

# Strip-tillage renovation of intermediate wheatgrass (*Thinopyrum intermedium*) for maintaining grain yield in mature stands

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## Preliminary Report

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## Abstract

Kernza® intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & Dewey], the first perennial grain crop to come to market in North America, can provide a number of ecosystem services when integrated into cropping systems that are dominated by annual grain crops. However, grain yield from Kernza is lower than comparable annual cereal crops such as wheat and oats. Also, although Kernza is a long-lived perennial that can persist for decades, grain yield tends to decline over time as Kernza stands age leading most farmers to replant or rotate to a different crop after 3–5 yrs. Increased intraspecific competition as stand density increases with age has been reported to cause grain yield declines. We investigated the effect of strip-tillage applied at two different timings, between the third and fourth grain harvests, from a Kernza stand in upstate New York. Strip-tillage applied in late fall as plants were entering dormancy increased grain yield by 61% when compared to the control treatment without strip-tillage. However, total crop biomass was not reduced resulting in a greater harvest index for the fall strip-tillage treatment. Strip-tillage applied before stem elongation the following spring reduced overall tiller density and total crop biomass but did not impact tiller fertility or grain yield compared to the control treatment without strip-tillage. Increased grain yield in the fall strip-tillage treatment was due to an increase in the percentage of tillers that produced mature seedheads. This suggests that grain yield decline over time is at least partially caused by competition between tillers in dense stands. Results support further research and development of strip-tillage and other forms of managed disturbance as tools for maintaining Kernza grain yield over time.

## Introduction

Perennial grain crops have the potential to produce staple foods and forage for livestock while mitigating many of the environmental externalities of annual grain production (Pimentel *et al.*, 2012; Crews *et al.*, 2018). Kernza® is a variety of intermediate wheatgrass (*Thinopyrum intermedium* Barkworth & Dewey) bred for grain production by researchers at The Land Institute, Salina, Kansas, USA (DeHaan *et al.*, 2018). Intermediate wheatgrass is a rhizomatous perennial grass native to the Caucasus region of Eurasia that has historically been used as a forage crop due to its high biomass production and good forage quality (Vogel and Jensen, 2001; Hendrickson *et al.*, 2005). Intermediate wheatgrass was selected for domestication as a perennial grain crop because of its relatively large seed size, favorable agronomic characteristics (i.e., lower shattering, more uniform height, more synchronous maturation) and better flavor profile than other candidate perennial grasses (Wagoner, 1990).

Increasing crop diversity in agroecosystems can restore ecosystem services and improve production efficiency (Asbjornsen *et al.*, 2014). This approach is viewed as an important component of broader changes to food systems that are necessary to ensure global nutritional security while maintaining or enhancing the natural capital that sustains agricultural production (Foley *et al.*, 2005). Development of intermediate wheatgrass as a perennial grain crop is largely motivated by its ability to contribute ecosystem services including enhanced soil health and water quality (Culman *et al.*, 2013; Jungers *et al.*, 2019), and the potential for soil carbon storage to mitigate anthropogenic climate change (Sprunger *et al.*, 2017, 2019; Pugliese *et al.*, 2019). These characteristics have also motivated food industries to develop products that incorporate Kernza as part of their corporate sustainability strategy (Lubofsky, 2016; Karnowski, 2017).

Despite advances in the development of Kernza as a perennial grain crop, low grain yields compared to annual small grains continue to be a potential barrier to adoption (Hunter *et al.*, 2020a). While adoption may not be wholly dependent on economic returns for farmers motivated by innovation and environmental benefits, crop productivity and profit margins are major factors in farmer decision-making (Marquardt *et al.*, 2016; Lanker *et al.*, 2019; Wayman *et al.*, 2019). Currently, Kernza grain yields range between 500 and 1700 kg ha<sup>-1</sup>

