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TALL FESCUE SEEDLING GROWTH IN RESPONSE TO PHOSPHOROUS FERTILIZATION

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ABSTRACT

Recent restrictions on phosphorus applications to turf have heightened interest in the practice of applying phosphorus to the seedbeds of soils having high soil test phosphorus. Greenhouse pot studies were conducted to determine the response of tall fescue (*Festuca arundinaceae* Schreb) seedling growth to phosphorus additions made to soils containing 52, 55, 64, 66, 97, 163, 170, and 277 mg kg^{-1} Mehlich III soil test phosphorus. Seedling above ground biomass was evaluated 23 to 24 days after seeding in a warm temperature regime that favored seedling emergence, and 43 days after seeding in a cool temperature regime that visibly delayed seedling emergence. No increase in seedling biomass occurred with added phosphorus in soils having 97 mg kg^{-1} or more initial soil test phosphorus in conditions that favored seedling emergence. On average the addition of 24, 48, and 96 kg ha^{-1} phosphorus, increased seedling growth by 14, 25, and 34%, respectively in soils having 52 to 66 mg kg^{-1} soil test phosphorus in the warm temperature regime, compared to not adding phosphorus to these soils. Seedling biomass production was increased with added phosphorus in soil having 163 mg kg^{-1} soil test phosphorus in the cool temperature regime but not in the warm temperature regime. Growth responses to added phosphorus were associated with non-phosphorus fertilized seedlings having phosphorus tissue contents below 2.6 g kg^{-1}. These results indicate phosphorus fertilization of newly seeded tall fescue needs to be linked to soil test results and to growing conditions.

Keywords

establishment, *Festuca arundinacea*, soil calibration

INTRODUCTION

Recent restrictions on phosphorus (P) applications to turf have heightened interest in the practice of applying P to newly seeded turf sites. Of specific interest is the practice of applying P at seeding to soils having high soil test P (Anonymous, 2003). This is a common practice that in the past has been included in many soil test recommendations (Sharpley et al., 1994; Sims, 1993). Implementation of this recommendation is now prohibited in some jurisdictions or is being reevaluated in areas where nutrient management recommendations are being used to guide phosphorus applications made to turf (Turner, 2003).

Many turfgrass professionals have argued that adding P at the time of seeding is both agronomically justified and is a sound nutrient management practice because it hastens turfgrass establishment, which in turn reduces sediment and particulate nutrient runoff losses. There is ample documentation in the literature to show that seedbed applications of P to turf sites having low to adequate soil test P hastens the establishment of most cool season turfgrass species (Christians et.al., 1981; Turner and Hummel, 1992). However, less is known about seedling response to P additions made to soils high in P.

Seedling growth is one of the most critical stages of turfgrass establishment. Late stage seedling growth is thought to be particularly sensitive to soil P availability due to the sparse nature of the seedling root system and because P from the seed is exhausted by this time. As a result, most differences in stand density are usually first observed 3 to 4 weeks after germination under conditions that favor growth (Turner and Hummel, 1992). Published information relating turfgrass establishment to soil test P has been based on percent cover data, and on measurements of growth collected well after seedling maturation (Christians et al., 1981; Juska et al., 1965; King and Skogley, 1969; Turner and Waddington, 1983). Percent cover data while valuable is often criticized as being subjective and difficult to reproduce (Richardson et al., 2001). Alternatively, plant growth data collected after seedling maturation may underestimate the actual P requirement for rapid seedling growth.

Information on seedling response to P additions made during periods of sub-optimal environmental conditions for growth is limited. Seeding at such times is a frequent occurrence when protracted inclement weather delays ground preparation late in the growing season. Reicher et al. (2000) examined the fertilizer requirements of Kentucky bluegrass (*Poa pratensis*) seeded at different times of year and found that starter fertilizer amounts of

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Table 1. Soils used to examine the response of tall fescue seedlings to P fertilization and the amount of soil added to the pots.

