8-1-1993

# Agronomic, Economic and Ecological Relationships in Alternative (Organic), Coventional, and Reduced-till Farming Systems

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B 718
September 1993

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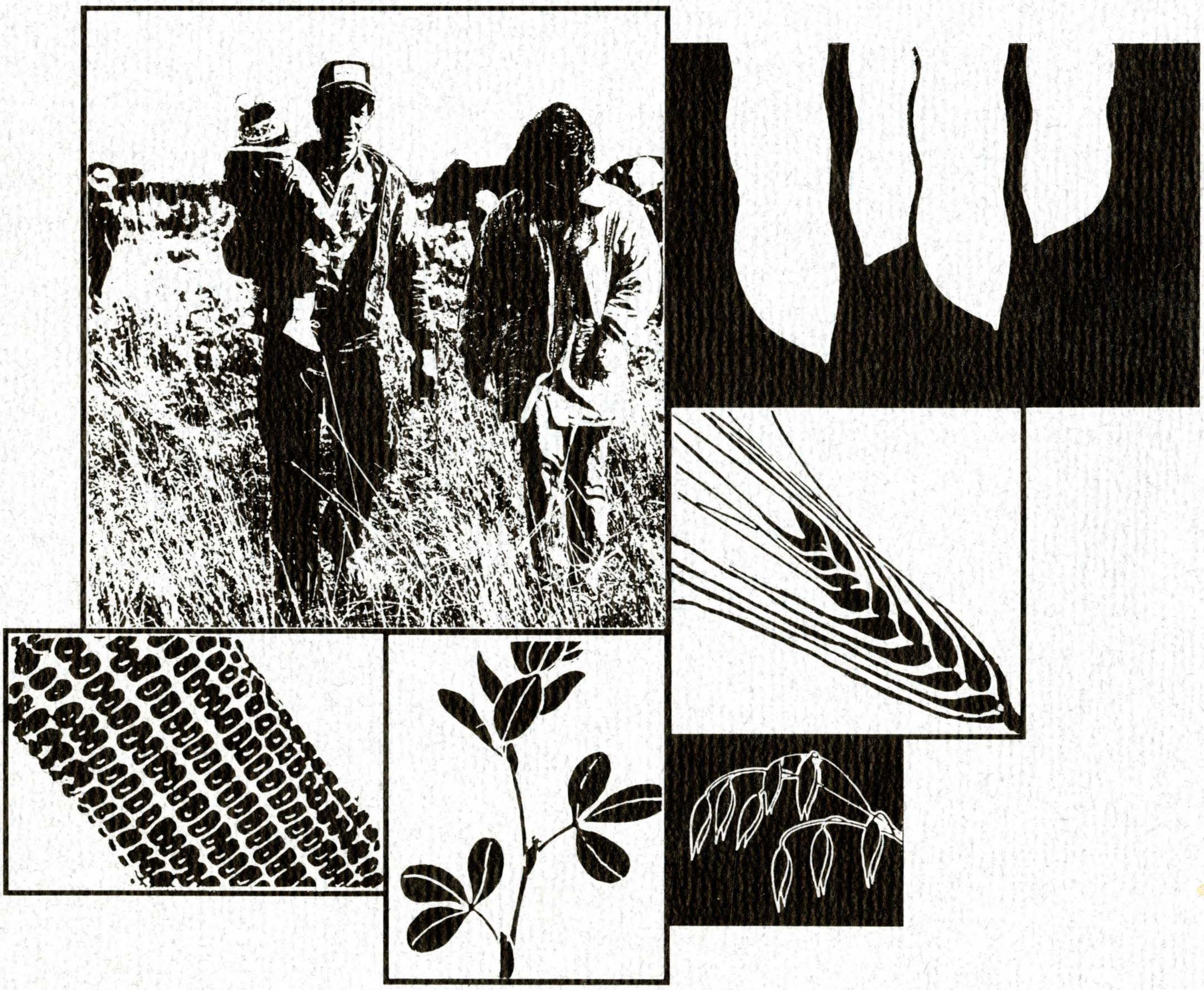
South Dakota State University
U.S. Department of Agriculture



## Acknowledgements

We very much appreciate the capable technical assistance provided by Loyal Evjen, Pat Wieland, Clarence Mends, Brad Farber, Steve Werner, David Vos, Allan Heuer, Kim Compton, David Becker, Lon Henning, Kellie Koehne, and Scott Van DerWerff. We also thank P.D. Evenson for his assistance with the statistical analyses, Russ McKinney for his assistance with insect identifications, and Ron Gelderman, Jim Gerwing, and Howard Woodard for their assistance in evaluating soil nutrients and for providing fertilizer recommendations. Don Taylor provided valuable advice and reviews at various stages of this project and also provided leadership for some of the farmer-researcher educational forums conducted as part of the project.

The advice and encouragement for undertaking this project provided by Allan, Charles and William Johnson; Fr. Leonard Kayser; and Dr. Ray Moore is gratefully acknowledged.

Special thanks to Jim Sims, Montana State University, and to our colleagues at SDSU: Don Taylor, Dean Dybing, and Jim Doolittle, for their very helpful review comments. We also thank Holly Gill, Mary Brashier, and Duane Hanson for assistance in the preparation of this bulletin.

Thanks also to Drs. M.L. Horton, F.A. Cholick, and P.E. Fixen for their constructive criticisms over the course of these studies.

B 718
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This bulletin was prepared, in part, with the support of USDA agreement No. 92-COOP-1-7266. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the USDA.

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# Agronomic, Economic, and Ecological Relationships in Alternative (Organic), Conventional, and Reduced-Till Farming Systems

Farming systems studies at SDSU were initiated in 1984 by the Plant Science Department at the request of individual crop producers and groups of producers. The Economics Department began a companion project in 1985. Over the study, from six to 12 researchers have collected and analyzed data. The involvement of researchers from both the natural and social sciences since almost the inception of this study was one of its most unique aspects, and the interaction of scientists from these various fields has contributed to meeting the project objectives.

Support for this project over the first several years was provided solely by the South Dakota Agricultural Experiment Station. From 1988-1993 additional funding was obtained through the USDA/LISA competitive grants program. The additional funds allowed us to undertake a number of additional investigations which have added substantially to the studies.

The initial phase of this project was on-farm studies in several farmers' fields near Madison, S.D., comparing the long-term productivity of alternative (organic) and conventional farming systems. While on-farm components of the project have continued, questions arising from both farmers and researchers prompted an expansion of the research in 1985 to also include experiment station trials.

This bulletin summarizes results in those trials at the Northeast Research Station near Watertown, S.D. Section A discusses crop performance and, briefly, the factors that appeared to influence yields. A more complete discussion of these factors is presented in Section C. Section B compares production in the various systems on a whole-farm (540 tillable acres) basis from several perspectives—harvested crop mass, total digestible nutrients (TDN), production relative to monetary and labor investments, energy relationships, and biofuel potential. Section C discusses various ecological relationships, including weeds, nematodes, insects, plant diseases, mycorrhizae, surface residues, soil water, and nutrients. Section D compares the economic performance of the systems. Section E compares the relative sustainability of the various systems.

The objectives of the experiment station trials were to:

- Measure yields in alternative, conventional and reduced-till farming systems.
- Compare whole-farm economic performance.
- Measure whole-farm productivity of the systems.
- Determine influence of farming system on soil nutrient relationships, soil temperatures, soil water content, bulk density, residue cover, and snow catch.
- Compare populations of plant feeding, predaceous, and microbial feeding nematodes.
- Determine populations of fungi and bacteria, and measure mycorrhizal associations and soil fungistatic properties.
- Determine effect of farming systems on earthworm populations.
- Determine weed species present and densities.
- Measure beneficial and harmful arthropod populations and measure insect damage.
- Compare the relative sustainability of the various systems.

This list of objectives represents various interests of the researchers and also reflects an attempt to obtain a holistic view of the processes that constitute a farming system.

## Literature Review

Crop production studies, including long-term crop rotations, have substantial historical precedence in South Dakota, and results of a series of studies over the period 1941-1962 were reported in several Agricultural Experiment Station bulletins. Most of the studies were concerned with the effects of fertilizer and irrigation on crop yields, although some experiments also measured effects of tillage (Puhr 1962, Hovland *et al* 1964).

Several forage legumes (alfalfa, red clover, or sweetclover) were included in some of the crop rotation experiments. Under irrigation, alfalfa in the rotation generally provided substantial yield benefits to the following corn crop (Fine *et al* 1964, Evenson and Fine 1964). In dryland studies conducted near Brookings, the benefits of legumes in the rotations were more variable, and in drier years crop yields following legumes were reduced (Puhr 1962).

Application of barnyard manure and retention of crop residues increased small grain yields in crop rotation studies near Highmore (Hovland *et al* 1964). Also, even though moisture was often limiting at Highmore, results in the long-term rotation studies questioned the benefits of both fallow and reduced tillage.

A recent review compared the productivity of organic and conventional systems over a wide range of environments, including the eastern U.S., U.S. Corn Belt, Germany, Australia, England, Israel, Sweden, and Switzerland (Stanhill 1990). This review indicated that yields in organic systems were higher in some instances and, on average, were within 10% of those obtained in conventional systems.

There is little current information based on long-term studies of the agronomic and economic performance of alternative (organic) farming systems in the north-central region of the U.S. A Nebraska study (Helmers *et al* 1986, Sahs and Lesoing 1985) indicated that alternative systems may perform best under drought stress.

Most experiment station trials in the Northern Plains are in early stages. Our transition-stage research in South Dakota (Smolik and Dobbs 1991), based on 5 years of research trials, indicated that alternative systems are potentially competitive with more conventional systems in mixed row crop-small grain regions. We have also reported effects of farming systems on soil temperature, bulk density, moisture, and surface residues (Rickerl and Smolik 1990), frost depth (Rickerl and Smolik 1989b), and mycorrhizae (Rickerl and Smolik 1989a, Ananth 1992). Additional information on weeds, disease suppressiveness, soil moisture, surface residues, snow catch, nutrients, nematodes, and earthworms has also been reported (Smolik *et al* 1991, 1992, 1993).

Agronomic and economic analyses have been conducted for an actual operating "low-input/sustainable" farm and an operating "conventional" farm. Data and analysis on this matched pair of east-central South Dakota farms for the 1985-89 5-year period were reported by Dobbs *et al* (1991b). Because of the dominance of corn and soybeans on the conventional farm, that farm was more profitable, on average, than the low-input farm during the 1985-89 period. The federal farm program during the late 1980s played a significant role in that comparative profitability.

Recently completed case studies in other parts of South Dakota show a conventional farm to be more profitable in a "typical" year in the late 1980s than a low-input farm in the south-central corn-soybean area. The studies show little difference in profitability between conventional and low-input farms in the northern and western wheat growing areas (Dobbs *et al* 1991a, 1992). In fact, when organic premiums are included for the low-input farms in the wheat growing areas, those farms are slightly more profitable than their respective conventional counterparts.

In Iowa, Duffy (1990) found lower average net returns over the period 1978-1989 for a low-input corn-oats-meadow (alfalfa-grass mixture) system than for a conventional (with standard chemical inputs) corn-soybean system. In Indiana, Purdue University researchers reported that adding alfalfa to the crop mix of conventional corn-soybean systems (to reduce the quantities of inorganic nitrogen fertilizer applications) adversely affects farm profitability (Lee *et al* 1991). A statistical analysis of farm records in Ohio indicated that crop farmers in that state are not spending "too much," from a profit maximizing standpoint, on synthetic fertilizers and other chemicals. The Ohio study also found that profitability "is not significantly improved on crop farms with legume based rotations" (Diallo *et al* 1990).

As a whole, the literature at this point in time tends to indicate that low-input systems are more likely to be economically competitive with conventional systems in the western, drier, wheat growing Great Plains portion of the north-central region (including parts of South Dakota) than in higher rainfall areas of the central and eastern Corn Belt (in such states as Iowa, Indiana, and Ohio). This is not to suggest that particular sustainable practices and systems cannot be profitable even in the Corn Belt. Low-input/sustainable systems may become more economically competitive in years to come across the entire North Central Region as federal farm programs evolve and as energy prices rise.

## Materials and Methods

Two studies were begun in 1985 at the Northeast Station. Study I emphasized row crops in three rotational systems: **alternate** (no commercial fertilizer or pesticides and no moldboard plow), oats/alfalfa-alfalfa-soybeans-corn; **conventional**, corn-soybeans-spring wheat; and **ridge-till**, corn-soybeans-spring wheat. The alternative rotation was patterned after that used by alternate-system farmers in the Madison, S.D., area (crop/livestock operations). Livestock were assumed to be part of the operation in the alternative system in Study I, and the oats/alfalfa plots received a fall application of feedlot manure.

Study II emphasized small grains and included three systems: **alternate**, oats/clover-clover (green manure)-soybeans-spring wheat; **conventional**, soybeans-spring wheat-barley; and **minimum-till**, soybeans-spring wheat-barley. All of the systems in Study II were assumed to be cash grain operations. Study II was included because small grains have traditionally been an important component of the crop mix in northeastern South Dakota, although row crops have become more prominent in recent years. Also, because moisture often limits crop production in South Dakota, the systems in Study II were designed to require less water than the systems in Study I that included more full-season row crops and alfalfa hay among the rotations.

Overall, crops harvested in these studies were representative of the dominant crops produced in northeastern South Dakota and in much of the Northern Plains.

The conventional and reduced-till systems received recommended rates of fertilizer and herbicides. Fertilizer applications were based on soil tests, and scouting helped determine appropriate herbicide treatments. The moldboard plow was used in the conventional systems following small grain harvest. Plots were approximately 3000 ft² in Study I and 2000 ft² in Study II. Yield and other data

## Table 1. Typical crop production practices in Study I (1986-1992).

| *System/Crop* | *Cultural Practices* |
|---|---|
| **Alternate** | |
| Corn: | Spring tooth harrow, field cultivate with harrow, plant, rotary hoe twice, cultivate twice, fall chisel plow (with sweeps). |
| Soybeans: | Spring tooth harrow, field cultivate with harrow, plant, rotary hoe twice, cultivate twice. |
| Oats/alfalfa: | Disk with harrow, packer behind drill, apply manure in fall (2.5 Ton/A dry wt) |
| Alfalfa: | Three cuttings, fall chisel plow and field cultivate. |
| **Conventional** | |
| Corn: | Field cultivate with harrow, plant, apply 64 lb N, 4 lb $P_2O_5$, band Lasso II at 7 lb, cultivate twice, fall disk. |
| Soybeans: | Apply Treflan 1.5-2 pt, disk twice and harrow, plant, cultivate twice. |
| Spring Wheat: | Field cultivate with harrow, drill, apply 72 lb N, 7 lb $P_2O_5$, spray Hoelon 2 pt plus Buctril 1 pt, or MCPA 1 pt, fall moldboard plow. |
| **Ridge-till** | |
| Corn: | Ridge plant, apply 70 lb N, 4 lb $P_2O_5$, band Lasso II at 7 lb, ridge cultivate twice, postemerge spray with Banvel 0.5 pt or Buctril 1 pt, shred stalks. |
| Soybeans: | Gramoxone 1.5 pt (1 yr), ridge plant, band Lasso II at 7 lb, cultivate twice, postemerge spray with Blazer 1.5 pt, or Poast 1-1.5 pt, or Pursuit 4 oz and Pinnacle 0.25 oz, or Cobra 15 oz. |
| Spring Wheat: | Field cultivate, hoe drill, apply 83 lb N, 7 lbs $P_2O_5$, spray with Hoelon 2 pt plus Buctril 1 pt or MCPA 1 pt, fall spray Roundup 1 qt (2 yr), fall chisel plow (w/sweeps). |

Average Seeding Rates: corn 18,900 seeds/A, soybean 1.1 bu/A, spring wheat 71 lbs/A, oats 57 lb/A, alfalfa 9.5 lb/A.

