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Effect of seeding depth on seedling growth and dry matter partitioning in American ginseng

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Greenhouse and field experiments with American ginseng (*Panax quinquefolius* L.) stratified seed sown at depths of 10 to 100 mm were carried out to determine effects of seeding depth on seedling emergence, growth and development and to calculate optimum seeding depth. The time to 50% seedling emergence (E_{50}) in the field increased linearly from 17 d at 20 mm seeding depth to 42.5 d at 80 mm. Seedling emergence and root weight (economic yield) at the end of the first year each increased quadratically with the increase of seeding depth. Maximum emergence and root yields were produced at sowing depths of 26.9 and 30.6 mm respectively. In a greenhouse pot experiment, increasing seeding depth from 10 to 100 mm increased partitioning of dry matter to leaves from 23.6% to 26.1%, to stems from 6.9% to 14.2%, and decreased dry matter to roots from 69.5% to 59.7%. Optimum seeding depth was 31.1 mm for a corresponding maximum root weight of 119.9 mg. A predictor equation [X (seeding depth, mm)=Y (seed weight, mg)/9.1+20.96] for seeding depth for ginseng, based on data for ten vegetable crops, their seed weights and suggested seeding depths, predicted a seeding depth of 28.3 mm for ginseng similar to that reported above for most pot and field experiments.

Keywords: Dry matter partitioning, *Panax quinquefolius*, Root dry weight

INTRODUCTION

Ginseng is an important minor crop in North America [1,2]. The ginseng plant is a slow-growing herbaceous perennial grown under shade for its highly valued root. Propagation of ginseng is by seed [3]. For most crops seeding should be done at a depth that ensures a continual moisture supply and good seedling anchorage [4].

For commercial ginseng growers the effects of seeding depth of American ginseng on seedling growth and performance have been summarized by Persons and Davis [1] and Curran and Curran [5]. Persons and Davis [1] suggested a seeding depth of 0.75 inches (about 20 mm) to 1 inch (about 25 mm). Curran and Curran [5] summarized available data on ginseng, mostly empirical, and suggested that the maximum seeding depth should be 25 mm and that 92 to 127 mm was too deep.

There is little research on ginseng seeding depth effects on plant performance. Li [6], in pot experiments with four seeding depths, showed that seedling emergence rate at a seeding depth of 15 mm was highest (64%) and days to complete emergence lowest (55%). Seedling root weight at 12.5, 25, and 50 mm sowing depth did not differ but was higher than that at 75 mm (mean of 0.75 vs. 0.55 g).

Deep seed sowing has a number of effects on seedling

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growth. For instance, there may be an increase in the time between seed germination and seedling emergence as found by Li [6] which largely determines the ranking of seedlings in the competitive hierarchy for growth resources [7]. An increase in hypocotyl or epicotyl length, as noted in deep seeding, will reduce the probability of the seedlings being capable of overcoming soil strength [8] and render the seedlings more susceptible to attack by pathogens [9]. Yu et al. [10] has shown, with Korean ginseng (*Panax ginseng* Meyer), that the deeper the seed was sown the higher was the incidence of damping-off caused by *Rhizoctonia solani*.

Very shallow seeding can lead to a high incidence of spider roots [11] which develop horizontally just below the soil surface and which are of very low quality [2]. However, provided the radicle of the germinating seed penetrates the soil, the seedling will develop normally with a tap root; such seedlings will have contractile roots [12,13] which ensures that the rhizome and the perennating bud are kept below the soil surface to prevent freeze damage.

The optimum seeding rate for American ginseng is based on commercial experience [1,2,5]. Generally, direct seeding is done at 112 kg ha^{-1} giving about 260 seed m^{-2} of growing area; at root harvest, 3 years later, only about 100 plants remain [14]. In the culture of Korean ginseng, Lee et al. [15] suggested a direct seeding rate of 55 to 83 seeds m^{-2} to optimize root size and total yield. At these seeding rates 67% of the plants were harvested which is about twice the survival rate of American ginseng seeded at higher rates. Similarly, survival rate in Lee et al. [15]'s experiment was 44% at 166 seeds m^{-2} which suggests higher plant loss with increasing seeding rate.

The objectives of this work were to determine the effects of seeding at different depths, under greenhouse and field conditions, on seedling germination, growth and development.

