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REDUCED TILLAGE EFFECTS ON WEED CONTROL, SOIL PROPERTIES, AND DOMINANT WEED SPECIES IN SOUTHEASTERN SOUTH DAKOTA

by

Mark A. Wrucke

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science
Major in Agronomy
South Dakota State University
1984

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REDUCED TILLAGE EFFECTS ON WEED CONTROL, SOIL PROPERTIES, AND DOMINANT WEED SPECIES IN SOUTHEASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

W. E. Arnold
Thesis Advisor
Date

M. L. Horton
Head, Plant Science Department
Date

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INTRODUCTION

In recent years, farmers have made dramatic changes in their tillage practices. The conventional plow-disk-drag system allows farmers to control weeds, remove crop residue, and prepare the soil for planting. The development of 2,4-D [(2,4-dichlorophenoxy) acetic acid] in the 1940's and of additional herbicides since then has greatly reduced the need for tillage to control weeds. Improvements in planting equipment allow farmers to use crop residue to their benefit. Farmers using tillage systems which leave residue on the soil surface can realize savings of time, labor, and equipment together with increased moisture and soil conservation while maintaining yields equal to conventional tillage.

As tillage is decreased, several potential problems become apparent. Incorporation of fertilizer becomes more difficult and nitrogen requirements may increase. Soil is slower to warm in the spring and may become more compacted without tillage to loosen the soil. Weed pressure may increase and weed species may change with reduced tillage. Crop residue can intercept herbicides applied and methods of herbicide application may have to be changed for optimum control. Crop diseases and insects may become more troublesome.

An evaluation of potential benefits and problems associated with reduced tillage systems in southeastern South Dakota would be beneficial to farmers. The objectives of this research were to determine: (1) whether presently available herbicides can effectively control weeds in reduced tillage systems planted in a corn-soybean rotation,

(2) the effect of reduced tillage systems on residual soil fertility and other soil properties, and (3) the potential for weed species shifts with reduced tillage systems in southeastern South Dakota.

LITERATURE REVIEW

Traditionally, seedbed preparation is accomplished by plowing and cultivation. This method has successfully met several objectives: suitable soil conditions for germination and root development, weed control, burial of crop and pest residues, and incorporation of fertilizer and pesticides. Crops can be grown satisfactorily using less tillage, but lack of weed control limited this concept until the development and introduction of suitable herbicides. Approximately 22% of all crops in 1980 were produced by some form of reduced tillage; it is projected that by 1990 over one-half of all cropland will be farmed with reduced tillage (12, 15).

Farmers are changing tillage practices for several reasons. Erosion due to wind and water is one of the most widespread problems in the United States. Terracing and contour farming have been used to reduce erosion, but conservation tillage systems may be more effective. Minimum or no-till production systems can reduce erosion up to 90% compared to 50% reduction with terrace or contour farming. The reduction attained with conservation tillage systems varies depending on the amount of crop residue left on the soil, soil texture, percent slope and length of slope, and the amount and intensity of wind and rainfall (43, 45, 76, 94, 97).

Another benefit of reduced tillage is a reduction of evaporative water loss from the soil. Transpiration accounts for only 30 to 50% of the total soil water loss, the remainder is due to evaporation (59). Crop residue insulates the upper soil profile, thus reducing evaporative loss during the early stages of crop growth. Rate of evaporation generally decreases with increased residue rates (10, 74). Tillage systems which leave substantial amounts of crop residue on the soil surface have resulted in a 33% or greater decrease in soil water loss from wet soil during a 20-day period (26). Water use efficiency of corn (Zea mays L.) grown without tillage can be as much as 100% greater than corn under conventional tillage (40); however, the cumulative evaporation losses under the two tillage systems will eventually be equal (10). During periods of drought, depletion of soil water in the upper foot of soil is delayed by 7 to 14 days (74).

Crop residue may increase water intake by reducing runoff and controlling erosion to levels 6 to 7 times less than that of plowed ground (7, 50). Mulch protects by intercepting and absorbing raindrop impact preventing surface sealing. Also, the degree of soil aggregation and rate of water infiltration is consistently greater under reduced tillage, but this varies greatly with soil type (2, 7, 12, 50).

Availability and costs of fuel and labor together with the continued trend toward larger farms and fewer workers stirred significant interest in reduced and no-till systems during the 1970's. Conservation tillage is well suited to modern farming because of less labor inputs. Depending on the system used, one-half the time required for conventional tillage systems can be saved. Fewer trips over the field increase the useable life of tillage equipment and, therefore, reduce equipment costs (15). Also, energy requirements for cultural operations in corn and sorghum (Sorghum bicolor) may be reduced up to

83%, thereby saving as much as three gallons of fuel per acre per year (96). Total energy savings is dependent on the tillage system used but energy requirements are generally less with reduced tillage systems.

Plowing and cultivating is the traditional and most effective method of weed control. As tillage practices are reduced, weed problems tend to increase (45, 52, 67, 89). Weed seed becomes concentrated at the soil surface resulting in increased weed pressure (90). Young weed seedlings growing at planting time may not be destroyed; this may result in increased herbicide requirements. Kapusta (35) in an experiment comparing weed control and soybean (Glycine max) yield in reduced tillage systems found poorest weed control in no-till plots. Large size of weeds when nonselective herbicides were applied and insufficient rainfall for activation after preemergence herbicide application were cited as reasons for this lack of control.

Residue on the soil surface may intercept and affect herbicide performance. Residue levels may exceed 5600 kg/ha and cover 60 to 80% of the soil surface (44, 67). The possible interaction of surface-applied herbicides with crop residue becomes very important. Grover (28) found that picloram (4-amino-3,5,6-trichloropicolinic acid) was not adsorbed on wheat (Triticum aestivum L.) straw or cellulose but was highly adsorbed on soil organic matter. Bauman (6) reported that approximately 30% less atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-striazine] reached the soil surface with a no-till system compared to a conventional system. Most of the intercepted atrazine disappeared without moving into the soil.

Martin and associates found that corn residue retained little of the herbicides atrazine, cyanazine 2-[[4-chloro-6-(ethylamino)-s-triazin-2-yl]amino]-2-methylpropionitrile , alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide], and propachlor (2-chloro-N-isopropylacetanilide) when simulated rainfall was applied within 12 hours of herbicide application (44). The initial 0.5 cm of water removed as much herbicide as the next 3.0 cm of water. In field studies, Erbach and Lovely (18) found that surface residue levels as great as 6200 kg/ha did not affect weed control with early spring applications of alachlor or atrazine. Greenhouse studies showed reduced weed control with these same compounds as residue level increased. When simulated rainfall was not applied, control was marginal. Robison and Wittmuss (67) achieved significantly lower weed yields in herbicide treated plots by reducing residue ground coverage from 73% to 47% with one additional disking operation.

Changes in predominant weed species frequently occur as tillage is reduced. Lack of spring tillage allows more of the early germinating broadleaf weeds such as Pennsylvania smartweed (*Polygonum pennsylvanicum* L.), giant ragweed (*Ambrosia trifida* L.), common ragweed (*Ambrosia artemisiifolia* L.), and common lambsquarter (*Chenopodium album* L.) to survive (92). These generally can be controlled by use of a nonselective herbicide at planting time. It is possible that the dominant broadleaf weeds may form a canopy over smaller grass plants. Once the broadleaf weeds are controlled, the grass weeds may be released to become dominant. Grass weeds tend to become more troublesome in continuous reduced tillage systems due to herbicide selectivity. Pollard and Cussans (62, 63) cite continued use of 2,4-D in cereal crops as causing dominance of annual bluegrass (*Poa annua* L.), wild oats (*Avena fatua*), and blackgrass (*Alopercurus myosuroides*) in direct drilled fields in England. Continuous use of atrazine and other triazine herbicides has lead to predominance of fall panicum (*Panicum dichotomiflurum*), field sandbur (*Cenchrus incertus*), and large crabgrass (*Digitaria sanquinalis* (L.) Scop.) in reduced tillage (80, 92).

The potential for perennial weed problems is increased with reduced tillage, especially in tillage systems without any form of deep tillage. Robertson and associates (66) reported that perennial weeds were more of a problem in no-till plots than conventional till plots after three years. Triplett and Lytle (80) observed that large colonies of perennial weeds developed from individual plants in no-till systems but not in conventional plots. Frequently observed perennial weed problems include herbacious weeds such as common dandelion (*Taraxacum officinale* Weber), common milkweed (*Asclepias syriaca* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), groundcherry (*Physalis* spp.), and hemp dogbane (*Apocynum cannabinum* L.) and woody species such as sassafras (*Sassafras albidium* (Nutt) Nees), brambles (*Rubus* spp.), and other small shrubs (92).

Yields under conservation tillage systems are quite variable and dependent on soil type and climatic conditions (33, 57, 76, 91). Willard et al. (91) reported that corn yields were significantly higher on plowed plots which had mulch added; however, they had trouble attaining a good stand of corn on the reduced tillage plots. Olson and Schoeberl (57) found that reduced tillage plots yielded as well as conventional plots and Jones et al. (33) reported that decreased tillage increased corn growth and yield. They found that over a six-year period yields were equal to or increased by 18 to 30% above that of conventional plots.

General trends regarding yields under conservation tillage systems have been established. Amemiya (4) and Van Doren and Ryder (82) report that in years of low rainfall, conservation tillage methods out-yielded conventional systems; but under adequate rainfall there was little difference. Van Doren and Triplett (83) increased yield on soils of low structural stability by approximately 34 kg/ha (0.54 bu/acre) with each addition of 1% crop residue on the soil surface; this increased the water infiltration rate and decreased evaporation. On soils with more structural stability, crop residue had no effect. Moschler et al. (54) agreed that soils with low infiltration rates produced higher yields with reduced tillage. Lal (39) reported higher infiltration rates and soil moisture, greater earthworm activity, and yields equal to conventional tillage with no-till systems in Nigeria.

Van Doren et al. (84) found a 13% reduction in yield for no-till corn on poorly drained soils, but an increase of 10% on well drained soils. Griffith and associates (27) also found lowest yields on poorly drained soils and noted that maintaining good germination and pest control on these soils was more difficult. Triplett et al. (81)

reported that well drained, silt loam soils required increased tillage as surface cover decreased. Also, maximum tillage systems did not yield as well under dry conditions as systems leaving 75 to 100% soil cover. With sufficient rainfall, tillage had no effect.

Plant height as an indication of total plant growth under reduced tillage systems appears to be related to geographical location. Willard et al. (91) at Ohio reported that corn height was greatest with conventional tillage. Several authors (32, 33, 74) in Virginia reported that plant heights increased as mulch cover increased and tillage decreased. Griffith et al. (27) found that in northern and eastern Indiana corn plant height was less and maturity was delayed as tillage decreased; the opposite effect was observed in southern Indiana. The effect of tillage on plant height appears to be related to other factors such as soil temperature and moisture which will vary geographically.

Soil temperature can greatly influence crop production. Plants vary greatly in response to soil and air temperatures. The minimum is the lowest temperature and the maximum is the highest temperature at which growth is exhibited with an optimum temperature occurring for each plant species. Optimum temperature for most temperate crops is about 20°C, yet, with some crops such as cotton (Gossypium hirsutum) and sorghum it is over 30°C (41, 70). Willis et al. (93) found that corn growth increased by a factor of 2.0 to 2.8 for each 10°C increase in soil temperature up to the optimum. Walker (88) reported that one degree increases in soil temperature from 12°C to 26°C increased corn seedling dry weight by 20 percent and each degree increase from 26°C to 35°C produced a 12 percent decrease. Lal (38) and Mederski and Jones (47) found that soil temperature affected nutrient uptake by corn; uptake of nitrogen, phosphorus, and potassium increased up to the optimum temperature and decreased above this temperature.

The thermal conductivity of a soil can be influenced by soil properties and surface mulch. Thermal conductivity increases with increasing bulk density due to greater soil particle contact. Thus, untilled soils, which are usually of higher bulk density, should have higher temperatures. However, untilled soils generally have higher soil moisture resulting in increased thermal capacity and in decreased soil temperature (12, 41).

