ORGANIC FARMING RESEARCH FOUNDATION

Project report submitted to the Organic Farming Research Foundation:

Project Title:

Sorghum-sudangrass grown as a cover crop for organic no-till vegetable production, and as a hay crop for the organic market

FINAL PROJECT REPORT

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Project summary

The development of organic and conservation tillage-based vegetable production systems will offer growers in the United States new economic opportunities and promote resource conservation. The purpose of this research project was to assess the impact of including a summer crop that serves as both cover crop and marketable hay crop in an organic fall vegetable production system. Sorghum sudangrass [*Sorghum bicolor* (L.) Moench X *S. sudanense* (Piper) Staph] is commonly cultivated as a forage crop for grazing, hay, or silage and has the potential to produce abundant biomass, suppress weeds through physical and chemical interference, and decrease soil compaction as a summer cover crop. Field studies were conducted to determine the effects of sorghum sudangrass mowing frequency and biomass removal as hay on cover crop biomass production, weed suppression by cover crop residues, and cover crop re-growth in a subsequent cabbage (*Brassica oleracea* L. var. capitata) crop under conventional and no-till organic management. Small plots of cabbage were planted as a test crop in mow-killed sorghum sudangrass residues to determine if sorghum sudangrass mulch reduced cabbage head weight and time to maturity. Results suggest that harvesting a sorghum sudangrass hay crop early in the summer growing season did not affect suppression of broadleaf, annual weeds by the cover crop mulch in a fall cabbage crop. In this study, however, the presence of sorghum sudangrass led to reduced cabbage head weight. Sorghum sudangrass may not be suitable as a cover crop immediately prior to conventional or no-till organic fall cabbage production because of its capacity to re-grow following mechanical kill by mowing and its ability to produce chemicals that may harmful to direct-seeded and transplanted vegetable crops. Economic analysis indicates that harvest and sale of a single cutting of hay from a sorghum sudangrass summer cover crop can provide additional income to a farm enterprise.

Introduction

Conservation tilled organic vegetable production presents several economic opportunities for growers in the southeastern United States while promoting natural resource conservation. Organic fruit and vegetable sales total more than $2 billion annually and consumer demand has grown at a pace of approximately 20% per year throughout the past decade (Dimitri and Greene, 2002). Growers for this market often receive price premiums between 10 and 30% (Sok and Glaser, 2001) and studies comparing organic and conventional production indicate that organic production is equally or more profitable than conventional (Dimitri and Greene, 2002). Additional economic benefits of certified or non-certified organic vegetable production are available to growers who use conservation tillage practices eligible for incentive payments under the Conservation Security Program (CSP), Conservation Reserve Program (CRP), and other programs administered by the federal government. Though the majority of acreage currently under conservation tillage is in row crop production, recent studies suggest that conservation tillage practices can be beneficial to the production of horticultural crops (Hoyt et al., 1994).

Among the practices rewarded by conservation incentive programs is cover cropping, an important component of conservation tillage systems for vegetable production. Cover crops can reduce soil erosion (Hartwig, 1988), limit runoff and surface water pollution (Hall et al., 1984), improve soil physical properties (Lal et. al, 1991), and influence soil fertility by providing a source of N for subsequent crops (Hoyt and Hargove, 1986) and capturing soil mineral N to prevent loss to leaching (Ranells and Wagger, 1997). When rotated into organic production systems, cover crops may also provide alternatives to chemical inputs for pest management, as they have been demonstrated to suppress weeds (Weston and Duke, 2003; Creamer et al., 1996), disrupt pest and disease cycles (Hartwig and Ammon, 2002), and suppress nematode populations (McSorley et al., 1994; Mojtahedi et al., 1993). As many cover crop species are traditionally raised as forage crops, a portion of the cover crop produced may be sold as organic hay to the growing organic dairy and livestock industries. The premiums for organic hay are estimated at 10-15% and may be higher (Lehnert, 1998).

Previous cover crop research has focused primarily on winter annual crops, though summer annual cover crops have potential applications in many regions of the United States. In the southeastern US, for example, summer annual cover crops may be rotated between spring and fall production seasons. In a study by Abdul-Baki et al., (1997) comparable yields of fall broccoli were achieved in a no-till system utilizing summer cover crop mulch and a conventional tillage system. Morse (2000) examined the potential of summer cover crops to provide weed suppression and sufficient N for organically grown fall broccoli, finding increased yields under no-till cover crop mulch compared to no-till bare soil. This study demonstrated that fertility and weed management are two major challenges in the development of no-till organic vegetable production systems, as N and weed competition were both yield limiting factors.

Creamer and Baldwin (2000) evaluated six legume, two broadleaved, and five grass species suitable for use as summer cover crops in North Carolina. Among the crops evaluated in this study was sorghum sudangrass, *Sorghum bicolor* (L.) Moench X *S. sudanense* (Piper) Staph. As a summer cover crop, this species has the potential to produce abundant biomass (Creamer and Baldwin, 2000), suppress weeds through physical and chemical interference (Creamer and Baldwin 2000; Weston et al., 1989) and decrease soil compaction (Wolfe et al., 1998). Sorghum sudangrass is commonly cultivated as a forage crop for grazing, hay, or silage (Chamblee et al., 1995), and would, therefore, be suited to the dual application as cover crop and hay crop in organic conservation tillage vegetable production.

