Fig. 3. Total chlorophyll content ($\text{mg}\cdot\text{liter}^{-1}$) of winter squash (*Cucurbita maxima* Duch. cv. *Delica*) treated with hot water at 50°C for 0, 3, 6, 9, and 12 min and stored at 10 (A) and 20°C (B) for 4, 8, and 12 weeks.

which fruits will maintain good appearance and less storage rots for up to 8 weeks, and thus can reach distant markets with better quality.

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Flowering and Seed Yield in Three Species of Prairie Plants

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Additional index words. *Tradescantia ohimensis*, *Dalea purpurea*, *Spartina pectinata*, native plants, establishment, flowering

Summary. Production of native seeds and seedlings for landscaping and restoration is an expanding horticultural industry in Minnesota, but seed yields of many species from wild stands are often small and vary widely in quality. In this work, we document phenological development and seed yield in cultivated and prairie-grown plants for *Tradescantia ohimensis* Raf. (Ohio spiderwort), *Dalea purpurea* Vent. (purple prairie clover), and *Spartina pectinata* Link (prairie cordgrass) at the Minnesota Landscape Arboretum. For *T. ohimensis*, seed yield under cultivation was significantly greater than in the prairie both seasons, with 2.5 g of seed recovered per plant in 1993. Under cultivation, seed yield of established *D. purpurea* was triple that of the prairie, yielding 34 seeds per inflorescence. *S. pectinata* grown under cultivation from seedlings or rhizome divisions produced seed in the first and second seasons, respectively, while plants in the prairie remained vegetative. Two-year-old seedlings produced 38 seeds per spike. Field cultivation of these native plant species resulted in increased seed yield and improved growth, while allowing phenological monitoring and the use of species-specific harvest practices.

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Increasing demand for native species for use in highway plantings, restoration, and landscaping projects has spurred the growth of the native wildflower and grass seed industry. Raising native plants from seed poses a challenge to growers who supply locally collected and produced native plants to an ever-increasing number of consumers. Seed yields of many species from wild stands are small, and vary in quality. One option is to grow plants for seed in cultivated stock plots, but we know little about the yield potential of these plants under a cultural regime. Cornelius (1950) documented yield for selections of seven species of native grasses in cultivation and yield for the same species in prairie remnants, but direct comparisons could not be made because of the logistics involved in cultivating several species, and climatic differences from location to location. Other research that has documented seed yield in prairie plants generally has compared different management regimes or natural disturbances within a prairie (Coffin and Lauenroth, 1992; Hartnett, 1991).

Still, some producers of native seeds are exploring the advantages of growing stock in small plots for better, more-uniform yields (Minnesota Dept. of Agr., 1993). Field cultivation of native plant species provides an opportunity to control inputs and competition, and to use species-specific harvest practices, making seed cleaning easier and resulting in higher seed purity. Because conditions that prevail during seed maturation influence seed dormancy and germination (Mayer and Poljakoff-Mayber, 1989), seed produced in the environment of a cultivated field might have greater germinability than seed harvested from the wild. However, a disadvantage to the cultivation of native plants is the potential for loss of genetic diversity through inadvertent selection.

Most native plant producers have some acreage under cultivation, ranging from 1 to 240 acres of forbs and/or grasses (Bohnen, 1994). However, half of them continue to harvest from remnant prairies for some of their needs. When members of the Minnesota Native Wildflower/Grass Producers Assn. and others were surveyed about production problems in general, their responses raised several questions concerning seed yield for three species in particular that often are har-

vested from remnant prairie (Bohnen, 1994). Growers noted that *Spartina pectinata* (prairie cordgrass), *Dalea purpurea* (syn. *Petalostemum purpureum*) (purple prairie clover), and *Tradescantia ohimensis* (Ohio spiderwort) (nomenclature follows Gleason and Cronquist, 1991) frequently produce low seed yields, often with low germinability as well.

We established field trials at the Minnesota Landscape Arboretum to compare seed yield of *Tradescantia ohimensis*, *Dalea purpurea*, and *Spartina pectinata* under cultivated field management vs. in a noncultivated managed prairie.