Crop residue on the soil surface can affect soil temperature. Allmaras (3) found that a straw mulch reduced the average 10 cm soil temperature by 1.2°C for the first six weeks after planting. Burrows and Larson (11) calculated that each ton of mulch decreased the 10 cm soil temperature 0.4°C; Greb (26) reported that maximum soil temperatures decreased 1.7°C per 1100 kg/ha of added straw mulch on the soil surface. Several researchers (11, 26, 27, 49, 57) reported lower soil temperature with increasing residue rates; others (3, 11, 14, 38, 47, 49, 93) related changes in rate of plant development with changes in soil temperature. Lindemann (42) found that root temperature altered plant growth, nodulation, and nitrogen fixation in soybeans with optimum growth and nodulation occurring at 25°C. Nitrogen fixation was greatest at 20°C. Evenson and Rumbaugh (20) reported less temperature fluctuation, lower soil temperatures, and increased regrowth of alfalfa (*Medicago sativa*) with mulch applied.

Mulched corn grown in the northern United States frequently suffers severe yield reduction compared to mulched corn in the south. Van Wijk et al. (86) found that in the south, root zone temperatures are near optimum due to higher air temperatures. Mock and Erbach (49) felt that lower temperatures under mulch are due to increased shading of the soil, greater soil moisture, and more reflectance of sunlight due to light colored residue. Moody et al. (50) found less daily temperature fluctuation with mulched soil; Cooper and Law (14) reported that soil temperature affected corn development for 3 to 4 weeks after emergence, the period when the apical meristem is below ground level. Olson and Horton (56) found that straw mulch applied six to seven weeks after planting increased yield over early mulched or non-mulched treatments.

One of the primary objectives of tillage is to produce a seedbed which allows maximum germination and plant development. Many authors (19, 49, 50, 91) have noted increased difficulty in attaining proper seed placement and maintaining germination under reduced tillage systems. Improvements in planting equipment are helping to eliminate this problem, however.

Soil physical properties can be changed directly or indirectly by tillage (29, 39, 77). Hughes and Baker (29) found that no-till plots were more resistant to structural change than conventional plots; this indicates that more favorable soil structure may be retained using reduced tillage. Several authors (7, 39, 51, 54) have reported increased organic matter at the surface of no-till plots due to residue buildup. Lal (39) emphasized the use of rotations depositing large amounts of crop residue on the soil surface to maintain soil structure.

Soil compaction is a physical property important to crop production which is influenced by tillage (24, 61). Flocker et al. (22) found that compacting soil to a certain density increased germination, but further compaction reduced germination and delayed emergence and blossom. Nelson and associates (55) reported that soil compaction adversely affected soybeans; plants in non-compacted soil made better use of soil moisture producing more extensive root systems and higher yields. Witsell and Hobbs (95) found up to two weeks delay in maturity of wheat and tomato (Lycopersicon esculentum) and yield reductions for wheat, sorghum, sudangrass (Sorghum bicolor ssp. sudanense) and tomato when grown on a compacted silt loam soil.

Normally compaction is associated with many passes of heavy machinery over the soil under wet conditions. Adams and associates (1) found reduced germination and delayed maturity of corn with increasing soil compaction due to vehicular traffic; Raghavan et al. (64) found yields decreased by as much as 50% with increasing machinery traffic. Compaction below wheels, especially under high load conditions and moderate slippage, result in increased bulk density and reduced air space and porosity in the cultivated layer (77).

Bulk density is often used to demonstrate relative compaction of the soil. Fuller described a compacted soil as a soil with an increase of 50% or more over the natural state bulk density; however, this will vary greatly with soil type (24). A parabolic relationship exists between bulk density and crop yield (37, 68); there is a peak range of bulk density at which a soil will produce maximum yield. This peak range varies with soil texture and is highly related to clay content.

Increasing clay content is associated with lower bulk densities and higher soil moistures. Compaction of clay or clay loam soil is less permanent than medium texture soils due to the greater shrink-swell forces of clay (48). Rosenburg and Willits (69) reported that an increase in bulk density from 1.3 to 1.6 g/cc on a sand soil increased barley (Hordeum vulgare) yield by 50%, the same increase on a loamy sand decreased barley yield by 37%. McKyes et al. (46) concluded that with a clay soil a deviation in soil density of 0.1 g/cc above or below the optimum produced a 30% reduction in corn yield.

Shear and Moschler (75) and Blevins et al. (9) reported that no-till systems had no effect on bulk density after 6 and 5 years, respectively, of continuous corn. Lal (39) working in Nigeria reported that increased earthworm activity in no-till plots prevented soil compaction and crusting of the soil surface. Other authors (12, 21, 25, 77) have reported significant increases in bulk density with reduced tillage. Generally, conventional tillage had the lowest bulk density, no-till the highest, and chisel plowing and other forms of reduced tillage were intermediate. Moldboard plowing loosens the soil by shearing and inverting the plow layer, though in heavy or compacted soils some dense clods may still exist (77). Chisel plows and other tillage equipment also loosen the soil. With no-till systems the cultivated layer is

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untouched resulting in an increase in bulk density.

Soil compaction can influence root growth. Research done by Schuurman (73) in the Netherlands showed that root development was more extensive in less compact soil resulting in increased water and nutrient uptake and development of the plant. A negative correlation between root growth and bulk density has been observed by several authors for many crops (42, 48, 60, 65, 87, 98). Rosenberg (68) reported that the maximum bulk density which allowed root growth was variable dependent on soil type. McCalla and Army (45) concluded and several authors (5, 13, 34) confirmed that with heavy mulches on the soil surface, roots tend to accumulate in the upper few centimeters of the soil. Barber (5) found more extensive and deeper growth of corn roots in plowed ground than in soils under reduced tillage; roots were finer and longer per gram in tilled soil.

Soil compaction appears to be a reversible effect normally requiring some form of tillage. Blake et al. (8) and Van Ouwerkerk (85) found that neither cropping nor irrigation produced a change in the bulk density of a compacted soil. Witsell and Hobbs (95) reported that freezing, thawing, and moisture changes tend to reduce compaction; McKyes et al. (46) concluded that chiselling and subsoiling reduced soil density, with subsoiling more suitable for breaking deep hardpans and promoting deeper root growth. Sloane and Pidgeon (77) demonstrated the importance of a moldboard plow for loosening the soil but noted that plow pans may develop.

The effect of reduced tillage on availability and distribution of soil nutrients has long been of concern. Much work has been done to determine the effect of tillage on nitrogen uptake and supply. Moschler et al. (54) and Lal (39) reported increased nitrate-nitrogen at the surface in no-till compared to conventional tillage. Dowdell and Cannell (17) found 2 to 5 times more nitrate-nitrogen at 30 cm with conventional tillage than with no-till when sampled in winter and early spring; by May no differences were detected. Stinner et al. (79) in a comparison of no-till and conventional tillage found less nitrate-nitrogen in the upper 50 cm of no-till but more total nitrogen. They concluded that slower decomposition of surface litter with no-till resulted in large nitrogen reserves in the upper soil strata. Plowing stimulated mineralization and nitrification resulting in increased nitrate-nitrogen.

Moschler et al. (53) did a study of residual fertility in soil continuously cropped for 11 years by conventional and no-till methods. They found slightly more nitrogen in the upper 20 cm of the no-till but no difference at the 20 to 40 cm level. The increase probably reflected mineralization of the increased organic matter of the soil surface. Doran (16) in a study of soil microbial changes in reduced tillage systems from seven United States locations found significantly more aerobic microorganisms and facultative anaerobes in the surface eight cm of no-till soils. Also, seven times as many denitrifier bacteria were at this level of no-till soils compared to conventional tillage. Below eight cm, conventional tillage contained more aerobic microorganisms and nitrifiers but fewer facultative anaerobes and denitrifiers than no-till. Thus, the potential rate of mineralization and nitrification is greater with conventional tillage while the rate of denitrification is greater with no-till.

The question of whether increased fertilization is needed with reduced tillage has also been considered with varying results. Parker et al. (58) found that soil nitrogen could move to and be immobilized in low-nitrogen residue at the soil surface. This resulted in decreased nitrogen uptake and yield in corn. However, this effect was overcome with additional nitrogen fertilizer. Ketcheson and Beauchamp (36) concluded that stover on the soil surface did not affect yields when normal fertilization practices were used. Sanford et al. (71) studied one rate of nitrogen fertilizer with corn stover residue and concluded that stover incorporated in the soil in the fall did not affect yield. If residue was left on the soil over winter, it should be removed in spring or extra nitrogen was required. Several authors (9, 29, 79) have reported that increased nitrogen fertilization has lead to decreased soil pH in no-till resulting in a need for more frequent liming.

Phosphorus is a relatively immobile essential element which leads to it being concentrated at the soil surface. Phosphorus is generally concentrated in the upper 20 cm of the soil with reduced tillage resulting in more available phosphorus at this level (53, 54, 75, 79). Kang and Yunusa (34) found that corn root density increased in the upper 10 cm of soil in reduced tillage in response to this concentration.

Potassium is also relatively immobile with zones of depletion and concentration occurring with reduced tillage (12, 19, 53). Moschler et al. (53) in their study of residual fertility with conventional and no-till methods found no difference with tillage at 0 to 20 cm but more potassium at 20 to 40 cm with conventional tillage. Schulte (72) and Willard et al. (91) reported more severe potash deficiency symptoms with no-till, and Willard et al. (91) noted that adding potassium fertilizer did not alleviate the problem.

MATERIALS AND METHODS

General Study

An experiment was established at the Southeast South Dakota Research and Extension Center, Beresford, South Dakota in the spring of 1972. A level, uniform area was chosen with a well-drained Egan silty clay loam soil (Udic Haplustolls; fine-silty, mixed, mesic) consisting of 22.8% sand, 49.3% silt, and 27.9% clay. Soil tests at project initiation indicate that this soil contained 3.5% organic matter, pH 5.9, 35 kg/ha phosphorus, 790 kg/ha potassium, and 11 kg/ha nitrogen. An average of 65 cm of rainfall is received annually. Precipitation deviations from normal for the ten years of this study are given in Table 1.

Two adjacent sites were established and maintained in a corn-soybean rotation. Corn was planted in one site, soybeans in the other; thus, both crops were present in the experiment each year. The experiment was designed as a randomized complete block with four replications in each site. Plots measured 6 m by 43 m with eight 76 cm rows per plot.

Tillage treatments were established as follows:

No-Till 1.	No-Tillage -- Fertilized
No-Till 2.	No-Tillage -- Fertilized
Disk.	Disk (Fall and spring) -- Fertilized
Conventional.	Fall Plow -- Spring Disk -- Fertilized
No-Till 3.	No-Tillage -- No Fertilizer

Table 1. Annual rainfall and deviation from normal for ten years at Beresford, South Dakota.

	Precipitation	
Year	Annual	Deviation
	cm	
1972	69.3	+ 4.0
1973	57.9	- 7.4
1974	38.7	-26.6
1975	65.4	+ 0.1
1976	32.6	-32.7
1977	68.1	+ 2.8
1978	66.5	+ 1.2
1979	70.4	+ 5.1
1980	43.3	-22.0
1981	59.1	- 6.2

No-till 1 and no-till 2 had similar tillage and fertilizer practices but different herbicide treatments. The disk system was disked once in the fall and once again in the spring immediately before planting. The conventional system was fall plowed and tilled in spring as needed for seedbed preparation. No-till 3 was changed to a cover crop system in 1978. These plots were fall plowed and planted to rye (_Secale cereale_). The rye was destroyed with a nonselective herbicide before planting in the spring. Each year, corn stalks were chopped and the appropriate tillage was done before planting soybeans. Soybean residue was spread with the combine at harvest. Also, a recommended insecticide was applied to the corn plots each year with the planter.

Different herbicides were applied to the tillage systems to achieve maximum weed control. Non-selective herbicides were generally applied to no-till plots to control existing vegetation at planting time. The herbicide treatments applied to each tillage system are summarized in Tables 2 and 3. All herbicides were applied with an experimental plot sprayer equipped with six Tee Jet 8002 flat fan nozzles spaced 51 cm apart. The boom was held approximately 46 cm above the vegetation present to provide uniform application over an area 3 m wide. The nozzles delivered 187 l/ha spray solution at 276 kPa pressure and ground speed of 4.83 km/hr.

Planting was done each year at the normally accepted time for crop production. Populations of 39,500 corn plants per hectare and 370,500 soybean plants per hectare were attempted each year. A competitive corn hybrid for the time of planting was chosen each year and

Table 2. Herbicides and rates (kg a.i./ha) applied to the soybean plots of each tillage system from 1972-1981. All compounds were applied preemergence unless otherwise indicated.

