Preliminary and Regional Reports

Effects of Variable Shading in a Greenhouse Study on Rhizome Weight, Root Length, and Bud Proliferation in Goldenseal

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Summary. **Goldenseal *(Hydrastis canadensis)* is an herbaceous perennial valued for its fleshy rhizomes, which contain the alkaloids hydrastine and berberine. While it is understood that relative shade influences growth and yield of goldenseal, optimal shade level for maximum rhizome mass and plant vigor under cultivation has not been established. Goldenseal plants grown from cold stratified rhizomes were kept under shade for 5 months in the greenhouse. Treatments were five different shade levels ranging from 60% to 95% of full shade, plus a control group in full sun. Measured variables included rootlet length, bud development, and rhizome mass. Plants grown under moderate shade (60 to 70%) produced longer and more numerous rootlets, more bud primordia, and had greater rhizome mass and healthier leaves than plants grown under extreme shade (95%) or in full sun. Decreasing shade density had a major impact on plant condition and growth. Those plants grown with the greatest sun exposure displayed 100% scorch damage to the foliage, in comparison to <35% damage in the moderate shade (30 to 40%). The results suggest that moderate shading may double yield in rhizome mass, and promote increased bud proliferation in subsequent seasons. Late season leaf vigor is not correlated with rhizome mass.**

Goldenseal, a member of the buttercup family (Ranunculaceae), is an herbaceous perennial indigenous to the deciduous forests of eastern North America. Its range extends along the Piedmont region from North Carolina to Alabama, west to Arkansas, Missouri, and Iowa, north into Minnesota, extreme southern Ontario and Michigan, east to New York, and the Appalachian mountains of New England (Duke and Foster, 1990). The plant is by no means abundant throughout this range. Major population distributions of goldenseal occur in the Ohio River valley of Pennsylvania, West Virginia, Kentucky, Ohio, and Indiana (Harding, 1972). Its preferred habitat is moist, well-drained loamy soil under a deciduous hardwood

Fig. 1. Hand cultivation of goldenseal in second-growth woodland, southwestern Ohio. Canopy trees and saplings are kept, and herbaceous layer is tilled for early spring planting.

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Table 1. Monthly average midday light intensities of the treatment groups, expressed as a proportion of full sunlight, under shade cloth in the greenhouse.

Treatment	Light intensity (lx)[z]	Available sunlight (%)
Control	951	100
1	422	40
2	328	30
3	212	20
4	118	10
5	47	5

[z]100 lx = 9.29 fc.

canopy. In the wild it is often found growing in association with wake-robin (*Trillium* spp.), ginseng (*Panax quinquefolius*), and black cohosh (*Cimicifuga racemosa*). While shaded areas of well-drained lowland soils tend to produce the most robust populations, goldenseal is adaptable and can occur in various soil types, in excessively moist areas, on precipitous slopes, in high light intensity, and even in grazed areas.

Morphologically, goldenseal is rather simple. The stem is produced from a small irregularly shaped rhizome. One to several stems per rhizome is the common condition, but very large specimens can produce as many as 30 stems. Each stem bears one to three, but usually two, palmately lobed leaves, subtending a solitary flower. The flower, though perfect, is not showy; it has many stamens, three petaloid sepals, and lacks petals. If fertilized, a small cluster of berries (several to 50) is produced. In a wild population most plants will flower annually, but few produce seed. Reproduction from seed appears to be sporadic, and seed viability is low (Davis, 1998). Goldenseal is a vegetatively colonizing plant, and its local spread is commonly asexual. The plant produces roots along the lateral axis of the rhizome. These roots can be as long as 50 cm (19.7 inches). At some point on a given root a bud will initiate, and a small plant will develop. Eventually the rootlet will decay, and the clone will be self-sufficient. Alternately, buds may initiate on the rhizome itself.

The small fleshy rhizome of goldenseal produces several alkaloids of interest to the pharmaceutical and herbal industries. The two most important of these are berberine and hydrastine. For the rhizome to have commercial value, these compounds must be present in concentrations greater than 2% and 4%, respectively (Epler, 1996). In its raw state goldenseal is an effective antibacterial agent and is used to treat sore throats and sores of the mouth; it is also currently marketed to improve immune function (Borchers et al., 2000). When extracted and concentrated the alkaloids berberine and hydrastine have antiseptic and antihemorrhagic properties (Becker and Castleman, 1994, Davis and McCoy, 2000). Hydrastine and berberine are also important chemical constituents of many common pharmaceutical preparations such as eyewashes. Native Americans (Cherokee, Iroquois, and Micmac) used goldenseal for a general tonic, and for treatment of fever, whooping cough, and pneumonia (Borchers et al., 2000).

