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No-till planting of pumpkin into a killed winter rye cover crop is a system used by growers in a number of states, including Indiana. Advantages mentioned by producers in addition to soil health benefits from the cover crop include cleaner pumpkins at harvest, and in rainy seasons, less mud in the field making a more pleasant experience for customers who pick pumpkins right from the field. There is interest in conducting more research in this production system at university research farms. The work reported here continues a project begun in 2019 to develop a workable system at the Pinney Purdue Ag Center for no-till pumpkin production after winter rye that can be used for demonstration and in future research to better understand and improve production practices. Common methods for killing rye in no-till systems include using a herbicide and roller-crimping so the trial included both methods.

Materials and Methods

The trial was conducted at the Pinney Purdue Ag Center near Wanatah, Indiana. The soil at the experimental site is a Tracy sandy loam. Results of the fall 2020 soil test are shown in Fig. 1.

Experimental plots were established in a stand of ‘Hazlett’ winter rye that had been drilled on Sept. 25, 2020, after soybean harvest. In early April, 2021, rye was 4-6 inches tall, tillering, and formed a thick solid stand in the rows.

The experiment included two establishment methods: direct-seed and transplant. Within each establishment method, three tillage treatments were arranged in a randomized complete block design with two replications (Fig. 2). Tillage treatments were applied to plots 20 ft. wide × 70 ft. long, in order to accommodate the large equipment available. The area used for crop production included five crop rows 5 ft. apart and 30 ft. long, in the middle of the 70-ft. tillage treatment. The experimental unit for data collection included 28 ft. of each of the center three ‘test’ rows, for a total area of 420 sq. ft. The outside two rows in each plot were ‘guard’ rows and no data were collected. A 6-ft. alley separated tillage plots. In the conventional tillage treatment, hereafter termed ‘BARE,’ rye termination began with tillage on Apr. 16, 2021, followed by four additional tillage operations to complete termination and prepare for planting. In the ‘HERB’ treatment, rye was treated with the herbicide glyphosate on May 12. At this time rye was at the boot stage and approximately 2-2.5 ft. tall. In this treatment crops were later no-till planted into the residue. In the ‘ROLL’ treatment, pumpkins were no-till planted and rye was killed by roller-crimping either just after seeding, or just before transplanting the crop. The variety in test rows was pumpkin (*Cucurbita pepo*) cultivar Bayhorse Gold. In direct-seeded plots pie pumpkins were planted in guard rows. In transplanted plots blue hubbard winter squash (*C. maxima*) cultivar Blue Magic was in the north guard row, and winter squash (*C. moschata*) cultivar Long Island Cheese was in the south guard row. Bayhorse Gold seed had been treated with FarMore F1 400 (mefenoxam, fludioxynil, azoxystrobin and thiamethoxam), Blue Magic and pie pumpkin seed with thiram, and Long Island Cheese seed was untreated.

Seedlings for transplants were started on May 28 in 50-cell round plug trays filled with Sungro Propagation Mix. On June 7 plants were moved outdoors to condition them for transplanting. Just prior to transplanting seedlings were fertilized with a solution containing 125 ppm N from Peter's Peat Lite Special, 20-10-20.

Field operations are listed in Table 1 and pesticide applications in Table 2. In the two direct-seeded replications pumpkins were planted using a John Deere Maxemerge planter set to drop seeds 10.15 inches apart (equivalent to 20,600 seeds/acre on a 2.5-ft. row spacing). Forty seeds were put in the hopper for each row. In ROLL and HERB treatments two 70-lb. sandbags were placed on each seeder unit to provide enough weight to create furrow of desired depth, about 1.5 inches. Emergence was recorded 7, 11, 17, and 20 days after seeding (DAS) and on July 1 plants were thinned to the desired population of 7 plants per row. In rows where fewer than 7 plants emerged, extra seedlings from other rows of the same treatment were transplanted in to establish the desired population. In the two transplanted replications greenhouse-grown pumpkin and squash seedlings were transplanted by hand on June 16, 4 ft. apart in rows.

Observations of plant growth, flowering and fruit development were made periodically by recording typical minimum and maximum number of leaves per plant, flower stage, and size of fruit.

