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Regeneration of Mugwort (*Artemisia vulgaris*) from Rhizome Sections in Sand, Pine Bark, and Soil Substrates[1]

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Abstract

Regenerative potential of mugwort (*Artemisia vulgaris* L.) rhizome sections has not been quantified when rhizomes are transplanted into substrates encountered in landscapes and nursery fields, container nurseries, or propagation beds. Mugwort regeneration in pine bark, sand, and soil substrates was analyzed by rhizome color, length, and the presence or absence of a leaf scale. Color of rhizomes, which darken with time, did not account for differences in growth among treatments. Contrary to previous research, 85, 78, and 69% of 2 cm-long rhizome sections produced both roots and shoots when grown in pine bark, sand, and soil substrates, respectively, during 45-day trials. Slightly less than 31% of rhizome fragments 0.5 cm long without a leaf scale produced both roots and shoots in soil. Though fewer rhizomes survived in soil, root and shoot fresh weights were greater than in pine bark and sand. When rhizome sections included a leaf scale, survival, fresh weights of roots and shoots, shoot height, leaf number and root lengths were greater, regardless of substrate type. Root initials emerged both adjacent to leaf scales and in the internode between leaf scales. Shoot emergence preceded root emergence from rhizome sections.

Index words: integrated pest management, root growth.

Species used in this study: Mugwort (*Artemisia vulgaris* L.).

Significance to the Nursery Industry

Mugwort, also called false chrysanthemum, is a non-native perennial aster named one of the 10 most problematic weeds in eastern U.S. nurseries. Mugwort is spread by rhizome pieces that contaminate cultivation equipment and root balls of nursery crops. Rototilling and cultivation that cuts rhizomes into small sections will reduce the proportion of pieces that survive, but will yield sufficient plant regeneration from surviving sections that mugwort populations and subsequent stand density are expected to increase. In this study, even rhizome sections 0.5 cm (0.25 in) long regenerated roots and shoots, with or without leaf scales, within 45 days. The greatest numbers of rhizomes produced plants when sections were grown in pine bark. Fewer plants were established on rhizome sections grown in soil, though these plants had the highest root and shoot biomasses. These results illustrate the need for nursery growers to maintain clean field-grown liner stock and indicate the potential for mugwort to become established in the landscape if infested container-grown nursery crops are transplanted. Growers and landscape managers should scout proactively for mugwort populations and initiate aggressive control strategies when populations are found.

Introduction

Mugwort or false chrysanthemum (*Artemisia vulgaris* L.) is a non-native perennial aster that has naturalized throughout the eastern United States (2, 12, 22). It can be found in nine Canadian provinces and half of U.S. states (2). Mugwort was named one of the 10 most problematic weeds in nurseries of the eastern United States (11, 12). While mugwort was listed as a noxious weed in Manitoba province (1), it is not listed as a federal or state noxious weed on lists in the United States and has been offered for retail sale (2).

Mugwort is thought to have originated in Europe, yet the geographic source of mugwort remains unclear and several hypotheses were proposed, based on historical accounts (2). *A. vulgaris* is extremely adaptable, tolerating soil and climatic variation across 56 countries. The geographic distribution from which mugwort was collected extends from Siberia and the northern Himalayas to Argentina and Hawaii (11). It was listed as a weed among 25 crops. In the eastern United States, mugwort has expanded beyond ornamental nurseries into pastures and corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean (*Glycine max* (L.) Merr.) fields (4, 5).

In addition, direct competition from mugwort is likely to be compounded by allelopathic interactions with other plants. Phenolic compounds in leachate extracts from mugwort leaf tissues reduced the growth of red clover (*Trifolium pratense* L.) with field soil (13) and barley (*Hordeum vulgare* L.) without field soil (14). Rhizomes also produce bioactive secondary metabolites, which have inhibited growth and germination of curly cress (*Rorippa nasturtium-aquaticum* (L.) Hayek) (2). Seed germination of alfalfa (*Medicago sativa* L.) was reduced by 25% when experimental soil substrates contained rhizome fragments (10).