Herbicides applied over the 7-year period varied from year to year, particularly in the reduced-till systems, and products listed include all of the materials applied from 1986-1992. Rates listed are actual/A.

Fertilizer rates also varied from year to year, and rates listed (lb/A) are the average for the 7-year period. Phosphorus and banded herbicides were applied at planting. Phosphorous fertilizer was applied only in 1988 and 1989. Nitrogen fertilizer was applied each year 2 to 3 weeks postplant. Most South Dakota soils are naturally high in plant-available potassium, and no potassium fertilizer was applied.

All row crops were planted in 36-inch rows. The spring tooth harrow was used early preplant in the Alt corn and soybeans to stimulate early weed seed germination prior to the final preplant tillage operation.

**Table 2. Typical crop production practices in Study II (1986-1992).**

| *System/Crop* | *Cultural Practices* |
|---|---|
| **Alternate** | |
| Oats/Clover: | Field cultivate with harrow, packer behind drill. |
| Clover: | Mow, chisel plow (with sweeps), field cultivate. |
| Soybeans: | Spring tooth harrow, field cultivate with harrow, plant, rotary hoe twice, cultivate twice. |
| Spring Wheat: | Field cultivate with harrow, drill, rotary hoe once, fall chisel plow (with sweeps). |
| **Conventional** | |
| Soybeans: | Apply Treflan 1.5-2 pt, disk twice and harrow, plant, cultivate twice. |
| Spring Wheat: | Field cultivate with harrow, drill, apply 62 lb N, 7 lb $P_2O_5$, spray with Hoelon 1 pt plus Buctril 1 pt, or MCPA 1 pt or Buctril 1 pt, fall moldboard plow. |
| Barley: | Field cultivate with harrow, drill, apply 21 lb N, 7 lb $P_2O_5$, spray with MCPA 1 pt, Buctril 1 pt, or Hoelon 1 pt, fall moldboard plow. |
| **Minimum-Till** | |
| Soybeans: | Plant, preemerge spray with Lasso 3 qt or band Lasso II 7 lb, post emerge spray with Poast 1.5 pt, or Blazer 1.5 pt, or Pursuit 4 oz and Pinnacle 0.25 oz, or Cobra 15 oz, fall spray with Roundup 1 qt (1 yr). |
| Spring Wheat: | Spring tooth harrow, apply 82 lb N, 7 lb $P_2O_5$, hoe drill, spray with Hoelon 2 pt plus Buctril 1 pt or MCPA 1 pt, fall spray with Roundup 1 qt (2 yr), fall chisel plow (with sweeps). |
| Barley: | Field cultivate, hoe drill, apply 52 lb N, 7 lb $P_2O_5$, spray with Hoelon 2 pt plus MCPA 1 pt, or Bronate 1 pt, or MCPA 1 pt, fall apply Roundup 1 qt (1 yr), fall chisel plow (with sweeps). |

Average seeding rates: Soybeans 1.1 bu/A, spring wheat 71 lb/A, barley 58 lb/A, oats 57 lb/A, sweet clover 5 lb/A, red clover 4 lb/A.
Herbicides varied from year to year, and products listed include all of those used from 1986-1992. Rates listed are actual/A.
Fertilizer rates are the average for the 7-year period, and rates listed are lb/A.

**Table 3. Crop hybrids[a] and cultivars used in farming systems studies, 1986-1992.**

| | ***Study I*** |
|---|---|
| **Crop** | |
| Oats | cv Moore, 1986-1987 |
| | cv Don, 1988-1992 |
| Alfalfa | cv Vernal |
| Corn-Alt | 3953, 1986-1987 |
| | 3790, 1988-1992 |
| Corn-Conv | 3906, 1986-1987 |
| & R-T | 3790, 1988-1992 |
| Soybeans | cv Simpson |
| Spring wheat[b] | cv Guard, 1986-1987 |
| | cv Butte 86, 1988-1992 |
| | ***Study II*** |
| **Crop** | |
| Oats | cv Moore, 1986-1987 |
| | cv Don, 1988-1992 |
| Red clover | cv Arlington |
| Yellow blossom sweetclover | cv Madrid |
| Soybean | cv Simpson |
| Spring wheat[b] | cv Guard, 1986-1987 |
| | cv Butte 86, 1988-1992 |
| Barley | cv Robust |

[a]Pioneer brand corn hybrids were used in all years.
[b]The Hessian fly resistant semi-dwarf variety 'Guard' was planted in the initial years of the studies because of Hessian fly infestations in the study area in the early 1980s. However, the infestations did not recur, and the standard height variety 'Butte 86' was planted in all subsequent years.

were obtained from the center area of each plot to minimize border effects. Treatments were replicated four times and arranged in randomized complete block designs. Field-scale equipment was used in planting, tillage, and harvest operations. Small grain yields were determined by harvesting an 8-ft wide swath from the center area of each plot. Soybean yields were based on four rows harvested from the center area of each plot and corn yields on two rows. Forage yields were measured by mechanically harvesting a 3 x 30-ft swath or, on occasions when a mechanical harvester was not available, by hand clipping a 3 x 3-ft area. Soil type in the study areas was predominately Brookings silty clay loam, 0-2% slope (fine-silty, mixed Pachic Udic Haploboroll).

The alternative (organic) systems in these studies included many of the components in the USDA (1980) definition of organic farming: "Organic farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds and other pests."

The alternative systems in these studies did not use a moldboard plow, thereby incorporating some aspects of reduced-till systems.

The "typical" crop production practices used in the various systems are listed in Tables 1 and 2, and crop cultivars and hybrids are listed in Table 3. More detailed lists of practices have been reported (Smolik and Dobbs 1991, Smolik *et al* 1991, 1992, 1993). Additional methods specific to a particular objective are included in the respective sections. The following abbreviations for the various systems are used in subsequent sections of this report: Alt (alternate), Conv (conventional), R-T (ridge-till) and M-T (minimum-till).

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# Section A
# **Crop Performance, 1986-1992**

**J.D. Smolik**

### Yields

Because these studies compared different farming systems, crop yields were influenced by a number of interacting factors that differed between systems, such as tillage, source and rate of nutrients applied, herbicides, and preceding crop or crops in the rotation. These factors were considered as part of the whole farming system.

Most experiment station research is conducted under tightly controlled conditions in which the researcher attempts to hold all factors constant except for one or two of interest. Such research is useful for determining the effect of a factor under a unique set of conditions, but it is not always useful or appropriate for determining the effect in a farming system.

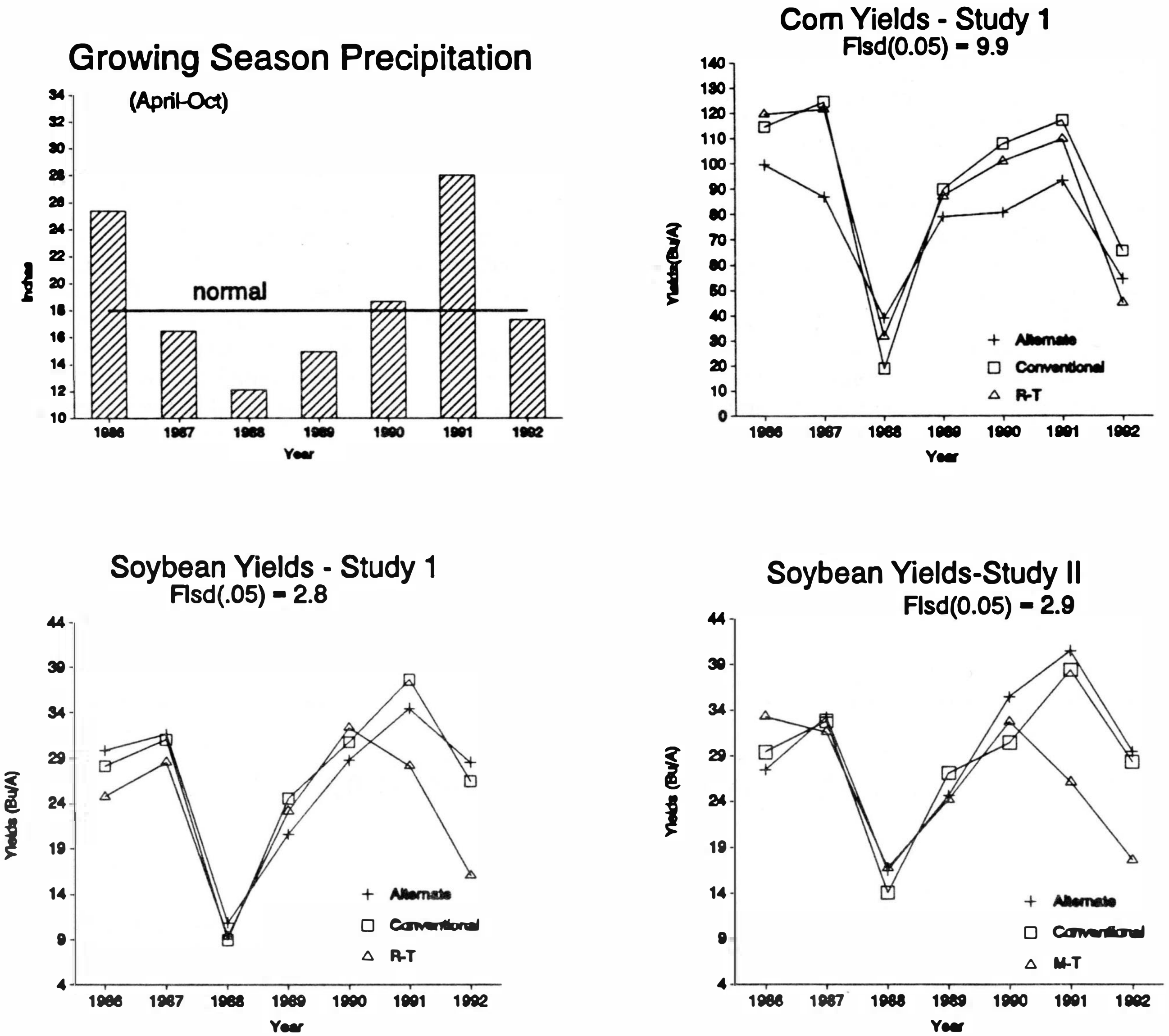
The major influences on crop yields in South Dakota (growing season precipitation, temperature, growing season length, topography, and soil type) were similar for all systems.

Growing season precipitation was above the long-term average in 3 years and below in 4 years (Fig 1), and 1991 was the wettest year in the 37-year history of the Northeast Station. Over the 7-year period of the studies, the average growing season precipitation (18.99 inches) was 1 inch above the long-term average.

Yield data for the establishment year (1985) are not included in this report because of probable carry-over effects associated with previous management and because of the absence of rotation and tillage effects.

Corn yields were substantially influenced by growing season precipitation (Fig 1). In most years corn yields were significantly higher in the Conv and R-T systems than in the Alt. Exceptions occurred in the 1988 drought year and in the cool growing season of 1992. Temperatures in June, July, and August of 1992 were the second coolest on record in South Dakota, and corn yields were low in all systems, with lowest yields

**Figure 1. Growing season precipitation and row crop yields, 1986-1992.**




in the R-T. The cooler soil temperatures associated with reduced-till systems (Rickerl and Smolik 1990) probably contributed to low R-T corn yields in 1992.*

Corn yields were lower in the Alt system in the early years of this study, probably due to lower nitrogen (N) levels, since the principal source of N in this system was alfalfa and its effects would not yet have been expressed.

The lower Alt corn yields in later years, we suspected, were a result of both low N levels and higher grassy weed (foxtail) populations. Because 1992 was the final year of the study, we tested these factors by applying N and Lasso II alone or in combination in the Alt corn. These treatments did not significantly increase yield, although there was a trend toward increased yield in the Lasso II treatment (Smolik *et al* 1993). It is possible the poor corn yields in 1992 masked treatment effects. Other factors that may have contributed to reduced Alt

* Fishers protected least significant difference (Flsd) at the 0.05 level of probability was used to compare yields. The Flsd is a statistic that allows comparisons of treatment means at a given level of probability. For instance, the Flsd (.05) for corn yields was 9.9 (Fig 1). This indicates

ment (farming system) means that differed by 9.9 bushels or more were due to farming system and not to chance.

corn yields in later years, particularly in comparison to Conv, are discussed in Section C.

Soybean yields, in most of the earlier years of the studies, were not significantly different between systems (Fig 1), and growing season precipitation had a major influence on yields.

However, in each of the last 2 years, soybean yields were significantly lower in the reduced-till systems (R-T and M-T). Soybeans in the reduced-till systems were also noticeably stunted in each of the last 3 years of the studies. Height reductions ranged from 13-40%, with the highest reductions occurring in 1992. Weed populations, including perennials such as quackgrass and Canada thistle, increased in the reduced-till systems in the later years of these studies (Section C). The increased weed problems in combination with herbicides applied for their control plus the higher dagger nematode populations (Section C) may have contributed to the lower soybean yields.

Spring wheat yields in the Conv system in Study I were significantly higher than R-T (Fig 2). Levels of common root rot were consistently higher in the R-T system, which may account in part for the lower yields.

The spring wheat in the R-T system complicated tillage operations in this system, and was included because small grains are an important component of the crop mix in northeastern South Dakota. However, in some years spring wheat was of substantial benefit to the system; for instance, in 1992 the R-T spring wheat yields were higher than R-T corn yields (51 bu/A for spring wheat vs. 45 bu/A for corn, see also Figs 1 and 2).