The supply of goldenseal is no longer exclusively from the harvest of plants from wild stands, as it had been for nearly a century and a half (despite some successful cultivation, see Fig. 1) (Stockberger, 1927; Davis, 1994). In the past the most devastating impact on wild populations has been habitat loss. Currently, however, the greatest threat to wild populations is the overzealous harvest for sale to wild herb wholesale houses (Robbins, 2000). Annual U.S. sale of medicinal herbs and related commodities is now more than $2 billion (Craig, 1999). In regions such as Appalachia, with perennially poor economic conditions, wild plant collection is a common source of supplementary income. American ginseng (*Panax quinquefolius*), for example, has been widely extirpated as a result of overcollection (Masood, 1997). In the past decade both price and demand for goldenseal have quadrupled. The increase in the market for goldenseal and other herbal supplements has two fronts. In the western hemisphere, it reflects a change in consumer medicinal preference, shifting from the synthetic or derived pharmaceuticals to more holistic or organic remedies. In Asia, the use of herbal medicines is a long established tradition. With the global increase in demand, wild populations of goldenseal have declined precipitously (Scott, 1999). The plant has threatened status in the U.S. and endangered status in North Carolina. In 1997 goldenseal was accepted for listing on Appendix II of the Convention of International Trade in Endangered Species (Robbins, 2000). With continued overharvest of wild populations, the need to develop cultivation criteria for goldenseal has become urgent.

Fig. 2. Range of goldenseal root size in experimental treatments. Rhizome on left is from the control (full sun) group, and the rhizome on left is from the 70% shade group.

Since goldenseal is an understory herb, one critical growth criterion that must be determined for its cultivation is the effect of relative light intensity on goldenseal rhizome development and subsequent bud proliferation. Stockberger (1927) recommended 75% shade for production beds. However, he found that low light levels tended to reduce both leaf and rhizome size. Davis and McCoy (2000) found best plant growth under 63% to 80% shade, but had higher stand counts and survivability under 47% and 63% shade, respectively; no data on root growth was available. This study's purpose was to determine optimum shade level for maximum rhizome growth and plant vigor in one growing season.

Methods and materials

In late February, goldenseal rhizomes (N = 350) that had been cold stratified for 5 months were removed from storage and planted in 0.9-L (1-qt) pots, in a standard soilless medium (MetroMix 360; O.M. Scott Co., Marysville, Ohio). The rhizomes were each about 25 mm (1 inch) long; each had a single terminal bud and no axillary buds at the

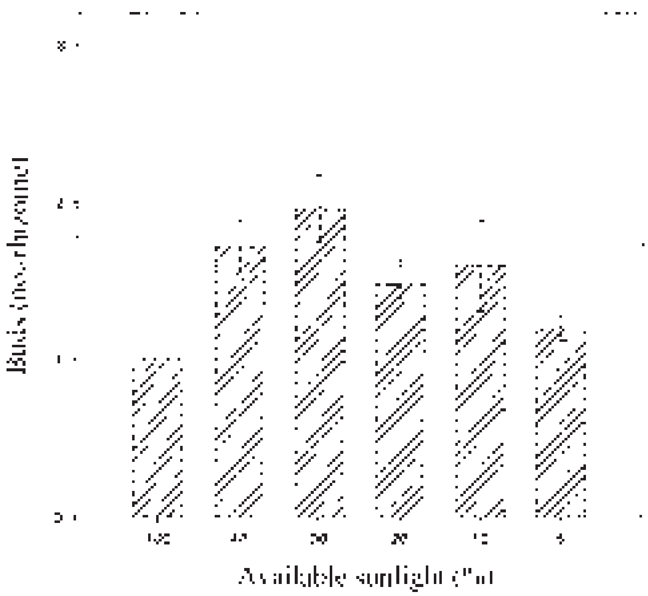

Fig. 3. Number of new buds (mean ± SE) per goldenseal rhizome for five levels of shade and a control (full sun) after 5 months of growth; N = 150, α = 0.05.

time of planting. The pots were set on benches in The Ohio State University Howlett Hall greenhouse (lat. 40°N), initially under no shade, to induce rapid bud break and sprouting. Day temperature was maintained at 22 °C (72 °F), and night temperature at 18 °C (65 °F). After most plants had sprouted (14 d), the pots were separated randomly into five different shade treatments and a control group (full sun). Shade was created by suspending one or more layers of fine-mesh, black polypropylene fabric at 1 m (3.3 ft) above the greenhouse benches. Shade treatments ranged from 60% to 95% shade (Table 1).

