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# Integrated Management Practices for Establishing Upland Switchgrass Varieties

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# Integrated Management Practices for Establishing Upland Switchgrass Varieties

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**Abstract:** Establishment of switchgrass (*Panicum virgatum* L.) is challenging, and failure in establishment may expose growers to considerable economic risk. The objectives of this research were to (i) evaluate whether management practices are variety-specific for the establishment of switchgrass and (ii) assess the effectiveness of cover crops as preceding crops on 'Shawnee' switchgrass establishment. Therefore, two studies were conducted at the University of Massachusetts Agricultural Experiment Station in Deerfield, MA, USA, in the 2011–2012 and 2012–2013 growing seasons. In Experiment 1, cover crop treatments (fallow, oat (*Avena sativa* L.) and rye (*Secale cereale* L.)) were the main plots, the two seeding methods (no-till drill and a cultipacker seeder (Brillion)) were the sub-plots, and the two varieties ('Cave-in-Rock' (CIR) and Shawnee)) were the sub-sub-plots. The second study was conducted using Shawnee switchgrass and involved the three cover crop treatments used in Experiment 1 using a cultipacker seeder with seed firming prior to planting but not afterwards (consistent in both experiments). The results indicated that a combination of oat and no-till resulted in higher tiller density (493%), lower weed biomass (77%), increased switchgrass biomass (SGB) (283%) and SGB to weed biomass (WB) ratio. Compared with Shawnee, CIR planted into a winter-killed oat residue had higher tiller density (93%), lower weed biomass (18%), higher switchgrass yield (128%) and thus a greater SGB:WB ratio (507%). Trends of switchgrass response to management practices, however, were similar between the two varieties, indicating that seed quality rather than management practices could influence switchgrass's response to management practices. In Experiment 2, Shawnee tiller density was suppressed by rye as the preceding crop, possibly due to late termination of rye. Shawnee switchgrass yields were below 1000 kg ha$^{-1}$ under all management practices; thus, harvesting should happen in the year following establishment. Future research should focus on comparing no-till drilling with cultipacker seeder with rolling not only before but after seeding to increase seed–soil contact.

**Keywords:** oat; rye; weed biomass; no-till; cultipacker; Cave-in-Rock; Shawnee; *Panicum virgatum*



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## 1. Introduction

Switchgrass (*Panicum virgatum* L.) is a warm-season ($C_4$) perennial grass with a fibrous root system. It is native to North America and has been grown for hay, forage and biofuel purposes [1,2]. After establishment, switchgrass is a high-yielding and self-sustaining bioenergy crop [3,4]; however, switchgrass establishment is often challenging, and failure to successfully establish switchgrass poses substantial economic risks to the growers [3]. Small seed size, seed dormancy, slow seedling development and the presence of weeds are factors that make switchgrass establishment difficult [4–7]. The difficulties in switchgrass establishment may severely affect crop yield, and more agronomic knowledge is required for its successful adoption by farmers.

Weed control is a major challenge in switchgrass establishment [8]. Reliable agricultural practices are required to control the weed pressure, which may include the use of cover crops, seeding methods and application of herbicides [4,8–11]. The use of cover crops in weed control is environment friendly and has been demonstrated for crops such as corn (*Zea mays* L.), soybean (*Glycine max* L.) and winter wheat (*Triticum aestivum* L.) [12–14]. Fast-growing cereals, including oat and rye, are widely used as cover crops due to their demonstrated weed-suppressing potential in different crops [13,15–18]. These cereal cover crops often establish well and produce high biomass, and therefore suppress weeds prior to planting the main crops [19–23]. Winter cereals such as rye also could control weeds due to their allelopathic compounds [24–26]. However, a limited number of reports are available in literature that have centered on evaluating the efficacy of oat and rye cover crops in controlling weeds in switchgrass's establishment phase [27,28]. A switchgrass establishment study conducted by Sadeghpour et al. demonstrated better weed control by rye and oat when compared with fallow [27]. However, a reduction in switchgrass density was reported in the case of rye, possibly due to high allelopathic compounds and root N immobilization due to late termination. Overall, Sadeghpour et al. concluded that, considering both weed control and switchgrass establishment, oat was a superior option to rye for switchgrass establishment [27]. A study by Keyser et al. reported that wheat was the only cover crop that positively influenced switchgrass establishment [29]. These authors did not report yield data in the establishment year but indicated no yield penalty in the succeeding years. Despite these findings, the literature lacks information on whether management practices for establishing switchgrass are variety-specific.

Different seedbed preparation methods are available for planting switchgrass, including conventional and no-till planting into killed sods or bare soil [6,30]. Although, each method has its own advantage over the other under certain circumstances, previous studies have shown a preference for using conventionally tilled seedbeds over no-till planting [31–33]. Use of firm seed beds showed considerably high switchgrass emergence in different studies [4,34,35], indicating the positive effect of compaction on switchgrass germination [36]. There are mixed reports showing switchgrass yield being unaffected, affected and dependent on the season or location available in the literature [11,37,38] for conventional and no-till planting methods.

Years of collaborative plant breeding efforts by researchers from the United States Department of Agriculture (USDA)—Agriculture Research Services (ARS), the University of Nebraska, Iowa State University and Purdue University resulted in the development and release of a new switchgrass cultivar, Shawnee, in 1995 [39]. It was developed from the base population of the cultivar CIR using a cycle of single restricted, stratified mass selection. The original germplasm for the cultivar was collected near a location close to Shawnee National Forest in southern Illinois and hence received the name "Shawnee". The cultivar was developed to enhance agronomic traits such as vigor, leafiness and absence of disease, along with improved forage quality and yield [39]. Although Shawnee has been evaluated in several studies [40–43], it is unclear whether it responds to integrated management practices including tillage and cover crops similarly to more common varieties such as CIR. Therefore, the main objectives of this study were to (i) evaluate whether integrated management practices for establishing switchgrass are variety-specific and (ii) assess the effectiveness of cereal cover crops on the establishment of Shawnee switchgrass.