Foliage of *A. vulgaris* appears similar to common ragweed (*Ambrosia artemisiifolia* L.) and ornamental chrysanthemums (*Chrysanthemum* spp.). Yet, unlike cultivated chrysanthemums and common ragweed, the lower surfaces of mugwort leaves are covered with a dense, silver-white pubescence. Leaf morphology and appearance varies highly, even within shoots on an individual plant (2, 22). Variability in shoot and rhizome structures, growth habit, seed productivity and viability are geographically apparent (2). In Canada and the United States, the most common ploidy level in mugwort biotypes is 2n = 16. Yet morphological and functional differences among *A. vulgaris* biotypes can be linked, in part, to worldwide differences among mugwort populations that yield

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a range of chromosome numbers from 2n = 16, 18, 24, 36, to 45 (16).

The upper portion of mature *A. vulgaris* stems, which can grow 2 m (6 ft) tall, yield rankly aromatic flower heads in panicles of 15 to 30 greenish-yellow disk-shaped florets in late summer (12, 22) (Fig. 1A). While individual mugwort plants can generate as many as 200,000 seeds in a season, variation in mugwort seed viability has been attributed to climatic factors (8, 12, 17). In the eastern United States, very few of these seeds are viable and are not attributed with successful spread of mugwort (2, 12, 22). Rather, weed dispersal occurs by rhizomes transported on contaminated cultivation equipment and ornamental nursery crop plants (4, 5, 12, 20, 22) (Fig. 1B).

In nursery fields, rhizomes are generally abundant in the upper 10 cm (4 in) of soil (18, 19). Histological sections of mugwort rhizomes treated with 10 ppm of the auxin herbicide fenac (2,3,6-trichlorophenylacetic acid) demonstrated that root primordia, having the appearance of 'buds', were initiated within 24 hr by activating the interfascicular cambium in the rhizome cortex (21). Guncan (9) reported that 75% of 'buds' on rhizome fragments 2 to 5 cm (0.75–2 in) long produced shoots, but no roots in the warm, humid climate along the Black Sea coast. Yet, longer sections of rhizomes readily produce ample roots and shoots during seasonal growth.

Once established, mugwort rhizomes gradually expand outward from the source, excluding other plants and forming a dense, monotypic stand (11, 12, 19, 20). In a single season, dry biomass from a single 15 cm (6 in) long rhizome section (24 g) increased 33× to 1,490 g (3.3 lb) dry mass for both roots and rhizomes. Experimental rhizome sections included a small amount of shoot tissue (4.5 g dry mass) that, in turn, increased to 527 g (1.2 lb) dry shoot biomass by the end of the season (11). Rogerson and Bingham (19) planted 5 cm (2 in) tall rooted mugwort plants with no rhizome system into 0.9 m square plots and grew them for 18 wk. At harvest, root and shoot biomass were recorded and extrapolated to provide biomass yield estimates. After 18 wk, rhizome and root biomass was 2,198 kg (4,712 lb) and shoot production yielded 1,432 kg (3,156 lb) per 0.4 hectare (acre). Rhizome lengths extended 114 km (70.8 mi).

Beyond commercial nurseries and production agriculture, the regenerative potential of mugwort from rhizomes is prob-

