Effect of shade, fertiliser and irrigation on the production of goldenseal (*Hydrastis canadensis* L.)

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Abstract

Goldenseal (*Hydrastis canadensis* L.; Ranunculaceae) is a North American perennial, woodland herb with roots and rhizomes that demand high prices as herbal medicines. Harvesting this species from wild populations has endangered its existence and greater effort is now being directed at growing it in managed stands. Two trials were conducted to investigate the effects of shade, fertiliser and irrigation on plant production. Goldenseal growth in full light was compared with that under 32, 57 and 84 % shade. Growth in the first year was best under 57 % shade, but in the second year higher growth was achieved under 84 % shade. In the second trial, fertiliser and irrigation treatments were applied to a goldenseal crop established in the previous year and grown for a further four years before harvest. Additional water increased the goldenseal root and rhizome production by 311 %. Fertiliser application had no beneficial effect on rhizome production and had little effect on the nutrient content of the roots and rhizomes. Calculation of the nutrients removed by harvesting a four-year-old crop of 2000 kg/ha showed that the amount of fertiliser needed on an annual basis to replace these losses was low.

***Additional Key Words*:** herbal medicine, rhizomegrowth, root production.

Introduction

Goldenseal (*Hydrastis canadensis* L.; Ranunculaceae) is a sought after North American medicinal herb that has been overharvested in the wild to an unsustainable level. As a consequence, it has been placed on the CITES list of endangered species to better control its trade (Foster, 1997; Bannerman, 1998). The future supply of goldenseal now relies on the development of sustainable cultivation systems (McGuffin, 1999).

In its natural habitat goldenseal is an uncommon perennial herb of the rich, deciduous, broadleaved forests of eastern North America. Growth rates are highest in the first month of the growing season, as the deciduous-forest canopy closes, with the above ground biomass peaking in mid-July (North America) before senescing to winter dormancy (Eichenberger and Parker, 1976). Goldenseal has been cultivated for many years in North America, particularly under natural forest canopies, with the main guidelines for production produced early last century (Henkel and Klugh,1908; Lloyd, 1912; van Fleet, 1914). Subsequent to these guidelines, little research has been published and together with 2 t/ha of cottonseed meal and leaf mould and a subsequent mulch of rotted stable descriptions of the agronomic factors that influence the growth of goldenseal are generally lacking.

Goldenseal requires shade for plant survival and optimum growth. Early recommendations suggested 50-75 % shade was needed in summer with less shade in spring. Also less shade was required at more northern North America localities than at southern localities (van Fleet, 1914; Hardacre, 1962). More recent studies in North Carolina showed that the highest goldenseal plant survival rate was at shade levels of 47-63 %, but the best plant growth occurred at 63-80 % shade (Davis and McCoy, 2000).

Rich, well fertilised soil is recommended for growing goldenseal. Hardacre (1962) noting that goldenseal could withstand very heavy applications of fertilisers and barnyard manure although heavy rates of acidic phosphatic fertiliser caused severe root rot in some situations. Henkel and Klugh (1908) suggested 56 kg/ha muriate of potash and 220-340 kg/ha superphosphate could be beneficial to goldenseal production. Van Fleet (1914) recommended 670 kg/ha potassium sulphate and over 2 t/ha of bonemeal (*ca* 180 kg/ha P, 90 kg/ha N) manure all worked into the soil prior to planting the crop. Davis and McCoy (2000) found that increased rates of ammonium nitrate reduced plant survival and root yields. There was no response to superphosphate and, therefore, they recommended only light fertiliser use, preferably from an organic source. They suggested that very low rates of a balanced NPK (20:20:20) fertiliser could be applied at the commencement of growth in spring.

Goldenseal grows best on free draining rather than heavy, poorly drained soils but best yields are achieved where there is continuous moisture (Hardacre, 1962). Under summer drought conditions goldenseal growth is checked, root growth is reduced and early plant senescence is induced (van Fleet, 1914; Davis and McCoy, 2000). Van Fleet (1914) recommended irrigation in dry periods but Davis and McCoy (2000) considered irrigation of goldenseal was rarely required under a forest canopy although they recommended summer mulches to retain soil moisture.

