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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.

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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

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