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The Effects of Soil Ph on *Setaria viridis* and *Abutilon theophrasti* Seedling Growth and Tissue Nutrients

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Abstract: Weeds vary in their response to soil pH in how they become established, grow and thrive. Knowledge of how a weed species responds to soil pH could help in evaluating their competitive ability against crops under different soil conditions and provide valuable insights into their biology and adaptation in agroecosystems. Studies were conducted to determine the effect of three soil pH (4.3, 5.3 and 6.9) on the seedling growth of *Setaria viridis* and *Abutilon theophrasti* in terms of seedling shoot biomass accumulation and tissue nutrient content. The effect of several postemergence-applied herbicides (bentazon, cyanazine and 2,4-D) on established seedlings of those species was also investigated. Untreated *Setaria viridis*, as well as untreated and treated (bentazon, cyanazine and 2,4-D) *Abutilon theophrasti*, seedlings accumulated less biomass as the soil pH decreased from neutral to acidic reaction. In both species this reduction in growth was associated with interference of uptake and incorporation of calcium, magnesium and phosphorus, as well as toxicity caused by excessive amounts of aluminum, manganese and zinc in seedling tissue. These nutrient imbalances also led to enhanced injury of *Abutilon theophrasti* with bentazon, cyanazine and 2,4-D.

Key words: *Setaria viridis*, *Abutilon theophrasti*, seedling growing, tissue nutrient

INTRODUCTION

Knowledge of how a weed species respond to soil pH could help in evaluating their competitive ability against crops under different soil conditions and provide valuable insights into their biology and adaptation in agroecosystems.

Effect of soil pH on plant growth and development: Weeds vary in their response to soil pH in terms of conditions under which they become established, grow and thrive[1]. Optimum soil pH values for the growth of plant species is difficult to ascertain, except for a specific soil type. Warm- and cool-season annual weed species are more tolerant of low soil pH than some weed species, while other plant species thrive only in a narrow soil pH range[2]. A large shift inpH may result in a population shift in major weed competitors within a crop. Weber and Best[3] found that dicotyledonous weeds are more prevalent in neutral soil (e.g. pH 7.0), whereas graminaceous weeds are more prevalent on acid soils (e.g. pH 5.0). Studies on the effect of soil pH on *Elymus repens* [tax] geographic distribution have shown that although *Elymus repens* prefers soils with neutral or alkaline pH[2,4], it will grow in pH ranges of 4.5-8.0[5,6]. Several weeds may also exhibit differential growth and competitiveness when grown in variable pH between 4.0 and 7.0[7].

Effect of soil pH on nutrient availability: Increased usage of high rates of nitrogenous fertilizers in continuous corn (*Zea mays* L.) production often tend to acidify the soil, especially lighter textured soils. If the nitrogen (N) in the fertilizer is in the ammonia form, or another form that undergoes nitrification, soil acidification will result in the absence of neutralizing calcium[8]. Sandy and sandy loam soils are more susceptible to this type of acidification. With this soil acidification, soil calcium (Ca), magnesium (Mg) and phosphorus (P) can become much less available to plants, while excessive soil aluminum (Al), manganese (Mn) and iron (Fe) availability can cause toxicity to plants[8,11].

Plants may grow poorly at low soil pHs due to the excessive availability of some micronutrients[12]. Weeds grown at high acidities have not been affected by acidity *per se*, but by Al toxicity. Sensitive species to low soil pH, such as *Cerastium vulgatum* L., *Taraxacum officinale* Weber, *Setaria glauca* (L.) Beauv., and *Poa pratensis* L. have been found to be susceptible to Al. Symptomology of Al toxicity are brown roots with fewer rootlets and discolored root tips. In competitive grass swards, in acidic soils, Al toxicity may control weeds because of their poor competitive ability. Excess Al causes plants to wilt and have decreased absorption of Ca, P, K, Mn and Fe[13]. Aluminum may reduce root permeability, or it may cause injury by competing with roots for specific nutrient ions.

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In acidic soils, Al is a good competitor for P, and excess Al may interfer both with uptake and utilization of P. It has been postulated that Al tolerance may involve organic acids produced in the rooting medium that could act as chelating agents of Al[14]. Gupta *et al.*[15] suggested that toxicity effects could be eliminated by increasing the soil pH to values greater than 5.5 with applications of lime. At these higher pHs Al has a lower solubility in soil. Manganese toxicity symptoms in barley occurred at pH values as high as 5.8 in the presence ofr large quantities of Mn.

