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REGISTRATION

Cultivar

Registration of 'Cedar Creek' switchgrass

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Abstract

'Cedar Creek' (Reg. no. CV-290, PI 700113) switchgrass (*Panicum virgatum* L.) was selected for increased winter survivorship for three cycles, using surviving plants from 'Kanlow'. The first two cycles were conducted at multiple locations in Wisconsin, and the third cycle was conducted at the Cedar Creek Ecosystem Science Reserve, East Bethel, MN. All seed production and increases were conducted by either Illinois State University or the University of Illinois. Field evaluations of the third-cycle population were conducted at five locations in Wisconsin between 2017 and 2021, located within USDA hardiness zones 3–5. Field experiments were planted in both 2016 and 2017. Averaged over the five locations and all trial years, Cedar Creek had 91% ground cover, compared with 96% for Cave-in-Rock, 95% for Shawnee, and 91% for Liberty. Biomass yield of Cedar Creek averaged 12.17 Mg ha^{-1}, which was 20% higher than Liberty, 30% higher than Cave-in-Rock, 31% higher than Shawnee, and 520% higher than Kanlow. Cedar Creek is a high-biomass lowland-type of switchgrass and is the first lowland-type adapted to USDA hardiness zones 3–5. Cedar Creek was released to the public by USDA-ARS in 2021.

1 | INTRODUCTION

Switchgrass (*Panicum virgatum* L.) was chosen in 1992 by the US Department of Energy as the model species for development of a perennial biomass crop in support of bioenergy production (McLaughlin & Kzsos, 2005; Sanderson et al., 2007). At the peak of activity, early in the 21st century, there was 12 switchgrass breeding programs in the United States and Canada. Because switchgrass is highly photoperiodic and each cultivar or ecotype is narrowly adapted to only a small number of hardiness zones (Vogel et al., 2005), each of these breeding programs had a regional focus, mostly working with locally adapted germplasm (Casler et al., 2012).

The USDA programs at Lincoln, NE, and Madison, WI, were the most significant exceptions to this rule. The Nebraska program was heavily focused on creating upland × lowland hybrids, combining the cold tolerance of the upland ecotypes with the high biomass and late flowering of the lowland ecotypes. Selection within some of these hybrids led to the development and release of the cultivar Liberty (Vogel et al., 2014). Conversely, the Wisconsin program has focused on collection of lowland germplasm from throughout the Gulf Coast and Southern Great Plains regions, focusing on growing these late-flowering accessions in USDA hardiness zones 3–5, followed by selection for survivorship following harsh winters (Poudel et al., 2020). 'Cedar Creek' (Reg. no. CV-290, PI 700113) represents the product of three cycles of selection for winter survivorship and recovery, derived from the cultivar Kanlow.

Abbreviations: ARL, Arlington; GC, ground cover; HAN, Hancock; Hyb, hybrid; Low, lowland; MSH, Marshfield; PDS, Prairie du Sac; SPN, Spooner; Up, upland.

2 | METHODS

2.1 | Breeding history

Drilled sward plots of Kanlow and numerous other cultivars were planted in 2008 at four locations in Wisconsin (Arlington, Hancock, Marshfield, and Spooner; shown in Table 1) in support of two published studies (Casler et al., 2014, 2018). Plots consisted of drilled rows approximately 15 cm apart with a seeding rate of approximately 6 kg ha^{-1} (500 seeds m^{-2}) of pure live seed. Because the two published studies used only a portion of the plots planted at each location, the remaining plots were available for use as selection nurseries.

Following significant winter mortality during the first two winters, a total of 37 surviving plants from Kanlow plots were selected. The 37 plants represented all survivors within a total area of 80 m^2 or a total number of approximately 40,000 pure live seeds planted (~0.001 selection intensity). The selection criteria were winter survivorship and winter recovery, as determined visually by choosing only plants with a minimum of 75% crown recovery approximately 10 days after initiation of spring growth. Selected plants were dug up, split into four clonal replicates, and transported to Normal, IL, in May 2010, where a polycross block was established. The design of the polycross block was a randomized complete block with four replicates, and plants were placed on a 1-m spacing. Ripe seed was harvested from each plant in September 2010. Seed was threshed and cleaned and then bulked in equal quantities to generate a single bulk population of seed, named WS10L (short for Wisconsin Switchgrass 2010 Lowland).

