amended pre-plant with Micromax (O.M. Scott, Marysville, Ohio) which had the following composition: 12% S, 0.1% B ($Na_2B_4O_7$), 0.5% Cu ($CuSO_4$), 12% Fe ($FeSO_4$), 2.5% Mn ($MnSO_4$), 0.05% Mo (Na_2MoO_4), and 1% Zn ($ZnSO_4$). Treatment rates were 0, 0.15, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$. The 0.9 $kg \cdot m^{-3}$ rate is the manufacturer's recommended rate for nursery crops grown in pine bark. Micromax was incorporated by hand before placing the substrate in 11.4-L containers.

Treatments were assigned in a complete randomized design and replicated 6 times. Oak seeds were cold stratified for 8 weeks. Twenty stratified seeds (Sheffield Seed Company, Inc., Locke, N.Y.) per container were sown just below the substrate surface on May 11, 2000. Seedlings germinated in approximately two weeks and were thinned to eight uniform seedlings per pot on June 7, 2000. Seedlings were irrigated by hand with a 500-ml solution of 300 $mg \cdot l^{-1}$ N (as ammonium nitrate), 45 $mg \cdot l^{-1}$P (as

phosphoric acid), and 100 $mg \cdot l^{-1}$ K (as potassium chloride) as needed. Trees were greenhouse-grown under a natural photoperiod with a daytime temperature of 24°C and a night temperature of 21°C.

On July 20, 2000, nutrients were extracted using the pour-through method (Yeager et al, 1983) from 4 subsamples per treatment, filtered, and analyzed for Cu, Zn, Fe, and Mn using inductively coupled plasma analysis. Substrate solution pH and electrical conductivity was also measured. The experiment was terminated October 2, 2000 at which time stem height was measured. Shoots were dried in an oven at 65°C for approximately 3 days and shoot dry weight was recorded. All data were submitted to regression analysis using SAS (version 6.12).

Experiment 2. Experiment 1 was repeated on June 4, 2001 with a few modifications. Micromax was incorporated into pine bark at 0, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$. Treatments were assigned in a complete randomized design and replicated 6 times. Five to six stratified seeds were planted per pot. Seedlings were fertilized as described above. Substrate solutions were extracted (Yeager et al, 1983) from 4 subsamples per treatment on August 6, 2001, filtered, and analyzed for EC, pH, Cu, Fe, Zn, and Mn. The experiment was terminated September 27, 2001. At this time height was measured. Approximately ten of the uppermost mature leaves were collected. Shoots and leaves were dried in an oven at 65°C and shoot dry weight was recorded. Leaf tissue was ground in a 40 mesh cyclone sample mill (U.D. Corp., Boulder, Colorado).

Approximately 250 mg of ground tissue was ashed for 4 hours at 450° C. Samples were dissolved in 20 ml of 0.3 N HNO_3, filtered, and brought up to 50 ml volume with 0.3 N HNO_3. Solutions were analyzed for Fe, Mn, Zn, and Cu using inductively coupled plasma analysis. All data were submitted to regression analysis using SAS (version 6.12).

Experiment 3. Experiment 1 was repeated for a third time on April 4, 2002 with a few modifications. Micromax was applied at 0, 0.15, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$. Treatments were assigned in a complete randomized design and replicated 4 times. Thirty stratified seeds were sown per pot on April 4, 2002 and thinned to 12 uniform seedlings per pot on May 2, 2002. Substrate solutions were collected on May 13, 2002, filtered, and analyzed for EC, pH, Fe, Mn, Zn, and Cu (described above). The experiment was terminated June 25, 2002 at which height was measured and leaf tissue samples were collected as described above. Shoots and leaves were dried in an oven at 65°C for approximately 3 days and shoot dry weight was recorded. Leaf tissue was ground, ashed, and analyzed (described above). All data were submitted to regression analysis using SAS (version 6.12).

Individual Micronutrient Experiments

Experiment 4. In this experiment a micronutrient mix was formulated based on the percentage of each micronutrient as stated on the Micromax label. Rates of Zn, Mn, Fe, and Cu were increased individually based on the grams of each nutrient in the following Micromax rates: 0, 0.15, 0.3, 0.6, 0.9, 1.8, or 2.7 $kg \cdot m^{-3}$, while holding all other micronutrients constant based on the grams of each micronutrient that would be added at the 0.9 $kg \cdot m^{-3}$ rate of Micromax (Table 1). For example, in the Fe experiment, Mn, Zn, and Cu were incorporated at 24, 9, and 4.5 $g \cdot m^{-3}$, respectively, and Fe was incorporated at rates of 0, 18, 36, 72, 108, 216, or 324 $g \cdot m^{-3}$.

As with Micromax, the micronutrient sources for the formulated mix were $FeSO_4$, $MnSO_4$, $ZnSO_4$, and $CuSO_4$. One hundred grams of dolomitic lime was mixed with each replication to serve as a carrier. The micronutrient-lime mixture was incorporated into the pine bark by hand and placed into 11.4-L containers. Each micronutrient was treated as a separate experiment and all experiments were conducted concurrently.