In addition to preemergence and postemergence herbicides listed in Table 2, specific weed species were removed by hand from the center three test rows in each plot because they were present early in the season at high levels and were not controlled by the herbicides. Eastern black nightshade (*Solanum ptychanthum*) in all plots, and marestail (horseweed, *Erigeron canadensis*) and common lambsquarters (*Chenopodium album*) in HERB and ROLL plots were removed on July 15. The number of eastern black nightshade plants and the time to remove them were recorded for each plot. BARE plots were also hand-hoed on this date to remove small emerged weeds. Postemergence herbicides were applied to treatments based on presence or absence of large numbers of weeds that they would control: Sandea was applied to HERB treatments, and for transplants only, to BARE treatments to control pigweeds, primarily. GrassOut Max was applied to HERB and ROLL treatments to control annual grasses and volunteer rye that had sprouted from the cover crop.

Pumpkins were harvested on Sept. 18. Pumpkins at least 90% orange were considered marketable if not rotting and there were no holes through the rind; unmarketable orange fruit were classified as 'cull.' Pumpkins that had started to turn but were less than 90% orange were classified as 'turning.' Pumpkins larger than 5 inches in diameter but not turning were classified as 'immature.' Number and weight of fruit in each category were recorded. A few fruit had rotted before harvest; these were counted but not weighed. The average weight per marketable pumpkin, total weight and number per plot, and percent by weight and number of each category were calculated.

Emergence trends were summarized with treatments means and standard errors. Harvest and weed data were analyzed using ANOVA followed by mean separation using Fisher's protected least significant difference at $P \leq 0.05$. For harvest data, establishment method and tillage treatment were fixed effects and rep within establishment was a random effect. Because establishment method was not replicated, it is not possible to be sure that any observed differences between direct-seeded and transplanted plots are attributable to establishment method, but the results are reported to add to the available data on this topic. For weed data, rep and tillage treatments were fixed effects; establishment method was not included in analysis. Weed counts were square-root-transformed and weeding time was log-transformed to stabilize variances. ANOVAs were performed using the Fit Model platform of JMP Pro version 16.1.0 with personality standard least squares, and for harvest data, restricted maximum likelihood (REML) method.

Results and Discussion

Fig. 3 summarizes rainfall and temperature for the 2021 growing season. June was warmer and wetter than normal, leading to more favorable soil moisture at planting than in 2020. The first half of July was drier than normal. The last half of July through August was wetter than normal, followed by a dry period in the first half of September. Temperatures were good for pumpkin growth during the season and there was enough rain that irrigation was applied only once, just after planting.

Emergence

Warm moist soils led to very quick emergence of pumpkins in BARE plots: by 4 DAS cotyledons were visible. Pumpkins took longer to emerge and final emergence was lower in HERB and ROLL treatments than in BARE (Figs. 4 and 5); this was observed in 2020 also. The HERB and ROLL treatments also showed more variability in emergence. This could in part be due to seed predation. In BARE plots no evidence of seed predation was observed; in HERB plots an average of 17±13, and in ROLL plots an average of 6.5±5.5 eaten seeds were observed. Thirteen-lined ground squirrels were numerous and are the most likely seed predator. Plots with the least emergence were closest to the edge of the field. We also observed that the seed furrow was not consistently closed in HERB and ROLL plots; this could have influenced emergence. Soil temperature was also likely lower in no-till plots due to the residue coverage: the weather station at the research center reported 4-inch average soil temperatures of 78.9°F and 76.2°F under bare ground and grass, respectively, for the week after seeding. By 20 days after seeding (DAS) emergence averaged 84% in BARE, 26% in HERB, and 45% in ROLL treatments. At that point plants were thinned to the desired stand.

Plant Size

Differences in emergence timing contributed to observed differences in plant growth stage in direct-seeded plots. By 17 DAS, plants in BARE plots had 2 to 3 true leaves, plants in HERB plots were at the cotyledon to 2-leaf stage, and plants in ROLL plots were at the cotyledon to 1-leaf stage (data not shown). Transplanted pumpkins also developed more quickly in the BARE plots, where by 12 days after transplanting plants were at the 3- to 5-leaf stage, compared to HERB plots at the 3- to 4-leaf stage, and ROLL plots at the 2- to 4-leaf stage.

Yield and Fruit Size

Tillage and establishment means for marketable number and weight are shown in Table 3 and overviews of harvested pumpkins are shown in Fig. 6. The number and weight of marketable pumpkins were greatest in BARE plots. HERB and ROLL plots were similar and produced 70% of the marketable number and 63% of the marketable weight in BARE plots. Averaged across all tillage treatments, marketable yield was 2789 pumpkins and 21.8 tons per acre. Direct-seeded pumpkins produced 80% of the marketable number and weight produced by transplanted pumpkins; the difference was not statistically significant.