Sorghum sudangrass has demonstrated a poor response to mechanical kill methods, including mowing, undercutting, and rolling (Creamer and Dabney, 2002). This is a significant drawback to its inclusion in rotation with organic conservation tilled vegetables, though management techniques such as increased mowing frequency may help to improve crop response to mechanical kill. Another notable characteristic of sorghum sudangrass is its allelopathic potential. Many sorghum species naturally produce chemicals that can disrupt the growth of neighboring plants in a process called allelopathy. These chemicals may contribute to weed suppression by sorghum sudangrass (Weston and Duke, 2003; Weston, 1996; Forney et al., 1985; Putnam and DeFrank, 1983; Putnam et al., 1983). Sorghum sudangrass mulch, for instance, has been demonstrated to inhibit germination of summer annual weeds including common purslane (*Portulaca oleracea* L.), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and smooth crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.) (Putnam and DeFrank, 1983). In addition, sorghum sudangrass residues have been shown to suppress broadleaf weed populations in no-till planted alfalfa (*Medicago sativa* L.) (Forney et al., 1985).

Though chemicals produced by sorghum sudangrass can help control weeds, the toxicity of sorghum sudangrass may also negatively affect cash crops. Geneve and Weston (1988) reported that the growth of Eastern redbud (*Cercis canadensis* L.) seedlings was reduced when co-cultivated with living sorghum sudangrass and when residues of this species were incorporated into the growing medium for redbud transplants. With regard to suppression of crop seed germination, large seeded-vegetable crops including common bean (*Phaseolus vulgaris* L.), cucumber (*Cucumis sativus* L.), and pea (*Pisum sativum* L.) have demonstrated greater tolerance to the presence of sorghum sudangrass residues than small seeded vegetables such as tomato (*Lycopersicon esculentum* Mill.), radish (*Raphanus sativus* L.), and lettuce (*Lactuca sativa* L.) (Putnam and DeFrank, 1983). These results indicate that there is a potential risk of interference with a transplanted or direct-seeded crop in both tillage and no-till systems which include sorghum sudangrass as a cover crop. Additional assessments of cover crop-crop interactions are needed to promote the development of no-till production systems for a broader range of crops such as transplanted vegetables. McKeown et al. (1998) have suggested that due to species-specific cover crop influences relative to disease, nematodes, and allelopathy, risks introduced by a cover crop to a conservation tillage system should be assessed. Small scale study of a test crop planted in cover crop residues is one means by which such an assessment can be made.

Project objectives

The purpose of this project was to investigate the potential of sorghum sudangrass to serve as both summer cover crop and marketable hay crop preceding no-till production of organic fall cabbage. The original stated objectives of this project were to determine best management practices for a non-leguminous summer cover crop in a no-till fall vegetable production system and to evaluate the efficacy of cover crop mid-season cutting for sale as hay. Based on the results of a 2003 field trial, these objectives were narrowed to the following:

1. To determine if increased mowing frequency can improve sorghum sudangrass response to this method of mechanical kill
2. To determine if removal of sorghum sudangrass biomass as hay decreases its weed suppressive capacity in no-till and conventionally tilled organic fall cabbage
3. To assess the effect of incorporated and surface applied sorghum sudangrass residues on cabbage head weight and time to maturity

*4. To provide growers an economic comparison of the proposed hay/cover crop system with other cover crop and tillage options for fall vegetable production

*Objective added based on the Organic Farming Research Foundation (OFRF) review of the original research proposal.

Materials and Methods

Field experiments took place in 2004 at the Center for Environmental Farming Systems (CEFS) in Goldsboro, North Carolina and the Upper Piedmont Research Station (UPRS) in Reidsville, North Carolina. At Goldsboro, the experimental soil was a Wickham loamy sand with 0-2% slope (WhA), and in Reidsville, the experimental soil was a Vance sandy loam with 0-2% slope (VaB).

Table 1. Sorghum sudangrass (SS) management treatments applied at Goldsboro and Reidsville, NC.

Location	Treatment	Initial cutting height (m)	Hay removed	Mowing frequency	Subsequent cutting height (m)	Number of cuts in season	No-till mulch
Goldsboro	1	1.2-1.5	Yes	Low	1.2-1.5	3	SS
	2	1.2-1.5	No	Low	1.2-1.5	3	SS
	3	1.2-1.5	No	High	0.6	4 to 5[z]	SS
	4						wheat straw
Reidsville	1	1.2-1.5	Yes	Low	1.2-1.5	2	SS
	2	1.2-1.5	No	Low	1.2-1.5	2	SS
	3	1.2-1.5	No	High	0.6	3 to 4[y]	SS
	4						wheat straw

[z]In Goldsboro, tilled sub-plots were cut 4 times and no-till sub-plots were cut 5 times due to 2 week difference in time of final kill.
[y]In Reidsville, tilled sub-plots were cut 3 times and no-till sub-plots were cut 4 times due to 2 week difference in time of final kill.