Soil	pH	OM (%)‡	Nutrient concentration (mg kg^{-1})†				Soil in pot (g)
			P	K	Ca	Mg	
Hagerstown, Silty Clay Loam Fine, mixed, semiactive, mesic Typic Hapludalfs	6.0	3.6	55	260	1123	54	508
Hagerstown, Clay Loam Fine, mixed, semiactive, mesic Typic Hapludalfs	6.4	2.9	66	290	1517	117	758
Matapeake, Sandy Loam Fine-silty, mixed, semiactive, mesic Typic Hapludults	6.8	1.8	52	151	770	52	836
Rumford, Sandy Loam Coarse-loamy, siliceous, subactive, thermic Typic Hapludults	7.3	2.3	64	115	990	58	821
Christiana, Clay Loam Fine, Kaolinitic, mesic Typic Paleudults	6.3	3.7	97	235	1358	207	703
Matawan, Loamy Sand Fine-loamy, siliceous, semiactive, mesic Aquic Hapludults	6.4	1.0	163	74	314	25	1072
Keyport, Loam Fine, mixed, semiactive, mesic Aquic Hapludults	6.2	2.6	170	270	933	131	889
Ochlockonee, Loam Coarse-loamy, siliceous, active, acid, thermic Typic Udifluvents	6.4	3.5	277	258	2276	149	877

†Mehlich III extraction followed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP) analysis.

‡Soil organic matter was determined by the Loss on Ignition Method.

0, 21 or 42 kg ha^{-1} N, and 0, 21 or 42 kg ha^{-1} P had no effect on turf cover for seeding dates in Sept. Nov. Mar. and May. Invariant turf response to P was attributed to high soil test P.

Turner (1980) conducted several soil calibration studies for the establishment of turfgrass monostands and mixtures in the late 1970's. These studies investigated the effect of P, K and limestone additions on the establishment of several turfgrass species. Soil calibration, however, was restricted to a single soil type (Hagerstown silt loam), and involved additions of P that would be considered excessive by most current nutrient management specialist. In addition, these studies did not include tall fescue, which is a widely used amenity grass in areas of the US where nutrient management guidelines are used to guide phosphorus applications to turf (Turner, 2003). The objective of this investigation was to determine the response of tall fescue seedling growth to P additions made to soils high in P. Seedling growth was evaluated under contrasting temperature conditions to determine the importance of sub-optimal growth conditions on soil test calibration of tall fescue seedling growth.

MATERIALS AND METHODS

Seedling response to P additions were evaluated in three greenhouse pot studies conducted at the University of Maryland Research Greenhouse Complex. The soils for these investigations were collected from five farm field sites located within Central Piedmont region of Maryland, two farm fields within Great Limestone Valley system of the Eastern U.S. (Hagerstown soils) and one farm field site within the Coastal Plain region of Maryland (Matawan soil). Soil collection at each site was restricted to the surface 10 cm of the plow layer. The soils were air dried and passed through a 4 mm screen prior to being placed into pots as described below. The chemical properties and taxonomic identification of the eight soils used in the three pots studies are presented in Table 1.

Thirteen centimeter deep trapezoidal shaped pots were used in all studies. The base of the pot was 7 cm x 7 cm while the lip was 9.5 cm x 9.5 cm. The pots were lined with a double layer of cheesecloth prior to adding soil to prevent soil loss from drainage holes located at the base of the pot. One hundred grams of white quartz sand was firmly packed into the bottom of each pot, after which soil sufficient to fill the pot to within 1 cm of the lip was added. The soil was added in approximately 150 cm^3 increments with each increment being firmly packed into the pot before making the next addition of soil. Exactly 106 pure live seeds of 'Millennium' tall fescue were evenly distributed over the top of the soil and the seed covered with a final addition of 25 g soil. The total oven dried weight equivalent of soil and sand added to the pot for each soil is shown in Table 1.