Year	No-Till 1	No-Till 2	Disk	Plow	No-Till 3, Cover Crop
1972	Alachlor (2.2)+ Linuron (1.1)	Alachlor (2.2)+ Bifenox (1.7)	Alachlor (2.2)+ Linuron (1.1)	Alachlor (2.2)+ Linuron (1.1)	Alachlor (2.2)+ Linuron (1.1)
1973	Alachlor (2.2)+ Linuron (1.1)+ Glyphosate (.6)	Alachlor (1.7)+ Bifenox (1.7)+ Glyphosate (.6)	Alachlor (2.2)+ Linuron (1.1)	Alachlor (2.2)+ Linuron (1.1)	Alachlor (2.2)+ Linuron (1.1)+ Glyphosphate (.6)
1974	Alachlor (2.2)+ Metribuzin (.6)+ Glyphosate (2.2)	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)+ (MSMA - Sodium Cacodylate)(4.5)
1975	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Bentazon (1.1)(Post)
1976	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Bentazon (1.1)(Post)
1977	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Metribuzin (.8)+ Oryzalin (1.7)+ Crop oil (5%)(Fall)+ Alachlor (2.2)
1978	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Paraquat (.8)+ X-77(.5%)
1979	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Bentazon (1.1)(Post)+ Paraquat (.8)+ X-77(.5%)
1980	Alachlor (2.2)+ Metribuzin (.6)+ Paraquat (.8)+ X-77(.5%)	Alachlor (2.2)+ Bifenox (1.7)+ Paraquat (.8) X-77(.5%)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Metribuzin (.6)	Alachlor (2.2)+ Bentazon (1.1)(Post)+ Paraquat (.8)+ X-77(.5%)
1981	Alachlor (2.8)+ Metribuzin (.6)+ Paraquat (.6)+ X-77(.5%)	Pendimethalin (1.7)+ Metribuzin (.6) (Fall)	Trifluralin 5G (1.1)(Fall)+ Metribuzin (.6)	Alachlor (2.8)+ Metribuzin (.6)	Alachlor (2.8)+ Bentazon (1.1)(Post)+ Paraquat (.6)+ X-77(.5%)

Table 3. Herbicides and rates (kg a.i./ha) applied to the corn plots of each tillage system from 1972-1981. All compounds were applied preemergence unless otherwise indicated.

Year	No-Till 1	No-Till 2	Disk	Plow	No-Till 3, Cover Crop
1972	Alachlor (2.2)+ Atrazine (1.1)+ Glyphosate (.28)	Alachlor (2.2)+ Dicamba (.28)+ Glyphosate (.28)	Alachlor (2.2)+ Atrazine (1.1)	Alachlor (2.2)+ Atrazine (1.1)	Alachlor (2.2)+ Atrazine (1.1) + Glyphosate (.28)
1973	Alachlor (2.2)+ Atrazine (1.1)+ Glyphosate (.28)	Atrazine (2.8) (Fall)	Alachlor (2.2)+ Atrazine (1.1)	Alachlor (2.2)+ Atrazine (1.1)	Alachlor (2.2)+ Atrazine (1.1)+ Glyphosate (.6)
1974	Alachlor (2.2)+ Cisanilide (2.2)+ Glyphosate (2.2)	Alachlor (2.2)+ Cisanilide (2.2)+ Paraquat (.8)	Alachlor (2.2)+ Cisanilide (2.2)	Alachlor (2.2)+ Cisanilide (2.2)	Alachlor (2.2)+ Cisanilide (2.2)+ (MSMA-Sodium Cacodylate) (4.8)
1975	Alachlor (2.2)+ Cyanazine (1.7)+ Paraquat (.8)	Alachlor (2.2)+ Cyanazine (1.7)+ Atrazine (2.2) (Fall)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Cyanazine (2.2)(Post)
1976	Alachlor (3.4)+ Cyanazine (2.2)+ Paraquat (.8)+ X-77 (.125%)	Alachlor (3.4)+ Cyanazine (2.2)+ Glyphosate (2.2)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Cyanazine (2.2)(Post)
1977	Alachlor (2.2)+ Cyanazine (1.7)+ Paraquat (.8)+ X-77(.5%)	Buthidazole (2.2)+ Crop oil (5%) (Fall)+ Alachlor (2.2)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Cyanazine (2.2)+ X-77(.5%)(Post)
1978	Alachlor (2.2)+ Cyanazine (1.7)+ Paraquat (.8)+ X-77(.5%)	Buthidazole (2.2)+ Crop oil (5%) (Fall)+ Alachlor (2.2)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Paraquat (.8)+ X-77(.5%)
1979	Alachlor (2.2)+ Cyanazine (1.7)+ Paraquat (.8)+ X-77(.5%)	Atrazine (2.2) (Fall)+ Alachlor (2.2)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Paraquat (.8)+ X-77(.5%)
1980	Alachlor (2.2)+ Cyanazine (1.7)+ Paraquat (.8)+ X-77(.5%)	Atrazine (2.2) (Fall)+ Alachlor (2.2)	Alachlor (2.2)+ Cyanazine (1.7)	Alachlor (2.2)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Paraquat (.8)+ X-77(.5%)
1981	Alachlor (2.8)+ Cyanazine (1.7)+ Paraquat (.6)+ X-77(.5%)	Atrazine (2.2) (Fall)+ Alachlor (2.8)	Alachlor (2.8)+ Cyanazine (1.7)	Alachlor (2.8)+ Cyanazine (1.7)	Cyanazine (2.2)+ Crop oil (5%)+ Paraquat (.6)+ X-77 (.5%)

either 'Corsoy' or 'Hodgson 78' soybeans were planted. Planting was done with a four row tool bar planter equipped with fluted coulters and John Deere 71 flex units. Insecticide was banded on the corn plots with the type of insecticide being rotated every two years.

Fertilization in 1972 and 1973 consisted of 112 kg/ha of 8-32-16 applied with the planter as a starter sideband in both the corn and soybean plots. Corn plots were sidedressed with 112 kg/ha of nitrogen in the form of ammonium nitrate. Soybean plots were sidedressed with 34 kg/ha of nitrogen also as ammonium nitrate. Fertilization was discontinued in 1974 to allow the study of tillage effects on residual fertility. Application of 112 kg/ha of 8-32-16 fertilizer as starter sideband was done again in 1980 and 1981.

Visual weed control ratings were taken for each of the dominant weeds consistently present throughout the experiment site. Crop plant heights were measured on September 5, 1979 and on August 5, 1981. Ten plants from the middle six rows of each plot were measured. Root pulling resistance, the kilograms of force required to vertically pull a corn plant from the soil, was measured on September 5, 1979. Force was measured using a dynamometer attached between a fulcrum and a cast iron clamp which was attached to the base of the plant. Ten plants from the center six rows in each plot were pulled. Plants adjacent to a vacant space or a previously pulled plant were not taken. At this time, root systems were inspected for possible damage due to insects or disease.

Crop yields were determined every year that the experiment made a crop. Soybean yields were determined by harvesting a measured area with a small plot combine, weighing the sample, and converting to kg/ha. From 1972 to 1978 corn yields were measured by hand harvesting all ears in a measured area, weighing the samples, correcting to 15.5% moisture, and converting to kg/ha. In 1979, the corn plots were mechanically harvested.

Soil Aspects

In 1979, the effect of eight years of reduced tillage on several soil factors was evaluated. Thermistors were buried in three replications of the no-till, disk, and plow systems. Thermistors were buried 7.6 cm deep in the middle of a row. Readings were taken daily at 1:00 pm with a Cole-Parmer Electronic Thermometer with an accuracy of ± 1 degree Fahrenheit. Soil temperatures were averaged by weeks for each tillage treatment.

Soil cores were taken at random from the center six rows of each plot on September 10, 1979. A 6.65 cm diameter core was taken to a depth of 122 cm. If the soil core compressed more than 1 cm in the probe, it was discarded. Each soil core was divided into 8 subsamples corresponding to different depths: 0-8, 8-15, 15-23, 23-31, 33-41, 48-56, 72-80, and 103-111 cm. Three more soil cores were taken from each plot in the same manner on November 11, 1981.

One sample at each depth in 1979 and all samples from 1981 were dried for 48 hours at 105°C in a soil oven. Samples were allowed to equilibrate to room temperature and weighed. Bulk density was calculated by dividing the weight of the sample by the volume of soil in the sample.

The other samples in 1979 were dried at low temperature (41°C), crushed and sieved through 2 mm mesh. These samples were then analyzed for organic matter, pH, soluble salts, available phosphorus and potassium, and nitrate-nitrogen. All soil tests were done using the procedures and facilities of the South Dakota State Soil Testing Laboratory (78).

Calibrated soil scoops were used to measure the soil used for each test and automatic pipettes measured the proper amount of each solution. Check soils were included in each series of samples tested as a check on equipment and technique. An Eberback Oscillating Shaker was used in preparation of the samples and Coleman Model 6C spectrophotometers were used for all colorimetric measurements. A Perkin-Elmer No. 372 Atomic Absorption Spectrophotometer was used for the potassium test. Individual testing procedures are summarized below.

1. Readily Oxidizable Organic Matter -- One gram of soil was measured from each soil sample with the calibrated scoop and placed into a 50 ml erlenmeyer flask. Ten ml of 2N $K_2Cr_2O_7$ - 10N H_2SO_4 digestion solution were added to each flask. The flasks were shaken for 5 minutes at 200 oscillations per minute and allowed to stand for approximately 16 hours. Twenty-five ml deionized water was then added with sufficient pressure to insure good mixing of the water and the dense digesting solution. This solution was then filtered through S + S No. 597 filter paper.

The Coleman Model 6C Spectrophotometer was set at 645 mu and adjusted to read 100% transmittance with the light blocked off. Several milliliters of the filtrate were placed in the 1 cm cell of the spectrophotometer and the percent transmittance was read. The organic matter content of the soil was determined by comparing the percent transmittance reading to a standard curve.

2. pH -- A calibrated soil scoop was used to measure 25 g of soil into a 120 ml paper cup. Twenty-five ml of deionized water were added with an automatic pipet; the mixture was stirred and allowed to stand for 30 minutes. A Beckman Zeromatic pH meter was used to measure pH. The pH meter was calibrated using buffer solutions of pH 6.0 and pH 8.0. Each sample was stirred before inserting the electrodes into the suspension. The pH was read directly from the meter to the nearest 0.1 pH unit. The electrodes were cleaned with deionized water between samples to prevent contamination.

3. Soluble Salts -- Soluble salts refers to the inorganic constituents in a soil which are soluble in water. These are mainly chlorides, sulfates, carbonates, and nitrates of calcium, magnesium, potassium, and sodium salts. This procedure measures the conductivity of the soil solution; the higher the conductivity, the higher the concentration of salts in the solution.

The soil-water mixture used for pH determination is filtered into small filtering vials and the filtrate is used to determine soluble salts. The instrument used was a Solu Bridge (Industrial Instruments Model RD-26) equipped with a pipette type conductivity cell (Model CI-G05X2). The Solu Bridge was standardized with a standard salt solution (0.7456 g of KCl dissolved in 1 liter of distilled water equal to 1.41 mmho/cm). Measurement was made by filling the pipette cell with filtrate and reading the conductivity directly from the meter. The cell was rinsed with distilled water between each sample.

4. Available Phosphorus -- A calibrated soil scoop was made to measure 1 gram of soil into 50 ml erlenmeyer flasks. Ten ml of 0.03N NH_4F, 0.025N HCl extracting solution was added to each flask and shaken for 2 minutes at 200 oscillations per minute. Immediately after shaking, the solution was filtered through S + S No. 597 filter paper into filter tubes which were marked at the 5 ml level. Caution was taken to make sure that the filtrate above the 5 ml mark was removed. By means of an aliquoter, 0.25 ml of molybdate reagent was added to each tube followed by 0.25 ml of the reducing reagent solution (1.3 g of 1-amino-2-naphthol-4-sulfonic acid + 2.6 g of sodium sulfite + 76.1 g of sodium metabisulfite dissolved in 500 ml distilled water). Each tube was then mixed with a vortex mixer and allowed to stand at least 15 minutes for color development; however, no sample was allowed to stand more than 45 minutes before measurement.

With the Coleman Model 6C Spectrophotometer set on 655 mu, the 100% transmittance was adjusted using distilled water and the 0% transmittance was adjusted with the light blocked off. The filtrate was placed in the curvette, percent transmittance was recorded, and kilograms of available phosphorus per hectare was determined from a standard curve.