## 2. Materials and Methods

### *2.1. Study Site Description*

All field experiments were conducted at the University of Massachusetts Agricultural Experiment Station Farm in South Deerfield, MA, USA (42°28′37′′ N, 72°36′2′′ W). Experiment 1 was conducted in the 2011–2012 growing season, whereas Experiment 2 was executed in 2011–2012 and replicated in 2012–2013. The soil at the site is a Hadley fine sandy loam (nonacid, mesic Typic Udifluvent) with a pH of 5.5 (1:1 soil:water ratio). Soil samples were collected using a hand probe (8 cores per plot) from 0–20 cm soil depth. The samples had organic matter content of 12 g kg$^{-1,}$ with Morgan-extractable nitrogen, phosphorous, potassium and calcium contents of 3, 9, 73, and 868 mg kg$^{-1}$, respectively. The soil pH value was adjusted by application of 1120 kg ha$^{-1}$ lime (calcium carbonate).

## 2.2. Experimental Design

### 2.2.1. Experiment 1

Experiment 1 was conducted in 2011–2012 and the experimental design was a split-split-plot design with 3 blocks. Cover crops (no cover crop, oat and rye) were the main plots. The sub-plots were 2 seeding methods, which included no-till drill and planting using a cultipacker seeder (Brillion drill). The sub-sub-plots were the two varieties (CIR and Shawnee).

### 2.2.2. Experiment 2

Experiment 2 was conducted in 2011–2012 and 2012–2013. To make presentation facile, from now on, 2011–2012 will be called "2012" and 2012–2013 will be called "2013". The experimental design was a randomized complete block design with 3 cover crop treatments including no cover crop, oat and rye.

## 2.3. Cultural Management Practices

### 2.3.1. Experiment 1

In mid-September, oat and winter rye were drilled at the rate of 96 and 112 kg ha$^{-1}$, respectively. Oat was winter-killed, but winter rye and weeds in the fallow plots were terminated using glyphosate (*N*-(phosphonomethyl) glycine) at a rate of 0.84 kg a.i. ha$^{-1}$ in late May. Cave-in-Rock and Shawnee switchgrass were planted on 28 June 2012 and 5 July 2013 in their respective plots using either a no-till drill (Kincaid Manufacturing, Haven, KS, USA) or a cultipacker seeder (Brillion Co., Milwaukee, WI, USA). Prior to planting with the cultipacker, the soil was leveled with 1 pass of the cultipacker. Switchgrass varieties were planted at seeding rate of 9 kg ha$^{-1}$ pure live seed with a row spacing of 15 cm. Each subplot was 3 m wide and 6 m long. One meter from the top and bottom of the plots and 0.5 m from each side of the plots was considered as the border. A broad spectrum application of pre-emergence atrazine (2-chloro-4-ethylamino-6-isopropyl-amino-*S*-triazine) at the rate of 1.1 kg a.i. ha$^{-1}$ along with quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) at the rate of 0.37 kg a.i. ha$^{-1}$, which was supplemented with a post-emergence application of 2,4-D ((2,4-dichlorophenoxy)acetic acid) (0.28 kg a.i. ha$^{-1}$) and dicamba (3,6-dichloro-*O*-anisic acid) (0.28 kg a.i. ha$^{-1}$). Pre-emergence herbicides were applied 1 day after planting using a custom-made sprayer. No nitrogen fertilizer was applied in the current studies due to weed pressure issues with the application of nitrogen in the establishment year [44]. As per the typical agronomic practices followed in Massachusetts, no irrigation was applied to the experimental sites in the current study [45].

### 2.3.2. Experiment 2

Similar to Experiment 1, oat and winter rye were drilled separately in their respective plots at the rate of 96 and 112 kg ha$^{-1}$, respectively. Oat was winter-killed, but winter rye and weeds in the fallow plots were terminated using glyphosate at a rate of 0.84 kg a.i. ha$^{-1}$ in late May. Shawnee switchgrass was planted into a tilled soil using a cultipacker seeder (Brillion Co., Milwaukee, WI, USA). The planting date for Shawnee switchgrass was similar to that in Experiment 1. Before planting, the soil was firmed using a pass of the cultipacker to improve establishment. Herbicide, nitrogen and irrigation management practices were similar to Experiment 1.

*2.4. Sample Collection and Analysis*

Sample collection was similar between the 2 experiments. Switchgrass tiller density was determined approximately 6 weeks after herbicide application. Weed biomass was determined using a hand clipper (GS model 700, Black and Decker (US) Inc., Towson, MD, USA) at a 10 cm stubble height, and the measurements were taken when the tiller density was counted (Mid-September). Switchgrass yield was measured in late October after a killing frost in 2012 and in 2013. Weight measurements for weed biomass and switchgrass yield were taken after the samples were dried in a forced air oven at 55 °C for 72 h.

*2.5. Data Analysis*

All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA). For Experiment 1, a mixed procedure was used. The main effects were cover crops, seeding methods and variety, and only block was considered a random effect. In Experiment 2, the main effects were year and cover crops, and block was a random effect. We used the Shapiro–Wilk test to determine the normality of the data. When the residuals were not normally distributed, based on the data type, the data were transformed using log or arcsine transformation. Data were back-transformed to be presented in tables and figures. Post-hoc Tukey's HSD (honestly significant difference) was used for comparing the means. JMP statistical software was used for regression analysis. All differences reported were significant at $p = 0.05$ unless otherwise stated. The figures were prepared using Sigmaplot 11.0 (SigmaPlot, Systat Software Inc., San Jose, CA, USA).