After seeding, the pots were placed into a water bath overnight to completely wet the soil from the base of the pots without disturbing the seed or soil surface. The pots were then allowed to drain for 4 hours after which the weight of each was recorded. The first day (i.e., Day 1), 4 hour drainage weight was subsequently used as the pot capacity weight of the soil for the duration of the study. On Day 2 of the studies mancozeb (zinc ion and manganese ethylene disdithiocarbamate) was applied at 1.46 g a.i. m^{-2} to prevent algae formation on the soil.

Phosphorous fertilization consisted of adding 25 mls of one of four P solutions to a pot 6 times over the course of the study. The solution contained 1 g L^{-1} NH_4NO_3, 0.75 g L^{-1} K_2SO_4, and either 0, 0.6, 1.2 or 2.4 g L^{-1} $(CaH_2PO_4)\cdot H_2O$. On a surface area basis, total P addition to the pot over the course of the study was equivalent to 0,

Table 2. Seedling growth response to P fertilization.

Study†	Soil	Response equation for growth (mg seedling^{-1})	r^2	n
I	Hagerstown	growth = 5.57 + 0.0238P‡	0.61	32
	Matawan	= 7.36	-	32
	Keyport	= 7.44	-	32
	Ochlockonee	= 7.91	-	32
II	Hagerstown	= 9.65 + 0.1148P - 0.00098P^2	0.53	16
	Matawan	= 10.20 + 0.03P	0.46	16
	Keyport	= 12.06	-	16
	Ochlockonee	= 15.56	-	16
III	Hagerstown	= 5.52 + 0.0223P	0.73	16
	Matapeake	= 6.70 + 0.0926P - 0.00068P^2	0.57	32
	Rumford	= 7.54 + 0.0178P	0.26	32
	Christiana	= 8.72	-	16

†The growth equations for Study I were obtained by pooling the data from the two repetitions of this study. The Hagerstown and Christiana soils were included in only one of the two repetitions of Study III, while the Matapeake and Rumford soils were included in both repetitions of this study. The growth equations for the Matapeake and Rumford soils were obtained by pooling the data for each soil from the two repetitions of Study III. Study II was conducted once.

‡P in the equation represents the total amount of P applied in kg ha^{-1}.

24, 48, and 96 kg ha^{-1}, respectively. Each soil by P treatment combination was replicated four times and the pots arranged in a completely randomized design on the greenhouse bench. The location of the pots were re-randomized after every nutrient solution addition.

Seedling response to P additions made to the Hagerstown (soil test P = 55 mg kg^{-1}), Matawan, Keyport and Ochlockonee soils were examined in Study I and Study II. The soil test P levels of the latter three soils were considered excessive by The University of Maryland soil testing laboratory (i.e., > 45 mg kg^{-1} Mehlich I soil test P) while soil test P for the Hagerstown soil was within the optimal category for crop yield response. In Study I the greenhouse was programmed to maintain a temperature of 25°C from 6:00 to 18:00 h, and a temperature of 15°C from 18:00 to 6:00 h. Supplement light delivering 83 to 113 mmol m^{-2} s^{-1} of photosynthetically active radiation at the canopy level was also provided from 6:00 to 20:00 h. In Study II the 6:00 to 18:00 h and 18:00 to 6:00 h temperatures were reprogrammed to 15 and 5°C, respectively. Actual greenhouse temperatures during both studies were measured every five minutes by a thermocouple psychrometer located 1 m above the pot lips.

Nutrient solutions were applied on Day 2, 4, 9, 11, 17, and 18 in Study I and on Day 2, 4, 19, 20, 31, and 33 in Study II. In Study I all pots received 80 mls of water 1 or 2 days after the second nutrient solution application made each week. In addition after seedling emergence, the pots were weighed once a week and the amount of water needed to achieve pot capacity added. A similar watering protocol was used in Study II with the exception that pots were weighed and watered to pot capacity once every 14 days. Nutrient solutions were applied over a longer period of time in Study II in an attempt to match P addition with a similar stage of seedling growth observed in Study I. This was also done to insure that there would not be a dramatic decline in soil solution P towards the end of Study II due to the longer duration of this study compared to Study I.