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at first harvest and then decline in subsequent years (Culman *et al.*, 2013; Jungers *et al.*, 2017; Dick *et al.*, 2019; Pugliese *et al.*, 2019; Hunter *et al.*, 2020a). Farmers report that developing crop management techniques that maintain yields over time is a top priority for research (Lanker *et al.*, 2019). Management interventions to improve grain yield in young stands and maintain yield as stands age have included crop defoliation after harvest, either by mowing (Pugliese *et al.*, 2019; Hunter *et al.*, 2020a) or grazing (Dick *et al.*, 2019), intercropping with legumes (Tautges *et al.*, 2018; Favre *et al.*, 2019), and increasing row spacing (Hunter *et al.*, 2020a). These efforts have had mixed results, with most showing yield benefits for the first few harvests but little progress toward sustaining yields in more mature stands. A recent study by Bergquist (2019) examined the use of banded herbicide applications, inter-row cultivation, inter-row burning and mowing to manage a Kernza stand in its third and fourth years of growth. Inter-row cultivation during the fall and herbicide applications during the spring after the second and third harvests resulted in the highest grain yields at the fourth harvest, but these yields were not statistically different from the control treatment.

Based on observations from previously cited research on Kernza stand management, it is likely that yield decline in Kernza stands over time is at least partially due to intraspecific competition that causes reduced seed production. Possible mechanisms for yield declines include (a) density-dependent interactions in the rhizosphere that decrease resource allocation to seed production (Tautges *et al.*, 2018), (b) changes in light quality at the crown that reduce reproductive tiller initiation or trigger light avoidance syndrome (Jungers *et al.*, 2017), and (c) water or nutrient limitation during critical periods of growth and reproduction (Tautges *et al.*, 2018; Hunter *et al.*, 2020b). Alternatively, shifts in whole-plant resource allocation from competitive to stress-tolerant strategies as plants age (Jaikumar *et al.*, 2016) may impose physiological limits on seed production in older stands, but stand-thinning could overcome these limits by stimulating new growth. These observations also suggest that yield declines with stand age are not caused by resource limitations across the entire stand, because total biomass production is generally maintained or increases from season to season, while harvest index declines.

Mechanical stand thinning can maintain seed yield over five harvests in intermediate wheatgrass forage varieties (Canode, 1965) and there have been calls for management research to focus on reducing intra-stand competition (Bergquist, 2019; Hunter *et al.*, 2020a). Here we report on an experiment using deep, narrow strip-tillage to disturb the root zone of a Kernza stand at two different times between the third and fourth grain harvests: in late fall when plants are entering dormancy and in early spring prior to stem elongation. The objective of this research was to determine whether strip-tillage increases grain yield of Kernza at the subsequent harvest. We hypothesized that strip-tillage would reduce tiller density but would increase resource allocation to seed production, measured as harvest index. Total biomass production and yield components were also measured.

## Methods

### Experimental design

This experiment was established in a field of Cycle 3 Kernza® intermediate wheatgrass from The Land Institute's breeding program, planted on August 26, 2014 at the Musgrave Research Farm