## 3. Results

*3.1. Weather Conditions*

Monthly growth degree-days ($GDD_{10}$ °C), observed from the Orange, MA, weather station, showed a decrease in the values from July to October in both the years, 2012 and 2013. Cumulative GDD for the 2012 and 2013 growing seasons (July through October) were 1985 and 1874, respectively (Table 1). Monthly precipitation showed a general increase in the 2012 growing season (July through October), whereas the values decreased in the 2013 growing season. Cumulative growing season precipitation in 2012 (163 mm) was much lower as compared with 2013 (352 mm) (Table 1). Compared with the 30-yr average, GDD was 8% and 13% lower in 2012 and 2013, and precipitation was 62% and 19% lower in 2012 and 2013, indicating that 2013 was more similar to the 30-yr average than 2012.

**Table 1.** Monthly and total growth degree days ($GDD_{10}$ °C) and precipitation (mm) in 2012 and 2013 as compared with the 30-yr average data at the University of Massachusetts experimental farm, South Deerfield.

| Month | GDD | | | Precipitation (mm) | | |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | 30-Year Average | 2012 | 2013 | 30-Year Average |
| July | 746 | 790 | 785 | 14 | 124 | 109 |
| August | 693 | 591 | 745 | 42 | 104 | 101 |
| September | 387 | 350 | 488 | 37 | 98 | 107 |
| October | 159 | 143 | 146 | 70 | 26 | 118 |
| Total | 1985 | 1874 | 2164 | 163 | 352 | 435 |

*3.2. Switchgrass Tiller Density*

3.2.1. Experiment 1

Switchgrass tiller density was significantly influenced by the cover crop, seeding method and variety (Table 2).

**Table 2.** Influence of cover crop, seeding method and switchgrass variety on switchgrass (SG) tiller density and biomass, weed biomass, and switchgrass/weed biomass ratio (SGB:WB) in the 2012 growing season.

| | | Tiller Density | SG Biomass | Weed Biomass | SGB:WB |
|---|---|---|---|---|---|
| | | ($m^{-2}$) | (kg $ha^{-1}$) | (kg $ha^{-1}$) | |
| | | Log Trans † | Log Trans | No Trans | Arcsine Trans |
| Cover crop | Fallow | 84.17 b | 649 b | 1852 a | 0.35 b |
| | Oat | 165.91 a | 1108 a | 1106 b | 1.00 a |
| | Rye | 80.42 b | 550 b | 983 b | 0.56 ab |
| Seeding methods | Cultipacker | 39.41 b | 384 b | 1773 a | 0.21 b |
| | No-till | 173.89 a | 1113 a | 853 b | 1.30 a |
| Variety | CIR | 145.88 a | 1024 a | 1134 b | 2.84 a |
| | Shawnee | 73.33 b | 509 b | 1493 a | 0.69 b |

Different letters next to the treatment means indicate a significant difference ($p < 0.05$). † Trans indicates that the data were transformed.

Tiller density increased from 39.41 tillers $m^{-2}$ to 173.89 tillers $m^{-2}$ when the planting method was changed from the cultipacker to the no-till drill (Table 2). The number of tillers in Cave-in-Rock (145.88 tillers $m^{-2}$) was higher than in Shawnee (73.33 tillers $m^{-2}$) in the establishment year. The highest tiller density was recorded when switchgrass was seeded after the oat cover crop (165.91 tillers $m^{-2}$) compared with rye (80.42 tillers $m^{-2}$) and fallow (84.17 tillers $m^{-2}$).

Significant interactions of cover crop with seeding method ($p < 0.05$) and of seeding method with variety ($p < 0.05$) were also observed. While cover crops had no effect on switchgrass tiller density when the cultipacker was used, a combination of oat as the cover crop with no-till drill increased switchgrass tiller density. In the no-till systems, switchgrass tiller density was 267 tillers $m^{-2}$ after oat, and 125 and 130 tillers $m^{-2}$ after rye and fallow, respectively (Figure 1A).

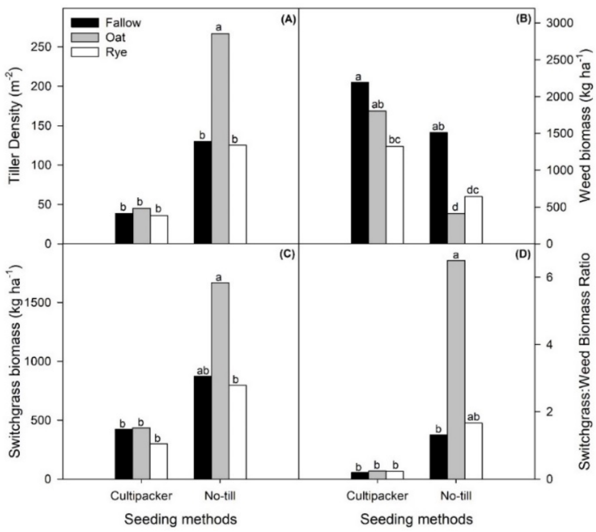


**Figure 1.** Effect of seeding method on switchgrass tiller density (**A**), weed biomass (**B**), switchgrass biomass (**C**) and switchgrass/weed biomass ratio (**D**) in the 2012 growing season. Data were averaged over Shawnee and CIR varieties (Experiment 1). Different letters at the tops of the columns represent significant differences ($p < 0.05$) between the treatments.