Methods and materials

Because native prairie plants are not common horticultural crops, some description of these three species is necessary to understand their growth and development. *Tradescantia ohimensis*, a member of the Commelinaceae, bears straplike leaves alternately on a succulent stem, with many vegetative shoots produced during the growing season. The bloom period is extended by the presence of numerous buds in each inflorescence. As a monocot, the floral parts are in 3s, and a seed capsule may contain up to six pitted, gray seeds, two per locule. Each blue flower is 2 to 3 cm across and lasts only a day, opening in the morning and shriveling by early afternoon (Runkel and Roosa, 1989).

Dalea purpurea is a deep-rooted, somewhat woody-stemmed member of the Fabaceae, with finely divided compound leaves often folded over at the edge (Gleason and Cronquist, 1991). The flowers are clustered in tight rose-purple cylindrical inflorescences or spikes, with each spike flowering basipetally. Lateral spikes are generally shorter than terminal spikes, and tend to begin flowering after the terminals.

Spartina pectinata is a warm-season rhizomatous grass of wet prairies that forms large clonal colonies (Runkel and Roosa, 1989). The coarse, sharp-edged leaf blades turn yellow in autumn. The flowering stems of *S. pectinata* may be 1 to 2 m tall, each bearing a stiff raceme with 10 to 20 upright branches (Hitchcock, 1951). Each branch of the raceme is a spike consisting of many sessile one-flowered spikelets (Soil Conservation Service, 1968).

Fifteen nonflowering plants each of *T. ohimensis*, *D. purpurea*, and *S. pectinata* were transplanted from established populations in the 20-year-old created Bennett/Johnson Prairie at the Minnesota Landscape Arboretum (lat. 44.52N, long. 93.37W) in early June 1992. Transplants were moved to a cultivated field plot on the Arboretum grounds within 1 mile of the prairie on the same day that they were dug, and planted in single blocks of three $\times$ five plants spaced 30 cm on center. Additional individuals were transplanted at the same time to account for losses during establishment. Another 15 undisturbed plants were identified and marked in the Bennett/Johnson Prairie for comparison of seed yields. All individuals of each species that were taken or marked came from the same area. By using transplants, we hoped to reduce potential differences between and within treatments due to population differences and to individual plant size.

We added one additional population of *Spartina pectinata* seedlings to the cultivated plot in June 1992 to allow comparison the following year between second-season seedlings and second-season divisions. These seedlings were produced from seeds collected on 10 Sept. 1991 in Polk Co., Minn., and germinated in the greenhouse in Dec. 1991.

The establishment season (Summer 1992) was generally wet and cool, and irrigation was used sparingly, as needed. A 10N-4.3P-8.3K inorganic granular fertilizer was applied to the cultivated plot in early July 1992 at the rate of 24.4 g·m⁻² (5 lb N/1000 ft²). The area was hand-weeded. In 1993, a black woven weed barrier was laid down around *D. purpurea* and *T. ohimensis* plants to reduce weed growth. Because of its rhizomatous growth habit, the weed barrier could not be placed around *S. pectinata*. The 1993 growing season was also unusually wet and cool (Bohnen, 1994), and irrigation was not necessary.

Ongoing management in the Arboretum's prairie consists of a controlled burn every 2 or 3 years. The prairie was not burned during the 1992 season, but was burned thoroughly in Apr. 1993.

Soil in the cultivated plot was fine-textured, with high organic matter and a pH of 7.4. The soil in the *Spartina*, *Tradescantia*, and *Dalea* ar-

eas in the prairie was of medium texture, with high organic matter and a pH of 6.4 to 6.7.

We measured seed yield both by number and weight. In addition, we documented number of inflorescences per plant, plant height, and above-ground dry weight as potential predictors of yield. Dry weight of *Tradescantia* was sampled at the end of the growing season by collecting every above-ground shoot from each plant in the study. Above-ground dry-weight samples for *Spartina* consisted of the three stems nearest the stake marking each plant in the cultivated plot and in the prairie. We could not measure end-of-season dry weights for *Dalea* because some leaf drop occurred before the seed was ready to harvest. Significant differences ($\alpha = 0.05$) between cultivated and prairie treatments were identified using independent sample *t* tests.