**Table 1.** Field operation dates from Kernza planting in August 2014 to sampling in August 2018

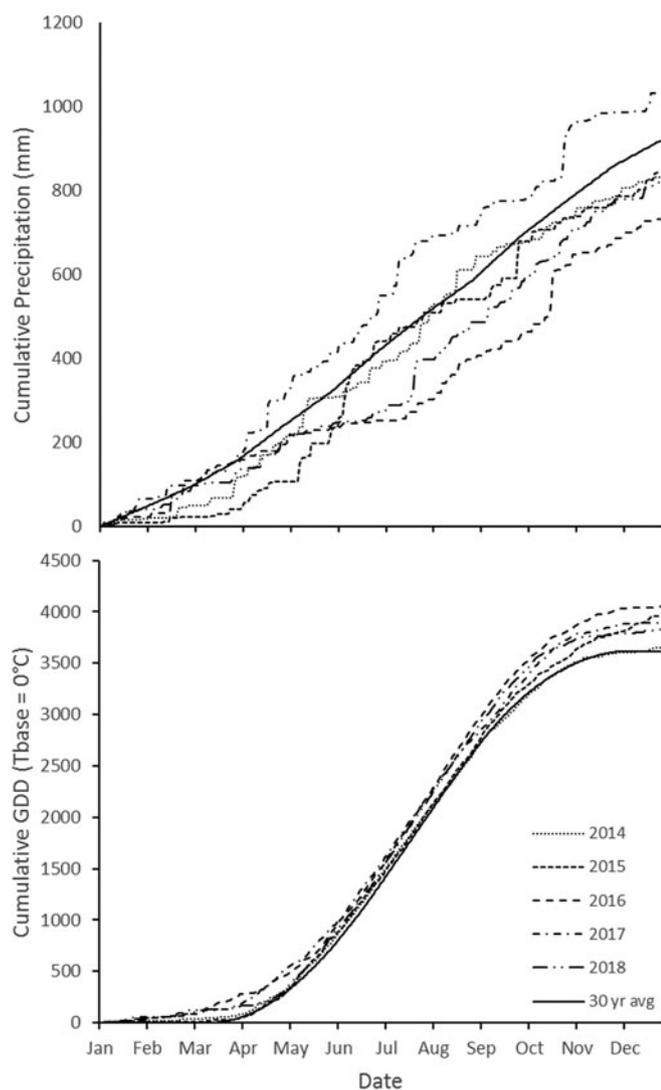
Date	Field operations
August 16, 2014	Field planted in 19 cm rows at 16.8 kg ha <sup>-1</sup> seeding rate
May 4, 2015	Fertilizer applied to supply 74 kg N ha <sup>-1</sup>
September 15, 2015	First grain harvest from the field
October 1, 2015	Straw is flail chopped to 10 cm height and removed from field
May 9, 2016	Fertilizer applied to supply 74 kg N ha <sup>-1</sup>
September 24, 2016	Grain harvest and straw removal
April 19, 2017	Fertilizer applied to supply 74 kg N ha <sup>-1</sup>
April 24, 2017	Harmony Extra SG, Banvel and Barrage herbicides applied to manage <i>Cirsium arvense</i>
August 28, 2017	Grain harvest and straw removal
October 20, 2017	Fall strip-tillage treatment applied
April 24, 2018	Fertilizer applied to supply 74 kg N ha <sup>-1</sup>
May 9, 2018	Spring strip-tillage treatment applied
August 31, 2018	Quadrat samples collected

in Aurora, New York, USA (42.7222N, 76.6636W). Field operations conducted between the field being planted and data collection are summarized in Table 1. Soil type at the site is Honeoye silt loam with a pH of 7.5 and 3.2% organic matter. Mean annual temperature was 9.1°C and mean annual precipitation was 918 mm for the most recent NOAA 30-yr climate averages (1981–2010), but annual temperatures tended to be higher and precipitation lower between 2014 when Kernza was planted and 2018 when the experiment was conducted (Fig. 1). The field was planted at a seeding rate of 16.8 kg ha<sup>-1</sup> in 19-cm rows using a John Deere No-Till Grain Drill model 1590. A tank mix of Harmony Extra SG (11.7 g ha<sup>-1</sup> thifensulfuron-methyl and 5.8 g ha<sup>-1</sup> tribenuron-methyl), Banvel (140.1 g ha<sup>-1</sup> dimethylamine salt of dicamba) and Barrage (288.1 g ha<sup>-1</sup> 2,4-D ester) was applied to the entire field on April 24, 2017 to manage an expanding population of Canada thistle [*Cirsium arvense* (L.) Scop.]. Grain was harvested and straw removed between late August and early September in 2015, 2016 and 2017.