MATERIALS AND METHODS

Seed propagation and planting

These pot and container experiments were carried out in a greenhouse at the University of Guelph, Guelph, Ontario, latitude 43º 32´N, longitude 80º15´W. Mature stratified ginseng seeds were purchased from a local Ontario grower in October. As there are no registered cultivars or selections these seeds are genetically diverse. These seeds were mixed with moistened mortar sand (1 seed/3 sand, v/v) and put in plastic containers which were held in a controlled environment room (4±1°C , 50±5% relative humidity) until the experiments were started in January.

For pot experiments ten seeds were planted equidistant within each wide (21 cm diameter) and deep (21 cm) pot and at seeding depths of 10, 40, 70, and 100 mm. In a second experiment seeding depths of 20, 40, 60, and 80 mm were evaluated. Average seedling population was 289 seedlings m^{-2}. The germination and growing media for the seedlings was ProMix BX (Les Tourbieres Premier LTEE, Riviere du Loup, QC, Canada) which is a general purpose growing medium of 75% to 85% Canadian sphagnum peat moss, perlite and vermiculite, plus dolomitic limestone, calcium nitrate, potash, superphosphate, frittered trace elements, and a wetting agent. The pH of the mixture was about 6.0. The pots were filled to within 3 cm of the top with the media.

Light transmission of the greenhouse was measured with a quantum, or line quantum, sensor (LI-COR, Lincoln, NE, USA). For 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. For each experiment, repeated at least twice, there was a minimum of 4 pots per treatment in a completely randomized design.

For container experiments three readily available plant-growing containers were chosen for evaluation: 6 L volume plastic pots of 21 cm diameter and depth, 0.95 L fiber pots of 10.5 cm diameter and depth and 500 mL volume, and 3.8 cm diameter, 16.8 cm deep, 150 mL volume Ropak Multi-pots (Stuewe & Sons Inc., Corvallis, OR, USA). All containers were filled to within 3 cm of the top with the ProMix BX germination and growing media. Seeding depth was 30 mm.

In the 6 L container 10 seeds were planted equidistant, 2 seeds were planted in each fibre pot and one seed planted in each multi-pot. The containers were placed in a greenhouse (21±2°C day, 16±2°C night) and shaded with knitted black polypropylene shade cloth to allow 30% of the outside light to reach the containers. For each experiment, which was repeated at least twice, there was a minimum of 4 pots per treatment.

A second container experiment was carried out to compare four seeding depths of 20, 40, 60, and 80 cm in 6 L pots and in the Ropak Multi-pots. The seed source, germination and growing media and other details are similar to those described above.

For the field experiments seedlings were established at a seeding rate of 112 kg ha^{-1} (about 215 seeds m^{-2} or 46.5 cm^2 space per seedling) and grown following standard cultural methods for American ginseng [2]. Briefly, seeds were planted on raised soil beds and covered with 5 to 10 cm of straw mulch. These soils are well-drained