Treatments were assigned in a complete randomized design and replicated six times. Five to six stratified seeds (Sheffield Seed Company, Inc., Locke, N.Y.) per container were sown just below the substrate surface June 4, 2001. Seedlings germinated in approximately two weeks and were irrigated and fertilized as described above. Trees were greenhouse-grown under natural photoperiod at a daytime temperature of 24°C and a night temperature of 21°C.

On August 6, 2001, substrate solutions were extracted using the pour-through method (Yeager et al, 1983), filtered, and analyzed for Cu, Zn, Fe, and Mn as described above. Substrate solution pH and EC were measured. Leachate was collected again before harvest. The experiment was terminated September 9, 2001 at which time plant height and dry weight were measured. In addition, leaf tissue samples were analyzed as described above for Cu, Fe, Mn, and Zn. All data were submitted to regression analysis using SAS (version 6.12).

Experiment 5. Micromax was analyzed and found to contain 2% zinc ($ZnSO_4$), 4% manganese ($MnSO_4$), 14% iron ($FeSO_4$), 1.5% copper ($CuSO_4$), and 0.01% boron ($Na_2B_4O_7$). A micronutrient mix was formulated based on the micronutrient percentage as determined by the lab analysis. Copper, Fe, Mn, and Zn were increased individually at corresponding Micromax rates of 0, 0.45, 0.9, and 1.8 $kg \cdot m^{-3}$ while all other micronutrients were held constant based on the grams that each micronutrient would be added at the 0.9 $kg \cdot m^{-3}$ rate of Micromax (Table 2). Each replication was mixed with 50 g of sand to serve as a carrier, rather than with lime, and incorporated into the pine bark. In addition, to determine the effect of each individual element, Cu, Fe, Mn, and Zn were added individually (without other micronutrients added) to the pine bark at the same variable rates as above (Table 2).

Treatments were assigned in a complete randomized design and replicated four

times. Thirty stratified seeds (Sheffield Seed Company, Inc., Locke, N.Y.) per container were sown just below the substrate surface April 4, 2002. Seedlings germinated in approximately two weeks and were thinned to 12 uniform seedlings per pot on May 2, 2002. Substrate solutions were collected May 13, 2002, filtered, and analyzed for Zn, Mn, Fe, and Cu as described above. Electrical conductivity and pH were also measured. The experiment was terminated June 24, 2002. At that time plant height and dry weight were recorded. Leaf tissue samples were analyzed for Cu, Fe, Mn, and Zn as previously described. All data were submitted to regression analysis using SAS (version 6.12).

RESULTS AND DISCUSSION

Micromax

Experiment 1-3. In 2000, maximum height and dry weight occurred at rates higher than manufacturer's recommended rate of 0.9 $kg \cdot m^{-3}$ (Figure 1 and 2). However, in 2001 and 2002, maximum height and dry weight occurred at rates at or below the manufacturer's recommended rate, except for dry weight in 2001, which was higher than 0.9 $kg \cdot m^{-3}$. The reason for variability between years is unclear. However, given the growth responses over the 3 years, the predicted increase in growth above the 0.9 $kg \cdot m^{-3}$ in 2000 does not warrant increasing rates of Micromax above 0.9 $kg \cdot m^{-3}$. Therefore, we conclude that the manufacturer's recommended rate of 0.9 $kg \cdot m^{-3}$ is sufficient for optimal growth of *Quercus palustris*. These results also support other studies which conclude that the addition of micronutrients to pine bark can increase growth (Wright et al. (1999a; 199b), Reavis et al. (1980), and Whitcomb (1980; 1979a; 1979b)).

Micronutrient substrate solution levels increased in response to increasing rates of Micromax, with the exception of Fe in 2000 and 2001 (Table 3). Copper was undetectable in the substrate solution in 2000 and 2001 and may reflect the fact that

copper is strongly adsorbed to organic matter (Mengel and Kirkby, 1987). The reason for the higher levels of Cu extracted from the substrate in 2002 may be related to the fact that a different lot of pine bark used in this experiment than the pine bark used in the 2000 and 2001 experiments. The pH (3.9-5.2) of the 2002 experiment was lower than the 2000 and 2001 (5.1-6.1) experiments, and may have increased the availability of micronutrients, like Cu. Micronutrient substrate levels in the pine bark corresponding to the 0.9 $kg \cdot m^{-3}$ rate for all three years are as follows: 1-3 ppm Mn, 0.1-0.2 ppm Fe, 0.5-1.0 ppm Zn, and 0.6 ppm Cu.

The additions of micronutrients and subsequent increase of micronutrients in the substrate solution was somewhat reflected in the leaf tissue. In 2001, Mn and Zn concentrations in the leaf tissue increased with increasing rate of Micromax (Table 4). However, increasing the rate of Micromax did not increase Fe, and Cu was undetectable. In 2002, leaf tissue Mn, Fe, and Zn increased as rate increased. Copper was detectable, but remained at a fairly steady level in the leaf tissue. Micronutrient sufficiency levels in the leaf tissue at the 0.9 $kg \cdot m^{-3}$ rate for 2001 and 2002 are as follows: 303-382 ppm Mn, 17-25 ppm Fe, 20-41 ppm Zn, and 5 ppm Cu.

Individual Micronutrient Experiments

Experiment 4-5. Increasing the rate of an individual micronutrient while holding all other micronutrients constant did not strongly affect growth in 2001 or 2002 (Table 5 and 6). Although there was some statistical significance in height and dry weight, a low R^2 shows a weak relationship between growth and increasing individual micronutrients while holding all others constant.