To develop goldenseal production in New Zealand we imported root cuttings from the USA in the early 1990s before this trade was prevented by the CITES classification. Following release from quarantine, the goldenseal planting stock has been gradually increased under shade-house conditions. Individual plants within the stock beds often exhibited mild to severe leaf chlorosis in summer and there was uncertainty as to whether this was caused by insufficient shade, insufficient water, or nutritional limitations. A small field trial was established to investigate the influence of fertiliser and irrigation on goldenseal production. A second field trial was established once more planting stock became available to better define the level of shade required for optimum growth.

Materials and Methods

Shade trial

This trial was conducted at the Crops for Southland Inc., New Crops Centre, Invercargill, on a Waikiwi silt loam. The trial consisted of five replicates of four shade treatments in randomised blocks in which an unshaded control was compared to treatments shaded with very light (26 % shade), light (52 % shade), and heavy (76 % shade) Donaghy's Sarlon® knitted horticultural cloth. Each plot was 2 m wide and 5 m long with the shade cloth held 1 m above the ground by Kerilea® metal hoops or alkthene pipe hoops.

Solar radiation was measured using Licor LI200SZ pyranometers mounted horizontally inside each shade structure.

Goldenseal rhizome segments were supplied from stock plants grown by Crop and Food Research in the Waikato. Thirty-nine plants were planted in each plot on 2 November 2000 with the plants in 3 rows at 30 x 30 cm centres. Any plants, including guard plants, that failed to emerge over the next two months were replaced by spare plants grown at the end of each plot. By the end of December 2000 5 % of plants had been replaced. Following planting a 50 mm deep mulch of composted peat-bark mixture was applied over the beds. In the second spring any plants that failed to emerge by 8 November 2001 (12 % of plants) were replaced by surplus plants from the same shade treatment to maintain plant density. These plants were not included in subsequent harvests. The trial was designed to run for three years with annual winter harvests of six fully guarded plants/plot. The first two harvests were made on 18 July 2001 and on 10 May 2002. Plants were lifted, washed, oven-dried and weighed. No irrigation or fertiliser was applied to the plots. Hand weeding was undertaken as required.

Fertiliser and irrigation trial

This trial was conducted in a shade structure covered with 50 % shade cloth on a Horotui sandy loam at the Waikato Research Orchard near Hamilton. The soil quick test analyses of the site over the trial period are given in Table 1. An 80 m^2 block of goldenseal plants spaced at 0.5 m within rows 1.0 m apart was planted in November 1997 without fertiliser and covered with a 1 cm mulch of untreated pine sawdust after planting to control weeds. A randomised block trial with four replicates was laid down on the established goldenseal between 25 November and 1 December 1998 to compare four treatments: no fertiliser or irrigation, irrigation, fertiliser, irrigation and fertiliser.

Table 1. Soil quick tests (0-15 cm) in control plots at beginning and end of trial period.

Date	pH	Ca	P	K	$S(SO_4)$	Mg
Nov 1997	5.3	2	45	2	49	4
June 2001	5.3	2	43	2	45	3.5

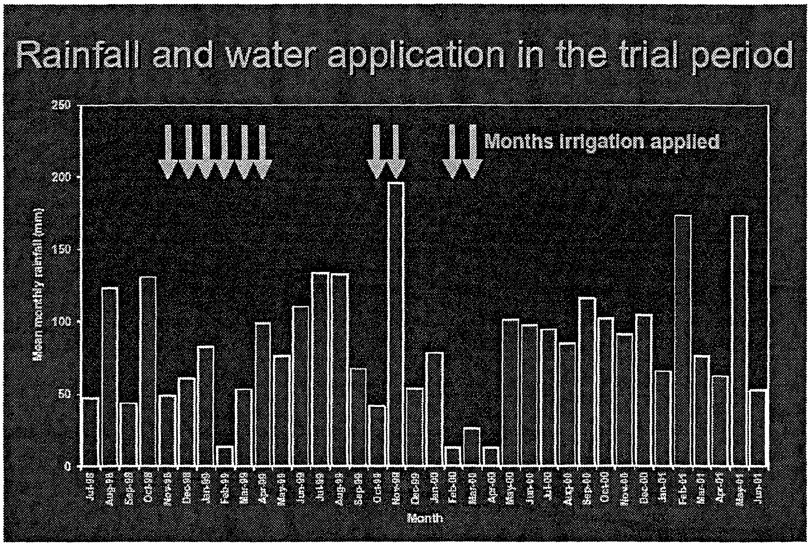

Figure 1. Monthly rainfall at the Waikato Research Orchard and when irrigation was applied during the trial period—July 1998 to June 2001.

