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Research article

Effect of boron nutrition on American ginseng in field and in nutrient cultures

John T.A. Proctor*, Barry J. Shelp

Department of Plant Agriculture, University of Guelph, Guelph, Ontario, Canada

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ABSTRACT

Field and nutrient cultures of American ginseng (*Panax quinquefolius* L.) were used to establish foliar symptoms related to boron (B) concentration in leaves and soils, and to evaluate radish as a time-saving model system for B nutrition. Application of excess B, 8 kg/ha versus the recommended 1.5 kg/ha, to field plantings of 2-, 3-, and 4-yr-old American ginseng plants just prior to crop emergence caused, within 4 wk after crop emergence, leaf symptoms of chlorosis followed by necrosis starting at the tips and progressing along the margins. The B concentration in leaves of 2–4-yr-old plants receiving 1.5 kg/ha B was 30 μg/g dry mass compared to 460 μg/g dry mass where 8 kg/ha B was applied. Similarly, B concentration in soils receiving the lower B concentration was 1.8 μg/g dry mass and 2.2–2.8 μg/g dry mass where the higher B concentration was applied. Application of 8 kg/ha B reduced the dry yield of 3rd-yr roots by 20% from 2745 kg/ha to 2196 kg/ha and 4th-yr roots by 26% from 4130 kg/ha to 3071 kg/ha. Ginseng seedlings and radish were grown under greenhouse conditions in nutrient culture with four B concentrations ranging from 0 mg/L to 10 mg/L. At 5 mg/L and 10 mg/L ginseng and radish developed typical leaf B toxicity symptoms similar to those described above for field-grown plants. Increasing B in the nutrient solution from 0.5 mg/L to 10 mg/L decreased, in a linear fashion, the root and leaf dry mass of ginseng, but not radish. Given the many similarities of ginseng and radish to B utilization, radish might be used as a time-saving model system for the study of B, and other micronutrients, in the slow-growing perennial ginseng.
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1. Introduction

American ginseng (*Panax quinquefolius* L.) is a minor crop in North America and there is little research information to assist growers of the crop [1,2]. Even data for mineral nutrition of the crop are sparse. Stoltz [3] described various foliar deficiency symptoms for ginseng grown in nutrient solutions. He reported that root fresh mass gain, the most important economic yield component, was most reduced by the omission of calcium, phosphorus, or magnesium from the nutrient solution. He did not study boron (B) nutrition. Khwaja and Roy [4] have given nutrient ranges in ginseng based on extensive sampling of growers' fields. Minimum and maximum B concentrations in leaves of 2–4-yr-old plants were: 5 μg/g, deficient; 5–15 μg/g, low; 16–50 μg/g, sufficient; 51–100 μg/g, high; and >100 μg/g, excessive.

Konsler and Shelton [5] and Konsler et al [6] described the effect of lime and phosphorus on the growth, nutrient status, and ginsenoside content of the ginseng root.

Ginseng production in Ontario, Canada, the major center for American ginseng culture, is on sandy and sandy-loam soil with low organic matter content, along the north shore of Lake Erie [7]. In general, these soils are low in B for production of many crops [8,9]. Previously, we reported that the rusty root of ginseng and associated internal browning of roots grown in the above-mentioned soils may be linked to B deficiency [10].

B is required by plants only in small amounts, therefore, over-application to crops can occur easily. Oliver [11] recommended that to maintain adequate soil levels of B for ginseng cultivation, 1–2 kg/ha should be applied when soil tests show ≤0.5 μg/mL. B is taken up through the plant roots as boric acid and transported with the transpiration flow. In most plants, B is highly immobile [12], being restricted to the transpiration stream. Accumulation of B can occur at the end of the transpiration stream in the leaves [13]. Manifestation of B toxicity shows as damage to tissues where it accumulates. Although B toxicity is crop-specific, it generally leads to chlorosis and necrosis starting at the edges of mature leaves [12,13].

* Corresponding author. Department of Plant Agriculture, University of Guelph, Guelph, Ontario N1G 2W1, Canada.
E-mail address: jtprocto@uoguelph.ca (J.T.A. Proctor).

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This development of necrotic areas can reduce leaf photosynthetic potential, cause a reduction of photosynthetic supply to the developing root system, the economic part of the ginseng plant, and restrict activity in the meristematic tissues. It is unclear why B is toxic to plants, or why some plants can tolerate B and evade toxicity [13]. Reid et al [14] concluded that, at high B concentrations, many cellular processes are retarded and these are often made worse in light by photoxidative stress.

Ginseng is a perennial plant requiring about 4 yr from seeding to root harvest, therefore, we examined the possibility of using radish as a time-saving model system in our B nutritional studies. Radish requires 3–6 wk from seeding to root harvest and B deficiency induces root splitting and brown heart disorder [15], similar to brown heart in ginseng [10]. Also, B toxicity in radish reduces root growth [16,17].

Lack of definitive data on B nutrition of American ginseng, the supposed deleterious effects on the leaves, roots, and meristematic regions, and an application of a high concentration of B to commercial ginseng plantings prompted this investigation. The objectives of this work with ginseng were to describe, in field plantings and nutrient cultures, the foliar symptoms associated with the application of different rates of B; to establish that foliar symptoms were due to B; to obtain general information about B nutrition, particularly toxicity; and to evaluate radish as a model system for the B nutrition of ginseng.