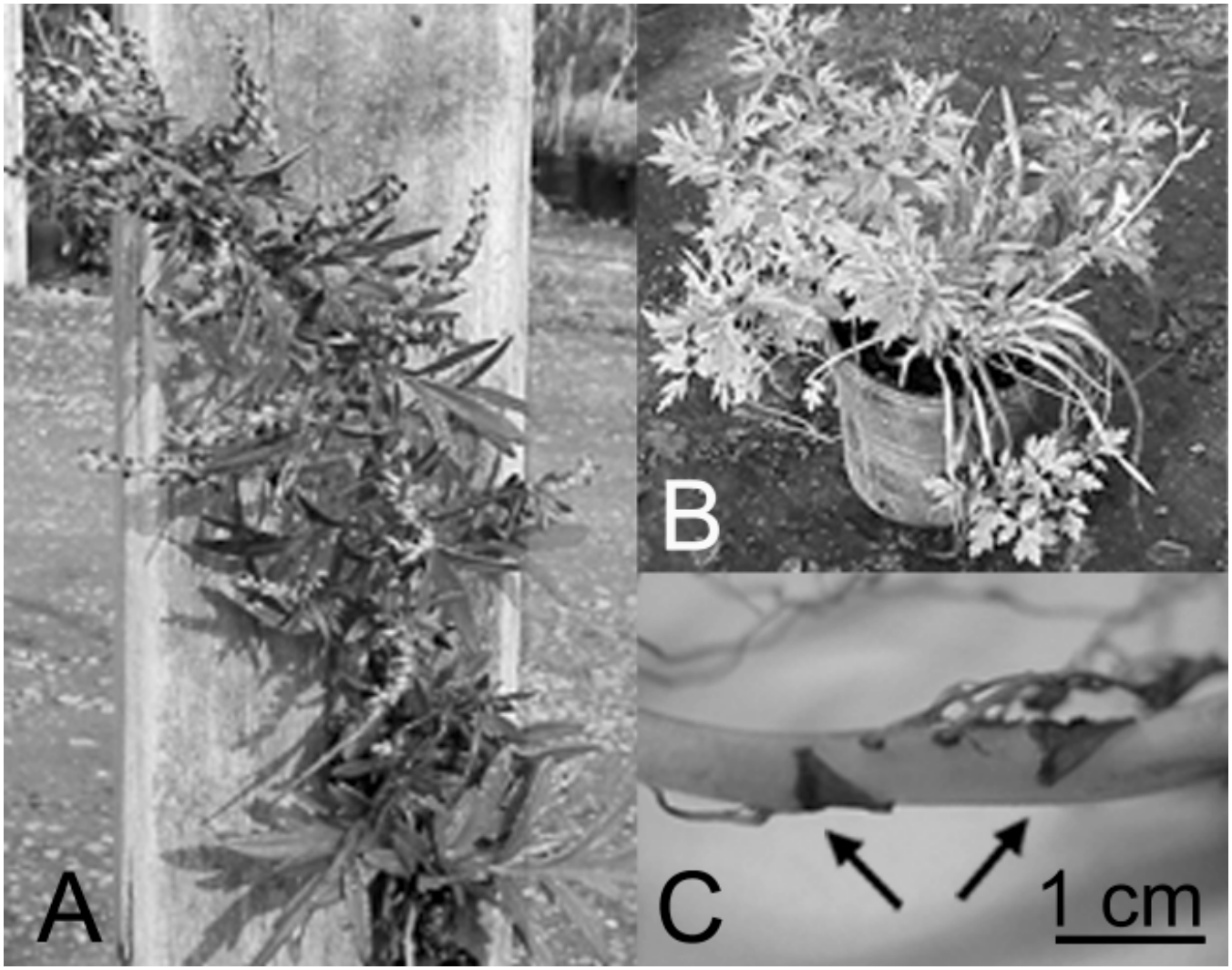

Fig. 1. Mugwort or False Chrysanthemum (*Artemisia vulgaris* L.) images demonstrate habit in flower (A.), infestation of a commercial nursery container of field-transplanted daylilies (B.), and a close-up view of a mugwort rhizome (C.) with leaf scales (arrows).

lematic for home gardeners and landscape maintenance professionals. Commercially available garden rototillers have cutting and digging tines that turn in excess of 240 rpm (e.g. Mantis Tiller, Schiller-Pfeiffer, Southampton, PA). Repeated rototilling and soil cultivation enables agricultural producers and home gardeners to achieve fine soil tilth 0.3 m or deeper in several soil types (7). Frequent cultivation is expected to subject rhizome fragments to mortality from desiccation, but population growth becomes problematic where cultivation is infrequent (2). Tillage releases seeds to germinate from sub-soil seed banks and may also amplify competition from weed populations when small rhizome sections readily propagate plant species, like mugwort (6). The objective of this research was to quantify the regenerative potential of mugwort rhizome sections transplanted into substrates that are encountered in landscapes and nursery fields, container nurseries, and propagation beds.

