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Winter Wheat (Triticum aestivum L.) as a Cover Crop
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# WINTER WHEAT (*Triticum aestivum* L.) AS A COVER CROP IN SUGAR BEET (*Beta vulgaris* L.) PRODUCTION

By

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# WINTER WHEAT (*Triticum aestivum* L.) AS A COVER CROP IN SUGAR BEET (*Beta vulgaris* L.) PRODUCTION.

## ABSTRACT

Conventional tillage practices leave soils vulnerable to wind and water erosion. Conservation tillage and cover crops can help to protect soils and crops grown in these soils. New herbicides give farmers a wide array of options to control cover crops and weeds in these systems.

Coarse textured soils in Michigan's sugar beet producing areas present a challenge in establishment and protection of sugar beet seedlings. Field research was conducted in 1995 and 1996 to study the effects of a winter wheat cover crop and tillage on sugar beet production. Cover crop management in the no-tillage and zone-tillage treatments was accomplished with an application of glyphosate at 840 g ai/ha, clethodim at 140 g ai/ha, or sethoxydim at 210 g ai/ha, or by cultivation. All treatments were evaluated for sugar beet populations, recoverable white sugar per hectare, sugar beet yield, percent sugar, weed density, and erosion potential.

No-tillage and zone-tillage treatments had lower sugar beet populations and yields than conventional tillage. The winter wheat cover crop suppressed weed emergence, prior to first cultivation. Winter wheat could not be controlled by cultivation alone. No-tillage and zone-tillage systems reduced potential for soil erosion compared to conventional tillage. Conventional tillage consistently had the highest return on investment for any of the treatments.

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## CHAPTER 2. WINTER WHEAT (*Triticum aestivum* L.) AS A COVER CROP IN SUGAR BEET (*Beta vulgaris* L.) PRODUCTION

# CHAPTER 1

# REVIEW OF LITERATURE

## INTRODUCTION

Sugar beets (*Beta vulgaris* L.) are one of two main sources of sugar in the world. However, increasing input costs, limited herbicide selection, difficulties with sugar beet stand establishment, low yields, and pressure from an environmentally aware populous are forcing changes in the production of sugar beets. Our research investigated utilizing winter wheat (*Triticum aestivum* L.) as a cover crop and planting sugar beets in no-tillage and zone-tillage systems to determine the influence of a cover crop and tillage system on sugar beet stand, yield and production costs.

Conventional tillage has been criticized for wasting energy and for contributing to soil erosion and air and water pollution (Mock and Erbach, 1977;  Bultena and Heiberg, 1983). Cover crops and conservation tillage practices leave plant residues on the soil surface, and thus reduce soil erosion and potential pollution of air and water. Implementing a system utilizing cover crops and conservation tillage can benefit agroecosystems in other ways (Wallace and Bellinder, 1992). Legume cover crops fix nitrogen in the soil (Stivers and Shennan, 1991; Frye and Blevins, 1989; Wagger, 1989; Wilson and Hargrove, 1986) to reduce nitrogen input costs. Cover crops also improve soil structure (Sarrantonio, 1992; Benoit et al., 1962; Wilson and Browning, 1945), reduce soil erosion and increase infiltration (Smith et al., 1987; Schackel and Hall, 1984; Mutchler and McDowell, 1990; Wilson and Browning, 1947), increase soil water and decrease soil water evaporation (Hill and Blevins, 1973; Mannering and Fenster, 1983), suppress weeds (Regnier and Stoller, 1987; Liebl and Worsham, 1983; Schilling et al., 1985; Enache and Ilnicki, 1990), reduce nitrate (and other soluble nutrients) leaching (McCracken et al., 1994; Jackson et al., 1993),and help to control pests (Kaakeh and Dutcher, 1993; Legg and Vincelli, 1989; Lamp et al., 1984; Bugg, 1991) .

Rye (*Secale cereale* L.) mulch has been shown to suppress seed germination and seedling growth of many dicot weed species (Schilling et al., 1985). Enache and Ilnicki (1990) showed that weed biomass in minimum tillage and no-tillage treatments was greater than that of conventional tillage treatments when no cover crop was seeded. However, a dead mulch system utilizing subterranean clover (*Trifolium subterraneum*) combined with a conventional tillage or minimum tillage system, resulted in the least weed biomass in the first year of the study (Enache and Ilnicki, 1990). In the next two years of the study a living mulch system of subterranean clover had the least weed biomass, regardless of tillage system.

## SUGAR BEET PRODUCTION

The sugar beet is a species of the Chenopodiaceae family, which also includes goosefoot, spinach, and other drought-resistant plants (xerophytes) (Silin, 1957). The sugar beet is a biennial plant, taking two growing seasons to produce seed. Sugar beets were planted in the year c. 2000 B.C. as they were depicted in Egyptian temples near the hieroglyph bnr, meaning “sweet” (Deerr, 1950). However, the sugar beet did not receive official recognition in Europe until 1583 A.D.

The sugar beet was first grown for its’ edible leaves. The sugar beet commercially produced in the United States was brought to Western Europe during the Crusades (Deerr, 1950) . The first modern use of sugar from sugar beets did not occur until 1800 in France and Germany (Deerr,1950). Sugar beets were planted in America in the mid-nineteenth century, but sugar beets did not become a major source of sugar for the United States until after World War I (Deerr, 1950). During World War II production of sugar from sugar beets intensified.

## History of Sugar Beet Production in Michigan

The first attempt to grow sugar beets in Michigan came in 1839, when a large potato grower, Lucius Lyon, brought the crop to Michigan's thumb region (Michigan Sugar Company, 1990). While production of the crop was fairly successful, manufacturing sugar from the beets was a total failure. In the late 1800's, a replacement was needed for Michigan's dying logging industry. The heavy fertile soils of Michigan's thumb region were ideal for sugar beet production and in 1898 Pioneer Michigan Factory opened. Michigan quickly became one of the largest producers of sugar beets in the United States.

Sugar beets are one of the most labor intensive crops grown, initially requiring as many as fifteen man hours per ton to produce (Silin, 1957). They were more labor intensive than most other crops because they were seeded to excessive populations, due to the lack of single germ seed stock, and then hand thinned. Weed control was accomplished through hand hoeing ,the use of mulches to suppress weeds, and mechanical implements. Chemical weed control was seldom used and confined to inorganic chemicals such as potassium and sodium chloride (Grisby and Stahler, 1950).

Animal manures and green manures were also applied to fields to put nutrients back into the soil. Defoliating, harvesting, and loading of sugar beets was all completed by hand.

The advent of World War II brought about many changes in the way that sugar beets were produced and the man hours required to produce them. Machines were developed to defoliate (Powers, 1942) and harvest sugar beets (Tramontini, 1942). Planters that would allow for accurate single seed placement (McBirney, 1942) and single germ seed were developed that would eliminate or greatly reduce the need for hand thinning. The development and production of synthetic fertilizers would reduce growers dependency on manures and cover crops for nutrients. The most important labor reducing innovation would be the discovery of selective herbicides that could be used in sugar beets to control weeds.

## Weed Control in Sugar Beets

In the late 1940's research was being conducted with organic chemicals such as propham (Schweizer and Dexter, 1987; Deming, 1950), sodium TCA (Grisby and Stahler, 1950) and endothall (Cormany and Eckroth, 1952). In the 1950's preemergence mixtures of TCA plus endothall were applied to control broadleaves and grasses (Cormany, 1954). Annual grasses were controlled effectively for the first time with postemergence applications of dalapon (Warren, 1954). In the early 1960's trifluralin, EPTC, chloropropham, and propham were developed for use as layby treatments in established sugarbeets (Schweizer and Dexter, 1987). In the mid 1960's researchers reported that pyrazon selectively controlled many broadleaf weeds when applied preplant, preemergence, or postemergence (Dawson, 1971; Meggitt, 1969). During the later half of the 1960's cycloate (Dawson, 1971), desmedipham (Laufesweiler and Gates, 1972), and phenmedipham (Meggitt, 1969) were shown to control specific weed species. The spectrum of weed control was broadened when cycloate was applied preplant incorporated, followed by a postemergence application of desmedipham, phenmedipham, or a mixture of these two herbicides (Dawson, 1974; Sullivan, 1973). In the 1970's diethatyl and ethofumesate became available for use. Diethatyl controlled selected grasses and broadleaf weed when applied preplant or preemergence (Lehman, 1974). Ethofumesate controlled grasses and broadleaf weeds either when applied alone or in mixtures preplant, and preemergence, or in mixtures postemergence (Ekins and Cronin, 1972; Sullivan, 1973). In the early 1980's sethoxydim received registration for postemergence control of grasses in sugar beets (Haagenson and Sullivan, 1983). In the late 1980's clopyralid was registered for control of selected broadleaf weeds (Renner, 1991). Recently quizalofop-P-ethyl and clethodim were registered for postemergence control of grasses and triflusulfuron-methyl for postemergence control of velvetleaf (*Abutilon theophrasti* Medic.) and wild mustard (*Brassica kaber*) (Starke, 1996).

