HortScience 58(11):1309–1313. 2023. https://doi.org/10.21273/HORTSCI17122-23

Cercocarpus ledifolius var. *intricatus* 'DoubleDown'

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Keywords. bonsai, cutting propagation, landscape plant, mountain mahogany, native plant

Bonsai (tray landscape, potted scenery, potted landscape, miniature trees, and rockery) is an artistic horticulture practice of developing aesthetically formed trees and landscapes in miniature with appropriately aesthetic containers. This has been practiced over a few thousand years in oriental cultures, including the ancient Chinese tradition of *penzai* or *penjing*, from which the art originated; the miniature living landscapes of Vietnamese *hòn non bộ*; and the Japanese variations of bonsai and "tray planting" (Gustafson 1995). To produce bonsai plants that share similar shapes and styles of mature, full-size trees, cultivation techniques are used, including leaf trimming, pruning, wiring, clamping, grafting, defoliation, and deadwood techniques (Zhao 2012). This practice is distinct from dwarfing in that dwarfing is a process to discover, breed, or genetically create a plant cultivar that is a permanent genetic miniature of standard members of its species (Ferrero-Serrano et al. 2019). Bonsai can be created from specimens of woody source materials that include cuttings, seedlings, or small trees. The source specimen should be relatively small and meet the aesthetic standards of bonsai. Nearly any perennial woody-stemmed tree or shrub species is suitable for bonsai development (Owen 1990) if they produce true branches and remain relatively small in a container environment through crown and root pruning. Slow-growing plant species with small leaves or needles are popular bonsai materials.

Cercocarpus ledifolius Nutt. (curl-leaf mountain mahogany, desert mountain mahogany) is an evergreen shrub or small tree of 1 to 8 m in height that occurs throughout the western United States. The shiny leaves are typically 1 to 3 cm long and 0.5 to 1 cm wide. The leaf is thick, with revolute margins that give rise to the name curl-leaf. Its flower is inconspicuous, with the fruit being an achene with a long, corkscrew, feather-like plume that gives the plant a fuzzy appearance from mid to late summer (Monsen et al. 2004). Curl-leaf mountain mahogany has merit as a potential landscape plant because of its evergreen nature, drought tolerance, temperature tolerance, and nitrogen-fixating ability (Center for Water-Efficient Landscaping 2023; Rupp and Wheaton 2014). It can grow in clay, sand, or loam soil in United States Department of Agriculture hardiness zones 3 to 9 (Plant Select® 2022). It is not particularly competitive, even though it has a deep root system. It is tolerant to browsing but is susceptible to root rot.

The taxonomy of *C. ledifolius* is complex because of the hybridization among three naturally occurring species: *Cercocarpus intricatus* (little-leaf mountain mahogany), *C. ledifolius*, and *Cercocarpus montanus* (alder leaf or true mountain mahogany) (Walker and Turley 1999). However, *C. intricatus* is no longer considered a separate species, and its current taxonomic status is *C. ledifolius* var. *intricatus* (S. Watson) M. E. Jones (little-leaf mountain mahogany, narrow-leaf mahogany, dwarf mountain mahogany) (Henrickson and Vanden Heuvel 2015). Little-leaf mountain mahogany is a small, densely branched evergreen shrub, rarely more than 2.5 m tall, with small leaves that can be so revolute as to appear needle-like (Center for Water-Efficient Landscaping 2023). It is smaller than the species and stays shrub-sized rather than approaching the small tree category. It also has a very dense and intricate branching pattern, with the stems being a significant part of its appearance that add a rather coarse texture. Little-leaf mountain mahogany is commonly found in harsh, dry, rocky sites with limited water and extreme summer temperatures in the southwestern United States, including Arizona, Nevada, and Utah (Henrickson and Vanden Heuvel 2015). It has great potential for use in urban landscaping as a fine small- to medium-size shrub for a sunny, dry spot or as a xeric specimen with small, inconspicuous flowers that transform into attractive, feathery seed plumes (Rupp and Wheaton 2014). It responds to light pruning and is adaptable for bonsai, with its small leaves and dwarf habit (Center for Water-Efficient Landscaping 2023). Therefore, it is of value to introduce and domesticate little-leaf mountain mahogany for low-water landscaping and bonsai production.