5. Available Potassium -- Two grams of soil were placed into 50

ml erlenmeyer flasks using a calibrated soil scoop. Ten ml of extracting solution (1 N ammonium acetate) was added to each flask; this solution was shaken for 10 minutes at 200 oscillations per minute and filtered into filter tubes through S + S No. 597 filter paper. The filtrate was refiltered if soil particles passed through the filter paper. The potassium concentration of the filtrates was determined using a Perkin-Elmer No. 372 Atomic Absorption Spectrophotometer which was standardized with 0, 200, 400, 600, and 800 ppm potassium standard solutions. The parts per million of available potassium was read directly from the spectrophotometer.

6. Water Soluble Nitrates -- This procedure uses a nitrate electrode to detect nitrate ions. The instrument used was a Beckman Model SS-2 pH meter equipped with an Orion Model 29-07 Nitrate Ion Electrode and an Orion Sleeve Junction Model 90-02 Reference Electrode.

Twenty grams of soil were measured into a nitrate rack using a calibrated soil scoop and 50 ml of deionized water was added. The racks were covered and shaken vigorously for 5 minutes with an Eberbach reciprocating shaker.

After shaking, the solution was mixed with a mechanical stirrer. During mixing, the vortex extended one-third to one-half the distance from the top of the liquid to the bottom of the beaker. The electrodes were placed in the solution, the meter was allowed time to stabilize and the millivolt reading was recorded from the meter. The electrodes were rinsed and dried between each sample. The parts per million of nitrate-N in solution was obtained directly from a standard curve.

Dominant Weed Species

Weed species shifts are frequently observed as tillage decreases and with continued use of certain herbicides. Weed samples were obtained from each plot of this experiment on August 17-18, 1981. Fifteen 625 cm^2 quadrants were clipped between the rows in each plot (Figure 1) and separated by weed species. The number of each species per quadrant was recorded and each weed species bagged separately. These samples were then dried for 7 days at 41°C and dry weights determined. To reduce variability, the square root transformation of the count data was used for statistical analysis. All data was subjected to the Waller-Duncan k-ratio T-test (k=100) for analysis.

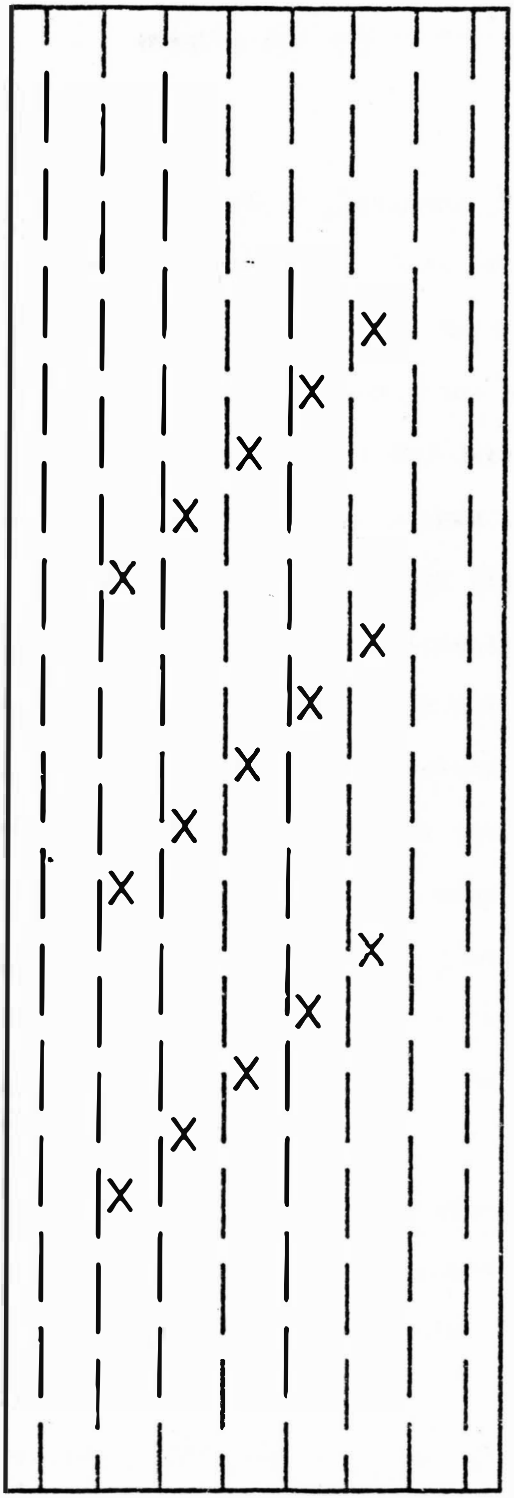

Figure 1. Typical sampling pattern used to obtain weed samples from all plots in August, 1981. A 625 sq. cm quadrant was clipped at each area marked with an 'x'.

RESULTS AND DISCUSSION

General Results

Crop yield is widely used to determine the significance of an agronomic practice. Soybean and corn yields are presented in Table 4 for all years in which data is available. No yield data was collected in 1975 and 1976 because of drought conditions and in 1978 and 1980 because of severe hail damage. Also, yield data is not shown for the corn plots in 1981 because of problems in data collection.

Yields in 1972 were quite high in all tillage systems with only the nonfertilized corn plots being significantly lower in yield. The lowest yielding soybean treatment, although not significant, was also the nonfertilized plot. Fertility was probably the major factor influencing yield. Corn and soybean yields were much lower in 1973 due to a hot, dry August and lower than normal annual precipitation. No-till 1 yielded significantly more soybeans than no-till 2 or the plow treatment. The reason for these differences is not readily apparent. The plow treatment may have been drier than the no-till treatments resulting in poor early growth. The differences between no-till 1 and no-till 2 may be related to soybean injury associated with bifenox [methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate]. No significant differences were found between treatments in the corn plots but lowest yield was in the nonfertilized plot.

Yields were low in 1974 due to severe drought; rainfall was 26.6 cm below normal for the year. Maximum soybean yield was with the plow treatment at 1210 kg/ha. The disk treatment yielded 269 kg/ha which

Table 4. Soybean and corn yield from each tillage system for the years 1972-1981.

		Grain Yield*				
Crop	Year	No-Till 1	No-Till 2	Disk	Plow	No-Till 3, Cover Crop
				(kg/ha)		
Soybeans	1972**	2285	2352	2352	2352	2218
	1973	1680 a	1411 b	1478 ab	1411 b	1478 ab
	1974	874 a	672 ab	269 b	1210 a	672 ab
	1975			No Data		
	1976			No Data		
	1977	1411 c	1008 d	1814 b	2083 ab	2352 a
	1978			No Data		
	1979	2218 a	1613 b	2419 a	2150 a	2285 a
	1980			No Data		
	1981	1210 b	672 c	1277 ab	1210 b	1478 a
	Ave.	1613 a	1277 b	1613 a	1747 a	1747 a
Corn	1972	7652 a	7715 a	7338 a	7903 a	5331 b
	1973**	1192	1380	1254	1568	690
	1974	314 c	314 c	1505 b	3826 a	0 c
	1975			No Data		
	1976			No Data		
	1977	4104 c	6272 bc	8028 ab	9094 a	5958 bc
	1978			No Data		
	1979	878 c	2822 b	2258 b	6586 a	3073 b
	1980			No Data		
	1981			No Data		
	Ave.	2822 d	3700 bc	4077 b	5770 a	3100 cd

*Means within each row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

**Values are not significantly different at the 5% level.

was significantly less than the plow plots and no-till 1. Crop yields were very low but showed great variation among tillage systems. The conventional system yielded significantly more than all other treatments and the disk system yielded significantly more than the no-till plots. Fertilizer applications were discontinued in 1974 which may account for some of the yield differences.

Large yield differences were observed in 1977. No-till 3 yielded significantly more soybeans than either of the other two no-till systems or the disk system but was not different from the plow system. Corn yield with conventional tillage was significantly better than with any of the no-till systems. In 1979, all soybean plots yielded equally except no-till 2 which was significantly lower. Corn yield with conventional tillage was much greater than all other treatments and lowest in no-till 1. Soybean yields were low in 1981 with the cover crop system yielding best and no-till 2 least.

Soybean yield averaged across all years indicates that tillage had little effect on soybean production. Only no-till 2 yielded significantly different. Highest average corn yield was with conventional tillage followed by the disking system. The cover crop system was not fertilized during the early years of the experiment which contributed to the lower average yield of this system. No-till 1 yielded significantly less corn than all other systems except the cover crop.

Weed control ratings provide some explanation for the large, annual yield differences between tillage systems. Weed control ratings from the second, fourth, sixth, eighth, and tenth years of this study will be considered. This provides insight as to weed development with time and corresponds to the years when soybeans were grown on the west site and corn on the east site. These years provide the most data since crop maturity was attained each year except the fourth, 1975, which was extremely dry in July and August.

Grass and broadleaf [kochia (Kochia scoparia), Pennsylvania smartweed, common dandelion] weed control was only fair in the soybean plots in 1973 with no significant differences detected (Table 5). Yield differences were slight with the plow system and no-till 2 yielding significantly less. The plow system had the lowest weed ratings for both grass and broadleaf weeds which may account for the reduced yield. It is interesting that no-till 2 yielded significantly less than no-till 1 even though equal weed control was attained. Some bifenox injury (stunting and leaf necrosis) was detected in no-till 2 which may have been severe enough to produce a yield difference.

All of the corn plots had good foxtail control but broadleaf weed control was significantly lower in no-tills 1 and 3 (Table 6). Although no significant yield differences were found, poorest yields corresponded with poorest broadleaf weed control. Also, no-till 3 was not fertilized which may have contributed to the reduced yield.

The importance of a non-selective herbicide for early weed control in reduced tillage systems was demonstrated in 1975 (Table 5). On the soybean site, no-till 3 was the only system which did not have spring tillage or an application of paraquat (1,1'-dimethyl-4,4'-bipyridinium ion), a non-selective herbicide. Grass weeds were actively growing at planting time and were not controlled with alachlor.

Table 5. Visual weed control ratings for the soybean plots of each tillage system from the second, fourth, sixth, eight, and tenth years of the experiment.

		Weed Control*				
Year	Weed	No-Till 1	No-Till 2	Disk	Plow	No-Till 3, Cover Crop
				(%)		
1973	Foxtail spp.**	75	75	75	44	50
	Broadleaf**	81	81	62	62	62
1975	Foxtail spp.	68 a	35 b	78 a	87 a	0 c
	Foxtail barley	87 a	33 b	95 a	74 a	0 b
	Common dandelion	5 bc	60 ab	66 a	74 a	0 c
1977	Foxtail spp.	15 b	8 b	84 a	98 a	92 a
	Barnyardgrass	0 b	8 b	85 a	98 a	93 a
	Broadleaf**	82	70	94	98	82
1979	Foxtail spp.	81 b	39 c	97 a	98 a	98 a
1981	Foxtail spp.	26 b	3 b	96 a	97 a	71 a
	Common lambsquarter	99 a	77 b	99 a	98 a	65 b
	Redroot pigweed	97 a	79 b	99 a	98 a	87 ab
	Pennsylvania smartweed	88 ab	15 c	97 a	92 a	70 b
	Common cocklebur	94 ab	87 ab	85 ab	66 b	99 a

*Means within each row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

**Values are not significantly different at the 5% level.

Table 6. Visual weed control ratings for the corn plots of each tillage system from the second, fourth, sixth, eight, and tenth years of the experiment.