Seedling response to added P was assessed by determining seedling dry biomass at the end of the studies. Above ground biomass was assessed on Day 23 or Day 24 in Study I by counting and excising all seedlings taller than 1 cm. The seedlings were cut at the soil surface using scissors and the plant material dried at 50°C until no change in weight was observed. Seedling data were collected in the exact same manner for Study II, except that above ground biomass was assessed on Day 43 of this study. Study I was repeated twice with Day 1 occurring on 18 Nov 2003 and on 23 Feb 2004. Seedlings were harvested on Day 24 and Day 23 of the first and second repetition of this study, respectively. Study II was conducted once with Day 1 occurring on 8 Jan 2004.

The P content of the seedlings was also determined in Studies I and II. After recording the seedling biomass, samples were placed in letter size envelopes that were stored at room temperature until needed for P analysis. The samples were dried a second time at 50°C for at least 24 h immediately before grinding the tissue to pass through a 2mm sieve. The P content of the seedlings was determined by nitric and perchloric acid digestion of the ground tissue followed by Inductively Coupled Plasma Atomic Emission Spectrometry analysis of the digestate (Isaac and Johnson, 1998).

Study III was conducted to further examine seedling response to P additions made to soils having 52 to 97 mg kg^{-1} soil test P. Study III was conducted in a manner identical to that described for Study I with the exception that different seeding dates were used in this study and the P content of the excised tissue was not determined. The study was repeated twice with the Matapeake, Rumford and Hagerstown (P = 66 mg kg^{-1}) soils being first wetted on 22 March 2004 and the Matapeake, Rumford

and Christiana soils being wetted for the first time on 19 April 2004.

Analysis of variance, single degree of freedom contrasts were used to determine the polynomial regression model that best described seedling response to added P for each soil. Regression analysis was then used to determine the coefficients for the model identified by the single degree of freedom contrasts. In Study I and for the soils present in both repetitions of Study III, the data were pooled prior to analysis.

RESULTS

Figure 1 shows the absolute maximum, minimum and daily average temperatures observed within the greenhouse for Studies I and II. There was a substantial lag in reaching the daily average maximum and minimum temperatures in both studies for the two respective time periods. The average measured temperature for the 6:00 to 18:00 time period in Study I was always less than 25°C but did exceed 22°C for the remainder of the programmed time period once this temperature was reached within the greenhouse. Similarly, once the temperature declined to 15°C during the 18:00 to 6:00 time period, the average temperature within the greenhouse did not vary by more than 1°C. A similar pattern was observed in the deviation of the average maximum temperature in Study II. In contrast, a much longer time period was required for the average minimum temperature to fall within 1°C of the average observed minimum greenhouse temperature for the 18:00 to 6:00 time period in Study II. A malfunction in the temperature regulation system of the greenhouse occurred on 19 and 20 Jan and on the night of 5 March. The former resulted in a temperature of 22°C being reached at 13:30 within the house on 20 Jan. The 5 March malfunction was responsible for all of the maximum temperature data shown in the middle graph of Fig 1. for the 18:00 to 6:00 time period.

The Hagerstown soil was the only soil in which a growth response to P fertilization was seen in both Study I and Study II (Table 2). Seedling response to added P was different for this soil in each study. In Study I, seedling growth in the Hagerstown soil increased in a linear manner with increasing P fertilization. In contrast seedling response to added P was more adequately described by a quadratic equation in Study II. The latter equation predicted addition of 59 kg ha^{-1} P would result in the most rapid rate of seedling growth over the 43 day establishment period. No response to P fertilization occurred in the three soils having 163 mg kg^{-1} or more soil test P in Study I. Under the cooler conditions and longer growth period of Study II, P fertilization of the Matawan soil (163 mg P kg^{-1}) significantly increased seedling growth.