Three sorghum sudangrass management treatments and one control treatment were replicated four times at each research location. After an initial cut was performed uniformly in all plots, three sorghum sudangrass management treatments were applied: (1) cut biomass removed from the field to simulate hay harvest, followed by low frequency mowing; (2) cut biomass left in the field, followed by low frequency mowing; (3) cut biomass left in the field, followed by high frequency mowing (Table 1). The control treatment was not planted with sorghum sudangrass.

On 25 May and 27 May, 2004, 4 x 6 m (12.75 x 20 ft) plots were established in Goldsboro and Reidsville, respectively. Prior to planting, 89 kg N/ha (100 lb N/A) as soybean meal and 1.8 kg B/ha (2 lb B/A) were applied at each field site. Sorghum sudangrass 'Haychow' was seeded at a rate of 35 kg/ha (40 lb/A) using a Sukup drill (Sukup Manufacturing Company, Sheffield, IA) in Goldsboro or Bush Hog® 7690 (Bush Hog®, LLC, Selma, AL) in Reidsville. At 36 (Goldsboro) and 40 (Reidsville) days after planting, the crop had reached a height of 1.2-1.5 m (3-4 ft), and a simulated hay cutting operation was conducted using a flail mower. The stubble height was 7.5-10.0 cm (3-4 in) to encourage re-growth. Stubble height in all subsequent mowing events, also performed with a flail mower, was 2.5-5.0 cm (1-2 in). Hay biomass was removed from designated plots to simulate hay harvest using hand rakes. Additional cutting operations in each plot were conducted each time the crop again reached a height of 1.2-1.5 m in low mowing frequency treatments or a height of 0.6 m in the high mowing frequency treatment.

Prior to transplanting fall cabbage, each whole plot was split into two sub-plots: conventional and no-till. Conventionally tilled sub-plots were mowed for the final time approximately two weeks prior to transplanting fall cabbage and rototilled twice before transplanting in order to incorporate sorghum sudangrass residues. The conventional tillage sub-plots not planted with sorghum sudangrass were subject to the same tillage regime. Emerged weeds were removed from conventionally tilled sub-plots immediately prior to the transplanting operation by flame weeding (Goldsboro) or tillage (Reidsville). No-till sub-plots were mowed with a flail mower to a stubble height of 2.5-5.0 cm (1-2 in) immediately prior to the transplanting operation. In no-till sub-plots without sorghum sudangrass, weeds were sprayed with glyphosate (N-phosphonomethyl glycine) two weeks prior to transplanting in order to eliminate any weeds that had emerged in the control treatment. A greenhouse study had previously demonstrated that wheat straw did not reduce cabbage transplant dry weight compared to sorghum sudangrass (Finney, 2005), therefore wheat straw was selected as the no-till mulch for the control treatment (Table 1, treatment 4). Wheat straw mulch was applied to the no-till control following cabbage transplanting at a rate equal to the total sorghum sudangrass biomass production in plots mowed with low frequency from which hay was not removed.

Cabbage (cv. Bravo) transplants were set by hand on 9 August, 2004 in Reidsville and using a no-till transplanter on 3 September, 2004 in Goldsboro. Cabbage was used as a test crop to determine production potential and examine possible negative impacts of sorghum sudangrass and tillage management on crop development. Each sub-plot contained a single row of cabbage 6 m (20 ft) in length with an in row spacing of 35 cm (14 in). An Organic Materials Review Institute (OMRI)-certified 4-2-4 fertilizer (Fertrell Feed-N-Gro, Bainbridge, PA) was applied at the recommended rate of 2230 kg/ha (2500 lb/A) at transplanting to provide 89 kg N/ha (100 lbs N/A). Pest management included weekly applications of capsacin (commercially available as Hot Sauce) during the first five weeks of growth to deter mammalian pests. Xentari (*Bacillus thuringensis*) was applied as needed based on weekly scouting for lepidopteran pests. Four weeks after planting, plants were side-dressed with 18 kg N/A (20 lb N/A) as sodium nitrate (SQM North America, Atlanta, GA). Use of irrigation systems at each location (a drip system in Goldsboro and overhead system in Reidsville) insured that plants received adequate moisture at planting and 2.5 cm (1 in) water weekly throughout the growing season. Conventionally tilled sub-plots were cultivated 3 and 6 weeks after transplanting. No-till sub-plots were not mowed or cultivated during the cabbage growing season.

Cover crop biomass, C, and N concentration

Prior to each sorghum sudangrass mowing event, cover crop and weed biomass were sampled in all sub-plots. Using a 0.5 m^2 frame, two samples per plot were cut and biomass sorted into cover crop, broadleaf weeds, and grass/sedge weeds. After drying samples at 70°C (160°F) for at least 48 hr, dry weights were recorded. Three intact sorghum sudangrass stems were retained for C and N concentration analysis at the time of hay harvest and prior to the final cutting event. Sorghum sudangrass sub-samples were ground to pass through a 1 mm screen, and a Perkin-Elmer (Norwalk, CT) model 2400 CHN elemental analyzer was used to determine total N and C concentrations.

