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# A bioenergy feedstock/vegetable double-cropping system

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ABSTRACT

Certain warm-season vegetable crops may lend themselves to bioenergy double-cropping systems, which involve growing a winter annual bioenergy feedstock crop followed by a summer annual crop. The objective of the study was to compare crop productivity and weed communities in different pumpkin production systems, varying in tillage, cover crop, and bioenergy feedstock/pumpkin double-cropping. Using a fall-planted rye (*Secale cereale*) + hairy vetch (*Vicia villosa*) mixture as a candidate feedstock, on average 9.9 Mg ha$^{-1}$ of dry biomass was produced prior to pumpkin planting. Pumpkin yields in the cover crop system, which involved leaving the bioenergy feedstock on the soil surface, ranged from 49% to 65% of the conventional pumpkin system. When the bioenergy feedstock was removed, pumpkin yields in the feedstock tillage system were comparable to the conventional pumpkin system. Weeds remained problematic in all cropping systems; however, cropping systems without tillage (i.e. no-tillage and feedstock no-till systems) had among the highest weed population densities in pumpkin. The feedstock tillage system reduced potentially leachable soil N in the spring, produced enough bioenergy feedstock to theoretically yield an estimated 3260 liters of ethanol ha$^{-1}$ without negatively affecting processing pumpkin yield, and had a farmgate value comparable to, or greater than, the conventional pumpkin production system currently used by growers.



## 1. Introduction

The Energy Independence and Security Act of 2007 revised the Renewable Fuels Standard, mandating production of 136 billion liters of biofuels by the year 2022. Perennial energy crops, such as switchgrass (*Panicum virgatum* L.) and Miscanthus (*Miscanthus x giganteus* Greef et Deu.), have received considerable attention in meeting this mandate (Heaton et al., 2008). Depending on the scenario, 9–14 million hectares of cropland would need to be converted to perennial energy crops in order to displace 30% of the U.S.'s current petroleum consumption (U.S. DOE, 2011). Most likely, bioenergy feedstocks will need to be derived from a variety of sources in order to increase both food and biofuel productivity in an environmentally sound manner (Cassman and Liska, 2007; Tillman et al., 2009). In addition to perennial grasses, bioenergy feedstocks include crop residues, wood and forest residues, municipal and industrial wastes, and bioenergy double-cropping systems. Bioenergy double-cropping systems involve growing a winter annual bioenergy feedstock crop followed by a summer annual crop (Heggenstaller et al., 2008). While these systems may not produce feedstock yields equivalent to perennial energy crops, they do not remove land from food production.

In concept a number of vegetable crops may fit bioenergy double-cropping systems; however, none of these systems have been developed and few, if any, have been tested. For instance, several vegetable crops grown in the Midwest U.S. require a relatively short summer growing season which is preceded by a long overwinter fallow period. Some vegetable crops, such as cucurbits, are planted late-spring once soils have warmed and risk of cool weather has passed. Conceivably, the fallow period between fall and late-spring could be used for production of a winter annual bioenergy feedstock. How feasible is a bioenergy feedstock/vegetable double-cropping system in the Midwest U.S.?

Pumpkin is one of the more popular vegetable crops grown in Illinois, the nation's largest pumpkin producing state. In Illinois, some 4800 ha of jack-o-lantern pumpkin (*Cucurbita pepo* L.) and 5700 ha of processing pumpkin (*Cucurbita moschata* Poir.) are grown annually (M. Babadoost, personal communication). Illinois accounts for >90% of the processing pumpkin production in the U.S. A warm-season vegetable, optimal soil temperature for pumpkin seed germination is 21–32 °C (Maynard and Hochmuth, 1997). In the central Midwest, pumpkin is often planted in June (Krammler et al., 2008; Wyenandt et al., 2011). Whether pumpkin could be grown successfully in a bioenergy feedstock/vegetable double-cropping system is unknown.