Positive growth responses to the addition of P were seen in all soils except the Christiana soil in Study III. Seedling response to added P for the Hagerstown soil in Study III (66 mg P kg^{-1}) was similar to the response seen in the Hagerstown soil examined in Study I (55 mg P kg^{-1}), even though the former had 20% more soil test P (Table 2). Growth response to P additions made to the Metapeake soil were best described by a quadratic equation that predicted maximum seedling growth with the addition of 68 kg ha^{-1} of P. Seedling growth without P fertilization was greater in the Rumford soil than in the Hagerstown or Metapeake soils. Seedling response to added P for the Rumford soil, while significant, was less than that for the Hagerstown or Metapeake soils.

Tissue P contents of the seedlings not receiving fertilizer P were lower in all soils under the cooler conditions of Study II than in Study I (Fig. 2). Comparative declines in the P content of seedlings not receiving P ranged from 17% in the Keyport soil to 57% in the Matawan soil. Phosphorus fertilization of all soils increased the P content of seedlings when compared to seedlings grown in the same soil not receiving P. Positive growth responses to added P were limited to soil and study conditions that resulted in non-P fertilized seedlings having P tissue contents less than 2.6 g kg^{-1}.

DISCUSSION

Integration of the area under the greenhouse mean temperature curve provides an alterative means by which the temperature regimes of Study I and Study II can be compared. Utilizing this means of comparison the average mean temperature for the first and second repetitions of Study I and for Study II were 19.2, 19.4 and 10.9°C, respectively. Steiner et al. (2001) examined the growth of 7 day old tall fescue seedlings for 42 days under constant temperature conditions and found three times more above ground biomass was produced at 20°C than at 10°C. Thus the temperatures conditions in Study I were more optimal for tall fescue seedling growth than the temperature conditions in Study II.

Seedling growth rates independent of P addition, under the two contrasting conditions of Study I and Study II can be calculated by dividing the regression intercept by the number of days each study was conducted. Average daily seedling growth rates for the Hagerstown soil were similar (0.24 vs. 0.22 mg dry mass, seedling^{-1} day^{-1}) for the two studies. This was consistent with visual observations that suggested a more advance state of seedling growth in all soils at the end of Study II compared to Study I. The longer evaluation period used in Study II likely facilitated more rapid seedling growth towards the end of the study as the seedlings were maturing. This latter period of increased growth would have compensated for the slower germination speed visually observed in Study II. Qian and Suplick (2001) have reported that lowering the 16 hr day/ 8 hr night temperature of a growth chamber from 25/15 to 15/5°C reduces the speed of tall fescue seed germination by 65%.

The strengths of the predictive relationships presented in Table 2 are consistent with previous turfgrass