Materials and Methods

In August 2000, a 0.6 × 0.6 × 0.15 m (2.0 × 2.0 × 0.5 ft) section of field soil containing mugwort rhizomes, roots and shoots was collected from the border of a commercial tree nursery near McMinnville, TN (35°41' N × 85°46' W). Rhizomes and roots from 0.15 m^2 plugs were washed and transplanted into 4:1 (v/v) sieved (5.7 mm) pine bark:medium-coarse (mined, washed) quartz sand. Mugwort cultures were grown throughout 2001 under 40% shade in an outdoor shade house and irrigated as needed. In 2002, a greenhouse study was undertaken to quantify regeneration potential of mugwort rhizome sections. Experimental growing substrates were chosen to represent those encountered in landscapes and nursery fields, container nurseries, and propagation beds. Rhizomes were dug and washed free of soilless substrate and all lateral and fine roots were removed. Because rhizomes appeared to darken with age, they were separated into white (newer) or brown (older) groups. Only rhizome sections that were 2.0 ± 0.5 mm (0.08 in) in diameter were used. Rhizomes were cut into 0.5 cm, 1.0 cm and 2.0 cm-long (0.2 in, 0.4 in, 0.8 in) sections. Half of the 0.5 and 1.0 cm sections were cut to include a leaf scale (Fig. 1C) while the other half had no leaf scale present. All 2.0 cm long sections included at least two leaf scales. Ten sectioned rhizomes per treatment were transplanted into 235 cm^3 (14.3 in^3) pots filled with either pre-moistened pine bark, quartz sand, or sieved (4 mm) field soil and grown for 45 days in June and July. Field soil (Sequatchie, fine-loamy, silicious, thermic Hapludults, pH 6.5) was collected from untreated grassland on the UT Plant Science Farm in Knoxville, TN (35°58' N × 83°55' W). Pine bark, sand and soil substrate bulk densities were 0.26, 1.39, and 1.08 g/cm^3 (0.06, 0.32, and 0.25 oz/in^3), respectively. Factorial combinations of 5 rhizome lengths, 3 substrates, and 2 rhizome colors were arranged in a randomized complete block design with six replicates. The study was repeated in July.

For the duration of greenhouse trials, plants were maintained at ambient photoperiod (about 12 h). Photosynthetic photon flux, measured at noon on a cloudless day, averaged 630 ± 145 □mol·m^{-2}·s at plant canopy height. Daytime greenhouse temperatures were maintained at 25 ± 3C (77 ± 5F) and 21 ± 3C (70 ± 5F) at night. Relative humidity was approximately 80%. Plants were irrigated by an automated mist system programmed to deliver 6 seconds of mist every 8 minutes from 1000 to 1600 hr. Every seventh day, between 0800 and 0900 hr, plants were provided 40 ml 150 mg L N as Peters 20.0N–8.6P–16.6K (Peters 20–20–20) water-soluble fertilizer (Peters General Purpose 20–20–20, Scotts–Sierra Horticultural Products, Marysville, OH).

After 45 days, substrates were washed from the roots and rhizomes. Shoot and root length and fresh weights were recorded for each recovered rhizome section. Intact but inactive sections, described as firm rhizome tissues with no evident putrefaction, were recorded. Recovered root or shoot portions were combined within treatment, dried for 48 hr at 60C (140F), and weighed. All data were subjected to analysis of variance using PROC GLM in SAS (SAS Institute, Cary, NC). Linear contrasts described significant differences in rhizome growth in the presence or absence of a single leaf scale. Means were separated using a LSD procedure (P = 0.05).

Results and Discussion

Rhizome color (appearing either white or brown) did not affect any of the measured growth variables in June and July trials (F = 0.46 to 2.44; df = 1, 2,352; P = 0.5 to 0.119). Therefore, rhizome color was pooled within treatment for model analysis. Growth of individual rhizome sections did not differ between June- and July-initiated trials for shoot (F = 0.13; df = 1, 2,351; P = 0.72) or root fresh weights (F = 1.86; df = 1, 2,351; P = 0.17) in this study. Thus, fresh weight data for rhizome sections were pooled across trials.

Table 1. Fresh biomass root and shoot production from individual mugwort rhizome sections grown for 45 days.

Substrate	Rhizome length (cm)	Rhizomes recovered	Shoot fresh mass		Root fresh mass	
	–/+ leaf scale	(%)	(g)		(g)	
Pine Bark	0.5 –	176 (73)	0.017		0.029	
	0.5 +	201 (84)	0.040		0.061	
	1.0 –	180 (78)	0.019	b	0.054	b
	1.0 +	211 (88)	0.059		0.092	
	2.0 ++	205 (85)	0.111		0.181	
Sand	0.5 –	156 (85)	0.008		0.027	
	0.5 +	162 (65)	0.038		0.061	
	1.0 –	157 (68)	0.026	b	0.062	b
	1.0 +	169 (70)	0.053		0.085	
	2.0 ++	188 (78)	0.099		0.158	
Soil	0.5 –	77 (32)	0.062		0.076	
	0.5 +	96 (40)	0.222		0.310	
	1.0 –	114 (48)	0.134	a	0.221	a
	1.0 +	130 (54)	0.350		0.465	
	2.0 ++	165 (69)	0.325		0.431	
Significance						
Substrate[z]			***		***	
Rhizome length			***		***	
Substrate × rhizome length			***		***	
– vs + [y]			***		***	

[z]Within columns, substrate means followed by the same letter are not significantly different by Fisher's LSD (P > 0.05).

