Limitations and Possibilities for Some Conservation Tillage Systems with Vegetable Crops in the Southern Plains of the United States

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SUMMARY. We conducted several experiments to determine the best system for production of spring cabbage (*Brassica oleracea* L. Capitata group) with conservation tillage (CT) in the southern plains of the United States. Rye (*Secale cereale* L.) was selected as the best cover crop to cover the soil in a short time. Raised beds were formed in the fall and planted with rye. With most studies, the rye was allowed to remain on the soil surface rather than being tilled into the soil. Planting densities, rates of nitrogen fertilizer, and herbicide materials were evaluated to determine the best system for cabbage production. In each study, various cover crop practices were compared with bare soil production systems. Soil erosion was reduced by the use of rye cover crops. Cabbage was produced in the CT system, but cabbage yields were higher in bare soil plots than in the rye-covered plots. We are also in the process of developing a system of CT that involves permanent bermudagrass [*Cynodon dactylon* (L.) Pers.] pastures and watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai]. This system allows both crops to be grown simultaneously on the same land.

Conservation tillage (CT) has many advantages, and the system can be applied to many different situations. However, the system must be modified and adapted to meet geographical, environmental, and cultural conditions within a given region. CT is more than just omitting cultivation from crop production. It involves carefully matching the attributes of all components of the tillage system to the crop that is being produced. CT will not always produce yields of the cash crop that equal yields of conventionally tilled crops. In this paper, we have documented several advantages and limitations to CT systems in the southern plains of the United States (southern plains). We have examined two different CT systems with two different cash crops, and have described certain weaknesses and strengths of both systems.

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Any cultural practice, including CT, should be evaluated on the basis of goals that are developed for the crop in question, for the profitability of that cropping system, and for the long-term environmental and ecological attributes of the system.

The primary purpose of CT is to reduce soil erosion, improve water infiltration, and improve the environment while allowing an acceptable yield of a given crop. CT is sometimes considered to be synonymous with minimum tillage, reduced tillage, low-till, no-till, and sustainable agriculture. All of these systems are designed to maintain as much vegetative cover on the soil as possible, and to minimize tillage. A cover crop could be maintained continually on the entire soil surface, or covers could be maintained in strips separated by tilled areas. All types of CT have been developed to protect the soil from erosion and hopefully to reduce the dependence on multiple passes through the field with cultivation equipment. While most CT systems are similar in concept to other CT systems, the techniques used to meet the objective of soil conservation will vary from crop to crop and region to region.

Conservation tillage entails a systems approach to farming, and involves techniques for management of various multidisciplinary strategies. A change in cultivation type or frequency would be expected to alter the microenvironment in such a way that weeds, diseases and insects would be affected, although the type of response may be determined by the crop, the pest, or the environment. The type and frequency of cultivation would also affect nutrient cycling and nutrient management.

The reasons for using CT in vegetable production in the southern plains are similar to the reasons for its use elsewhere. However, CT might not be acceptable to a vegetable grower if the size or quality of individual fruit or other marketable units is reduced. Because of market requirements that are placed on fresh produce, a vegetable crop that does not meet stringent size, shape, and appearance qualifications has little value. Each head of cabbage or tomato (*Lycopersicon esculentum* Mill.) fruit must pass certain quality standards that are based on the individual fruit. With a fresh market crop, total yield might be reduced by 25%, but marketable yield could be reduced by 100%, if the size of individual heads, fruit, etc. does not meet a minimum size requirement.

The purpose of this paper is not to document the many advantages of CT. Instead, we wish to discuss some of the problems that we have encountered while developing a CT system in the southern plains. We also wish to discuss new production systems that are being developed that are based on CT practices.

Background and justification for development of a conservation tillage system

This paper describes results of research conducted in southern Oklahoma. We initiated a project to develop a system for planting cabbage in late February or March. Saturated soils from spring rains often made it difficult to plow or cultivate soils in late winter or early spring before planting. These cool wet soils were not conducive to cabbage growth.