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Weed interference is a major challenge to commercial pumpkin production. Few herbicides can be applied over the crop, including clethodim, clomazone (processing pumpkin only), DCPA, ethalfluralin, halosulfuron, and sethoxydim (Jahala et al., 2013). These herbicides suppress a relatively narrow spectrum of weed species. Halosulfuron is the only registered herbicide that can be applied postemergence which controls some broadleaf weed species; however, crop injury is a risk (Krammler et al., 2008). Considerable interest exists in using rye (*Secale cereale* L.) or rye + legume mixtures in pumpkin production as a weed management tactic (Harrelson et al., 2007; Vanek et al., 2005; Wyenandt et al., 2011). Tillage, including interrow cultivation prior to vining, has been a standard pumpkin production practice. Interest in no-till pumpkin production has been on the rise in recent years; however, Walters and Young (2012) characterize the increased reliance on the few herbicides in no-till systems. The extent to which annual bioenergy feedstock production influences the weed community and weed control in double-cropped pumpkin is unknown.

The objective of the study was to compare crop productivity and weed communities in different pumpkin production systems, varying in tillage, cover crop, and bioenergy feedstock/pumpkin double-cropping.

## 2. Materials and methods

### 2.1. Site description

Three field experiments were conducted in the summers of 2010, 2011, and 2012 at the University of Illinois Crop Sciences Research and Education Center, Urbana, IL. Separate fields were used for each experiment. The soil at each site was Flanagan silt loam (fine, smectitic, mesic Aquic Argiudoll) averaging 4.1% organic matter and pH of 5.7. In all years, the previous crop was soybean. The following species were observed at low to moderate plant population densities throughout each field: common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.), ivyleaf morningglory (*Ipomoea hederacea* Jacq.), prostrate knotweed (*Polygonum aviculare* L.), and waterhemp (*Amaranthus rudis* Sauer). Fields were irrigated as needed to facilitate rapid crop emergence and offset abnormally low rainfall.

#### 2.1.1. Experimental approach

Four pumpkin production systems were tested in 2010. The conventional system was preceded by an over-winter fallow period, then seedbed preparation involved a two-pass operation of a field cultivator immediately preceding pumpkin planting, followed by interrow cultivation just prior to plant vining. The no-till system also was preceded by an over-winter fallow period, but without tillage operations before or after planting. The cover crop system involved a previous-year early-fall planting of a '*HiRye 500*' rye and '*VNS (2010 only, Variety Not Stated) and Purple Bounty (2011 & 2012, USDA)*' hairy vetch (*Vicia villosa* Roth) mixture drilled at 100 kg seed ha$^{-1}$, on 17.8-cm rows. The following spring, the cover crop was treated with a postemergence burndown application of glyphosate (1262 g ae ha$^{-1}$) and carfentrazone (35 g ai ha$^{-1}$) in mid-May. Approximately two weeks later, the cover crop was flattened with a custom-fabricated roller-crimper developed according to specifications identified by the Rodale Institute (Mirsky et al., 2009). The feedstock no-till system was similar to the cover crop system, in that the rye + hairy vetch mixture was seeded similarly the previous fall. However, the feedstock was allowed to grow to within two days before pumpkin planting, then the feedstock was cut 5 cm above the soil surface and removed from plots. Tillage operations were not performed in the no-till system. A fifth pumpkin production system, the feedstock tillage system, was added as a treatment in 2011 and 2012. The feedstock tillage system was identical to the feedstock no-till system, with the exception that after feedstock removal, seedbed preparation involved two passes each of a disk and field cultivator, followed by interrow cultivation just prior to plant vining. In order to isolate the effect of the rye + hairy vetch on cropping system parameters, fertility management was maintained identical across treatments by not applying fertilizer. Dates of field activities are identified in Table 1.