Increasing the rate of Mn increased the level of Mn in the substrate solution for both years (Table 7 and 8). Increasing Fe resulted in an increase in Fe in solution for 2002 only, but of particular interest is that increasing Fe resulted in an increase in Zn in solutions for both years. Other differences were slight. In 2001, adding Cu significantly decreased Mn and Zn, although Cu levels were undetectable.

Similar to the results from the substrate solutions, increasing the rate of Fe increased the concentration of Zn in the leaf tissue (Table 9), but not in 2002 (Table 10). As the rate of Mn was increased, tissue Mn levels increased for both years. Other affects were slight. Micronutrient levels in the leaf tissue which are sufficient for plant growth as cited by Jones (1998) are as follows: 5-30 ppm Cu, 100-500 ppm Fe, 20-300 ppm Mn, and 27-100 ppm Zn. Copper was undetectable in the leaf tissue in 2001, but well within the sufficiency range in 2002. Micronutrient sufficiency ranges in the leaf tissue for both

years were within or above sufficiency range for each element with the exception of iron which was below the sufficiency range for both years, and copper which was undetectable in 2001.

The higher concentration of micronutrients in the substrate solution and tissue for 2002 compared to 2001 is likely due to the lower pH in 2002 which increases micronutrient availability (Mengel and Kirby, 1987) and the higher rate of micronutrient additions which were added in 2002 after an analysis of Micromax revealed higher nutrient content than reported by the manufacturer. The use of sand rather than lime as a carrier could also account for the difference in pH between 2001 and 2002. Wright et al. (1999a) demonstrated higher levels of micronutrients in solution at a lower pine bark pH compared to a higher pine bark pH.

When either Mn or Fe were added to the pine bark at increasing rates in the absence of other micronutrients, plant height and dry weight increased in a quadratic fashion with a large increase in growth with the initial application followed by a smaller increase in growth as application rates increased (Table 11). However, increasing either Cu or Zn applications to pine bark resulted in a linear increase in height and dry weight, suggesting that optimal growth could be obtained at rates beyond those which were applied in this study. One conclusion might be that micronutrient requirements for this study were met by applying individual micronutrients, especially Cu, since highest shoot dry weight (37.8 g) was produced at the highest rate of copper, with evidence that higher rates of applied copper could result in even greater growth. As stated before, copper is

readily adsorbed to the organic substrate which limits its availability for plant uptake. However, this line of reasoning does not explain why Cu does not appear to be limiting in pine bark since there was no increase in growth when the rate of Cu additions was increased in conjunction with other micronutrients in 2001 and 2002 (Table 5 and 6). It seems plausible that Cu present in the bark is made available for uptake when other micronutrients are added. The addition of other micronutrients may displace Cu from adsorption sites into the substrate solution, therefore making Cu more available for uptake. The same scenario would hold true for the other micronutrients since none, when added individually at increasing rates in conjunction with other micronutrients, resulted in a growth response (Table 5 and 6). In some way the requirement for each micronutrient is met by all others when one micronutrient is not added, as well as the converse that the requirements of all micronutrients are met by a single micronutrient application when micronutrients are not added (Table 11).

Micronutrient substrate solution concentrations extracted from the pine bark are shown in Table 12. What is most interesting is that the addition of any individual micronutrient at the lowest rate dramatically reduced all micronutrients in the substrate solution followed by a subsequent increase as the application rate increased. Increased plant growth between 0 $g \cdot m^{-3}$ and the initial application rate (Table 11) could account for this decrease since increased growth results in increased nutrient uptake and could lower substrate solution (Table 12). However, increasing the rate of a single micronutrient had little affect on the concentration of micronutrients in the leaf tissue (Table 13).

SUMMARY

From the results of this study, we conclude that the manufacturer's recommended rate of 0.9 $kg \cdot m^{-3}$ of Micromax is sufficient for increased growth of *Q. palustris*. Increasing the rates of an individual micronutrient while holding all others constant did not significantly increase growth. However, maximum growth of *Q. palustris* could be obtained by a single micronutrient application. Therefore, future research may include the addition of various rates of micronutrients, including rates beyond those applied in this study, to increase growth of tree species which have been shown to increase growth with micronutrient additions. It may also be of interest to investigate the substrate dynamics of pine bark when one micronutrient is applied in the presence of others and when one micronutrient is applied in the absence of others.

Tables

Table 1. Rates of micronutrients incorporated in pine bark in 2001.

Nutrient	Constant rate	Variable rates						
	$g \cdot m^{-3}$	$g \cdot m^{-3}$						
Fe	108	0	18	36	72	108	216	324
Mn	24	0	4	8	16	24	48	72
Zn	9	0	1.5	3	6	9	18	27
Cu	4.5	0	0.75	1.5	3	4.5	9	13.5

Table 2. Rate of micronutrients incorporated in pine bark in 2002.