## COVER CROP SYSTEMS

A cover crop is a crop that is planted solely to benefit the soil, the environment or another crop (Sarrantonio, 1994). Cover crops can be categorized in many different ways. They can be divided into the time of the year in which they are established; spring seeded, interseeded/ underseeded/ overseeded, and fall seeded. They can be grouped by the way in which they are utilized in agricultural systems; green manure, smother crop, and catch crop. Finally, some terms are used to the describe the actual cover cropping system, i.e. winter cover crop and living mulch. Many of the terms used to describe cover crops and others are interchangeable with one another.

### Green Manures

Green manuring is defined as the process of incorporating a crop into the soil to affect some agronomic improvement, such as improving soil structure, conserving such leachable nutrients as nitrate, or, in the case of legume green manures, to increase soil nitrogen content (Stivers and Sheenan, 1991). Some researchers feel that a green manure is not a true cover crop, in that it is established only to enhance soil productivity, rather than to prevent erosion or nutrient leaching or for the suppression of weeds (Pieters and McKee, 1938). However, a green manure does exhibit many of these other characteristics, even though that is not the specific reason for planting the cover crop.

### Smother Crops

Smother crops are established as a method of weed control. Smother crops can suppress weed emergence through shading of the ground, competing with the weed seedlings for nutrients and water, and/or through the use of allelopathic substances (DeHaan et al., 1994). When researchers and growers have a better understanding of allelopathy and other forms of plant interference, smother crops could become an effective way to control weeds in production agriculture.

### Catch Crops

A catch crop or nutrient “sink” is used to refer to a cover cropping system that is established for the purpose of holding soluble nutrients in the soil profile for future use. The main nutrient targeted by catch crop systems is nitrate, which can easily leach out of the soil profile, especially through the winter months or other extended fallow periods. Modern agriculture has the tendency to over apply nitrogen, phosphorus, and potassium so as not to have them be the limiting factor in crop production. Winter grains and grass cover crops have the ability to take up large quantities of nitrogen much more efficiently than legumes (Shipley et al., 1992).

### Living Mulches

In a typical living mulch system, row crops, such as corn, soybeans, or vegetables, are seeded into a low growing, pre-established winter grain, perennial legume, grass sod (Echtenkamp and Moomaw, 1989; Vrabel et al.,1983), or winter annual legume cover crop (Enache and Ilnicki, 1990). Living mulches are normally established to provide early season weed suppression. Unfortunately the mulches that exhibit the most weed suppression also have a tendency to suppress the row crop. Living mulches, therefore, normally require management by a herbicide application, partial tillage, or mowing to reduce their interference with row crop establishment, growth, and yield (Hartwig, 1988; Regnier and Stoller, 1987). Spring seeded oats (*Avena fatua* L.) and perennial ryegrass (*Lolium perenne* L.) that remained unsuppressed by chemical treatment provided excellent broadleaf control compared to no-cover plots, but were too competitive for acceptable yields of cabbage (*Brassica oleracea capitara* L.) and sugar beets (Hughes and Sweet, 1979). However, if the living mulch is properly managed, yields that are very competitive with conventional tillage are possible (Elkins et al., 1983).

### Spring Seeded

A spring seeded cover crop is one that is established from mid to late winter until spring planting of a row crop. Grasses, small cereal grains and legumes have all been used as spring seeded cover crops (Nelson, et al.,1991). Grasses and small cereal grains appear to be the best spring covers because they grow well when soil and air temperatures are cool and provide a very rapid ground cover which reduces soil erosion and weed emergence. One problem with a spring seeded cover that grows very aggressively is it can compete with the row crop if not controlled. Dehaan et al. (1994) showed a consistent four percent reduction in corn yields with a spring seeded cover crop. In sugar beet research conducted in Yaxley, England, barley (*Hordeum vulgare* L.) was planted in the spring and sugar beets were sown between the rows of emerged barley (Palmer, M., 1983). Fluazifop-P-butyl was applied to control the barley just prior to the barley reaching the labeled height.

## Interseeding

Interseeding or intercropping is the practice of cropping more than one species simultaneously (Eaglesham et al., 1981). Interseeding a legume or a legume/grass mixture can be very beneficial in providing nitrogen to the crop, and reducing soil erosion (Scott et al., 1987), stimulating soil activity (Singh et al., 1986), and reducing pest problems (Lambert et al., 1987). Studies by Scott et al. (1987) showed that depending on the species, planting time and weather, an interseeded legume cover crop could fix anywhere from eight to one hundred kg/ha of nitrogen in the soil. The interseeded cover crop also provided an extra ten to eighty percent ground cover (Scott et al., 1987), again dependent upon species, planting time and weather.

Another benefit of interseeding is earlier establishment of alfalfa (*Medicago* *sativa* L.). First year production of alfalfa was increased when interseeded at planting time or last cultivation of field corn, instead of waiting until after harvest to establish the alfalfa (Nordquist and Wicks, 1974). However, the alfalfa did decrease corn yields by up to thirty three percent.

### Fall Seeded

Fall seeded, or winter cover crops, are established in early to late autumn, usually after the preceding crop has been harvested. However, many are also interseeded directly into the previously growing crop (Nordquist and Wicks, 1974). Selection of a type and species of fall cover crop depends upon the main benefits that a producer is hoping to obtain.

### Legumes

Many legumes have been evaluated as cover crops. Some of the more common legumes for use as cover crops include alfalfa, crimson clover (*Trifolium incarnatum* L.), red clover (*Trifolium pratense* L.), subterranean clover, hairy vetch (*Vicia villosa*), bigflower vetch (*Vicia grandifiora*) and common vetch (*Vicia sativa*) (Smith et al., 1987).

Legumes are very popular winter covers, because they provide nitrogen (Frye and Blevins, 1989; Stivers and Shennan, 1991; Wagger,1989; Wilson and Hargrove,1986) thereby reducing or eliminating the need for commercial nitrogen to be applied to a spring seeded crop. Green manures, as legumes are often called, are used for precisely that reason, nitrogen fixation for future use by another plant. Legumes accomplish this nitrogen fixation with the help of bacteria rhizobia, which live symbiotically with the legume and fixes nitrogen from the gaseous nitrogen found in the atmosphere. Planting legumes has been shown to increase corn (Holderbaum et al., 1990; Smith et al., 1987), cotton (Stevens et al., 1992), and tomato yields (Stivers and Shennan, 1991). The legume must be properly managed so that it does not compete directly with the crop, but grows long enough to supply the crop with as much of the necessary nutrients as possible. Certain legumes, such as hairy vetch, have been known to fix over three hundred kg/ha of nitrogen, but ninety kg/ha to one hundred and eighty kg/ ha is the common amount (Sarrantonio, 1994). About twenty to sixty percent of all the nitrogen that the legume has collected will be made available to the plant in the first growing season, depending on the weather, management practices and other outside factors (Sarrantonio, 1994).

A cover crop can be managed by mechanical means, such as mowing or cultivation (Dabney et al., 1990), or by the use of herbicides (Dabney and Griffin, 1987; Griffin and Dabney, 1990). While increasing yields with proper cover crop management is possible, the reverse is also true. Allowing the cover crop to become too competitive with the row crop can greatly reduce crop yield and quality.

## Non-legumes

Non-legumes include grasses, sods and winter cereal grains. Cereal rye is probably the most popular winter cover crop in this category. It exhibits excellent winter hardiness, grows vigorously in cool weather, competes very well with weeds, and most producers are very familiar with it. The effectiveness of winter rye as a cover crop is mixed, especially in sugar beets. Wilson and Smith (1992) showed improved sugar beet stand and yield when sugar beets were planted into a rye cover crop compared to conventional production methods, while Fornstrom and Boehnke (1976) showed that rye suppressed beet yields by competing too vigorously with the crop. Proper management of the rye was the key as Fornstrom and Boehnke allowed the rye to get too large before trying to control it, while Wilson and Smith controlled the rye cover crop early in its growth stage with excellent results. If the rye was small at the time of planting , the producer could wait until after the crop has emerged and control the rye with a selective grass herbicide such as sethoxydim or fluazifop-P-butyl (Wilson and Smith, 1992).

Winter wheat is another popular winter cover crop. It does not grow as vigorously as rye and is much easier to control (Wilson and Smith, 1992). Sugar beet yield increased using winter wheat (Wilson and Smith,1992), but only when properly managed so it did not compete with the sugar beet crop. Barley and oats (*Avena sativa* L.)have also been planted effectively in many vegetable systems to benefit crop yields and the soil environment (Simmons and Dotzenko, 1975).

## BENEFITS OF COVER CROP SYSTEMS

### Nitrogen Fixation

Nitrogen fixation is one of the main benefits of utilizing cover crops, especially legumes. As this subject has already been covered in fall seeded legume section we shall now summarize the other benefits of cover crops.

### Soil Structure

Conventional tillage practices have a tendency to greatly reduce the organic matter in the soil (Mock and Erbach, 1977). Organic matter holds and recycles nutrients, nurtures soil microorganisms and increases the water holding capacity of the soil (Munawar et al., 1990, Sarrantonio, 1994). Organic matter holds up to twenty times its own weight in water (Sarrantonio, 1994). This can be very beneficial, especially in very arid regions. Cover crops, especially grasses and small grains, increase the humus in the soil. This in turn can increase the carbon to nitrogen ratio, which can improve crop growth.

Increased aggregate size in the soil is also a benefit of increased organic matter. This reduces crusting and allows for better air and water filtration throughout the soil. This promotes better and larger root growth which can improve crop growth, yield and quality.