The interaction of cover crop with variety indicated that Shawnee, when planted in a fallow system, performed poorly (130 tillers $m^{-2}$) and significantly lower than CIR (225 tillers $m^{-2}$) when planted after oat (Figure 2A).

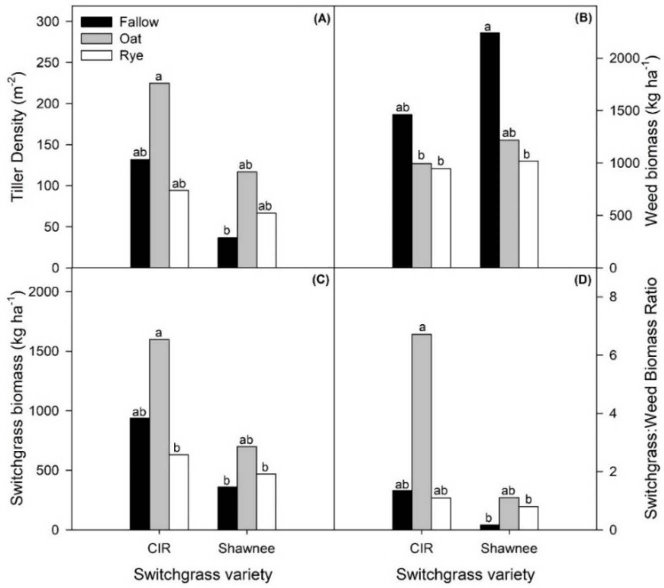


**Figure 2.** Effect of switchgrass variety on switchgrass tiller density (**A**), weed biomass (**B**), switchgrass biomass (**C**) and switchgrass/weed biomass ratio (**D**) in the 2012 growing season (Experiment 1). Data were averaged over the no-till and cultipacker seeding methods. Different letters at the tops of the columns represent significant differences ($p < 0.05$) between the treatments.

3.2.2. Experiment 2

Shawnee tiller density was significantly higher following oat in 2013 (70 tillers $m^{-2}$) but not in 2012. This difference reflected the year-to-year variation between the 2 years (Figure 3A).

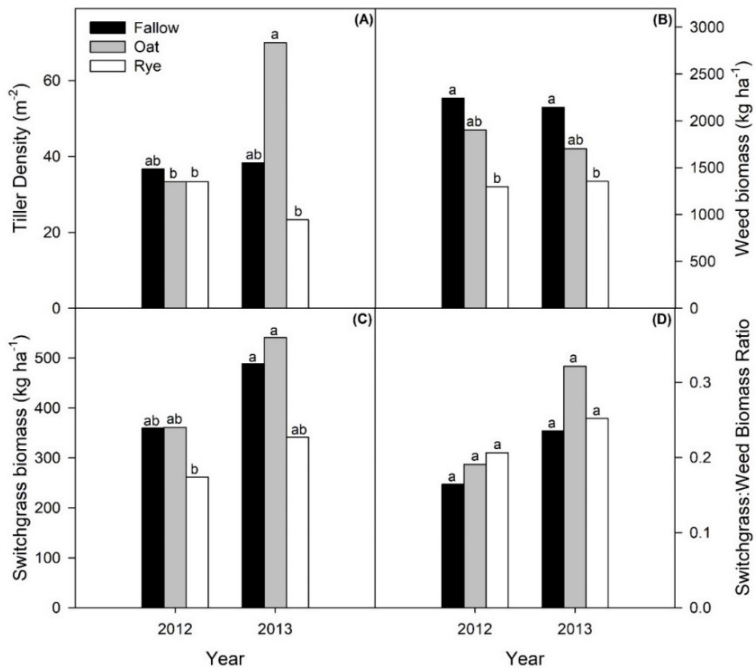


**Figure 3.** Comparison of switchgrass tiller density (**A**), weed biomass (**B**), switchgrass biomass (**C**) and switchgrass/weed biomass ratio (**D**) in the 2012 and 2013 growing seasons for the Shawnee switchgrass variety (Experiment 2). Different letters at the tops of the columns represent significant differences ($p < 0.05$) between the treatments.

### 3.3. Weed Biomass

#### 3.3.1. Experiment 1

Weed biomass was significantly higher in the fallow control (1852 kg ha$^{-1}$) compared with oat (1106 kg ha$^{-1}$) and rye (983 kg ha$^{-1}$) (Table 2). Using a cultipacker and disturbing the soil increased weed biomass by twofold compared with no-till management (Table 2). Higher CIR stand density compared with Shawnee was reflected in lower weed biomass in CIR and indicated a possible relationship between switchgrass stand density and weed biomass.

The interaction of seeding method and cover crop indicated that planting oat and rye prior to no-till drilling of switchgrass resulted in the lowest weed biomass (408 kg ha$^{-1}$ for oat and 641 kg ha$^{-1}$ for rye, respectively) (Figure 1B). The highest weed biomass was measured in the fallow treatment in both the cultipacker (2193 kg ha$^{-1}$) and no-till drill (1510 kg ha$^{-1}$) systems, reflecting the effectiveness of cereal crops at controlling weeds. There were no statistical differences between weed biomass under fallow and oat as the preceding crop prior to planting switchgrass with a cultipacker, indicating the possible quick decomposition of oat with soil disturbance and the lack of soil cover for reducing weed pressure.

The interaction of variety with cover crop was also significant for weed biomass (Figure 2B). Weed biomass was the highest in Shawnee when no cover crop was used (fallow control) and was the least in oat and rye, regardless of the variety (Figure 2B).