Table 4 shows total (marketable, turning, cull, and immature) pumpkin number and weight, and average weight per marketable pumpkin. Tillage effect on these yield components differed in the direct-seeded and transplanted plots. In direct-seeded plots, BARE treatments produced the highest total number and weight and the largest marketable fruit, and HERB and ROLL treatments did not differ significantly. In transplanted plots, BARE also produced the highest total number and weight, but HERB produced more weight than ROLL. In transplanted plots, average weight of a marketable pumpkin was not affected by tillage.

Weed Pressure

By July 15, Eastern black nightshade plants were more numerous in plots where the rye cover crop was killed by herbicide in May (HERB) or tillage in April (BARE) than where it was killed by roller-crimping in June (ROLL) (Figure 7A). There were 80 to 110 times as many nightshade plants in the HERB plots as in the ROLL plots. It took 3 to 4 times longer to remove the nightshade by hand in the plots with more plants (Figure 7B). As was observed in 2020, nightshade emerged in HERB plots before pumpkins were planted, and it was not controlled by postemergence herbicides.

Data were not collected on numbers or percent cover of other weed species, but observations indicated that common purslane and carpetweed escaped control and covered significant areas in HERB plots, but were not as heavy in ROLL or BARE plots. Volunteer cereal rye emerged by early July in HERB and ROLL plots. The post-applied grass herbicide appeared to suppress its growth. In contrast to 2020, marestail density was much lower in 2021, and handweeding in mid-July removed most of it quickly.

Soil Conditions

This project has not quantified changes in soil characteristics due to the tillage treatments, but observations are consistent with reports from many previous trials. There is reduced soil splash onto pumpkin leaves and fruit, improved water infiltration, and greater crumb soil structure in surface soil.

Summary and Conclusions

Pumpkins produced greater yield in conventional tillage than in no-till in this trial. The effects of tillage treatment on marketable yield were similar for direct-seeded and transplanted crops, with BARE plots producing 40% more by number and 58% more by weight than no-till plots. In direct-seeded plots, the BARE treatment produced the largest marketable pumpkins, 22% heavier than in no-till plots. In transplanted plots pumpkin size was not affected by tillage treatments. Weed pressure differed among the tillage treatments before in-season control measures in July: HERB and BARE had more weed pressure than ROLL. For direct-seeded crops, emergence was slower and more variable in no-till treatments than in conventional tillage. The longest delay in emergence occurred where rye was killed by roller-crimping.

In 2020 we concluded that to improve the no-till system it would be important to improve planting depth and covering of seed in direct-seeded plots; assure adequate soil moisture during planting and establishment; and achieve better weed control, in particular for marestail and eastern black nightshade. In 2021, we did improve planting depth by adding weight to seed units, assured adequate soil moisture by irrigating right after planting, were fortunate to have a field with less marestail, and removed eastern black nightshade earlier in the season. Key challenges that remain for direct-seeded no-till pumpkins are achieving good furrow closure and reducing seed predation. For both direct-seeded and transplanted pumpkins, the next steps include exploring ways to overcome other factors that reduce growth and yield. Certainly pumpkin yield is not the only measure of success in this system–the benefits of reduced tillage and biomass input to the soil that have been documented by many others also have much value.

Acknowledgments

G. Tragesser and Pinney-Purdue Agricultural Center staff managed field operations. B. Hoffman and R. Nemit assisted with crop management, data collection and entry; students from the Valparaiso University Biology Club assisted with harvest. J. Rorick, Purdue University, provided advice on cover crop and equipment management and observations of soil conditions.

Table 1. Schedule of field and greenhouse activity for 2021 no-till pumpkin, Pinney Purdue Ag Center, Wanatah, IN.

DATE	Operation
4/9/21	broadcast 50 lb N/acre; urea
4/16, 5/13, 5/21, 6/3, 6/11/21	tillage (BARE treatment)
5/28/21	seed in greenhouse
6/11/21	seed in field
6/14/21	roll/crimp rye
6/16/21	transplant
6/16-17/21	irrigate, 0.5 in., overhead sprinkler
7/2/21	side dress 60 lb N/acre; UAN
7/15/21	handweed
9/18/21	harvest

Table 2. Pesticide applications for 2021 no-till pumpkin, Pinney Purdue Ag Center, Wanatah, IN.