Nutrient	Constant rate	Variable rates		
	$g \cdot m^{-3}$	$g \cdot m^{-3}$		
Fe	124	0	62	124	248
Mn	36	0	18	36	72
Zn	18	0	9	18	36
Cu	14	0	7	14	27

Table 3. Substrate solution micronutrient concentrations in pine bark amended with various rates of Micromax

	2000			2001			2002			
Rate $kg \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Mn ppm	Fe ppm	Zn ppm	Mn ppm	Fe ppm	Zn ppm	Cu ppm
0	0.87[z]	0.06	0.19	0.25[y]	0.11	0.56	0.51[y]	0.09	0.37	—
0.15	0.82	0.04	0.17	—	—	—	0.52	0.14	0.23	—
0.3	0.81	0.06	0.18	0.39	0.12	0.63	0.63	0.13	0.31	—
0.6	0.98	0.32	0.20	0.71	0.10	0.87	1.05	0.16	0.32	0.002
0.9	2.66	0.09	0.45	1.44	0.07	1.10	1.91	0.21	0.58	0.009
1.8	6.47	0.11	1.02	6.24	0.06	2.07	6.66	0.24	1.60	0.02
2.7	7.77	0.10	1.57	22.13	0.11	6.29	8.65	0.29	2.02	20.04
Linear[x]	<0.0001	NS	<0.0001	0.0002	NS	0.0003	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic	NS[w]	NS	NS	0.0343	0.0266	NS	NS	NS	NS	NS
R^2	0.56	0.04	0.57	0.50	0.25	0.46	0.67	0.64	0.64	0.81

[z] Means reported are for n = 6 observations.

[y] Means reported are for n = 4 observations.

[z] Pr > F.

[w] Not significant at $\alpha = 0.05$.

Table 4. Micronutrient leaf tissue concentrations of *Q. palustris* seedlings grown in pine bark amended with various rates of Micromax.

	2001			2002			
Rate	Mn	Fe	Zn	Mn	Fe	Zn	Cu
$kg \cdot m^{-3}$	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0	366[z]	33	13	211[y]	22	34	6
0.15	—[x]	—	—	217	18	31	5
0.3	215	21	12	232	25	47	4
0.6	331	15	16	261	27	41	9
0.9	382	17	20	303	25	41	5
1.8	476	19	28	333	33	54	5
2.7	657	17	45	429	28	49	5
Linear[W]	<0.0001	NS[V]	<0.0001	<0.0001	0.0029	0.0087	NS
Quadratic	0.0380	NS	0.0033	NS	0.0216	NS	NS
R^2	0.58	0.07	0.74	0.83	0.29	0.24	0.01

[Z] Means reported are for n = 6 observations.

[Y] Means reported are for n = 4 observations.

[x] Pr > F.

[W] Not significant at $\alpha = 0.05$.

Table 5. Height and dry weight of *Q. palustris* seedlings grown in pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2001.

Experiment	Rate $g \cdot m^{-3}$	Height cm	Dry weight g	Experiment	Rate $g \cdot m^{3}$	Height cm	Dry weight g
Fe	0	42.2[z]	4.67	Mn	0	39.9	5.63
	18	40.0	4.86		4	38.9	4.92
	36	41.7	6.35		8	40.0	5.75
	72	38.2	4.99		16	44.8	5.86
	108	38.6	4.96		24	51.6	7.53
	216	38.1	4.74		48	43.5	6.22
	324	38.5	4.92		72	40.9	6.26
	Linear	NS	NS		Linear	NS	NS
	Quadratic	NS	NS		Quadratic	0.0101	NS
	R^2	0.04	0.07		R^2	0.16	0.03
Zn	0	46.2	6.51	Cu	0	44.5	5.47
	1.5	44.2	7.0		0.75	46.0	6.31
	3	46.3	7.02		1.5	50.2	8.1
	6	42.8	6.5		3.0	42.9	6.19
	9	47.4	7.08		4.5	45.8	7.15
	18	53.2	7.56		9.0	42.3	5.98
	27	53.2	7.85		13.5	42.5	6.97
	Linear[y]	0.0037	NS		Linear	NS	NS
	Quadratic	NS[x]	NS		Quadratic	NS	NS
	R^2	0.19	0.06		R^2	0.04	0.05

[z] Means reported are for n = 6 observations.

[y] Pr > F.

[x] Not significant at $\alpha = 0.05$.

Table 6. Height and dry weight of *Q. palustris* seedlings grown in pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2002.

Experiment	Rate	Height	Dry weight	Experiment	Rate	Height	Dry weight
			g				g
	$g \cdot m^{-3}$	cm			$g \cdot m^{-3}$	cm	
Fe	0	30.1[z]	2.76	Mn	0	31.1	2.8
	62	27.6	2.38		18	29.3	2.63
	124	29.3	2.79		36	30.4	2.92
	248	27.7	2.54		72	26.4	2.63
	Linear	NS	NS		Linear	NS	NS
	Quadratic	NS	NS		Quadratic	NS	NS
	R^2	0.05	0.007		R^2	0.27	0.04
Zn	0	28.1	2.55	Cu	0	29.4	3.1
	9	27.3	2.62		7	30	2.89
	18	28.6	2.61		14	28	2.82
	36	28.2	2.35		28	29.9	2.96
	Linear[y]	NS[x]	NS		Linear	NS	NS
	Quadratic	NS	NS		Quadratic	NS	NS
	R^2	0.004	0.19		R^2	0.06	.26

[Z] Means reported are for n = 4 observations.

[Y] Pr > F.