The experiment was set up as a randomized complete block design with three treatments replicated five times. Strip-tillage treatments were applied using an Unverferth Zone-Builder Subsoiler Model 122 (Figs. 2 and 3). Treatments were: (1) strip-tillage on October 20, 2017 after substantial post-harvest regrowth ('fall strip-tillage'); (2) strip-tillage on May 9, 2018 after green-up but prior to stem elongation ('spring strip-tillage'), (3) and an untreated control that had not been tilled or cultivated since the field was planted ('control'). Plots measured 4.6 m wide by 24.4 m long. The entire field was top-dressed with a 50:50 mix by weight of ammonium sulfate (21-0-0) and urea with nitrogen inhibitor (45-0-0) at a rate of 224 kg ha<sup>-1</sup> on April 24, 2018. Similar fertilizer applications were made from 2015 through 2017.

### Data collection

Data were collected during August 2018 at physiological grain maturity, coinciding with the fourth grain harvest from the



**Fig. 1.** Cumulative growing degree days ( $T_{base}=0^{\circ}\text{C}$ ) and precipitation for each of the 5 yrs between Kernza planting in 2014 and the fourth grain harvest in 2018 reported in this study. The most recent NOAA 30-yr climate averages (1981–2010) are included to provide context.

field. Biomass was harvested by hand from two  $0.5\text{ m}^2$  quadrats in each plot on August 31. One quadrat was placed in a representative location in each of the north and south halves of the plot selected to avoid edge effects. Within each quadrat, all plant tissue was clipped at the soil surface and separated into crop or weed in the field. Weed species present were recorded for each plot. Crop biomass was separated into stems and seedheads in the field and both were counted. All biomass samples were then dried at  $65^{\circ}\text{C}$  for a minimum of 5 days before weighing. Seedhead samples were further processed to assess hand-harvested yield and components of yield. Twenty seedheads were randomly selected from each sample to be hand threshed and the grain dehulled, with seedhead length, spikelet count, floret count and seed count all recorded for these subsamples. The remaining seedheads from each sample were then threshed and dehulled with a hand deawner/debearder (Hoffman Manufacturing Inc., Corvallis, Oregon, USA). From these data, the percentage of tillers that were fertile (i.e., produced a seedhead), harvest index and thousand kernel weight were also calculated. Non-seed biomass separated from seedheads during

this process was added to stem biomass to obtain a value for total aboveground vegetative biomass for each sample. All grain yields reported were dehulled and corrected to 13% market moisture content.

### Data analysis

All data were analyzed using one-way ANOVA in R version 3.5.3 (R Core Team, 2019). The lmer function from the lme4 package was used for linear mixed-effects models for each response variable with tillage treatment as the fixed effect and block as a random effect. ANOVA assumptions were checked using the leveneTest function from the car package to confirm the homogeneity of variance and the shapiro.test function from the stats package to confirm that residuals were normally distributed. Pseudo  $R^2$  values and likelihood-ratio tests were calculated to assess model goodness-of-fit using the nagelkerke function from the rcompanion package. Post-hoc comparisons of marginal means using Fisher's protected LSD were conducted using the marginal, CLD and pairs functions from the lsmeans package. All tests used  $\alpha = 0.05$  as the cutoff for significant effects.

### Results

Fall strip-tillage increased grain yields compared with spring strip-tillage and control treatments (Table 2). Dehulled grain yield from the fall strip-tilled treatment increased 61% ( $P = 0.025$ ) relative to the control treatment. Total tiller density  $\text{m}^{-2}$  was marginally reduced by 24% in the fall strip-tillage treatment when compared to the control treatment ( $P = 0.058$ ). Spring strip-tillage reduced tiller density to a greater extent, with tiller counts 29% lower ( $P = 0.030$ ) than the untilled control. Stand density was similar between fall and spring strip-tillage treatments ( $P = 0.679$ ). Fertile tiller density (i.e., tillers bearing mature seedheads  $\text{m}^{-2}$ ) was highest in fall-tilled plots, 43% higher than the control ( $P = 0.035$ ) and 86% higher than the spring-tilled plots ( $P = 0.005$ ). Thus, the overall effect of the fall strip-tillage treatment was to increase tiller fertility (i.e., the percentage of tillers that produced a mature seedhead) from 19% in the control treatment to 35% in the fall strip-tillage treatment ( $P = 0.003$ ), leading to an increased grain yield after fall strip-tillage. Tiller fertility in the spring strip-tillage treatment was similar to the control treatment ( $P = 0.9067$ ).