Effect of soil pH on herbicide availability: Soil pH has a profound influence on the efficacy of herbicides, primarily in the way it affects detoxification of these pesticides by the soil. Postemergence-applied herbicides act directly on shoot tissues that intercept the chemical, but can also act on underground tissues after that time when the chemicals enter the soil. A plant stressed by pH conditions in the soil may also respond to herbicides differently than an unstressed plant. Little is known of the effect of postemergence-applied herbicides on plants grown in different pH soils.

The objectives of this study was to determine the effect of soil pH (4.3, 5.3, 6.9) and several postemergence-applied herbicides (bentazon, cyanazine and 2,4-D) on *Setaria viridis* (L.) Beauv. and *Abutilon theophrasti* (L.) Medic. seedling shoot biomass and nutrient content.

MATERIALS AND METHODS

Plant material: Seeds of *S. viridis* were collected in Elora, Ontario, while those of *A. theophrasti* were collected in Middleport, Ontario, Canada. The seeds were planted in 9 x 6 x 6 cm deep pots (324 cm^2 soil volume) containing several different pH soils. Plants were selected at emergence for uniform size, color, developmental stage of growth and vigor. Each pot was thinned after emergence to 8 *S. viridis* and 10 *A. theophrasti* plants for the first repetition, and 10 and 15 per pot (respectively) for the second repetition, of the experiment. Plants were treated 2 wks after planting: *S. viridis*, 2-3 leaves, 2-3 cm height; *A. theophrasti*, 2 leaves, 2-3 cm height. Plants were harvested 4 wks after planting (untreated *S. viridis*, 3 leaves; untreated *A. theophrasti*, 4 leaves). Data collected at that time was fresh weight per pot, shoot tissue above the soil surface.

Growth environment: Plants were grown in controlled environment chambers. The environmental conditions were 16 h, 20°C light period, 8 h, 15°C dark period, with 66% relative air humidity. The photon flux density during the light period was 440 μm quanta m^{-2} s^{-1}.

Table 1: Soil pH and particle size fractions for the soils used in the experiment

Soil Type	pH	(%) Sand	(%) Silt	(%) Clay
Watrin loamy sand	4.3	89.0	6.6	4.5
Watrin loamy sand	5.3	88.0	7.4	4.5
Watrin sand	6.9	91	5.3	4.1

Soil: Soil for this study was obtained from a farm in Delhi County, Ontario, Canada with a history of high nitrogen fertilization and continuous corn production for several years (Table 1). Soil pH was determined at the beginning of the experiment using the paste method utilizing de-ionized water and a Corning pH meter and electrodes. These pH evaluations were conducted by the Ontario Ministry of Agriculture and Food (OMAF) Soil Testing Laboratory, operated by the University of Guelph, Department of Land Resource Science, Ontario Agricultural College, Guelph, Ontario.

Herbicide treatment: Three herbicides were used in this study: bentazon (3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide), cyanazine (2-[[4-chloro-6-(ethylamino)1,3,5-triaz-2-yl]amino]-2-methylpropanenitrile) and 2,4-D ((2,4-dichlorophenoxy) acetic acid amine). Preliminary studies (data not reported) were conducted to determine a single herbicide rate to apply to plants. This rate was to be a standard (control) of comparison to evaluate soil pH effects on weeds: the rate resulting in 50% seedling shoot growth reduction (I_{50}) on plants grown at soil pH 6.9. The I_{50} rates determined for *A. theophrasti* was 0.75 kg a.i. ha^{-1} bentazon, 0.15 kg a.i. ha^{-1} cyanazine, and 0.35 kg a.i. ha^{-1} 2,4-D amine. These herbicides were applied postemergence with a stationary mounted herbicide spray applicator delivering 187 L ha^{-1} water volume.