We constructed raised beds to promote drainage, increase the rate of soil warming, and thus encourage early growth of cabbage. Because heavy machinery cannot be operated effectively on wet soils, we constructed the beds in the fall when the soil was drier, and then planted them with cabbage the following spring. However, beds constructed on sandy soils in the fall and exposed to heavy rains during the winter were seriously eroded at planting time. Thus, a predicament existed in that beds were required, but could not be constructed at planting time.

We needed a planting system based on fall-constructed beds planted with cover crops. The fall-constructed beds were built in September or October, and were seeded immediately with a cover crop. The cover crop provided initial growth during the fall and early winter, and protected the bed from erosion during the winter and early spring.

Selecting plant species suitable for a winter cover crop

The initial studies discussed here have been published in detail, and will only be summarized in this paper. The first step involved selecting a cover crop that was well adapted to the southern plains region. The main objectives were to select a plant species that would germinate well, grow quickly during

the first few weeks, and provide a maximum amount of soil cover. A legume species was desired because of the added benefit from nitrogen (N) fixation. Fourteen plant species, including legumes and non-legumes, were seeded at one location in Oklahoma in 1987, and at two locations in Oklahoma in 1988. Measurements taken included the portion of soil covered by the cover crop, the height of the cover crop on selected dates, and mortality of the cover crop after application of glyphosate (Roundup) [isopropyl-amine salt of N-(phosphono-methyl)glycine].

Nelson et al. (1991) described this research in detail. They found that the most complete ground cover was obtained with rye. With three studies, rye covered 93%, 65%, and 83% of the soil. The legumes that provided the greatest portion of soil cover were either crimson clover (*Trifolium incarnatum* L.) or hairy vetch (*Vicia villosa* Roth). The percent soil covered by these two legumes ranged from 83% to 18%, but in most cases was significantly less than the amount of soil covered by rye. Thus, rye was selected as the cover crop with the fastest soil covering capabilities. Hairy vetch was chosen as the legume with the best soil-covering capability.

EFFECT OF RYE AND HAIRY VETCH ON INTEGRITY OF RAISED BEDS. The next step in development of the project was to determine the capability of the cover crop to preserve the integrity of raised beds. Beds that were 3 ft (0.9 m) wide, 30 ft (9.1 m) long, and 8 inches (20 cm) tall, on 6-ft (1.8-m) centers were formed in mid-October. One-third of the beds was seeded with hairy vetch, one-third with rye, and one-third was left bare. Each cover crop treatment was further divided into subplots, with each subplot receiving one of four nitrogen (N) rates, either 40, 80, 120, or 160 lb/acre (45, 90, 134, 179 kg ha⁻¹). Cabbage was transplanted into the beds the following spring. Two rows of cabbage were planted per bed, with 1 ft (0.3 m) between rows and also 1 ft (0.3 m) between plants in a row.

Roberts and Cartwright (1991c) have described this work in detail. They found that the cover crop growth was minimal from planting time until March of the following year. The height of the individual beds was measured in November, March, and July. While the height of all beds decreased during the winter, beds planted with rye were

taller than the other beds at the end of the season. The height of beds covered with hairy vetch was not significantly different from the height of beds with bare soil, probably because there was little growth of vetch during the winter and early spring when most soil was eroded. Thus, the rye cover crop preserved the height of the raised beds, but the hairy vetch did not.

EFFECT OF RYE ON INSECT PESTS OF CABBAGE. One beneficial aspect of the system evaluated by Roberts and Cartwright (1991b, 1991c) was that cabbage grown in cover crops had fewer insect pests than did cabbage grown on bare soil. Abundant cabbage loopers (*Trichoplusia ni* Hubner), thrips (*Frankliniella* sp.), and aphids [*Brevicoryne brassicae* (L.)] were noted throughout the growing season. With most observations, there were fewer loopers, thrips, and aphids on the cabbage grown in rye than on the cabbage grown on bare soil. These observations were noted at all levels of N fertilization. At this stage of the experiments, we had selected a cover crop that would reduce soil erosion, and cabbage that was grown in this cover crop had fewer insects than did cabbage that was grown on bare soil.