Weed biomass in transplanted cabbage

Prior to mechanically weeding conventionally tilled sub-plots at 3 and 6 WAT and at cabbage harvest (12 WAT), weed and sorghum sudangrass re-growth biomass were sampled. Using a 0.25 m^2 frame, two biomass samples were cut from each sub-plot (both conventional and no-till). Weed and re-growth biomass were sorted, dried, and weighed following the procedure used for cover crop biomass. At harvest, a sub-sample of sorghum sudangrass was retained to analyze for total N and C concentrations.

Cabbage head weight and time to maturity

Stand counts were recorded for each sub-plot at 1 and 2 weeks after transplanting cabbage, and misses and dead plants were replanted. In each sub-plot, ten plants were designated for harvest. Marketable heads were harvested from the designated plants in each sub-plot at ten day intervals beginning on 1 November and 19 November in Reidsville and Goldsboro, respectively. The intended weight for marketable heads was 1.0 kg or more, though final classification of marketable heads included all heads weighing 0.5 kg or more. At harvest, each marketable head and four wrapper leaves were cut and weighed. The remaining biomass of each plant was also cut and weighed. Thirty days after the first harvest, plants that had not produced a head or which had a head weighing less than 0.5 kg (categorized as ‘culls’) were harvested. Whole plants were cut and weighed to determine the fresh weight. In no-till plots at Reidsville, whole plants were dried for 48 hr at 160°F to determine dry weight. If less than ten marketable heads and culls were harvested from a sub-plot, the difference was categorized as deaths.

Statistical analysis

Data were analyzed by analysis of variance (ANOVA) using the glm procedure in Statistical Analysis Software (SAS) with mean separation by Fisher’s least significant difference (LSD) (Younger, 1998).

Project Results

Sorghum sudangrass hay yield

Hay harvest in Goldsboro was 8.0 t/ha (3.6 tons/acre) and 5.7 t/ha (2.5 tons/acre) in Reidsville.

Sorghum sudangrass biomass production

The amount of biomass produced during the summer season was 11.5-14.4 t/ha and 6.7-9.9 t/ha in Goldsboro and Reidsville, respectively (Table 2). In Goldsboro, sorghum sudangrass biomass was lowest in plots subjected to high frequency mowing (11.5 t/ha). When hay was not removed in Reidsville, high frequency mowed plots produced less sorghum sudangrass biomass (6.7 t/ha) than low frequency mowed plots (9.9 t/ha).

Table 2. Accumulated sorghum sudangrass (SS) biomass produced prior to cabbage planting and accumulated SS re-growth during the cabbage growing season in no-till sub-plots in Goldsboro and Reidsville, NC.

	Goldsboro		Reidsville	
Sorghum sudangrass management	SS biomass ($t{\cdot}ha^{-1}$)	SS re-growth ($t{\cdot}ha^{-1}$)	SS biomass ($t{\cdot}ha^{-1}$)	SS re-growth ($t{\cdot}ha^{-1}$)
hay removed, low mowing frequency	14.4a[z]	0.7	8.0ab[y]	8.5
hay not removed, low mowing frequency	14.0a	1.6	9.9a	10.7
hay not removed, high mowing frequency	11.5b	1.5	6.7b	9.9

[z]Mean separation within columns by Fisher's least significant difference test at P ≤0.05.
[y]Data on accumulated SS biomass in Reidsville were transformed to sqrt(x) before analysis. Mean separation within columns by Fisher's least significant difference test at P ≤0.05. Means were back transformed for presentation.

Biomass of sorghum sudangrass re-growth in cabbage

The amount of sorghum sudangrass which re-grew in no-till sub-plots during the cabbage season was 0.7-1.6 t/ha in Goldsboro (Table 2). In Reidsville, re-growth biomass was 5 to 11 times greater (8.5-10.7 t/ha). At each location, re-growth biomass was not found to be statistically different between sorghum sudangrass management treatments.

Biomass of sorghum sudangrass residues applied to no-till cabbage

Sorghum sudangrass management affected the quantity of biomass returned to the field as mulch for no-till cabbage production (Table 3). In Goldsboro, sorghum sudangrass biomass returned to the soil surface was lowest when hay was removed from plots (7.9 t/ha) and highest when hay was not removed and plots were subject to low mowing frequency (15.0 t/ha). In Reidsville, the greatest biomass was returned to the soil surface when hay was not removed and plots were subject to low mowing frequency (1.2 t/ha). The quantity of residue applied to no-till plots on the day of planting was also affected by sorghum sudangrass management (Table 3). At both locations, plots under high frequency mowing had the lowest level of biomass application immediately prior to cabbage planting (Goldsboro: 0.2 t/ha, Reidsville: less than 0.1 t/ha).

Table 3. Main effect of sorghum sudangrass (SS) management on SS biomass returned to soil surface as mulch in no-till cabbage and SS biomass cut at the final mowing operation in no-till cabbage at Goldsboro and Reidsville, NC.