DATE	PRODUCT NAME	ACTIVE INGREDIENT	MANU-FACTURER	PEST	RATE
5/12/21	Durango[z]	glyphosate	Corteva	rye, weeds	24 fl. oz./A
6/15/21	Strategy Dual Magnum[y]	ethalfluralin+clomazone s-metolachlor	Loveland Products Syngenta	weeds	3 pt./A, 1 pt./A
7/9/21	Arctic	permethrin	Winfield Solutions	Striped cucumber beetle, squash bug, squash vine borer	8 fl. oz./A
7/9/21	Sandea[x]	halosulfuron	Gowan Co.	pigweed, velvetleaf	14.2 g/A
7/19/21	Arctic	permethrin	Winfield Solutions	squash vine borer	8 fl. oz./A
7/26/21	GrassOut Max[w]	clethodim	Agrisel USA, Inc.	emerged grasses	8 fl oz./A
7/30/21	Quintec Bravo weather stick	quinoxyfen chlorothalonil	DuPont Dow Agrosciences	powdery mildew, downy mildew, black rot	6 fl. oz./A 3 pt./A
8/12/21	Arctic	permethrin	Winfield Solutions	squash bug	8 fl. oz./A
8/13/21	Rally 40 WSP	myclobutanil	Dow AgroSciences	powdery mildew	5 oz./A
8/13/21	Ranman 400SC	cyazofamid	Summit Agro USA	downy mildew	2.75 fl. oz./A

[z]Durango was applied only to HERB treatment.
[y]Strategy and Dual Magnum were broadcast in direct-seeded plots and applied only between rows in transplanted plots.
[x]Sandea was applied only to HERB treatments and to transplanted BARE treatments.
[w]GrassOut was applied only to HERB and ROLL treatments.

Table 3. Main effects of tillage treatment and establishment method on number and weight of marketable pumpkins Pinney Purdue Ag Center, Wanatah, IN, 2021.[z]

Tillage treatment	Marketable pumpkin no.		Marketable pumpkin wt.	
	per plot	*per acre*	*lb/plot*	*ton/acre*
BARE	33.8 A	3500	558 A	28.9
HERB	24.3 B	2515	370 B	19.2
ROLL	22.8 B	2359	334 B	17.3
Establishment				
Direct-seed	23.8 A	2472	376 A	19.5
Transplant	30.0 A	3111	465 A	24.1

[z]Means for tillage treatment or establishment followed by the same letter do not differ significantly at P<.05 according to Fisher's Protected LSD. Per acre values are estimated by multiplying per plot (420 sq.ft.) values by 103.7.

Table 4. Total number and weight of pumpkins and average weight per marketable pumpkin for direct-seeded and transplanted pumpkins in three tillage treatments, Pinney Purdue Ag Center, Wanatah, IN, 2021.[z]

Tillage treatment	Direct-Seeded					Transplanted				
	Total no.		Total wt.		Ave. mkt. fruit wt.	Fruit no.		Fruit wt.		Ave. mkt. fruit wt.
	per plot	*per acre*	*lb./plot*	*ton/acre*	*lb.*	*per plot*	*per acre*	*lb./plot*	*ton/acre*	*lb.*
BARE	43.0 AB	4459	676 ACD	35.1	17.5 A	46.0 A	4770	689 AB	35.7	15.6 AB
HERB	28.5 C	2995	372 BEF	19.3	14.1 B	37.0 BC	3837	561 CE	29.1	16.0 AB
ROLL	27.5 C	2852	364 BEF	18.9	14.5 B	35.0 BC	3630	481 DF	25.0	14.6 AB

[z]Total includes marketable, turning, cull, and immature. Means for each response followed by the same letter do not differ significantly at $P<.05$ according to Fisher's Protected LSD. Per acre values are estimated by multiplying per plot (420 sq.ft.) values by 103.7.

Test	Value
OM	1.8%
pH	6.7
P*	90 ppm
K	135 ppm (6.5%)
Mg	210 ppm (32.7%)
Ca	650 ppm (60.8%)
CEC	5.3 meq/100g

Test	Value
S	10 ppm
Zn	4.9 ppm
Mn	54 ppm
Fe	50 ppm
Cu	1.5 ppm
B	0.3 ppm

Interpretation for Field Crops
Very High
High
Medium
Low

*Bray P1 equivalent

Figure 1. Fall 2020 soil test results for the experimental field.