Seed of WS10L was planted into dedicated drilled sward plots in 2011, totaling 20 m^2 at each of three locations: Arlington, Marshfield, and Spooner, WI. Following significant winter mortality during the first winter, a total of 76 plants were dug up and transported to Normal, IL, in May 2012 for establishment of the second-cycle seed production nursery. Replication and design of the second-cycle polycross block were identical to that described for the first cycle.

Core Ideas

- Three cycles of recurrent selection for winter survivorship increased ground cover by 6.5 times over the parent cultivar Kanlow.
- Selection for winter survivorship increased biomass yield of the resulting population by 4 times over the parent cultivar Kanlow.
- Cedar Creek is adapted to USDA hardiness zones 3–5, the first lowland-type cultivar to be adapted to this region.

The second-cycle selection intensity was 76/30,000 = 0.0025. Ripe seed was harvested from each plant in September 2012. Seed was threshed, cleaned, and bulked in equal quantities to generate a single bulk population of seed, named WS12L (short for Wisconsin Switchgrass 2012 Lowland).

Seed of WS12L was shipped to Dr. James Eckberg at the University of Minnesota to support an evaluation of several diverse switchgrass ecotypes at the Cedar Creek Ecosystem Science Reserve, East Bethel, MN. Seed was germinated in a glasshouse during winter 2012/2013, and approximately 2200 seedlings were transplanted into a restored prairie ecosystem in April 2013 at a spacing of approximately 1 m between transplants. After significant winter mortality during the first two winters, a total of 24 surviving WS12L plants were dug up and transported to Dixon Springs, IL, in May 2015 (selection intensity = 0.01). Replication and design of the third-cycle polycross block were identical to that described for the first cycle. Ripe seed was harvested from each plant in September 2015. Seed was threshed, cleaned, and bulked in equal quantities to generate a single bulk population of seed, with the experimental name WS15L (short for Wisconsin Switchgrass 2015 Lowland). Seed was produced on this block again in 2016.

TABLE 1 Characteristics of the five locations used for selection and evaluation of Cedar Creek switchgrass.

Location	Latitude	Longitude	Hardiness zone	Soil type
	˚N	˚W		
Arlington	43˚18.00′	89˚21.15′	5a	Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll)
Hancock	44˚7.33′	89˚32.15′	4b	Plainfield loamy sand (mixed, mesic Typic Udipsamment)
Prairie du Sac	43˚21.13′	89˚45.27′	5a	Richwood silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll)
Marshfield	44˚38.65′	90˚8.08′	4a	Withee silt loam (fine-loamy, mixed, superactive frigid Aquic Glossudalf)
Spooner	45˚49.63′	91˚52.17	3b	Murrill silt loam (fine-loamy, mixed, mesic Typic Hapludult)

2.2 | Field evaluations

Seed of WS15L, produced in 2015, was used to establish simulated sward plots at four Wisconsin locations in May 2016 (Arlington, Hancock, Marshfield, and Spooner) (Table 1). Simulated sward plots consisted of 18 4-month-old transplants in a 3 by 6 arrangement, with a 30-cm spacing between adjacent plants and a 60-cm spacing between adjacent plots. The entire experiment had a total of 30 populations in four replicates and a randomized complete block design; more details are provided by Poudel et al. (2020). This experiment included Kanlow, WS12L, and WS15L as three of the 30 populations. Survivorship was scored on each plant following the first two winters, and biomass yield was measured on each entire plot following killing frost in 2017–2019 using a flail-type harvester with a 9-cm cutting height (Poudel et al., 2020).