Results and discussion

***Tradescantia ohienensis*.** Plants in cultivation established quickly and surpassed in size and flowering those in the prairie treatment during the first year (Table 1). For both seasons, mean above-ground dry weight was significantly greater in cultivation than in the prairie. Correspondingly, both mean number of shoots per plant and mean number of inflorescences per plant were greater each year under cultivation than in the prairie treatment.

Anthesis began in both treatments in early to mid-June. The bloom period lasted 16 weeks under cultivation and was longer than that of the prairie in both years. In 1992, the mean number of open flowers peaked at the end of August, probably delayed by transplant shock (data not shown). In 1993, the mean number of open flowers under cultivation peaked at 25 per plant during the week of July 16 (Fig. 1). The peak period of seed recovery began 3 weeks later in 1993, lasting from 5 to 26 Aug.

In 1993, the mean weight of total recovered seeds per plant based on weekly sampling was significantly greater under cultivation than in the prairie (Table 1). "Recovered seed" underestimates the actual yield because many seeds were dropped or dispersed between the weekly sampling dates. Cultivated plants also showed a significantly greater total potential flower number, as determined by a comprehensive sampling of buds and barren or pollinated flowers. In 1993, in the prairie, the mean number of total potential flowers per plant was 13, while under cultivation the mean number of potential flowers per plant was 1807. Potential seed number was estimated by counting the number of expanded capsule locations. This figure gives a high estimate of actual seed production because, in some instances, the locular position had expanded, although the seed had not fully devel-

oped. Therefore, actual mean yield during the second season under cultivation was somewhere between 749 and 1827 seeds per plant over the entire season.

Lower yield in the prairie plot could be attributed to resource limitation. In the prairie, where competition between grasses and other forbs for light, water, nutrients, and space is intense, *T. ohienensis* grew tall and did not branch or produce basal shoots. Each flowering stem terminated in one or at most two inflorescences. In 1993, 27% of the plants had only vegetative shoots and did not develop flowering stems at all. The percentage of plants that flowered was greater in 1993 than it was in 1992, perhaps due in part to the effect of the April burn. Conversely, all plants under cultivation had several flowering stems that frequently branched and terminated in many closely clustered inflorescences. *T. ohienensis* under cultivation showed an indeterminate growth habit, with new shoots and inflorescences developing until frost. Plants in the prairie began to senesce by early August.

Pollinator frequency appeared to be an additional limiting factor in seed production. During weekly sampling, pollinator activity was not noticed in the prairie plot. However, honeybees of the Order Hymenoptera, Superfamily Apoidea (J. Fetzer, personal communication) were seen regularly in the cultivated plot. Flower flies of the Order Diptera, Family Syrphidae, also were seen daily.

Daily anthesis seems to be weather-dependent, as shown by the dips in the line graph for number of open flowers (Fig. 1). However, this did not seem to influence the number of seeds recovered under cultivation. When harvesting in the prairie, timing is critical because fewer flowers and thus fewer seeds are produced. Information about number of seeds developed, seed dispersal, and number of open flowers might be used to predict better an optimum time to harvest *T. ohienensis*. Under cultivation, it may be possible to make two harvests using this information.

During these trials, we were able to sweep dispersed seed up from the weed barrier used around the plants. It might be possible to harvest in this manner from a small cultivated plot by using a small shop vacuum. One possible disadvantage to this technique is

Table 1. *Developmental phenology, growth, and seed yield of Tradescantia ohienensis grown under cultivation vs. managed prairie*².