The advantages of the rye-based cover crop system did not come without cost, as lower yields were obtained from cabbage grown in rye than from cabbage grown on bare soil. Increasing the rate of N applied to the plots increased the yield, but the high rate of N (160 lb/acre (179 kg·ha⁻¹)) in rye resulted in less cabbage yield than did the low rate of N (40 lb/acre (45 kg·ha⁻¹)) applied to plots in bare soil.

The advantages of the system (protection of the raised beds and reduced insect pressures) encouraged us to conduct a series of follow-up studies to determine why the use of rye resulted in reduced yield of cabbage. The slope of the yield response curve to N led us to hypothesize that an even higher rate of N might overcome this yield reduction.

Materials and methods— General protocols

A series of experiments was initiated to determine the cause of the repressive effect of rye on cabbage yield. Each of the experiments was conducted in a similar fashion to our initial experiments. The studies were replicated, generally with four replications. The plots were randomized within complete

blocks. Plots were generally 30 ft (9.1 m) long and 6 ft (1.8 m) wide. The field was moldboard plowed and disked, and fertilizer and lime were applied based on soil test results and Oklahoma State University recommendations. Raised beds were constructed in the center of each plot, with the raised portion of the bed being ≈3 ft (0.9 m) wide and 8 inches (20 cm) tall. With each experiment, the beds were constructed in the fall, usually in October. In our initial study, even the fastest growing legumes produced very little growth before April. Because we needed a cover crop on the beds during the winter months, all of our follow-up studies were conducted with rye. The beds were seeded with rye immediately after being formed, and the rye was allowed to grow during the fall and winter. In experiments where planting density was not a variable, the seeding rate was 75 lb/acre (84 kg·ha⁻¹). The seed was drilled into the plots ≈1 inch (2.5 cm) deep, in rows ≈6 inches (15.2 cm) apart. The seeded area covered the 6-ft (1.8-m) width of the plot, and included the raised bed and the furrow between the beds.

With each of the following experiments, cabbage 'Solid Blue 760' was seeded into styrofoam trays in a greenhouse, using commercial potting media (Redi-Earth, Scotts, Marysville, Ohio). When the plants were ≈4 inches (10 cm) tall, we transplanted them into the field. With the earlier studies, we used a mechanical, tractor-mounted transplanter to plant the cabbage. We had difficulty using the transplanter in the small plots because of the rye residue that covered the soil and because the soil had not been tilled since the previous fall. In the later studies we transplanted the cabbage by hand.

No additional cultivation or tillage was performed at any time after the rye was planted. Wet soils at planting time prevented the use of any cultivation equipment before the time the cabbage was planted. Also, raised beds impose certain restrictions on the use of standard cultivation equipment, and our intention was to develop a technique that did not require the use of cultivation equipment during crop production. With these restrictions, either real or self-imposed, we decided to plant directly into a standing cover of rye. In most of the following studies, where herbicides were not a variable, we allowed the rye to grow until ≈1 week before transplanting the cabbage plants.

Before transplanting, we applied glyphosate to the entire field. We allowed the rye to remain standing in place in the plots. In most cases, the rye was between 2 and 3 ft (0.6 and 0.9 m) tall at the time glyphosate was applied.

When the cabbage was mature, we harvested the heads, removed excess stalk and leaves, and weighed the heads. Heads were judged to be marketable based on USDA standards for size, shape, and lack of physical defects. The results presented in the remainder of this paper are based on the weight of the marketable cabbage.

Interactions among rye cover crops, nitrogen, and cabbage yield

In the first follow-up experiment we applied a range of N from 40 to 160 lb/acre (45 to 179 kg·ha⁻¹). We expected living rye to compete with the cabbage for nutrients, and we expected decomposing rye to immobilize nitrogen. These expectations led us to hypothesize that the yield reduction seen when cabbage was grown in standing rye might be a result of N deficiency.

This experiment was conducted according to the general protocols, but N was used as a treatment variable. We applied N at rates of 30, 90, 150, 210, and 270 lb/acre (34, 101, 168, 235, 302 kg·ha⁻¹). We applied these rates to plots planted with rye, and also to plots maintained as bare soil with no cover crop. All N was applied in a split application, with half applied at planting and half ≈1 month later. We applied the N by hand, as a surface application, using granular ammonium nitrate.