Seed produced at Dixon Springs was planted in drilled sward plots at all five Wisconsin locations shown in Table 1 in May 2017. The 2017 experiments included Cave-in-Rock, Shawnee, and Liberty cultivars plus five additional experimental populations and WS15L arranged in a balanced lattice design with four replicates at each location. Plot size was 0.9 m by 2.0 m and consisted of five drilled rows and a seedling rate as described above. Plots were not fertilized with nitrogen. Biomass was harvested on each entire plot after killing frost in 2018 through 2021 using a flail-type harvester with a 9-cm cutting height. Dry matter determinations were made on a post-harvest grab sample of approximately 300–500 g. Samples were dried for 7 days at 60°C.

Data from the 2016 and 2017 field experiments were analyzed by linear mixed models with populations and cycles as fixed effects and locations and years as random effects (Littell et al., 1996). For each of the 2016 and 2017 groups of experiments, a separate analysis was conducted for each location, and a combined analysis across locations was conducted. The combined analysis included a heterogeneous errors model due to heterogeneous errors across locations (Littell et al., 1996). All interactions were treated as random effects. Years were treated as a repeated measure in all analyses using the compound symmetry covariance with or without heterogeneous errors, depending on which model was the better fit based on Akaike's information criterion (Littell et al., 1996). LSD values with $p = 0.01$ or 0.05 were used for all statistical comparisons.

3 | CHARACTERISTICS

Cedar Creek has retained the basic morphology and appearance of Kanlow. It is characterized by a relatively low stem density, large stem diameter, and the typical bluish tint to leaves and stems that is often observed for many lowland ecotypes. Flowering time of Cedar Creek was not altered by selection and generally occurs in late September in southern Wisconsin, but it seldom reaches flowering in northern Wisconsin due to early killing frost. Cedar Creek will not form viable seed in Wisconsin, in any natural field environment, due to the late-flowering trait.

Figure 1 shows direct and indirect responses to selection for winter survivorship, as measured after 3 years in simulated sward plots at several locations. Three cycles of selection were required to achieve improvements in performance sufficient to warrant renaming WS15L for release as Cedar Creek switchgrass (Figure 1). Whereas the first two cycles led to significant improvement in both survivorship and biomass yield, these populations were not sufficiently winter hardy for commercial release. The third cycle, conducted in east-central Minnesota, appeared to have unlocked sufficient additive genetic variability to generate a lowland-type cultivar that could be considered as adapted to USDA hardiness zones 3–5. Biomass yields of WS10L, WS12L, and WS15L (Cedar Creek) tracked closely with genetic increases in winter survivorship.

Cedar Creek was equal to Liberty in 3-year ground cover but slightly lower than the two adapted upland-type cultivars Cave-in-Rock and Shawnee (Table 2). Cedar Creek was significantly higher in biomass yield than all three check cultivars at Arlington and Prairie du Sac. At Hancock and Spooner, Cedar Creek was significantly higher in biomass yield than the two upland-type cultivars but was not different from Liberty. At Marshfield, where the experimental error rate was highest among the five locations, Cedar Creek was higher in biomass yield only compared with Kanlow. Averaged over the five locations, Cedar Creek was significantly higher in biomass yield compared with all four check cultivars: 20% higher than Liberty, 30% higher than Cave-in-Rock, and 31% higher than Shawnee (all $P < 0.05$).

4 | DISCUSSION AND CONCLUSIONS

The failure of the first two cycles (WS10L and WS12L) to have sufficient survivorship for commercialization parallels observations made from a 13-location set of field trials that covered a broader range of environments (Casler et al., 2018). That study showed the potential for significant improvements in adaptation of lowland ecotypes to the northern United States, demonstrating that winter survivorship is a heritable trait in switchgrass, but none of the lowland populations in that study was ready for commercialization. Another parallel between that study and the current one was the trend for reduced genetic expression at the most northern locations. The genetic improvements of biomass yield from Cedar Creek tended to be greater for the more southern locations (Table 2), which was also observed by Casler et al. (2018) on a broader geographic scale.