[x] Not significant at $\alpha = 0.05$.

Table 7. Substrate solution micronutrient concentrations for pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2001.

		Fe				Mn	
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	0.12[z]	0.07	0.09	0	0.08	0.12	0.25
18	0.18	0.08	0.21	4	0.08	0.12	0.31
36	0.48	0.08	0.28	8	0.23	0.11	0.39
72	0.12	0.08	0.21	16	0.08	0.11	0.34
108	0.39	0.08	0.34	24	0.15	0.08	0.21
216	0.14	0.09	0.35	48	0.40	0.07	0.25
324	0.31	0.07	0.48	72	1.03	0.10	1.02
Linear[y]	NS[x]	NS	<0.0001	Linear	<0.0001	NS	0.0266
Quadratic	NS	NS	NS	Quadratic	0.0437	0.0028	NS
R^2	0.003	0.03	0.47	R^2	0.49	0.40	0.18

		Zn				Cu	
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	0.11	0.14	0.21	0	0.27	0.09	0.43
1.5	0.26	0.13	0.33	0.75	0.16	0.07	0.53
3	0.11	0.10	0.20	1.5	0.06	0.09	0.27
6	0.07	0.07	0.22	3	0.09	0.09	0.36
9	0.12	0.10	0.26	4.5	0.08	0.09	0.39
18	0.11	0.09	0.22	9	0.09	0.08	0.29
27	0.22	0.07	0.35	13.5	0.05	0.07	0.19
Linear	NS	0.0062	NS	Linear	0.0169	NS	0.0177
Quadratic	NS	NS	NS	Quadratic	NS	NS	NS
R^2	0.08	0.25	0.15	R^2	0.21	0.04	0.20

[Z] Means reported are for n = 6 observations.

[Y] Pr > F.

[x] Not significant at $\alpha = 0.05$.

Table 8. Substrate solution micronutrient concentrations for pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2002

Fe				Mn			
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	5.90[z]	0.17	1.54	0	1.7	0.26	1.29
62	6.17	0.22	1.57	18	2.72	0.21	1.26
124	10.51	0.28	2.83	36	3.08	0.19	0.93
248	9.44	0.28	2.8	72	13.35	0.25	1.90
Linear[y]	NS[x]	0.0289	0.0119	Linear	<0.0001	NS	NS
Quadratic	NS	NS	NS	Quadratic	0.0066	NS	NS
R^2	0.18	0.30	0.37	R^2	0.74	0.16	0.28

Zn				Cu			
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	5.97	0.27	1.24	0	6.58	0.22	1.83
9	5.56	0.21	1.12	7	6.69	0.22	1.71
18	7.02	0.23	1.67	14	11.91	0.25	2.56
36	4.37	0.19	1.96	28	5.53	0.20	1.18
Linear	NS	NS	0.0214	Linear	NS	NS	NS
Quadratic	NS	NS	NS	Quadratic	NS	NS	NS
R^2	0.08	0.19	0.32	R^2	0.16	0.10	0.18

[z] Means reported are for n = 6 observations.

[y] Pr > F.

[x] Not significant at $\alpha = 0.05$.

Table 9. Micronutrient concentrations in the leaf tissue of *Q. palustris* seedlings grown in pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2001.

		Fe				Mn	
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	218[z]	35	35	0	199	39	57
18	250	32	31	4	186	30	43
36	254	39	38	8	213	38	54
72	227	40	74	16	193	57	43
108	234	35	37	24	218	46	59
216	229	41	68	48	309	44	42
324	242	51	83	72	396	38	45
Linear[y]	NS[x]	NS	0.0002	Linear	<0.0001	NS	NS
Quadratic	NS	NS	NS	Quadratic	NS	NS	NS
R^2	0.01	0.13	0.42	R^2	0.72	0.08	0.06

		Zn				Cu	
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm
0	239	35	66	0	218	51	43
1.5	211	33	44	0.75	188	34	41
3	213	63	47	1.5	182	54	36
6	232	42	75	3	175	30	42
9	215	54	60	4.5	170	24	38
18	222	33	51	9	191	25	36
26	279	46	96	13.5	190	33	47
Linear	0.0190	NS	0.0465	Linear	NS	NS	NS
Quadratic	0.0309	NS	NS	Quadratic	NS	NS	NS
R^2	0.19	0.11	0.14	R^2	0.15	0.10	0.10

Z Means reported are for n = 6 observations.

Y Pr > F.

x Not significant at $\alpha = 0.05$.

Table 10. Micronutrient concentrations in the leaf tissue of *Q. palustris* seedlings grown in pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2002.

		Fe					Mn		
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm
0	369[z]	33	69	9	0	268	46	89	8
62	411	32	82	10	18	339	46.	70	6
124	362	35	52	29	36	291	40	54	5
248	412	54	81	12	72	498	34	55	5
Linear[y]	NS[x]	0.0043	NS	NS	Linear	0.0013	0.0016	0.0008	0.0012
Quadratic	NS	NS	NS	NS	Quadratic	NS	NS	0.003	0.0212
R^2	0.03	0.45	0.10	0.10	R^2	0.53	0.52	0.56	0.54
		Zn					Cu		
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm
0	336	46	58	6	0	342	30	50	6
9	367	37	48	5	7	390	26	50	7
18	365	36	60	5	14	449	26	46	7
36	369	34	69	5	28	411	31	48	8
Linear	NS	0.0173	NS	NS	Linear	0.0303	NS	NS	0.0017
Quadratic	NS	NS	NS	NS	Quadratic	0.003	0.0009	NS	NS
R^2	0.03	0.34	0.19	0.11	R^2	0.65	0.60	0.21	0.52

[z] Means reported are for n = 4 observations.