As in the first experiments, increased rates of N resulted in increased cabbage yield, but application of extra N was not sufficient to overcome the yield suppression from rye (Table 1). With most levels of N, the bare soil treatments produced a yield greater than the yield from the corresponding rye-covered plot. Also, the highest rate of N in combination with rye resulted in cabbage yields similar to that of the low rate of N with bare soil. We did not overcome the negative effect of rye on cabbage yield by increasing the N rate.

Effect of plant density of rye on cabbage yield

This experiment was conducted according to the general protocols, but we varied the seeding density of

Table 1. Effect of fertilizer nitrogen and a rye cover crop on cabbage yield.^z

Treatment	Cabbage yield (tons/acre)	
	Bare soil	Rye covered
Nitrogen (lb/acre)		
30	5.7 a**y	4.1 a
90	7.7 a	5.3 b
150	8.1 a	6.2 b
210	9.9 a	6.1 b
270	10.2 a	6.1 b

^z1 lb/acre = 1.12 kg·ha⁻¹; 1 ton/acre = 2.24 t·ha⁻¹.

^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test; comparisons within rows (comparing cover treatments within N levels).

Table 2. Effect of rye seeding density on cabbage yield.^z

Treatment	Cabbage yield (tons/acre)
Bare soil	17.3 a**y
Rye (75 lb/acre)	6.0 b
Rye (150 lb/acre)	8.8 b

^z1 lb/acre = 1.12 kg·ha⁻¹; 1 ton/acre = 2.24 t·ha⁻¹.

^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test.

rye. We planted rye at rates of 75 or 150 lb/acre (84 or 168 kg·ha⁻¹). The control treatment was maintained as bare soil throughout the study by hand hoeing or pulling weeds.

The yield of cabbage from both treatments that had been seeded with rye was considerably lower than was the yield from the bare soil treatments (Table 2). We did not overcome the negative effect of rye on cabbage yield by modifying the seeding rate of rye.

Effect of rye density and nitrogen on cabbage yield

This experiment was conducted according to the general protocols, but main plots were seeded with rye at rates of 75 or 150 lb/acre (84 or 168 kg·ha⁻¹). Each plot was then further

divided into subplots with N applied at rates of 0, 50, 100, 150 or 200 lb/acre (0, 56, 112, 168, 224 kg·ha⁻¹).

In this experiment, the cabbage did not mature to a marketable size, and thus there was no yield in the treatments planted with rye (Table 3). We did not overcome the negative effect of rye on cabbage yield by modifying the planting density of rye or by applying extra nitrogen.

Interactions among rye cover crops, herbicides, and cabbage yield

Because we were not able to overcome the yield reduction noted in treatments with rye by increasing the rate of N, and because the negative effect existed at two seeding densities, we developed a different hypothesis to explain this yield reduction. We had observed that rye tended to reduce weed populations early in the season, shortly after the cabbage was planted. However, by harvest time, the plots planted with rye usually contained a substantial number of weeds, and we hypothesized that the weed pressure might be contributing to the yield reduction. Because a standing cover of rye precluded the use of conventional cultivation techniques, we resorted to application of herbicides to control weeds. This experiment was conducted according to the general protocols, but we applied glyphosate to determine if this herbicide applied just before planting would kill all vegetation, including weeds, and thus overcome the yield reduction from rye. Treatments in this study included cabbage grown in bare soil, cabbage grown in plots seeded with rye and sprayed with glyphosate, and cabbage grown in plots seeded with rye without glyphosate.

Treatments with rye and not sprayed with glyphosate had essentially no marketable heads, while the

treatments with bare soil produced the greatest yield (Table 4). We did not overcome the yield reduction from rye by applying glyphosate.