Item	1992		1993	
	Cultivation	Prairie	Cultivation	Prairie
Shoot emergence	---	4 June	21 Apr.	14 May
Visible flower buds	16 June	23 June	2 June	10 June
First anthesis	23 June	29 June	10 June	20 June
First mature seed capsule	29 July	21 July	30 July	6 Aug.
End of bloom period	14 Oct.	29 July	1 Oct.	20 Aug.
Shoot dry weight/ plant (g)	30.3 ± 5.4*	1.0 ± 0.2	32.9 ± 7.7*	1.8 ± 0.4
No. shoots/plant	10.5 ± 0.9*	2.0 ± 0.4	16.1 ± 2.2*	2.0 ± 0.3
No. inflorescences/ plant	22.1 ± 3.8*	0.3 ± 0.2	49.3 ± 10.4*	1.1 ± 0.2
No. recovered seeds/ plant	114.1 ± 35.0*	0.3 ± 0.3	749.1 ± 207.3*	0.2 ± 0.2
Seed weight/plant (g)	---	---	2.5 ± 0.7*	0.001 ± 0.001
No. mature seeds capsules/plant	---	---	709.3 ± 158.8*	0.1 ± 0.1
No. buds and flowers	---	---	1775.8 ± 379.6*	12.9 ± 2.7

²Mean ± 1 SE, n = 15.

³No data.

*Significantly greater than the same-year prairie mean at P ≤ 0.05.

Fig. 1. Number of open flowers and recovered seeds per plant per day for *Tradescantia ohiensis* under cultivation; $n = 15$. Plants were sampled weekly from 1 June to 15 Oct. 1993.

the potential for induction of secondary dormancy in the seeds if left too long on the black heat-absorbing weed barrier. A synthetic mulch with a light-colored upper surface might be more appropriate.

***Dalea purpurea*.** This species, sensitive to disturbance, suffered some loss upon transplanting. For most individuals, the stems died back then resprouted from latent buds near the base. This regrowth resulted in plants with a spreading habit the first season. In 1993, their growth habit was upright and similar to that of the plants in the prairie treatment. Above-average rainfall contributed to an outbreak of the fungal organisms *Pythium* and

Rhizoctonia in 1992, followed by deer and rabbit damage in 1993, reducing the number of plants sampled in 1993 to four in the cultivated plot and eight in the prairie. Because some plants under cultivation were only partially damaged by grazing, most of the *Dalea* seed yield data were analyzed on a per-inflorescence basis rather than whole plant.

In both seasons, flower spikes were visible in the prairie about a week earlier than in the cultivated plot (Table 2). Both the beginning and end of anthesis occurred earlier in the prairie treatment as well. Seed development in 1992 in the prairie took ≈ 15 weeks from first anthesis to seed maturity.

No seed was harvested from the cultivated plot in 1992; only six of the 15 plants under cultivation developed inflorescences the first year. The transplants flowered later and consequently did not have fully matured seeds before the plants were killed by a hard frost in November.

In 1993, seed in the cultivated plot was harvested about 2.5 weeks after the prairie plot. Mean number of inflorescences initiated per plant in 1993 was not significantly different between treatments, but not all of these developed into flowering, seed-producing inflorescences. The total number of inflorescences that flowered in 1993 could only be documented for the prairie treatment because of the grazing damage in the cultivated treatment. However, average inflorescence weight in the cultivated plot was significantly greater than in the prairie. Seed weight and number per inflorescence also showed a 3-fold increase under cultivation. Even with rabbit damage to individuals, the cultivated plants still surpassed those of the prairie in total seed weight per plant.

A larger percentage of the inflorescences initiated probably developed and flowered in the cultivated plot in response to greater resource availability. Pollinator frequency and efficiency also may have been factors supporting increased seed set. Honey bees and sweat bees (not identified to species) were seen on inflorescences of *D. purpurea*, and bumblebees also were noted in the cultivated area. Weevils, a chewing insect, were abundant on both stems and inflorescences in both treatments throughout the season, although no damage was noted.

***Spartina pectinata*.** By October of the establishment year, transplants were producing tillers. By the end of the 1993 season, mean dry shoot weight of the seedlings and divisions was significantly greater than in the prairie treatment (Table 3).