#### 3.3.2. Experiment 2

Weed biomass was significantly influenced by the cover crop but not by year or the interaction of cover crop with year (Table 3). The weed biomass was 1325 kg ha$^{-1}$ when rye was the preceding crop, which was 26% and 40% lower than those measured in the oat and fallow treatments, respectively, indicating that rye was consistently an effective cover crop for controlling weeds.

**Table 3.** Influence of cover crop on switchgrass (SG) tiller density and biomass, weed biomass and switchgrass/weed biomass ratio (SGB:WB) in the 2012 and 2013 growing seasons.

| | | Tiller Density | SG Biomass | Weed Biomass | SGB:WB |
|---|---|---|---|---|---|
| | | **(m$^{-2}$)** | **(kg ha$^{-1}$)** | **(kg ha$^{-1}$)** | |
| | | **No Trans †** | **No Trans** | **No Trans** | **Arcsine Trans** |
| Year | 2012 | 34.44 a | 327 b | 1813 a | 0.18 b |
| | 2013 | 43.89 a | 457 a | 1734 a | 0.26 a |
| Cover crop | Fallow | 37.50 ab | 424 ab | 2193 a | 0.19 a |
| | Oat | 51.67 a | 451 a | 1803 b | 0.25 a |
| | Rye | 28.33 b | 302 c | 1325 c | 0.23 a |

Different letters next to the treatment means indicate significant differences ($p < 0.05$). † Trans indicates that the data were transformed.

### 3.4. Switchgrass Biomass

#### 3.4.1. Experiment 1

Switchgrass biomass yield (dry matter basis) was significantly higher when planted after oat (1108 kg ha$^{-1}$) than after fallow (649 kg ha$^{-1}$) and rye (550 kg ha$^{-1}$) (Table 2). Switchgrass biomass yield was greater under no-till (1113 kg ha$^{-1}$) than under the cultipacker seeder (384 kg ha$^{-1}$). Cave-in-Rock had higher switchgrass biomass yield (1024 kg ha$^{-1}$) compared with Shawnee (509 kg ha$^{-1}$).

No-till planting switchgrass into oat resulted in the greatest switchgrass biomass (1669 kg ha$^{-1}$), indicating that a combination of oat and no-till resulted in excellent switchgrass establishment that produced harvestable yield in the establishment year. Regardless of the cover crop, when switchgrass was seeded using a cultipacker seeder, switchgrass biomass yields were low and did not justify harvesting in the establishment year (Figure 1C).

Between the two varieties, CIR performed well when planted into oat as the previous crop. In general, rye resulted in lower switchgrass and weed biomass, indicating that rye was not a suitable cover crop option prior to switchgrass and that extra management practices are needed to ensure successful switchgrass production following rye as a cover crop.

3.4.2. Experiment 2

Switchgrass biomass yield was low in both years (327 and 457 kg $ha^{-1}$ in 2012 and 2013, respectively). Switchgrass yields were higher after oat (541 kg $ha^{-1}$) and fallow (488 kg $ha^{-1}$) in 2013 than after rye (261 kg $ha^{-1}$) in 2012 (Table 2). Within each year, there were no significant differences among cover crops.

*3.5. Switchgrass:Weed Biomass Ratio*

3.5.1. Experiment 1

The switchgrass:weed biomass (SGB:WB) ratio was 1 in oat, but lower than 1 in both fallow (0.35) and rye (0.56), indicating failure to establish switchgrass while controlling weeds effectively. Similarly, the no-till drill resulted in a SGB:WB ratio above 1 (1.30), which was sixfold higher than with the cultipacker seeder. Cave-in-Rock also had a SGB:WB ratio of 2.84, which was fourfold higher than Shawnee, indicating that in the current study, CIR was established better.

In the no-till drill system, when switchgrass was established following oat, the SGB:WB ratio was 6.5, indicating that a combination of oat and no-till resulted in effective switchgrass establishment. The ratio of SGB:WB was similar among all cover crops when switchgrass was planted using a cultipacker seeder. Planting CIR switchgrass into oat also resulted in higher switchgrass establishment (6.7) than Shawnee when planted into the fallow control.

3.5.2. Experiment 2

The ratio of SGB:WB was below 1 in all cover crop treatments. The SGB:WB ratio in 2013 (0.26) was significantly higher than in 2012 (0.18) (Table 2).

## 4. Discussion

Previous research has been inconsistent on the effect of planting method for establishing switchgrass. For example, Sadeghpour et al. reported that a cultipacker seeder can perform as effectively as a no-till drill in Massachusetts, but only if the soil was rolled before planting and twice after planting, and suggested increasing the equipment's weight to reduce the number of passes to make this more practical for growers [27]. In Oklahoma, Butler et al. reported no difference between the two methods but suggested that no-till drill offers opportunities to control soil erosion and, when possible, could be a reliable establishment method [46]. Research has shown that the effect of seeding method on switchgrass establishment could be soil type-dependent; in sandy soils in Massachusetts, no-till was effective in conserving soil moisture by not disturbing the soil, and herbicide termination resulted in more consistent switchgrass establishment.

In general, an increase in tiller density increased switchgrass yield in both trials but the effect on weed biomass was not consistent. There was a positive linear relationship between switchgrass tiller density and switchgrass biomass in Experiment 1 ($R^2$ = 0.91; $p < 0.0001$) and Experiment 2 ($R^2$ = 0.50; $p < 0.0011$) (data not shown). The lower $R^2$ in Experiment 2 could be due to higher weed pressure and a lower SGB:WB ratio, indicating that tiller density was not high enough to make a significant impact on weed pressure and that thus, switchgrass biomass was influenced. In Experiment 1, there was a negative exponential relationship between tiller density and weed biomass, reflecting that effective switchgrass establishment could reduce weed pressure. This proved to be true due to the lack of a relationship between low tiller density in Experiment 2, with high weed pressure existing in that trial.