Total crop biomass was similar between fall strip-tillage and control treatments ( $P = 0.3579$ ) at around  $7000\text{ kg ha}^{-1}$ . Spring strip-tillage reduced crop biomass by 27% ( $P = 0.005$ ) compared to the control treatment. There were no differences between treatments for yield components including counts of spikelets, florets or seeds per seedhead, or thousand kernel weight (Table 2). Harvest index was higher in the fall strip-tillage treatment than the control treatment ( $P = 0.0129$ ) due to the combination of higher grain yields and marginally lower total crop biomass production. Harvest index for spring-tilled plots was intermediate between, and similar to, the harvest index for both the fall-tilled and the untilled control plots. Weed biomass was low across the experiment and no differences were observed between treatments.

### Discussion

Strip-tillage in the fall substantially increased grain yield in the subsequent harvest, demonstrating that stand thinning can improve grain yields in older Kernza stands. Reducing overall



**Fig. 2.** Strip-tillage treatment being applied using Unverferth Zone Builder Subsoiler Model 122.

stand density, and likely intraspecific competition, appears to have allowed the remaining *Kernza* plants to grow more vigorously and produce more seedheads per unit area given enough time between disturbance and harvest. Strip-tillage treatments did not affect spikelet and floret counts per seedhead at harvest, however, indicating that differences in seed production were not driven by differences in inflorescence size that have been reported in other perennial grasses (Abel *et al.*, 2017). Even strip-tillage in the spring reduced competition between reproductive tillers as there was no difference in yield despite lower stand density compared to the control. Similar effects on seedhead density were reported in previous work using stand thinning to stimulate seed production of other perennial cool-season grasses. In a study using Kentucky bluegrass (*Poa pratensis* L.), Evans (1980) found edge effects affecting panicle density, with higher panicle density closer to areas where sections of row had been removed after seed harvest and lower density in areas further from disturbance, suggesting competition for light and space decreased floral induction. The disturbance caused by strip-tillage is likely to have altered some environmental conditions, including light quality, that influence floral induction, but other factors such as photoperiod and temperature are more seasonally dependent (Kalton *et al.*, 1996). Stand-thinning via strip-tillage after harvest could also

increase seed production in the following year by stimulating new growth that has a higher capacity for photosynthesis and carbon assimilation during seed development, but may have lower tolerance of extreme cold and other abiotic stress (Jaikumar *et al.*, 2016). Tillage practices may also influence soil nutrient availability by altering soil conditions and stimulating decomposition of soil organic matter (Gómez-Rey *et al.*, 2012), but this effect was not examined in this experiment.

Differences between the fall and spring strip-tillage treatments indicate that the timing of disturbance used for stand thinning is important. In this experiment, spring-tillage reduced overall stand density by a similar amount as fall-tillage, but crop biomass production, tiller fertility and grain yields were lower after spring-tillage indicating lower crop vigor after disturbance in the spring. Previous research on the impact of spring forage harvest timing on intermediate wheatgrass tiller persistence found that disturbance prior to stem elongation was associated with lower tiller mortality than disturbance later in the growing season (Hendrickson *et al.*, 2005). It is possible that disturbance after plants break dormancy in the spring is not conducive to seed production, either due to added stress during a critical period of growth or incompatibility with plant phenology. The annual reproductive cycle of intermediate wheatgrass begins with tiller