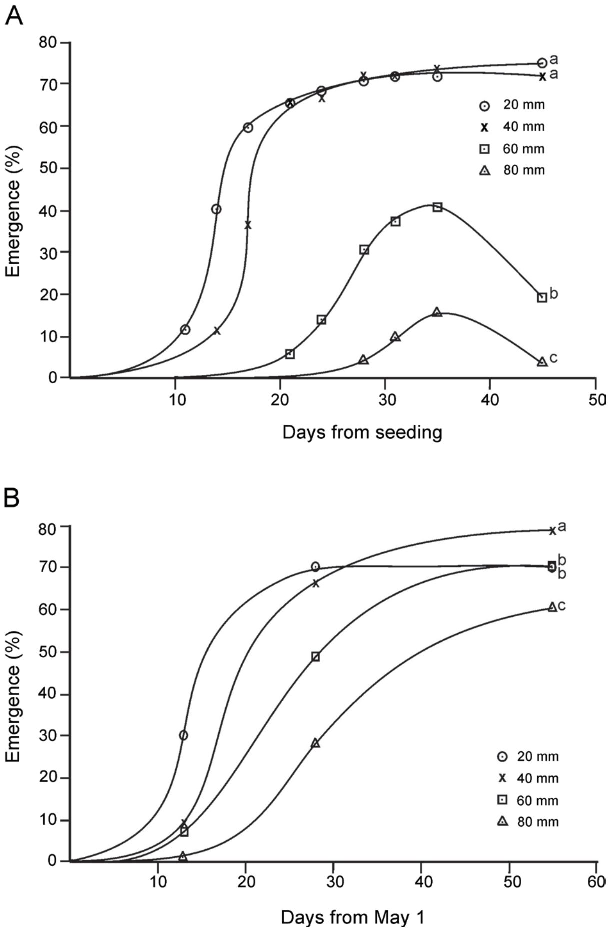

Fig. 1. Seedling emergence from seeds sown at four depths, 20, 40, 60, and 80 mm, in Ropak containers in a greenhouse (A) and the field (B). May 1 is the usual first seedling emergence date. Means for final emergence followed by different letters are significantly different at $p<0.05$, by Duncan's multiple range test.

and coarse-textured and provide little resistance to ginseng seedling emergence and growth [16]. Woven black polypropylene shade was placed 2 m above the beds to reduce solar radiation to an optimal 20% to 30% of full sunlight. Standard commercial practices for pest control were followed [2].

Plant sampling

In the pot experiments seedling emergence was recorded every 5 to 10 d (Fig. 1). Seedlings were harvested at the end of the growing season of about 100 d after seeding. Stem length was measured and then leaf area of each seedling was determined using a LI-3100 leaf area meter (LI-COR). Each seedling was then separated into leaves with petioles, stem and root, and dried at 80°C to constant weight.

In the field experiments seedling emergence was recorded every 5 to 10 d (Fig. 1). At the end of the growing season 10 plants were randomly selected and dug from each of four replications. Sample size was considered representative [17]. The dug plants were placed in plastic bags and taken to a constant temperature room held at 20±1°C. Plant measurements were the same as those made for seedlings harvested in the pot and container experiments as outlined above.

Predicting seeding depth

Gray [18] provided a guide, based on seed size, for depth of seeding some common vegetables. Using Gray's guide, but using seed weight instead of seed size from Knott et al. [19], linear regression analysis was used to determine the relationship between the seed weights (mg, Y) of ten vegetable crops [19] and their suggested seeding depths (mm, X) [18]. The seed weights included a range of seed sizes from large, such as sweet corn and snap beans, range 187 to 250 mg, to small such as beet and cucumber, range 17.5 to 25 mg. The equation was: Y=a+bX where Y is the vegetable seed weight, X is the seeding depth, a is the Y intercept and b is the slope.

After the regression equation was calculated it was rearranged to X (predicted seeding depth for ginseng)=Y (seed weight for ginseng)-a/b, to solve for X, with a seed weight of 64 mg [2].

Where appropriate, data were analyzed using the SAS ver. 9.1 (SAS Institute Inc., Cary, NC, USA). Best fit curves for relationships for both seedling emergence and seedling root yield and seeding depth were calculated using polynomial models after the data from several experiments had been normalized to 100% at a seeding depth of 40 mm. Optimum values of seeding depths and their respective maxima were determined by differentiation of best-fit quadratic functions.

RESULTS AND DISCUSSION

Seedling emergence patterns in a container and in the field

The seedling germination response curves for ginseng growing in the greenhouse in Ropak containers and in the field showed similar patterns (Fig. 1). Generally, there was a rapid emergence in the first 20 d in the containers in the greenhouse (Fig. 1A) and the first 30 d in the field (Fig. 1B). Thereafter, emergence was slow with final germination completed by about 45 d in the greenhouse and 55 d in the field.

The time to 50% seedling emergence (E_{50}) was about 14.7 d at a seeding depth of 20 mm and 17.7 d at 40 mm (Fig. 1A). Seeds sown at 60 mm and 80 mm never reached 50% emergence which is probably a reflection of the poor germination environment of a possible perched water table at these depths in Ropak containers. This has implications for the choice of seeding locations for ginseng production. For example, we have reported earlier [20] that ginseng growers have been selecting rental land because of attractive prices but these lands include wet sands with poor drainage. Such sites will likely lead to low seed germination and poor crop establishment.