Origin

Examined in this study, *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' was selected in Clark County, NV, USA, on 21 May 2010 for its dwarf growth habit. The parent plant was also distinguished by a procumbent growth habit (Fig. 1A). Seventy-seven terminal cuttings were collected on 21 May 2010 and held on ice and in a cooler at 4 °C until stuck on 24 May 2010. An initial attempt to root collected cuttings was done by using three concentrations of Dip'n® Grow [1% indole-3-butyric acid (IBA), 0.5% 1-napthaleneacetic acid (NAA); Dip'n® Grow, Clackamas, OR, USA] in 50% ethanol following a quick-dip technique (3 s, 1 cm deep). Cuttings were treated with 0, 2000/1000 $mg \cdot L^{-1}$ IBA/NAA or 4000/2000 $mg \cdot L^{-1}$ IBA/NAA. The cuttings were stuck in a rooting substrate containing perlite (Hess perlite, Malad City, ID, USA) and sphagnum peatmoss at a

Fig. 1. Mother plant (**A**) of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' and its vegetative-propagated plants in landscapes in Hyde Park, UT (**B**: planted on 17 Apr 2021 as a 11.5-year-old plant in a 36-L container; **C**: planted on 9 May 2020 as a two-year-old plant in a 3.8-L container), Red Hills Desert Garden, St. George, UT (**D**: planted in 2019), Rock Alpine Garden, Denver Botanic Gardens, Denver, CO (**E**: planted in 2022; photo credit: Mike Kintgen), and Utah State University campus, Logan, UT (**F**: planted on 27 Sep 2016 as a roughly-two-year-old plant in a 3.8-L container). The mother plant has both a dwarf and procumbent habit in the wild, whereas vegetative-propagated plants retain only the dwarf habit in the landscape.

Received for publication 13 Feb 2023. Accepted for publication 8 May 2023.
Published online 27 Sep 2023.
This research was supported in part by the United States Department of Agriculture (USDA) National Institute of Food and Agriculture Hatch projects (UTA01352, UTA01381, and UTA01666), the Utah Department of Agriculture and Food Specialty Crop Block Grant program, Utah State University's Center for Water-Efficient Landscaping, and the Utah Agricultural Experiment Station (UAES). We are grateful for the Open Access Funding Initiative at Utah State University Libraries for funding publication charges.
This article was approved as UAES journal paper no. 9687.
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Fig. 2. New leaves (**A**), typical shoot growth and appearance (**B**), inconspicuous flowers (**C**), and feathery seed plumes (**D** and insert) of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'. Leaves are revolute, resulting in a needle-like appearance.

volumetric ratio of 3:1. Cuttings were placed on a bench with an intermittent mist system during the day using reverse-osmosis water in a single-gable glass greenhouse with 60% shade and temperatures set at 21 °C during the day and 15.6 °C at night. Misting was controlled by a timer and applied for 7 s every 12 min, with vertical baffles of spunbond polyester fabric to reduce airflow across benches. Bottom heat at 25 to 30 °C was provided using an electric heating mat (Propagation Heat Mat; Grower's Nursery Supply, Salem, OR, USA).

After 7 weeks, only one cutting was rooted from the treatment with 4000/2000 mg·L^{-1} IBA/NAA. All plants for subsequent propagation and research were from this single-rooted cutting. This plant grew to 65 cm tall in a 36-L injection-molded polypropylene container (#10 Squat; 41.3 cm in diameter at the top, 30.5 cm in height; Nursery Supplies, Orange, CA, USA) before being transplanted to a landscape in 2021 (Fig. 1B). The dwarf habit is retained in the landscape and the nursery (Fig. 1B–D). Plants in the landscape do not have the procumbent habit, which suggests it is in the parent plant as a result of climate and/or browsing, not genetics.

Description

Cercocarpus ledifolius var. *intricatus* 'DoubleDown' plants have an average internode length of 3.9 mm in greenhouse conditions (Fig. 2A and B). This contrasts with other little-leaf mountain mahoganies, which have internode lengths ranging from 4 to 13 mm in the field (Henrickson and Vanden Heuvel 2015). The leaves of *C. ledifolius* var. *intricatus* 'DoubleDown' are dull green in both the landscape and the nursery (Fig. 2B), and are generally smaller than other little-leaf mountain mahoganies. The average length and width of fully developed leaves are 5.3 and 1.2 mm, respectively, in contrast to 18 and 4 mm for a more typical selection. The longest leaves approach 10 to 11 mm in length. Flowers are inconspicuous and yellowish (Fig. 2C), and fruits are feathery seed plumes that are 2.0 cm in length on average (Fig. 2D).