**Table 1**
Timeline of activities in pumpkin cropping system studies conducted over a 3-year period in Urbana, IL.

| Activity | 2009–10 | 2010–11 | 2011–12 |
|---|---|---|---|
| Cover crop/feedstock planting | 29-Sep | 21-Sep | 12-Oct |
| Cover crop burndown | 14-May | 18-May | 14-May |
| Cover crop rolling | 25-May | 1-Jun | 23-May |
| Feedstock harvest | 26-May | 1-Jun | 23-May |
| Preplant N sampling | 20-May | 17-May | 14-May |
| Preplant soil water sampling | 19-May | 17-May | 14-May |
| Pumpkin planting | 27-May | 3-Jun | 6-Jun[a] |
| PRE herbicide application | 28-May | 3-Jun | 23-May |
| Interrow cultivation | 12-Jun | 12-Jun | 6-Jun |
| Weed counts before POST | 16-Jun | 24-Jun | 22-Jun |
| POST herbicide application | 17-Jun | 30-Jun | 22-Jun |
| Interrow cultivation | 17-Jun | 17-Jun | 26-Jun |
| Weed counts after POST | 28-Jun | 17-Jul | 6-Jul |
| Pumpkin harvest | 15–20 Sept | 15–18 Sept | 1–11 Oct |

[a] June 6 was replanting of failed plantings on May 23 and May 29 due to seed predation.

Cropping system treatments were arranged in a randomized complete block design with four replications. Each experimental unit (i.e. plot) measured 6.1 m wide by 12.2 m long. A 9.0 m alley was established between blocks to allow for cultivation treatments. A 3.0-m alley was established between plots within a block to allow for late-season foliar fungicide applications per University of Illinois recommendations (M. Babadoost, personal communication). In late May or early June of each year, seed of 'Dickenson' processing pumpkin was planted 3.2 cm deep in two 76-cm spaced rows, 12.2 m in length, down the center of each plot using a no-till vacuum planter (Monosem NG+ no-till planter; Monosem, Inc., Edwardsville, KS) at 26-cm in-row seed spacing. Two weeks after crop emergence, plants were thinned to on average 52-cm in-row plant spacing.

Within one day of planting, all plots were treated with a postemergence application of glyphosate at 867 g ae ha$^{-1}$ to control emerged weeds. At this time, a preemergence application of clomazone at 841 g ai ha$^{-1}$ was made. Approximately three weeks after planting, halosulfuron-methyl was applied at a rate of 53 g ai ha$^{-1}$ with 0.5% (v/v) of non-ionic surfactant.

### 2.2. Data collection

Immediately before the glyphosate burndown application in the cover crop system, plants were clipped 5 cm above the soil surface within two 0.25 m$^{-2}$ sampling frames per plot, then oven-drying samples to constant mass to calculate dry matter yield. In the two feedstock systems, the same sampling approach was used to determine dry matter yield of the feedstock at the time of feedstock harvest.

Relative to the conventional system, crop stunting was assessed three and six weeks after planting (e.g. plants 1/10 the size of the conventional system were scored 10% crop stunting, plants 1/4 the size of the conventional system were scored 25% crop stunting, etc.). At the time of pumpkin harvest, fruits weighing greater than 0.5 kg with a well-developed skin (i.e. could not be punctured with a fingernail) were considered marketable. All marketable fruits were harvested, counted, and weighed by plot. Farmgate value of each

**Table 2**
Monthly mean air temperature and water supply (precipitation + irrigation) departure from the 30-year average for field trials in Urbana, IL from 2010 to 2012 (Illinois Climate Network, 2013).

| Month | Departure from average | | | | | |
|---|---|---|---|---|---|---|
| | Air temperature (C) | | | Water supply (cm) | | |
| | 2010 | 2011 | 2012 | 2010 | 2011 | 2012 |
| January | −3.3 | −2.5 | 3.2 | −2.1 | −3.6 | 2.8 |
| February | −3.2 | −0.6 | 2.5 | −1.4 | 4.1 | −2.6 |
| March | 1.4 | 0.1 | 7.5 | 0.2 | −3.7 | −3.1 |
| April | 3.2 | 0.7 | 1.1 | −4.1 | 9.5 | −3.5 |
| May | 0.9 | −0.6 | 3.0 | −1.5 | 0.3 | −2.8 |
| June | 1.5 | 0.6 | 0.1 | 10.5 | 0.0 | −3.6 |
| July | 0.9 | 3.0 | 3.8 | 2.0 | −1.0 | −5.5 |
| August | 2.0 | 1.2 | 0.3 | −5.4 | −5.1 | 4.6 |
| September | 0.6 | −1.3 | −0.9 | 0.0 | −1.1 | 6.4 |
| October | 1.2 | 0.7 | −1.6 | −5.6 | −2.2 | 5.4 |
| November | 0.1 | 1.9 | −0.6 | 0.4 | 2.6 | −6.6 |
| December | −4.0 | 3.1 | 3.7 | −0.4 | 0.0 | −1.7 |