## Soil Erosion

One of the main objectives for planting a cover crop is to reduce soil erosion. Cover crops reduce soil erosion by three separate mechanisms. First, cover crops help to increase water infiltration, thereby reducing soil and water runoff (Hill and Blevins, 1973; Mannering and Fenster, 1983). Secondly, a cover crop will help to deplete soil water, especially in the spring, by transpiration through the growing plant material (Hill and Blevins, 1973; Mannering and Fenster, 1983). Finally, a cover crop can shield the soil surface from the direct impact of falling rain (Hill and Blevins, 1973; Mannering and Fenster, 1983). This reduces compaction of the soil surface and maintains soil permeability, thus, all these factors show that cover crops simultaneously conserve soil and water (Munawar et al., 1990). Cover crops can reduce soil erosion from twenty-five to ninety percent, depending on the cover crop, the establishment date, residues left by the previous crop, environmental conditions and management practices that are followed (Sarrantonio, 1994). Many times the cost of seeding the cover crop is justified by the value of the topsoil that it is protecting.

Wind erosion is probably even more of a threat to sugar beet producers than water erosion because wind erosion directly effects stand establishment in many sugar beet growing areas (Fornstrom and Boehnke, 1976). Studies in Wyoming showed using a barley cover crop reduced potential soil loss from wind erosion from one hundred and nine mt./ha per year to thirty mt/ha per year (Fornstrom and Boehnke, 1976). The barley cover coupled with a minimum tillage system kept wind soil erosion at a minimum and protected young sugar beet seedlings grown on light textured soils (Simmons and Dotzenko, 1975).

## Soil Water Conservation

Cover crops can maintain soil water in arid regions. Maintaining crop residues on the soil surface shades the soil, decreases soil water evaporation, slows surface runoff and increases water evaporation (Munawar et al., 1990). Cover crops can preserve water and soil at the same time. Early killed rye provided significantly better soil water conservation than late killed rye, (Munawar et al., 1990) because the early killed rye flattened out on the soil surface and provided a protective cover. The late killed rye remained standing and allowed the soil surface to be partially exposed. The late killed rye also utilized more soil water through plant and evapotranspiration (Munawar et al., 1990).

## Weed Control

Cover crops provide partial or complete weed control. Cover crops interfere with the germination or growth of weeds or interfere with the completion of the weeds natural life cycle. Interference can be broken into three main categories; competition, allelomediation and allelopathy (Putnam and Tang, 1986). A cover crop such as rye is a strong competitor with most weeds for light, water, or nutrients (Barnes and Putnam, 1981). Controlling the cover crop through chemical or mechanical means creates a dense mulch that is a barrier to weed germination and early growth. Allelomediation is the selective harboring of an organism to the benefit of the host plant (Szezpanski, 1977). Allelopathy is another way in which a cover crop may control weeds.

Molisch (1937) defined allelopathy as the chemical interactions among all plant that stimulate as well as inhibit one another. However, today a more accurate definition would probably be the detrimental effect of one species on the germination, growth or development of another species (Putnam and Duke, 1978). Plants showing allelopathic traits actually produce their own natural herbicides called allelopathic agents. These allelopathic agents include phenolic acids, aliphatic acids, aldehydes, ketones, benzoic acids, terpenoids, coremarins and flavonoids (Cochran et al., 1977). These allelochemicals are found in plant tissue and residues and are capable of weed inhibition and suppression. Winter wheat straw inhibited germination and seedling growth of many different broadleaf weeds (Steinsiek et al., 1982)

Cover crops of wheat, barley, oats, rye, grain sorghum and sudan grass [ *Sorghum arundinaeum* ( Desv. ) Stapf. ] effectively suppressed weeds (Liebl et al., 1992; Schilling et al., 1985; Barnes and Putnam, 1983; Putnam and DeFrank, 1983). A rye cover crop in a no-till vegetable production system reduced total weed biomass up to 95% when compared to the residue free controls (Barnes and Putnam, 1983).

## Managing Nutrients

Cover crops can also be used to manage nutrients in the soil (Jackson et al., 1993; Shipley et al., 1992). Uptake of soluble, and therefore leachable, nutrients by the cover crop maintains these nutrients in the soil profile (Sarrantonio, 1994), thus reducing the leaching of these nutrients, especially nitrate-nitrogen into the groundwater (Angle et al., 1993; Jackson et al., 1993; Shipley et al., 1992). Grasses and winter grains are much better at being nutrient "sinks" or "banks" than legumes. Grasses and winter grains are three times more efficient at taking up nitrates than legumes (Cover Crops Handbook,1994). Many grasses and winter grains grow very well in cool autumn weather, thereby establishing a more extensive root system. This allows them to uptake more water from the soil, thereby reducing the rate of nitrate leaching (Sarrantonio, 1994).

## Pest Prevention and Control

Cover crops may help in controlling insect pests. Cover crops can provide cover for natural predators (Legg and Vincelli, 1989). Aphids and thrips are attracted to various clovers, hairy vetch, and cereal rye (Managing Cover Crops Profitably, 1994). The cover crop may also be unappealing to insect pests due to the color of the cover crop, an odor that the plant exudes, or the taste of the cover crop. Additionally, certain insects thrive in a more open, monoculture system, such as conventional till, as compare to the extensive trash and residue found in a cover crop system.

Some cover crops also have a deleterious effect on nematodes, bacteria and fungi that are destructive to the principal crop. Rye suppresses many of the *Pythium* species (Managing Cover Crops Profitably, 1994). Alfalfa has been shown to reduce the infestations of the fungus *Sclerotium rolsii* (Managing Cover Crops Profitably, 1994).

## RISKS OF COVER CROP SYSTEMS

### Interference

A major risk with cover crops is that if they are not properly managed they will compete with the crop for water, nutrients and sunlight resulting in yield loss and reduction in crop quality. Cover crops can also have allelopathic effects on crops, thereby interfering with proper crop development (Putnam and Tang, 1986). Finally, soils higher in organic matter may reduce herbicide effectiveness by binding the herbicide to the organic matter.

### Soil Water Conservation

The detrimental effects of water conservation is that the soil may be too wet from conserving moisture and thus, delay planting or impede harvest. Loss of soil nitrogen and fertilizer nitrogen is greater due to the fact that soil moisture is increased (Munawar et al., 1990). Compaction may also be increased due to the fact that wet soils are more easily compacted than dry soils.

### Nitrate Leaching

Nitrate leaching could increase under the proper environmental conditions with a mulch or cover crop (Munawar et al., 1990). Greater water retention due to higher organic matter and ground shading could lead to increased nitrogen leaching (Doran et al., 1984). Denitrifying bacteria thrive in higher organic systems, this could lead to larger nitrogen losses due to denitrification. Nitrogen management is more critical in conservation tillage systems than in conventional tillage (Doran et al.,1984).

### Soil Temperature

Lower soil temperatures due to soil shading and higher moisture contents can delay crop germination and seedling growth. Sugar beet emergence is affected by the soil temperature, soil moisture, aeration, and physical impedance (Bowen, 1966). A temperature drop of a few degrees below the optimum range of 25 to 35 C can cause a dramatic reduction in sugar beet emergence (Radkee and Bauer, 1969). Soil temperature can also effect microbial degradation, altering the breakdown of the mulch and its allelopathic effects on weeds and on the row crop. Higher temperatures usually lead to increased microbial degradation.

### Pests

Cover crops can also harbor pests, just as many weeds will act as a host plant for detrimental insects, fungi and bacteria (Mumford and Doney, 1984). Proper selection of the cover crop, planting time, and management are extremely important to how effective the cover crop will be to suppression of a pest specie.

Problems that could occur associated specifically with a winter wheat in sugar beet production are numerous. The main problems that could be introduced from winter wheat are fungal pathogens belonging to the genera *Phythium, Rhizoctonia,* and *Fusarium* (Whitney and Duffus, 1995). These fungi can cause serious problems in sugar beets and winter wheat, especially in the seedlings of both crops. Cool, moist soils are where many of these pathogens thrive and these conditions are enhanced under a cover crop system.

Insects that are major problems in cereal grains can also be a problem in sugar beets, such as aphids, armyworm, and certain cutworms (Whitney and Duffus, 1995). Many of these insects exist in the top few inches of soil and are generally controlled by fall plowing and spring tillage. However, utilizing a winter wheat cover crop system would eliminate or greatly reduce tillage, which may increase populations. Disease and insect problems may increase under a cover cropping system.

## COVER CROPS IN SUGAR BEET PRODUCTION

The use of cover crops in sugar beets is not an original idea. Cover crops were used before the development of chemical fertilizers to put nutrients back into the soil for sugar beet production. Modern day sugar beet production does not need cover crops for a fertilizer, but they can help to produce higher quality and higher yielding sugar beets. They are most helpful in early season seedling protection.

The Norfolk Agricultural Station in Britain has been studying using cover crops in sugar beet production to reduce wind damage since 1980 (Matthews, 1983; Nuttal, 1982). Living mulch systems (Fornstrom and Boehnke, 1976) and conservation tillage systems (Simmons and Dotzenko, 1974) have been researched in the United States with contradicting evidence of their effectiveness. One year the winter cover crop or the living mulch system was very competitive with conventional tillage, while in another year the conventional tillage system was significantly superior.