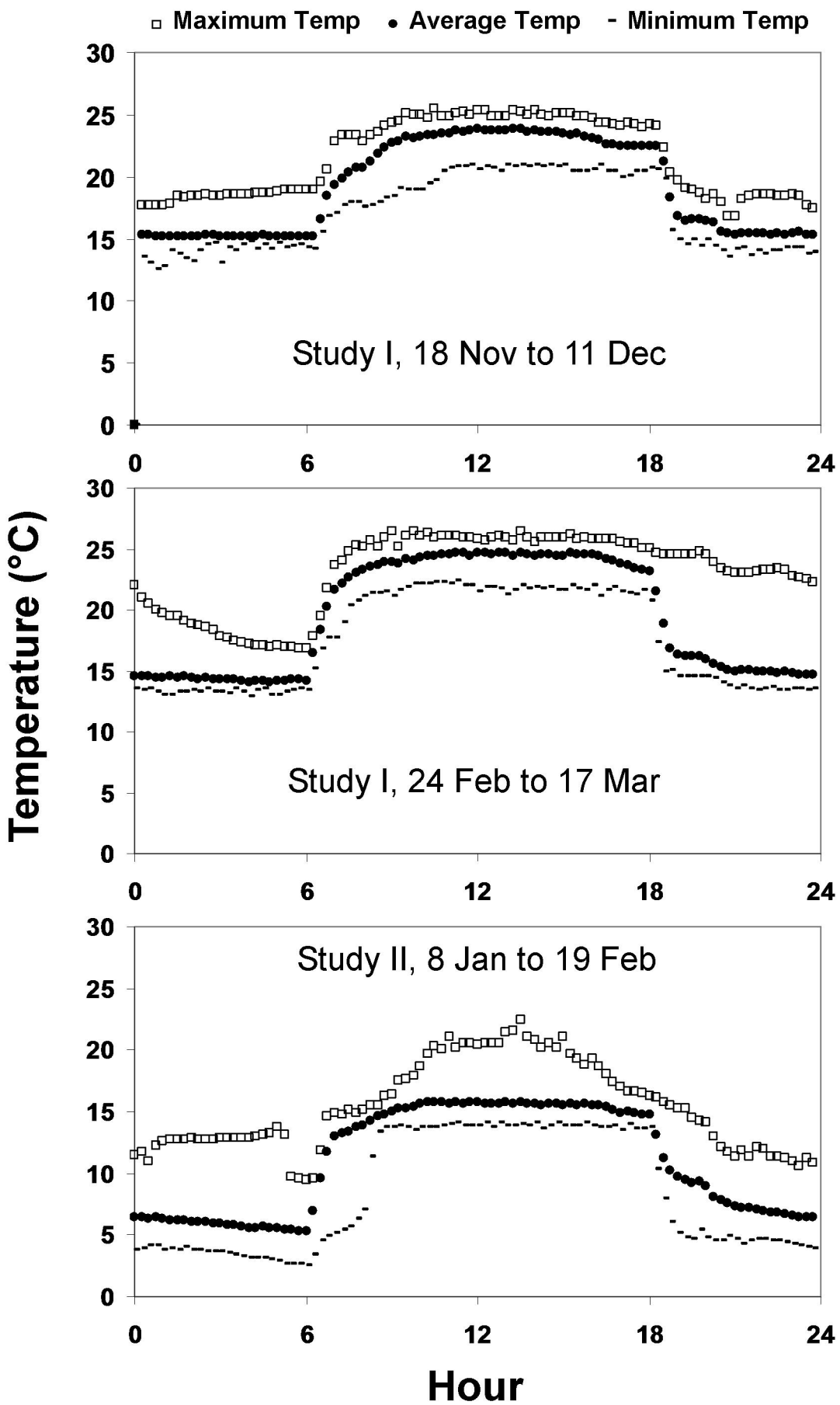

Figure 1. Maximum, minimum and average air temperature 1 meter above the pot lips reported every 15 minutes for the two repetitions of Study I and for the sole repetition of Study II.