cropping system was determined by multiplying pumpkin yield by pumpkin cash rate, and for double-cropping systems, adding the product of dry feedstock biomass and feedstock cash rate. Pumpkin cash rate was \$44 $Mg^{-1}$ of marketable fruit (M. Babadoost, personal communication). Estimates of feedstock cash rate vary from \$40 to \$60 $Mg^{-1}$ of dry biomass (U.S. DOE, 2011); in this analysis feedstock cash rate was \$50 $Mg^{-1}$.

Weed seedlings were counted in four 0.25-$m^{-2}$ sampling frames randomly placed throughout each plot before, and several weeks after, postemergence herbicide application. At the time of 2011 and 2012 pumpkin harvest, fresh aboveground weed biomass was harvested from four 0.25-$m^{-2}$ sampling frames randomly placed throughout each plot and weighed.

Soil samples were collected shortly before pumpkin planting, approximately four weeks after planting, and following pumpkin harvest (2011 and 2012 only). Five 2.0-cm diameter soil cores were collected to a depth of 25 cm for each plot. Soil cores used for nitrogen analysis were dried, ground, and concentrations of $NO_3$-N and $NH_4$-N were determined (A & L Great Lakes Laboratories, Inc., Fort Wayne, IN). Soil water was determined gravimetrically from cores taken for that purpose. Dates of sampling activities are identified in Table 1.

### 2.3. Statistical analyses

Since the feedstock tillage treatment was not tested in 2010, analyses were performed within each year. Diagnostic tests of residuals indicated weed population density met assumptions of homoschedasticity and normality following log transformation, while other response variables met ANOVA assumptions without transformations. To determine the effect of cropping system on soil N, soil water, weed population density, weed biomass, crop stunting, crop yield, and farmgate value, data were analyzed using general linear models fit by restricted maximum likelihood. Treatment means were compared using protected, Bonferroni-corrected multiple comparisons at $\alpha = 0.05$. All analyses were performed in SYSTAT version 13.00.05 (SYSTAT Software Inc., 2009).

## 3. Results and discussion

Conditions late spring and throughout the summer were generally warm and often relatively dry for central Illinois. For instance, mean monthly air temperature was greater than the 30-year average for the period of March through October, with few exceptions (Table 2). The 2012 season was unusually warm beginning in January and was identified as the second warmest year on record for Champaign County, Illinois. Two of the first three months of each year experience below-average water supply (Table 2). Rainfall patterns following pumpkin planting differed greatly by year, too. In order to accumulate 20 cm of total water after planting, 26, 51, and 81 days were needed in 2010, 2011, and 2012, respectively. Even with supplemental irrigation, annual water supply each year was below the 30-year average of 104 cm.

### 3.1. Biomass productivity

Cover crop biomass yield was 6.4, 11.2, and 10.4 Mg $ha^{-1}$ in 2010, 2011, and 2012, respectively. Feedstock biomass yield averaged 7.5, 13.1, and 9.1 Mg $ha^{-1}$ in 2010, 2011, and 2012, respectively. Rye dominated the rye + hairy vetch mixture, as evidenced by rye accounting for 95% of the biomass in samples. Overall, biomass yield of the feedstock was comparable to yield of 'Shawnee' switchgrass, but approximately one-half the yield of a hybrid switchgrass (U.S. DOE, 2011).

### 3.2. Soil water and nitrogen

Prior to pumpkin planting, feedstock systems had lower gravimetric soil water content than conventional and no-till systems in two of three years (data not shown); the exception being in 2011 when abnormally high rainfall was observed in April, resulting in similar soil water content across all systems at the May sampling date. Also, surface residues in the cover crop system often conserved soil water after planting. For instance, gravimetric soil water content was higher in the cover crop system in 2010 and 2011 compared to other systems during pumpkin growth.