		Weed Control*				
Year	Weed	No-Till 1	No-Till 2	Disk	Plow	No-Till 3, Cover Crop
				(%)		
1973	Foxtail spp.**	84	75	85	81	78
	Broadleaf	40 b	91 a	64 ab	90 a	35 b
1975	Foxtail spp.**	98	81	92	86	74
	Foxtail barley	99 ab	97 b	99 a	99 a	99 a
	Kochia**	49	50	41	50	50
	Pennsylvania smartweed	83 a	74 ab	24 b	73 ab	98 a
	Common dandelion	28 b	98 a	15 b	50 b	30 b
1977	Foxtail spp.	0 b	89 a	80 a	90 a	86 a
	Barnyardgrass	0 c	94 a	84 ab	94 a	81 b
	Broadleaf	0 c	95 a	87 ab	92 ab	84 b
1979	Foxtail spp.	87 ab	89 ab	69 b	97 a	92 ab
	Common dandelion	38 c	8 d	75 b	99 a	98 a
1981	Foxtail spp.	0 c	30 bc	58 ab	83 a	28 bc
	Field sandbur	41 b	40 b	49 b	99 a	25 b
	Foxtail barley	35 b	75 ab	95 a	74 ab	99 a
	Common cocklebur	90 a	92 a	75 ab	65 b	93 a
	Redroot pigweed	96 a	98 a	85 a	78 a	38 b

*Means within each row followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

**Values are not significantly different at the 5% level.

Alachlor is a preemergence grass herbicide which is effective only on germinating weeds, not those already emerged. Spring disking together with alachlor provided good grass control in both the disk and plow systems. Paraquat was applied to both no-tills 1 and 2 and fair weed control was attained. Paraquat may have shown more activity had it been applied with a non-ionic surfactant. Significantly better foxtail (Setaria spp.) and foxtail barley (Hordeum jubatum) control was observed in no-till 1 than in no-till 2. Both of these systems were identical except for the broadleaf herbicides applied. Metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one], which was applied to no-till 1, will provide some control of emerged annual grasses whereas bifenox, applied to no-till 2, will not. Apparently the application of metribuzin to no-till 1 resulted in increased grass weed control.

Weed control was fairly consistent in all corn plots in 1975 (Table 6). Cyanazine as a preemergence application will adequately control most emerged weeds and provide residual control of many germinating weeds. Marginal kochia control was seen in all plots but good Pennsylvania smartweed control was obtained except with the disk system. Poor common dandelion control was achieved in all tillage systems except no-till 2. This system had a fall application of atrazine which may have increased control of this weed.

Soybean yields in 1977 appear well related to weed control. Weed control was excellent in both no-till 3 and the plow system (Table 5). The fall application of metribuzin plus oryzalin (3,5-dinitro-

N^4,N^4-dipropylsulfanilamide) in no-till 3 prevented early spring weed growth and provided season long control of all weeds. Slightly less weed control was achieved in the disk system resulting in reduced yield.

Lowest weed ratings and yields were found in no-till 1 and no-till 2. Limited rainfall (6 mm) during the two weeks following herbicide application may explain the poor weed control in both no-till 1 and 2. No-till systems develop high levels of residue on the soil surface which can intercept and retain herbicides. Bauman (6) reported that 30% less herbicide reached the soil surface in a no-till system compared to conventional tillage. Erbach and Lovely (18) found reduced weed control with increasing residue rates; however, simulated rainfall shortly after herbicide application increased weed control. Martin and associates (44) found that 0.5 cm of simulated rainfall applied within 12 hours of herbicide application removed almost all herbicide retained by corn residue except with cyanazine. Also, although rainfall was applied relatively soon, some herbicide loss through volatilization was detected. Crop residue on the soil surface of no-tills 1 and 2 probably intercepted herbicides applied on these tillage systems. Rainfall was inadequate to remove the intercepted herbicide allowing weeds to emerge.

In 1977, the fall application of buthidazole 3-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-4-hydroxy-1-methyl-2-imidazolidinone and crop oil or spring tillage provided very good weed control in the corn plots of no-till 2, the disk system, and the plow system (Table 6). Yield was significantly higher in the plow system than any no-till system but was not different from the disk system. The double application of cyanazine applied to no-till 3 provided good weed control but yield was reduced. Rainfall was insufficient after herbicide application to allow good weed control in no-till 1. This resulted in corn yielding less than half as much as the conventional tillage system.

In 1979, foxtail control was excellent in all tilled soybean plots (Table 5). Also, foxtail control was significantly better in no-till 1 than in no-till 2. The poor weed control in no-till 2 resulted in yields significantly lower than all other tillage systems. No-till 3 was changed to a rye cover crop system in 1978. Paraquat plus X-77 effectively destroyed the rye cover crop in the spring of 1979. Very few weeds emerged through the cover crop resulting in excellent weed control and soybean yield.

In the corn plots, the plow system gave significantly better foxtail control than the disk system; the other systems were intermediate (Table 6). It appears that a single spring disking does not effectively control emerged grassy weeds as well as multiple disking in the plowed plots or paraquat plus X-77 in the other systems. Common dandelion was a problem in no-tills 1 and 2, was present in the disk system, and was effectively controlled in both the conventional and crop cover systems. Both of these systems were fall plowed which will provide good cultural control of this perennial weed (80).

Although weed control was equal in both the plow and cover crop systems, corn yield was doubled in the plow system. The plow system also yielded significantly better than either no-till or the disk system. Although weed control was reduced with the reduced tillage systems, it is doubtful that weed control alone can explain the large yield differences. Soil moisture and fertility differences at planting may be responsible for yield differences between the plow and cover crop systems. The rye cover crop was nearly one meter high and starting to produce heads when it was destroyed at corn planting time. Use of soil moisture and nutrients by the rye may account for some reduction in corn yield.

Weed control was very good in the soybean plots of both the disk and plow systems in 1981 (Table 5). Common cocklebur (Xanthium pensylvanicum) was the only weed problem with poorest control in the plow system. In the cover crop system, good control of foxtail, redroot pigweed (Amaranthus retroflexus L.), and common cocklebur was attained. Common lambsquarter and Pennsylvania smartweed were more troublesome. Bentazon [3-isopropyl-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide], the broadleaf herbicide applied in this system, will control these weeds only if they are very small at herbicide application. Broadleaf weeds were 5-10 cm tall at application time resulting in reduced control. Weed control in no-till 1 was significantly better than no-till 2 for all weeds except foxtail and common cocklebur. The fall application of pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] plus metribuzin appears to have been deactivated at planting time resulting in decreased control. Soybean yields appear to be related to weed ratings. Poorest yield was in no-till 2 which had poorest weed control and highest yield was with the cover crop system which had good weed control. The plow system yielded significantly less than the cover crop system probably due to increased common cocklebur competition.

In the corn plots, weed control was generally good in both the disk and plow systems; common cocklebur occurred in both systems but predominately in the plow system (Table 6). Field sandbur was troublesome in all tillage systems except the plow system. Foxtail barley was present mainly in no-till 1 indicating that some form of tillage or atrazine application may be needed for control. No-till 2 had good control of broadleaf weed species but only fair to marginal control of grasses. This is indicative of the selectivity of the fall applied atrazine. Atrazine provides good control of broadleaf weeds but erratic control of grasses. The grass weeds were actively growing at the time of alachlor application resulting in poor grass control.

Large differences in crop growth in 1979 and 1981 lead to measurement of other growth parameters. Corn and soybean heights from 1979 and 1981 and corn root extraction measurements from 1979 are shown in Table 7. Soybean plants were significantly taller in the disk system than either no-till or the cover crop system in 1979 and were significantly taller than all treatments except the cover crop system in 1981. Soybean yield was also greatest in this treatment in 1981. Corn plants were significantly taller in the plow plots than in all other tillage systems in 1979 with heights reflecting yield very

Table 7. Soybean and corn heights in August of 1979 and 1981 and corn root extraction pressure from 1979 in each tillage system.

Tillage System	Soybean Height*		Corn Height		Corn Root Extraction Pressure
	1979	1981	1979	1981	1979
	cm		cm		(kg)
No-Till 1	48 c	91 b	168 d	173 b	81 d
No-Till 2	53 b	89 b	193 b	234 a	112 b
Disk	58 a	99 a	178 c	226 a	98 c
Plow	56 ab	91 b	236 a	236 a	151 a
Cover Crop	43 d	94 ab	193 b	191 b	108 bc

*Means within each column followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

closely. No-till 2, the disk system, and the plow system were not significantly different in height but all were taller than either no-till 1 or the cover crop system in 1981. Generally, there was greater variation between tillage systems in 1979 than in 1981 but in both years soybeans were tallest in the disk plots and corn was tallest in the conventional tillage plots. These findings are in agreement with others (27, 91) stating that crop heights are generally taller in conventional tillage.

In a study of the effect of root characteristics on root pulling resistance, Jenison (31) concluded that root pulling resistance was a good indicator of total root development. Corn root pulls were taken at maturity in 1979 as a measure of root development. Significantly more force was required to pull corn plants in the conventional system than in all other systems (Table 7). Roots from the plowed plots were generally longer, finer, and more dense than those from other tillage systems. Root penetration in the reduced tillage plots was shallower with the root system being more diffuse along the soil surface. No insect damage was detected on roots from any tillage system, nor were there any differences in plant lodging.

Soil Aspects

Soil temperatures were measured in the no-till, disk, and plow systems from July through September of 1979. Temperature was lowest in the no-till system during the first several weeks of growth (Table 8). Mock and Erbach (49) found that crop residue on the soil surface will reduce soil temperature due to increased shading, soil moisture, and

Table 8. Average 7.6 cm soil temperatures 4, 7, and 10 weeks after planting in the no-till, disk, and conventional tillage systems in 1979.

	Weeks After Planting		
	4 Weeks	7 Weeks	10 Weeks
	°C		
No-Till	23.9	25.4	20.5
Disk	25.3	26.3	21.0
Plow	25.7	25.7	19.9
Average	25.0	25.8	20.5

reflectance of sunlight. The effect of crop residue diminished as crop canopy developed with little difference in soil temperature apparent at seven and ten weeks. Walker (88) reported that each degree increase in soil temperature from 12 to 26°C increased seedling dry weight 20 percent. Thus, soil temperature differences early in the growing season may account for some of the height differences observed between tillage systems.

Bulk density measurements were taken in 1979 and 1981 (Table 9). In 1979, no significant differences were detected between the surface 8 cm of the tillage systems with the disk system having the lowest bulk density. Large differences between tillage systems occurred at the 8-15 cm depth with the cover crop system being significantly lower than all other treatments. The disk system had a bulk density of 1.41 g/cc which was significantly greater than either the plow system or cover crop system. A tandem disk generally penetrates to a depth of only 10-12 cm which may result in soil compaction immediately below this level. The cover crop plots had lowest average bulk density in the upper 31 cm probably due to incorporation of larger amounts of crop residue in this region. Only slight differences occurred in bulk density between tillage systems at depths below 31 cm.

Bulk densities were generally higher in 1981 than in 1979 (Table 9). In 1981, the disk system had significantly lower bulk density in the surface 8 cm than all other tillage systems. At the 8-15 cm level both no-tills and the disk system had significantly greater bulk density than the plow or the cover crop systems. Only slight differences

Table 9. Average bulk density at eight depths from the upper 120 cm of the soil profile with each tillage system in 1979 and 1981.

	Bulk Density*									
	No-Till 1		No-Till 2		Disk		Plow		Cover Crop	
Depth (cm)	1979	1981	1979	1981	1979	1981	1979	1981	1979	1981
	(g/cc)									
0-8	1.19 nop	1.28 lmn	1.21 l-p	1.30 k-n	1.12 p	1.20 o	1.15 p	1.30 i-n	1.18 op	1.28 n
8-15	1.33 g-k	1.44 e	1.40 f-i	1.40 f	1.41 fgh	1.43 ef	1.31 ijk	1.32 g-m	1.21 l-p	1.33 g-k
15-23	1.28 j-n	1.35 gh	1.28 j-n	1.34 g-j	1.25 k-o	1.34 g-j	1.27 j-o	1.34 ghi	1.20 m-p	1.31 h-n
23-31	1.25 k-o	1.29 k-n	1.27 j-n	1.28 mn	1.29 j-m	1.27 n	1.32 h-k	1.30 j-n	1.20 m-p	1.27 n
33-41	1.36 f-j	1.35 gh	1.30 jkl	1.34 g-j	1.35 g-k	1.35 g	1.28 j-n	1.32 g-l	1.30 jkl	1.32 g-l
48-56	1.42 fg	1.48 d	1.44 ef	1.45 de	1.42 fg	1.43 ef	1.42 fg	1.43 ef	1.41 fgh	1.43 ef
72-80	1.48 de	1.59 abc	1.64 a	1.58 abc	1.56 a-d	1.56 bc	1.54 de	1.56 bc	1.55 a-d	1.55 c
103-111	1.64 ab	1.60 ab	1.63 abc	1.60 ab	1.54 cd	1.58 abc	1.55 a-d	1.61 a	1.55 b-d	1.58 abc

*Means within any column or row for each year followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (K=100).

were detected among tillage systems at any depth below 15 cm. The increased bulk density at the 8-15 cm level must be the result of disk action or continued wheel packing without the loosening action of a moldboard plow. Compaction was probably not apparent in the 0-8 cm depth of the no-tills due to increased organic matter from the residue on the soil surface. Other authors (12, 21, 25, 77) have reported similar increases in bulk density with reduced tillage.