Spring wheat yields in Study II were not different between systems in most years except 1991 and 1992 when yields were significantly higher in the Alt system compared to Conv and M-T (Fig 2). Lower spring wheat yields in both studies in 1991 were a result of high infection levels of Fusarium head scab experienced in the warm, moist 1991 growing season.

We began using spring wheat cv Butte 86 in 1988 and from 1988-1992 saw significant reductions in wheat height in the Conv and M-T systems compared to Alt. Height reductions ranged from 8-13% and may have been the result of herbicides. Spring wheat cv Guard was used in the initial years of the study (Table 3), and no height reductions were observed.

The higher spring wheat yields in the Alt system compared to Conv and M-T and the higher soybean yields compared to R-T and M-T that were recorded in the later years of these studies are interesting. These results tend to corroborate the opinions of farmers who have adopted alternate systems and who believe crop yields are equal to or greater than more conventional systems (Miller 1992). Stanhill (1990) also noted higher yields in organic systems for some products.

Barley yields in the Conv system were higher than M-T in all years except the drought year of 1988 (Fig 2). Growing season precipitation was a major factor influencing both barley and spring wheat yields except for the 1991 scab epidemic.

Oat yields generally did not follow precipitation trends (Fig 1 and 3); yields were low in most years. The position of oats in the Alt system rotations was probably the dominant factor influencing yields. Oats followed corn in Study I and spring wheat in Study II, and both of these crops have high nitrogen requirements. The low soil N levels following these crops (Section C) were apparently the principal reason for generally low oat yields.

Alfalfa yields followed precipitation trends (Figs 1 and 3); good stands of alfalfa were obtained in all years of the study. We suspect the consistently good alfalfa stands were obtained in part because we used a packer behind the drill and because of the absence of any herbicide carryover in the Alt system. Carry-over can interfere with stand establishment in more conventional systems. Also, oats were seeded at a low rate (Table 1); short-stature, early maturity varieties were used; and nitrogen levels were low (Section C). All of these conditions probably resulted in a less competitive oat nurse crop.

Alfalfa yields tend to decline with increasing stand age, due primarily to pest problems caused by weeds, diseases, insects, and nematodes. In the Alt system, alfalfa was normally harvested only the year after seeding, and the young, vigorous stands probably contributed to the overall good yields. The young stands avoided the pest problems associated with long-term stands and were also more easily incorporated without a moldboard plow. In the wet 1991 season, one cutting of alfalfa also was obtained following oat harvest.

Clover (green manure) yields also followed precipitation trends except for 1986 (Fig 3). We saw substantial clover weevil damage on sweetclover in 1986. Beginning in 1987 we seeded a 50:50 mixture of yellow sweetclover and red clover. The mixture did not eliminate weevil damage, but we did achieve good clover stands.

Growth of red clover in the seeding year was visually greater

**Figure 2. Spring wheat and barley yields, 1986-1992.**

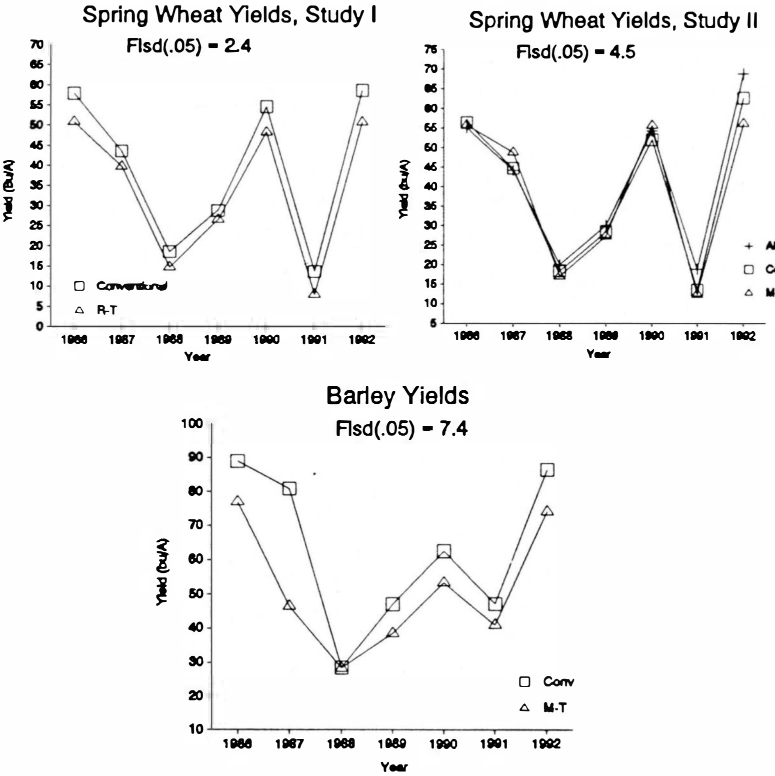
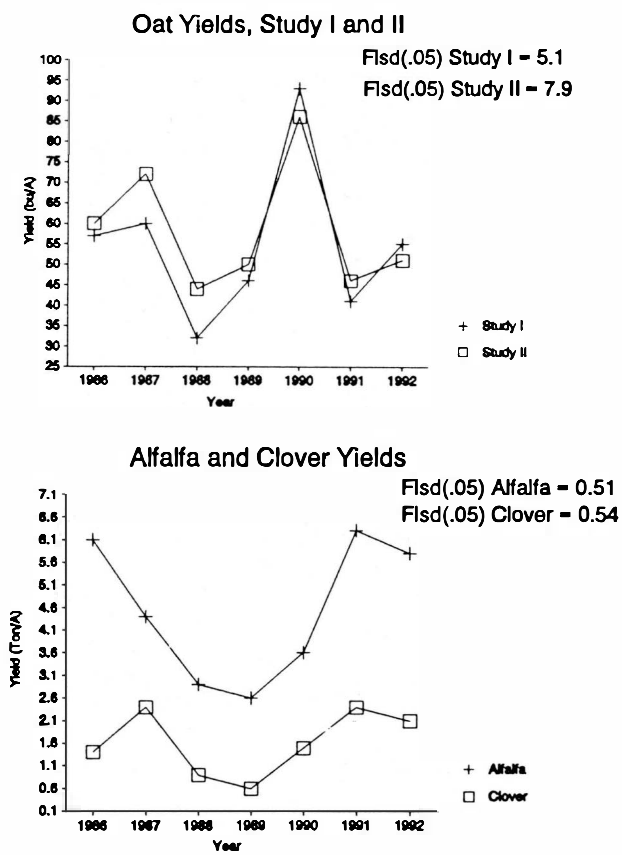



**Figure 3. Oat, alfalfa, and clover (green manure) yields, 1986-1992.**




than growth of sweetclover; however, red clover did not consistently overwinter, and clover yields in 1988, 1989, and 1990 were primarily sweetclover. Red clover survived the winter very well in each of the last 2 years, and clover yields in 1991 and 1992 were approximately 50% red clover.

## Elemental Analyses and Protein

In the later years of the studies, the effects of farming systems on elemental composition of grains and oilseeds were compared. The percentage of nitrogen (N), phosphorus (P), and potassium (K) in grains and oilseeds was not significantly different between similar crops within a system in most instances, although percentage N was significantly lower in Alt spring wheat (Table 4).

Protein was also significantly lower in Alt spring wheat compared to Conv and M-T and, averaged over the period 1987-1992, protein was 15.6% in Alt, 16.2% in Conv, and 16.4% in M-T. In the last 4 years of the study, we determined 1,000 kernel weights for the spring wheat, and in each of the 4 years the weights were numerically higher in the Alt system and significantly higher in 1992.

The differences in kernel weights may account in part for the lower percentage protein in the Alt spring wheat because of the different ratio between endosperm and embryo. Most of the protein in spring wheat is located in the embryo, and the greater proportion of endosperm in the more plump Alt system wheat would have reduced the relative percentage of protein.

**Table 4. Elemental analyses of grains and oilseeds, Study I and II.[a]**

| System | Crop | %N | %P | %K |
|---|---|---|---|---|
| Conv. | Barley | 2.06 | 0.339 | 0.54 |
| M-T | Barley | 2.04 | 0.342 | 0.53 |
| Alt. | Sp. Wheat | 2.54 | 0.371 | 0.48 |
| Conv. | Sp Wheat | 2.79* | 0.367 | 0.48 |
| M-T | Sp Wheat | 2.80* | 0.364 | 0.48 |
| Conv. | Sp. Wheat | 2.71 | 0.377 | 0.48 |
| R-T | Sp. Wheat | 2.73 | 0.362 | 0.49 |
| Alt-I | Oats | 1.86 | 0.392 | 0.46 |
| Alt-II | Oats | 1.82 | 0.387 | 0.45 |
| Alt. | Corn | 1.45 | 0.276 | 0.48 |
| Conv. | Corn | 1.50 | 0.285 | 0.50 |
| R-T | Corn | 1.55 | 0.273 | 0.49 |
| Alt. | Soybean | 6.38 | 0.559 | 1.75 |
| Conv. (I) | Soybean | 6.15 | 0.562 | 1.80 |
| R-T | Soybean | 6.27 | 0.524 | 1.78 |
| Alt. | Soybean | 6.39 | 0.546 | 1.75 |
| Conv. (II) | Soybean | 6.20 | 0.532 | 1.84 |
| M-T | Soybean | 6.35 | 0.532 | 1.78 |

[a]Small grain data are average of 1990, 1991, and 1992; corn and soybean data are average of 1991 and 1992. Data provided by the SDSU Soil Testing and Plant Analysis Laboratory.
* = Significant increase compared to Alt ($Flsd_{.05}$ = 0.22).

Percentage N and protein in the Alt soybeans tended to be higher than the Conv and reduced-till in both studies in each of the last 2 years of the studies. In 1992 both 1,000 seed weight and percentage protein were highest in Alt soybeans (Smolik *et al* 1993).

## Summary

Corn yields in all systems were substantially influenced by growing season precipitation. Corn yields in the Conv and R-T systems were generally higher than Alt, except for the 1988 drought year and the cool 1992 season.

Soybean yields in the earlier years of the studies were generally not different between systems, and precipitation had a major influence on yields. In the last 2 years, soybean yields in the reduced-till systems (R-T and M-T) were significantly lower than the other systems.

Spring wheat yields in both studies were closely related to growing season precipitation, except for the very wet 1991 season, when a scab epidemic severely reduced yields in all systems. In Study I, spring wheat yields in the Conv system were consistently higher than R-T. In Study II, spring wheat yields in the Alt system were significantly higher than Conv and M-T in the last 2 years of the study.

Barley yields in Study II were higher in the Conv system in most years. Oat yields generally did not follow precipitation trends, and yields appeared to be primarily influenced by the position of oats in the Alt system rotations. Yields of alfalfa in Study I and clover (green manure) in Study II generally followed precipitation trends, and ranged from moderate to excellent over the study period.

Farming system generally did not have a significant influence on elemental composition of grains and oilseeds.

# Section B
# Whole-Farm Productivity of Systems, 1986-1992

**J.D. Smolik**

One of the objectives in using larger-than-normal-size plots in these studies was to obtain more realistic yield data. Based on conversations with neighboring farmers over the course of this study, we found that crop yields in these studies were generally very comparable to yields on farms with soil types similar to those at the Northeast Station.

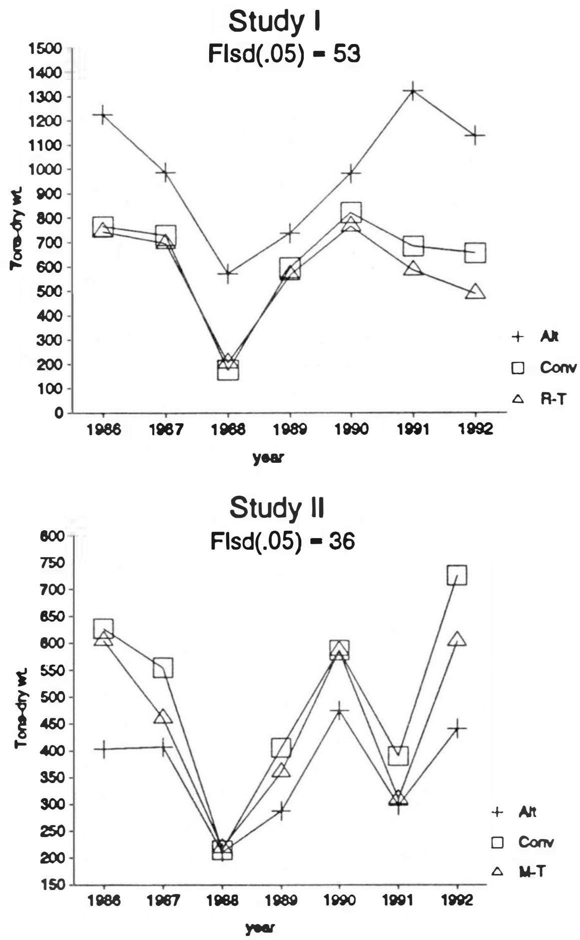
The similarity in average growing season precipitation over the 7-year period to the long-term average (Fig 1) also adds to the credibility of the study results. Comparing crop yields in these studies to county-wide averages is another method of assessing the applicability of the results. Yields of corn, soybeans, spring wheat, and barley in these studies over a 5-year period (1986-1990), compared to Codington County averages over the same period (South Dakota Agricultural Statistics Service), ranged from nearly equal for soybeans to 30% higher for spring wheat. Somewhat higher yields might have been expected in our studies because soils at the station are deep, well-drained, and gently sloping.

## Crop Mass

Results presented in Figs 1, 2, and 3 are expressed on a per-acre basis. These types of yield comparisons are only one method of comparing productivity and are of limited use when different crops and lengths of rotations are involved in comparisons. Economic returns are often used for comparing productivity in different systems (Section D).

Another measure of productivity is the crop mass (dry weight of grain, oilseeds, and alfalfa forage) produced and removed from the various systems. Fig 4 compares crop mass removed on a yearly basis over the past 7 years. These whole-farm estimates are based on 540 tillable acres with set-aside met each year. Set-aside requirements were included because the federal farm program in existence over the course of the studies had a major influence on the types of crops farmers planted, the number of acres planted, and the economic returns.

**Figure 4. Crop mass (total dry weight of plant material) removed from systems on a whole-farm basis (540A), 1986-1992.**




The Alt system in Study I, in terms of crop mass removed, consistently out-produced Conv and R-T systems. A major reason productivity was higher in the Alt system was the inclusion of a forage-legume (alfalfa) in the rotation.

The greatest differences in production between the Alt system and the Conv and R-T systems occurred in years with abnormal precipitation: 1986 and 1991 were well above normal in precipitation and 1988 was well below.