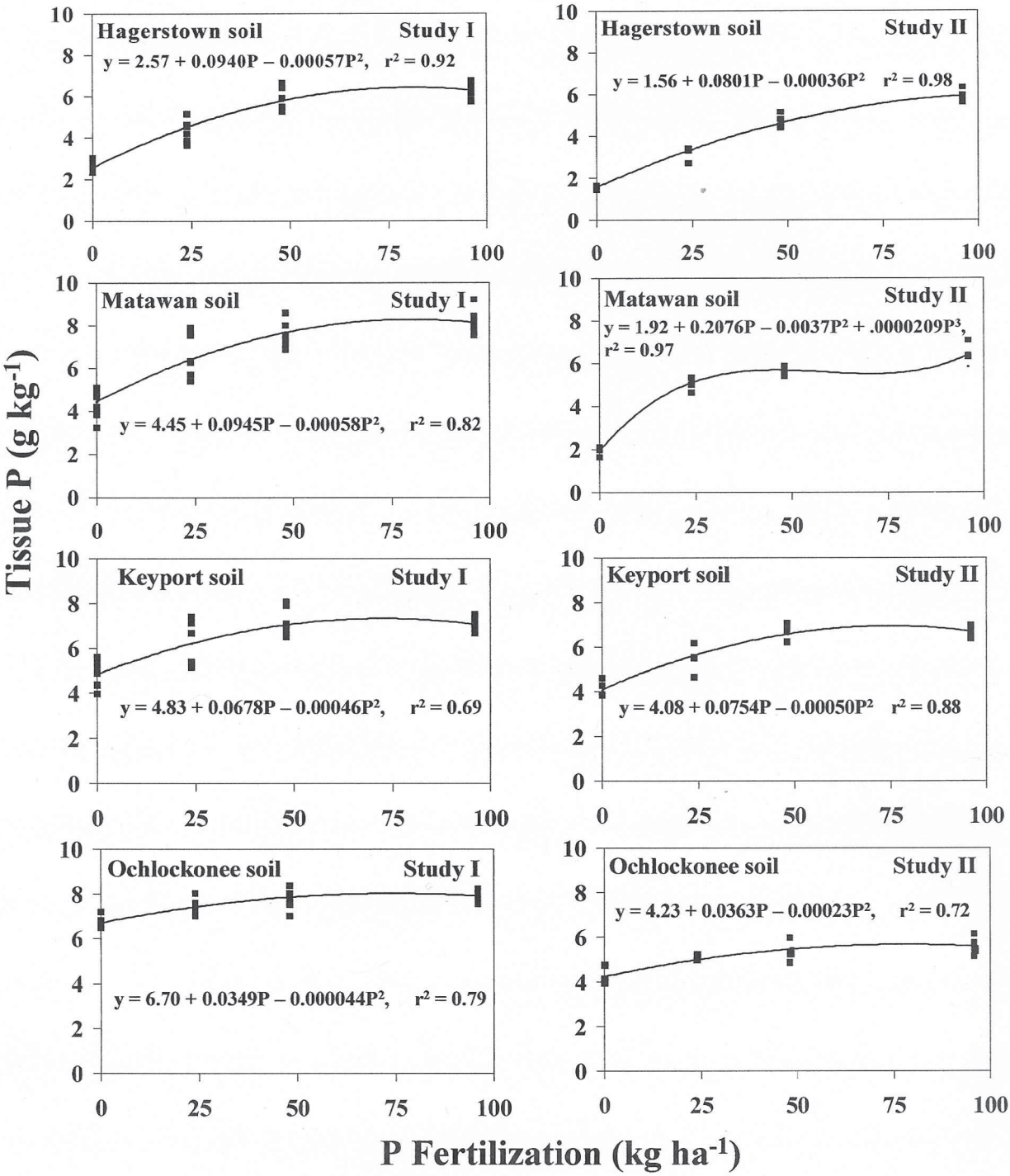

Figure 2. Seedling P tissue concentration in response to P fertilization.

establishment soil calibration efforts (Turner and Waddington, 1983). The moderate r^2 values associated with these relationships indicate that factors other than P availability affected seedling growth. With the exception of the 96 kg ha^{-1} addition of P made to the Hagerstown soil, seedling response to fertilizer P in the Hagerstown and Matawan soils was greater in Study II than in Study I. Enhanced growth responses to P additions seen in Study II appear to be the result of reduced P uptake occurring under the cooler conditions of this study. Although soil temperature was not measured, it was presumably higher in Study I than in Study II. Declining soil temperatures below 25°C reduce the ability of tall fescue roots to absorb P (Barber, 1995, Reinbott and Blevins 1994) and diminishes the desorption of liabile P into available soil solution P. The latter process is usually the more restrictive of the two in reducing P uptake (Singh and Jones, 1977) in cold soils. It is readily attenuated however, by P addition to the

soil. Because overall seedling growth was greater in Study II than Study I, it is unlikely that the more favorable response to added P seen in Study II was the result of a less extensive root growth in Study II.