Cereal cover crops have been shown to be effective in reducing weed biomass, but growers are concerned that cover crops could reduce the tiller density and biomass production of the cash crops as well [47,48]. Sadeghpour et al. reported rye is an excellent crop to control weeds, but found lower switchgrass tiller density in rye but improved switchgrass tiller density with oat, in line with findings of this study [28]. In Experiment 2, Shawnee's tiller density was consistently low after rye as a cover crop, reflecting the difficultly of establishing it in rye. This could be due to rye's extensive root system, which makes it difficult to plant into, and the fact that rye has allelopathy [24–26]. One strategy to avoid such an issue is to skip the cash crop row when planting rye. This decreases the intersecting zones between a cash crop and the rye cover crop, and improves the cash crop's establishment [48].

Previous research in Massachusetts indicated that oat, when planted early, is able to accumulate a great amount of biomass [19] and, when terminated by frost, can cover the soil but does not induce immobilization; therefore, it allows the cash crop to be established. Over-wintering cover crops such as rye and wheat, if not terminated early (this was the case in our study), can severely tie up N, use water and reduce the cash crop's establishment and production [47–50]. These reasons explain the differences between oat and rye in improving switchgrass tiller density. While our findings support previous research in Massachusetts, in Tennessee, Keyser et al. indicated that, except in one location, there were no differences between oat and rye in establishing switchgrass [29], suggesting that management practices for improving switchgrass establishment are site-specific.

The differences between CIR and Shawnee reflected their traits and indicated variation among bags of seeds. In a preliminary trial, Sadeghpour et al. (unpublished) found faster germination, longer leaves and taller seedlings in CIR than in Shawnee, possibly explaining the better performance of CIR in this trial than Shawnee. In general, CIR has been used as the main variety in Massachusetts, but our results are in contrast with a previous report by Sadeghpour et al., who indicated no differences between Shawnee and CIR in terms of emergence [51], confirming that perhaps the differences in the seeds used in this study versus a previous trial resulted in the differences in switchgrass tiller density and yield between CIR and Shawnee.

## 5. Conclusions

Previous reports have all agreed that integrating winter cereals into the establishment year of switchgrass could benefit the production system by reducing soil erosion, increasing switchgrass establishment, offering opportunities for no-till, and offsetting the establishment cost by harvesting the winter cereal crop. In our trials, integrating a winter-killed cover crop (oat) resulted in better switchgrass establishment, and rye as cover crop resulted in lower switchgrass establishment. Managing cover crops is part of switchgrass establishment and thus, when a winter cereal cover crop was terminated late, it could negatively affect the establishment of a small-seeded crop like switchgrass. Disturbing the soil encourages the emergence of weeds, while no-till drilling with heavy herbicide control burndown could result in better switchgrass establishment in soils with a coarse texture in Massachusetts. The cultipacker seeder is the main method for establishing switchgrass but to increase establishment with that method, future research should focus on increasing seed–soil contact by rolling the plots after seeding and evaluating the economic costs associated with this management approach compared with no-till drilling the seeds.