Although crop production systems had no effect on $NH_4$-N before pumpkin planting or after pumpkin harvest, an effect on $NO_3$-N was observed early. Concentration of $NO_3$-N near pumpkin planting was ∼3-times higher in conventional and no-till systems, compared to the cover crop or feedstock systems (data not shown). Spring N sequestration by winter cover crops has been shown to reduce $NO_3$-N losses in summer annual cropping systems (Kaspar et al., 2012). Heggenstaller et al. (2008) found a double-cropping system utilizing triticale grown overwinter as a feedstock captured more $NO_3$-N and reduced soil inorganic N, in both the spring and fall, compared to corn alone. Results of the present study suggest bioenergy feedstock/pumpkin double-cropping systems may reduce $NO_3$-N leaching during the spring; however, fertilizer inputs during the summer may need to be increased, relative to the conventional system, to maximize pumpkin yield.

### 3.3. Weed communities

Cropping systems without tillage had among the highest weed population densities in pumpkin. Regardless of sampling time, the no-till system had the highest weed population density in 2010 (Table 3). In 2011 and 2012, the feedstock no-tillage system had among the highest weed population densities. In contrast, the conventional and feedstock tillage systems had among the lowest weed population densities. These results are not surprising, since tillage provides an additional mortality factor that few emerged annual weeds can escape.

Did lower early-season weed population density result in reduced weed biomass later? No. Weed biomass at the time of pumpkin harvest was similar across all cropping systems (Table 3). Late-season weed biomass averaged 143 g $m^{-2}$ in 2011 to 1560 g $m^{-2}$ in 2012. Despite utilizing a combination of cultural, mechanical, and chemical weed control tactics, excessive weed biomass observed in all cropping systems highlights the significant

**Table 3**
Total weed population density before and after POST herbicide application, and aboveground fresh biomass at pumpkin harvest (2011 and 2012 only).[a]

| Cropping system | 2010 | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|
| | Density before POST (no. $m^{-2}$) | Density after POST (no. $m^{-2}$) | Density before POST (no. $m^{-2}$) | Density after POST (no. $m^{-2}$) | Biomass at harvest (g $m^{-2}$) | Density before POST (no. $m^{-2}$) | Density after POST (no. $m^{-2}$) | Biomass at harvest (g $m^{-2}$) |
| Conventional | 1.1b | 0.4c | 2.9b | 2.4ab | 133a | 12.9ab | 0.9b | 1581a |
| No-till | 8.1a | 6.3a | 5.1ab | 2.0ab | 83a | 15.9ab | 14.9a | 2769a |
| Cover crop | 0.8b | 0.3c | 1.3b | 0.9b | 218a | 8.0ab | 13.1a | 795a |
| Feedstock tillage[b] | – | – | 2.0b | 4.5ab | 153a | 4.1b | 0.9b | 1180a |
| Feedstock no-till | 1.7b | 1.8b | 21.6a | 11.9a | 123a | 40.4a | 17.6a | 1168a |

[a] Mean separation within columns by protected, Bonferroni-corrected multiple comparisons at $\alpha = 0.05$.
[b] Feedstock tillage system was not included in 2010.

**Table 4**
Plant stunting (relative to conventional cropping system) 3 and 6 weeks after planting (WAP), fruit number, and pumpkin yield.[a]

| Cropping system | 2010 | | | | 2011 | | | | 2012 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stunting 3WAP (%) | Stunting 6WAP (%) | Fruit no. (no. $ha^{-1}$) | Yield (Mg $ha^{-1}$) | Stunting 3WAP (%) | Stunting 6WAP (%) | Fruit no. (no. $ha^{-1}$) | Yield (Mg $ha^{-1}$) | Stunting 3WAP (%) | Stunting 6WAP (%) | Fruit no. (no. $ha^{-1}$) | Yield (Mg $ha^{-1}$) |
| Conventional | 0b | 0c | 8168a | 57.1a | 0c | 0d | 7468a | 43.9ab | 0b | 0b | 7097a | 36.1a |
| No-till | 6b | 0c | 7495a | 52.1ab | 0c | 0d | 7434a | 47.4a | 0b | 0b | 6290ab | 29.1ab |
| Cover crop | 28a | 50a | 5949a | 30.3c | 56a | 73a | 4608a | 21.4c | 21a | 25a | 5449ab | 23.3ab |
| Feedstock tillage[b] | – | – | – | – | 18b | 23c | 6829a | 41.3ab | 10ab | 26a | 6593ab | 32.4a |
| Feedstock no-till | 41a | 26b | 6487a | 37.6bc | 26b | 35b | 6559a | 36.9b | 20a | 39a | 3969b | 14.4b |