	Goldsboro		Reidsville	
Sorghum sudangrass management	SS biomass returned ($t{\cdot}ha^{-1}$)	SS biomass at final mow ($t{\cdot}ha^{-1}$)	SS biomass returned ($t{\cdot}ha^{-1}$)	SS biomass at final mow ($t{\cdot}ha^{-1}$)
hay removed, low mowing frequency	7.9c[z]	2.4a	0.4b	0.4a
hay not removed, low mowing frequency	15.0a	3.1a	1.2a	0.4a
hay not removed, high mowing frequency	11.7b	0.2b	0.7b	0.0b

[z]Mean separation within columns by Fisher's least significant difference test at P ≤0.05.

Weeds in transplanted cabbage at 6 WAT in Goldsboro

At 6 WAT in Goldsboro, sorghum sudangrass re-growth (considered a weed in cabbage) was 7.7-24.5 g/0.5m^2 (Table 4). In no-till cabbage, the biomass of broadleaved weeds [including henbit (*Lamium amplexicaule* L.), purslane speedwell (*Veronica peregrina* L.), and common chickweed [*Stellaria media* (L.) Vill.]] was highest in plots that had been subjected to high frequency mowing (37.8 g/0.5m^2) and lowest under wheat straw mulch (0.5 g/0.5m^2; Table 4). Broadleaf weed biomass was not statistically different between plots subjected to low mowing frequency. Broadleaf weed biomass in low frequency mowed no-till sub-plots was similar to broadleaf weed biomass in conventionally tilled sub-plots. Grass and sedge weed populations were too low to analyze at this location. In no-till cabbage, total weed biomass was similar in all sub-plots with sorghum sudangrass mulch due to the presence of sorghum sudangrass re-growth.

Table 4. Interactive effects of sorghum sudangrass (SS) management and tillage on weed biomass in transplanted cabbage at 6 weeks after transplanting (WAT) in Goldsboro, NC.

		Weed biomass ($g \cdot 0.5\ m^{-2}$)			
Tillage	*Sorghum sudangrass management*	SS re-growth	broad-leaf	grass/ sedge[y]	total
no-till	hay removed, low mowing frequency	24.5	3.3b[z]	0.0	27.8a
	hay not removed, low mowing frequency	10.4	8.9b	0.0	19.3a
	hay not removed, high mowing frequency	7.7	37.8a	7.0	52.6a
	wheat straw mulch		0.5c	0.0	0.5b
conventional	hay removed, low mowing frequency		4.1	0.0	4.1
	hay not removed, low mowing frequency		4.2	0.0	4.2
	hay not removed, high mowing frequency		2.4	0.4	4.4
	no SS		5.6	0.8	6.3

[z]Data were transformed to log(x+.00005) before analysis. Mean separation within columns by Fisher's least significant difference test at $P \leq 0.05$. Means were back transformed for presentation.
[y]Data on grass/sedge weed biomass in Goldsboro was not subject to analysis of variance due to a low number of sub-plots that contained grass and sedge weeds.

Weeds in transplanted cabbage at 6 WAT in Reidsville

By 6 WAT in Reidsville, re-growth of sorghum sudangrass in no-till plots was substantial (5.0-5.4 t/ha). Re-growth was considered a competitor with both the cabbage crop and broadleaf weeds. Despite the actively growing sorghum sudangrass present in no-till cabbage, grass and sedge weed biomass was higher in no-till (12.6 $g/0.5m^2$) than in tilled (1.4 $g/0.5m^2$) cabbage at Reidsville (Table 5).

Table 5. Main effects of sorghum sudangrass (SS) management and tillage on weed biomass in transplanted cabbage at 6 weeks after transplanting (WAT) in Reidsville, NC.

	Weed biomass ($g \cdot 0.5\ m^{-2}$)	
Sorghum sudangrass management	broadleaf	grass/sedge
hay removed, low mowing frequency	1.8	5.7b
hay not removed, low mowing frequency	0.7	2.9b
hay not removed, high mowing frequency	1.3	19.3a[z]
no SS, wheat straw mulch	0.7	0.1b
Tillage		
no-till	0.4b[z]	12.6a
conventional	1.8a	1.4b

[z]Data were transformed to log(x+.00005) before analysis. Mean separation within columns by Fisher's least significant difference test at $P \leq 0.05$. Means were back transformed for presentation.

Cabbage head weight and time to maturity in Goldsboro

In Goldsboro, the total number of marketable cabbage heads harvested, the average head size, and the number of heads harvested on the first harvest date were higher in conventionally tilled cabbage than in no-till cabbage (Table 6). Under conventional tillage production, 100% of cabbage transplants produced a marketable head and nearly 90% of marketable heads were ready for harvest on the first harvest date. Under no-till, 84% of cabbage transplants produced a marketable head and 32% of marketable heads were ready for harvest on the first harvest date. Average head weight of conventionally tilled cabbage was 1.65 kg/head, higher than the average head weight for no-till cabbage (1.14 kg/head). Regardless of tillage regime, cabbage preceded by sorghum sudangrass demonstrated a lower head weight (1.29 - 1.35 kg/head) then cabbage in the control plots (1.62 kg/head).

Table 6. Main effects of sorghum sudangrass (SS) management and tillage on cabbage survival, head size, and maturity at Goldsboro, NC.

