The Contribution of No-Tillage Crop Production to Sustainable Agriculture

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Abstract

No matter how one may define sustainable agriculture, use of soil-conserving cropping practices, less synthetic herbicide inputs, and as good as or better weed control would be compatible components. Previously, these components have been considered to be incompatible by some, since it was widely believed that soil-conserving practices required increased pesticide use, including herbicides. However, we have shown that environmental and ecological differences between no-till and conventional tillage can enhance the control of certain weed species in no-till cropping systems. We have shown that with proper choice and manipulation of cover crops and residues, it is often possible to reduce the number and/or amount of herbicides needed. Thus, in eliminating tillage, which restricts weed seeds to poor germination sites, by utilizing allelochemicals leaching from a killed cover crop, and using newer, more effective herbicides when needed, weed management in no-till has become much more effective.

In North Carolina, although results have been variable, we have grown soybean (*Glycine max* L.), tobacco (*Nicotiana tabaccum* L.), corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and sunflower (*Helianthus annus* L.) in killed heavy mulches of rye (*Secale cereale* L.) without herbicides, other than a non-selective one to kill the rye. Early-season control of broadleaved weeds such as sicklepod (*Cassia obtusifolia* L.) morningglory spp. (*Ipomoea* spp.) cocklebur (*Xanthium strumarium* L.) prickly sida (*Sida spinosa* L.) and pigweed spp. (*Amaranthus* spp.) has been 80 to 90% successful. Rye has been the most weed-suppressing cover crop among several small grains and subterranean clover (*Trifolium subterraneum* L.) and crimson clover (*Trifolium incarnatum* L.) the most suppressive legumes. Currently in the Southeastern U. S., it appears that it will still be most practical to use a non-selective herbicide for cover crop kill and selective postemergence herbicides as needed for late-season weeds and especially for grasses and perennial weeds. This approach will still enhance agricultural sustainability because; (a) productive top-soil will be conserved, (b) herbicide use (especially preemergence herbicides) can be reduced, and (c) herbicides for cover crop kill and postemergence selective herbicides have little potential for environmental contamination.

Key words : allelopathy, cover crops, herbicide reduction, mulch, weed control

Introduction

By the year 2025, 83% of the expected global population of 8.5 billion will be living in developing countries. Agriculture has to meet the challenge of providing enough food and fiber. Major adjustments will be needed to increase food production in a sustainable way and enhance food security. One of the priorities identified in the United Nations Programme of Action, "Earth Summit Agenda 21" in 1992 to create a sustainable agriculture and rural development was land conservation and improved management of inputs (Anon., 1992). Since weed management is one of the largest inputs in agriculture, what is the rela-

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tionship of weed management to sustainable agriculture ?

In order to discuss weed management for sustainable agriculture, it would appear desirable to define "Sustainable Agriculture" and the position weed scientists have taken on this subject. Following is a portion of a position statement compiled by a committee within the Weed Science Society of America.

"Our present agricultural system provides the United States with an abundant, diversified, high-quality, reasonably priced food supply. However, agriculture is and always has been in a constant state of change where producers must overcome numerous constraints in crop production. A major biological constraint to crop production is weeds, with which the Weed Science Society of America (WSSA) has been vitally concerned. To be sustainable, agriculture must be profitable; therefore, economical weed management will play a significant role in Sustainable Agriculture -----."

In agreement with this position, therefore, use of soil-conserving cropping practices, less synthetic herbicide inputs, and as good or better weed control would be compatible components of sustainable agriculture. Weed scientists and other agriculturalists in the Asian-Pacific area would probably not disagree. Many agricultural workers, however, believe these components incompatible, since it has been widely thought that conservation tillage, especially with use of cover crops, requires increased pesticide use, including herbicides.

Most of the benefits of cover crops are well known. They provide wind and water erosion control, conserve soil moisture by reducing evaporation and increasing infiltration, increase organic matter, increase fertility by recycling nutrients, add nitrogen (if legumes), and improve soil stucture. It is now known that certain cover crops can also improve weed control by increasing mulch and allelopathically suppressing weed growth. This can improve agricultural sustainability and environmental quality, especially in protection of surface and groundwater, by reducing, or eliminating in some cases, the need for preemergence herbicides.