The plants received identical cultural treatments consisting of regular watering; the greenhouse maximum temperature remained about 30 °C (87 °F) and was never above 32 °C (90 °F). After 5 months of growth and monitoring, random samples (n = 25) were harvested from each of the six groups. Stems and leaves were removed and the rhizomes were washed free of medium (Fig. 2). While fresh, the rhizomes were evaluated to determine the number of new terminal buds and of adventitious (lateral) buds, and the length of the longest root per rhizome was measured. Numbers of terminal buds per rhizome per treatment were compared to bud numbers of unplanted rhizomes retained from the original lot. All treatment and control rhizomes were then oven dried at 60 °C (140 °F) and individually weighed. Analysis of variance (SAS Institute, 1998) was performed on three data sets: rhizome plus root dry weight (biomass), number of new terminal buds, and length of longest root per rhizome. All data means met expectations of normality and homoscedasticity and did not require transformation.

Results

The number of new terminal buds was significantly higher (F = 3.91, P = 0.0023) for all treatments receiving between 60% to 90% shade. The average difference among treatment groups was about two per rhizome in the moderate shade treatments, or twice those in either full sun or 95% shade (Fig. 3). In addition to this 2-fold difference (for the four moderate shade treatments), there were more buds in the 70% shade treatment, up to eight per rhizome.

Length of the longest root per rhizome ranged from an average 8.8 cm (3.46 inches) in the full sun treatment to 19.24 cm (7.58 inches) in the 70% shade group (Fig. 4). Differences were significant (F = 6.17, P < 0.0001) at three levels. The 60% and 70% shade groups were similar to each other at 17 to 19 cm (6.7 to 7.5 inches), and the 80%, 90%, and 95% shade treatments were also statistically similar at 12 to 14 cm (4.7 to 5.5 inches).

Differences in rhizome dry weight repeated the trends observed in the other two data sets. Rhizomes in the 70% shade treatment averaged almost 11 g (0.39 oz), more than double the weight of the control (full sun) group (Fig. 5). Again, the 70% shade treatment had the greatest observable difference (F = 11.1, P < 0.0001), followed by the 80% and 60% shade groups in the same rank or t grouping. Rhizome weight in the 90% and 95% shade treatments did not differ from the full sun group, with averages ranging from 6.5 to 5.0 g (0.23 to 0.18 oz).

Plant condition varied markedly among treatments. The foliage of the 95% shade group remained green and robust for the 5-month duration of the experiment. The 90% shade group showed minor sun scorch and yellowing, and the 80% group significantly more. However, the foliage of the control group, as well as that of the 60% and 70% shade treatments, had all yellowed and withered completely by the end of June, or after about 3 months. In the wild, goldenseal generally goes dormant between July and the end of September, depending on available moisture, with stems dying back to the rhizome.

Our results suggest that full sun and 5% available sunlight have almost the same inhibitory effects on rhizome mass, root length, and bud initiation in goldenseal. Bud number and root length were optimal at 60% to 70% shade, and rhizome mass was greatest at 70% to 80% shade.

Discussion

It has long been recognized that goldenseal (like ginseng) requires special conditions for cultivation, to mimic conditions of the forest understory (Stockberger, 1927; Harding, 1972) (Fig. 1). It has become necessary as a

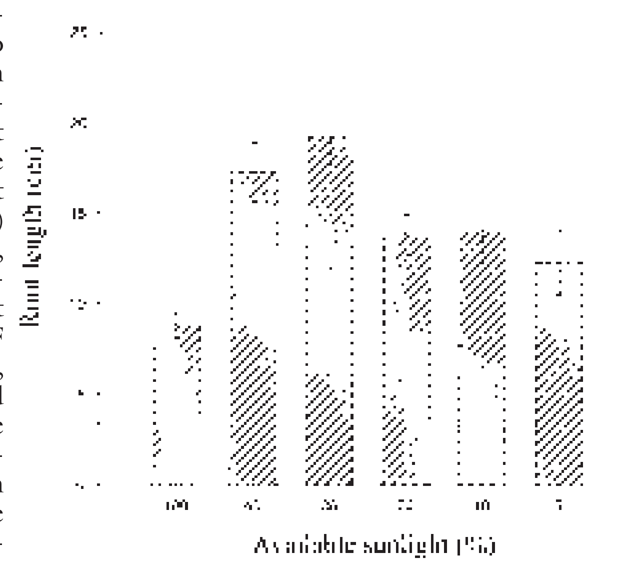

Fig. 4. Length of longest root (mean ± SE) per goldenseal rhizome for five levels of shade and a control (full sun) after 5 months of growth; N = 150, α = 0.05. 1 cm = 0.4 in.