The productivity of the Alt system was closely related to growing season precipitation (see Fig 1), while productivity in the Conv and R-T deviated substantially in 1991. Low wheat yields due to the 1991 scab epidemic were primarily responsible for the deviation.

An area of concern in regard to maintenance of long-term production is the decline in productivity of the R-T system compared to the Conv, particularly in the last 3 years (Fig 4).

In Study II, productivity of the Alt system generally was less than Conv and M-T (Fig 4), although in the 1988 drought year productivity was nearly equal in all systems. Productivity in all the systems was related to growing season precipitation except for 1991.

Small grains are a major part of the crop mix in the systems in Study II, and Fusarium head scab greatly reduced the productivity of all systems in 1991.

The productivity of the M-T system generally was less than the Conv system, especially in the last 2 years of the study. Possible reasons for decline in productivity in the R-T and M-T systems are discussed under crop yields and in Section C.

Regression analyses were used to relate production to growing season precipitation. The only system in which the relationship was nearly linear (a straight line) was in the Alt system in Study I, and the $r^2$ was 0.79. The $r^2$ is a statistical measure of the amount of variation in crop mass that was related to precipitation. For instance, an $r^2$ of 1.0 would indicate that all of the variation in crop mass was directly related to growing season precipitation. The $r^2$'s in the other systems were all less than 0.33. The best relationships were obtained with quadratic equations (curved lines), and $r^2$ in the various systems were: Study I; Alt 0.88, Conv 0.92, R-T 0.78, Study II; Alt 0.89, Conv 0.85, M-T 0.82. The curved line relationship indicates production tended to decline in the wettest years, due to such factors as the scab epidemic. Also, the quadratic relationships indicate growing season precipitation alone was inadequate to predict production, and that other factors, such as plant diseases, previous year's precipitation, and temperature must also be considered.

## Average Yearly Productivity

The average yearly crop production, herbicides applied, crop mass removed, total digestible nutrients (TDN) produced, and average number of acres planted to a particular crop on a whole-farm basis are listed in Tables 5 and 6. In Study I, the average yearly corn production in the Alt system was 32 and 34% less than R-T and Conv, respectively, and soybean production was 10 and 23% less.

The major reason corn production was lower in the Alt system was because, on a whole-farm basis, 22% fewer acres were planted to corn in an average year (Table 5). The difference in soybean production between the Alt and Conv was due almost entirely to the fewer acres planted to soybeans in the Alt system. The higher per-acre soybean yields in the Alt system compared to R-T offset most of the acreage reduction effect, and soybean production was only 10% less.

Although corn and soybean production was lower, the crop mass removed from the Alt system was 57% and 72% higher than Conv and R-T, respectively. The higher production in the Alt system was primarily due to the forage legume (alfalfa) in the Alt system. The R-T system required higher inputs of both fertilizer and herbicides (Table 5 and Section C), and these higher inputs coupled with sometimes lower crop production influenced economic returns (Section D).

**Table 5. Average whole-farm production of systems in Study I and herbicide applied, 1986-1992 (540 tillable acres, set-aside met each year*).**

| | | System | |
|---|---|---|---|
| Crop | Alternate | Conventional | Ridge-Till |
| Corn (bu) | 9,678 | 14,772 | 14,150 |
| Soybean (bu) | 3,381 | 4,373 | 3,756 |
| Spring Wheat (bu) | | 6,443 | 5,563 |
| Oats (bu) | 7,003 | | |
| Alfalfa (tons) | 579 | | |
| Crop Mass Removed (dry wt.-tons)[a] | 994 | 632 | 578 |
| TDN (tons)[b] | 684 | 558 | 511 |
| Herbicide (lbs a.i.) | 0 | 459 | 595 |
| Avg. A/crop[c] = | 127 | 162 | 162 |

* Over the 7-yr period set-aside averaged 10% per year in Conv and R-T, and 6% in Alt.

[a] Conversions to dry weight based on No. 2 corn at 56 lb/bu and 15.5% moisture, soybean and spring wheat at 60 lb/bu and 13% moisture, and oats at 32 lb/bu and 13% moisture.

[b] Total digestible nutrients produced assuming all grain, oilseeds, and alfalfa forage were fed to ruminant livestock. Digestibilities: corn = 90%, soybean = 82%, spring wheat and oats = 89%, alfalfa = 55% (J. Wagner, ruminant livestock specialist, SDSU, pers comm).

[c] Average number of acres planted to each crop in the system.

**Table 6. Average whole-farm production of systems in Study II, and herbicide applied, 1986-1992 (540 tillable acres, set-aside met each year*).**

| | System | | |
|---|---|---|---|
| **Crop** | **Alternate** | **Conventional** | **Minimum-Till** |
| Soybean (bu) | 3,994 | 4,633 | 4,222 |
| Spring Wheat (bu) | 5,606 | 6,403 | 6,332 |
| Barley (bu) | - - | 10,202 | 8,333 |
| Oats (bu) | 7,900 | | |
| Crop Mass Removed (dry wt.-tons)[a] | 361 | 501 | 449 |
| TDN (tons)[b] | 314 | 429 | 385 |
| Herbicides (lbs a.i.) | 0 | 346 | 668 |
| Avg. A/crop[c] = | 135 | 162 | 162 |

*Set-aside averaged 10% per year in Conv and M-T systems. The unharvested clover (green manure) in the Alt system comprised 25% of the acres, and consistently exceeded set-aside requirements.
[a] Conversions to dry weight based on soybean and spring wheat at 60 lb/bu, oats at 32 lb/bu, and barley at 48 lb/bu (all crops at 13% moisture).
[b] Total digestible nutrients produced assuming all crops were fed to ruminant livestock. Digestibilities: soybean = 82%, spring wheat and oats = 89%, and barley = 85%.
[c] Average number of acres planted to each crop in the system.

**Table 7. Variability in whole-farm productivity of systems, 1986-1992.**

| | System | Average Productivity | Deviation from 7 yr Avg. | CV |
|---|---|---|---|---|
| **Study I** | | | | |
| | Alternate | 994[a] | +33%[b] -43% | 27%[c] |
| | Conventional | 632 | +30% -72% | 34% |
| | Ridge-Till | 578 | +32% -64% | 33% |
| **Study II** | | | | |
| | Alternate | 361 | +32% -41% | 27% |
| | Conventional | 501 | +45% -57% | 35% |
| | Minimum-Till | 449 | +35% -51% | 35% |

[a] Average crop mass (tons-dry wt) removed from systems on a whole-farm basis, 1986-1992.
[b] Variability is based on departure from the average productivity. For instance, in the Alt system in Study I the highest production occurred in 1991, and 1,321 tons were removed from the system on a whole-farm basis. This was 33% above the 7-year average in this system.
[c] Coefficient of variation.

The total digestible nutrients (TDN) produced are also noted in Table 5. It is, of course, highly unlikely that all of the crops produced in the various systems would be fed to ruminant livestock, but TDN is another useful measure of productivity of systems with different crops and rotations.

The TDN in the Alt system was 23 and 34% higher than Conv and R-T, respectively. The lower TDN compared to crop mass removed, particularly in the Alt system, was primarily a result of the lower digestibility of alfalfa forage compared to grains and oilseeds. Another assessment of the livestock feed potential is presented in Table 8.

In Study II, whole-farm soybean production in the Alt system was 5 and 14% less than M-T and Conv, respectively, and spring wheat production was 11 and 12% less (Table 6). The higher per-acre yields of both soybeans and spring wheat in the Alt system were not sufficient to offset the 17% fewer acres planted to those crops in the Alt system in an average year (Table 6).

The crop mass removed from the Alt system in Study II was 20 and 28% less than M-T and Conv. The lower production in the Alt system was primarily a result of fewer acres planted and also the low oat yields in the Alt system relative to barley yields in Conv and M-T.

Relative to inputs of fertilizer and herbicides (Table 6 and Section C), production in the Alt system was remarkably high. Clover (green manure) was a very good substitute for the more traditional inputs (fertilizers and herbicides) in the other systems. The M-T system required higher inputs of fertilizer and herbicides (Table 6 and Section C), and these higher inputs reduced economic returns in this system (Section D). The TDN production in the Alt system was 19 and 27% lower than M-T and Conv, respectively.

## Variability in Production

Stability in crop production is an important element in the long-term sustainability of a farming system and also provides a measure of response to climatic and biotic stress. One measure of the stability of a system is the range in productivity, as measured by the deviation from the average for each system.

In Study I, the year-to-year range in productivity in terms of crop mass removed from the Alt system was +33 to -43% (Table 7). In the Conv system the range was +30 to -72%. The R-T range was +32 to -64%. Thus, productivity was most stable in the Alt system and most variable in the Conv system. In Study II, the range in productivity was again less in the Alt system, compared to Conv and M-T (Table 7) and was most variable in the Conv.

The coefficient of variation (CV), another measure of variation, was also lower in the Alt systems in both studies (Table 7). These results differ from those of Stanhill (1990) who found no evidence that production in organic (alternative) systems was less variable than conventional systems.

The wettest year in the 37-year history of the Northeast Station was 1991, which indicates we may have approached production potential in the systems. The greatest reduction in productivity of all systems occurred in the 1988 drought (Fig 4); the percentage reductions in productivity were less in the Alt systems than in the Conv and reduced-till (Table 7). Improved relative performance of Alt systems under drought stress has been reported in other studies (Sahs and Lesoing 1985).

## Livestock Feed Potential

Another long-term objective of these studies was to investigate the possible effects if alternative systems became more widely adopted. One of the questions concerning legume-based systems is how the increased amount of alfalfa produced would be utilized.

Currently, the principal use of alfalfa is for livestock feed, primarily ruminant livestock. Also, 70 to 80% of the corn produced in the U.S. is reportedly fed to livestock. Assuming the corn, alfalfa, and soybean meal produced by the systems in Study I (Table 5) were fed to ruminant livestock, the total digestible nutrients (TDN) produced in the Alt system are 47 and 57% higher than in the Conv and R-T, respectively (Table 8). The alfalfa TDN was equivalent to approximately 15,000 bu of corn, which would more than make up for the reduced amount of corn produced in the Alt system (Table 5). Protein production in the Alt system was 2-2.25 times as much as that in the Conv and R-T systems, respectively (Table 8).

Ruminants are not the only livestock that can utilize alfalfa. Studies in Iowa indicate alfalfa could comprise 25% of the diet for market swine and up to 96% of the diet for gestating sows (Honeyman 1991).

Overall, it appears that Alt systems would provide adequate amounts of livestock feed. However, wide-scale adoption of these types of systems would likely have a major influence on how livestock are produced. Alfalfa is a bulky commodity and is expensive to transport compared to corn; thus, it would be most efficient to feed it near where it is produced. This would mean an increase in on-farm produced livestock, as opposed to current large-scale confinement feeding operations. Increased numbers of livestock on farms would also facilitate the return of nutrients to the land through manure additions.

## Return to Economic Expenditures

Another important measure of the productivity of systems is the return to monetary and labor investments.

In Study I, crop mass removed from the Alt system per dollar invested in all production costs was 78 and 100% greater than Conv and R-T, respectively (Table

**Table 8. Total digestible nutrients (TDN) and protein produced by systems in Study I assuming all corn, alfalfa, and soybean meal were fed to ruminant livestock.**

| | System | | |
|---|---|---|---|
| | Alternate | Conventional | Ridge-till |
| TDN (tons)[a] | 594 | 405 | 379 |
| Protein (tons)[b] | 152 | 75 | 68 |

[a] Average yearly production based on 540 tillable acres, set-aside met. Assumes corn 90% TDN, alfalfa 55% TDN, and soy meal 80% TDN.
[b] Amount of protein produced. Assumes corn 10% protein, soy meal 44% protein, and alfalfa 17% protein.

9). The TDN production per dollar invested in the Alt system was 38% and 57% greater than Conv and R-T, respectively. In Study II, the range in productivity per dollar invested was comparatively narrow (Table 9), and both crop mass removed and TDN were highest in the Conv system and lowest in M-T.

Productivity per hour of labor required for all field activities is compared in Table 10. With respect to crop mass removed, the Alt system in Study I produced nearly one ton per hour of labor; it also was the most productive in terms of TDN. Although average production in the R-T system was less than Conv (Table 5), the productivity per hour of labor in the Conv system was slightly lower than in the less labor-intensive R-T system.

In Study II, the relationships among the systems were the reverse of that in Study I, and both crop mass removed and TDN per hour of labor were highest in the Conv system and lowest in the Alt (Table 10). A more complete discussion of economic relationships is included in Section D.

**Table 9. Productivity of systems relative to dollars invested for all production costs, including land and labor (1986-1992).**

| | System | | |
|---|---|---|---|
| | Alternate | Conventional | Ridge-Till |
| **Study I** | | | |
| Crop mass produced[a] (lbs/$) | 32 | 18 | 16 |
| TDN (lbs/$)[b] | 22 | 16 | 14 |
| | Alternate | Conventional | Minimum-Till |
| **Study II** | | | |
| Crop mass produced[a] (lbs/$) | 15 | 16 | 14 |
| TDN (lbs/$)[b] | 13 | 14 | 12 |

[a] Crop mass removed from systems each year (dry weight of all grain, oilseeds, and alfalfa forage) per dollar invested (Table 27).

[b] Total digestible nutrients produced each year per dollar invested, assuming all grain, oilseeds, and alfalfa forage were fed to ruminant livestock.

**Table 10. Productivity of systems relative to labor inputs (1986-1992).**

| System | | | |
|---|---|---|---|
| | Alternate | Conventional | Ridge-Till |
| **Study I** | | | |
| Crop mass[a] (lbs/hr) | 1,908 | 1,401 | 1,408 |
| TDN[b] (lbs/hr) | 1,312 | 1,237 | 1,245 |
| | Alternate | Conventional | Minimum-Till |
| **Study II** | | | |
| Crop mass[a] (lbs/hr) | 845 | 1,092 | 1,021 |
| TDN[b] (lbs/hr) | 735 | 935 | 876 |

[a] Crop mass removed from systems (total dry weight of grains, oilseeds, and alfalfa forage) per hour of labor. Labor information provided by T. Dobbs and L. Henning, Economics Dept, SDSU.

[b] Total digestible nutrients produced per hour of labor assuming all grain, oilseeds, and alfalfa forage were fed to ruminant livestock.

## Study I vs. Study II

Because Study I and II were separate experiments they can not be compared statistically. However, the study areas were separated by only a 50-ft alleyway and were located on similar soils, therefore some general observations may be appropriate.

The systems in Study I, in terms of crop mass removed from the systems, were more productive than the systems in Study II in most years (Fig 4). This might have been expected since, in the Conv and reduced-till systems, a full-season crop (corn) was included in Study I as opposed to a short-season crop (barley) in Study II.