Each plot consisted of a single row of five plants with a common guard between adjacent plots. No plants were replaced where deaths occurred. Three plants from the centre of the row (1.5 m^2) were harvested at the completion of the trial.

The irrigation treatment was applied using a low pressure horticultural T tape laid along the individual rows of the goldenseal. These individual lines were 7 m long with an expected water delivery from the T-tape of 4.7 l/hr/m. The rainfall over the trial period and the timing of the irrigation is shown in Figure 1. The water status of the site was monitored using a "Jet Fill" tensiometer model 2725 to measure the soil tension and in the second season (1999-2000) it was used as a guide for water application based on when the soil tension exceeded 15 kPa. The field capacity of the Horotui sandy loam in the 15-17 cm soil depth is nominally 10 kPa with a water content of 44 % v/v and with the readily available moisture held between 10 and 100 kPa. At 15 kPa the water content would approximate 42 % v/v (M. McLeod, pers. comm.). In 1998-99 the water was applied from December 1998 until April 1999, which kept the soil at field saturation. The irrigated treatment had a mean tensiometer reading of 3.7 kPa compared to the mean unirrigated tensiometer reading of 12.7 kPa. In 1999-2000 water was applied on 22 October, 3 November, 8 February and 9 March when the tensiometer reached the trigger point of 15 kPa. Water was applied until the tensiometer reading in the irrigated treatment was 2-4 kPa, which was respectively 1 hour or 2, 1, or 11 days respectively, for each water application. In 2000-01 the trial was not irrigated as the tensiometer readings did not go above the trigger point of 15 kPa because of regular rainfall.

The fertiliser treatment consisted of 3 t/ha of 15 % potassic serpentine superphosphate and 1 t/ha of diammonium phosphate broadcast, raked into the surface sawdust mulch. A month later 1 t/ha of dolomite was applied.

The trial was kept weed-free by hand weeding during the summer months and with contact herbicides applied in winter when the goldenseal was dormant.

The trial was harvested by hand on 5 June 2001, the three plants were washed, dissected into buds, rhizomes and roots, dried at 65°C, and weighed to record yields. Rhizomes and roots from replicates one and three were subsampled for macro nutrient analyses by standard methods.

Analysis of variance using a GENSTAT package was carried out on the trial data. Log transformations were carried out on the individual plot data and the back transformed means with bias correction presented.

Table 2. The effect of four levels of shade on the growth of goldenseal over two years.

Shade cloth grade	Relative irradiance	Planted weight (g)	Fruit harvested weight/plant (g)	
			Year 1	Year 2
No shade	1.00	9.9	8.8	9.6
26 % shadecloth	0.68	10.4	10.5	21.0
52 % shadecloth	0.43	8.8	16.5	32.4
76 % shadecloth	0.16	9.9	12.4	44.5
sed		0.9	0.81	2.08
Significance		NS	***	***

Table 3. Effect of irrigation and fertiliser on goldenseal production (g DM/m^2).

	No irrigation		Irrigation		
	No Fert.	+ Fert.	No Fert.	+ Fert.	LSR (5 %)
Bud	0.6	0.7	3.6	1.8	4.2
Rhizome	11.6	12.4	51.9	31.8	3.4
Root	21.0	17.7	110.7	63.5	2.7
Total	33.2	30.8	166.2	97.1	3.8

Table 4. The nutrient content % of goldenseal rhizomes and roots.

	No irrigation		Irrigation		
	No Fert.	+ Fert.	No Fert.	+ Fert.	SED
Rhizomes					
N	4.35	4.70	4.84	4.92	0.433
P	0.57	0.64	0.66	0.65	0.035
S	0.34	0.42	0.51	0.53	0.038
Mg	0.32	0.35	0.42	0.47	0.020
Ca	0.18	0.19	0.15	0.17	0.016
K	0.62	0.59	0.60	0.66	0.045
Roots					
N	2.92	2.56	2.50	2.95	0.142
P	0.37	0.42	0.41	0.45	0.037
S	0.29	0.35	0.37	0.50	0.039
Mg	0.34	0.39	0.42	0.54	0.047
Ca	0.37	0.39	0.35	0.35	0.016
K	1.34	1.17	1.20	1.04	0.115

Table 5. The effect of irrigation and fertiliser applications on soil quick test values (0-15 cm) at harvest.