Sorghum sudangrass management	no. of heads harvested	average head size (kg)	no. of heads 1st harvest
hay removed, low mowing frequency	9.0	1.32b[z]	5.6
hay not removed, low mowing frequency	9.3	1.29b	5.6
hay not removed, high mowing frequency	8.6	1.35b	5.6
no SS, wheat straw mulch	10.0	1.62a	7.1
Tillage			
no-till	8.4b[z]	1.14b	3.2b
conventional	10.1a	1.65a	8.8a

[z]Mean separation within columns by Fisher's least significant difference test at $P \leq 0.05$

Cabbage survival, head weight and time to maturity in Reidsville

Cabbage no-till transplanted into sorghum sudangrass residues produced no marketable heads in Reidsville (Table 7), though 93% of no-till transplanted, wheat straw mulched cabbage plants produced heads with an average an average head size of 1.41 kg/head. Conventional tillage led to total harvest rates of 88-98% and 53-88% maturity on the first harvest date. Average head weight for conventionally tilled cabbage was 1.31-1.88 kg/head.

Table 7. Interactive effects of sorghum sudangrass (SS) management and tillage on cabbage survival, head size, and maturity at Reidsville, NC.

Tillage	*Sorghum sudangrass management*	no. of heads harvested	average head size (kg)	no. of heads 1st harvest
no-till	hay removed, low mowing frequency	0		
	hay not removed, low mowing frequency	0		
	hay not removed, high mowing frequency	0		
	wheat straw mulch	9.3	1.41	4.8
conventional	hay removed, low mowing frequency	9.8	1.52ab[z]	6.8
	hay not removed, low mowing frequency	9.3	1.31b	5.3
	hay not removed, high mowing frequency	9.8	1.57ab	8.8
	no SS	8.8	1.88a	6.5

[z]Mean separation within columns by Fisher's least significant difference test at $P \leq 0.05$

6. Conclusions and Discussion

Hay yield and economic comparison

Hay yields observed in Goldsboro and Reidsville were within the range of previously reported potential hay yield for sorghum sudangrass. The USDA does not currently post average prices for organic non-alfalfa hay, making it difficult to estimate the possible income generated by hay harvest. Further, hay prices vary significantly by season and region. A survey of on-line classified ads from buyers and sellers of organic non-alfalfa hay suggests that $125/ton is a good estimate of the price of organic sorghum sudangrass hay in the southeastern US. Using this estimate, an economic analysis of four sorghum sudangrass cover crop management systems was performed (Table 8). The analysis takes into account only those operations relevant to summer cover crop production and subsequent vegetable production affected by summer cover crop hay production and tillage. The final values represent the return above variable costs, as opposed to income. The analysis demonstrates that performing an early summer cut for hay sale can recover the costs of using a sorghum sudangrass as a cover crop prior to conventionally tilled and no-till fall vegetable production and generate additional income. Potential return above variable costs is greatest when sorghum sudangrass is harvested and sold as hay and the fall vegetable is no-till transplanted ($147.27/acre).

Impacts of increased mowing frequency on sorghum sudangrass response to mow kill

In our trial, cutting frequency had no effect on sorghum sudangrass response to mow kill, as evidenced by similar re-growth levels between treatments at both locations (Table 2). Increasing mowing frequency did not reduce the amount of sorghum sudangrass which re-grew in no-till production. Re-growth levels were different between locations, however, which may have been due to several factors. Overhead irrigation was used at Reidsville and may have contributed to greater sorghum sudangrass re-growth than observed in Goldsboro, where a drip irrigation system was in place. We also performed our final mowing and cabbage transplanting operation in Goldsboro after a series of significant rainfall events. Running equipment through the field under wet conditions may have caused compaction that slowed and/or prevented sorghum sudangrass tillering (re-growth). We also observed that excessive soil moisture led to burying of sorghum sudangrass stubble by foot traffic.

Effect of hay harvest and cutting frequency on weed suppression in fall cabbage by sorghum sudangrass cover crop mulch

Previous research has demonstrated that no-till mulch of sorghum sudangrass is effective in suppressing annual, broadleaf weeds (Forney et al., 1985; Putnam and DeFrank, 1983; Putnam et al., 1983). Results from Goldsboro suggest that harvesting a hay crop from a sorghum sudangrass cover crop does not decrease its capacity to suppress broadleaf weeds under no-till conditions (Table 4). Further, mowing the cover crop each time it reached a height of 1.2-1.5 m (3-4 ft) during the summer season provided the same level of broadleaf weed control in no-till cabbage as conventional tillage at this location. However, increasing cutting frequency of the cover crop reduced broadleaf weed suppression by the resulting no-till mulch. Sorghum sudangrass management did not have an impact on broadleaf weed appearance in conventionally tilled cabbage.

Sorghum sudangrass residue level needed to suppress broadleaf weeds

It is generally accepted that increasing the quantity of cover crop residue will decrease the appearance of annual, broadleaf weeds. Data collected in Goldsboro indicate that there are additional cover crop factors that influence broadleaf weed control in no-till systems. First, the timing of cover crop residue application relative to planting a subsequent crop can

Table 8. Economic comparison of four model systems for summer cover crop production prior to organic fall vegetable production.