However, there were some notable exceptions. In the 1988 drought year, production was higher in the Conv and M-T systems in Study II compared to Conv and R-T in Study I; and in the cool 1992 season, a favorable small grain year, production was again higher in Study II's Conv and M-T systems. The greatest disparity in production between the studies occurred in the wettest year, 1991. Results in these studies suggest the systems in Study II are best adapted to drier, cooler environments, whereas the systems in Study I would likely perform best in warmer, more moist environments.

## Energy Relationships

One of the principal concerns regarding the long-term sustainability of most current farming systems is their heavy reliance on fossil fuels, primarily oil and natural gas, both of which are nonrenewable resources. Major energy inputs in regional farming systems are fuel, machinery production and maintenance, fertilizer, pesticides, drying, transportation, and seed production (Goering and Daugherty 1982, Keeney and DeLuca 1992). Fuel, fertilizer, pesticides, and their transportation constituted approximately 70% of the energy used each year in the production of a variety of nonirrigated crops in the north-central region (Goering and Daugherty 1982).

The average yearly energy consumption on a whole-farm basis (540A) in Study I and II for fuel, nitrogen fertilizer, and pesticides (herbicides) is given in Table 11. All energy values are expressed as gallons of No. 2 diesel fuel and can be converted to British Thermal Units (BTU) by multiplying by 138,690 (Ikerd *et al* 1992).

Data in Table 11 is not meant to imply that diesel fuel is the principal energy source for all the inputs listed. For example, the major energy source in manufacture of nitrogen fertilizer is natural gas. Energy data are presented as diesel fuel equivalents for ease of comparison of the different systems where a variety of energy sources are involved.

In Study I, energy consumed for fuel, N fertilizer, and pesticides in the Alt system was 68 and 71% less than the Conv and R-T systems, respectively. The Alt system in Study II used 70-75% less energy than the Conv and M-T systems (Table 11). The most energy intensive systems in both studies were the reduced-till (R-T and M-T), and even though fuel use was reduced in these systems, the increase in fertilizer and pesticide (herbicide) use more than offset the fuel savings.

The above comparisons assume that the remaining 30% of the major energy inputs for machinery (11%), drying (5%), and seed (14%), (Goering and Daugherty 1982) would not differ substantially between systems. This seems a reasonable assumption since all of the systems produce both row and small grain crops.

The haying equipment required in the Alt system in Study I would add to the equipment needs, but such equipment would be used on fewer acres per crop each year. This should extend the useful life of the implements. Less tillage equipment would be used in the reduced-till systems, but the heavier planters, drills, and cultivators required in these systems would partially offset any energy gains.

The crop mass produced in each system on a whole-farm basis (540A) relative to energy consumed for fuel, N fertilizer, and pesticides is compared in Table 12. The Alt system in Study I was approximately five to six times more productive per unit of energy consumed than were the Conv and R-T systems. In Study II, the Alt system was approximately two to three times more productive per energy unit than Conv and M-T.

Relative to total digestible nutrients (TDN) produced, the Alt system in Study I was approximately four to five times more productive per unit of energy input (Table 13). In Study II, TDN production per unit of energy was similar to the crop mass relationship.

As world population increases, the demand for energy will also rise, and the probability of energy shortages will increase. In such an event, the productivity relationships in Tables 12 and 13 will acquire increased importance.

## Bio-Fuel Potential of Systems

One potential solution to energy shortages is conversion of agricultural products to fuel (Goering and Daugherty 1982, Keeney and DeLuca 1992). The liquid fuel production potential, after deducting energy consumed in the fuel production process for corn, soybeans, or spring wheat produced in the various systems on a whole-farm basis (Tables 5 and 6), is compared in Table 14. Again, for comparative purposes all data are expressed as No. 2 diesel fuel. The energy consumed in the production of ethanol is from a recent study (Marland and Turhollow 1991) and assumes a highly efficient facility.

After deducting **only** the energy required for oil extraction or ethanol production, the potential fuel production was highest in the Conv system in both studies (Table 14).

Converting a major proportion of the crops produced in a system to liquid fuel could result in food shortages. However, converting enough of the crops to fuel to counterbalance a major portion of the energy consumed in the various systems (Table 11) would enhance their energy-related sustainability. The Alt system in Study I used 2,657 DFE each year (Table 11), and each bushel of soybeans, after deducting energy for oil extraction, would produce 1.19 DFE (4025 DFE ÷ by 3,381

### Table 11. Average whole-farm (540A) energy inputs expressed as diesel fuel equivalents (DFE) in Farming Systems Studies, 1986-1992.[a]

| Study I | Alternate | System Conventional | Ridge-Till |
|---|---|---|---|
| Fuel[b] | 2,657 | 2,371 | 2,300 |
| Nitrogen fertilizer[c] | NA | 5,445 | 6,129 |
| Pesticides[d] | NA | 459 | 595 |
| Total | 2,657 | 8,275 | 9,024 |
| | **Alternate** | **Conventional** | **Minimum-Till** |
| **Study II** | | | |
| Fuel[b] | 1,868 | 2,506 | 2,084 |
| N Fertilizer[c] | NA | 3,288 | 4,639 |
| Pesticides[d] | NA | 346 | 668 |
| Total | 1,868 | 6,140 | 7,391 |

[a] All values expressed as gal No. 2 diesel fuel (1 gal=138,690 BTU).
[b] Fuel use in each system was based on crop production practice information in Tables 1 and 2 combined with crop enterprise budgets (Section D).
[c] 4 lb of N fertilizer = 1 gal No. 2 diesel fuel, includes transportation (Duffy 1991).
[d] 1 lb (a.i.) pesticides = 1 gal No. 2 diesel fuel, includes transportation (M. Duffy, Iowa State University, pers comm).
* NA = Not applicable. The energy required for additional weed control operations and for practices associated with the forage legumes is included in the fuel inputs.

### Table 12. Average whole-farm (540A) production of systems relative to energy inputs for fuel, N fertilizer, and pesticides (1986-1992).

| Study I | Alternate | System Conventional | Ridge-Till |
|---|---|---|---|
| Production (lbs/gal)[a] | 748 | 153 | 128 |
| | **Alternate** | **Conventional** | **Minimum-Till** |
| **Study II** | | | |
| Production (lbs/gal)[a] | 386 | 163 | 122 |

[a] Crop mass removed from systems (dry weight of grains, oilseeds, and alfalfa forage) per gal of No. 2 diesel fuel equivalent of energy consumed for fuel, N fertilizer, and pesticides each year (Table 11).

### Table 13. Average whole-farm total digestible nutrients (TDN) produced by each system relative to energy inputs for fuel, N fertilizer, and pesticides. (1986-1992)

| Study I | Alternate | System Conventional | Ridge-Till |
|---|---|---|---|
| TDN (lbs/gal)[a] | 515 | 135 | 113 |
| | **Alternate** | **Conventional** | **Minimum-Till** |
| **Study II** | | | |
| TDN (lbs/gal)[a] | 336 | 140 | 104 |

[a] TDN per gal of No. 2 diesel fuel equivalent of energy expended for fuel, N fertilizer, and pesticides each year (Table 11).

bu, Tables 5 and 14). Thus, 2,233 bushels of soybeans (2657 + by 1.19), or 66% of the average yearly amount of soybeans produced in the Alt system, would need to be converted to equal the energy consumed. Effects on productivity of the system would be minor, with only a 1% decrease in crop mass removed and a 2% reduction in TDN (Table 15).

In the Conv and R-T systems, considerably more energy was consumed (Table 11), and 100% of the soybeans would need to be converted plus 26% of the corn in the Conv system and 41% in the R-T system to equal energy consumed. Crop mass in the Conv system would be reduced 13% and TDN would be reduced 14%. The greatest impact on production would occur in the least energy efficient system (R-T), where crop mass would be reduced 19% and TDN would be reduced 21% (Table 15).

In Study II, conversions to liquid fuel to balance energy consumed (Table 11) would require only 39% of the soybeans produced in the Alt system, and effects on productivity would again be minor with a 2% reduction in both crop mass and TDN production (Table 16). In the Conv and M-T systems, 100% of the soybeans would be required plus 15% of the Conv spring wheat and 56% of the M-T spring wheat. The Conv production in terms of crop mass would be reduced 8% and TDN by 9%. In the M-T system, the crop mass would be reduced 17% and TDN 19%. Again, the greatest effects on production would occur in the reduced-till system.

The relationships in Tables 15 and 16 assume that livestock would be available to utilize the byproducts from liquid fuel production. Long-distance transport of the byproducts would substantially alter the energy relationships.

## Net Bio-Fuel Production

Information in Tables 15 and 16 indicates that all of the systems could meet a major proportion of their energy equivalency needs; however, the impact on production would be far less in the Alt systems. Another method of comparing the liquid fuel production potential in the various systems is the net or residual production per bushel after deducting the energy consumed for fuel, N fertilizer, and pesticides (Table 11), and for liquid fuel production.

The net ethanol production per bushel of corn in Study I was positive for all systems, but was two to three times higher in the Alt system (Table 17).

Net ethanol production per bushel of spring wheat in Study II was positive only for the Alt system. The net soybean oil fuel (DFE) production was positive only for the Alt systems in both studies (Table 18). Data in Tables 17 and 18 demonstrate that the **net** liquid fuel production potential per bushel of grain or oilseeds varies substantially between systems and is heavily dependent on how the crop is produced.

## Summary

The Alt systems were 4-year rotations and the Conv and reduced-till were 3-year rotations; therefore, on a whole-farm basis (540A), the production of an individual crop common to all systems was less in the Alt system due to fewer acres planted to each crop.

**Table 14. Liquid fuel production potential in diesel fuel equivalents utilizing average yearly amounts of corn, spring wheat, or soybeans produced in farming systems (whole-farm basis).[a]**

| Study I | System | | | | |
|---|---|---|---|---|---|
| Alternate | | Conventional | | Ridge-Till | |
| Soybean[b] | Corn[c] | Soybean[b] | Corn[c] | Soybean[b] | Corn[c] |
| 4,025 | 7,677 | 5,206 | 11,717 | 4,473 | 11,223 |

| Study II | System | | | | |
|---|---|---|---|---|---|
| Alternate | | Conventional | | Minimum-Till | |
| Soybean[b] | Spring Wheat[d] | Soybean[b] | Spring Wheat[d] | Soybean[b] | Spring Wheat[d] |
| 4,756 | 3,736 | 5,516 | 4,266 | 5,026 | 4,218 |

[a] All values expressed as No. 2 Diesel fuel equivalent (DFE). Energy required for oil extraction (34,600 BTU/bu) or ethanol production (42,000 BTU/gal ethanol) has been deducted. Value for oil extraction based on Goering and Daugherty (1982), and value for ethanol production based on Marland and Turhollow (1991).
[b] Soybean oil production (DFE) based on bushel soybean X 1.44 = 1 gal No. 2 diesel fuel. Assumes soybean with 20% oil content and that soybean oil has 90% of the energy of No. 2 diesel fuel. 1 gal. No 2 = 138,690 BTU.
[c] Ethanol production (DFE) from corn.
[d] Ethanol production (DFE) from spring wheat.
Note: 1 gal ethanol = 86,000 BTU, 1 bushel corn = 2.5 gal ethanol, 1 bushel spring wheat = 2.1 gal ethanol (D. Iseminger, South Dakota Corn Utilization Council, pers comm).

**Table 15. Yearly crop, meal, crop mass, and TDN production in Study I after converting some or all of soybeans, plus a portion of corn in Conv and R-T, to liquid fuel to equal energy consumed for fuel, oil extraction, ethanol production, N fertilizer, and pesticides.**

| | System | | |
|---|---|---|---|
| Production | Alternate | Conventional | Ridge-Till |
| Corn (bu) | 9,678 | 10,887 | 8,408 |
| Soybean (bu) | 1,148 | 0 | 0 |
| Spring Wheat (bu) | — | 6,443 | 5,563 |
| Oats (bu) | 7,003 | — | — |
| Alfalfa (T/A) | 579 | — | — |
| Soybean meal (tons-dry wt) | 46 | 90 | 77 |
| Corn byproduct[a] (tons-dry wt) | — | 31 | 46 |
| Crop mass produced: (tons-dry wt) | 981 | 547 | 467 |
| Reduction in crop mass compared to initial:[b] | 1% | 13% | 19% |
| TDN (tons):[c] | 672[a] | 477 | 404 |
| Reduction in TDN: compared to initial[b] | 2% | 14% | 21% |

[a] Assumes 16 lb of byproduct per bushel of corn.
[b] Compare to data in Table 5.
[c] Total digestible nutrients, assuming all was fed to ruminant livestock. Digestibility of corn byproduct = 75%, soybean meal = 80%. (J. Wagner, pers comm).

**Table 16. Yearly crop, meal, crop mass, and TDN production in Study II after converting some or all of soybeans plus a portion of spring wheat in Conv and M-T to liquid fuel to equal energy consumed for fuel, oil extraction, ethanol production, N fertilizer, and pesticides.**

| System<br>Production | Alternate | Conventional | Minimum-Till |
|---|---|---|---|
| Soybean (bu) | 2,424 | 0 | 0 |
| Spring Wheat (bu) | 5,606 | 5,466 | 2,781 |
| Barley (bu) | — | 10,202 | 8,333 |
| Oats (bu) | 7,900 | — | — |
| Soybean meal (tons-dry wt) | 32 | 92 | 87 |
| Spring Wheat by- product (tons-dry wt)[a] | — | 10 | 39 |
| Crop mass produced (tons-dry wt) | 352 | 462 | 373 |
| Reduction in crop mass compared to initial:[b] | 2% | 8% | 17% |
| TDN[c] | 308 | 392 | 311 |
| Reduction in TDN compared to initial[b]: | 2% | 9% | 19% |

[a] Assumes 22 lb of byproduct per bushel of spring wheat (G. Doig, Alcotech, pers comm). Digestibility of byproduct = 75%

[b] Compare to data in Table 6.

[c] Total digestible nutrients assuming above was fed to ruminant livestock.

Because of the different crops and lengths of rotations, the productivity of the systems was measured by comparing crop mass (total dry weight of all plant material) removed from a system or by comparing TDN (total digestible nutrients if all harvested plant material were fed to ruminant livestock).

Productivity in terms of crop mass removed from a system on a whole-farm basis was highest in the Alt system in Study I in all years of the studies. The inclusion of alfalfa in the Alt system in Study I substantially improved the overall productivity. In Study II, productivity in the Alt system was generally less than Conv and M-T, although in the 1988 drought year, productivity was nearly equal in all systems.