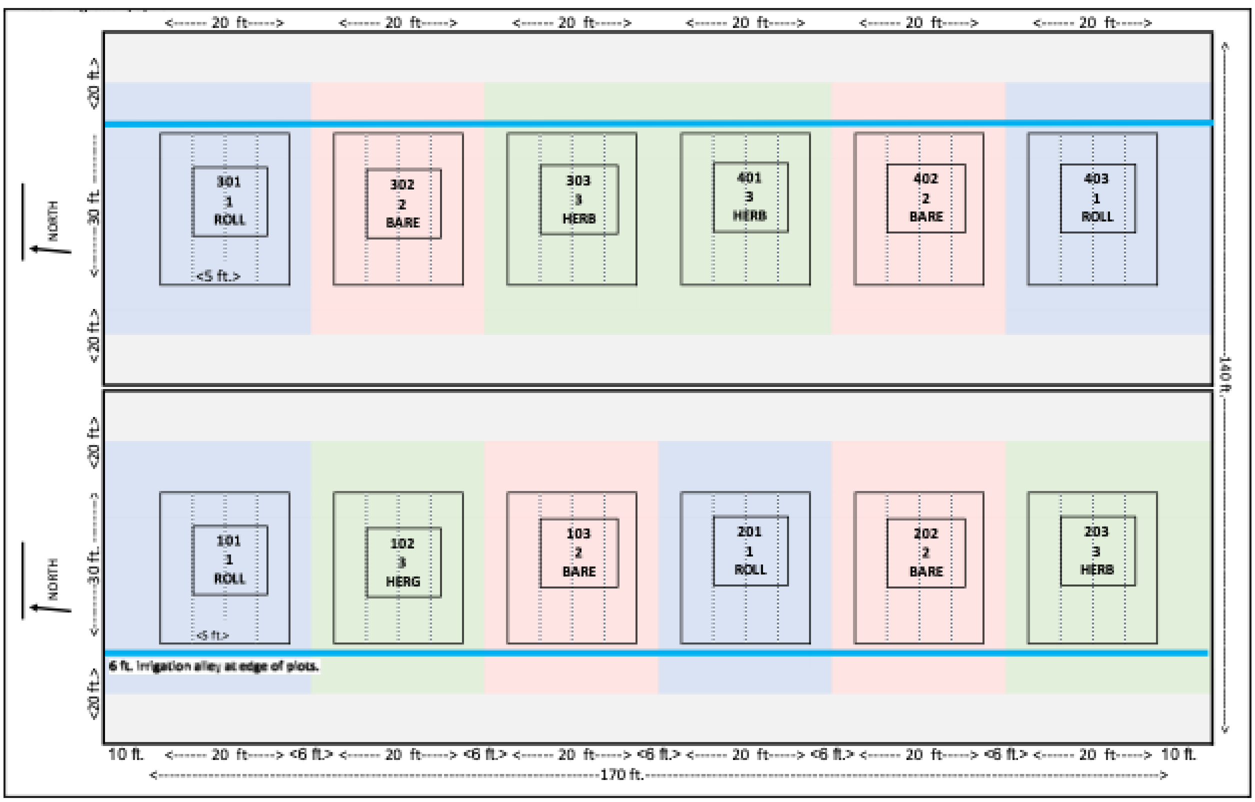


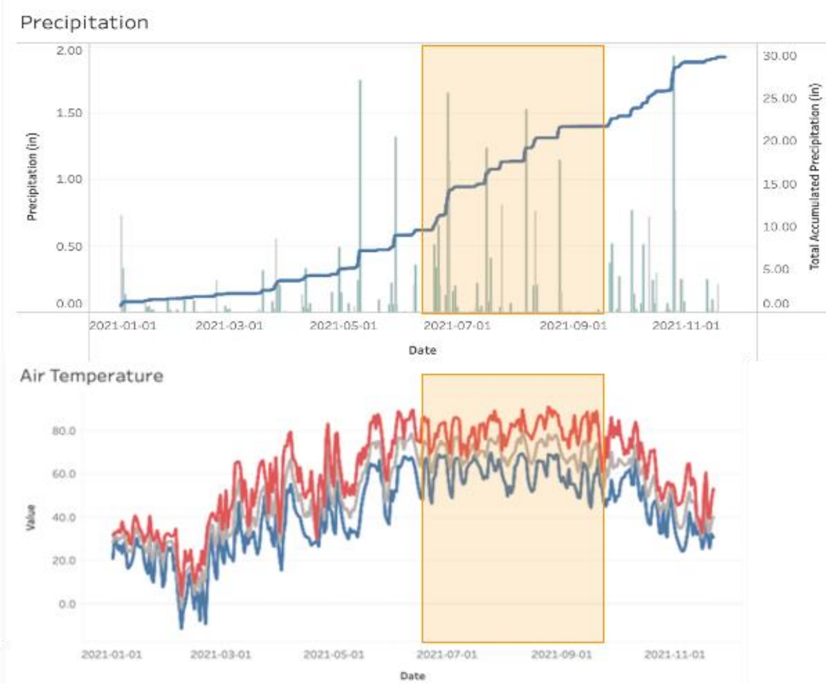
Figure 2. Diagram of experiment, Pinney Purdue Ag Center, Wanatah, IN 2021. Plots 101 through 203 were direct-seeded. Plots 301 through 403 were transplanted.