Wilson and Smith (1992) conducted research using winter wheat and winter rye cover crops for the establishment of sugar beets. In successive years sugar beet stands were increased when sugar beets were seeded between two rows of fall seeded rye or wheat. They also found in one out of the two years that yields were significantly higher in the cover crop systems than in the conventional tillage systems. The other year showed no significant difference between the two years. Proper and effective management of the cover crops was very important to how well the sugar beets grew. Glyphosate applied before planting provided superior cover crop suppression and control than either sethoxydim or fluazifop-P applied postemergence.

Recently much of the research in cover cropping systems has been conducted by the sugar beet growers themselves as cover cropping and high residue farming gains acceptance. Some are using the cover crops simply for crop protection, while others are searching for increased benefits. In Alberta, Canada a grower is planting sugar beets into a straw mulch from the previous years wheat crop (Llewelyn-Jones, 1993). The straw is shredded, para-tilled and planted to sugar beets in the spring. The Norby's of Montana are utilizing a corrugator/ridger/cover crop seeder to prepare their sugar beet fields with ridges and cover (Lilleboe, 1994). Huron County's Innovative Farmers are looking at a variety of combination of reduced tillage systems in conjunction with mulches and cover crops (LuCureux, 1996). Montana growers are also looking at strip tillage machines utilizing the previous years cereal grain straw as a cover (Lilleboe, 1996). All of these researchers and growers are having success using cover crops and mulch systems to produce sugar beets that are equal to or better in yield and quality than conventional tillage sugar beets.

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# CHAPTER 2

## WINTER WHEAT (*Triticum aestivum* L.) AS A COVER CROP IN SUGAR BEET (*Beta vulgaris* L.) PRODUCTION.

## ABSTRACT

Coarse textured soils in Michigan's sugar beet producing areas present a challenge in establishment and protection of sugar beet seedlings. Field research was conducted in 1995 and 1996 to study the effects of a winter wheat cover crop and tillage on sugar beet production. Cover crop management in the no-tillage and zone-tillage treatments was accomplished with an application of glyphosate at 840 g ai/ha, clethodim at 140 g ai/ha, or sethoxydim at 210 g ai/ha, or by cultivation. All treatments were evaluated for sugar beet populations, recoverable white sugar per hectare, sugar beet yield, percent sugar, weed density, and erosion potential.

No-tillage and zone-tillage treatments had lower sugar beet populations and yields than conventional tillage. The winter wheat cover crop suppressed weed emergence, prior to first cultivation. Winter wheat could not be controlled by cultivation alone. No-tillage and zone-tillage systems reduced potential for soil erosion compared to conventional tillage. Conventional tillage consistently had the highest return on investment for any of the treatments.

# INTRODUCTION

Sugar beet growers have experienced reduced profit per acre due to soil losses from water and wind erosion, stand loss from wind damage, cost of sugar beet replanting and resulting yield losses. Conservation tillage and utilization of cover crops could be integrated into a sugar beet production system to protect sugar beet seedlings from wind and water erosion. Legume cover crops can fix nitrogen in the soil and help to reduce nitrogen input costs (Stivers and Shennan, 1991; Frye and Blevins, 1989; Wagger, 1989; Wilson and Hargrove, 1986). All cover crops can improve soil structure (Sarrantonio, 1992; Benoit et al., 1962; Wilson and Browning, 1945), reduce soil erosion and increase infiltration (Mutchler and McDowell, 1990; Smith et al., 1987; Wilson et al., 1947), increase soil water and decrease soil water evaporation (Mannering and Fenster, 1983; Hill and Blevins, 1973), reduce nitrate (and other soluble nutrients) leaching (McCracken et al., 1994; Jackson et al., 1993), suppress weeds (Regnier and Stoller, 1987; Liebel and Worsham, 1983), and help to control pests (Kaakeh and Dutcher, 1993; Lamp et al.,1984).

Research has been conducted in the United States and Great Britain to determine the effectiveness of small grain cover crops in sugar beet production (Wilson and Smith, 1992; Matthews, 1983; Fornstrom and Boehnke, 1976). Barley (*Hordeum vulgare* L.) was used as a cover crop to reduce wind erosion and sugar beet losses in Wyoming (Fornstrom and Boehnke, 1976). Matthews (1983) showed that there were also alternative techniques available for reducing wind erosion. These included a polyvinyl acetate copolymer to be applied to sandy soils, tree lines and hedgerows, heavy liming with sugar beet lime, and applying a slurry evenly across the field. Wilson and Smith (1992) showed improved stand and yield when a cover crop was planted to help protect sugar beet seedlings. In Yaxley, England, barley was seeded in the spring and sugar beets were sown between the rows of emerged barley with favorable results (Palmer, 1983).

Small grain cover crops of wheat (*Triticum aestivum* L.), barley, oats (*Avena sativa* L.), and rye (*Secale cereale* L.) have been shown to effectively suppress weeds (Schilling et al.,1985; Barnes and Putnam, 1983; Putnam and DeFrank, 1983). The adoption of conservation-tillage cropping systems decreased densities of annual broadleaf weeds while increasing populations of annual grasses and perennial broadleaf weeds (Wrucke and Arnold, 1985). Minimum-tillage and no-tillage treatments had greater weed biomass than that of conventional tillage treatments when no cover crop was seeded (Enache and Ilnicki, 1990). However, the use of a cover crop significantly reduced weed biomass in three years of the study, regardless of tillage system (Enache and Ilnicki, 1990).

The main objectives of our research were: investigate various management practices for controlling a winter wheat cover crop in sugar beet production; study the effects of a winter wheat cover crop and tillage on weed density; study sugar beet response to a winter wheat cover crop in zone-tillage and no-tillage systems; evaluate potential wind and water erosion protection of utilizing winter wheat cover crop; and study economic returns of all treatments.

Clethodim recently received registration for use in sugar beets. Soil conditions are much different from the soils which many of the other studies were conducted on. We determined the effectiveness of herbicides and mechanical processes to control winter wheat and investigated the benefits of planting in zone-tillage and no-tillage systems for sugar beet production.

## MATERIALS AND METHODS

Field research was conducted in Freeland, Michigan in 1995 and 1996. Both sites were part of a Tappan-Londo-Poseyville soil complex with zero to 3 percent slope. In 1995 the soil type was a Poseyville sandy loam (coarse-loamy, mixed, mesic Psammaquentic Hapludalfs) with a soil pH of 7.3 and 1.1% organic matter. In 1996 the soil type was a Poseyville sandy loam with a soil pH of 7.0 and 1.8% organic matter. The previous crop at each site was Michigan Improved Vine Cranberry beans. The plot was prepared for wheat planting with a light disking. In the fall of 1994 and 1995 'Harus' winter wheat was seeded with a Case IH 5400[1] minimum tillage drill, on 19 cm spacings, at a rate of 2.5 bu. per hectare.

American Crystal 'ACH 185' sugar beets were planted on May 1, 1995 and Monohybrid Company 'E-17' was planted on May 14, 1996. Sugar beets were seeded in 76 cm row spacings with a John-Deere 7000[2] planter at a rate of 135,850 seeds/ha. The wheat was 20 to 25-cm in height at planting in 1995 and 10 to 15-cm in height in 1996. Pyrazon was applied in a 25-cm band over the row at planting with a hydraulically driven pump using 8003 flat fan nozzles calibrated to deliver 280.5 L/ha at a pressure of 207 kPa. Kalium potash ( 0-0-62 ) was broadcast in the fall at a rate of 224 kg/ha. Liquid urea ammonium nitrate was broadcast over the winter wheat in March at a rate of 234 L/ha. A dry fertilizer 14-18-12-1-1 (nitrogen-phosphorus-potassium-zinc-manganese)

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[1] J.I.CASE, Hamilton, Ontario L8N4C4

[2] Deere and Company, Moline, IL 61265-1304

was placed in a band 5-cm to the side of and 5-cm below the seed at a rate of 280 kg/ha.

The experimental design was a randomized complete block with four replications. There were ten treatments in 1995 and thirteen treatments in 1996. In each year a conventional tillage treatment was included as a control. Conventional tillage was completed with one pass of a 9.1 m Wilrich Soil Saver[3] to a depth of 7.5-cm. Zone-tillage was done with a Roggenbuck Trans-till[4] which tilled a 25-cm band to a depth of 7.5-cm into which the sugar beets were planted. Soil temperatures varied at the time of planting depending upon tillage practice and soil type. No-tillage treatments varied in temperature from 15 C in the finer textured areas to 18 C in the coarse textured soils. Zone-tillage and conventional tillage treatments soil temperatures was similar ranging from 16 C in the finer textured soils to 20 C in the coarse textured soils.

Glyphosate, clethodim, and sethoxydim were all applied with a 9.14 m spray boom with 80015E nozzles spaced 51 cm apart and calibrated to deliver 93.5 L/ha at a pressure of 276 kPa. Ground speed was a constant 7.2 kmph and the boom was adjusted to be 48-cm above the height of the winter wheat.