The productivity of the reduced-till systems (R-T and M-T) was generally similar to that of the respective Conv systems in both studies in the earlier years (1986-1990), but productivity in both reduced-till systems was substantially lower than the Conv in the last 2 years of the studies. This decline in productivity provided an example of the importance of long-term studies in evaluating different farming systems.

The variability in productivity of the Alt systems in both studies was less than that of the Conv and reduced-till.

The TDN produced in the Alt system in Study I was 23 to 34% higher than the Conv and R-T systems, respectively. The TDN production in the Alt system in Study II was 19 and 27% less than M-T and Conv.

The livestock feed potential of the systems in Study I was compared by assuming all alfalfa, corn, and soybean meal produced in the systems on a whole-farm basis were fed to ruminant livestock. The TDN production in the Alt system was 47 and 57% higher than in the Conv and R-T systems, respectively, and protein production in the Alt system was 2-2.25 times higher.

The return to monetary investments was also compared, and in Study I the crop mass removed from the Alt system per dollar invested in production costs, including land and labor, was 78% to 100% greater than the Conv and R-T systems. In Study II, the range in crop mass removed per dollar invested in the various systems was comparatively narrow, and crop mass removed was highest in the Conv system and lowest in the M-T. Production per hour of labor required for all field activities was highest in the Alt system in Study I and the Conv system in Study II.

Energy consumed for fuel, N fertilizer, and pesticides on a whole-farm basis in the Alt system in Study I was 68 and 71% less than the Conv and R-T systems, respectively. The Alt system in Study II used 70 to 75% less energy for the above inputs than did the Conv and M-T systems.

Crop mass removed from a system per unit of energy consumed was five to six times higher in the Alt system in Study I compared to the Conv and R-T systems. In Study II, the Alt system was approximately two to three times more productive per energy unit than the Conv and M-T systems.

The liquid fuel (soybean oil or ethanol) production potential on a whole-farm basis, after deducting **only** the energy consumed in the fuel production processes, was

**Table 17. Effect of farming system on net ethanol production from corn in Study I, and from spring wheat in Study II.**

| Net ethanol production per bushel[a] | System | | |
|---|---|---|---|
| | Alternate | Conventional | Ridge-Till |
| Corn | 0.84 gal. | 0.38 gal. | 0.25 gal. |
| | Alternate | Conventional | Minimum-Till |
| Spring Wheat | 0.54 gal. | -0.47 gal. | -0.81 gal. |

[a] Ethanol remaining after compensating for the amount of energy consumed for fuel, N fertilizer, and pesticides (Table 11), and the energy required for ethanol production. Based on average corn or spring wheat yields and input use (1986-1992).

**Table 18. Effect of farming system on net soybean oil fuel production (diesel fuel equivalent) in Study I and II.**

| Net production (DFE) per bushel of soybean[a] | System | | |
|---|---|---|---|
| | Alternate | Conventional | Ridge-Till |
| Study I: | 0.40[b] | -0.70 | -1.21 |
| | Alternate | Conventional | Minimum-Till |
| Study II: | 0.72 | -0.13 | -0.56 |

[a] Production remaining after deducting the energy consumed for fuel, N fertilizer, and pesticides (Table 11), plus the energy required for oil extraction. Based on average soybean yields and input use (1986-1992).
[b] Production expressed as gal of No. 2 diesel fuel, 1 bu soybeans = 1.44 gal DFE.

highest in the Conv and reduced-till systems. Converting enough of the crops produced in the various systems to liquid fuel to counterbalance the energy consumed for fuel, N fertilizer, and pesticides, plus the energy required for liquid fuel production, had the greatest effect on production in the reduced-till systems, and the least effect in the Alt systems.

The **net** or residual liquid fuel production per bushel of either soybeans, corn, or spring wheat, after deducting energy consumed for fuel, N fertilizer, and pesticides, and liquid fuel production processes, was positive for soybeans only in the Alt systems. The net ethanol production for corn in Study I was positive for all systems, but was two to three times higher in the Alt system compared to Conv and R-T. In Study II, the net ethanol production per bushel of spring wheat was positive only in the Alt system.

Overall, results in these studies suggest Alt systems represent a viable alternative to more conventional types of farming systems in this agroclimatic area.

# Section C:
# **Ecological Relationships**

## Weed Populations

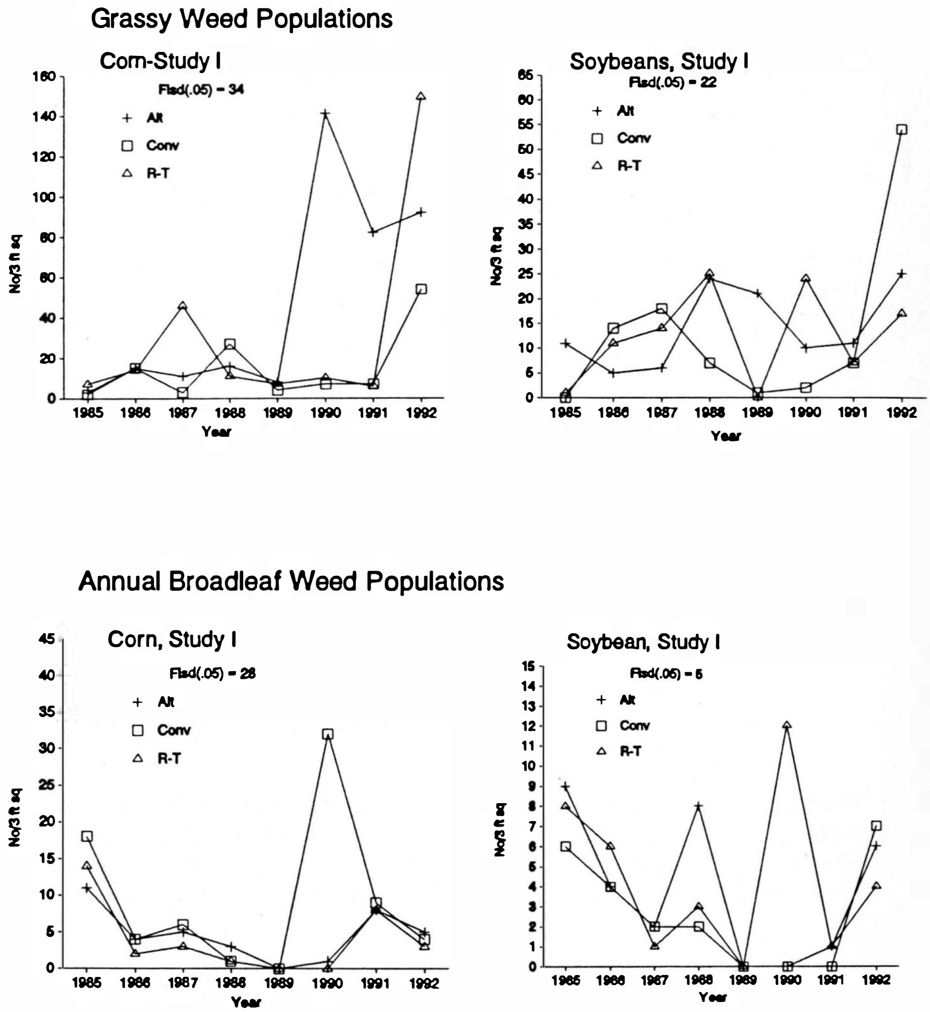
D.H. Rickerl, L.J. Wrage,
J.D. Smolik, and T.A. Machacek

Weeds and the methods employed in their control can have a substantial effect on the agronomic and economic performance of farming systems. Concerns about uncontrollable weed infestations can also influence the adoption of alternative farming systems.

The mechanical and chemical weed control practices used in these studies are summarized in Tables 1 and 2. The soybeans were also “walked” (hand-weeded) in most years in all systems for control of broadleaved weeds. The average amount of time required to walk the soybeans was Study I: Alt 0.64 hr/A, Conv 0.82 hr/A, R-T 0.99 hr/A; Study II: Alt 1.40 hr/A, Conv 0.80 hr/A, M-T 1.29 hr/A.

Weed populations were measured in all years of the studies.

**Figure 5. Weed populations in corn and soybeans in Study I.**




Weed numbers and weed biomass included in this report were those recorded in late June or early July in the small grains and in late July or early August in the row crops.

Grassy weed populations were primarily *Setaria* spp (green and yellow foxtail), although in the last 2 years of the studies quackgrass and downy brome were also detected in the R-T and M-T systems. Broadleaved weed populations were dominated by annuals and included redroot pigweed, lambsquarter, prostrate pigweed, Russian thistle, kochia, wild buckwheat, pale smartweed, and oxalis.

Grassy weed populations in corn were not consistently different between systems in the early years of the studies (Fig 5) but increased significantly in the Alt system in 1990-1992. Grassy weed densities were generally low in the Conv and R-T systems except for 1992, when populations were significantly higher in both systems. The unusual weather patterns in 1992 resulted in erratic herbicide performance, which apparently contributed to increased grassy weed populations in the Conv and R-T systems.

Grassy weed populations in soybeans were not consistently different between systems over the entire study period, except for a substantial increase in the Conv system in 1992 (Fig 5). In general, the grassy weed populations in Study I reflected crop and seasonal, rather than system, differences.

Populations of annual broadleaved weeds in corn were generally very similar between systems, except for the Conv system in 1990 (Fig 5). The dominant broadleaf in the Conv corn in 1990 was Russian thistle. There were no apparent reasons for the significant increase in populations of this weed in 1990.

Broadleaved weed numbers in soybeans in Study I varied considerably over the study period and were not consistently different between systems (Fig 5). Numbers were significantly higher in the R-T system in 1990, due to increased populations of Russian thistle.

In Study II, grassy weed numbers in soybeans were significantly higher in the Alt system in 1989 (Fig 6). Numbers were also significantly higher in the M-T system in 1986 and 1989. Populations of grassy weeds in the Conv soybeans were consistently very low throughout the entire period. Grassy weed densities in spring wheat in Study II were generally highest in the Alt system (Fig 6) but were also high in the Conv system in 1990. Although numbers were high in the Alt system, information in Table 22 indicates they probably did not substantially influence spring wheat yields.

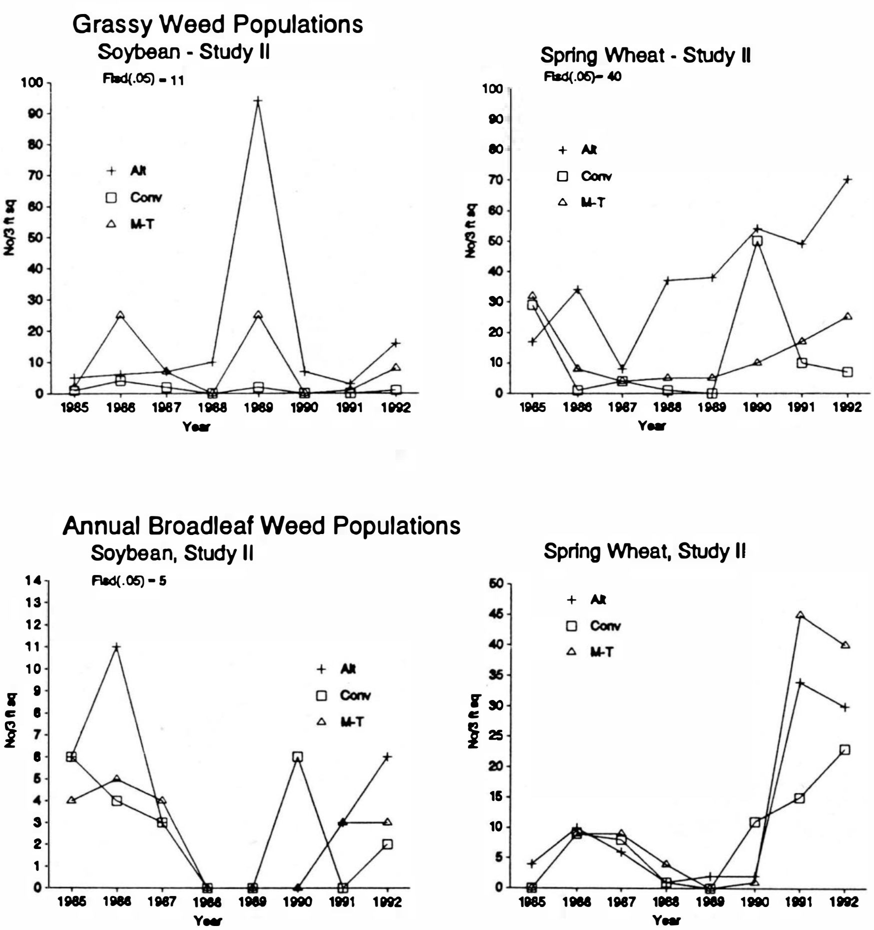
Populations of annual broadleaved weeds in soybeans were erratic in all systems (Fig 6) and generally were low over the study period. Numbers of annual broadleaves in spring wheat increased in all systems in the last 2 years of the study, and highest numbers occurred in the M-T system (Fig 6).

Populations of perennial broadleaves are not included in Figs 5 and 6, due primarily to their low numbers and erratic occurrence. In the early years of the studies, perennial broadleaf populations were dominated by dandelion. However, in the last 2 years of the studies Canada thistle was encountered more frequently in the R-T and M-T systems, and broad-spectrum herbicides were applied (Tables 1 and 2) for control of both Canada thistle and quackgrass.

The general absence of severe weed problems in all of the systems in these studies probably resulted from a combination of factors. All of the systems contained both small grain and row crops and included both warm- and cool-season plants. This diversity of crops aided in breaking weed reproduction cycles and also gave us the opportunity to employ a range of mechanical and chemical methods of weed control. The inclusion of weed suppressive forage legumes (alfalfa or clover) in the Alt systems and their associated cultural practices also aided in weed control.

In the initial years of the studies a monoculture, continuously cropped, no-till winter wheat was included in Study II. Over a 3-year period (1986-1988) winter wheat yields decreased from 51 to 10 bu/A in this system. Populations of downy brome (cheatgrass) increased rapidly in spite of substantial herbicide inputs, and by 1988 downy brome had become the dominant plant in the system with nearly 100 plants per square foot. The failure of this monoculture after only 3 years is further evidence of the value of rotations in weed control.

**Figure 6. Weed populations in soybeans and spring wheat in Study II.**




## Weed Seed Germination Studies

D.H. Rickerl

Soil reserves of weed seed have been used as an indicator of the long-term effects of weed control practices. We measured how farming systems affected soil weed seed banks from 1987 to 1989 and in 1992 in Study I and in 1988, 1989, and 1992 in Study II. The measurements in 1992, the last year of the studies, would help indicate the long-term effects of the systems. Soil weed seed densities were determined by collecting soil samples in the fall to a depth of 6 inches from three random areas in each plot. The samples from each plot were pooled, and a 2000 $cm^3$ subsample was placed in a flat in the greenhouse. Flats were watered, and weed emergence over a 2-3 month period was recorded. The greenhouse germination studies represented soil weed seed banks from all crops in each rotation.