We then reasoned that weeds emerging after the application of glyphosate might be reducing the yield of the cabbage. We initiated an experiment to determine if herbicides with a residual activity would control weeds and perhaps overcome the yield reduction in treatments planted with rye. This experiment was conducted according to the general protocols, but herbicides were used as a treatment. Rye was seeded in the fall, and sprayed with glyphosate the following spring. After the application of glyphosate, we applied DCPA (Dacthal) (dimethyl-tetrachloroterephthalate); sethoxydim (Poast) {2-[1-(ethoxy-imino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexene-1-one}; bensulide (Prefar) [S-(O,O-Diisopropylphosphorodithioate) ester of N-(2-mercaptoethyl) benzene sulfonamide]; or trifluralin (Treflan) [2,6-dinitro-n,n-dipropyl-4-(trifluoromethyl) benzenamine (9ci)]. An additional treatment was seeded with rye and left without herbicide. A control treatment consisted of bare soil that was maintained weed free by hoeing.

Yields were similar among all treatments that were planted with rye, whether they were treated with one of four herbicides or no herbicide at all (Table 5). All of the treatments planted with rye produced less marketable weight than did the treatment that was maintained as bare soil. We were not able to overcome the negative effect of rye by using herbicides to kill the rye or to control weed growth in the plots.

Determining the part of the rye plant causing yield reduction of cabbage

At this point we had attempted to overcome the negative effect of rye on cabbage yield by applying more N, by adjusting the seeding density of rye, and by applying various herbicides to control rye and weeds. None of these efforts was successful. As a follow-up study, we designed an experiment to determine whether the negative effect of rye was a result of the rye foliage or the rye roots. We established one treatment as bare soil and a second treatment was planted with rye. A third treatment was not seeded, but received rye foliage that was cut and removed from the plots in the

Table 3. Effect of fertilizer nitrogen and a rye cover crop at two seeding densities on cabbage yield.^z

Nitrogen (lb/acre)	Cabbage yield (tons/acre)		
	Bare soil	Rye (75 lb/acre)	Rye (150 lb/acre)
0	24.7	0	0
50	18.3	0	0
100	30.4	0	0
150	28.1	0	0
200	30.9	0	0

^z1 lb/acre = 1.12 kg·ha⁻¹; 1 ton/acre = 2.24 t·ha⁻¹.

Table 4. Effect of rye and glyphosate on cabbage yield.^z

Treatment	Cabbage yield	
	(tons/acre)	
Bare soil	17.5 a	**y
Rye, glyphosate	7.4 b	
Rye, no glyphosate	0.2 c	

^z1 ton/acre = 2.24 t·ha⁻¹.^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test.**Table 5. Effect of rye and herbicides on cabbage yield.^z**

Treatment	Cabbage yield	
	Herbicide	(tons/acre)
Rye	Dacthal	4.2 b
Rye	Poast	3.8 b
Rye	Prefar	3.2 b
Rye	Treflan	2.8 b
Rye	None	3.9 b
Bare soil	None	17.3 a

^z1 ton/acre = 2.24 t·ha⁻¹.^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test.

second treatment. Thus, the second treatments had rye roots, but the foliage was removed and placed on the plots in the third treatment. The third treatment did not have any rye roots, but did have foliage from the second treatment. Thus, one treatment had rye roots, one treatment had rye foliage, and one treatment was maintained without rye.

Both treatments containing rye had much lower yields of cabbage than did the treatment that was maintained as bare soil (Table 6). The yield reduction in the second treatment (growing rye) could have been associated with soil fertility or plant nutrition, but the third treatment (manually distributed rye) should not have been affected in such a way. We concluded from this study that the negative effect of rye on cabbage yield was not nutritional, and was not weed related, but was instead correlated with plant material or debris from the rye.

We conducted a final study to help determine the relationship between rye cover crops and cabbage production. The treatments were similar to those in the previous study and are described as follows:

- 1) Maintained as bare soil throughout the study.
- 2) Seeded with rye. Rye was allowed to grow, the foliage was cut at the soil surface, and the foliage was transferred from the plot to plot 4

described below.