Propagation

The common practice of vegetative regeneration is required for producing clones with the same traits as a mother plant, as demonstrated for *C. montanus* (Gucker 2006; Paudel et al. 2020). In general, rooting of mountain mahoganies appears to be highly variable, depending upon the selection (Rupp 2013). 'DoubleDown' little-leaf mountain mahogany is on the more difficult-to-root end of the spectrum of ease of rooting in *C. ledifolius*. When the mother plant was of a sufficient size to produce significant numbers of cuttings under cultivation, a series of experiments were conducted from 2014 to 2022 to develop an effective protocol for propagating it using terminal cuttings. Rooting hormones, rooting substrates, and wounding treatments were studied. Table 1 summarizes the cutting preparation and general environmental conditions.

From 2014 to 2017, the mother plant was chilled in a cooler at 4 °C during the winter, moved out in spring, and grown in a glass greenhouse. On 21 May 2014, terminal cuttings (47.8 ± 5.7 mm in length) of the current season's growth were collected (Table 1). Leaves were removed from the bottom of each cutting. Cuttings were treated across all treatments with a variety of pesticides at label-recommended rates, including ZeroTol® (1% ZeroTol®; 27.1% hydrogen dioxide, 2.0% peroxyacetic acid; BioSafe Systems, Hartford, CT, USA), Aliette® (0.66 g·L^{-1}, 80% fosetyl aluminum, 6.18% nonylphenol ethoxylate, 4.4% lignosulfonic acid, 0.16% crystalline quartz; Bayer CropScience, Research Triangle, NC, USA), and Cleary 3336 (thiophanate-methyl 41.25%; Cleary Chemical Corporation, Dayton, NJ, USA). A 1.0-cm wound was made by scraping the bark off one side of the cutting using a knife perpendicular to the stem axis. Cuttings were assigned randomly and dipped in 1000/500 mg·L^{-1} IBA/NAA as Dip'n® Grow in 25% ethanol for 5 s, or dipped in 1.0-cm-deep water and then in 3000 mg·L^{-1} IBA as talc-based Hormodin 2 (Hormodin®; OHP, Mainland, PA, USA) before sticking in a moist rooting substrate containing perlite and Canadian sphagnum peatmoss at a volumetric ratio of 4:1. Cuttings were placed on the bench with the intermittent mist system controlled at 30 vapor pressure deficit (VPD) units using a Water Plus VPD mist controller (Phytotronics, Earth City, MO, USA). The misting duration was 12 s and the bottom heat was set at 22 °C. The propagation greenhouse conditions were as described previously. The experiments followed a completely randomized design, with three replications of each treatment and seven cuttings in each replicate. Four weeks later (i.e., 18 Jun), the number of roots and length of the longest root were determined for each cutting. The rooting (or not) of each cutting was recorded at harvest and analyzed as binary data. An analysis of variance was conducted for all data. All statistical analyses were performed with PROC GLIMMIX procedures using a Statistical Analysis Software (SAS) software (university edition; SAS Institute, Cary, NC, USA). Log transformation was performed for the number of roots and the length of the longest root. There was no significant difference between the two types of rooting hormones in terms of rooting percentage, number of roots per cutting, and length of the longest root formed (Table 2). On average, 71% and 57% of cuttings rooted, with 2.9 and 4.2 roots per cutting and 1.2 cm and 1.3 cm long for the longest root, respectively, when cuttings were treated with 1000/500 mg·L^{-1} IBA/NAA as Dip'n® Grow or 3000 mg·L^{-1} IBA as talc-based Hormodin 2 (Table 2, Fig. 3). This experiment was repeated on 16 Jun 2015 with the same protocol, except terminal cuttings averaged 35.6 mm long and the mist frequency was set at 20 VPD units for 10 s (Table 1). At that

Table 1. General information for cutting preparation of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' and environmental conditions for propagation experiments conducted in 2014–17 and 2021–22.