Weed densities were generally higher in the Alt systems than in the Conv or reduced-till systems (Table 19). The suppressive effects of alfalfa and clover on grassy weeds were shown in the greenhouse germination studies.

Comparisons of soil weed seeds from middle years to those from the final year indicated weed seeds did not increase in any system. In several instances, numbers were significantly lower in the final year.

Regression analyses showed no correlations between total weed seed densities and yield. Field weed populations did not consistently differ among systems (Figs 5 and 6) indicating that, although soil weed seed banks were higher for the Alt system, they were not being expressed in the field.

These studies indicated that soil seed bank densities do not successfully predict either weed populations or weed impacts on yield, and that alternative systems do not necessarily contribute to long-term increases in the soil weed seed bank.

**Table 19. Greenhouse weed seed germination as influenced by crop and system, Study I and II.**

| Greenhouse Germination | | | | | | | |
|---|---|---|---|---|---|---|---|
| Study I | | | | Studyll | | | |
| System | Crop | Grasses | Bdlf | System | Crop | Grasses | Bdlf |
| Alt | Oat/Alfalfa | 75[a] | 12 | Alt | Oat/Clover | 37[b] | 12 |
| | Alfalfa | 29 | 3 | | Clover | 20 | 6 |
| | Soybean | 43 | 3 | | Soybean | 33 | 4 |
| | Corn | 64 | 4 | | Sp. Wheat | 9 | 3 |
| Conv | Corn | 7 | 2 | Conv | Soybean | 1 | 2 |
| | Soybean | 6 | 2 | | Sp. Wheat | 4 | 2 |
| | Sp. Wheat | 3 | 1 | | Barley | 5 | 1 |
| R-T | Corn | 13 | 3 | M-T | Soybean | 2 | 5 |
| | Soybean | 8 | 3 | | Sp. Wheat | 2 | 5 |
| | Sp. Wheat | 7 | 2 | | Barley | 6 | 4 |
| Flsd$_{.05}$= | | 34 | 7 | | | 15 | 7 |
| **System Means** | | | | | | | |
| Alt | 1987 | 2 | 14 | Alt | | — | — |
| | 1988 | 54 | 1 | | | 36 | 7 |
| | 1989 | 146 | 54 | | | 30 | 7 |
| | 1992 | 10 | 3 | | | 8 | 4 |
| Conv | 1987 | 1 | 14 | Conv | | — | — |
| | 1988 | 5 | 1 | | | 7 | 2 |
| | 1989 | 10 | 1 | | | 1 | 1 |
| | 1992 | 6 | 1 | | | 2 | 0 |
| R-T | 1987 | 2 | 22 | M-T | | — | — |
| | 1988 | 11 | 3 | | | 3 | 9 |
| | 1989 | 16 | 4 | | | 2 | 4 |
| | 1992 | 8 | 1 | | | 5 | 2 |
| Flsd$_{.05}$= | | 38 | 11 | | | 17 | N.S. |

[a] Average number of plants per 2000 cm$^3$ soil, 1987-1989 and 1992
[b] Average number of plants per 2000 cm$^3$ soil, 1988, 1989, and 1992
N.S. = No significant difference between systems.

# Mechanical and Chemical Weed Control Studies in Corn, Soybeans, and Spring Wheat

J.D. Smolik, T.A. Machacek, and D.H. Rickerl

Some of the concerns regarding alternative farming systems are the relative effectiveness and costs of mechanical vs. chemical methods of weed control (Taylor *et al* 1992). A related issue is the establishment of threshold levels for weed damage to crops.

Over the course of the farming systems studies, the Alt systems often appeared "weedier" than the other systems, particularly the Conv, and there was concern about the influence of weeds on crop yields.

To address these concerns, a series of companion studies was initiated in 1989 at the Northeast Station which would compare the effectiveness and costs of mechanical and chemical weed control methods and, with the aid of regression analyses, establish relationships between weed populations and yield of corn, soybeans, and spring wheat.

These studies were conducted on soil types similar to those in the farming systems. Tillage operations in most years consisted of fall chisel plowing followed by field cultivating and harrowing in the spring. A moldboard plow was not used in any of the studies. N fertilizer applications in corn and spring wheat were based on moderate yield goals (100-bu corn and 50-bu wheat).

All experiments were arranged in randomized complete block designs with four replications. Spring wheat was drilled in 7-inch rows, and plots were 12 to 20 ft wide. An 8-ft-wide swath from the center of each plot was harvested for yield determination. Row crops were planted in 36-inch rows and, except for 1989, plots were four rows wide. The corn plots in 1989 were two rows wide, and the entire plot was harvested for yield. In all subsequent years only the center two rows of the corn plots were harvested for yield determination. All four rows of the soybean plots were harvested for yield. All plots were mechanically harvested except for 1992, when the corn plots were hand-harvested and mechanically threshed. Over the 4 years of the studies, plot lengths ranged from 28 to 60 ft. Weed populations were estimated with the aid of a 1-ft-square wire frame at three random locations in each plot.

After weeds were counted, they were clipped at soil level, oven dried at 130 F, and weighed to determine biomass. Weed populations were sampled just prior to harvest in spring wheat and in mid-August in most years in row crops. Economic relationships in these studies were based on data supplied by T. Dobbs, S. Van Der Werff, and L. Henning, SDSU Economics Department.

Costs for the various treatments included fuel, lubricants, herbicides, repairs, labor, and fixed costs. Gross returns were based on current year's South Dakota selling price minus only weed control costs, and did not include deficiency payments.

Planting dates and crop cultivars were similar to those in the farming systems studies, and the timing of the various weed control treatments was also similar. The first rotary hoeing or drag harrow operation was conducted prior to emergence of the row crops, usually 2 to 5 days after planting, the second rotary hoeing was 7 to 14 days after planting. The first cultivation was approximately 1 month after planting, the second 2 to 3 weeks later. In 1991 a third cultivation was performed in soybeans approximately 2 months after planting. Herbicide treatments in corn and soybeans consisted of Lasso II (alachlor) at 7 lb actual banded at planting. The rotary hoe operations in spring wheat were performed 2 and 4 weeks after emergence.

In both corn and soybean the dominant weeds were *Setaria* spp, primarily green and yellow foxtail. Populations of broadleaves in corn and soybean were low in most years, and were not significantly influenced by weed control treatments in most instances. Thus, for the corn and soybean studies, only foxtail is considered.

## Corn

In 1989 the highest yielding treatments were cultivating twice (2X) or cultivating twice plus rotary hoeing and/or dragging (Table 20). The highest economic return occurred in the hoe 1X, cult 2X treatment.

Based on regression analyses, approximately four foxtail plants per $yd^2$ resulted in a 1-bu yield loss. For biomass, a bushel of corn was lost for each 128 lb/A (dry weight) of foxtail.

In 1990, yields were lowest in the check and cult 1X treatments and did not differ significantly in the remaining treatments. Foxtail numbers and biomass were much higher in 1990 compared to the previous year, and the range in yields associated with various levels of weed control was greater than in 1989 (Table 20).

The highest economic returns in 1990 occurred in the cult 2X and Lasso II plus cult 1X treatments. The relationship between yield and foxtail numbers was similar to 1989. The relationship for biomass indicated that a bushel of corn was lost for each 100 lb/A of foxtail produced.

The highest yields and economic returns in 1991 occurred in the Lasso II plus cult 2X treatment. Foxtail numbers were very high in 1991, but individual plants were smaller. Precipitation was high in 1991 (Fig 1), and weeds continued to emerge over much of the growing season, which resulted in a greater proportion of smaller foxtail plants. The regression analyses indicated a bushel of corn was lost for every 15 foxtail plants per $yd^2$ or for each 46 lb/A of foxtail produced.

Corn yields were low in the cool 1992 growing season, but the treatment rankings for yields and economic returns were similar to those in 1991 (Table 20). The relationship between yield and foxtail numbers was similar to that in 1991, and the biomass relationship indicated a bushel of corn was lost for each 110 lb/A of foxtail produced.

Except for 1991, the relationships between corn yield loss and foxtail biomass did not vary substantially across years; however, relationships for foxtail numbers were considerably different in the first 2 years compared to the last 2. Results indicate mechanical methods can provide very good levels of foxtail control in corn, but the early season in-row foxtail control provided by Lasso II, supplemented by cultivation, generally enhanced economic returns.

**Table 20. Effect of mechanical and chemical weed control treatments on weed populations, corn yields, and economic returns.**

| Treatment | Yield(Bu/A) | Foxtail (No./3 $ft^2$) | Foxtail biomass (lb/A) | Weed control costs($/A) | Gross economic return ($/A) |
|---|---|---|---|---|---|
| | | 1989 | | | |
| Check | 58.9[a] | 28 | 2,105 | 0.00 | 120.75[c] |
| Cult 1X | 60.8 | 30 | 2,242 | 4.26[b] | 120.38 |
| Cult 2X | 78.9 | 11 | 114 | 8.52 | 153.23 |
| Drag 1X, Cult 2X | 77.9 | 16 | 464 | 11.46 | 148.24 |
| Hoe 1X, Cult 2X | 81.2 | 7 | 50 | 10.89 | 155.57 |
| Hoe 2 X, Cult 2X | 79.6 | 13 | 25 | 13.26 | 149.92 |
| Drag 1X, Hoe 1X, Cult 2X | 81.8 | 9 | 6 | 13.83 | 153.86 |
| $Flsd_{.05}$ = | 7.9 | 12 | 799 | | |
| | | 1990 | | | |
| Check | 43.0 | 73 | 4,664 | 0.00 | 90.30 |
| Cult 1X | 69.1 | 26 | 1,695 | 4.26 | 140.85 |
| Cult 2X | 99.9 | 11 | 768 | 8.52 | 201.27 |
| Hoe 1X, Cult 2X | 91.2 | 5 | 77 | 10.89 | 180.63 |
| Hoe 2X, Cult 2X | 95.8 | 17 | 384 | 13.26 | 187.92 |
| Drag 1X, Cult 2X | 88.1 | 9 | 416 | 11.46 | 173.55 |
| Drag 1X, Hoe 1X, Cult 2X | 95.2 | 13 | 896 | 13.83 | 186.09 |
| Lasso II + Cult 1X[d] | 101.0 | 10 | 528 | 10.21 | 201.89 |
| $Flsd_{.05}$ = | 13.1 | 14 | 1,019 | | |
| | | 1991 | | | |
| Check | 17.1 | 347 | 3,125 | 0.00 | 36.77 |
| Cult 1X | 45.8 | 213 | 2,261 | 4.26 | 94.21 |
| Cult 2X | 71.7 | 82 | 665 | 8.52 | 145.64 |
| Lasso II + Cult 2X | 84.4 | 86 | 652 | 15.17 | 166.29 |
| $Flsd_{.05}$ = | 9.5 | 80 | 681 | | |
| | | 1992 | | | |
| Check | 24.0 | 190 | 4,573 | 0.00 | 48.00 |
| Cult 1X | 54.8 | 77 | 1,087 | 4.26 | 105.34 |
| Cult 2X | 62.2 | 72 | 256 | 8.52 | 115.88 |
| Lasso II + Cult 2X | 68.7 | 99 | 96 | 15.17 | 122.32 |
| $Flsd_{.05}$ = | 8.1 | 42 | 668 | | |

[a] Average of four replications.
[b] Costs include fuel, lubricants, herbicide, repairs, labor, and fixed costs.
[c] Returns minus only weed control costs.
[d] Lasso II was banded at planting at 7 lb/A actual.

## Soybeans

The highest soybean yields and economic returns in the 1990 study occurred in the hoe 1X, cult 2X and in the hoe 2X, cult 2X, walk treatments (Table 21). Results of the regression analyses indicated a bushel of soybeans was lost for every 20 foxtail plants per yd$^2$ and that a bushel was lost for each 230 lb/A (dry weight) of foxtail produced.

In 1991, the highest yield and economic return occurred in the Lasso II plus cult 3X treatment. A very heavy rain in late June resulted in a flush of foxtail, and a third cultivation was required. Regression analyses indicated a bushel of soybeans was lost for every 43 foxtail plants per yd$^2$ and one bushel was lost for each 192 lb/A of foxtail.

Soybean yields were low in 1992 and not significantly different between the cult 2X and Lasso II plus cult 2X treatments (Table 21). The highest economic return occurred in the cult 2X treatment. In 1992, 100 foxtail plants per yd$^2$ resulted in a 1-bu yield loss, and a bushel was lost for each 246 lb/A of foxtail produced.

Results of the weed control studies in soybeans indicate mechanical methods alone can provide levels of foxtail control equal to those obtained with herbicide supplemented with cultivation. Yields and economic returns in some instances were higher with only mechanical methods.

**Table 21. Effect of mechanical and chemical weed control treatment on weed populations, soybean yield, and economic returns.**

| Treatment | Yield(Bu/A) | Foxtail (No./3 ft$^2$) | Foxtail biomass (lb/A) | Weed control costs($/A) | Gross economic return ($/A) |
|---|---|---|---|---|---|
| | | 1990 | | | |
| Check | 20.5[a] | 58 | 2,642 | 0.00 | 118.00[c] |
| Cult 1X | 32.8 | 3 | 19 | 4.26[b] | 185.98 |
| Cult 2X | 34.5 | 8 | 77 | 8.52 | 191.58 |
| Hoe 1X, Cult 2X | 37.2 | 4 | 96 | 10.89 | 204.87 |
| Hoe 2X, Cult 2X | 36.0 | 6 | 80 | 13.26 | 195.54 |
| Drag 1X, Cult 2X | 36.4 | 6 | 511 | 11.46 | 199.66 |
| Drag 1X, Hoe 1X, Cult 2X | 32.9 | 14 | 214 | 13.83 | 176.99 |
| Hoe 2X, Cult 1X | 32.9 | 5 | 182 | 9.00 | 181.82 |
| Hoe 2X, Cult 2X, Walk | 37.3 | 1 | 3 | 15.40 | 200.94 |
| Lasso II + Cult 1X[d] | 33.9 | 6 | 118 | 10.21 | 186.41 |
| Flsd$_{.05}$ = | 3.1 | 21 | 451 | | |
| | | 1991 | | | |
| Check | 24.8 | 222 | 2,536 | 0.00 | 130.20 |
| Cult 1X | 31.0 | 167 | 1,945 | 4.26 | 158.49 |
| Cult 3X | 38.0 | 31 | 134 | 12.78 | 186.72 |
| Lasso II + Cult 3X | 40.1 | 28 | 64 | 19.43 | 191.10 |
| Flsd$_{.05}$ = | 3.7 | 55 | 672 | | |
| | | 1992 | | | |
| Check | 8.3 | 207 | 1,861 | 0.00 | 43.58 |
| Cult 1X | 12.3 | 117 | 1,343 | 4.26 | 60.32 |
| Cult 2X | 16.9 | 130 | 368 | 8.52 | 80.21 |
| Lasso II + Cult 2X | 17.1 | 124 | 413 | 15.17 | 74.61 |
| Flsd$_{.05}$ = | 2.0 | N.S. | 672 | | |

[a] Average of four replications

[b] Costs include fuel, lubricants, herbicide, repairs, labor, and fixed costs

[c] Returns minus only weed control costs.