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## References

1. Kumar, P.; Lai, L.; Battaglia, M.L.; Kumar, S.; Owens, V.; Fike, J.; Galbraith, J.; Hong, C.O.; Faris, R.; Crawford, R.; et al. Impacts of nitrogen fertilization rate and landscape position on select soil properties in switchgrass field at four sites in the USA. *CATENA* **2019**, *180*, 183–193. [CrossRef]
2. Kumar, S.; Lai, L.; Kumar, P.; Feliciano, Y.M.V.; Battaglia, M.L.; Hong, C.O.; Owens, V.N.; Fike, J.; Farris, R.; Galbraith, J. Impacts of nitrogen rate and landscape position on soils and switchgrass root growth parameters. *Agron. J.* **2019**, *111*, 1046–1059. [CrossRef]
3. Sadeghpour, A.; Hashemi, M.; Jahanzad, E.; Herbert, S.J. Switchgrass stand density and yield as influenced by seedbed preparation methods in a sandy loam soil. *Bioenergy Res.* **2015**, *8*, 1840–1846. [CrossRef]
4. Monti, A.; Venturi, P.; Elbersen, H. Evaluation of the establishment of lowland and upland switchgrass (*Panicum virgatum* L.) varieties under different tillage and seedbed conditions in northern Italy. *Soil Tillage Res.* **2001**, *63*, 75–83. [CrossRef]
5. Moser, L.E.; Vogel, K.P. Switchgrass, big bluestem, and indiangrass. In *Forages: An Introduction to Grassland Agriculture*, 5th ed.; Barnes, R.F., Miller, D.A., Nelson, C.J., Eds.; Iowa State University Press: Ames, IA, USA, 1995; pp. 409–420.
6. Parrish, D.J.; Fike, J.H. The biology and agronomy of switchgrass for biofuels. *BPTS* **2005**, *24*, 423–459. [CrossRef]
7. Kimura, E.; Fransen, S.C.; Collins, H.P.; Guy, S.O.; Johnston, W.J. Breaking seed dormancy of switchgrass (*Panicum virgatum* L.): A review. *Biomass Bioenergy* **2015**, *80*, 94–101. [CrossRef]
8. Sadeghpour, A.; Hashemi, M.; DaCosta, M.; Gorlitsky, L.E.; Jahanzad, E.; Herbert, S.J. Switchgrass establishment and biomass yield response to seeding date and herbicide application. *Agron. J.* **2015**, *107*, 142–148. [CrossRef]
9. Monti, A. *Switchgrass: A Valuable Biomass Crop for Energy*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012.
10. Mitchell, R.B.; Vogel, K.P.; Berdahl, J.; Masters, R.A. Herbicides for establishing switchgrass in the central and northern Great Plains. *BioEnergy Res.* **2010**, *3*, 321–327. [CrossRef]
11. King, M.A.; Waller, S.S.; Moser, L.E.; Stubbendieck, J.L. Seedbed effects on grass establishment on abandoned Nebraska Sandhills cropland. *J. Range Manag.* **1989**, *42*, 183–187. [CrossRef]
12. Johnson, G.A.; Defelice, M.S.; Helsel, Z.R. Cover crop management and weed control in corn (*Zea mays*). *Weed Technol.* **1993**, *7*, 425–430. [CrossRef]
13. Moore, M.J.; Gillespie, T.J.; Swanton, C.J. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. *Weed Technol.* **1994**, *8*, 512–518. [CrossRef]
14. Hiltbrunner, J.; Liedgens, M.; Bloch, L.; Stamp, P.; Streit, B. Legume cover crops as living mulches for winter wheat: Components of biomass and the control of weeds. *Eur. J. Agron.* **2007**, *26*, 21–29. [CrossRef]
15. Liebl, R.; Simmons, F.W.; Wax, L.M.; Stoller, E.W. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). *Weed Technol.* **1992**, *6*, 838–846. [CrossRef]
16. Teasdale, J.R.; Beste, C.E.; Potts, W.E. Response of weeds to tillage and cover crop residue. *Weed Sci.* **1991**, *39*, 195–199. [CrossRef]
17. Price, A.J.; Reeves, D.W.; Patterson, M.G. Evaluation of weed control provided by three winter cereals in conservation-tillage soybean. *Renew. Agric. Food Syst.* **2006**, *21*, 159–164. [CrossRef]
18. Isik, D.; Kaya, E.; Ngouajio, M.; Mennan, H. Weed suppression in organic pepper (*Capsicum annuum* L.) with winter cover crops. *Crop Prot.* **2009**, *28*, 356–363. [CrossRef]
19. Hashemi, M.; Farsad, A.; Sadeghpour, A.; Weis, S.A.; Herbert, S.J. Cover-crop seeding-date influence on fall nitrogen recovery. *J. Plant Nutr. Soil Sci.* **2013**, *176*, 69–75. [CrossRef]
20. Sadeghpour, A.; Jahanzad, E.; Esmaeili, A.; Hosseini, M.; Hashemi, M. Forage yield, quality and economic benefit of intercropped barley and annual medic in semi-arid conditions: Additive series. *Field Crop. Res.* **2013**, *148*, 43–48. [CrossRef]
21. Jahanzad, E.; Jorat, M.; Moghadam, H.; Sadeghpour, A.; Chaichi, M.-R.; Dashtaki, M. Response of a new and a commonly grown forage sorghum cultivar to limited irrigation and planting density. *Agric. Water Manag.* **2013**, *117*, 62–69. [CrossRef]
22. Esmaeili, A.; Sadeghpour, A.; Hosseini, S.; Jahanzad, E.; Chaichi, M.; Hashemi, M. Evaluation of seed yield and competition indices for intercropped barley (*Hordeum vulgare*) and annual medic (*Medicago scutellata*). *Int. J. Plant Prod.* **2012**, *5*, 395–404.
23. Zandvakili, O.R.; Hashemi, M.; Chaichi, M.R.; Barker, A.V.; Afshar, R.K.; Mashhadi, H.R.; Oveysi, M.; Sabet, M. Role of cover crops and nicosulfuron dosage on weed control and productivity in corn crop. *Weed Sci.* **2020**, *68*, 664–672. [CrossRef]
24. Erocli, L.; Masoni, A.; Pampana, S. Weed suppression by winter cover crops. *Allelopath. J.* **2005**, *16*, 273–278.
25. Erocli, L.; Masoni, A.; Pampana, S.; Arduini, L. Allelopathic effect of rye, brown mustard and hairy vetch on redroot pigweed, common lambsquarter and knotweed. *Allelopath. J.* **2007**, *19*, 249–256.
26. Tabaglio, V.; Marocco, A.; Schulz, M. Allelopathic cover crop of rye for integrated weed control in sustainable agroecosystems. *Ital. J. Agron.* **2013**, *8*, 35–40. [CrossRef]
27. Sadeghpour, A.; Hashemi, M.; DaCosta, M.; Jahanzad, E.; Herbert, S.J. Switchgrass establishment influenced by cover crop, tillage systems, and weed control. *BioEnergy Res.* **2014**, *7*, 1402–1410. [CrossRef]