Increased bulk density in the no-till systems and the disk system may provide some explanation for lower root pull measurements in these plots. McKyes et al. (46) reported that a change in bulk density of 0.1 g/cc above or below the optimum for a soil could reduce yield by 30%. Raney et al. (65) reported reduced root growth in fine-textured soils with bulk density of 1.4 g/cc or greater. Thus, bulk density levels at the 8-15 cm depth may have influenced root growth. Soil in this experiment was a silty clay loam which may have adversely affected root growth at the higher bulk densities of 1.4 g/cc or greater.

Soil samples from the upper 120 cm of the soil profile were evaluated in 1979 for several properties in an effort to identify other factors contributing to the large variation in plant growth and yield. Analysis was conducted for organic matter, pH, soluble salts, and three soil fertility elements, phosphorus, potassium, and nitrogen.

Organic matter was significantly higher in the surface 8 cm of no-till 1 than in all other tillage systems (Table 10). No-till 2 was significantly higher than either the plow or cover crop system and the

Table 10. Percent organic matter at eight depths of the soil profile with each tillage system in 1979.

Depth (cm)	Organic Matter* No-Till 1	No-Till 2	Disk	Plow	Cover Crop
			(%)		
0-8	3.2 a	3.0 b	2.8 bc	2.6 de	2.7 cd
8-15	2.5 de	2.5 de	2.5 de	2.5 de	2.6 de
15-23	2.4 ef	2.4 ef	2.5 de	2.7 cd	2.5 de
23-31	1.8 ij	1.9 ij	2.1 gh	2.0 hi	2.3 fg
33-41	1.4 kl	1.5 kl	1.6 jk	1.6 k	1.6 k
48-56	1.2 mno	1.2 mn	1.2 mn	1.2 mn	1.3 lm
72-80	0.7 qr	0.8 pq	1.0 op	1.0 no	0.8 pq
103-111	0.5 rs	0.5 rs	0.4 s	0.6 rs	0.6 qrs

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

disk system was significantly higher than the plow system. No differences were detected at the 8-15 cm level but at 15-23 cm both no-till systems were significantly lower than the plow system. Differences were more variable at the 23-31 cm depth with the cover crop system having the highest value at 2.3%. Below this level, very few differences between tillage systems were detected for organic matter.

These results are in agreement with those of other researchers (7, 9, 39, 54). Organic matter increases at the surface of the no-till plots are generally attributed to collection of plant residue. As decomposition occurs, no tillage is done to incorporate organic material to deeper depths resulting in an increase in the surface few centimeters. Tillage operations such as moldboard plowing produce a mixing of the crop residue throughout the plow layer resulting in more consistent organic matter levels in the surface 23 cm. This is evident by the lack of significant differences between the upper three sample depths in the plow and cover crop system.

Soil pH differences were nonsignificant between all tillage systems at all depths except for no-till 1 being significantly higher than the plow system in the surface 8 cm (Table 11). Changes in pH with different tillage practices appear to vary in the literature with regard to type and amount of fertilizer applied. Blevins et al. (9) reported lower soil pH in no-till versus conventional tillage as nitrogen fertilizer rate increased. Shear and Moschler (75) reported that no-till plots needed more frequent liming than conventional tilled

Table 11. Soil pH at eight depths of the soil profile with each tillage system in 1979.

	pH*				
Depth (cm)	No-Till 1	No-Till 2	Disk	Plow	Cover Crop
0-8	6.8 e-h	6.5 h-m	6.5 h-m	6.5 i-m	6.6 g-l
8-15	6.4 j-m	6.2 m	6.3 lm	6.3 m	6.4 j-m
15-23	6.5 h-m	6.4 klm	6.2 m	6.3 m	6.5 i-m
23-31	6.6 g-l	6.6 f-k	6.5 i-m	6.5 i-m	6.5 h-m
33-41	6.7 f-j	6.8 efg	6.7 e-i	6.7 f-j	6.6 f-k
48-56	7.0 cde	6.9 def	6.9 efg	6.8 efg	6.8 e-h
72-80	7.2 bc	7.3 bc	7.2 bc	7.2 c	7.2 cd
103-111	7.6 a	7.6 a	7.7 a	7.5 ab	7.6 a

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

plots when fertilizer was applied. Moschler et al. (53) in a study of residual fertility under various tillage systems found increased soil pH with no-till systems. This increase was assumed to be from chemical or biological causes. Results from Moschler's study which did not have fertilizer applied for eleven cropping years are similar to our study which did not have fertilizer applied for the previous six years.

Soluble salt levels were low in all tillage systems with no significant differences occurring between any of the systems at any depth (Table 12). Soluble salts are naturally low in this soil and are not normally considered a problem.

Phosphorus levels in no-till 2 and the disk system were significantly higher in the surface 8 cm than in either the plow or cover crop system (Table 13). No-till 1 was at an intermediate level. A significantly higher level of phosphorus was present in the surface 8 cm of both no-tills and the disk system than in any depth below 8 cm. The plow system had no significant differences at any level in the upper 23 cm of soil. This indicates that phosphorus was more evenly distributed in the upper 23 cm of the conventional tillage system due to the mixing action of the plow. Only slight differences were detected between tillage systems at depths below 23 cm.

Soil samples taken in 1974 indicated an average of 34 kg/ha in the surface 15 cm for all tillage treatments. All tillage systems were below this level in 1979 when an average value for the surface 15 cm is calculated. This decrease is probably due to crop removal. Those systems with the highest average soybean yield were generally lowest in

Table 12. Soluble salt measurements at eight depths of the soil profile with each tillage system in 1979.

	Soluble Salts*				
Depth (cm)	No-Till 1	No-Till 2	Disk	Plow	Cover Crop
	(mmho/cm)				
0-8	0.43 abc	0.44 ab	0.35 a-f	0.36 a-f	0.38 a-e
8-15	0.35 a-f	0.38 a-e	0.31 c-f	0.29 def	0.32 b-f
15-23	0.32 b-f	0.32 b-f	0.32 b-f	0.34 a-f	0.32 b-f
23-31	0.31 c-f	0.33 b-f	0.32 b-f	0.29 ef	0.31 b-f
33-41	0.35 a-f	0.34 a-f	0.28 ef	0.30 d-f	0.24 f
48-56	0.31 c-f	0.31 c-f	0.31 c-f	0.32 b-f	0.32 b-f
72-80	0.37 a-f	0.38 a-e	0.31 c-f	0.34 a-f	0.36 a-f
103-111	0.40 a-e	0.36 a-f	0.36 a-f	0.46 a	0.42 a-d

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

Table 13. Phosphorus level at eight depths of the soil profile with each tillage system in 1979.

Depth (cm)	No-Till 1	No-Till 2	Disk	Plow	Cover Crop
	Phosphorus* (kg/ha)				
0-8	30 ab	37 a	40 a	21 b-e	22 bcd
8-15	10 g-j	16 c-j	17 c-i	26 bc	11 e-j
15-23	10 g-j	11 d-j	17 c-h	20 b-f	12 d-j
23-31	6 j	8 hij	10 f-j	8 g-j	9 g-j
33-41	7 hij	6 ij	9 g-j	9 g-j	12 d-j
48-56	7 hij	8 g-j	10 f-j	9 g-j	7 h-j
72-80	13 d-j	13 d-j	9 g-j	15 c-j	11 e-j
103-111	15 c-j	18 c-g	13 d-j	25 bc	13 d-j

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

phosphorus. Increased phosphorus levels at the surface in reduced tillage systems have been reported by several researchers (12, 39, 53, 54, 75). Moschler et al. (53) assumed this increase to be from chemical or biological causes. Since phosphorus is an immobile element, it will not move through the soil profile unless physically moved with a tillage operation.

Potassium level was significantly higher in the surface 8 cm of no-till 1 than in any tilled system (Table 14). No-till 2 and the disk system were both significantly higher than either the plow or cover crop systems at this depth. Also, potassium levels in the surface 8 cm of both no-tills and the disk system were significantly higher than at any depth below 8 cm. No significant differences were detected between levels in the upper 23 cm of the plow system. Potassium is a relatively immobile element which may concentrate at the soil surface due to chemical and biological causes unless physically moved with a tillage operation (53). Soil test levels of potassium in 1974 average 790 kg/ha for the surface 15 cm. All tillage treatments except the two no-tills were lower than this level in 1979 indicating removal through grain production. Yields were generally lowest in the no-till systems which may account for this lack of removal.

Nitrate-nitrogen levels were very low at all depths in all tillage systems (Table 15). A maximum level of 8 kg/ha was found in the upper 8 cm of no-till 2. Although some significant differences were found between depths and tillage systems, all levels were extremely low. Nitrogen deficiency symptoms consisting of stunting and

Table 14. Potassium level at eight depths of the soil profile with each tillage system in 1979.

	Potassium*				
Depth (cm)	No-Till 1	No-Till 2	Disk	Plow	Cover Crop
			(kg/ha)		
0-8	1065 a	1018 ab	962 b	626 cde	722 c
8-15	534 e-l	563 e-i	516 f-m	668 cd	585 d-g
15-23	461 j-m	445 j-m	456 j-m	579 d-g	603 def
23-31	449 klm	454 j-m	460 j-m	440 lm	568 e-i
33-41	492 g-m	508 f-m	483 h-m	470 i-m	495 g-m
48-56	533 e-l	541 e-k	510 f-m	552 e-j	542 e-k
72-80	521 f-m	508 f-m	497 g-m	540 e-k	540 e-k
103-111	447 klm	424 m	428 m	447 klm	460 j-m

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

Table 15. Nitrate-nitrogen level at eight depths of the soil profile with each tillage system in 1979.

	Nitrate-Nitrogen*				
Depth (cm)	No-Till 1	No-Till 2	Disk	Plow	Cover Crop
	(kg/ha)				
0-8	2 b	8 a	2 b	3 ab	2 b
8-15	2 b	7 ab	2 ab	6 ab	2 b
15-23	2 b	4 ab	3 ab	6 ab	2 ab
23-31	2 b	3 ab	2 b	3 ab	2 b
33-41	2 b	3 ab	2 b	2 ab	2 b
48-56	2 b	3 ab	2 b	2 b	2 b
72-80	2 b	2 ab	2 b	2 b	2 b
103-111	2 b	2 b	2 b	3 ab	2 b

*Means followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio T-test (k=100).

yellowing of lower leaves were more apparent in corn plants in the reduced tillage systems. The average nitrate-nitrogen level in 1974 was 6 kg/ha. All treatments except no-till 2 were slightly lower for the surface 15 cm in 1979. No fertilizer was applied to any of the tillage systems between 1974 and 1979 so any nitrogen available for plant growth must be due to nitrogen fixation or mineralization.

Dowdell and Cannell (17) concluded that mineralization of soil nitrogen decreased in no-till plots compared to conventional tillage. Doran (16) reported decreased aerobic microorganism populations and increased populations of denitrifying microorganisms in no-till soils compared to conventional tilled soils. Soybean plants can biologically fix nitrogen; thus, nitrogen is not generally a yield limiting factor. Corn plants cannot fix nitrogen so it must be obtained from the soil. If mineralization of nitrogen is decreased and dentrification increased, less nitrogen would be available for the corn plant under no-till conditions. This decrease in nitrogen may provide some explanation for the significantly lower corn yields in the reduced tillage treatments.

Tillage practices can significantly affect several soil properties. Organic matter, phosphorus, and potassium have been shown to concentrate in the surface 8 cm with reduced tillage systems. Concentration of essential elements needed for plant growth may limit uptake of these elements in reduced tillage systems. Conventional tillage produced a more even distribution of these soil properties throughout the plow layer. It does not appear that any one soil property can be used to explain all differences between tillage systems. Rather, it is probably a combination of several soil and weed control factors which have influenced the yield of corn and soybeans in this study.

Dominant Weed Species

Weed species shifts have been observed with changes in tillage (23, 63, 80, 92). Changes in soil environment will likely alter the composition of weed floras by influencing germination and establishment. Increased and continuous use of certain herbicides will also allow certain plant species to dominate. Weed counts and weights were taken from all plots of this experiment in 1981 to determine the influence of tillage practices and herbicide use on weed species.