The E_{50} in the field was 17 d for seeds planted at 20 mm, 23 d at 40 mm, 28.5 d at 60 mm, and 42.5 d at 80 mm (Fig. 1B). There was a linear increase in E_{50} with seeding depth, Y (E_{50})=7.25+0.41X (seeding depth), R^2=0.94. Final emergence at day 55 was highest (79%) at 40 mm, similar (70%) at 20 and 60 mm and lowest (60%) at 80 mm depth (Fig. 1B). For this experiment an optimum seeding depth of 40 mm for optimal final emergence was suggested.

Seedling emergence and final seedling population were similar at 20 and 40 mm depth in the greenhouse and at all depths in the field experiments (Fig. 1). In the pot experiments no mulch was added to the top of the growing media but was added in the field. Mulch addition in the field is necessary to combat repeated soil freeze-thaw cycles and reduced root yields [16] but this would not occur in the greenhouse pot experiments. Although a direct comparison of the presence or absence of mulch was not made, the data presented here suggest that added mulch has little effect on seedling emergence and growth from seeding at different depths.

Final seedling emergence and seeding depth

There was a quadratic response of percent seedling emergence to increasing seeding depth (Fig. 2). Although the linear model fit [seedling emergence (Y)=112.03-0.47 seeding depth (X), R^2=0.78] was significant, the more appropriate fit for these data was a quadratic equation giving an optimum seeding depth for maximum seedling emergence as shown for other seeded crops [21]. The quadratic fit, $Y=91.7+0.43X–0.008X^2$, gave a maximum for percent seedling emergence of 97.5% at a seeding depth of 26.9 mm (Fig. 2)

Too shallow seeding, i.e., less than 10 mm and not included in these studies, may lead to desiccation of the seedlings and low plant populations. Even if shallow-planted seeds survive and germinate, there is the likelihood that the resultant seedlings will scavenge for water and mineral nutrients horizontally and not penetrate deeply into the soil. Such behavior leads to the formation of low quality 'spider' roots as described and illustrated in Roy et al. [11]. This plant behavior, known as 'plasticity' is relatively common in plant species particularly in stress situations [22].

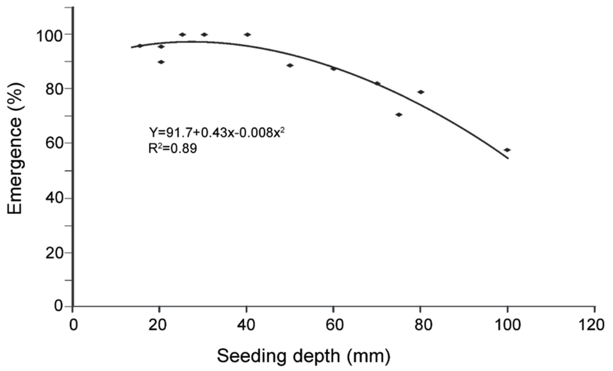

Fig. 2. Quadratic relationship between ginseng seedling emergence and seeding depth. There are two values at 30 mm and three at 40 mm so *n*=15. The maximum values, calculated from the equation, are for Y, 97.5% and for X, a seeding depth of 26.9 mm.

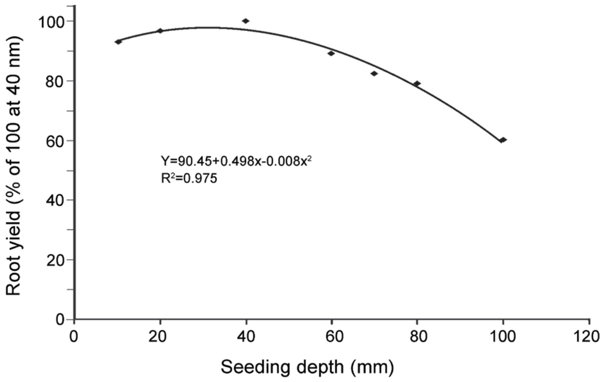

Fig. 3. Quadratic relationship between ginseng seedling root weight and seeding depth. There are two values at a seeding depth of 40 mm so *n*=8. The maximum values, calculated from the equation, are for Y, 97.5% and for X, a seeding depth of 30.6 mm.

Too deep seeding, at depths greater than about 50 mm (Fig. 2), reduced seedling emergence in an apparent linear fashion. Specific details about how deep planting affected dry matter partitioning within seedlings is discussed below.

Similar studies with other crop species having similar seed size, e.g., pigeon pea (*Cajanus eajan* L.) [23], okra (*Abelmoschus esculentus* L.) [24], and asparagus (*Asparagus officinalis* L.) seeds [25], and crowns [26], showed delayed emergence, thinner seedling stands and lower crop yields as depth increased.