Variable	2014	2015	2016	2017	2017	2021	2022
Starting date	21 May	16 Jun	25 Jun	5 Jan	9 Jun	2 Oct	22 Sep
Ending date	18 Jun	14 Jul	27 Jul	17 Feb	25 Jul	10 Dec	22 Nov
No. of cuttings[i]	42	63	89	113	226	192 and 128	128 and 64
Replications (subsamples)	3 (7)	4 (7, 8)	5 (7, 9, 10)	10 (3, 5, 6, 8)	6 (14, 18, 19)	6 (8) and 8 (8)	4 (8)
Length of cuttings (mm ± *SD*)	47.8 ± 5.7	35.6 ± 4.7	52.9 ± 15.5	104.6 ± 10.0	60.3 ± 15.0	52 ± 14	46 ± 12
Bottom leaves removed (cm)	1.5	1.5	1.5	4	2	2	2
Misting (VPD[ii] units)	30	20	40	40	25	60	60
Misting duration (s)	12	10	12	12	10	10	10
Bottom heat (°C)	22	22	22	22	23	24	24
Greenhouse shade (%)	60	60	60	None	60	None	None
Greenhouse day-temperature setting (°C)	18.3	18.3	18.3	18.3	18.3	18.3	18.3
Greenhouse night-temperature setting (°C)	15.6	15.6	15.6	15.6	15.6	15.6	15.6
Length of experiment (weeks)	4	4	4	6	6	10	8

[i] A total of 192 and 128 cuttings were used for the rooting hormone study, and 128 and 64 cuttings were used for the wounding study in 2021 and 2022, respectively.
[ii] Vapor pressure deficit.

Table 2. Effect of rooting hormones on the root formation of terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'.[i]

Variable	Dip'n® Grow	Hormodin 2
Rooting (%)	71.4 a[ii]	57.1 a
No. of roots	2.9 a	4.2 a
Length of the longest root (cm)	1.2 a	1.3 a

[i] Terminal cuttings were treated with 1000/500 mg·L^{-1} indole-3-butyric acid (IBA)/1-napthaleneacetic acid as Dip'n® Grow or 3000 mg·L^{-1} IBA as talc-based Hormodin 2. This experiment was initiated on 21 May and ended on 18 Jun 2014.

[ii] The same letters within a row denote the lack of a significant difference between hormone treatments as computed using Tukey's method for multiplicity at α = 0.05.

Fig. 3. Rooted terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'. A profusion of roots in the wounded region of the stems formed when cuttings were treated with 1000 mg·L^{-1} indole-3-butyric acid and 500 mg·L^{-1} 1-napthaleneacetic acid as Dip'n® Grow (Clackamas, OR, USA).

time, only 8% of 63 cuttings rooted (data not shown).

On 25 Jun 2016 and 5 Jan 2017, terminal cuttings were collected from current or previous season's growth, respectively. The cuttings were prepared as described earlier and were treated with 3000/1500 mg·L^{-1} IBA/NAA as Dip'n® Grow or 3000 mg·L^{-1} IBA as talc-based Hormodin 2 (Table 1). The experimental design and data analysis method were the same as described previously, except, in the 5 Jan 2017 experiment, there was no shade and a 15-h photoperiod was maintained. In 2016, rooting was similar between the two types of rooting hormones (Table 3). There were 44% and 50% of cuttings rooted, with 5.6 and 7.1 roots per cutting, at 4.7 and 3.5 cm long for the longest root, respectively, when cuttings were treated with 3000/1500 mg·L^{-1} IBA/NAA as Dip'n® Grow or 3000 mg·L^{-1} IBA as talc-based Hormodin 2 (Table 3). In 2017, hormone type did not have a significant effect on rooting or the length of the longest root (Table 3). But, cuttings treated with 3000 mg·L^{-1} IBA as talc-based Hormodin 2 formed 50% more roots than those with 3000/1500 mg·L^{-1} IBA/NAA as Dip'n® Grow (Table 3).

In addition, rooting substrates were investigated to evaluate their effects on the root formation of 'DoubleDown' little-leaf mountain mahogany on 9 Jun 2017 (Table 1). Cuttings were prepared as described and were treated with 3000 mg·L^{-1} IBA as talc-based Hormodin 2. In addition to the 60% shade, a single layer of spunbond polyester fabric was also suspended above the mist bench. The cuttings were stuck in a rooting substrate containing Canadian sphagnum peatmoss plus perlite or perlite plus vermiculite (Therm-O-Rock West, Chandler, AZ, USA) at a volumetric ratio of 1:4 and 2:1, respectively. Rooting substrate containing peatmoss plus perlite was better than that with perlite plus vermiculite (Table 4). On average, 66% and 38% of cuttings rooted, with 4.1 and 2.5 roots per cutting, and with a length of 1.6 and 0.7 cm for the longest root, respectively, when cuttings were stuck in a rooting substrate containing peatmoss plus perlite or perlite plus vermiculite, respectively (Table 4).