2. Materials and methods

2.1. Field experiments

For the field experiments, seedlings were established at a seeding rate of 112 kg/ha (about 215 seeds/m^2 or 46.5 cm^2 space per seedling) and grown following standard cultural methods for American ginseng [18]. Seeds were planted on raised soil beds and covered with 5–10 cm of straw mulch. Woven black polypropylene shade was placed 2 m above the beds to reduce solar radiation to an optimal 20–30% of full sunlight. Standard commercial practices for pest control were followed [18]. Field experiments were carried out with 2-, 3-, and 4-yr-old plants using 1-m^2 plots having guards also of 1 m^2. Treatments of B were 1.5 kg/ha (control) and 8 kg/ha. They were replicated four times in a randomized complete block design with four blocks. The broadcast soil-applied commercial fertilizer was applied prior to crop emergence and was based on superphosphate, potassium chloride, ammonium sulfate, magnesium sulfate, and zinc sulfate (N 9.0%, P 7.0%, K 7.4%, Ca 8.5%, S 9.8%, Mg 8%, and Zn 0.9%). Sodium borate (14% B) was added to the blended mixture to produce final B rates of 1.5 kg/ha and 8 kg/ha.

2.2. Greenhouse experiments with ginseng and radish

These pot experiments were carried out in a greenhouse without supplemental lighting at the University of Guelph, Guelph, Ontario; latitude 43° 32′ N, longitude 80° 15′ W. Ginseng mature stratified seeds were purchased from a local Ontario grower in October. These seeds were mixed with moistened mortar sand (1 seed/3 sand, v/v) and put in plastic containers that were held in a controlled-environment room (4 ± 1 °C, 50 ± 5% relative humidity) until the experiments were started in January. For the radish (*Raphanus sativus* L. cv. Cherry Belle), experimental seeds were purchased from a commercial seed house.

For the pot experiments with the two plant species, 10 seeds were planted equidistant within each wide (21 cm diameter) and deep (21 cm) pot. Seed germination averaged 60%. Seeding depths of 40 mm for ginseng and 20 mm for radish were used. The germination and growing medium for all seedlings was vermiculite. The pots were filled to within 3 cm of the top with the vermiculite.

Table 1
Effect of broadcast application of B at two rates on the soil elemental composition of test fields containing different age ginseng plants[1)]

B rate, plant age	Soil pH	OM (%)	Macroelement (ppm)				Microelement (μg/g dry mass)		
			P	K	Ca	Mg	Mn	Zn	B
1.5 kg/ha									
3 yr	5.4	2.1a*	93.2a	138.7ab	456.5	51.5ab	52.5	30.5a	1.8a
8 kg/ha									
2 yr	5.5	2.0b	63.0c	159.7a	470.7	46.0b	47.2	41.0b	2.7bc
3 yr	5.4	1.5b	79.0b	116.5b	473.0	49.7ab	60.5	47.0b	2.8c
4 yr	5.4	2.1a	83.2b	149.2a	482.7	57.7a	62.2	47.0b	2.2ab

* Mean separation in columns by different letters by Duncan's multiple range test, $p < 0.05$.
OM, organic matter.
1) The soil was sampled 2 mo after the fertilizers were applied.

Light transmission of the greenhouse was measured with a quantum, or line quantum, sensor (LI-COR, Lincoln, NE, USA). For the ginseng greenhouse experiments, 30% of the incident light at the top of the seedlings was established by suspending different thicknesses of knitted black polypropylene shade cloth above the pots. Radish plants were grown under ambient light. For each experiment, repeated at least twice, there was a minimum of four pots per treatment in a completely randomized design.

Plants were managed and fertilized as described previously [15]. Every 3rd day plants were fertilized with 1 L full-strength Hoagland's solution as described by Knott et al [19]. The standard (control) solution was prepared with distilled water and contained 0.5 mg/L B and 200 mg/L calcium. Four B treatments were used: 0 mg/L, 0.5 mg/L, 5 mg/L, and 10 mg/L.

2.3. Soil and plant sampling

In the field experiments, soil samples were taken 2 mo after fertilizer application (Table 1) [20]. At the end of the growing season, the 2-yr-old plantings were discarded because leaf damage was extensive and root growth was reduced to the point that predicted yield at harvest would not generate a profit. At the end of the growing season, all roots in the 1-m^2 areas of each of 3- and 4-yr-old plantings were dug by hand. The harvested roots were washed free of soil, dried to constant weight at 38 °C, and weighed. These yields were then converted to kg/ha.

In the pot experiments, at the end of the growing season of 70 d for radish and 100 d for ginseng, plants were assessed for foliar symptoms and then harvested. The roots were also assessed visually for deficiency or toxicity symptoms of root color and surface texture and cracking, and given a rating of 0 for no symptoms and 1, 2, and 3 for mild, moderate, and severe, respectively. Each seedling was then separated into leaves and roots and dried to constant weight at 80 °C.

Where appropriate, data were analyzed using SAS version 9.1 (SAS Institute, Cary, NC, USA). Descriptive statistics such as means and standard deviations were calculated. Regression analysis was used to evaluate relationships between ethephon application and plant response in field experiments, and between ethephon application and plant response of both ginseng and radish plants grown in pots in greenhouse experiments.

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