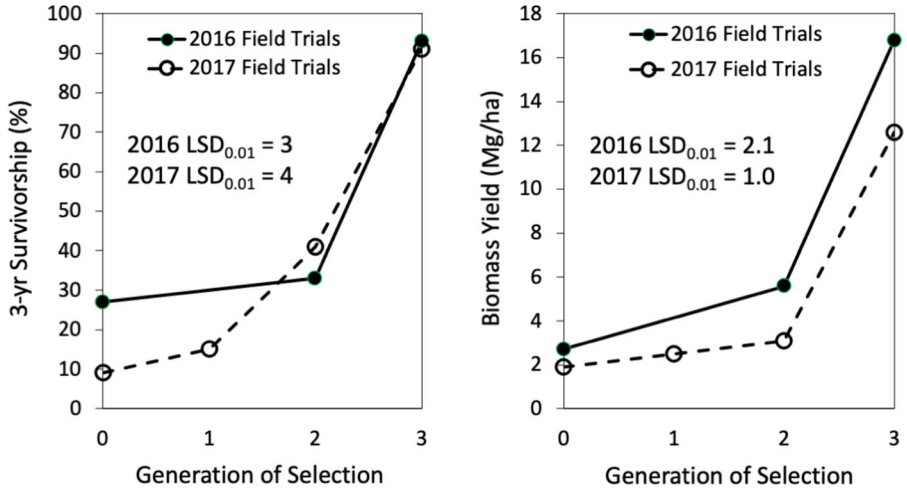

FIGURE 1 Trajectories of selection gains made from three cycles of selection for winter survivorship within the switchgrass cultivar Kanlow (Cycle 0) to create the cultivar Cedar Creek (Cycle 3): 3-year survivorship on the left and biomass yield on the right, each based on means over four locations for the 2016 trials or five locations for the 2017 trials.

TABLE 2 Mean ground cover and biomass yield for five switchgrass cultivars evaluated at five locations in Wisconsin in 2018–2021, averaged over all trials and years for each location.

			Biomass yield					
Cultivar	**Type**	**GC**	**ARL**	**HAN**	**PDS**	**MSH**	**SPN**	**Mean[a]**
		%	Mg ha^{-1}					
Cave-in-Rock	Up	96	11.93	5.04	11.37	9.45	8.56	9.27
Shawnee	Up	95	11.59	4.36	10.31	9.30	8.35	8.28
Liberty	Hyb	91	12.09	6.09	12.98	10.34	9.33	10.17
Kanlow	Low	10	2.67	1.23	2.29	2.77	0.87	1.97
Cedar Creek	Low	91	14.67	7.41	16.45	11.73	10.59	12.17
$LSD_{0.05}$		4	2.17	1.66	2.67	3.12	1.80	1.00

Abbreviations: ARL, Arlington; GC, ground cover; HAN, Hancock; Hyb, hybrid; Low, lowland; MSH, Marshfield; PDS, Prairie du Sac; SPN, Spooner; Up, upland.
[a]Mean over all five locations.

In conclusion, Cedar Creek represents the first lowland-type of switchgrass to be adapted to USDA hardiness zones 3–5 in the northern tier of the United States. This genetic improvement derives from cryptic genetic variability within the cultivar Kanlow, which originated near the Kansas–Oklahoma border in USDA hardiness zone 7. This represents a simple geographic expansion of the adaptation range for lowland switchgrass of 1300 km. The field trials reported herein were conducted for up to 4 years at up to five locations, suggesting that this genetic improvement has at least a minimum longevity of 4 years in situ, but anything longer than that cannot be predicted or warranted.

5 | AVAILABILITY

Cedar Creek was released to the public by the USDA in August 2021. As a public cultivar, anyone can request seed, and we ask that seed requests be sent simultaneously to three people: both authors and the USDA caretaker of the seed (dklee@illinois.edu, mdcasler@wisc.edu, john.raasch@usda.gov). Seed of Cedar Creek has been deposited with the USDA National Plant Germplasm System, Germplasm Resources Information Network (GRIN), and a small seed sample is available immediately after publication upon request from GRIN. Syn2 seed was produced in 2021 on a 2000-plant nursery established in 2018 in Champaign, IL. Additional Syn2 seed production is planned for 2022 and 2023.

AUTHOR CONTRIBUTIONS

Michael D. Casler: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **DoKyoung Lee**: Conceptualization; data curation; investigation; methodology; project administration; resources; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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