**Fig. 3.** Soil disturbance after strip-tillage with Unverferth Zone Builder Subsoiler Model 122.

development during regrowth after harvest, followed by reproductive tiller induction during overwintering, and floral development the following spring (Majerus, 1988; Heide, 1994; Cattani and Asselin, 2018). Disturbance at later stages of this process would therefore have greater potential to reduce fertile tiller density as there would be less opportunity for reproductive tiller replacement even if resources were otherwise abundant. Some perennial grasses are able to produce new reproductive tillers in the spring after vernalization, but these tillers tend to be smaller and produce fewer seeds and disturbance after this secondary induction would only stimulate regrowth of vegetative tillers (Abel *et al.*, 2017). Moreover, any tillers that are newly established in the spring may compete for resources with larger tillers produced the previous fall, potentially reducing seed yield via reduced inflorescence size or reduced seed set (Aamlid *et al.*, 1997). It is also plausible, however, that disturbance during spring in our experiment, which did not negatively impact grain yields relative to the control, might have a positive effect on yield at the second harvest after treatment.

Fourth-year Kernza grain yields obtained in our study are comparable to yields reported in two recent field experiments in Minnesota. In a study examining the effects of row spacing and crop defoliation on grain yield, Hunter *et al.* (2020a) reported a

mean grain yield of 276 kg ha<sup>-1</sup> across all management treatments, slightly higher than the 219 kg ha<sup>-1</sup> from our fall strip-tillage treatment. The Minnesota study utilized Cycle 4 Kernza seed, and thus genetic improvement may be partly responsible for higher average grain yields. Increased row spacing also had a positive effect on grain yields in their study, with an average fourth-year yield for their 15-cm row spacing treatment of 244 kg ha<sup>-1</sup>, a yield similar to our fall strip-tillage value. In a study examining the effects of inter-row cultivation, herbicide application, burning, and mowing on Kernza yield, Bergquist (2019) reported fourth-year Kernza grain yields ranging between 50 and 300 kg ha<sup>-1</sup>. Grain yield after fall inter-row cultivation averaged 231 kg ha<sup>-1</sup>, which is similar to yields for our fall strip-tillage treatment but was not statistically different from their control treatment yield of 208 kg ha<sup>-1</sup>.

Prior to this experiment, Kernza grain yields measured in a separate part of the same field but not within the area of this experiment exhibited steady decline from 930 kg ha<sup>-1</sup> in 2015, the first year after planting, to 600 kg ha<sup>-1</sup> in 2016, and 315 kg ha<sup>-1</sup> in 2017, the third year after planting and the harvest just before strip-tillage was implemented (data not shown). These grain yields show a similar pattern of decline in seed production as other reports in the literature. Hunter *et al.* (2020a) report first-year Kernza grain

**Table 2.** Summary of ANOVA results for mean (s.e.) components of yield from fourth-year Kernza intermediate wheatgrass harvested in the season following fall, spring or no (control) management disturbance from strip-tillage

Yield components	Units	$F_{2,8}$	Pr(>F)	Fall	Spring	Control
Grain yield	kg ha <sup>-1</sup>	5.172	0.036	219.4 (34.0) a	134.3 (26.9) b	136.4 (4.4) b
Crop biomass	kg ha <sup>-1</sup>	7.726	0.007	6775 (475) a	5300 (375) b	7290 (220) a
Harvest index	kg kg <sup>-1</sup>	5.086	0.038	0.032 (0.005) a	0.025 (0.004) ab	0.019 (0.001) b
Tiller density	m <sup>-2</sup>	4.023	0.046	763.0 (47.5) ab	716.2 (56.8) a	1004.0 (110.8) b
Seedhead count	m <sup>-2</sup>	7.741	0.013	261.2 (23.5) a	140.2 (29.8) b	182.2 (12.6) b
Tiller fertility	%	11.215	0.005	34.7 (4.0) a	19.2 (3.1) b	18.8 (1.7) b
Spikelet count	seedhead <sup>-1</sup>	0.175	0.842	17.1 (0.6) a	16.9 (0.6) a	16.6 (0.5) a
Floret count	seedhead <sup>-1</sup>	0.855	0.461	56.0 (5.3) a	56.5 (4.0) a	50.6 (2.0) a
Seed count	seedhead <sup>-1</sup>	0.313	0.740	29.6 (3.6) a	31.0 (2.7) a	28.4 (1.9) a
Thousand kernel wt.	g	0.025	0.975	5.09 (0.16) a	5.05 (0.03) a	5.07 (0.16) a
Weed biomass	kg ha <sup>-1</sup>	0.432	0.664	182.22 (113.6) a	115.80 (78.8) a	76.52 (33.5) a