From 2021 to 2022, more than 40 plants (4–7 years old), cloned from the mother plant and grown in 8.5-L injection-molded polypropylene containers (#3; 23.5 cm in diameter at the top, 22.9 cm in height; Nursery Supplies), were used to improve the propagation of 'DoubleDown' little-leaf mountain mahogany further. During the winters of 2020–22, they were chilled in a polyethylene greenhouse with temperatures maintained above freezing, removed in the spring, and grown in a glass greenhouse.

On 2 Oct 2021, healthy terminal cuttings were collected, wrapped in a moist paper towel, and placed on ice and in a cooler at 4 °C until used (Table 1). One experiment was conducted to determine the effect of rooting hormone type and concentrations for cutting propagation, the other was conducted to determine the best wounding method for cutting propagation. For the hormone study, 192 terminal cuttings were prepared as described earlier and treated with plant growth regulators as Dip'n® Grow in 25% ethanol (1000/500 or 3000/1500 mg·L^{-1} IBA/NAA), talc-based Hormodin 1 (1000 mg·L^{-1} IBA), or Hormodin 2 (3000 mg·L^{-1} IBA) (Table 5). For the wounding study, 128 terminal cuttings were collected and divided into two groups. One group of cuttings was wounded by scraping one side (0.5–1 cm long) of the cutting base (scrape), the other group was wounded by making three to five perpendicular cuts (1 mm deep) to the wood around the base (cut). Wounded cuttings were then treated with 3000 mg·L^{-1} IBA as talc-based Hormodin 2. All cuttings were stuck in a rooting substrate with perlite and Canadian sphagnum peatmoss at a ratio of 4:1 in 180-mL inserts (8 cm depth; Landmark Plastic Corporation, Akron, OH, USA). Cuttings were placed on the bench with the intermittent mist system set at 60 VPD units and a bottom heat of 24 °C. The experiment was conducted using a completely randomized design. Ten weeks later (i.e., 10 Dec 2021), cuttings were evaluated for rooting, number of roots per cutting, and length of the longest root. All data were analyzed as described earlier. There was a significant difference among hormone treatments (Table 5). Cuttings treated with Hormodin 1 and Hormodin 2 had the greatest rooting percentage of 38% and 42%, respectively, compared with 19% and 10% for the Dip'n® Grow treatments (Table 5, Fig. 4). However, the number of roots and the length of the longest root were similar among all hormone treatments. Cuttings scraped on one side had a greater rooting percentage when compared with cuttings wounded with cuts (Table 6). Although the number of roots and length of the longest root were relatively high for cuttings scraped on one side, there were no statistical differences between the two wounding methods. These two experiments were repeated on 22 Sep 2022. There were no significant differences among hormone treatments (Table 5). Cuttings scraped on one side had a greater rooting percentage when compared with cuttings wounded with cuts (Table 6). There was no difference between the two wounding treatments in terms of number of roots and length of the longest root.

In summary, rooting of 'DoubleDown' little-leaf mountain mahogany was highly variable, with a 25% to 71% and 10% to 97% success rate for experiments conducted during 2014–17 and 2021–22, respectively (Tables 2–6).

Table 3. Effect of rooting hormones on the root formation of terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'.[i]

	2016		2017	
Variable	Dip'n® Grow	Hormodin 2	Dip'n® Grow	Hormodin 2
Rooting (%)	44.4 a[ii]	50.0 a	26.8 a	24.6 a
No. of roots	5.6 a	7.1 a	6.0 b	11.9 a
Length of the longest root (cm)	4.7 a	3.5 a	2.0 a	3.6 a

[i] Terminal cuttings were treated with 3000/1500 mg·L^{-1} indole-3-butyric acid (IBA)/1-napthaleneacetic acid as Dip'n® Grow or 3000 mg·L^{-1} IBA as talc-based Hormodin 2. This experiment was initiated on 25 Jun 2016 and on 5 Jan 2017, and ended on 27 Jul 2016 and on 17 Feb 2017.