The majority of row-crop acreage in the Southeastern U. S. is on Coastal Plain soils, an area described by the U. S. Environmental Protection Agency as having a high potential for leaching of pesticides into groundwater. Similar areas as to leaching potential exist in the corn-soybean region of the Midwest. The primary weed management system for the U. S.'s 1.2 million acres of corn is the preemergence application of a combination of atrazine and alachlor, making them the most widely used herbicides in the U. S. In preliminary surveys, detectable residues of both atrazine and alachlor have been found in a small percentage of water wells (Williams *et al*., 1988). Programs to lessen the potential for groundwater contamination from pesticides have already been established and others seem inevitable (Zinn and Tieman, 1989; Zinn, 1989). These programs may involve changes in use patterns, restrictions for certain areas or states, or canceling the registered uses for certain products. As examples, atrazine and atrazine-containing herbicides became restricted use products on September 1, 1990 because of groundwater concerns. Currently, the USEPA is reviewing triazine herbicides for possible further restrictions on use in the U. S. On October 24, 1990, the manufacturer of alachlor canceled its use in the state of Florida because the cost of required groundwater tests made further sales in that state unprofitable. We understand that some countries in the Asian-Pacific area also have groundwater pesticide concerns.

The Conservation Provisions of the U. S. 1985 Food Security Act (Farm Bill) encouraged owners of highly erodible, cropped land to have approved conservation plans fully implemented by January, 1995. One means of achieving compliance in the Southeast will be the increased use of no-till planting. Much greater use of cover crops will be required to meet conservation guidelines for soil protection at planting time (30% ground cover for most of the U. S., 50% in N. C.) (Worsham, 1990). These provisions were strengthened in the 1990 Farm Bill and there will likely be stronger provisions for protecting the environment in the 1995 Farm Bill, including incentives to reduce pesticide use.

Recent developments in weed management for crops planted without tillage into killed cover crops will be discussed in this paper. The suppression of broadleaved weeds by certain cover crop mulches, possible reasons for this, and the implications for improvement of agricultural sustainability and of environmental quality, especially groundwater quality, will be discussed.

Weed suppression by cover crops

Herbicides will continue to be a key component in most integrated weed management systems in the foreseeable future. Some problems and potential problems, however, are receiving increasing attention and concern. Such problems include persistence in soil, contamination of the environment (especially groundwater), crop injury, an increase in herbicide-resistant weeds, increased costs of discovering and developing new herbicides, enhanced soil biodegradation, and container disposal (Worsham, 1991; Worsham and Blum, 1992).

Because of these problems and other potential ones, increased attention is being focused on alternative ways of controlling weeds. Allelopathic suppression of weeds as a possible alternative weed management strategy has received increased study in recent years. Many papers and reviews on cover crops used, allelochemicals identified or suspected, and the degrees of weed control obtained from mulches have been published (see references 2, 3, 4, 5, 6, 8, 10, 11, 12, 15, 16, 17, 18, 21, 23, 24, 26, 27, 29, 30, 31, 32).

From results of laboratory experiments and observations of farmers in Japan, Brazil, and the USA, 46

Table 1 Effect of straw management and tillage on weed suppression in no-till planted crops in North Carolina[a] (Worsham, 1989)

Straw and tillage treatment	% Control[b]	
	Rye mulch[c]	Wheat mulch[c]
Remove straw and till soil	9 a	30 a
Remove straw, no-tillage	43 b	50 b
Remove straw, till and replace	60 c	60 c
Leave straw, no-tillage	76 d	81 d

[a] Average results from research in corn, soybeans, and tobacco, 1980-1986.
[b] Early-season ratings on redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), morningglory sp. (*Ipomea* spp.), prickly sida (*Sida spinosa* L.), and sicklepod (*Cassia obtusifolia* L.).
[c] Means within a column followed by the same letter are not significantly different as determined by Walker-Duncan T-test (K-ratio=100).

Table 2 The effects of mulch, tillage, and diphennamid on weed control in flue-cured tobacco at two locations in North Carolina[a]

Treatment	Weed control[b]	
	Broadleaved[c]	Grass[d]
Tilled no herbicide	8 e	47 c
Tilled plus herbicide	52 d	67 bc
No-till, no herbicide	68 bc	71 abc
No-till plus herbicide	87 ab	94 a
No-till, rye mulch, no herbicide	79 bc	54 bc
No-till, rye mulch plus herbicide	97 a	80 ab

[a] Modified from Shilling *et al.* (1986 b).
[b] Rating taken four weeks after transplanting. Means within a column followed by the same letter are not significantly different as determined by Waller-Duncan T-test (K-ratio=100).
[c] Redroot pigweed, common lambsquarter, and common ragweed.
[d] Goosegrass [*Eleusine indica* (L.) Gaertn] and large crabgrass (*Digitaria sanguinalis* L.).

plants for summer cover crops and 54 plants for winter cover crops were selected by Fujii and Waller (Fujii and Waller, 1994) for field tests for weed control. Some promising allelopathic plants were found.