Spartina pectinata did not flower in either the prairie or among the cultivated divisions in 1992. Seed production for native warm-season grasses during 1992 was poor overall in Minnesota according to the native wildflower and grass producers, probably due to unseasonably cool temperatures. Even in more-seasonable years, however, seed production by *S. pectinata* is sporadic. However, flow-

Table 2. *Developmental phenology, growth, and seed yield of Dalea purpurea grown under cultivation vs. managed prairie in 1993².*

Item	Cultivation	Prairie
Spikes began to form	9 July	2 July
First anthesis	6 Aug.	30 July
Last anthesis	1 Oct.	2 Sept.
Hand-harvest of seeds ³	26 Oct.	8 Oct.
No. inflorescence initiated/plant	35.0 ± 7.2 ^{NS}	29.1 ± 4.8
Weight/inflorescence (g)	0.36 ± 0.03*	0.25 ± 0.02
Seed weight/inflorescence (g)	0.043 ± 0.005*	0.015 ± 0.003
No. seeds/inflorescence	33.5 ± 3.8*	11.5 ± 2.3
Seed weight/plant (g)	0.49 ± 0.16 ^x *	0.22 ± 0.05
No. seeds/plant	379.8 ± 119.5 ^x *	173.4 ± 47.3

²Mean ± SE; cultivated n = 4, prairie n = 8.

³By this date, the florets had turned from green to gray and could be stripped easily from the spike.

^xBased on incomplete sampling of the four individual plants.

^{NS}*Nonsignificant or significantly greater than the prairie mean at P ≤ 0.05.

Table 3. *Growth and seed yield in 1993 of Spartina pectinata grown under cultivation and in managed prairie².*

Item	Prairie	Cultivated divisions	Cultivated seedlings
Dry weight of three shoots (g)	8.5 ± 0.5 ^y	22.5 ± 2.5 ^x	24.0 ± 3.0 ^{y,NS}
No. inflorescences/plant	None	4	10
No. spikes/inflorescence	None	16.1 ± 1.1	18.5 ± 1.0 ^{NS}
Weight/spike (g)	None	0.11 ± 0.01	0.17 ± 0.02*
No. spikelets/spike	None	46.2 ± 1.8	59.4 ± 2.5*
No. seeds/spike	None	13.2 ± 2.2	38.3 ± 5.0*

²Mean ± 1 SE, n = 10, except as indicated.

^yMean ± 1 SE, n = 13.

^xMean ± 1 SE, n = 13.

^{NS}*Nonsignificant or significantly greater than division mean at P ≤ 0.05.

ering and seed production did occur in the seedlings in 1992, the same season they were planted. The divisions flowered and produced seed in 1993, the second season under cultivation. The prairie plants did not flower either year of this study. For a clonal plant such as this grass, various environmental factors may determine the ability of a plant to flower and produce seed. Producers have observed that seed production occurs at the outside edge of a *Spartina* population. Perhaps this grass, like a clump of old iris, needs division to rejuvenate the plant and promote flowering.

Mean number of inflorescences per plant was greater among the seedlings than the divisions, but the mean number of spikes per inflorescence was not significantly different. However, other yield components, such as mean weight per spike, mean spikelet number per spike, and mean number of filled spikelets per spike, were significantly greater for seedlings than for divisions. The differences in second-year seed yield between the seedlings

and divisions in cultivated treatments could be attributed to either propagation or population differences. Further research into the use of young stands for seed production is needed.

Insect activity was not noticed on *S. pectinata* during the growing season, but a large number of seed bugs of the Order Hemiptera, Family Lygaeidae (J. Fetzer, personal communication), were discovered in dry-weight samples. Seed damage in *S. pectinata* by chewing insects was noted as a problem by one commercial producer who has frequently found holes chewed through the inflorescence (A. Wade, personal communication).

Conclusions

Cultivation can significantly increase seed yield for *T. ohimensis* and *D. purpurea*, and perhaps for *S. pectinata*. Resource limitation in the prairie may influence seed yield by limiting resources available for reproductive as well as vegetative efforts. This was especially evident for *T. ohimensis*, which, under cultivation, produced eight times

as many shoots per plant as in the prairie. Improved yield under cultivation for *D. purpurea* appeared to be more a result of increased seed set per inflorescence than increase in vegetative growth. The *S. pectinata* trial suggests that yield can be increased in young stands. Equally important, cultivation may increase reliability of seed set, enabling native seed producers to keep pace with increasing demand. In addition, because it reduces dependence on prairie remnants, production of seed from stock plots may be a more ecologically sound method of supplying seed to both private and public entities interested in environmentally sound landscapes.

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