Rainfall	in.	DFN*
May	2.94	-0.68
June	4.78	0.84
July 1st half	2.49	-0.31
Jul-Aug.	6.44	0.61
Sept (1-19)	0.03	-1.69

Temperature	Ave.	DFN GDD†
May	57.3	-15
June	71.1	+93
July	70.6	-30
Aug.	72.1	115
Sept (1-19)	66.1	+33

*Departure from normal for May 3-30, May 31-June 27, June 28-July 18, July 19-Aug. 29, and Aug. 30-Sept. 19.
†Departure from normal for Growing degree days base 50.

Source: USDA NASS, Indiana Field Office https://www.nass.usda.gov/Statistics_by_State/Indiana/Publications/Crop_Progress_&_Condition/index.php acessed 11/22/2021



Source: Indiana State Climate Office. 2021. Purdue Mesonet Data Hub. https://ag.purdue.edu/indiana-state-climate/purdue-mesonet/purdue-mesonet-data-hub/. Accessed 11/22/2021.

Figure 3. Weather summary for 2021 at Pinney Purdue Ag Center, Wanatah. Sources: Temperature and precipitation from Indiana State Climate Office. Purdue Mesonet Data Hub. https://ag.purdue.edu/indiana-state-climate/purdue-mesonet/purdue-mesonet-data-hub/. Accessed 11/22/2021. Departures from normal from USDA National Agricultural Statistics Service, Indiana Field Office https://www.nass.usda.gov/Statistics_by_State/Indiana/Publications/Crop_Progress_&_Condition/index.php accessed 11/22/2021.

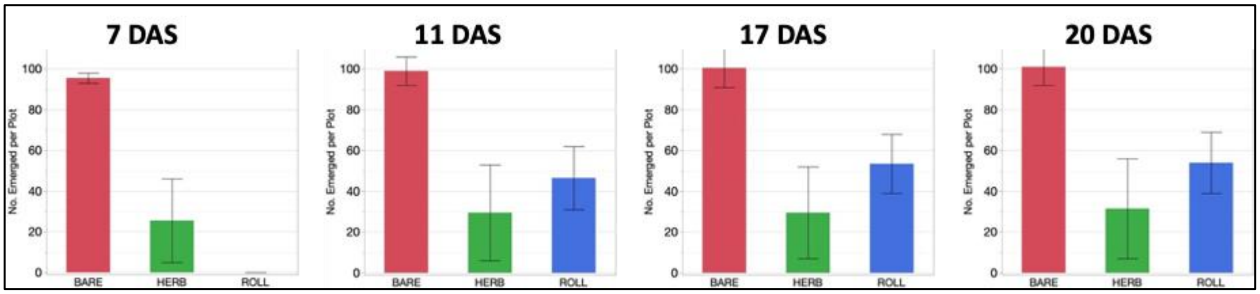


Figure 4. Emergence of pumpkins in three tillage treatments, 7, 11, 17 and 20 days after seeding (DAS), Pinney Purdue Ag Center, Wanatah, IN, 2021. BARE=conventional tillage; HERB=no-till planted into glyphosate-killed rye; ROLL=no-till planted into rye killed by roller-crimping after planting. 120 seeds planted per plot. Mean of two replications ± standard error.