Results of work in North Carolina

Our work in North Carolina over a number of years has indicated that leaving a small grain mulch and not tilling give 75 to 80% early-season control of a number of annual broadleaved weeds (Table 1). Removing straw, tilling and replacing straw gives 60% control. Removing straw and not tilling give 40 to 50% control and removing straw and tilling the soil, without herbicides, give little to no control of these weeds (Table 2). It was concluded that not tilling accounted for some weed control but having straw alone contributed even more. Not tilling plus having a straw mulch gave the highest degree of weed control (Worsham, 1989).

Among five no-tillage systems studied by Shilling *et al*. (1986 b) using desiccated small grains for weed suppression, rye generally provided the best broadleaved weed control (Table 3). Rye has also been particularly effective in studies by Putnam and DeFrank (1983), Barnes *et al*. (1986) and Worsham (1984). The high biomass production of shoots and roots, winter hardiness, and phytotoxicity of the residues make this grass crop very effective in no-tillage soil conservation cropping systems.

Shilling *et al*. (1986 b) reported research in which they attempted to partition the weed control effects from tillage alone, no-tillage, and no-tillage plus mulch with and without a preemergence herbicide in tobacco (Table 3). Tillage alone without herbicide gave 8% early-season control of broadleaved weeds and 47% control of annual grasses. Adding a soil-applied herbicide gave 52 and 67% control of broadleaved weeds and grasses, respectively. Not tilling, without herbicide or mulch, gave 68 and 71% control. The no-till treatment without mulch plus herbicide yielded 87 and 94% control. Rye mulch alone, no-till without herbicide gave 79 and 54% control, respectively, of broadleaved and grass weeds and rye mulch plus herbicide in no-till gave 97 and 80% control. Results from the same treatments with wheat, oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) were similar. These results confirm the need for not tilling plus having a mulch to achieve the highest degree of weed control without a preemergence herbicide.

In a study in 1989 to determine the difference in weed suppressing ability of a number of rye cultivars, after rye kill, no additional herbicides were needed for weed control in no-till corn, soybean, or grain sor-

Table 3 Effects of small grain mulch and tillage on weed control at two locations over two years in North Carolina[a]

Mulch type[b]	% Weed control[d]	
	Broadleaved[e]	Grass[f]
Rye	85 ab	70 b
Wheat	74 c	61 bc
Barley	75 c	54 bc
Oats	80 bc	64 b
None	63 d	41 d
None[c]	90 a	81 a

[a] Modified from Shilling *et al.* (1986 b).
[b] All treatments had 6.7 lb/A diphenamid and 3.3kg/ha glyphosate applied to kill grain and provide residual weed conrol.
[c] Tilled and rebedded prior to transplanting tobacco and cultivated twice.
[d] Means within a column followed by the same letter are not significantly different as determined by Waller-Duncan T-test (K-ratio=100). Rating are in early-season; about 4 weeks after transplanting.
[e] Redroot pigweed, common lambsquarters, and common ragweed.
[f] Large crabgrass and goosegrass.

Table 4 **Early-season weed control in corn from cover-crop/tillage systems and PRE Herbicides (Clayton and Rocky Mt., NC, 1992[a])**

Cover/crop Tillage system	Broadleaved weed[b]		Grasses[b]	
	PRE[c]	UTC[c]	PRE[c]	UTC[c]
	%			
Rye/no-till	97 a	87 b	95 ab	84 b
Crimson clover/no-till	98 a	65 c	94 b	64 c
Sub. clover/no-till	99 a	82 b	97 a	72 c
Hairy vetch/no-till	98 a	42 d	94 b	42 d
No cover/no-till	98 a	23 e	98 ab	24 e
No cover/conv. till	96 a	0 f	92 a	0 f

[a] Adapted from Yenish (1994) .
[b] Means within a type of weed followed by the same letter are not different at $P \leqq 0.05$ according to Fisher's Protected LSD test of arsine transformed data. Data recorded 45 days after planting.
[c] PRE = 1.4kg/ha atrazine + 2.2kg/ha metolachlor applied preemergence. UTC = check without herbicide.

Table 5 **Effect of rye seeding rate on mulch and weed biomass (Reidsville, NC 1994[a])**

Seeding rate kg/ha	Rye biomass g/m^2	Biomass of grass weeds	Biomass of broadleaved weeds
0	0	5.2	81.9
67	225	4.2	12.1
134	244	13.9	15.3
202	285	2.0	2.6

[a] Preliminary data from Nagabhushana *et al.* (1995). Data taken 45 days after planting.

ghum. In 1990, however, weed control from the rye mulch alone was not adequate (Hinen and Worsham, 1990).