[y]Linear contrast in absence (–) or presence (+) of leaf scales on 0.5 and 1.0 cm rhizome sections significantly different at P < 0.001 (***). All 2.0 cm rhizome sections included more than 1 leaf scale, thus were not included in contrast analyses.

Table 2. Regeneration potential and growth characteristics of mugwort rhizome sections grown in a greenhouse for 45 days starting June 10 and July 19, 2003.

Substrate	Rhizome length	Rhizomes recovered	Shoot height	Leaf number	Root length	Inactive rhizomes	Root dry mass	Shoot dry mass
	(cm)	(%)	(cm)		(cm)		(g)	(g)
					June/July			
Pine Bark	0.5 –	81 (68)	0.26	0.47	1.26	2.9	0.03	0.01
	0.5 +	97 (81)	1.40	3.59	5.88	0.5	0.06	0.03
	1.0 –	88 (73)	0.86 a	1.52 c	3.51 a	3.0 a	0.06 a	0.02 b
	1.0 +	106 (88)	2.10	4.65	7.38	0.1	0.10	0.06
	2.0 ++	103 (86)	2.90	7.30	9.65	0.1	0.24	0.12
Sand	0.5 –	69 (58)	0.28	1.20	1.49	2.8	0.03	0.01
	0.5 +	85 (71)	1.16	4.31	4.88	0.8	0.09	0.05
	1.0 –	78 (65)	0.68 b	2.34 b	3.03 a	2.2 a	0.07 a	0.03 b
	1.0 +	92 (77)	1.61	5.40	6.24	0.2	0.09	0.05
	2.0 ++	102 (85)	2.32	7.82	7.71	0.1	0.23	0.12
Soil	0.5 –	19 (16)	0.73	1.53	2.39	0.9	0.04	0.04
	0.5 +	35 (29)	1.68	4.43	6.87	0.6	0.07	0.07
	1.0 –	40 (33)	0.59 a	1.35 a	2.04 a	2.2 a	0.04 a	0.04 a
	1.0 +	49 (41)	2.36	7.14	7.76	0.5	0.17	0.13
	2.0 ++	72 (60)	2.32	7.33	7.18	0.6	0.24	0.15
Significance								
Substrate[z]			*	***	NS	NS	NS	***
Rhizome length			***	***	***	***	***	***
Substrate × rhizome length			NS	NS	*	NS	NS	NS
– vs +[y]			***	***	***	***	***	***
					July/August			
Pine Bark	0.5 –	95 (79)	0.09	0.39	1.15	6.8	0.03	0.01
	0.5 +	104 (87)	0.60	3.46	5.29	1.2	0.06	0.02
	1.0 –	95 (79)	0.23 b	1.17 b	2.43 b	5.8 a	0.04 b	0.01 b
	1.0 +	105 (88)	0.92	4.30	7.45	1.2	0.10	0.04
	2.0 ++	102 (85)	1.07	5.34	8.26	0.2	0.18	0.06
Sand	0.5 –	87 (73)	0.05	0.35	0.49	6.8	0.03	0.01
	0.5 +	77 (64)	0.40	3.17	2.10	1.6	0.03	0.01
	1.0 –	79 (66)	0.19 b	1.48 b	1.71 c	4.7 a	0.04 b	0.01 b
	1.0 +	77 (64)	0.71	4.39	3.77	1.0	0.06	0.03
	2.0 ++	86 (72)	1.15	5.41	5.26	0.3	0.13	0.05
Soil	0.5 –	58 (48)	0.73	0.72	0.86	4.4	0.04	0.03
	0.5 +	61 (51)	1.68	4.71	5.50	2.5	0.20	0.27
	1.0 –	74 (62)	0.59 a	1.95 a	2.17 a	5.2 a	0.24 a	0.15 a
	1.0 +	81 (68)	2.36	8.67	9.23	1.1	0.60	0.43
	2.0 ++	93 (78)	2.32	9.94	11.6	0.3	0.66	0.46
Significance								
Substrate[z]			***	***	***	NS	***	***
Rhizome length			***	***	***	***	***	***
Substrate × rhizome length			***	***	***	**	***	***
– vs +[y]			***	***	***	***	***	***

[z]Within columns, substrate means followed by the same letter are not significantly different by Fisher's LSD ($P > 0.05$).