- 3) Seeded with rye. Rye was cut by hand and allowed to fall in place on the surface of the soil in the same plot.
- 4) Not seeded with rye. Rye foliage that had been removed from treatment 2 was transferred to the soil surface of this set of plots.
- 5) Not seeded with rye. A rye suspension was sprayed on the soil and on the cabbage plants. This suspension was formulated by removing the rye foliage from adjacent areas of the field, grinding and pulverizing the foliage in a kitchen-type blender, and spraying the suspension onto this set of plots. The rye foliage was gathered from an area identical in size to one of the treated plots. The only difference between this treatment and treatment 4 was that the rye in this treatment was pulverized in a blender and was sprayed onto the plot.
- 6) This plot was seeded with rye and sprayed with glyphosate at the time the cabbage was planted.

There was a dramatic reduction in yield with both treatment 2 and treatment 3 relative to the bare soil (Table 7). Treatments 2 and 3 both had rye roots remaining in the plot throughout the cabbage growing season. Treatment 6 also had rye roots. In this treatment, glyphosate was used to kill the rye at the time the cabbage was planted, so no root growth would have occurred after this time. Any root growth that occurred up until this time would have remained in the plots. Treatments 4 and 5 may have slightly repressed the cabbage growth, but the reduction was not as dramatic as with treatments 2 and 3. These two treatments had rye foliage but not rye roots in the soil. These results suggest that the main deleterious effect of rye was coming from the rye roots.

Discussion: Limitations to cabbage production with a rye-based conservation tillage system

Our first experiment involving cabbage grown in a rye-based cover crop CT system produced a lower yield than did the bare soil plots. We then investigated several mechanisms to attempt to understand the cause of this yield reduction, and hopefully to overcome the limitation.

We added additional nitrogen to the rye-covered plots, but this did not overcome the yield reduction. Knavel and Herron (1985) had examined fall planted cabbage grown in sudangrass (*Sorghum vulgare* var. *sudanense*). They found that cabbage growth was also suppressed when the sudangrass was allowed to reach a 12-inch (30-cm) height, and they suggested that nitrogen deficiency might be the cause of the yield reduction. However, we were not able to overcome the yield reduction by adding nitrogen.

We examined two different densities of rye, but found that both densities reduced the yield of cabbage. We looked at interactions among rye density, nitrogen, and cabbage yield, and found that when rye was used as a cover, yields were lower than when cabbage was grown on bare soil. We applied various herbicides, both contact and residual, to the rye-covered plots but found that the cabbage yield was still lower than it was in bare soil plots. We determined that both foliage and roots of the rye plant were involved in the yield reduction, but found that more of an effect may come from the roots than from the foliage.

In every experiment, we had a higher yield with the bare soil than when we used rye. We conducted stud-

Table 6. Effect of seeded rye and manually distributed rye on cabbage yield.^z

Treatment		Cabbage yield (tons/acre)
Winter	Spring	
Bare soil	Bare soil	29.7 a
Rye	Rye removed	2.5 b
Bare soil	Rye added	1.6 b

^z1 ton/acre = 2.24 t·ha⁻¹.^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test.**Table 7. Effect of seeded rye, manually distributed rye, and sprayed rye extracts on cabbage yield.^z**

Cabbage yield	
Treatment	(tons/acre)
1) Bare soil	21.7 a ^{a**y}
2) Rye removed	4.2 c
3) Rye mowed	2.4 c
4) Foliage added	17.1 ab
5) Rye extract	17.7 ab
6) Roundup	12.3 b

^z1 ton/acre = 2.24 t·ha⁻¹.^yMean separation at $\alpha = 0.05$ by Duncan's multiple range test.

ies to show that this effect was not nutritional, and was not caused by weed competition. Instead, we hypothesize that some substance in the rye that was toxic to the cabbage plants caused the effect.

Rye has been shown to have allelopathic properties (Barnes and Putnam, 1983; Liebland and Worsham, 1983; Putnam, 1986; Shilling et al., 1985), and we hypothesize that allelopathy could have caused the yield reduction in each of these studies. We suggest that the main allelopathic properties were coming from the rye roots, although there is some evidence in the last two studies to indicate that the rye foliage was also contributing to the allelopathic effect.