Predominately four grass species were found in this experiment. Significantly more green foxtail (*Setaria viridis* [L.] Beauv.) plants were found in no-till 1 than any other tillage system; it was present in nearly every subsample from no-till 1 (Table 16). No-till 2 contained significantly more green foxtail plants than any of the tilled systems. The plow system contained the fewest green foxtail plants with only one third of all subsamples containing this weed. Sample weights and total weed yields were similar to the count data for each treatment (Table 17). It appears that spring tillage will greatly reduce foxtail competition. Paraquat was applied to no-till 1 and the cover crop system but may not have completely controlled all of the emerged foxtail at planting. Foxtail numbers were particularly high in the soybean plots of no-till 2 in 1981. The fall application of pendimethalin plus

Table 16. Frequency and number of samples of the predominant grass weed species found in each tillage system in 1981.

	Green Foxtail[a]		Field Sandbur		Barnyardgrass		Foxtail Barley	
Tillage System	Freq.[b]	# of Samples[c]	Freq.	# of Samples	Freq.	# of Samples[d]	Freq.	# of Samples
No-Till 1	255.4 a	14.3 a	26.6 b	4.4 b	5.0 ab	2.6	70.0 a	4.5 a
No-Till 2	142.1 b	9.5 b	64.6 ab	5.9 ab	11.9 a	3.8	0.0 b	0.0 b
Disk	37.3 cd	7.8 bc	62.5 ab	5.1 b	6.4 ab	3.1	0.3 b	0.3 b
Plow	23.3 d	5.1 c	0.4 c	0.4 c	2.6 ab	1.4	0.0 b	0.0 b
Cover Crop	63.0 c	10.6 b	121.2 a	8.3 a	1.0 b	0.9	0.0 b	0.0 b

[a] Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

[b] Frequency is the total number of plants counted in the fifteen subsamples collected from each plot.

[c] Number of samples is the number of subsamples taken from each plot in which the weed was found.

[d] Values are not significantly different at the 5% level.

Table 17. Average sample weight and weed yield of the predominant grass weed species found in each tillage system in 1981.

Tillage System	Green Foxtail[a]		Field Sandbur		Barnyardgrass		Foxtail Barley	
	Sample Weight[b]	Weed Yield	Sample Weight	Weed Yield	Sample Weight	Weed Yield	Sample Weight	Weed Yield
	(gm)	(kg/ha)	(gm)	(kg/ha)	(gm)	(kg/ha)	(gm)	(kg/ha)
No-Till 1	234.4 a	2500	32.7 ab	349	17.3 ab	185	11.2 a	119
No-Till 2	167.0 a	1785	77.4 a	826	32.8 a	350	0.0 b	0
Disk	44.1 b	470	71.7 a	765	16.6 ab	177	0.2 b	2
Plow	29.4 b	314	0.6 b	6	11.6 ab	124	0.0 b	0
Cover Crop	65.2 b	695	96.3 a	1027	3.5 b	37	0.0 b	0

[a] Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

[b] Total weight in grams of the fifteen 625 cm^2 subsamples from each plot.

metribuzin may have been deactivated to a large degree allowing emergence of green foxtail.

Field sandbur is another predominant grass weed found in this study; it occurred most often in the cover crop system (Table 16). The plow system contained significantly less sandbur than any other tillage system. Sample weights and weed yields were similar to the count data with all tillage systems (Table 17). Most sandbur plants were found in the corn plots indicating lack of herbicidal control. Paraquat plus cyanazine was applied to the corn plots in the cover crop system. Cyanazine provides only marginal control of actively growing sandbur plants. Also, the large amount of rye residue in these plots may have prevented good coverage and contributed to reduced weed control. Alachlor provides variable control of sandbur which may explain limited control in all the reduced tillage plots. The disk system had significantly more sandbur present than the plow system indicating that light spring tillage is not effective in controlling this weed. It appears that both spring and fall tillage together with an appropriate herbicide program is needed to effectively control field sandbur.

A light barnyardgrass (Echinochloa crusgalli [L.] Beauv.) infestation was also present with only slight differences in occurrance between tillage systems (Table 16). No-till 2 had significantly more plants present and larger sample weight than the cover crop system. No-till 2 had the fall application of pendimethalin plus metribuzin in the soybeans and fall applied atrazine and spring applied alachlor in the corn. Fall herbicide application generally resulted in poor grass control in this experiment. Barnyardgrass counts and weights were lowest in the cover crop system indicating that it may have had difficulty emerging through the heavy residue in these plots (Table 17).

Foxtail barley was a problem in no-till 1 but not in no-till 2 or any other tillage system (Tables 16 & 17). Foxtail barley is a short-lived perennial weed with fibrous roots but no rhizomes. Generally, tillage operations, even shallow tillage with a disk, will control this type of perennial. It is interesting that it was a problem in no-till 1 but not in no-till 2. No-till 2 consistently contained fall applied herbicides in the corn plots and had fall applied herbicides in the soybean plots in 1981. These fall applied compounds may have retained enough activity through the winter to prevent reestablishment early the following spring.

Grass weeds increased greatly in the no-till systems compared to the conventional tillage system (Figure 2). The disk and cover crop systems were at intermediate levels. This increase in grass weed species with reduced tillage has been detected by other researchers (23, 63, 80, 92) with several possible reasons cited. Spring tillage is generally very effective in controlling annual grasses; with no-till systems this cultural control is lost (63). Increased growth of early germinating broadleaf weed species has also been cited as a cause of increased grass problems (92). Early growth of annual broadleaf weeds may provide a canopy over low growing grass species which can intercept nonselective herbicides applied to these plots. This results in death of the broadleaf plants with little injury to the grass weeds.

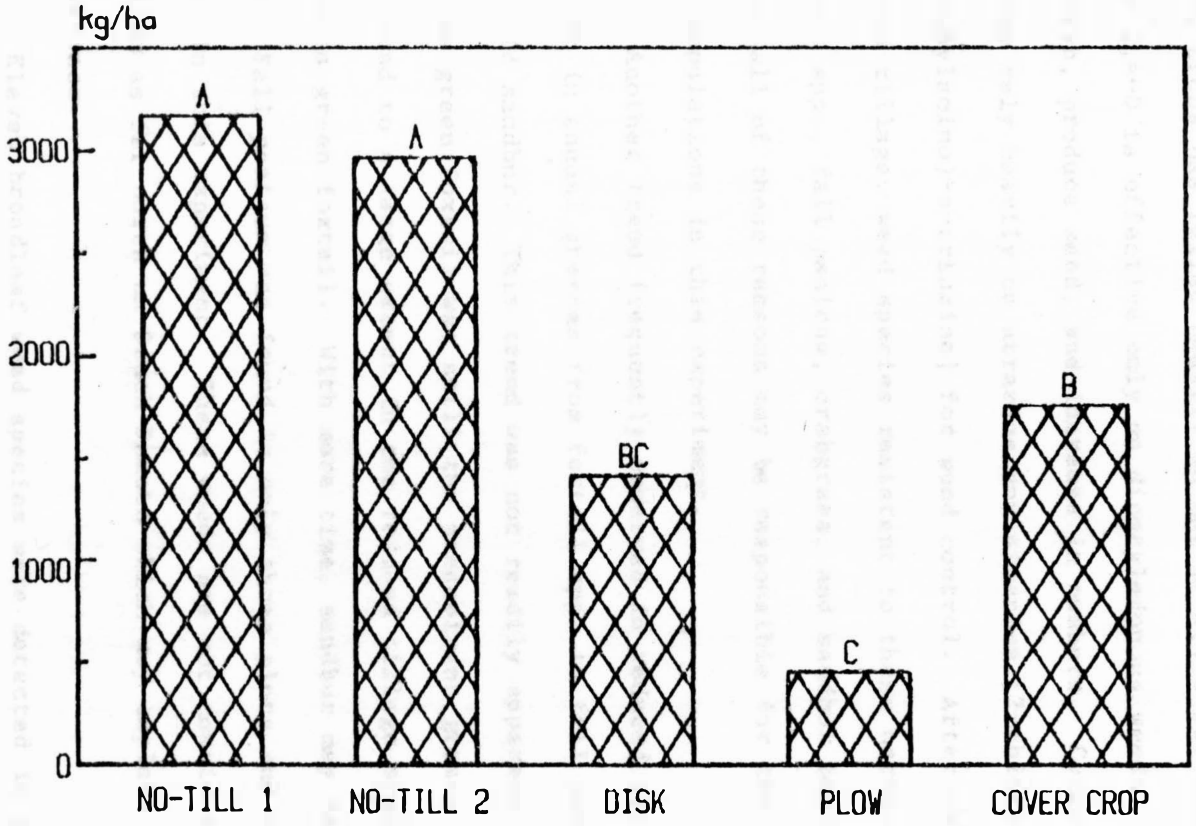

Figure 2. Total grass weed yield from each tillage system in 1981. Bars with the same letter on them are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

Herbicide selectivity has also been cited as a possible reason for increased grass populations (23, 80, 92). Much of the work done in cereal crops has relied heavily on use of 2,4-D for weed control. Since 2,4-D is effective only on dicotyledonous weeds, monocots tend to flourish, produce seed, and increase in numbers. Continuous corn systems rely heavily on atrazine and simazine [2-chloro-4,6-bis(ethylamino)-s-triazine] for weed control. After several years of reduced tillage, weed species resistent to these herbicides such as foxtail spp., fall panicum, crabgrass, and sandbur begin to dominate. Any or all of these reasons may be responsible for the increased grass weed populations in this experiment.

Another trend frequently observed in reduced tillage systems is a shift in annual grasses from foxtail spp. to fall panicum, crabgrass, or field sandbur. This trend was not readily apparent in this experiment as green foxtail was still the predominant grass. Field sandbur was found to a large extent in the reduced tillage systems but not as often as green foxtail. With more time, sandbur may have become dominant. Fall panicum was found in only three plots and crabgrass was not found in this experiment. These weeds are not considered to be a problem as far north as South Dakota which may explain their lack of occurrence.

Eleven broadleaf weed species were detected in this experiment but only four species varied significantly between tillage systems. Significantly more Pennsylvania smartweed was present in no-till 2 than in no-till 1, the disk, or the plow system (Table 18). Average sample

Table 18. Frequency and number of samples of the predominant annual broadleaf weed species found in each tillage system in 1981.

Tillage System	Penn. Smartweed[a] Freq.[b]	Penn. Smartweed[a] # of Samples[c]	Cocklebur Freq.	Cocklebur # of Samples	Prostrate Pigweed Freq.	Prostrate Pigweed # of Samples	Lambsquarter Freq.	Lambsquarter # of Samples
No-Till 1	1.7 b	0.9 b	0.1 bc	0.1 bc	0.4 b	0.5 ab	0.0 b	0.0 b
No-Till 2	18.5 a	4.1 a	0.1 bc	0.1 bc	0.1 b	0.1 b	0.0 b	0.0 b
Disk	0.1 b	0.1 b	0.8 ab	1.0 ab	0.4 b	0.5 ab	0.1 b	0.1 b
Plow	1.6 b	1.0 b	1.3 a	1.4 a	6.6 a	1.9 ab	0.0 b	0.0 b
Cover Crop	2.9 ab	2.3 ab	0.0 c	0.0 c	4.3 ab	2.6 a	1.9 a	2.0 a

[a] Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

[b] Frequency is the total number of plants counted in the fifteen subsamples collected from each plot.

[c] Number of samples is the number of subsamples taken from each plot in which the weed was found.

Table 19. Average sample weight and weed yield of the predominant annual broadleaf weed species found in each tillage system in 1981.

	Penn. Smartweed[a]		Cocklebur		Prostrate Pigweed		Lambsquarter	
Tillage System	Sample Weight[b] (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)	Sample Weight[c] (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)
No-Till 1	66.0 b	704	9.7 ab	103	0.9	10	0.0 b	0
No-Till 2	243.4 a	2596	0.3 b	3	0.2	2	0.0 b	0
Disk	2.1 b	22	37.2 ab	397	0.6	6	0.0 b	0
Plow	27.2 b	290	47.9 a	511	6.6	70	0.0 b	0
Cover Crop	19.2 b	205	0.0 b	0	5.0	53	19.4 a	207

[a] Means within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan k-ratio t-test (k=100).