	No irrigation		Irrigation		
	No Fert.	+ Fert.	No Fert.	+Fert.	SED
pH	5.3	5.4	5.7	5.8	0.062
Ca	1.7	2.0	3.0	4.2	0.236
P	43.0	63.7	39.2	53.5	2.31
K	2.0	2.0	2.2	2.0	na[1]
Mg	3.5	5.7	18.0	26.0	2.18
$S(SO_4)$	45.2	61.5	34.7	33.7	5.33

na[1] – not analysed

Table 6. Calculated nutrient removal in the roots (64 % of crop) and rhizomes (36 % of crop) of a four-year-old goldenseal crop of 2000 kg/ha DM.

	Nutrient concentration		
Nutrient	Root (%)	Rhizome (%)	Nutrient Removed (kg/ha)
N	2.72	4.90	70
P	0.43	0.62	10
K	1.12	0.63	19
Mg	0.48	0.44	9
S	0.43	0.52	9
Ca	0.35	0.16	6

Results

Shade trial

The irradiance measurements defined the shading treatments as 32, 57 and 84 % shade with these shade levels being within 5 to 8 % of the manufacturer's specifications for the individual cloths (Table 2). In the first year of growth, plants grown under 57 % shade gave the highest production ($P < 0.001$) with less or more shade giving lower plant weights (Table 2). In the second year plant production was highest under 84 % shade with each increase in shade up to this maximum level giving increased production ($P < 0.001$). The unshaded goldenseal plants survived but did not increase in weight over the 18-month trial period compared to plants grown under 84 % shade, which increased in weight 4.5 times (Table 2).

Fertiliser and irrigation trial

The water applied in the summer of 1998-99 and 1999-2000 increased the production of goldenseal by 311 % ($P < 0.01$) over the trial period with the additional fertiliser giving no benefit (Table 3). The dominant production was in the root component. With irrigation there was little change in the ratio of plant components with and without fertiliser with the roots making up 66 %, rhizomes 32 %, and buds 2 % of the underground biomass. The root component of the biomass was less without irrigation and was lowest (57.5 %) where fertiliser was applied without irrigation (Table 3).

The application of fertiliser resulted in an increased S concentration in the roots of the goldenseal ($P < 0.04$), but not in the rhizomes (Table 4). Irrigation increased the concentration of both S and Mg in the roots (S, $P = 0.028$; Mg, $P = 0.04$) and rhizomes S, $P = 0.013$; Mg, $P = 0.005$) with no interaction between fertiliser and irrigation treatments. The treatments had no effect on the N, P, Ca, and K levels in the roots and rhizomes with the exception of a significant interaction between fertiliser and irrigation ($P = 0.027$) for the N concentrations in the roots (Table 4). The rhizomes had higher concentrations of N, P and S and lower levels of Mg, Ca and K in the rhizomes than the roots.

The soil quick tests taken when the trial was harvested showed that the Ca ($P < 0.001$), P ($P < 0.001$), and Mg ($P= 0.009$) soil levels were elevated from the initial application of fertiliser, but there was no effect on the soil pH, K and S levels (Table 5). Irrigation depressed the soil P ($P = 0.002$) and S ($P = 0.001$)levels and increased the soil pH ($P = 0.002$), Ca ($P = 0.001$) and Mg ($P = 0.001$) levels. Fertilizer x irrigation interactions were recorded for Ca ($P = 0.015$) and S ($P = 0.048$) soil tests. The Ca levels were highest where both treatments were applied and S was highest where fertiliser was applied without irrigation. All K soil test levels were similar (Table 5).

A calculation of the nutrient removal from harvesting a four-year-old 2000 kg/ha crop of goldenseal showed that N followed by K were the major nutrients removed by harvesting (Table 6). To replace the nutrients removed only small quantities of fertiliser would be required on an annual basis.