[a] Mean separation within columns by protected, Bonferroni-corrected multiple comparisons at $\alpha = 0.05$.
[b] Feedstock tillage system was not included in 2010.

challenge weeds pose to commercial pumpkin production (Walters and Young, 2012).

### 3.4. Pumpkin productivity

The cover crop and feedstock systems stunted early-season pumpkin growth. Greatest crop stunting (up to 73%) occurred in the cover crop system (Table 4). The feedstock no-till system stunted pumpkin up to 41%, whereas the feedstock tillage system stunted pumpkin growth 26% or less. Pumpkin growth in the conventional and no-till systems was comparable. How pumpkin growth responses compare to previous research on cover crop residues is difficult to ascertain, since existing literature focuses primarily on fruit yield rather than plant growth or development.

Marketable fruit number in the conventional system averaged 8170, 7470, and 7100 fruits $ha^{-1}$ in 2010, 2011, and 2012, respectively. Fruit number was similar across cropping systems, with two exceptions; compared to the conventional system, fruit number was lower in the cover crop system in 2011 and feedstock no-till system in 2012 (Table 4).

The conventional and no-till systems produced among the highest marketable pumpkin yields, averaging 54.6, 45.7, and 32.6 Mg $ha^{-1}$ in 2010, 2011, and 2012, respectively. These yields are within the range of jack-o-lantern pumpkin yields observed in the Midwest (Walters and Young, 2012), but near or below the industry average of 58 Mg $ha^{-1}$ for processing pumpkin (Babadoost, personal communication). Yield in feedstock systems was dependent on tillage. The feedstock tillage system yields were comparable to the conventional system (Table 4). In contrast, the feedstock no-till system reduced 2012 pumpkin yield compared to the conventional system. The cover crop system was one of the lowest yielding systems observed, with yields ranging from 49% to 65%