28. Sadeghpour, A.; Hashemi, M.; DaCosta, M.; Gorlitsky, L.E.; Jahanzad, E.; Herbert, S.J. Assessing winter cereals as cover crops for weed control in reduced-tillage switchgrass establishment. *Ind. Crops Prod.* **2014**, *62*, 522–525. [CrossRef]
29. Keyser, P.D.; Ashworth, A.J.; Allen, F.L.; Bates, G.E. Evaluation of small grain cover crops to enhance switchgrass establishment. *Crop Sci.* **2016**, *56*, 2062–2071. [CrossRef]
30. Sanderson, M.A.; Schmer, M.; Owens, V.; Keyser, P.; Elbersen, W. Crop management of switchgrass. In *Switchgrass*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 87–112.
31. Oldfather, S.; Stubbendieck, J.; Waller, S. Evaluating revegetation practices for sandy cropland in the Nebraska Sandhills. *J. Range Manag.* **1989**, *42*, 257–259. [CrossRef]
32. Potvin, M.A. Establishment of native grass seedlings along a topographic/moisture gradient in the Nebraska Sandhills. *Am. Midl. Nat.* **1993**, *130*, 248–261. [CrossRef]
33. Teel, A. *Management Guide for the Production of Switchgrass for Biomass Fuel in Southern Iowa*; University Extension; Iowa State University: Ames, IA, USA, 2003.
34. Mitchell, R.B.; Vogel, K. Germination and emergence tests for predicting switchgrass field establishment. *Agron. J.* **2012**, *104*, 458–465. [CrossRef]
35. Miesel, J.R.; Renz, M.J.; Doll, J.E.; Jackson, R.D. Effectiveness of weed management methods in establishment of switchgrass and a native species mixture for biofuels in Wisconsin. *Biomass Bioenergy* **2012**, *36*, 121–131. [CrossRef]
36. Venturi, P.; Monti, A.; Elbersen, W. Soil tillage and switchgrass (*Panicum virgatum* L.) establishment. In Proceedings of the Conference on Energy and Agriculture towards the Third Millennium, Athens, Greece, 2–5 June 1999; pp. 76–84.
37. Rehm, G. Importance of nitrogen and phosphorus for production of grasses established with no-till and conventional planting systems. *J. Prod. Agric.* **1990**, *3*, 333–336. [CrossRef]
38. Harper, C.A.; Morgan, G.D.; Dixon, C.E. Establishing native warm-season grasses using conventional and no-till technology with various applications of Plateau herbicide. In Proceedings of the Eastern Native Grass Symposium, Lexington, KY, USA, 3–6 October 2004; pp. 63–70.
39. Vogel, K.P.; Hopkins, A.A.; Moore, K.J.; Johnson, K.D.; Carlson, I.T. Registration of 'Shawnee' Switchgrass. *Crop Sci.* **1996**, *36*, 1713. [CrossRef]
40. Cibin, R.; Trybula, E.; Chaubey, I.; Brouder, S.M.; Volenec, J.J. Watershed-scale impacts of bioenergy crops on hydrology and water quality using improved SWAT model. *Gcb Bioenergy* **2016**, *8*, 837–848. [CrossRef]
41. Ha, M.; Wu, M. Land management strategies for improving water quality in biomass production under changing climate. *Environ. Res. Lett.* **2017**, *12*, 034015. [CrossRef]
42. Trybula, E.M.; Cibin, R.; Burks, J.L.; Chaubey, I.; Brouder, S.M.; Volenec, J.J. Perennial rhizomatous grasses as bioenergy feedstock in SWAT: Parameter development and model improvement. *Gcb Bioenergy* **2015**, *7*, 1185–1202. [CrossRef]
43. Guo, T.; Cibin, R.; Chaubey, I.; Gitau, M.; Arnold, J.G.; Srinivasan, R.; Kiniry, J.R.; Engel, B.A. Evaluation of bioenergy crop growth and the impacts of bioenergy crops on streamflow, tile drain flow and nutrient losses in an extensively tile-drained watershed using SWAT. *Sci. Total Environ.* **2018**, *613*, 724–735. [CrossRef] [PubMed]
44. Sadeghpour, A.; Gorlitsky, L.; Hashemi, M.; Weis, S.; Herbert, S. Response of switchgrass yield and quality to harvest season and nitrogen fertilizer. *Agron. J.* **2014**, *106*, 290–296. [CrossRef]
45. Farsad, A.; Herbert, S.; Hashemi, M.; Sadeghpour, A. An automated suction lysimeter for improved soil water sampling. *Vadose Zone J.* **2012**, *11*. [CrossRef]
46. Butler, T.J.; Stein, J.D.; Pittman, J.J.; Interrante, S.M. Seedbed Preparation and Planting Depth Affect Switchgrass Establishment and Yield. *Crop Forage Turfgrass Manag.* **2016**, *2*, 1–6. [CrossRef]
47. Lacey, C.; Nevins, C.; Camberato, J.; Kladivko, E.; Sadeghpour, A.; Armstrong, S. Carbon and nitrogen release from cover crop residues and implications for cropping systems management. *J. Soil Water Conserv.* **2020**, *75*, 505–514. [CrossRef]
48. Sadeghpour, A.; Adeyemi, O.; Hunter, D.; Luo, Y.; Armstrong, S. Precision planting impacts on winter cereal rye growth, nutrient uptake, spring soil temperature and adoption cost. *Renew. Agric. Food Syst.* **2021**, 1–6. [CrossRef]
49. Jahanzad, E.; Barker, A.; Hashemi, M.; Eaton, T.; Sadeghpour, A.; Weis, S. Nitrogen release dynamics and decomposition of buried and surface cover crop residues. *Agron. J.* **2016**, *108*, 1735–1741. [CrossRef]
50. Weidhuner, A.; Afshar, R.K.; Luo, Y.; Battaglia, M.; Sadeghpour, A. Particle Size Affects Nitrogen and Carbon Estimate of a Wheat Cover Crop. *Agron. J.* **2019**, *111*, 3398–3402. [CrossRef]
51. Sadeghpour, A.; Hashemi, M.; Herbert, S.J. A simple vigor test for adjusting switchgrass seeding rate in marginal and fertile soils. *Grassl. Sci.* **2014**, *60*, 252–255. [CrossRef]