[ii] The same letters within a row and year denote the lack of a significant difference between hormone treatments as computed using Tukey's method for multiplicity at α = 0.05.

Table 4. Effect of rooting substrates on the root formation of terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'.[i]

Variable	Peat + perlite	Perlite + vermiculite
Rooting (%)	66.4 a[ii]	38.4 b
Number of roots	4.1 a	2.5 b
Length of the longest root (cm)	1.6 a	0.7 b

[i] Terminal cuttings were treated with 3000 mg·L^{-1} indole-3-butyric acid as talc-based Hormodin 2 and stuck in a rooting substrate containing Canadian sphagnum peatmoss plus perlite or perlite plus vermiculite at a volumetric ratio of 1:4 and 2:1, respectively. This experiment was initiated on 9 Jun and ended on 25 Jul 2017.

[ii] The same letters within a row denote the lack of a significant difference between rooting substrate treatments as computed using Tukey's method for multiplicity at α = 0.05.

Table 5. Effect of different rooting hormones on the root formation of terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'.[i]

	2021			2022		
Rooting hormone	Rooting (%)	No. of roots	Length of the longest root (cm)	Rooting (%)	No. of roots	Length of the longest root (cm)
1000 mg·L^{-1} IBA	18.8 ab[ii]	3.5 a	2.2 a	50.0 a	7.1 a	1.9 a
3000 mg·L^{-1} IBA	10.4 b	3.8 a	3.3 a	12.5 a	2.8 a	2.7 a
Hormodin 1	37.5 a	3.9 a	3.4 a	52.2 a	3.4 a	2.2 a
Hormodin 2	41.7 a	3.5 a	1.8 a	35.0 a	3.3 a	2.4 a

[i] Terminal cuttings were treated with different rooting hormones [1000/500 and 3000/1500 mg·L^{-1} indole-3-butyric acid (IBA)/1-napthaleneacetic acid as Dip'n® Grow, and 1000 and 3000 mg·L^{-1} IBA as talc-based Hormodin 1 and Hormodin 2, respectively]. This experiment was initiated on 2 Oct 2021 and on 22 Sep 2022, and ended on 10 Dec 2021 and on 22 Nov 2022.

[ii] The same letters within a year and column denote the lack of a significant difference among hormone treatments as computed using Tukey's method for multiplicity at α = 0.05.

These data indicate that 'DoubleDown' little-leaf mountain mahogany cuttings have the potential for rooting at commercially viable rates, but further research is needed to reduce the variability.

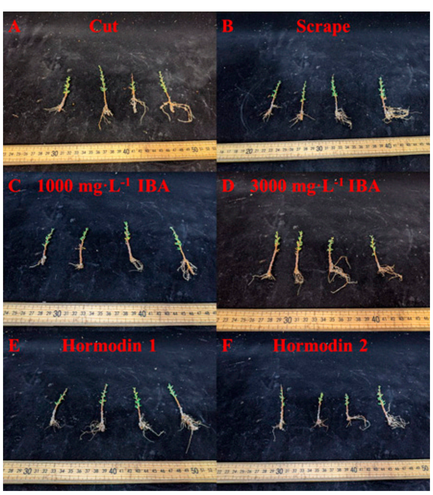

Fig. 4. Rooted cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' in the experiment carried out on 2 Oct 2021. (**A, B**) Terminal cuttings were wounded by making three to five perpendicular cuts (1 mm deep) to the wood around the base (Cut) or slicing through the bark down to the wood and then scraping one side (0.5–1 cm long) of the cutting at the bottom (Scrape). (**C–F**) Terminal cuttings were treated with different rooting hormones: 1000/500 mg·L^{-1} (**C**) and 3000/1500 mg·L^{-1} (**D**) indole-3-butyric acid (IBA)/1-napthaleneacetic acid as Dip'n® Grow (Clackamas, OR, USA) or 1000 and 3000 mg·L^{-1} IBA as talc-based Hormodin 1 (**E**) and Hormodin 2 (**F**) (OHP, Mainland, PA, USA), respectively.