Final seedling weight and seeding depth

Seedling root yield responded quadratically to increasing seeding depth (Fig. 3). The optimum seeding depth was 30.6 mm for a corresponding maximum yield of 120.1 mg (97.9% of the maximum yield at 40 mm).

Table 1. Effect of four sowing depths (10, 40, 70, and 100 mm) on the dry matter (mg) partitioning to leaves, stems, and roots of ginseng seedlings grown in pots

Sowing depth (mm)	Dry matter content and percentage of total dry matter in				
	Leaves	Stems	Roots	Total dry weight (mg)	Root to shoot ratio
10	38.8 (23.6)	11.4 (6.9)	114.4 (69.5)	164.6	2.28
40	40.1 (22.7)	13.5 (7.7)	122.7 (69.6)	176.3	2.29
70	36.2 (23.7)	15.5 (10.1)	101.2 (66.2)	152.9	1.96
100	32.5 (26.1)	17.6 (14.2)	74.1 (59.7)	124.1	1.48
Mean	36.9 (24.0)	14.5 (9.7)	103.1 (66.2)	154.5	2.00

Data are reported as the amount (mg) and the percentage (%) of the total dry weight (100%).

Dry matter partitioning and seeding depth

The mean percentage dry matter partitioning was greatest for roots (66.2%), followed by leaves (24.0%) and stems (9.7%) (Table 1). This partitioning for roots is similar to that reported previously in 11 experiments where it ranged from 61.4% to 76.1% [27]. As sowing depth was increased from 10 to 100 mm partitioning of dry matter to leaves increased from 23.6% to 26.1% and to stems increased from 6.9% to 14.2%, while partitioning to roots decreased from 69.5% to 59.7% (Table 1 and Fig. 4). The root to shoot ratio also decreased from 2.28 at a seeding depth of 10 mm to 1.48 at 100 mm.

The seedling root weight in this pot experiment responded linearly to seeding depth (Fig. 4A).Consideration of the individual data for root weight (Table 1 and Fig. 4A) suggested that a seeding depth of 30 to 40 mm was optimal and produced a corresponding root yield of about 120 mg. Leaf weight also declined linearly with seeding depth (Table 1 and Fig. 4A) but at a much lower rate. Stem weight increased linearly with seeding depth from 10 to 100 mm (Fig. 4A). The decrease in leaf area was linear as seeding depth increased from 10 to 100 mm (Fig. 4B). Stem length increased linearly with seeding depth (Fig. 4B) as did stem weight. Generally, seedlings that emerged from greater depths are less vigorous and likely more susceptible to diseases [10].

This partitioning of dry matter to the stem was as at the expense of root dry weight. Partitioning of dry matter to stems is poor carbon economy as the leaf abscises at the end of the growing season; partitioning to the roots is preferable as they, and the associated rhizome, are the perennating plant organs. Choice of seeding depth should reflect strategies for optimizing dry matter partitioning to storage organs.