[b] Total weight in grams of the fifteen 625 cm^2 subsamples from each plot.

[c] Values are not significantly different at the 5% level.

weight was greater in no-till 2 than in all other tillage systems with no-till 2 producing a total weed yield of nearly 2600 kg/ha (Table 19). No significant differences were found between any of the other tillage systems. The large infestation of Pennsylvania smartweed in no-till 2 is probably related to herbicides in the corn which tended to provide marginal weed control. In the soybeans, prior to 1981, bifenox was applied to these plots for broadleaf weed control. Bifenox provides erratic control of Pennsylvania smartweed allowing the population of this weed to increase.

A light infestation of common cocklebur was observed in this experiment with significantly more plants found in the plow system than in either no-till system or the cover crop system (Table 18). Cocklebur populations and dry weights were not significantly different between the disk and plow systems (Table 19). No cocklebur plants were found in the cover crop system indicating excellent control with bentazon in soybean plots and cyanazine in corn plots. Metribuzin was applied to all other soybean plots and cyanazine or atrazine was applied to the corn plots. Thus, spring tillage is indicated as the reason for increased cocklebur problems in the disk and plow system. Some weeds such as common milkweed have been shown to have increased germination with shallow tillage (30). It is possible that a similar situation may occur with common cocklebur.

Significantly more prostrate pigweed (Amaranthus graecizans L.) plants were found in the plow plots than in either no-till or the disk system, however, more subsamples in the cover crop system contained prostrate pigweed (Table 18). No significant differences were observed between tillage treatments for sample weight (Table 19). It appears that fall plowing is responsible for the increased infestation of this weed. Weed counts and yields were very low for this weed in all tillage systems indicating that prostrate pigweed is not expected to be a major weed problem with any tillage system.

Common lambsquarter was found only in the cover crop system; it was completely controlled in the other tillage systems (Table 18). All plants were found in the soybean plots in 1981. Bentazon was the only broadleaf herbicide applied in the cover crop system with metribuzin applied to the other tillage systems. Bentazon will provide adequate control of common lambsquarter if applied to seedlings but has no residual soil activity. A very light infestation was found (207 kg/ha weed yield) which indicates that some of the common lambsquarter plants were controlled (Table 19). Those that were not controlled may have been too large for adequate control at the time of herbicide application or may have emerged after herbicide application.

In general, annual broadleaf weeds did not appear to be a large problem with any tillage system. The largest infestation was that of Pennsylvania smartweed in no-till 2. This appeared related to use of herbicides which were ineffective in controlling this weed and was not related to tillage. Cocklebur was more of a problem in those plots with spring tillage. Other weeds such as prostrate pigweed and common lambsquarter were effectively controlled in all tillage systems with proper selection of herbicides. Black nightshade (Solanum nigrum), kochia, prostrate vervain (Verbena bracteata Lag. & Rodr.), redroot pigweed, venice mallow (Hibiscus trionum L.), and wild buckwheat (Polygonum convolvulus L.) are other annual broadleaf weeds found in this experiment. Meadow salisfy (Tragopogon major Jacq.), a biennial weed, was also present. All of these weeds were found in very low populations with no differences between tillage systems. Greatest total broadleaf weed weight was found in no-till 2 (Figure 3). These plots had fall applied herbicides which resulted in poor weed control. No differences in total broadleaf weed weights were found between the other tillage systems.

Previous work has found that annual dicotyledonous weeds tend to become less troublesome in reduced tillage systems (62, 63, 80). It has been observed that early germinating broadleaf weeds such as Pennsylvania smartweed, giant ragweed, common ragweed, and common lambsquarter dominate early in the growing season on reduced tillage systems (92). Although these weeds may be present at planting time, they are easily controlled with herbicides. The eventual domination of grass weeds in reduced tillage systems generally results in decreased populations of broadleaf weeds (63, 80). This effect was also observed in this study with more grass than broadleaf weeds present in all tillage systems except the plow system (Figures 2 & 3).

A light scattering of several perennial weeds was found in this study; however, no differences between tillage systems were detected (Table 20). Common milkweed was found in all tillage systems except no-till 1. Greatest weed yield was with the disk system at 75 kg/ha

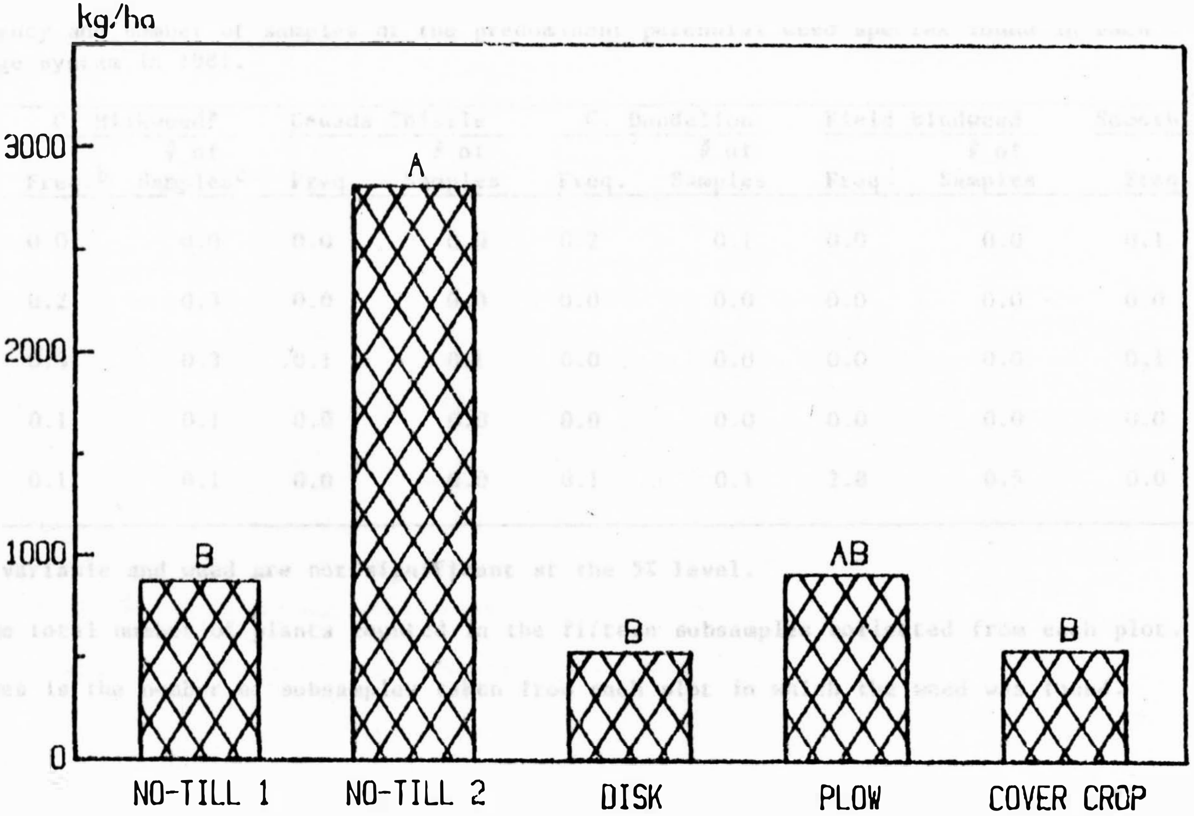

Figure 3. Total broadleaf weed yield from each tillage system in 1981. Bars with the same letter on them are not significantly different at the 5% level using the Waller–Duncan k-ratio t-test (k=100).

Table 20. Frequency and number of samples of the predominant perennial weed species found in each tillage system in 1981.

	C. Milkweed[a]		Canada Thistle		C. Dandelion		Field Bindweed		Smooth Groundcherry	
Tillage System	Freq.[b]	# of Samples[c]	Freq.	# of Samples	Freq.	# of Samples	Freq.	# of Samples	Freq.	# of Samples
No-Till 1	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.1	0.1
No-Till 2	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Disk	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Plow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cover Crop	0.1	0.1	0.0	0.0	0.1	0.1	2.8	0.5	0.0	0.0

[a] Means for each variable and weed are not significant at the 5% level.

[b] Frequency is the total number of plants counted in the fifteen subsamples collected from each plot.

[c] Number of samples is the number of subsamples taken from each plot in which the weed was found.

Table 21. Average sample weight and weed yield of the predominant perennial weed species found in each tillage system in 1981.

	C. Milkweed[a]		Canada Thistle		C. Dandelion		Field Bindweed		Smooth Groundcherry	
Tillage System	Sample Weight[b] (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)	Sample Weight (gm)	Weed Yield (kg/ha)
No-Till 1	0.0	0	0.0	0	0.1	1	0.0	0	0.5	5
No-Till 2	1.0	11	0.0	0	0.0	0	0.0	0	0.0	0
Disk	7.0	75	1.8	19	0.0	0	0.0	0	1.1	12
Plow	2.3	25	0.0	0	0.0	0	0.0	0	0.0	0
Cover Crop	0.1	1	0.0	0	0.0	0	3.8	41	0.0	0

[a] Means for each variable and weed are not significant at the 5% level.

[b] Total weight in grams of the fifteen 625 cm^2 subsamples from each plot.

(Table 21). Jeffery and Robison (30) found increased germination of common milkweed seed with light tillage. This may account for the slight increase in milkweed yield in the disk system.

Canada thistle, common dandelion, field bindweed (Convolvulus arvensis L.), and smooth groundcherry were also present in low populations (Tables 20 & 21). These weeds were generally found in only one or two plots indicating encroachment from nearby alleyways. The low infestation of perennial weeds may be largely due to the application of glyphosate [N-(phosphonomethyl)glycine] to all plots in the spring of 1978 and 1980. Glyphosate will provide effective control of many perennial weeds by translocating throughout the plant producing eventual death of both roots and top growth. Control was excellent both years that glyphosate was applied resulting in greatly reduced perennial weed populations.

As tillage is reduced, the potential for perennial weed problems is increased. Triplett and Lytle (80) reported that large colonies of perennial weeds in no-till systems developed from individual plants. Little or no invasion of perennial weeds was noted in tilled areas. Both perennial grass and broadleaf weeds were detected in reduced tillage plots by Pollard and Cussans (62). Perennial weeds can be controlled in reduced tillage systems through conscientious use of herbicides, however, it is recommended that reduced tillage systems not be used in areas with established perennial weed problems (92).

It is interesting to note that significantly more subsamples containing no weeds were found in the plow and disk systems than in either no-till system or the cover crop system. On the average, 7 of the 15 subsamples from the plow plots and 5 of the 15 subsamples from the disk plots contained no weeds. This is indicative of the generally better weed control achieved in these plots.

SUMMARY

This experiment was designed to determine the effect of reduced tillage systems on weed control, several soil properties and residual soil fertility, and potential weed species shifts.

Weed control was generally best in the conventional tillage systems; however, good weed control was attained in the reduced tillage systems with proper use of herbicides. Application of a nonselective herbicide for control of emerged weeds at planting time proved beneficial in the no-till systems. Fall application of atrazine and other residual herbicides showed promise as a weed control program in reduced tillage. The cover crop system started in 1978 generally had good weed control but some problem with interception of herbicide by the rye residue may exist. Yields appear to be related to weed control in some years of this experiment.

Soil temperatures were lowest initially in the no-till systems and highest in the conventional system. Greatest bulk density was found at the 8-15 cm depth of the disk system. Only slight differences in pH and soluble salts were detected between tillage systems. Organic matter, phosphorus and potassium were concentrated at the soil surface in the reduced tillage systems and more evenly distributed throughout the plow layer in the conventional system. Nitrate-nitrogen was very low in all plots but nitrogen deficiency symptoms were more distinct in the reduced tillage systems. Differences in mineralization and denitrification between tillage systems may provide some explanation.

Grass weeds such as green foxtail and field sandbur were more

troublesome in the no-till systems than in the tilled system. Pennsylvania smartweed was a problem in no-till 2 due to inadequate herbicidal control. Generally, broadleaf weeds were not present in large numbers in any of the tillage systems. Some perennial weeds were observed but none showed any trend in regard to tillage.

From this study, it appears that weeds can be controlled in reduced tillage systems with proper selection and application of herbicides. Grass weeds may become dominant as tillage is reduced while broadleaf weeds tend to decrease in number. Fertility management becomes more crucial and occasional deep tillage may be required to maintain high yields in reduced tillage systems.

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