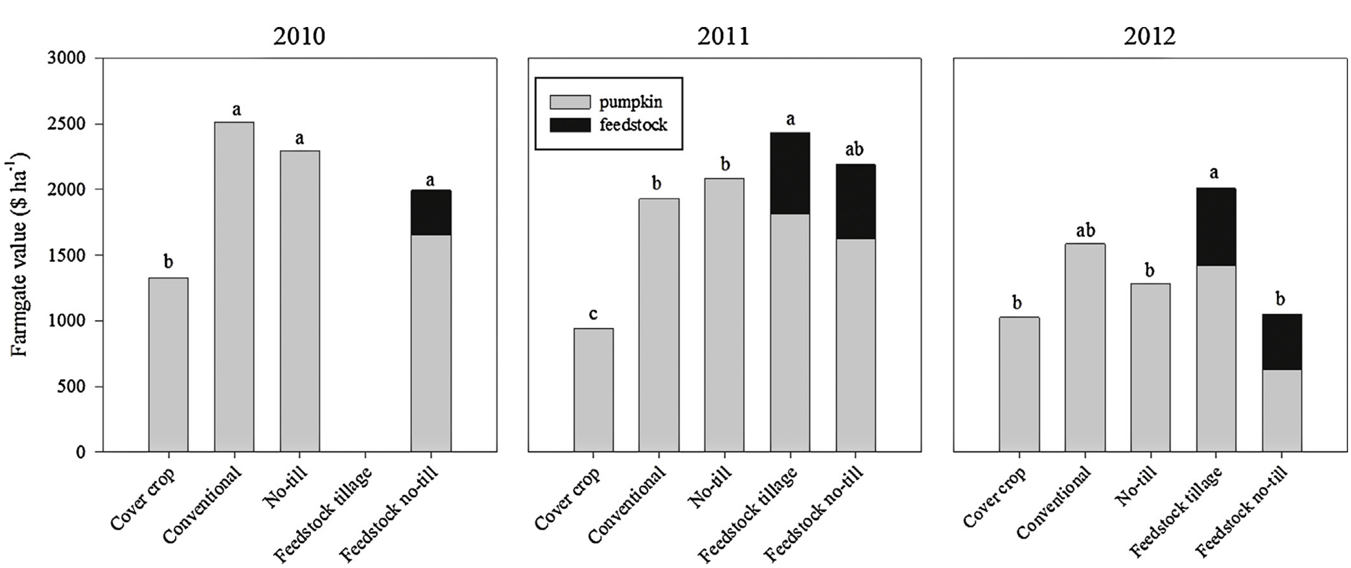


**Fig. 1.** Farmgate value of processing pumpkin, plus feedstock biomass in double-cropping systems, in pumpkin production systems tested in Urbana, IL, 2010–2012. Mean separation within years by protected, Bonferroni-corrected multiple comparisons at $\alpha = 0.05$. Feedstock tillage system was not included in 2010.

of the conventional system. Yield of jack-o-lantern pumpkin in fall-seeded, spring-killed rye + hairy vetch was comparable to or exceeded pumpkin yield in a bare soil control when cover crop residues were less than 4 Mg $ha^{-1}$ (Wyenandt et al., 2011). Rye may not affect certain cash crops at moderate residue rates, but can negatively affect crop production as residue rates increase (Mirsky et al., 2012). Based on the present work, there appears to be a threshold above which processing pumpkin yield is compromised by cover crop biomass, perhaps between 4 and 6 Mg $ha^{-1}$ of rye + hairy vetch biomass. Poor crop establishment (Teasdale et al., 2008), allelopathy (Barnes and Putnam, 1983), and soil N immobilization (Wells et al., 2013) have been identified as factors accounting for poor plant performance in rye-based cover crop systems.

### 3.5. Farmgate value

Farmgate values between the conventional and no-till systems were comparable. Assuming a pumpkin cash rate of $44 $Mg^{-1}$, farmgate value of these two systems averaged $2400, $2010, and $1430 $ha^{-1}$ in 2010, 2011, and 2012, respectively. However, these systems were not the most profitable. Farmgate value, biomass plus pumpkin, in the feedstock tillage system was comparable to, or exceeded, farmgate value of the conventional system (Fig. 1). The same cannot be said of the feedstock no-till system, because farmgate value of the system was less than the conventional system in 2012. The effect of tillage on feedstock system performance likely is driven in part by the fact that tillage killed some early-season weeds that otherwise persisted in no-till systems. Tillage also facilitates nutrient cycling through decomposition of plant residues within the plow layer.

Integrating a bioenergy feedstock into a vegetable double-cropping system resulted in a new, value-added product. Using a theoretical ethanol conversion efficiency of 330 liters ethanol $Mg^{-1}$ of dry biomass (Wallace et al., 2005), feedstock systems could produce an average of 3260 liters of ethanol $ha^{-1}$. Assuming a retail price of $0.80 $liter^{-1}$ of ethanol, feedstock systems produced biomass that could result in ethanol valued at $2610 $ha^{-1}$.

## 4. Conclusions

Should a growing use of biofuels threaten the supply of feedstock available for biofuel production, bioenergy feedstock/vegetable double-cropping systems warrant closer study in the quest to achieve both food and fuel production. The feedstock tillage system tested in this research produced enough feedstock biomass to theoretically yield an estimated 3260 liters of ethanol $ha^{-1}$ without negatively affecting processing pumpkin yield. With the feedstock valued at $50 $Mg^{-1}$, the feedstock tillage system's farmgate value was comparable to, or exceeded, the conventional pumpkin production system currently used by growers. Weeds persisted in the feedstock tillage system, but no worse than in the conventional system. Moreover, potentially leachable soil N was reduced in the feedstock tillage system late-spring, compared to the conventional system. However, future research is needed to (1) improve weed control in pumpkin, (2) more fully understand nutrient dynamics when fertilization is increased to maximize pumpkin yield, and (3) as feedstock markets develop, quantify the economics of integrating bioenergy feedstock production into vegetable double-cropping systems.

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