	Amount/acre					$/acre			
Tillage:	*conventional*	*conventional*	*conventional*	*conservation*		*conventional*	*conventional*	*conventional*	*conservation*
Cover crop:	*no cover crop*	*cover crop*	*cover crop, hay*	*cover crop, hay*	$/unit	*no cover crop*	*cover crop*	*cover crop, hay*	*cover crop, hay*
Fertilizer (kg N)									
Poultry litter[z]		100	100	100	0.40		40.00	40.00	40.00
Seed (kg)									
Sorghum sudangrass		40	40	40	0.50		20.00	38.50	38.50
Custom operations (# of operations per season)[y]									
Field conditioner (pre-cover crop)		1	1	0.5	3.39		3.39	3.39	1.70
Grain drill, 16'		1	1	1	7.55		7.55	7.55	7.55
Flail mower (cover crop management)		3	3	3	7.31		21.93	21.93	21.93
Disk (weed control in fallow)	2				6.36	12.72			
Disk (cover crop incorporation/field prep)	2	2	2		6.36	12.72	12.72	12.72	
Field conditioner (pre-cash crop)	1	1	1		3.39	3.39	3.39	3.39	
Transplanter, 2 row	1	1	1		36.60	36.60	36.60	36.60	
Subsurface tiller transplanter, 2 row				1	36.60				36.60
Rolling cultivator, 6 row (in season weed control)	2	2	2		3.28	6.56	6.56	6.56	
Sub-total of variable costs						*71.99*	*152.14*	*170.64*	*146.28*
Hay operations (# of operations per season)									
Mower-conditioner (hay harvest)			1	1	13.57			13.57	13.57
PTO baler			1	1	17.20			17.20	17.20
Hand labor, raking (hours)			4	4	14.50			58.00	58.00
Less 1 flail mowing operation			-1	-1	7.31	0.00	0.00	-7.31	-7.31
Sub-total of variable costs						*0.00*	*0.00*	*81.46*	*81.46*
Total variable costs						**71.99**	**152.14**	**252.10**	**227.74**
Hay receipts[x]						**0.00**	**0.00**	**375.00**	**375.00**
Return above variable costs						**-71.99**	**-152.14**	**122.90**	**147.27**

[z]cost includes material and application fees.
[y]Equipment operation costs taken from Ferriera (2004).
[x]based an a 3 t/ac yield and market price of $125/ton.

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affect weed suppression. In plots mowed infrequently, we observed that broadleaf weed suppression in cabbage was unaffected by the removal of nearly half of the sorghum sudangrass biomass two months prior to cabbage transplanting. We believe that this was due to the fact that these plots had the same quantity of residue applied at the time of transplanting (Table 3). In addition, though high frequency mowing generated 11.7 t/ha of cover crop mulch in Goldsboro, broadleaf weed suppression was poor in this cover crop management system. This result may have been due to the quality of residues generated in the frequently mowed system. Plants were less mature when cut and were likely to have decomposed more rapidly than residues of more mature plants, leading to inadequate soil coverage and poor weed suppression.

Effect of tillage on weed suppression in fall cabbage

In Reidsville, grass and sedge weeds were more prevalent than broadleaf weeds. Grass and sedge weed biomass in tilled cabbage (1.4 g/0.5 m^2) was lower than no-till (12.9 g/0.5 m^2) suggesting that the no-till system did not provide adequate control. The dominant weed in this category was the perennial species yellow nutsedge (*Cyperus esculentus* L.). Previous research has concluded that no-till systems employing cover crops have the highest weed pressure from perennial species (Putnam et al., 1983). Other species present in the cabbage crop were summer annual grasses including smooth crabgrass (*Digitaria ischaemum* Schreb. Ex. Muhl.), goosegrass [*Eleusine indica* (L.) Gaertn.)], fall panicum (*Panicum dichotomiflorum* Michx.), and broadleaf signal grass [*Urochloa platyphylla* (Munro ex Wright) R. Webster]. These species had also been present in the growing cover crop, indicating that they were established prior to cabbage planting and re-grew following mowing in no-till sub-plots. Our results offer evidence that mechanical cultivation may provide better control of perennial species and established annual grasses than no-till.

Effect of tillage and sorghum sudangrass on cabbage head weight and time to maturity

No-till production of organic cabbage following a sorghum sudangrass cover crop led to reductions in head weight and increased time to maturity compared to conventional tillage in Goldsboro. No-till cabbage in Reidsville was a crop failure. This result may have been due to the effects of tillage on environmental factors that influence plant growth, such as nutrient availability, soil moisture, soil temperature, and compaction. Soil data indicate that differences in N availability and soil moisture between tilled and no-till cabbage were not agronomically significant in this study (data not shown). Soil compaction, which has been cited as a potential cause of yield reduction in no-till cabbage in previous studies (Bottenberg et al., 1997; Hoyt and Walgenbach, 1995), was not monitored in this study.