Discussion

The shading trial results reported here are interim results as a third harvest is expected to be made in May 2003. These results show plants growing under an 84 % shade cover gave 37 % more plant growth than plants growing under 57 % shade and over double the growth of plants growing under 32 % shade cover. This high shade requirement of goldenseal is slightly higher than the range of 63 to 80 % shade suggested by Davis and McCoy (2000) in North Carolina. Since it was the highest rate tested it may not have measured the highest level of plant response to shade. Van Fleet (1914) suggested that less shade may be needed for goldenseal at higher latitudes but our research at latitude 46°S does not support this as the shade requirement was as high, if not higher, than that recommended for North Carolina (latitude 36°N).

Under summer drought conditions goldenseal will go into early dormancy with a resultant loss of root production (van Fleet, 1914; Davis and McCoy, 2000), but in moist summers goldenseal plants may persist until winter (Henkel and Klugh, 1908). The additional water applied in the first two seasons of our trial gave a large increase in the production of the goldenseal and confirmed the comments of Hardacre (1962) that continuous moisture is required for the best root yields. The results show that goldenseal is very sensitive to short-term dry conditions because the unirrigated treatments in the first two years received rainfall of 65-70 mm/month for the October to March period, enough to maintain a reasonably moist soil under 50 % shade.

Unpublished research has shown that goldenseal is a shallow rooted species and consequently susceptible to fluctuations in surface moisture. It also emphasises the need for mulches to lessen moisture fluctuations (Hardacre, 1962; Davis and McCoy, 2000). The goldenseal plants with the additional water still suffered from leaf margin chlorosis and gradual lamina decay in late summer with no marked differences between any of the treatments in the progression towards dormancy. Goldenseal grown under the cooler conditions of Otago and Southland have produced autumn growth without the lamina decay found in the Waikato. This suggests that the hotter summer conditions of the Waikato may adversely affect the summer growth of goldenseal. The high rates of N, P, K, S and Mg applied in this trial have proved of no benefit to the production of goldenseal and the result does not support the need for high fertiliser use recommended by van Fleet (1914) and Hardacre (1962). The fertiliser application did not affect plant numbers or disease levels, as suggested by Hardacre (1962). In our experiment more plants (92 %) survived in the irrigation and fertiliser treatment than in the control (66 %), or the irrigation and fertiliser alone (75 %) treatments (data not presented). Overall 23 % of the plants died with considerably more deaths occurring in replicates 1 and 3 (37 %) than in replicates 2 and 4 (8 %), but the reason for these differences were not apparent. The fertiliser in our trial was applied to an established crop whereas recommendations in the literature were for high fertiliser levels to be applied to beds prior to planting (van Fleet, 1914, Hardacre, 1962). Our lack of response to the high rates of fertiliser are supported by the results of Davis and McCoy (2000) who reported decreased root yields at high rates of ammonium nitrate. This lack of response indicates a low fertiliser requirement to maintain goldenseal stands. However, the fertility requirement at planting to achieve high production is unknown and requires greater definition. The fertiliser application had no effect on the nutrient concentrations in the roots and rhizomes of the goldenseal with the exception that an elevated S level occurred in the roots. Both Mg and S levels increased in the roots and rhizomes following irrigation, but the concentrations differed little from those in the fertiliser treatment and so cannot be attributed to irrigation. Calculation of the nutrients removed in a harvest of the roots and rhizomes shows that any fertiliser requirement to replace the nutrients removed is minimal. This provides more evidence that the annual nutrient requirement for goldenseal is low and provides support to the recommendations of Davis and McCoy (2000) that only low levels of balanced fertiliser are required as an annual dressing.

The calculated yield of goldenseal from the irrigated treatment was 1500-1700 kg/ha DM. In spite of being grown at a very low plant density the yield is within the range of those most commonly reported of 1100 to 2200 kg/ha DM in North Carolina, but less than their reported best yields of 3300 kg/ha (Davis and McCoy, 2000).

This research has highlighted the need for adequate shade and irrigation to grow goldenseal and the limited response of this crop to fertiliser. Research to more closely define the shade requirement of goldenseal is still in progress. Irrigation and fertiliser treatments applied in the Waikato trial did not overcome leafmargin chlorosis and leaf senescence in late summer, indicating that yet to be determined factors were influencing plant growth. Further research on the environmental requirements of goldenseal is necessary to resolve this. Trials in southern New Zealand suggest that goldenseal may be more environmentally suited to cooler summer conditions than those experienced in northern New Zealand.

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