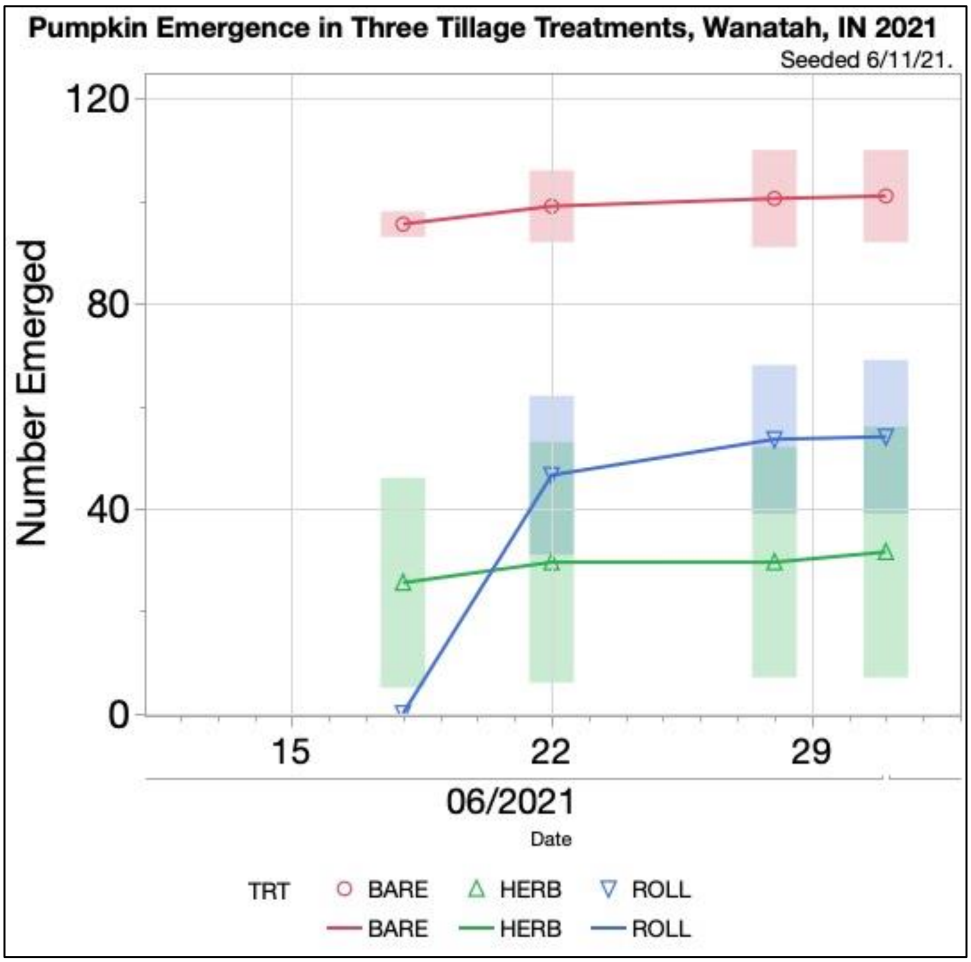
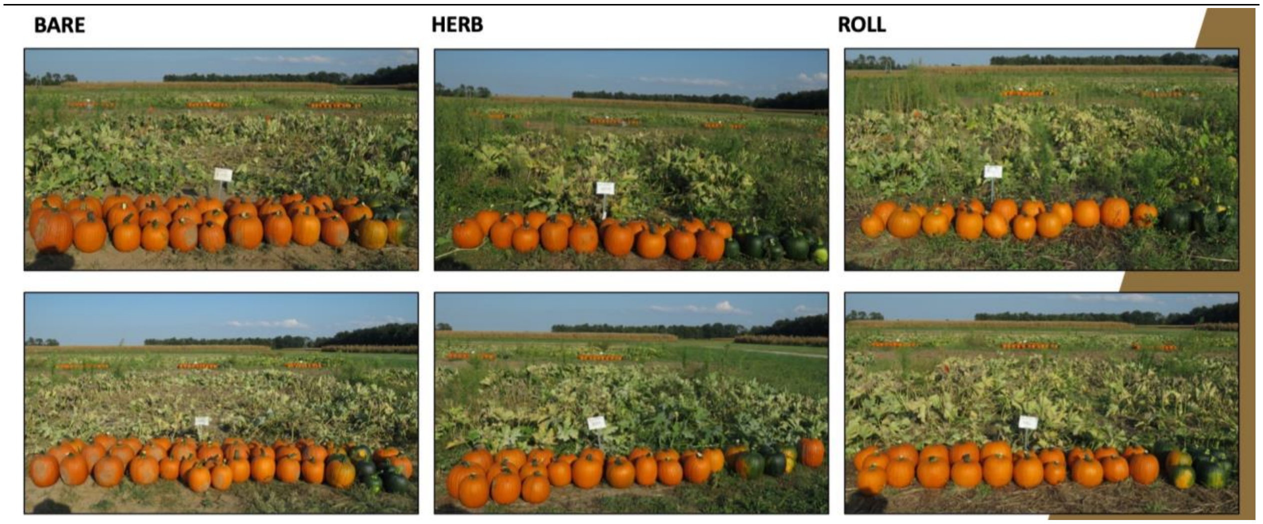
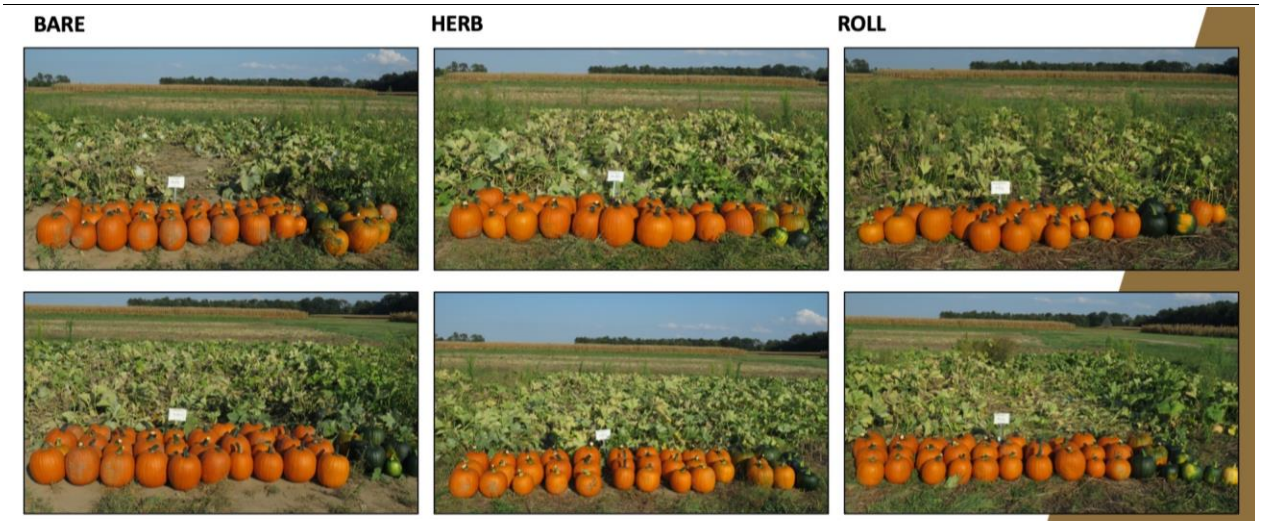