Plant tissue nutrient analysis: After harvest, plants were analyzed for concentrations of several important macro- and micro-nutrients: Al, Ca, Fe, K, Mg, Mn, N, P and Zn. These seedling nutrient analyses were conducted by the Plant Analysis Laboratory of the OMAF Soil Testing Laboratory[16]. All plant material was dried to a constant weight, and ground in a 20-mesh mill fitted with stainless steel knives and screen. The ground material was placed in moisture-proof containers. Analysis of Ca, K, Mg, N and P utilized the wet ashing procedure of Thomas *et al.*[16]. For Al, Fe, Mn and Zn analysis, dry ashing was done by placing the plant material in a muffle furnace at 470°C for 24 h and then dissolving it in 0.4 *M* HCl. After ashing, readings of Al, Ca, Fe, K, Mg, Mn and Zn were made by a Varian Model AA-175 atomic absorption apparatus, whereas readings for N and P were made by a Technicon Auto Analysers II.

Experimental design: The experiments were done using a completely randomized experimental design. The parameters and levels of the *A. theophrasti* treatments were: 3 soil pH (4.3, 5.3, 6.9); and 3 herbicides at two application rates (untreated and treated: bentazon, cyanazine, 2,4-D). The parameter and levels of the *S. viridis* treatments were 3 soil pHs (4.3, 5.3, 6.9). Each experiment was conducted twice, with 4 replications used in the repetition and 12 replications in the second. Measurements made included seedling shoot fresh weight per pot and seedling tissue nutrient contents. Data were analyzed using ANOVA and means were separated using Duncan's Multiple Range Test at the p=0.05 level.

RESULTS AND DISCUSSION

Effect of soil pH on weed seedlings: *S. viridis* and *A. theophrasti* shoot weight decreased as the soil pH decreased from 6.9 to 5.3 to 4.3 (Table 2). As the soil pH decreased in this range, the concentration of Al, Mn, and Zn increased in both *S. viridis* and *A. theophrasti* shoot tissue (Table 3). Shoot concentrations of Fe in *S. viridis*, and nitrogen in *A. theophrasti*, also increased with decreasing soil pH. With decreasing soil pH, shoot Ca, Mn and P decreased in both weed species. *S. viridis* shoot K content decreased with decreasing soil pH. In all other instances untreated *S. viridis* and *A. theophrasti* macro- and micro-nutrient concentrations did not change with changing soil pH.

Effect of soil pH and herbicides on weed seedlings: No shoot growth differences in *S. viridis* plants grown in different pH soils was observed when treated with bentazon, cyanazine or 2,4-D. The effect these herbicides had on *A. theophrasti* in reducing seedling fresh weight was dependent on the soil pH they were grown in. As soil pH decreased from 6.9 to 4.3, *A. theophrasti* plants treated with the same rate of these individual herbicides accumulated less fresh weight. As the soil pH decreased from 6.9 to 4.3, the concentration of Al and Mn increased in *A. theophrasti* shoot tissue treated with the three herbicides (Table 4). Concentrations of N in *A. theophrasti* shoots treated with 2,4-D, and Zn content in those treated with bentazon and 2,4-D, increased with

Table 2: The effect of soil pH on *Setaria viridis* and *Abutilon theophrasti* seedling shoot biomass

	Shoot fresh weight (mg per pot)	
Soil pH	*S. viridis*	*A. theophrasti*
4.3	601 B[a]	997 C
5.3	820 A	1109 B
6.9	927 A	1392 A

[a]Means within a column (the same species) with the same letter are not significantly different at the p=0.05 level with the Duncan's Multiple Range Test

Table 3: The effects of soil pH and several postemergence-applied herbicides on *Setaria viridis* and *Abutilon theophrasti* seedling shoot nutrient contents