[y]Linear contrast in absence (–) or presence (+) of leaf scales on 0.5 and 1.0 cm rhizome sections significantly different at $P < 0.001$ (***). All 2.0 cm rhizome sections included more than 1 leaf scale, thus were not included in contrast analyses.

In contrast to previous research, which reported shoot but no root initiation on 75% of rhizome fragments 2 to 5 cm (0.8–2.0 in) long (9), 85, 78, and 69% of 2 cm (0.8 in) long rhizome sections produced both roots and shoots when grown in pine bark, sand, and soil substrates, respectively (Table 1). Rhizomes in soil produced more root and shoot fresh weights than sections grown in either pine bark or sand soilless media (Table 1). Though plants in all substrates were fertilized weekly, soil fertility was not quantified and preexisting nutrient levels likely explain the greater growth of plants in soil (Tables 1 and 2). Still, fewer rhizome sections survived in soil than in other media, regardless of length (Table 1). Only 69% of 240 2.0 cm (0.8 in) long rhizome sections produced plants when grown in soil. Fewer than 32% (77) of 0.5 cm (0.2 in) long rhizome sections, having no leaf scale, were able to regenerate root or shoot tissues in soil.

More rhizomes survived and root and shoot fresh weights were increased when 0.5 and 1.0 cm (0.2 and 0.4 in) long sections included a leaf scale ($F = 37.3$ and 78.4 (roots and shoots); df = 1, 2,367; $P < 0.0001$). This trend was consistent, regardless of substrate type (Table 1). Root initials emerge both adjacent to leaf scales and in the internode be-

tween leaf scales (Fig. 1C). Still, 32 to 85% of 0.5 cm (0.2 in) long sections with no leaf scale survived to produce both roots and shoots across substrates (Table 1).

Observations among mugwort growth characteristics were generally consistent, but mortality was higher among rhizomes transplanted in June, particularly in soil: therefore, several growth parameters were analyzed separately by trial (Table 2). In both trials, shoot height, leaf number and root lengths were greater when 0.5 and 1.0 cm (0.2 and 0.4 in) long rhizome sections included a leaf scale.

Notably, more inactive sections were recovered later in the season from all substrates 45 days after July-harvested rhizomes were transplanted (Table 2). Rhizome sections were considered inactive if they still maintained tissue turgor and showed no evidence of putrefaction upon recovery. Though these sections were not tested further, if root primordia develop once conditions become favorable, inactive pieces of rhizome will function like a seed bank. Further, because evaluators frequently quantify shoot biomass production following herbicidal weed control treatments but may not report root biomass, short-duration studies that do not account for rhizome regeneration may overestimate the control efficacy of management actions (4, 5).

The presence of a leaf scale regulates the initiation of rhizome growth. Fewer inactive rhizome sections were recovered when similarly sized sections included a leaf scale, regardless of substrate type (Table 2). In a preliminary trial, 0.5 and 1.0 cm (0.2 and 0.4 in) long rhizome sections generated shoot tissues within 6 days and before root tissues were apparent (data not shown). Rogerson et al. (21) reported high levels of reserve polysaccharide storage in mugwort rhizomes, but did not report the time of year or phenological status of the plants from which rhizome samples were collected. The mechanism for rhizome growth initiation may be related to carbohydrate partitioning but cannot be conclusively attributed. In fact, comparisons of mugwort with perennial common yarrow (*Achillea millefolium* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), common dandelion (*Taraxacum officinale* G.H. Weber *ex* Wiggers), and colt's foot (*Tussilago farfara* L.), found that *A. vulgaris* allocated the least amount of total resources to reproductive structures: only 2.3% of total resources to seed related organs and 8.9% to vegetative reproductive structures (i.e., rhizomes) (3).

Still, photosynthesis in early emerging shoot tissues would provide energy for subsequent rhizome and root development. This adaptation would enhance the likelihood that mugwort will become established when transplanted by contaminated equipment. Regardless of substrate type, high proportions of rhizome sections as small as 0.5 cm (0.2 in), including those without leaf scales, were able to produce shoots and roots within 45 days when irrigated. Productivity among measured growth parameters was greatest in soil. Though soil fertility was not tested, higher macro- and micronutrient levels in soil are expected to explain this observation. While *A. vulgaris* growth was limited in the absence of lime and magnesium, with greater growth recoveries demonstrated when magnesium was added without lime (15), the role that fertility plays in mugwort growth and dispersal has not been adequately characterized.

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