Figure 5. Emergence of pumpkin in conventional (BARE) and no-till (HERB and ROLL) plots, Pinney Purdue Ag Center, Wanatah, IN, 2021. HERB=rye cover crop killed with glyphosate before seeding. ROLL=rye cover crop roller-crimped after seeding. 120 seeds planted per plot. Mean of two replications ± standard error.

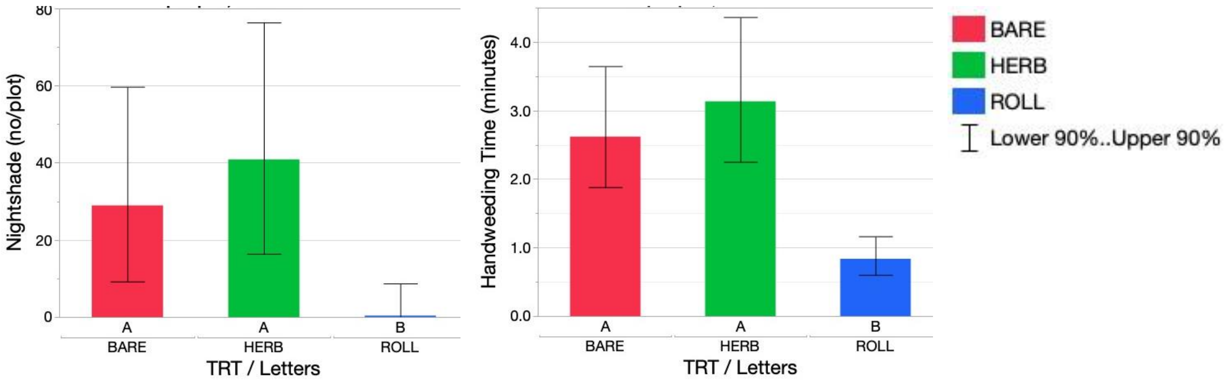


A.



B.

Figure 6. Overview of pumpkin harvest in three tillage treatments, Pinney Purdue Ag Center, Wanatah, IN, 2021. A. Direct-seeded plots. B. Transplanted plots.



A. B.

Figure 7. Mean eastern black nightshade number (A) and time to handweed pumpkins (B) in three tillage treatments. Bars labelled with the same letter do not differ significantly at P<.05 according to Fisher's protected LSD