Fertilizer Study

On 18 Mar 2022, rooted cuttings were transplanted into 0.9-L black square pots (10.5 × 10.5 cm at the top, 15.5 cm in height; A.M.A. Horticulture Inc., Kordlok, ON, Canada) with Metro-Mix® 820 (Canadian Sphagnum peatmoss, 35% to 45% composted pine bark, coir, coarse perlite, and dolomitic limestone; SunGro Horticulture, Agawam, MA, USA) and watered with Logan City potable water (electrical conductivity, 0.35 ± 0.01 dS·m^{-1}; pH, 7.7 ± 0.2) as needed. On 13 Jul 2022, a fertilizer study was designed in which plants were divided into two groups. One group was irrigated with potable water and the other group with a nutrient solution. The nutrient solution was prepared by adding 0.8 g·L^{-1} 15N–2.2P–12.5K water-soluble fertilizer (Peters Excel 15-5-15 Cal-Mag Special; ICL Specialty Fertilizers, Dublin, OH, USA) to the potable water. Plant height, number of shoots, and number of leaves were recorded as initial growth data. Plants were irrigated with 150 mL potable water or nutrient solution every 3 to 5 d as needed. On 25 Oct 2022, plant height, number of shoots, and number of leaves were recorded. Chlorophyll estimation was performed following the protocol explained by Barnes et al. (1992), with some modifications. In brief, 0.1 g of leaf tissue was cut into smaller pieces and placed in tubes containing 10 mL 99.9% dimethyl sulfoxide solvent (Fisher Chemical, Fair Lawn, NJ, USA) and incubated in a water bath at 60 to 65 °C for 90 min. A 3-mL aliquot was used, and absorption was measured at 665 nm and 648 nm in a ultraviolet/visible spectrophotometer (BioMate 3S; Thermo Fisher Scientific, Madison, WI, USA). Afterward, chlorophyll a and b concentrations were calculated [Chlorophyll a (mg/g) = ($14.85A^{665} – 5.14A^{648}$) and Chlorophyll b (mg/g) = ($25.48A^{648} – 7.36A^{665}$)]. In addition, leaf color was recorded, and all references to color numbers are from the Royal Horticultural Society (RHS) (2015).

'DoubleDown' little-leaf mountain mahogany grew slowly, and no significant difference in height was found for plants in both groups (Table 7). However, plants irrigated with the nutrient solution had 70% and 82% more shoots and leaves, respectively, compared with those with potable water. Plants irrigated with the nutrient solution had a greater chlorophyll a content than those with potable water (Table 7), although chlorophyll b contents were the same. When 'DoubleDown' little-leaf mountain mahogany was irrigated with potable water, moderate yellowish green (RHS 138 A) to moderate olive green (RHS 137 A) and moderate yellowish green (RHS 138 D) to moderate yellow green (RHS 137 A) were observed for the adaxial and abaxial leaf surfaces, respectively. When plants were irrigated with the nutrient solution, the color of the adaxial leaf surface was moderate olive green (RHS 137 A) to grayish olive green (RHS NN137 A), and the color of the abaxial surface was moderate yellow green (RHS 138 C) to light yellowish green (RHS 136D).

Performance

Little-leaf mountain mahogany plants available in the nursery are usually seed-propagated because they are easily propagated by seeds (Center for Water-Efficient Landscaping 2023). There is a need in the landscape industry for dwarf evergreen plants (e.g., *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown') (Fig. 1B–F). Its characteristics include a slow growth rate with heavy, intricate branching. The evergreen leaves are highly persistent and resistant to winter sun scald. Little-leaf mountain mahogany has never shown any susceptibility to insect pests in our studies. It is somewhat recalcitrant to propagation by cuttings, but rates of 10% to 97% have been achieved. It is susceptible to root rot in propagation.

Cercocarpus ledifolius var. *intricatus* 'DoubleDown' is readily transplanted, but its use in the landscape has been limited to date. It appears to do well in a dry, well-drained, weed-free environment and, therefore, it would be desirable in most low-water landscapes. When growing in a container, it can go for extended dry periods without showing drought stress. There is no commercially standard cultivar with which to compare this plant. This plant should be adaptable over a wide geographic area. Its native soil is a Mountmummy-Thesisters-Maryjane association, with the top 30.5 cm being extremely gravelly loam or 30.5 to 61.0 cm of extremely cobbly fine sandy loam on bedrock. It is a well-drained soil with slopes of 30% to 75%. Given