There were six cover crop management systems. These systems were glyphosate applied 7 days before sugar beet planting, glyphosate applied at planting, glyphosate applied 5 to 8 days after planting, sethoxydim or clethodim applied when the wheat reached 20-cm in height, and mechanical control with no herbicide application. All glyphosate treatments contained 840.3 g ai/ha + liquid urea ammonium nitrate at 4% v/v

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[3] Wilrich, Wahepton, ND 58704

[4] Roggenbuck Inc., Snover, MI 48472

+ nonionic surfactant (NIS)[5] at 1/2% v/v. In 1996, due to adverse weather conditions, the late glyphosate application was not applied until eight days after planting which led to a significant ($P < 0.05$) reduction in sugar beet stand count. Clethodim at a rate of 140 g ai/ha + crop oil concentrate (COC)[6] and sethoxydim at 210 g ai/ha + liquid urea ammonium nitrate at 9.33 L/ha + COC at 2.33 L/ha were applied when the wheat reached 20-cm in height. Mechanical control utilized a Hiniker[7] cultivator.

Cover left on the soil surface by the cover crop was visually evaluated before the second cultivation and this visual evaluation was then used to determine the potential reduction in soil erosion. Two equations were utilized to estimate potential wind and water erosion with and without the cover crop in each system. Potential soil erosion from runoff was based on the Natural Resource Conservation Service's estimates and the revised universal soil loss equation (RUSLE) ( Renard et al., 1992). The equation is

$A = R \times K \times L \times S \times C \times P$ where:

> A= the computed spatial average and temporal soil loss per unit of area expressed in units of K and period of R ( e.g., $t/ac^{-1}/yr^{-1}$).
>
> R= the rainfall and runoff factor, the number of rainfall erosion index units and a factor for snow melt where runoff is significant.
>
> K= the soil erodibility factor, the soil loss per erosion index unit for a specified soil as measured on a unit plot, which is a 22.1-m length of a uniform 9% slope in continuous clean tilled fallow.

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[5] Activator 90, a mixture of alkyl polyoxyethylene ether and free fatty acids. Loveland Industries, Inc., P.O. Box 1289 Greely, CO 80632

[6] Herbimax, 83% petroleum oil, 17% surfactant. Loveland Industries, Inc., P.O. Box Greely, CO 80632

[7] Hiniker Company, Mankato, MN 56002-3407

L= the slope-length factor, the ratio of soil loss from the field slope length to that from a 22.1-m length under ideal conditions.

S= the slope-steepness factor, the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise ideal conditions.

C= the cover and management factor, the ratio of soil loss from an area with specified cover and management that from an identical area in tilled continuous fallow.

P= the supporting practice factor, the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.

The soil saved is then assigned an economic value based on estimates of future productivity losses and the cost to attempt to replace that productivity.

While not very susceptible to water erosion due to its' gentle slopes and high permeability, a Poseyville soil is highly vulnerable to severe wind erosion due to its soil texture and the fact that it is usually found on ridges or rills in fields. Potential wind erosion is estimated by utilizing the wind-erosion prediction equation (WEQ) (Troeh et al., 1991). The equation is $E = f(I' \times K' \times C' \times L' \times V)$ where:

E= predicted soil loss, given in metric tonnes per hectare per year (mt./ha-yr)

I'= the soil-erodibility factor, mt./ha-yr. This is the potential soil loss from a wide, unsheltered, isolated field with a bare, smooth, non crusted surface.

K'= soil ridge roughness factor. The height of ridges and the distance between them are used to figure this factor.

C'= climatic factor. This is a combination of wind velocity, which effects wind erosion directly, and precipitation and temperature, which effects surface soil moisture and plant growth.

L'= width of field factor, ft. The width of field is the unsheltered distance in the downwind direction.

V= vegetative factor. The protection offered by vegetation depends on how much dry matter it contains, its texture, whether living or dead, standing or flat

.

By utilizing these two formulas, estimates were given as to the amount of soil conserved by each system for this specific soil type.

Zone-tillage would require more residue to provide the same protection as a no-tillage system due to the fact that part of the field is tilled (Dr. Delbert Mokma personal interview). Therefore, zone-tillage treatments were analyzed using a hybrid factor that allowed for the assessment of the undisturbed soil as well as the tilled soil. This allowed for a more accurate picture of the effects of zone-tillage on reducing water and wind erosion.

Water erosion is greatest near the bottom of a rill because as the water's momentum increases, so does its soil carrying abilities. If a soil is losing 5 mt./ha-yr, it is probably losing 3 to 4 mt./ha-yr on the upper part of the rill and 6 to 7 mt./ha-yr on the bottom of the rill. Wind erosion is affected by completely different parameters than water erosion. Rainfall enhances water erosion while decreasing wind erosion, while hot, dry weather will increase the possibility of wind erosion and reduce the possibility of water erosion. Water erosion is greatest near the base of a rill where the water is moving with the most velocity, where as wind erosion is greatest on the windward side of the rill and at the peak of the rill (Troeh et al.,1991). This forces us to look at wind and water erosion as two separate forces working together to erode soils.

Weed densities were counted in the row and between the row on the day of cultivation. Two 91-cm by 25-cm areas were counted in each treatment. The following formula was devised to estimate the cost of hand hoeing on a per hectare basis. The formula $[(5+(5*\text{wd m}^{-2}/16.25))*2.47]$[8] gives a fairly accurate estimate of hoeing costs per hectare, assuming that the wage rate is $5.00/hr and that weed densities are given in plants/$m^{-2}$.

Sugar beets were defoliated with a mechanical topper and twenty feet of the center two rows were hand dug and weighed to determine yield per hectare on September 28, 1995 and October 17, 1996. A sample of sugar beets from each plot was taken to the Michigan State University Bean and Beet Research Farm to be cleaned and sliced to obtain a sugar slurry sample. Sugar purity tests were conducted by Michigan Sugar Company in Carrollton, Michigan. Percent sugar was then used to obtain a payment rate based on a simplified form of Michigan Sugar's[9] payment schedule.

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[8] Formula developed by Dr. Karen Renner.

[9] Michigan Sugar Company, Carrollton, MI 48724

# RESULTS AND DISCUSSION

## Cover Crop Control and Weed Density

In 1995 and 1996 the most cover was found in the no-tillage plots that received no herbicide treatment (Table 1). This treatment had a significantly ($P < 0.05$) higher percent cover than any other system and clearly showed that mechanical control alone did not control the winter wheat cover crop. The trash cultivator could not handle all of the residue that accumulated in this system.

In 1995 heavy winter wheat residue (residue > 50 % cover) reduced sugar beet stand significantly (Table 1.). However, in 1996 only the conventional tillage system had significantly better stands than the plots with heavy residue (Table 1). This is probably due to the fact that the height of the winter wheat cover crop at sugar beet planting in 1996 was less than fifty percent of the height of the 23-cm winter wheat cover crop in 1995. Sethoxydim and clethodim were applied six days before sugar beet planting in 1995 because the cover crop was already 20-cm. In 1996, sethoxydim and clethodim were not applied until eight days after planting. While adequate cover is a major benefit of a cover crop system, if it is allowed to compete with the row crop, it becomes more detrimental than beneficial. Sugar beets are not very competitive when they first emerge from the ground and an aggressive cover crop can easily choke them out.

Glyphosate applied prior to, at, or following sugar beet planting provided the best control of the cover crop (data not presented). This is confirmed by Wilson and Smith's (1992) results showing that glyphosate provided significantly better control of winter wheat and winter rye than sethoxydim. Timing of application affected the amount of wheat residue left on the soil surface after first cultivation. Glyphosate applied a week prior to planting significantly reduced cover crop residues from thirty-five percent in 1995 and forty percent in 1996 compared to the residue remaining on plots treated with glyphosate five to eight days after planting and thirteen percent in 1996 compared to glyphosate applied at planting (Table 1). However, caution must be used when applying glyphosate after planting as sugar beet injury can occur under the proper conditions.

In 1995 and 1996 clethodim provided better control of the winter wheat cover crop than sethoxydim (Table 1). No-tillage systems with an application of sethoxydim had sixty-eight percent cover in 1995 and seventy-five percent cover in 1996, while the clethodim treatment left twenty-five percent cover in 1995 and twenty-three percent cover in 1996. Zone-tillage systems treated with clethodim also showed significantly better winter wheat control with the clethodim than those treated with the sethoxydim. In 1995, the clethodim treatment had only fifteen percent residue after the first cultivation. In 1996, only fourteen percent residue remained following an application of clethodim compared to fifty-nine percent following the application of sethoxydim in the zone-tillage system (Table 1). Small grain cover crops can be utilized and controlled within a modern sugar beet production system, however, a herbicide application is necessary for adequate control.

Weed densities in 1996 were almost twice that of 1995 in all treatments (Table 1). This could be due to: increased weed emergence in the wet spring of 1996; increased weed pressure at the second site; or the wheat did not shade the ground effectively in early 1996 and light was available for weed seed germination.

In both 1995 and 1996 the conventional tillage system had significantly higher weed densities than any other system at the time of first cultivation (Table 1). This is probably due to tillage stimulating weed seed germination and/or the lack of a winter wheat cover crop to shade the ground and suppress weed germination and growth. In 1995 and 1996 redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), eastern black nightshade (*Solanum ptycanthum* L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), wild mustard (*Brassica kaber*), and common chickweed (*Stellaria media* L.) made up over ninety percent of the weeds at the sites (Table 2). Over ninety five percent of the weeds found in the conventional tillage system were common lambsquarters, eastern black nightshade, Pennsylvania smartweed and redroot pigweed. Common chickweed and wild mustard grew readily in the cover crop systems but were not found where glyphosate was applied (Tables 2 and 3).