N = 5. Treatment means within each yield component sharing the same letter are not significantly different at  $\alpha = 0.05$ .

yields of 775 kg ha<sup>-1</sup> declining to 300 kg ha<sup>-1</sup> by the third year of their experiment, and Bergquist (2019) report average grain yields of 340 and 50 kg ha<sup>-1</sup> in their second and third years, respectively. Total crop biomass measured in the same field as our experiment averaged 5000 kg ha<sup>-1</sup> yr<sup>-1</sup> for each of the first three growing seasons (data not shown), which is on the low end of the typical range of 5000–11,000 kg ha<sup>-1</sup> reported in the literature (Bergquist, 2019; Dick *et al.*, 2019; Hunter *et al.*, 2020b; Jungers *et al.*, 2017; Tautges *et al.*, 2018). Total crop biomass did increase to ~7000 kg ha<sup>-1</sup> in the fall strip-tillage and control treatment plots in 2018, which is consistent with many reports of total biomass production increasing as Kernza stands age.

The intensity of disturbance may be an important factor in determining whether management aids or hinders Kernza grain yields. While our study did not vary the type of disturbance or disturbance intensity, other research has demonstrated that higher-intensity disturbance using banded herbicide applications or more intense tillage have not improved or maintained Kernza grain yield (Bergquist, 2019). Striking a balance with management interventions that optimize reproductive sink capacity by reducing competition between tillers without causing excessive damage that hinders crop vigor is an important stand management goal that warrants further research (Hunter *et al.*, 2020a). Moreover, other types of targeted disturbance that differ in intensity and their effect on the crop should be assessed as options for managing Kernza and other perennial grains. For example, burning straw and stubble after harvest of intermediate wheatgrass was more effective than mechanical thinning at maintaining high seed yields in one early study (Canode, 1965). Clearly, there are many types of cultivation and chemical thinning strategies that require research attention.

### Limitations and recommendations for further research

As this experiment was not replicated in time or space, we encourage further investigation of stand-thinning using strip-tillage before proposing broader recommendations for utilizing strip-tillage in Kernza production. Based on these results and evidence from other published studies, future research on using strip-tillage to maintain Kernza yields should focus on the specific timing and intensity of disturbance during the fall, including

treatments implemented soon after grain harvest. Moreover, data should be collected over multiple growing seasons to better understand any longer-term effects of the disturbance. We also recommend research into the effects of strip-tillage after the first and second grain harvests from Kernza stands when grain yields are still relatively high. For example, would strip-tillage after the second grain harvest increase grain yield of the third harvest similar to the increase we observed from strip tillage between the third to fourth grain harvests in this study?

### Conclusion

Kernza intermediate wheatgrass has the potential to improve the sustainability of cereal grain production by contributing additional ecosystem services including soil health improvement, water quality protection and potential for soil carbon storage. Improving grain yield of Kernza through optimized crop management will facilitate the adoption of the crop, allowing these environmental benefits to be gained across a wider range of agricultural systems. In this experiment, strip-tillage of a Kernza stand in late fall after the third grain harvest increased grain yield of the fourth harvest the following year. This effect was likely due to a reduction in intraspecific competition between reproductive tillers after tillage. Strip-tillage applied in early spring reduced stand density but did not impact yields. Further research into different types, timings and intensities of disturbance should be a priority in developing management recommendations for Kernza and other perennial grain crops.

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