Soil test calibration relates soil test level and the addition of fertilizer to the likelihood a crop response will be observed. In practice, soil test calibration groups soil test results into several interpretative categories from which fertilizer recommendations are then made. Many laboratories in the US use four interpretative categories,"Low", "Medium", "High" and "Very High" (or "Excessive") (Sims, 1993). The "Low" and "Medium" categories are associated with crop response probabilities of 80 to 100%, and 50%, respectively (Dahnke and Olson, 1990). The "High" category identifies soils that are likely to show little to no response, while the " "Very High" category indicates that it is extremely unlikely nutrient addition would result in a favorable growth response. Although a limited number of soils were examined in this investigation it is readily apparent that the likelihood of a favorable tall fescue seedling growth response to P fertilization is high for the four soils having a Mechlich III soil test P between 52 and 66 mg kg^{-1}. Using the aforementioned criterion, the four soils as a group would be categorized as "Low" for the purpose of making a P fertilizer recommendation for tall fescue establishment from seed. This is in contrast to soil test P levels that have been use for the maintenance of established turf. Mehlich III soil test P in the 52 to 66 mg kg^{-1} range has been more commonly categorized as "Medium" or "High" for this purpose (Carrow et al., 2004).

Enhanced seedling growth in the soils having 97 to 277 mg kg^{-1} soil test P was restricted to a single instance (Matawan soil) in Study II. All of the soils in this group had excessive P for crop growth as determine by the University of Maryland soil test lab. No reductions in seedling growth occurred, however with added P. The response seen in the Matawan soil was more representative of what would be expected of a soil categorized as "High" (as compared to excessive) in soil test P.

In a study investigating coastal plain soils in the mid-Atlantic region of the USA, Sims (1989) found that the Bray-1 and Mehlich-III extracts provided similar soil test P results. Turner and Waddington (1983) examined the establishment of Kentucky bluegrass, chewings fescue (*Festuca rubra* var. commutata) and perennial ryegrass (*Lolium perenne*) and concluded that a Bray-1 soil test P of 49 to 80 mg kg^{-1} resulted in the most rapid rate of establishment of the three species. They also found that adding 400 kg ha^{-1} P to a Hagerstown silt loam having a Bray-1 soil test P of 27 mg kg^{-1} increased chewings fescue percent cover by 12%, five weeks after seedling. A comparable increase in tall fescue seedling growth was seen 23 to 24 days after seeding with the addition 24 kg ha^{-1} P to the Hagerstown soils in Study I and III. The Hagerstown soils in Study I and Study III had an average soil test P of 61 mg kg^{-1}. This would appear to indicate that tall fescue seedling growth is more sensitive to fertilizer P than is chewings fescue establishment, when the latter is evaluated as percent soil cover. The greenhouse pot studies also indicate that the soil test P threshold for tall fescue seedling response to added P is near the upper portion of soil test P range reported by Turner and Waddington (1983) for rapid chewings fescue and perennial ryegrass establishment.

CONCLUSIONS

The data presented here show that under conditions of rapid seedling development (i.e., favorable temperature and soil moisture), P addition at seedling will have little impact on tall fescue seedling growth in soils having 97 mg kg^{-1} or more soil test P. Conversely, positive seedling growth responses to added P may occur in soils having more than 97 mg kg^{-1} soil test P when conditions do not favor rapid initial seedling growth. Significant increases in growth occurred with added P in soils previously categorized as having optimal soil test P for crop yields. On average the addition of 24, 48, and 96 kg ha^{-1} P, under favorable growth conditions, increased seedling growth by 14, 25, and 34%, respectively in soils having optimal P for crops in Maryland (52 to 66 mg kg^{-1} soil test P). These results indicate that P fertilization of newly seeded tall fescue needs to be linked to soil test results and to growing conditions. They also reveal that the P needs of seedling turfgrass are higher than those associated with crop yield responses. Thus sufficiency ranges developed for other crops may not be appropriate for turfgrass establishment. Separate soil test calibration for turfgrass establishment is warranted and should be used as one of the principal criterion for determining when P additions to newly seeded sites should be made.

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