If certain features of our system had been changed, the results might have been different. For one thing, we did not attempt to cultivate any of the plots. If we had been able to disk or plow the rye residue into the soil, the plant material would probably have decomposed more quickly, and the allelopathic effect would have been minimized earlier in the cabbage growth cycle. However, the intent behind our studies was to develop a system that did not include cultivation.

Another feature we might have changed was to use a cover crop other than rye. Rye had been selected because it gave the quickest growth and most complete soil cover of any plant tested in our first screening study. However, it might have been advantageous to select a less vigorous cover crop that might have had less of an allelopathic effect.

A third feature that we might have changed was to allow more time between the application of glyphosate to the rye and the time that cabbage was planted. We could also have applied glyphosate to a narrow band in the center of the bed well in advance of planting cabbage. Either of these techniques would have allowed a longer time for the allelopathic materials to decompose. The time interval between these events was minimal in our studies. Air temperature in Oklahoma normally goes from relatively mild to hot temperatures [70 to 90 °F (21 to 32 °C)] in about a 30 d period from May to June. We needed to minimize the time interval between glyphosate application and cabbage planting in order to maximize our growth of rye and still be able to harvest cabbage before the onset of hot weather prevented the formation of high quality cabbage heads.

The judgement as to whether or

not this system was successful depends on the parameters against which the outcome is judged. The rye did allow formation of beds in the fall that could be planted with cabbage the following spring. Without some type of cover crop, the beds would not have remained intact until planting time. Cabbage could be planted into these beds, and would in most cases produce a low-yielding, but marketable crop. This is in contrast to a crop that might not be planted at all if the soil had to be tilled in late winter or early spring when the soil was too wet for equipment to be used.

The rye cover-crop system also reduced the abundance of insects on the cabbage. This could be explained by pest-predator-plant interactions that changed the ecosystem enough to discourage the buildup of pest populations. However, it might also be explained by a reduction in growth and vigor of the cabbage plant, which produced a slower growing cabbage plant that was less attractive to the pests than was the more vigorous cabbage in the bare soil treatments.

Because we were able to maintain the integrity of the raised beds when planted with rye, we assume that a rye cover crop would lessen soil erosion, relative to a soil that remained bare throughout the winter. The long term effects of lessened soil erosion can not be measured in monetary terms, and it might be argued that any reduction in yield is acceptable as long as soil erosion is minimized. Cover crops other than rye might be selected that would be more appropriate for cabbage production while also reducing soil erosion.

With all of these positive attributes, the fact cannot be overlooked that the rye cover crop system resulted in reduced yields of the cabbage in comparison to conventional tillage systems in every experiment we conducted. If maximizing yields and short term profits are the only basis against which this system is judged, then the system was not successful. If ecosystem benefits and soil maintenance are valued above short-term yields and profits, then the conclusion might be different.

Potential for developing a watermelon grass based conservation tillage system

The previously described rye and cabbage system was based on winter

cover crops and an early spring cash crop. We would expect a shallow-rooted crop such as cabbage (Maynard and Hochmuth, 1997) to be affected by a competing cover crop more so than would a deep-rooted crop such as watermelon. More recently, we have been working toward a system based on watermelon and perennial grasses. We are attempting to develop a system that will allow permanent pasture grasses and watermelon to be produced on the same land in the same year.

While watermelons normally produce more income per acre than do cattle, much of the land planted to watermelon is subject to erosion when not kept under a plant cover. Watermelons should be grown in a given field no more than 1 out of 4 years to prevent an increase in soilborne pathogens that may reduce, or eliminate, crop yields. Because of this, watermelon growers need access to at least four times the amount of their annual watermelon acreage. The risk of outbreaks of soilborne diseases is reduced on land that previously has been used as pasture, and grassland is thus desirable as a site for rotation with watermelons. However, most cattle farmers are unwilling and even unable to convert a permanent pasture into row-crop watermelons, and then reestablish the pasture after melon harvest is completed.