[y] Pr > F.

[x] Not significant at $\alpha = 0.05$.

Table 11. Height and dry weight of *Q. palustris* seedlings grown in pine bark amended with various rates of a single micronutrient in 2002.

Experiment	Rate $g \cdot m^{-3}$	Height cm	Dry weight g	Experiment	Rate $g \cdot m^{-3}$	Height cm	Dry weight g
Fe	0	21.1[z]	1.19	Mn	0	19	1.44
	62	29.9[y]	2.76		18	27.3	2.3
	124	32.5	2.95		36	26.1	2.38
	248	30.6	2.96		72	29.6	2.43
	Linear[x]	NS[w]	NS		Linear	NS	NS
	Quadratic	0.01	0.01		Quadratic	<0.001	0.04
	R^2	0.63	0.58		R^2	0.47	0.48
Zn	0	18.3	1.39	Cu	0	19.2	1.24
	9	19.8	1.7		7	21.5	1.55
	18	22.2	1.51		14	26.1	2.21
	36	26.7	2.7		27	28.3	3.15
	Linear	0.003	0.03		Linear	<0.0001	<0.0001
	Quadratic	NS	NS		Quadratic	NS	<0.0001
	R^2	0.58	0.36		R^2	0.77	0.85

[Z] Means reported are for n = 1 observation.

[Y] Means reported are for n = 4 observations.

[X] Pr > F.

[w] Not significant at $\alpha = 0.05$.

Table 12. Substrate solution micronutrient concentrations for pine bark amended with various rates of a single micronutrient in 2002.

		Fe					Mn		
Rate	Mn	Fe	Zn	Cu	Rate	Mn	Fe	Zn	Cu
$g \cdot m^{-3}$	ppm	ppm	ppm	ppm	$g \cdot m^{-3}$	ppm	ppm	ppm	ppm
0	35.82[z]	0.43	7.65	0.19	0	16.71	0.39	3.74	0.08
62	1.0[y]	0.22	1.03	—[x]	18	2.45	0.16	0.58	—
124	1.08	0.19	0.8	—	36	5.76	0.20	0.52	—
248	4.3	0.35	2.13	—	72	4.03	0.18	0.51	—
Linear[w]	NS[V]	NS	NS	NS	Linear	NS	NS	NS	NS
Quadratic	0.009	0.004	0.001	0.002	Quadratic	NS	NS	0.003	0.001
R^2	0.69	0.77	0.66	0.72	R^2	0.22	0.28	0.69	0.74
		Zn					Cu		
Rate	Mn	Fe	Zn	Cu	Rate	Mn	Fe	Zn	Cu
$g \cdot m^{-3}$	ppm	ppm	ppm	ppm	$g \cdot m^{-3}$	ppm	ppm	ppm	ppm
0	18.94	0.26	3.94	0.07	0	19.07	0.41	5.11	0.09
9	0.589	0.11	0.83	—	7	0.55	0.10	0.35	—
18	0.80	0.17	1.32	—	14	0.66	0.16	0.57	—
36	0.71	0.12	1.19	—	28	0.73	0.13	0.47	—
Linear	NS	NS	NS	NS	Linear	NS	NS	NS	0.03
Quadratic	0.002	NS	0.01	0.002	Quadratic	0.002	NS	0.005	NS
R^2	0.71	0.37	0.56	0.71	R^2	0.72	0.38	0.65	.36

z Data reported at 0 is for n = 1 observation.

y Means reported is for n = 4 observations.

x Concentration is not detectable.

w Pr > F.

V Not significant at $\alpha = 0.05$

Table 13. Micronutrient concentrations in the leaf tissue of *Q. palustris* grown in pine bark amended with various rates of a single micronutrient in 2002.

		Fe					Mn		
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm
0	201[z]	21	29	6	0	258	43	58	6
62	240[y]	52	67	9	18	406	30	49	3
124	233	46	54	14	36	437	31	49	3
248	208	46	47	8	72	395	33	46	3
Linear[x]	0.04	NS[w]	0.03	NS	Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	Quadratic	NS	NS	NS	0.005
R^2	0.32	0.04	0.38	0.08	R^2	0.29	0.31	0.17	0.65
		Zn					Cu		
Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm	Rate $g \cdot m^{-3}$	Mn ppm	Fe ppm	Zn ppm	Cu ppm
0	295	41	148	12	0	286	31	65	7
9	254	35	59	4	7	263	25	76	11
18	265	44	80	4	14	289	26	60	9
36	248	35	90	3	28	256	29	46	8
Linear	NS	NS	NS	0.01	Linear	NS	NS	NS	NS
Quadratic	NS	0.001	NS	NS	Quadratic	NS	0.04	NS	NS
R^2	0.27	0.68	0.29	0.44	R^2	0.03	0.35	0.10	0.06

[Z] Means reported are for n = 1 observation.