In a preliminary study in 1990, redroot pigweed (*Amaranthus retroflexus* L.) control four weeks after planting no-till corn, cotton, soybeans, or tobacco was 81% in rye, 79% in subterranean clover, 72% in crimson clover, 41% in hairy vetch, 39% in no cover no-till, and 0 in conventionally tilled plots. No preemergence or postemergence herbicides were used. Postemergence herbicides were needed later in the season for complete weed control for most crops (Worsham, 1991).

Weed control by rye, crimson clover, subterranean clover, and hairy vetch (*Vicia villosa* Roth.) cover crops was evaluated in no-tillage corn and cotton (*Gossypium hirsutum* L.) during 1992 and 1993 (Table 4) (Yenish, 1994). Conventional tillage and no-cover, no-tillage treatments were included for comparison. Rye, crimson clover, and subterranean clover gave the best weed suppression. Although some of the cover crops gave significant early-season weed control, they did not entirely replace herbicides. Additions of preemergence and/or postemergence herbicides with the mulches gave the highest crop yields, particularly in cotton.

There is more recent evidence, however, that a cover crop can be manipulated to achieve greater weed control in the subsequently planted no-till crop. We found that increasing the seeding rate of rye, using a cultivar that tended to produce higher biomass, and killing the cover crop as close to planting time as possible all increased weed suppression. A very thick surface mulch provided adequate weed suppression for up to 10 weeks after transplanting tobacco (Table 5) (Nagabhushana *et al*., 1995).

In efforts to partition weed suppression effects between physical barriers of cover crops and allelopathy, we found that the duration of weed suppression by rye cover crops more closely followed the disappearance of certain allelochemicals (DIBOA, DIBOA-glucoside, and BOA) from rye residue than the disappearance of the residue itself (Yenish *et al*., 1995). Published estimations of weed suppression duration also more closely follow the disappearance of BIBOA-glucoside and related compounds from rye residue than the disappearance of the residue (Barnes *et al*., 1986 ; Doll and Bauer, 1991 ; Teasdale, 1993).

Implications of allelopathic cover crops in no-tillage for sustainable agriculture

As described in this paper, many cover crops temporarily suppress annual broadleaved weeds and there is evidence that this suppression in some cases may eliminate the need for preemergence soil-applied herbicides at time of planting summer crops. This has several benefits compatible with aims of sustainable agriculture. First, the cost of extra herbicide application is eliminated. The potential for groundwater contamination is lessened because herbicides used to kill the cover crops are foliar-applied and do not reach in soil. Postemergence herbicides will probably still be required for most crops, but since these, if needed, are usually used at much lower rates than preemergence herbicides, less will reach the soil, and most have low to very low groundwater contamination potential according to the ranking index by Weber (1990).

A method of evaluating groundwater contamination potential by changing to a postemergence weed management approach was given by Hoag (1990) for soybeans. Using his "cost-environmental hazard predictive model", by changing from the most herbicide-intensive, environmentally risky system to an environmentally desirable postemergence herbicide only, the groundwater risk potential was reduced by 65% at no extra cost to the producer. Further risk reduction was possible at very little cost. The new selective postemergence herbicides for corn should allow great reduction in environmental risk and groundwater contamination potential for this major acreage crop also.

The other well-known properties of cover crops that benefit the environment and sustainable agriculture such as wind and water soil erosion control, nutrient recycling, conserving soil moisture, increasing soil fertility and structure etc., would still be available with any allelopathic cover crops. There are disadvantages and potential problems, however, with the use of cover crops. Some of these are: Cost of establishing, difficulty in killing (especially legumes), leaching of nitrates (if legumes), lowering of soil temperatures in spring, depletion of soil moisture in the spring, the unknown effects of releasing natural phytotoxins into the environment, and possible increase of certain insects and diseases.

Fujii and Waller (1994) concluded that the use of living mulches as well as mixed plantings is necessary to develop a profitable, sustainable agriculture. Narwal (1994) reported that in the near future, allelopathy-mediated weed control technology may be available which will be free from environmental pollution and suitable for future sustainability of agriculture.

More research is needed on the extent to which use of cover crops allelopathic to weeds can be substituted for herbicides. More research is especially needed to determine the factors influencing the degree of weed suppression as results are variable now. Finally, more research would have to be done to provide the information needed to help growers integrate these new practices into on-going crop production practices and rotations.

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