Sorghum sudangrass introduced additional factors to the no-till system that may have led to poor cabbage production, namely resource competition and chemical interference. Re-growing sorghum sudangrass competed with the cabbage crop for nutrient, light, and water resources. In Reidsville specifically, sorghum sudangrass re-grew rapidly and was observed to shade cabbage transplants before they grew out of the transplant stage of development. Further, though it is nearly impossible to separate the effects of resource competition by re-growing sorghum sudangrass from chemical interference by sorghum sudangrass residues, it is possible that allelopathy contributed to head weight reduction in no-till cabbage at Goldsboro. A greenhouse study found that cabbage transplant dry weight was lower under sorghum sudangrass residues than wheat straw mulch, a suggestion that chemical properties of sorghum sudangrass mulch may negatively impact transplant growth (Finney, 2005).

Cabbage head weight in Goldsboro was highest when cabbage was not preceded by sorghum sudangrass, regardless of whether residues were left on the surface or incorporated (Table 6). A similar, though less significant, trend was observed in tilled cabbage at Reidsville (Table 7). In tilled plots, statistical analysis indicates that as the quantity of sorghum sudangrass incorporated increased, the average cabbage head weight decreased. Because resource competition was not a factor in tillage systems, the decrease in head weight was likely due to allelopathy. The potential for sorghum sudangrass to inhibit seed germination and seedling development is well documented (Weston and Duke, 2003; Weston, 1996; Forney et al., 1985; Putnam and DeFrank, 1983; Putnam et al., 1983), though negative interference with transplanted crops has not been thoroughly investigated. One previous study of the interaction between sorghum sudangrass residues and a transplanted crop found that incorporated residues led to reduced growth of Eastern redbud transplants in pot culture (Geneve and Weston, 1988).

Overall recommendations

Sorghum sudangrass can be managed as a single cutting hay crop without negatively impacting weed suppressive qualities of the cover crop. Critical to optimization of weed suppression by the cover crop is cutting frequency following hay harvest. Frequent cutting can lead to greater weed biomass in the subsequent cash crop. Cutting less frequently (such as each time the crop reaches 1.5m) will provide residue levels that offer adequate weed suppression, particularly of broadleaf weed species.

Effective cover crop kill is a significant impediment to organic no-till production. Effectiveness of mowing as a means of killing a grass cover crop such as sorghum sudangrass was not improved with increased cutting frequency in this experiment. In order to utilize summer cover crops which exhibit similar tillering and re-growth capacity in no-till fall vegetable production, for example pearl millet, improvement of mechanical technologies (such as the addition of a crimper to rolling equipment) or manipulation of the cover crop to improve kill response should be investigated.

Though cabbage yield was reduced in no-till production in this study, previous studies have demonstrated that no-till production can lead to cabbage yields comparable to conventional tillage (Hoyt et al., 1996; Wilhoit et al., 1990; Knavel, 1989). Several researchers have cited the necessity of a transitional period when converting from conventional tillage to no-till in order to realize yield benefits instigated by improved soil structure and greater water infiltration under no-till (Hargrove et al., 1992; Radcliffe et al., 1988). Continuation of the current study may demonstrate less drastic yield reductions in no-till culture following the transition period, however, incompatibility between sorghum sudangrass cover crop residues and transplanted cabbage would likely continue to limit yield. Sorghum sudangrass introduced several competitive factors including cover crop re-growth and allelopathic potential which negatively impacted the growth of cabbage in both no-till and conventional tillage. The species may pose similar risks to other transplanted vegetables.

The results of this study suggest that sorghum sudangrass is not a suitable summer cover crop prior to fall vegetable production. This species may, however, have applications as a summer cover prior to the planting of a winter cover crop or preceding a spring crop. Harvest of a hay crop during the summer cover crop season does not negatively impact weed suppressive qualities of the cover crop and may provide additional income for growers who integrate sorghum sudangrass into their production rotation.

7. Outreach

The results of this study have been shared through a public seminar offered at North Carolina State University and a master's thesis available on the internet. In addition, information regarding cover crop management in organic production systems and no-till organic vegetable production will be presented at a grower's conference in November, 2005 and at the International Federation of Organic Agriculture Movements (IFOAM) conference in September, 2005. The production of a manuscript for publication in the journal HortScience is also in process.

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9. Addenda

Plots at Reidsville, NC immediately prior to cabbage transplanting: August 9, 2005.

Transplanting

Sub-surface tiller transplanter used in Goldsboro, NC.

Transplanting operation in Goldsboro, NC: September 2, 2004. In areas of high residue, manual closure of the planting furrow was required around some plants.

Goldsboro: 6 weeks after transplanting cabbage

No-till with wheat straw mulch

Conventional tillage of sorghum sudangrass residues

No-till with sorghum sudangrass residues

Reidsville: 6 weeks after transplanting cabbage

Significant re-growth of no-till sorghum sudangrass

Goldsboro at the time of 1^{st} harvest

Conventionally tilled cabbage

Cabbage no-till transplanted into sorghum sudangrass residues

Re-growth of no-till sorghum sudangrass in Reidsville

Ten weeks after planting: conventionally tilled cabbage (row 1); no-till cabbage under wheat straw mulch (row 2); re-growth of no-till sorghum sudangrass (row 3)