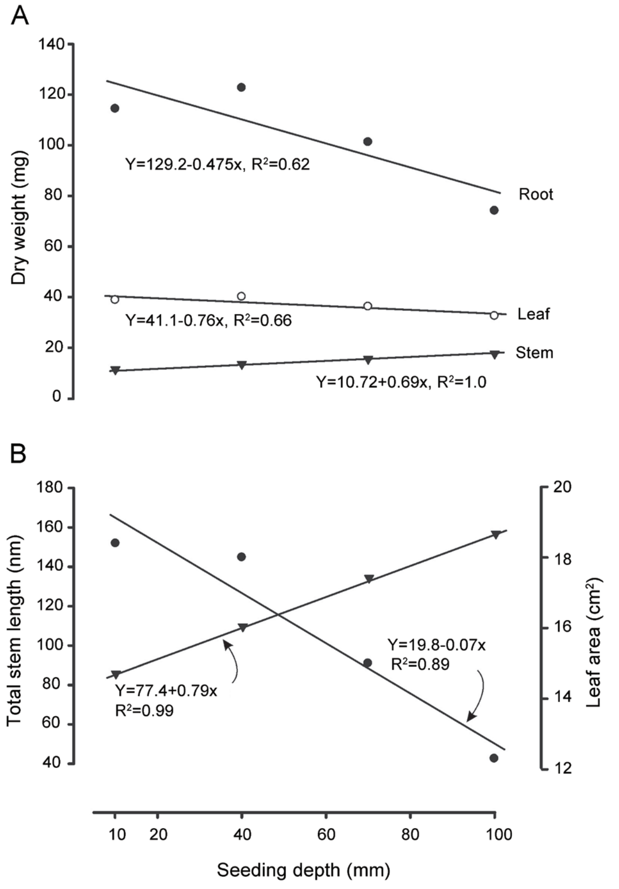

Fig. 4. The effect of four ginseng seeding depths, 10, 40, 70, and 100 mm on dry matter accumulation and partitioning in roots, leaves and stems (A), and on leaf area and total stem length (B). Fitted equations and their significance are shown.

Shanmuganathan and Benjamin [28] reported that deep sowing of spring cabbage (*Brassica oleracea* L. var. capitata L.) increased the proportion of dry matter in the hypocotyl at the expense of the cotyledons. The less pronounced effect in ginseng is likely due to the greater

Table 2. Growth of American ginseng seedlings in response to container choice

Container	Seedling measurement						
	Leaf area (cm^2)	Stem length (mm)	Root length (mm)	Dry weight (mg)			
				Root	Stem	Leaf	Total
6 L plastic pots	15.1a[1]	78b	56a	71a	13a	28a	112a
0.5 L fiber pots	15.4a	97a	60a	73a	14a	30a	117a
Ropak Multi-pots	14.5a	82b	57a	77a	13a	28a	118a

Seedlings were harvested after 100 d.

[1] Means within columns followed by different letters are significantly different by Duncan's multiple range test, $p<0.05$.

endosperm reserves in ginseng. A ginseng seed weighs 67 mg whereas cabbage seed weighs about 3 mg [18].

In summary, in this pot experiment deeper seeding increased stem length, reduced stem length above soil level, and reduced leaf area and root dry weight. Optimum seeding in this pot experiment was about 31 mm.

Container experiments

Experiment 1

Seedling leaf area, root length, and root, stem, leaf and total dry weights were not influenced by the container in which they were grown (Table 2). This would suggest that there is a wide choice of experimental growing containers for ginseng seedling studies in controlled environments using the chosen growing medium. Caution is necessary here as the three containers selected were relatively deep, 10.5 to 21 cm (see Materials and Methods above). Shallow containers allow excess soil water and poor aeration to occur because of a perched water table formed at the bottom of the container after irrigation and drainage [29,30]. Such soil water conditions are poor for ginseng root growth. As the mean root length was 56 to 60 mm (Table 2) the Ropak Multi-pots were probably just deep enough to avoid the perched water table given that seeding was at 30 mm.

Experiment 2

In this experiment where seeding depths of 20, 40, 60, and 80 mm in 6 L pots and in Ropak Multi-pots were compared there were no differences in the root dry weights at harvest. Mean root dry weight from the 4 planting depths was 63.7 mg and the range of values was 53 to 72 mg. This would suggest that in pot experiments there is a wide range of seeding depths although there was a trend to declining root weights at planting depths from 60 to 80 mm.

Predicting ginseng seeding depth

The general regression equation for seed weights (Y) and seeding depths for the ten vegetable crops was $Y=-190.8+9.1\ X$ with $R^2=0.89$, with upper and lower 95% confidence intervals of -278.7 and -102.9 respectively for the intercept, and of 11.7 and 6.4 respectively for the slope, and p significant at <0.001 for both.

When the equation was rearranged to solve for the predicted seeding depth for ginseng, an average medium size ginseng seed weighing 67 mg [2], a seeding depth of 28.3 mm was obtained; for large seed weighing 91 mg it was 31 mm, and for small seed weighing 53 mg it was 26.8 mm. These predictions are in close agreement with a value of 30 mm reported in this study from pot and field experiments.

In summary, these experiments with seeding of stratified North American ginseng seed showed that seeding depth can have profound effects on seedling emergence, seedling growth and development, and dry matter partitioning within the seedling, particularly to the economically important dried root. Data from these experiments, and use of a developed predictor equation, suggested an optimum seeding depth of about 30 mm. This information will be useful in optimizing crop production strategies.

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