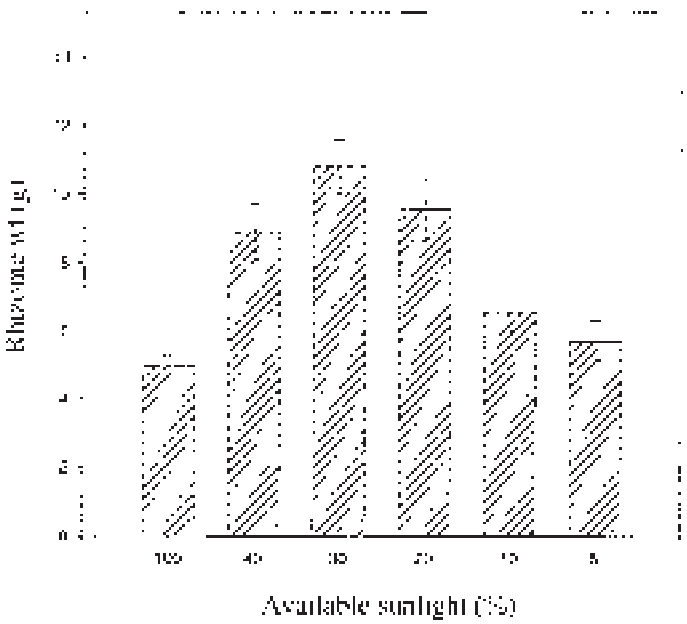

Fig. 5. Mean goldenseal rhizome dry weight (mean ± SE) for five levels of shade and a control (full sun) after 5 months of growth; N = 150, α = 0.05, 1 g = 0.04 oz.

result of the exploitation of wild populations to develop specific criteria for cultivation, especially the effect of light intensity on development and plant health. Shading has long been known to have a beneficial effect on growth for goldenseal and other native understory herbs in cultivation, but the effects have not been quantified. For some shade crops, high light levels produce aesthetically inferior plants, but more offsets and vegetative mass (Sawyer, 1998). With goldenseal, however, biomass, not plant appearance, is the marketable commodity, unlike herbaceous perennials grown as ornamentals (Sawyer, 1998). Light quality, intensity and periodicity are important factors that control plant development and morphogenesis, including leaf senescence (Behera and Biswal, 1998). Shade treatments at 70% to 80% have been found to promote rooting in certain softwood cuttings (Murphree et al., 2000) and this level of shade also prolonged leaf retention and improved foliar color.

In the floriculture industry, there has been significantly increasing production of medicinal herbs in greenhouses. However, glazing material affects the quality of natural light, blocking ultraviolet radiation, changing the angle of incidence and causing the leaves of plants to heat more than they would outside. While goldenseal is normally an outdoor crop, our data indicate that the plant responds well to higher light intensities than formerly thought (see Davis and McCoy, 2000). Other parameters for outdoor growing, such as fertilizer regime, still need to be defined. Further work with goldenseal will address soil nutrient balances and interspecific competition

While bud proliferation and root length are similarly influenced by degree of light intensity, rhizome biomass may be differently affected both by duration of growth and amount of shade. Goldenseal is a multiple season crop; it is usually 4 years before the rhizome reaches maximum size, after which it begins to decay and is replaced by adventitious plantlets. Whether the alkaloid concentrations will decrease in larger or more rapidly grown rhizomes is an important question. In ginseng, root concentrations of secondary compounds are known to increase with plant age. In goldenseal, both bud set and root length are good indicators of future gains in biomass. Given the determinate annual growth of goldenseal, the rhizome's bud number is a direct predictor of the number of leaves that can be expected during the next season's growth. For goldenseal, it may be possible that after two or more seasons of growth, a treatment of higher light intensity (e.g., only 20% shade) would yield higher alkaloid concentrations simply because more buds would result in more photosynthetic leaf area.

Root length is an indication of establishment and plant vigor and a measure of the plant's ability to obtain nutrients and water. While water stress was not a factor in this experimental design, on native sites water stress is an important variable and can greatly affect yields and establishment from year to year. If this one year experiment were continued, we predict that the disparity in the measured variables would increase in subsequent years. We suggest that although goldenseal will vegetatively proliferate well under a wide range of light intensity, rhizome biomass is optimal under growing conditions of about 70% shade.

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