Glyphosate significantly lowered weed densities when applied five to eight days after planting compared to earlier glyphosate applications in both zone-tillage and no-tillage applications (Table 1). Fewer weeds had emerged at the time of the earlier applications of glyphosate, and weeds emerging later were not controlled. There was also significantly more residue on the soil surface following the later application of glyphosate. This may have contributed to suppression of weed emergence. When glyphosate is compared to clethodim we see that the glyphosate is clearly controlling some of the broadleaf weeds, while the clethodim does not. This is very evident in 1996 where we had greater weed densities.

However, where sethoxydim applications left significantly more residue on the soil surface compared to clethodim, weed pressure was still greater in both the no-tillage and zone-tillage systems in 1996. This suggests that allelopathic substances released by the wheat following the clethodim application was suppressing weeds.

Cultivation appeared to nullify any beneficial effects of the cover crop on weed control. The weed densities prior to the second cultivation were more evenly dispersed (Table 1 and 3). The weed spectrum does shift slightly though, because of the tillage application of the first cultivation, to almost entirely annuals. Few of the winter annuals survived the first cultivation, and few, if any, emerged as new seedlings (Table 3).

## Pests

Cooler soil temperatures, increased soil moisture, and reduced tillage applications can enhance pathogen and insect problems, especially in highly susceptible plants such as sugar beets (Whitney and Duffus, 1995). Many of the species of fungi that infect sugar beet seedlings (genera *Pythium, Fusarium,* and *Rhizoctonia*) thrive under cool, moist soil conditions, such as would be found utilizing a cover crop system. Reduced tillage allows for higher levels of insects to survive in the soil, especially armyworms and cutworms. These species are drawn to stubble fields and winter wheat fields to lay their eggs for overwintering. However, over the two years of this study we saw no increase in disease or insects in any of the cover crop systems compared to the conventional tillage system.

## Sugar Beet Populations

In 1995 sugar beet populations were significantly greater in the conventional tillage compared to all no-tillage treatments and all zone-tillage treatments, except where clethodim was applied postemergence in zone-tillage (Table 1). Zone-tillage treatments with either glyphosate applied preemergence or clethodim applied postemergence had similar populations that were significantly greater than all of the no-tillage stands counts. In 1996 sugar beet populations in the conventional tillage were significantly greater than all of the no-tillage treatments and all of the zone-tillage treatments, except zone-tillage with sethoxydim applied postemergence. From these two years of data it would appear that tillage improved sugar beet populations.

Plots treated with glyphosate one week before planting in the no-tillage system in 1995 had significantly greater populations than other no-tillage treatments, except where glyphosate was applied at planting in the no-tillage system. However, in 1996, sugar beet populations were greater in the no-tillage system treated with sethoxydim than in other systems, except no-tillage treated with glyphosate one week prior to planting. Sugar beet populations were similar in 1995 in all zone-tillage treatments except for zone-tillage with no herbicide application which had sugar beet populations reduced over seventy percent from its counterparts. In 1996, however, all glyphosate treatment's sugar beet populations were significantly lower than the populations of both postemergence treatments and the herbicide free treatment. This would lead to the assumption that glyphosate in 1996 somehow reduced sugar beet emergence in the zone-tillage. This could have occurred by 1.) the glyphosate actually came in contact with the sugar beet seedlings though fissures in the soil surface, 2.) the glyphosate transferred from the dying tissue of the wheat residue to the sugar beet seedlings that came into contact with it, or 3.) the timing of the application allowed for the allelopathic potential of the wheat to be concentrated enough to kill the sugar beet seedlings.

## Sugar Beet Yield

In 1995, sugar beet yield in the zone-tillage system with glyphosate applied at planting and in conventional tillage was greater than in all other treatments (Table 4). In 1996 sugar beets planted in conventional tillage had greater yield than in all other systems (Table 4).

Sugar beet yield was thirty to forty percent less than conventional tillage in glyphosate no-tillage treatments in 1995, and thirty to seventy percent lower in glyphosate no-tillage treatments in 1996 (Table 4). Clethodim and sethoxydim no-tillage treatments yields were forty to sixty percent lower than the conventional tillage treatments in 1995 and 1996 (Table 4). Sugar beet yields in the zone-tillage treatments were thirty five to sixty percent lower with the clethodim treatments in 1995 and 1996, and fifty percent lower with the sethoxydim treatment when compared to the conventional tillage system (Table 4). This shows how poor control of the cover crop and/or poor sugar beet stand establishment can lead to poor yields. In 1995, zone-tillage with glyphosate applied at planting yielded seven percent greater than the conventional tillage treatment (Table 4). Proper cover crop management combined with good stand establishment can result in improved sugar beet yields. Wilson and Smith (1992) showed improved sugar beet yields with their study of winter wheat and winter rye cover crops. Glyphosate applied at planting appears to be the most consistent system over two years utilizing a cover crop, regardless of tillage system.

Percent sugar was a full percentage point higher in 1996, than in 1995 when averaged over all treatments (Table 4). Sugar beets were planted thirteen days later and harvested nineteen days later in 1996, than in 1995. In 1995 and 1996 the zone-tillage clethodim treatment had the highest percent sugar. Glyphosate five to eight days after planting in the zone-tillage treatments had significantly reduced percent sugar compared to the conventional tillage (Table 4).

Conventional tillage had the highest recoverable white sugar per hectare over the two years (Table 4). The table shows that yield affects recoverable white sugar more than percent sugar does. Percent sugar only makes a real difference when yields are very close together, such as the zone-tillage with the clethodim application and the no-tillage with the glyphosate applied seven days before planting (Table 4). Although the difference is not significant in terms of recoverable white sugar per hectare, it does make a distinct difference in economic returns, that will be discussed later.

## Water and Wind Erosion Potential

Tolerable soil loss (T-value) is the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith, 1978). The results from applying the RUSLE clearly show the benefit of a cover crop for reducing the effects of water erosion by up to ninety-nine percent, even in soils such as the Tappan-Londo-Poseyville complex that are at a very low risk for water erosion (Table 5).While slopes of this type of soil can range up 3 percent, many of the soils in this region are less than 1 percent slope. Even though the potential soil erosion in conventional tillage is below the Natural Resource Conservation Service's recommended limit of 11.2 mt./ha-yr (T-value) on a Poseyville soil type, wind erosion must also be considered. T-values are for all types of erosion, not for each individual segment. It should also be noted that these are just estimates using climatic averages, in an inclement year, water and wind erosion could be much more severe. If the percent cover (Table 1) is taken into account, it shows that only a ten percent cover in a no-tillage system can reduce water erosion by fifty percent.

Wind erosion is a severe threat to a Poseyville soil type. Conventional tillage management systems and large, open fields enhance the effects of wind erosion. Conventional systems exceed the T-value on wind erosion potential alone (Table 5), so when potential wind erosion values are added to potential water erosion values, conventional systems exceed the T-value by two and three times. The no-tillage and zone-tillage systems treated with glyphosate seven days before planting also exceeded the T-value for a Poseyville soil when water and soil erosion are looked at collectively. The zone-tillage system with clethodim applied post also is over the T-value, however, even these systems are a vast improvement over the soil loss potential possible in a conventional tillage system. The remainder of the tillage systems are well below the recommended soil loss potential levels.

Reduction of the wind and water erosion potential of the soil implies that we should be providing more protection to the sugar beet seedlings. This is due to the fact that less erosion means that there is less of a chance for damage to the sugar beet seedling from wind erosion. By analyzing the percent cover data again (Table 1) and the erosion potential data (Table 5), it is clear that as little as ten percent cover in the no-tillage treatments and twenty-five percent cover in the zone tillage is reducing the erosion potential of this soil by fifty percent. A small amount of residue left on the soil surface can provide some protection to sugar beet seedlings. How much residue is enough depends on soil type, environmental conditions, and the producer.

## Economic Analysis

In 1995, pre-harvest variable costs (Kay and Edwards, 1994)for the different treatments ranged from a high of $490.00/ha for the zone-tillage plot with the clethodim application, to a low of $370.00/ha for the no tillage plot with no herbicide application. Hand hoeing costs were highest in the conventional tillage, with a cost of $140.00/ha.

The treatment that generated the largest net return on investment (ROI) (Kay and Edwards, 1994) in 1995 was the zone tillage with an application of glyphosate at planting, $1163.00/ha. This treatment generated $61.00/ha more per acre than did the conventional tillage, which generated $1102.00/ha. The remainder of the treatments had a significant reduction in ROI (Table 6).

In 1996 the conventional tillage system had the highest ROI at $1287.00/ha, while the glyphosate applied five to eight days after planting only had $273.00/ha ROI.

The two treatments with the highest input costs in 1995 and 1996 also returned the most on the initial investment (Table 6). Proper management and cultural practices affected returns much more than input costs. Profitability of sugar beets is linked to yield per acre and not to percent sugar, as percent sugar is only critical when yield per hectare is similar between two or more treatments.