We would like to develop a system that will allow row-crop watermelon production in an established pasture or meadow for 1 year without damaging the stand of grass for the following years. An even better system would allow for production of both pasture grasses and watermelon on the same land in the same year. We are attempting to combine the advantages of watermelon production and bermudagrass pastures into one production system that can be used in the same field in the same year. Our approach is to grow watermelon in strips in a perennial pasture or meadow. Only a small portion of the pasture is tilled and planted with melons, and the pasture is then allowed to return to grass. With this system, cattle producers might diversify their operations, minimize risk, and improve farm profits. Watermelon producers can reduce soil erosion and also reduce the risk of soilborne pathogen diseases to the watermelon crop.

Very little has been reported relative to the work that we are attempting. There is no information concerning any

attempts to grow watermelons in strip-tilled areas in a permanent pasture. However, the concept of strip-tillage, living mulches, and maintenance of permanently grassed areas between rows has been examined with other crops, including corn (*Zea mays* L.) (Elkins et al., 1977, 1978), soybeans [*Glycine max* (L.) Merr.] (Dadson and Boakye-Boateng, 1975), coffee (*Coffea arabica* L.) (Chandler et al., 1969), fruit trees (Baxter, 1970), and strawberries (*Fragaria × ananassa* Duchesne) (Newenhouse and Dana, 1989). Standing vegetation has been used for windbreaks for fruit and vegetable crops (Baker, 1977). In a broader sense, conservation techniques have been tested for vegetable production (Hoyt et al., 1994), but not as strip till in permanent pastures.

Strip tillage has also been examined for vegetable production systems (Loy et al., 1987), but the crops were pepper (*Capsicum annum* L.) and winter squash (*Cucurbita maxima* L.) in New Hampshire. The between-row area was planted with blue grass (*Poa pratensis* L.), fescue (*Festuca rubra* L.), ryegrass (*Lolium perenne* L.), and clover (*Trifolium repens* L.). While the concept is similar to the work we are doing, the crops and the grasses were so different from watermelon and bermudagrass that results are not directly relevant to our work. In Oklahoma, we have examined CT for various vegetable crops (Nelson et al., 1991; Roberts and Cartwright, 1991a, 1991b, 1991c), and groundcovers have been tested with peach trees [*Prunus persica* (L.) Batsch.] (Huslig et al., 1993). While the concept is similar, the details and the crops are not closely connected. Although there are similarities in concept between this and other projects, no other work has been reported with watermelons in strip tilled fields. Also, no work has been reported combining vegetable production of any sort into a bermudagrass pasture setting.

We have conducted research for 3 years in Oklahoma and Texas to develop such a system. Fields of bermudagrass have been used to grow both hay and watermelons. One technique has been to plant watermelons in the field as early as possible in the spring. Another technique is to take one cutting of hay from the field in the spring, and then plant strips of watermelon into the grass stubble. The first technique involves harvesting watermelons before harvesting hay, while the second technique involves harvesting hay before water-

melons. Either technique has potential, and the choice of techniques is primarily dependent upon the market that watermelon growers are attempting to meet.

After 3 years, we have documented success with the system. The tilled strips that were planted with watermelons in 1 year may be overgrown with bermudagrass later during the same year, and will certainly be overgrown with grass the following year. We have not encountered a noticeable change in either insect or disease occurrence in the watermelons with any of the treatments in this system.

After 3 years of research, the main limitation to watermelon growth in this system seems to be our ability to control weeds. Bermudagrass may be classified as a weed when it interferes with watermelon production, even though it is also classified as a crop when grown between the tilled strips or when it is grown before or after the crop of watermelons. If grasses are completely controlled in the tilled and planted row, broadleaf weeds can become a problem within the row.

The system that is being developed will allow multi-cropping of both bermudagrass and watermelon. This system combines the advantages of a perennial crop with an annual crop. The system encourages crop diversity, and utilizes the advantages of crop polyculture. The system allows the production of a crop that is normally grown by clean culture without subjecting vast amounts of soil surface to erosion by wind or water. The system allows crop rotation within a given field, and thus lessens the chance of pathogen or parasite accumulation. The system allows production of a high value horticultural crop and a perennial soil-covering forage from one field in 1 year.

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