[Y] Means reported are for n = 4 observations.

[X] Pr > F.

[w] Not significant at $\alpha = 0.05$.

Figures

Figure 1. Height of *Q. palustris* seedlings grown in pine bark amended with various rates of Micromax (2000) n = 6 per treatment level, Pr = <0.0001, (2001) n = 6 per treatment level, Pr = 0.0004, and (2002) n = 4 per treatment level, Pr = <0.0001.

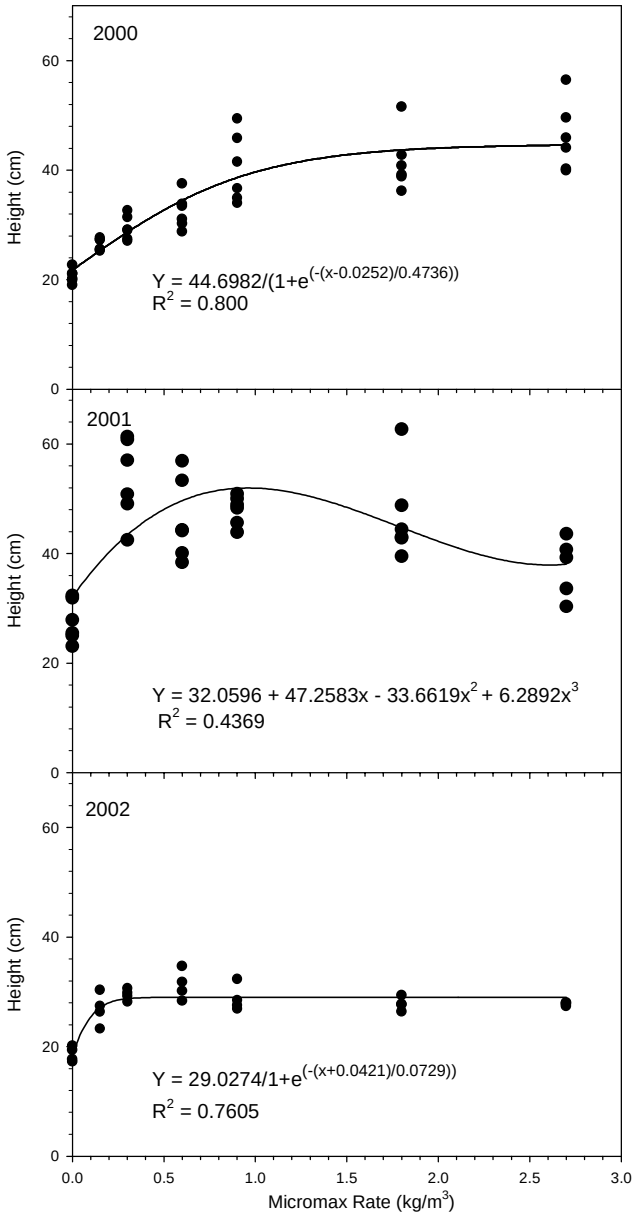
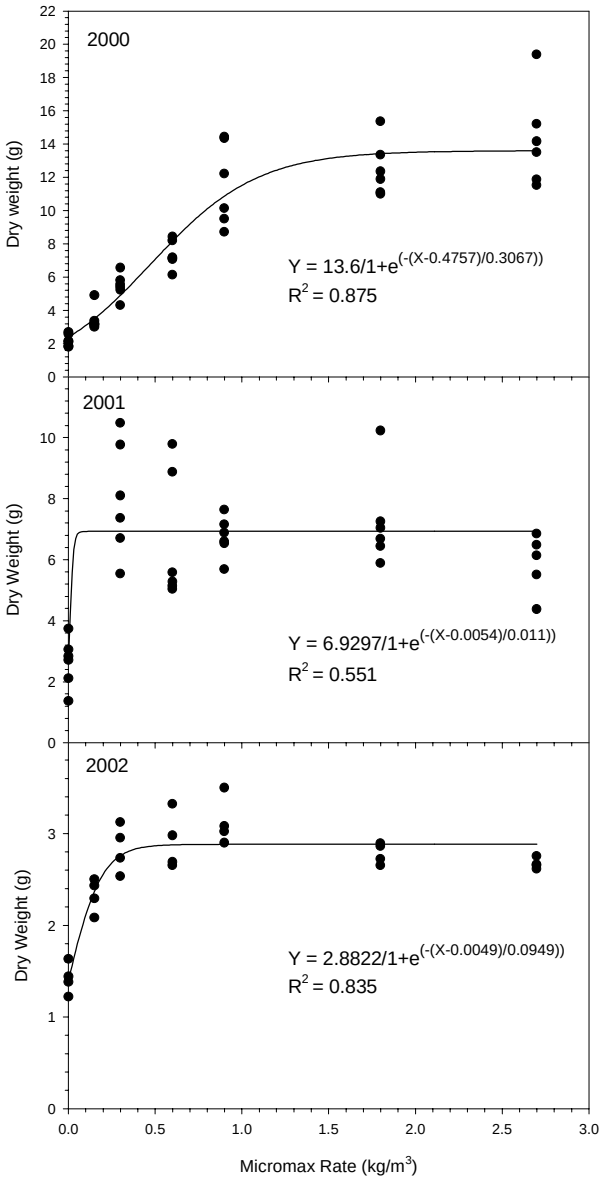


Figure 2. The dry weight of *Q. palustris* seedlings grown in pine bark amended with various rates Micromax (2000) n = 6 per treatment level, Pr = <0.0001, (2001) n = 6 per treatment level, Pr = <0.0001, and (2002) n = 4 per treatment level, Pr = <0.0001.