## Implications

Applying glyphosate after planting can reduce sugar beet populations and significantly reduce yields. Caution should be used when applying glyphosate just before sugar beet emergence. Clethodim provided better control of the winter wheat cover crop than sethoxydim. Preemergence treatments should be done with clethodim. Finally, stand establishment is vital to yield potential. No-tillage treatments should be seeded at higher plant populations than zone-tillage or conventional tillage due to cooler soil temperatures. Generally, sugar beet populations were lower in the no-tillage and sugar beets emerged later and were smaller at first cultivation than zone-tillage or conventional tillage treatments.

## Summary

Mechanical control alone is not an option for the proper management of a winter wheat cover crop. Glyphosate applications controlled the winter wheat cover crop and resulted in the least residue remaining. Clethodim provided better control of a winter wheat cover crop than sethoxydim and also resulted in less residue compared to sethoxydim, but more than glyphosate. Cover crops may also suppress weeds, but should be used in conjunction with a herbicide program that manages the cover crop. Reduced tillage and a winter wheat cover crop resulted in lower weed densities at the time of first cultivation, but not second cultivation.

Conventional tillage was the most consistent system for establishing sugar beet stand and producing the final crop. Conventional tillage had the highest populations and produced the greatest yields over the two year period. Conventional tillage also had very respectable results in terms of percent sugar, especially when compared to the other systems.

However, conventional tillage practices do not protect the soil, especially early in the growing season when sugar beets are small. Cover crops can provide residue to ensure soil protection and reduce water and wind erosion. The benefits of a cover crop in terms of limiting erosion are obvious from Table 5. However, sugar beet production must be profitable and the highest and most consistent profits over the two years of the research were in the conventional tillage system. If other systems are going to be implemented they must be able to have a return on investment equal to or greater than that of conventional tillage.

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**Table 1. Percent cover, sugar beet populations, and weed densities in 1995 and 1996.**

| Tillage | Cover Crop Management | Cover | | Sugar Beet Population | | Weeds at First Cultivation | | Weeds at Second Cultivation | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | 1996 | 1995 | 1995 | 1995 | 1996 | 1995 | 1996 |
| | | ------------% ------------ | | --beets/30 m of row-- | | -------plants/m$^{-2}$------- | | ------- plants/m$^{-2}$------- | |
| No-tillage | Glyphosate-7DBP[1] | 10 | 8 | 86 | 89 | 75 | 156 | 46 | 61 |
| No-tillage | Glyphosate-PRE[2] | 16 | 21 | 80 | 87 | 67 | 121 | 55 | 142 |
| No-tillage | Glyphosate-5DAP[3] | 45 | 48 | 75 | 51 | 30 | 61 | 35 | 108 |
| No-tillage | Sethoxydim-Post[4] | 68 | 75 | 50 | 101 | 37 | 154 | 34 | 155 |
| No-tillage | Clethodim-Post[4] | 25 | 28 | 75 | 75 | 52 | 83 | 48 | 175 |
| No-tillage | Cultivation Only[5] | 100 | 95 | 44 | 84 | 42 | 89 | 33 | 102 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | 10 | -- | 76 | -- | 138 | -- | 142 |
| Zone-tillage | Glyphosate-PRE[2] | 23 | 28 | 112 | 78 | 37 | 179 | 43 | 158 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | 38 | -- | 55 | -- | 101 | -- | 150 |
| Zone-tillage | Sethoxydim-Post[4] | -- | 59 | -- | 104 | -- | 211 | -- | 96 |
| Zone-tillage | Clethodim-Post[4] | 15 | 14 | 120 | 102 | 71 | 119 | 35 | 102 |
| Zone-tillage | Cultivation Only[5] | 83 | 78 | 33 | 98 | 85 | 221 | 31 | 104 |
| Conventional | | 0 | 0 | 129 | 116 | 127 | 318 | 45 | 128 |
| LSD$_{(.05)}$ | | 7 | 3 | 9 | 13 | 15 | 39 | 12 | 31 |

[1] 7 days before planting.
[2] day of planting.
[3] 5 to 8 days after planting.
[4] applied when wheat reached 20 cm in height.
[5] no herbicides were used to manage cover crop, only tillage.
Glyphosate was applied at 840 g ai/ha + liquid urea ammonium 4%v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha. Clethodim was applied at 140 g ai/ha. Both sethoxydim and clethodim had crop oil concentrate added at a rate of 2.33 L/ha.
--treatment not applied in 1995.

**Table 2. Distribution of dominant weeds before first cultivation in 1995 and 1996. Weed density include in and between the row weed densities.**

| Tillage | Cover Crop Management | AMARE | | CHEAL | | SOLPT | | POLPE | | STEME | | BRAKA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 |
| | | plants/m$^{-2}$ | | | | | | | | | | | |
| No-tillage | Glyphosate-7DBP[1] | 1 | 29 | 6 | 98 | 31 | 1 | 7 | 2 | 7 | 4 | 5 | 0 |
| No-tillage | Glyphosate-PRE[2] | 1 | 29 | 1 | 69 | 27 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| No-tillage | Glyphosate-5DAP[3] | 5 | 7 | 4 | 44 | 10 | 0 | 4 | 6 | 2 | 2 | 0 | 0 |
| No-tillage | Sethoxydim-Post[4] | 1 | 14 | 1 | 100 | 9 | 3 | 2 | 16 | 12 | 19 | 2 | 0 |
| No-tillage | Clethodim-Post[4] | 1 | 8 | 5 | 60 | 22 | 0 | 5 | 7 | 8 | 5 | 6 | 0 |
| No-tillage | Cultivation Only[5] | 2 | 7 | 3 | 47 | 7 | 4 | 4 | 24 | 15 | 6 | 6 | 0 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | 10 | -- | 112 | -- | 1 | -- | 4 | -- | 5 | -- | 0 |
| Zone-tillage | Glyphosate-PRE[2] | 1 | 8 | 3 | 132 | 20 | 0 | 1 | 2 | 2 | 3 | 0 | 0 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | 16 | -- | 88 | -- | 0 | -- | 2 | -- | 1 | -- | 0 |
| Zone-tillage | Sethoxydim-Post[4] | -- | 14 | -- | 169 | -- | 0 | -- | 19 | -- | 7 | -- | 0 |
| Zone-tillage | Clethodim-Post[4] | 0 | 12 | 7 | 98 | 36 | 2 | 1 | 1 | 13 | 4 | 1 | 0 |
| Zone-tillage | Cultivation Only[5] | 2 | 18 | 4 | 183 | 35 | 0 | 7 | 10 | 17 | 8 | 8 | 0 |
| Conventional | | 3 | 22 | 13 | 267 | 50 | 4 | 52 | 22 | 0 | 0 | 0 | 0 |
| LSD$_{(.05)}$ | | 1 | 8 | 2 | 31 | 13 | 1 | 9 | 7 | 3 | 2 | 3 | 0 |

[1] 7 days before planting.
[2] day of planting.
[3] 5 to 8 days after planting.
[4] applied when wheat reached 20 cm in height.
[5] no herbicides were used to manage cover crop, only tillage.
Glyphosate was applied at 840 g ai/ha + liquid urea ammonium nitrate 4% v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha + liquid urea ammonium nitrate at 9.33 L/ha + crop oil concentrate at 2.33 L/ha. Clethodim was applied at 140 g ai/ha + crop oil concentrate at 2.33 L/ha.
--treatment not applied in 1995.

Table 3. Distribution of newly emerged dominant weeds before second cultivation in 1995 and 1996.

| Tillage | Cover Crop Management | AMARE | | CHEAL | | SOLPT | | POLPE | | STEME | | BRAKA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 |
| | | plants/$m^{-2}$ | | | | | | | | | | | |
| No-tillage | Glyphosate-7DBP[1] | 7 | 3 | 7 | 43 | 10 | 0 | 2 | 2 | 2 | 2 | 1 | 0 |
| No-tillage | Glyphosate-PRE[2] | 7 | 21 | 6 | 119 | 7 | 0 | 2 | 0 | 0 | 2 | 0 | 0 |
| No-tillage | Glyphosate-5DAP[3] | 8 | 9 | 6 | 94 | 19 | 2 | 1 | 2 | 1 | 0 | 1 | 0 |
| No-tillage | Sethoxydim-Post[4] | 6 | 27 | 4 | 117 | 12 | 0 | 1 | 7 | 5 | 6 | 0 | 0 |
| No-tillage | Clethodim-Post[4] | 11 | 21 | 7 | 104 | 34 | 2 | 11 | 88 | 5 | 0 | 1 | 0 |
| No-tillage | Cultivation Only[5] | 5 | 7 | 2 | 31 | 6 | 1 | 2 | 47 | 8 | 0 | 2 | 0 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | 4 | -- | 121 | -- | 0 | -- | 22 | -- | 1 | -- | 0 |
| Zone-tillage | Glyphosate-PRE[2] | 11 | 2 | 3 | 161 | 15 | 0 | 1 | 3 | 0 | 1 | 1 | 0 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | 5 | -- | 136 | -- | 0 | -- | 6 | -- | 1 | -- | 0 |
| Zone-tillage | Sethoxydim-Post[4] | -- | 15 | -- | 63 | -- | 0 | -- | 20 | -- | 1 | -- | 0 |
| Zone-tillage | Clethodim-Post[4] | 6 | 10 | 3 | 71 | 14 | 1 | 2 | 33 | 6 | 1 | 0 | 0 |
| Zone-tillage | Cultivation Only[5] | 2 | 12 | 4 | 56 | 11 | 1 | 0 | 5 | 7 | 1 | 0 | 0 |
| Conventional | | 6 | 37 | 6 | 58 | 18 | 1 | 10 | 22 | 0 | 0 | 1 | 0 |
| $LSD_{(.05)}$ | | 3 | 8 | 2 | 18 | 7 | 0 | 2 | 15 | 1 | 1 | 1 | 0 |

[1] 7 days before planting.