	Nutrient Content pH		
Treatments	4.3	5.3	6.9
Aluminum	$\mu L\ L^{-1}$		
S. viridis-Untreated	60[a] A	27 B	26 B
A. theophrasti-Untreated	24 A	21 AB	13 B
A. theophrasti-Bentazon	51 A	23 B	15 B
A. theophrasti-Cyanazine	73 A	32 B	18 C
A. theophrasti-2,4-D	51 A	25 B	17 B
Calcium	%		
S. viridis-Untreated	0.15 B	0.26 A	0.22AB
A. theophrasti-Untreated	0.46 B	1.20 A	1.31 A
A. theophrasti-Bentazon	0.95 C	2.01 B	2.71 A
A. theophrasti-Cyanazine	0.97 B	2.13 A	2.27 A
A. theophrasti-2,4-D			
Iron	$\mu L\ L^{-1}$		
S. viridis-Untreated	306 A	155 B	149 B
Magnesium	%		
S. viridis-Untreated	0.20 C	0.45 A	0.35 B
A. theophrasti-Untreated	0.18 C	0.52 A	0.45 B
A. theophrasti-Bentazon	0.26 B	0.81 A	0.75 A
A. theophrasti-Cyanazine	0.32 C	0.83 B	1.02 A
A. theophrasti-2,4-D	0.25 B	0.61 A	0.66 A
Manganese	$\mu L\ L^{-1}$		
S. viridis-Untreated	117 A	51 B	16 C
A. theophrasti-Untreated	193 A	65 B	76 B
A. theophrasti-Bentazon	399 A	83 B	108 B
A. theophrasti-Cyanazine	392 A	95 B	110 B
A. theophrasti-2,4-D	258 A	61 B	79 B
Nitrogen	%		
A. theophrasti-Untreated	1.63 A	1.53 AB	1.30 B
A. theophrasti-Cyanazine	3.08 A	2.90 B	3.18 A
A. theophrasti-2,4-D	2.52 A	2.25 AB	2.07 B
Phosphorus	%		
S. viridis-Untreated	0.14 B	0.12 B	0.26 A
A. theophrasti-Untreated	0.17 B	0.14 B	0.26 A
A. theophrasti-Bentazon	0.31 B	0.30 B	0.58 A
A. theophrasti-Cyanazine	0.35 B	0.33 B	0.63 A
A. theophrasti-2,4-D	0.31 B	0.31 B	0.43 A
Potassium	%		
S. viridis-Untreated	3.01 B	3.46 A	3.71 A
Zinc	$\mu L\ L^{-1}$		
S. viridis-Untreated	51 A	44 B	36 C
A. theophrasti-Untreated	60 A	51 B	27 C
A. theophrasti-Bentazon	138 A	123 A	103 B
A. theophrasti-2,4-D	88 A	74 B	51 C

[a]Nutrient concentration means within an individual treatment and nutrient (row) with the same letter are not significantly different at the p=0.05 level with the Duncan's Multiple Range Test

Table 4: The effect of soil pH and postemergence-applied herbicide treatment on *A. theophrasti* seedling shoot biomass

	Shoot fresh weight (mg per pot) pH		
Treatments	4.3	5.3	6.9
Bentazon (0.75 kg a.i. ha^{-1})			
Untreated	1005[a] C	1144 B	1487 A
Treated	663 E	843 D	721 E
Cyanazine (0.15 kg a.i. ha^{-1})			
Untreated	1005 B	1144 B	1487 A
Treated	513 D	766 C	746 C
2,4-D amine (0.35 kg a.i. ha^{-1})			
Untreated	973 C	1016 C	1426 A
Treated	666 D	1149 B	1013 C

[a]Means with the same letter within a herbicide treatment are not significantly different at the p=0.05 level with the Duncan's Multiple Range Test

decreasing soil pH. As the soil pH decreased from 6.9 to 4.3, *A. theophrasti* shoot content of Ca, Mn and P decreased in those plants treated with a three herbicides evaluated. In all other instances, macro- and micro-nutrient concentrations in *A. theophrasti* treated with the three herbicides did not change with changing soil pH.

Untreated *S. viridis*, and herbicide treated and untreated *A. theophrasti*, seedlings accumulated less biomass as the soil pH decreased from a neutral to acidic reaction. In both species this growth reduction was associated with interference of uptake and incorporation of calcium, magnesium and phosphorus, as well as toxicity caused by excessive amounts of aluminum, manganese and zinc in seedling tissue. In the lowered nutrient conditions induced by the sandy soils by excessive rates of nitrogen fertilization, these nutrients may have become less available for plant growth. The toxicity could be caused by excessive amounts of Al, Mn and Zn due to their greater abundance in lower pH soils. Both causes probably caused the observed growth reductions of *S. viridis* and *A. theophrasti*. The more acidic soils used in these experiments was caused by long term use of nitrogen fertilization in continuous corn cropping. Under these acidic conditions, soil Ca, Mg and P became limiting to weed growth, while simultaneously Al, Mn and Fe may have been excessive, toxic. In the case of *Abutilon theophrasti* treated with bentazon, cyanazine and 2,4-D, these nutrient imbalances resulted in enhanced injury.

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