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APPENDIX

Table 1. Mean pH of pine bark amended with various rates of Micromax for each year.

Rate	pH		
$kg \cdot m^{-3}$	2000	2001	2002
0	5.6	5.7	5.1
0.15	5.7	—[z]	4.8
0.3	5.7	5.4	5.1
0.6	5.8	5.5	4.9
0.9	5.4	5.9	4.8
1.8	5.4	6.0	4.7
2.7	5.4	5.2	4.6

[z] Treatment not included in 2001.

Table 2. The mean pH for pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2001.

Fe		Mn	
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	5.7	0	5.9
18	5.9	4	5.3
36	5.7	8	5.5
72	5.8	16	5.6
108	5.7	24	5.9
216	5.8	48	5.5
324	6.0	72	5.5

Zn		Cu	
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	5.6	0	5.9
1.5	5.8	0.75	5.6
3	5.6	1.5	5.7
6	5.6	3	5.6
9	5.5	4.5	5.7
18	5.5	9	5.7
27	5.7	13.5	5.7

Table 3. The mean pH for pine bark amended with various rates of an individual micronutrient while holding other micronutrients constant in 2002.

	Fe		Mn
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	5.0	0	4.1
62	4.8	18	5.2
124	4.5	36	4.6
248	4.5	72	4.9
	Zn		**Cu**
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	4.3	0	4.9
9	4.7	7	4.5
18	4.0	14	4.6
36	4.1	28	4.6

Table 4. The mean pH for pine bark amended with various rates of a single micronutrient in 2002.

	Fe	Mn	
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	4.3	0	4.4
62	5.0	18	5.5
124	5.2	36	5.0
248	4.4	72	4.9
	Zn	Cu	
Rate $g \cdot m^{-3}$	pH	Rate $g \cdot m^{-3}$	pH
0	4.4	0	4.4
9	4.6	7	5.3
18	4.3	14	5.1
36	4.4	28	5.2

Table 5. The average electrical conductivity (mS/cm) measured weekly for each experiment for each year.

Experiment	EC		
	2000	2001	2002
Micromax	0.77	0.67	0.63
Fe + micros	—[z]	0.8	0.9
Fe alone	—	—	0.88
Mn + micros	—	0.58	0.7
Mn alone	—	—	0.64
Zn + micros	—	0.85	0.82
Zn alone	—	—	0.65
Cu + micros	—	0.47	0.87
Cu alone	—	—	0.5

[z] Experiment not conducted that year.

Table 6. Total micronutrients content of the leaf tissue of *Q. palustris* seedlings in pine bark amended with various rates of a single micronutrient in 2002.

Experiment	Rate	Total Cu	Total Mn	Total Fe	Total Zn	Experiment	Rate	Total Cu	Total Mn	Total Fe	Total Zn
	$g \cdot m^{-3}$	mg	mg	mg	mg		$g \cdot m^{-3}$	mg	mg	mg	mg
Fe	0	1.7[z]	42.2	5.8	21.1	Mn	0	1.0	44.6	7.4	10.0
	62	3.2	80.4	17.3	22.5		18	0.7	112.8	8.4	13.4
	124	4.6	82.6	13.7	22.9		36	0.8	125.4	8.7	13.8
	248	2.9	73.8	16.5	17.7		72	0.8	112.9	9.9	13.4
	Linear[y]	NS[x]	NS	NS	NS		Linear	NS	NS	NS	NS
	Quadratic	NS	NS	NS	NS		Quadratic	NS	0.0224	NS	NS
	R^2	0.18	0.16	0.07	0.10		R^2	0.10	0.47	0.17	0.27
Zn	0	0.3	9.6	1.0	1.4	Cu	0	1.1	42.6	4.6	9.7
	9	0.6	39.8	5.4	9.2		7	1.9	48.7	5.2	14.0
	18	0.7	51.3	8.4	15.2		14	2.7	73.9	6.9	14.3
	36	0.9	68.6	9.7	25.7		28	3.4	96.9	11.1	17.5
	Linear	NS	0.0011	0.0016	NS		Linear	0.0108	0.0002	<0.0001	NS
	Quadratic	NS	NS	NS	NS		Quadratic	NS	NS	NS	NS
	R^2	0.30	0.64	0.17	0.27		R^2	0.46	0.74	0.87	0.11

[z] The mean reported is for n = 4 observations.

[y] Pr > F

[x] Not significant at $\alpha = 0.05$

Vita

Lisa Kelk grew up in Oshkosh, WI. She graduated from the University of Minnesota in 1999 with a B.S. in Environmental Horticulture. In May of 2002, she received a M.S. in Agriculture and Extension Education at Virginia Tech. She received a second M.S. in Horticulture at Virginia Tech in September of 2002. During her graduate experience Lisa was the graduate alumni coordinator for the Virginia Tech Agriculture Alumni Association. She was also a member of Omicron Theta Tau and Alpha Tau Alpha.