[2] day of planting.

[3] 5 days after planting.

[4] applied when wheat reached 20 cm in height.

[5] no herbicides were used to manage cover crop, only tillage.

Glyphosate was applied at 840 g ai/ha + liquid urea ammonium nitrate 4% v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha + liquid urea ammonium nitrate 9.33 L/ha + crop oil concentrate at 2.33 L/ha. Clethodim was applied at 140 g ai/ha + crop oil concentrate at 2.33 L/ha.

--treatment not applied in 1995.

Table 4. Harvest populations, sugar beet yield in metric tons per hectare, percent sugar, and recoverable white sugar in kg/ha in 1995 and 1996.

| Tillage | Cover Crop Management | Harvest Populations | | Yield | | Sugar | | Recoverable White | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 |
| | | -------Beets/30 m row------ | | -------------mt/ha------------ | | ---------------%--------------- | | -------------kg/ha------------ | |
| No-tillage | Glyphosate-7DBP[1] | -- | 64 | 35.5 | 27.7 | 15.85 | 16.99 | 3800 | 3470 |
| No-tillage | Glyphosate-PRE[2] | -- | 81 | 39.2 | 40.6 | 16.16 | 17.04 | 4300 | 4980 |
| No-tillage | Glyphosate-5DAP[3] | -- | 40 | 33.9 | 17.9 | 15.88 | 16.58 | 3680 | 2110 |
| No-tillage | Sethoxydim-Post[4] | -- | 88 | 21.5 | 33.9 | 16.19 | 16.98 | 2380 | 4220 |
| No-tillage | Clethodim-Post[4] | -- | 54 | 23.9 | 29.8 | 15.51 | 16.92 | 2480 | 3650 |
| No-tillage | Cultivation Only[5] | -- | 61 | 9.0 | 22.4 | 15.98 | 16.99 | 1000 | 2760 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | 68 | -- | 28.7 | -- | 17.26 | -- | 3620 |
| Zone-tillage | Glyphosate-PRE[2] | -- | 69 | 58.0 | 33.1 | 15.58 | 16.94 | 6180 | 4130 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | 50 | -- | 28.3 | -- | 16.85 | -- | 2540 |
| Zone-tillage | Sethoxydim-Post[4] | -- | 87 | -- | 29.2 | -- | 17.28 | -- | 3750 |
| Zone-tillage | Clethodim-Post[4] | -- | 87 | 35.4 | 22.6 | 16.75 | 17.23 | 4140 | 2880 |
| Zone-tillage | Cultivation Only[5] | -- | 54 | 3.6 | 15.4 | 14.55 | 16.59 | 340 | 1840 |
| Conventional | | -- | 105 | 54.0 | 58.1 | 16.25 | 17.16 | 6080 | 7170 |
| $LSD_{(.05)}$ | | | 7 | 7.8 | 6.1 | NS | NS | 630 | 780 |

[1] 7 days before planting.
[2] day of planting.
[3] 5 days after planting.
[4] applied when wheat reached 20 cm in height.
[5] no herbicides were used to manage cover crop, only tillage.
Glyphosate was applied at 840 g ai/ha + liquid urea ammonium nitrate 4% v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha + liquid urea ammonium nitrate at 9.33 L/ha + crop oil concentrate at 2.33 L/ha.Clethodim was applied at 140 g ai/ha + crop oil concentrate at 2.33 L/ha.
--treatment not applied in 1995.

Table 5. Potential erosion in metric tons per hectare per year (mt./ha-yr) by water and wind in 1995 and 1996 using the revised universal soil loss equation and the wind-erosion prediction equation.

| Tillage | Cover Crop Management | Water Erosion 1% Slope |  | Water Erosion 3% Slope |  | Wind Erosion 1% Slope |  | Wind Erosion 3% Slope |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 |
|  |  | mt./ha-yr |  |  |  |  |  |  |  |
| No-tillage | Glyphosate-7DBP[1] | 2.5 | 2.5 | 5.6 | 5.7 | 5.6 | 10.1 | 10.8 | 17.9 |
| No-tillage | Glyphosate-PRE[2] | 2.3 | 2.2 | 5.2 | 4.9 | 1.3 | 0.5 | 1.8 | 0.8 |
| No-tillage | Glyphosate-5DAP[3] | 1.5 | 1.4 | 3.4 | 3.3 | 0 | 0 | 0 | 0 |
| No-tillage | Sethoxydim-Post[4] | 0.9 | 0.7 | 2.0 | 1.6 | 0 | 0 | 0 | 0 |
| No-tillage | Clethodim-Post[4] | 2.1 | 2.1 | 4.6 | 4.8 | 0.4 | 0.2 | 0.6 | 0.3 |
| No-tillage | Cultivation Only[5] | 0.1 | 0.1 | 0.1 | 0.3 | 0 | 0 | 0 | 0 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | 3.2 | -- | 6.9 | -- | 5.6 | -- | 10.8 |
| Zone-tillage | Glyphosate-PRE[2] | 2.8 | 2.6 | 5.9 | 5.6 | 0 | 0 | 0 | 0 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | 2.2 | -- | 4.8 | -- | 0 | -- | 0 |
| Zone-tillage | Sethoxydim-Post[4] | -- | 1.5 | -- | 3.2 | -- | 0 | -- | 0 |
| Zone-tillage | Clethodim-Post[4] | 3.0 | 3.1 | 6.5 | 6.6 | 2.2 | 2.2 | 5.6 | 5.6 |
| Zone-tillage | Cultivation Only[5] | 0.6 | 0.8 | 1.3 | 1.7 | 0 | 0 | 0 | 0 |
| Conventional |  | 5.2 | 5.2 | 10.5 | 10.5 | 17.9 | 17.9 | 31.4 | 31.4 |

[1] 7 days before planting.
[2] day of planting.
[3] 5 days after planting.
[4] applied when wheat reached 20 cm in height.
[5] no herbicides were used to manage cover crop, only tillage.
Glyphosate was applied at 840 g ai/ha + liquid urea ammonium nitrate 4% v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha + liquid urea ammonium nitrate at 9.33 L/ha + crop oil concentrate at 2.33 L/ha. Clethodim was applied at 140 g ai/ha + crop oil concentrate at 2.33 L/ha.
--treatment not applied in 1995.
The tolerable soil loss (T-value) for a Poseyville soil is 11.2 mt./ha-yr.

Table 6. Economic analysis of input costs and return on investment (ROI) in 1995 and 1996 in dollars per hectare.

| Tillage | Cover Crop Management | 1995 |  | 1996 |  |
|---|---|---|---|---|---|
|  |  | Input Costs | ROI | Inputs Costs | ROI |
|  |  | $/ha |  |  |  |
| No-tillage | Glyphosate-7DBP[1] | 1015 | 390 | 1054 | 167 |
| No-tillage | Glyphosate-PRE[2] | 1033 | 552 | 1145 | 640 |
| No-tillage | Glyphosate-5DAP[3] | 966 | 381 | 974 | (204) |
| No-tillage | Sethoxydim-Post[4] | 939 | (70) | 1175 | 322 |
| No-tillage | Clethodim-Post[4] | 982 | (54) | 1128 | 180 |
| No-tillage | Cultivation Only[5] | 842 | (481) | 989 | 1 |
| Zone-tillage | Glyphosate-7DBP[1] | -- | -- | 1147 | 138 |
| Zone-tillage | Glyphosate-PRE[2] | 1096 | 1163 | 1182 | 273 |
| Zone-tillage | Glyphosate-5DAP[3] | -- | -- | 1096 | 144 |
| Zone-tillage | Sethoxydim-Post[4] | -- | -- | 1110 | 199 |
| Zone-tillage | Clethodim-Post[4] | 1040 | 445 | 1071 | (59) |
| Zone-tillage | Cultivation Only[5] | 852 | (722) | 1063 | (398) |
| Conventional |  | 1093 | 1102 | 1300 | 1287 |

[1] 7 days before planting.

[2] day of planting.

[3] 5 to 8 days after planting.

[4] applied when wheat reached 20 cm in height.

[5] no herbicides were used to manage cover crop, only tillage.

Glyphosate was applied at 840 g ai/ha + liquid urea ammonium nitrate 4% v/v + nonionic surfactant ½% v/v. Sethoxydim was applied at 210 g ai/ha + liquid urea ammonium nitrate at 9.33 L/ha + crop oil concentrate at 2.33 L/ha. Clethodim was applied at 140 g ai/ha + crop oil concentrate at 2.33 L/ha.

--treatment not applied in 1995.

Parentheses () denote negative return on investment.