Table 6. Effect of wounding techniques on the root formation for terminal cuttings of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown'.[i]

	2021		2022	
Variable	Cut	Scrape	Cut	Scrape
Rooting (%)	20.3 b[ii]	42.2 a	14.3 b	96.9 a
No. of roots	3.0 a	4.1 a	2.9 a	3.4 a
Length of the longest root (cm)	1.4 a	2.3 a	4.8 a	3.9 a

[i] Terminal cuttings were wounded with cuts or scraped on one side before all cuttings were treated with 3000 mg·L^{-1} indole-3-butyric acid as talc-based Hormodin 2. This experiment was initiated on 2 Oct 2021 and on 22 Sep 2022, and ended on 10 Dec 2021 and on 22 Nov 2022.

[ii] The same letters within a row and year denote the lack of a significant difference between wounding treatments as computed using Tukey's method for multiplicity at $\alpha = 0.05$.

Table 7. Leaf chlorophyll a and b contents, plant height increment, number of shoots, and number of leaves of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' when irrigated with potable water or nutrient solution.[i]

Variable	Chlorophyll a (mg·g^{-1} fresh wt)	Chlorophyll b (mg·g^{-1} fresh wt)	Ht increment (cm)	No. of shoots	No. of leaves
Potable water	13.8 b[ii]	1.9 a	0.4 a	1.0 b	22.4 b
Nutrient solution	14.9 a	1.9 a	0.4 a	1.7 a	40.8 a
P value	<0.0001	0.53	0.95	0.0006	<0.0001

[i] This experiment was initiated on 18 Mar 2022 and ended on 25 Oct 2022.

[ii] Means with the same lowercase letters within a column are not significantly different among treatments by Tukey's method for multiplicity at $\alpha = 0.05$.

the elevation and latitude of the mother plant, it should be cold hardy in zones 2 through 6.

Cercocarpus ledifolius var. *intricatus* 'DoubleDown' also has potential as a novelty plant for bonsai production (Fig. 5). Bonsai is a horticultural art that develops artistically formed trees in ornamental containers. This art has been practiced for more than 1000 years in oriental cultures. To produce bonsai, plant specimens should be small and meet the aesthetic standards of bonsai. *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' is a dense, twiggy evergreen shrub with small leaves and dwarf habit. Its characteristics include a slow growth rate and limited apical dominance (Figs. 1B–F and 5). Following winter chilling, many lateral buds break, resulting in a profusion of new shoot growth, which can be trimmed or trained as desired. The new shoots are plastic and, when bent for 2 to 3 weeks, will retain the induced shape. In young plants, it produces vertical, horizontal, and cascading growth. The ratio of trunk size to overall plant size is high, providing an old, heavy-looking stem on fairly small plants. It is strongly evergreen and retains leaves even along the main stem. It is adapted to coarse, porous soil. As a young, rooted cutting, it will continue to produce new growth as long as it is kept under warm temperatures and exposed to long daylight hours. Such growth will generally be an extension of the terminal shoot, with lateral shoots developing primarily after chilling.

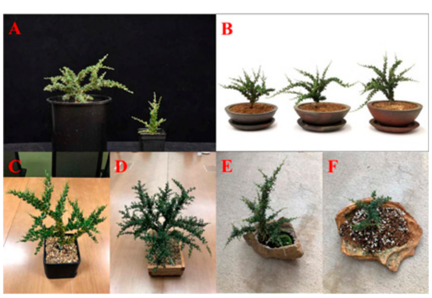

Fig. 5. Bonsai plants of *Cercocarpus ledifolius* var. *intricatus* 'DoubleDown' in containers. (**A**) The plant in the 3.8-L pot (left) is 18-months old, whereas the plant in the 0.5-L pot (right) is 6-months old. (**B–F**) Representative photos of bonsai plants grown in different containers or rocks. (**B**) Photo credit: Todd Hayes, Utah State University Ceramics Program.

Availability

Cercocarpus ledifolius var. *intricatus* 'DoubleDown' was originally collected from Clark County, NV, USA. This accession has been registered in the Utah State University Inventor Portal (www.ipso.usu.edu) and was approved for disclosure with Invention ID No. D20051. Information about plant materials, licensing, and propagation agreements can be obtained from L.R. (larry.rupp@usu.edu) or Y.S. (youping.sun@usu.edu) at Utah State University (Logan, UT, USA).

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