[d] Lasso II banded at planting at 7 lb/A actual.

## Spring Wheat

The same four treatments were repeated in each of the 3 years in the spring wheat studies. There were no significant differences in yield in any of the years, and weed populations were significantly influenced by treatments only in 1990 (Table 22). The very low yields in 1991 were a result of a severe epidemic of Fusarium head scab. In the first 2 years, the highest economic returns occurred in the check treatment. In 1992, they were highest in the hoe 1X treatment. Foxtail numbers were moderately high in most treatments but, as indicated by the biomass values, the plants were small. The weight of individual broadleaved weeds was also low.

Spring wheat is a cool-season grass, whereas foxtail is a warm-season grass. It appears that spring wheat planted in a timely manner will out-compete foxtail. The application of herbicides to control foxtail and broadleaved weeds did not consistently improve yields and in 2 of 3 years resulted in substantial reductions in economic returns.

Comparing the yields of the checks in the above studies with the yields of the best weed control treatments each year over the study period indicated the following ranking of crop competitiveness with weeds: spring wheat > soybean > corn. The respective average yield losses for the above comparisons and crops were 5%, 43%, and 58%.

Table 22. Effect of mechanical and chemical weed control treatments on weed populations, spring wheat yield, and economic returns.

| Treatment | Yield(Bu/A) | Weed numbers (No./3 ft²) | | Weed biomass (lb/A) | | Weed control costs($/A) | Gross economic return ($/A) |
|---|---|---|---|---|---|---|---|
| | | Foxl | Bdlf | Foxl | Bdlf | | |
| **1990** | | | | | | | |
| Check | 48.4[a] | 92 | 36[b] | 137 | 235 | 0.00 | 113.74[d] |
| Hoe 1X | 49.0 | 130 | 34 | 387 | 294 | 2.37[c] | 112.78 |
| Hoe 2X | 43.1 | 83 | 23 | 343 | 186 | 4.74 | 96.55 |
| Hoelon + Buctril[e] | 48.3 | 30 | 2 | 74 | 4 | 20.78 | 92.73 |
| $Flsd_{.05}$ = | N.S. | 47 | 15 | 109 | 174 | | |
| **1991** | | | | | | | |
| Check | 16.3 | 143 | 23 | 499 | 208 | 0.00 | 46.46 |
| Hoe 1X | 14.5 | 158 | 30 | 537 | 138 | 2.37 | 38.96 |
| Hoe 2X | 15.2 | 135 | 10 | 333 | 65 | 4.74 | 38.58 |
| Hoelon + Buctril | 15.3 | 102 | 17 | 185 | 58 | 22.71 | 20.90 |
| $Flsd_{.05}$ = | N.S. | N.S. | N.S. | N.S. | N.S. | | |
| **1992** | | | | | | | |
| Check | 45.9 | 119 | 58 | 240 | 784 | 0.00 | 146.88 |
| Hoe 1X | 49.7 | 144 | 24 | 259 | 368 | 2.37 | 156.67 |
| Hoe 2X | 46.7 | 146 | 27 | 208 | 572 | 4.74 | 144.70 |
| Hoelon + Buctril | 53.3 | 142 | 22 | 214 | 28 | 23.06 | 147.50 |
| $Flsd_{.05}$ = | N.S. | N.S. | N.S. | N.S. | N.S. | | |

[a] Average of four replications
[b] Broadleaved weeds were primarily redroot pigweed, Kochia, Russian thistle, wild buckwheat, and lambsquarter.
[c] Costs include fuel, lubricants, herbicide, repairs, labor, and fixed costs.
[d] Returns minus only weed control costs.
[e] Hoelon applied at 2 pt/A and buctril at 1 pt/A (Actual/A).

## Estimated Yield Losses in Farming Systems Studies

The results of the companion weed control studies indicate that weeds did not substantially influence spring wheat yields in the farming systems. Regression equations based on data in Tables 20 and 21 were used to estimate yield loss due to foxtail in corn in Study I and soybeans in Study I and II. In most regression analyses, the best relationships (highest $r^2$) were obtained with foxtail biomass. In the corn studies, the $r^2$, averaged over the 4 years, was .66 for foxtail numbers and .75 for foxtail biomass. The average $r^2$ in the soybean studies was .48 for foxtail numbers and .70 for foxtail biomass.

The $r^2$ is an estimate of how much of the variation in yield is due to a particular factor. For instance, the regression analyses in the corn studies indicated 75% of the variability in yield was related to foxtail biomass. The lower $r^2$ for foxtail numbers was probably a result of late-season weed flushes which can result in high numbers of small plants that probably have little effect on yield.

Although estimating weed biomass is both time consuming and labor intensive, foxtail biomass data in corn and soybeans was also obtained in the last 3 years of the farming systems studies and was used to estimate yield losses.

In 1990 in Study I, the estimated yield loss due to foxtail in Alt corn was approximately 17 bu and the yield loss in the Conv and R-T systems was approximately 4 bu in each system (Table 23). Estimated corn yield loss in 1991 ranged from approximately 11 bu in the Alt system to 2 to 3 bu in Conv and R-T. In 1992 the highest corn yield loss (approximately 5 bu) occurred in the R-T system.

The estimated yield loss in soybeans was low in all years and in Study I ranged from approximately 2 bu in the Alt and R-T systems in 1990 to less than 1 bu in all other years. In Study II, estimated soybean yield losses were negligible in all years and never exceeded 1 bu.

Data in Table 23 should be interpreted with some caution, because many of the factors that influenced crop yields in the farming systems studies, such as tillage, nutrient application, previous crop, and herbicides applied, were not duplicated in the companion studies. It does appear, however, that foxtail probably had a substantial influence on corn yields in some years of the studies, particularly in the Alt system.

**Table 23. Estimated corn and soybean yield losses due to foxtail in Study I and II.**

| System | 1990 Foxtail biomass (lb/A) | 1990 Yield loss (bu/A) | 1991 Foxtail biomass (lb/A) | 1991 Yield loss (bu/A) | 1992 Foxtail biomass (lb/A) | 1992 Yield loss (bu/A) |
|---|---|---|---|---|---|---|
| STUDY I | | | | | | |
| | | | Corn | | | |
| Alt | 1,711 | 17.1[a] | 521 | 11.3 | 258 | 2.3 |
| Conv | 432 | 4.3 | 131 | 2.8 | 310 | 2.8 |
| R-T | 381 | 3.8 | 109 | 2.4 | 539 | 4.9 |
| | | | Soybean | | | |
| Alt | 512 | 2 | 176 | 0.8 | 160 | 0.7 |
| Conv | 5 | 0 | 73 | 0.3 | 109 | 0.4 |
| R-T | 446 | 2 | 51 | 0.2 | 16 | 0.1 |
| STUDY II | | | | | | |
| | | | Soybean | | | |
| Alt | 122 | 0.5 | 15 | 0.1 | —[b] | — |
| Conv | 3 | 0 | 0 | 0 | — | — |
| M-T | 0 | 0 | 10 | 0 | — | — |

[a] Yield loss estimated with regression equations developed from data in Tables 20 and 21.
[b] Biomass data was not collected in soybeans in Study II in 1992.

## Nematode and Oligochaete Populations

J.D. Smolik

Nematodes are unsegmented roundworms, and the soil-inhabiting forms are usually very small (approximately 1/25 inch long). Because of their small size and the specialized techniques required to extract and identify them, the role of nematodes in crop production systems is often overlooked.

Plant parasitic nematodes are obligate parasites: their survival is dependent on a living plant host. Most plant parasitic nematodes feed on or in plant roots, and the damage they inflict is often chronic in nature. Nematode damage can easily be confused with other potential problems such as nutrient deficiency or moisture stress. In South Dakota, significant nematode damage to corn, spring wheat, sorghum, and sunflowers has been documented (Smolik 1972, 1977, 1987, Smolik and Evenson 1987). In the western portion of the state, nematodes in native range consume more plant material than do cattle (Scott *et al* 1979, Smolik 1974, Smolik and Lewis 1982).

Populations of plant feeding, predaceous, and microbial feeding nematodes were measured at harvest in all years of the studies and over the growing season from 1985 to 1989. In general, highest populations occurred at harvest, and only harvest populations are included in this report.

From four to six soil samples were randomly collected from the root zone to a depth of approximately 6 inches in each plot. On several occasions root samples were also collected; however, no plant parasites were detected in the roots. Nematodes were extracted from soil by the Christie-Perry method and numbers of plant parasites were recorded in seven taxonomic groupings: *Tylenchorhynchus, Helicotylenchus, Paratylenchus,* Tylenchinae/Psilenchinae, *Xiphinema, Pratylenchus,* and *Hoplolaimus.* Populations of plant parasites were composed primarily of *Paratylenchus projectus* (pin nematodes) and *Xiphinema americanum* (dagger nematodes), and the remaining groups of plant parasites will not be considered in this report. The predaceous and microbial feeding groups were composed of a variety of species, and specific identifications have not been completed.

Populations of Oligochaetes (pot worms) were also measured, and these small earthworms (about 1/16-1/4 inch long) were extracted by a modified Christie-Perry method.

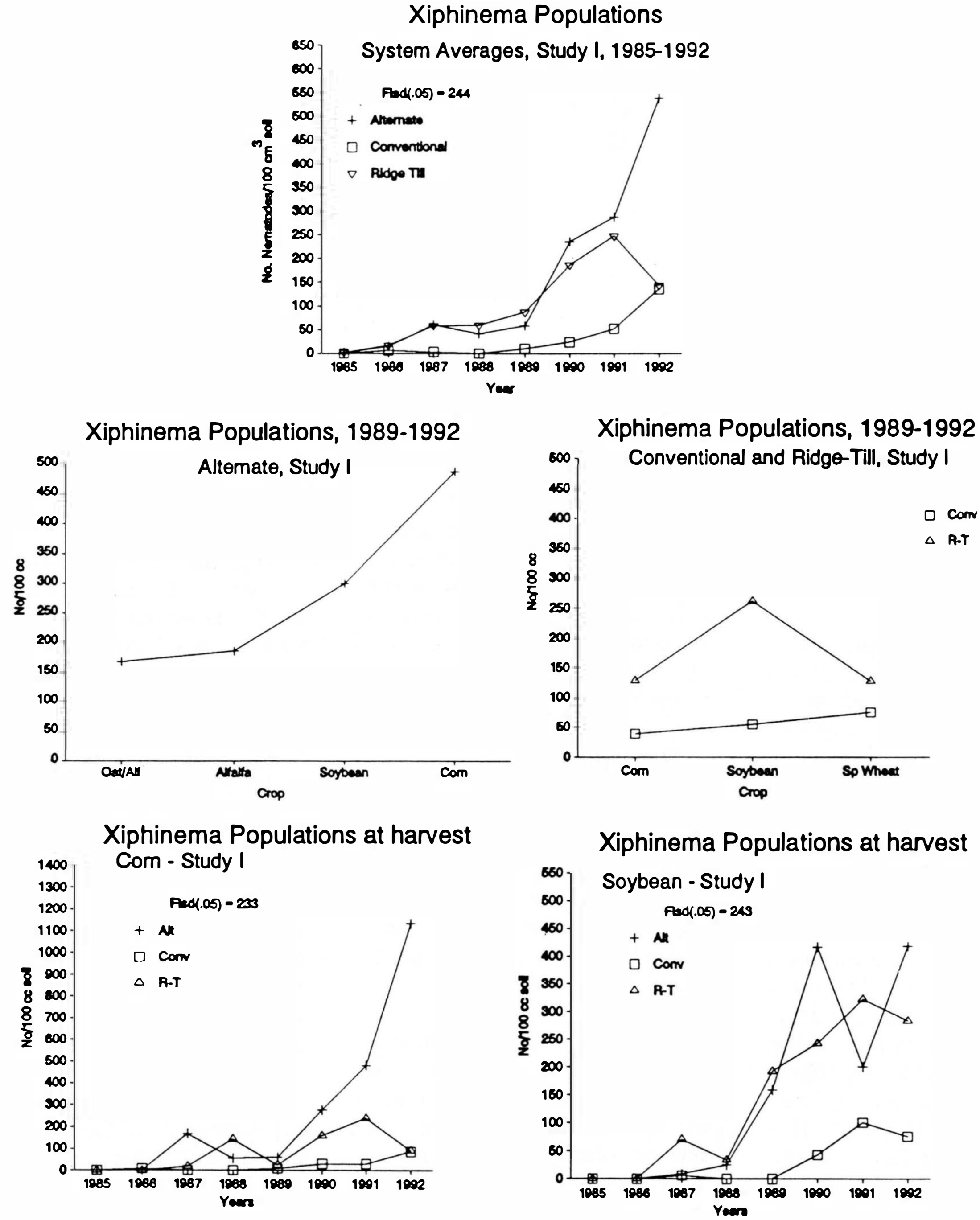
### Dagger Nematodes

Populations of *Xiphinema* (dagger nematodes) in Study I, averaged over all crops in a system, were generally highest in Alt and R-T systems, especially since 1989 (Fig 7). Highest dagger nematode populations in1989-1992 occurred in corn and soybeans in the Alt and R-T systems, while numbers in the Conv system did not differ substantially between crops.

Dagger nematodes prefer relatively undisturbed habitats, and apparently the inversion tillage (moldboard plow) used in the Conv system results in less favorable conditions for this nematode. Dagger nematode numbers in corn and soybeans were low in the early years of the study but increased substantially in the Alt and R-T systems in later years (Fig 7). Populations in Alt corn were very high in 1992 but decreased in R-T corn.

Dagger nematode populations in Study II (Fig 8), averaged over all crops in a system, were generally lower than in Study I, and in the later years of the study numbers in the Alt and M-T were higher than in the Conv. The greater proportion of short-season crops in Study II was probably responsible for the overall lower populations, since food supplies for this obligate parasite would be more limited. Populations in the Alt system averaged over the last 4 years of the study (1989-1992)

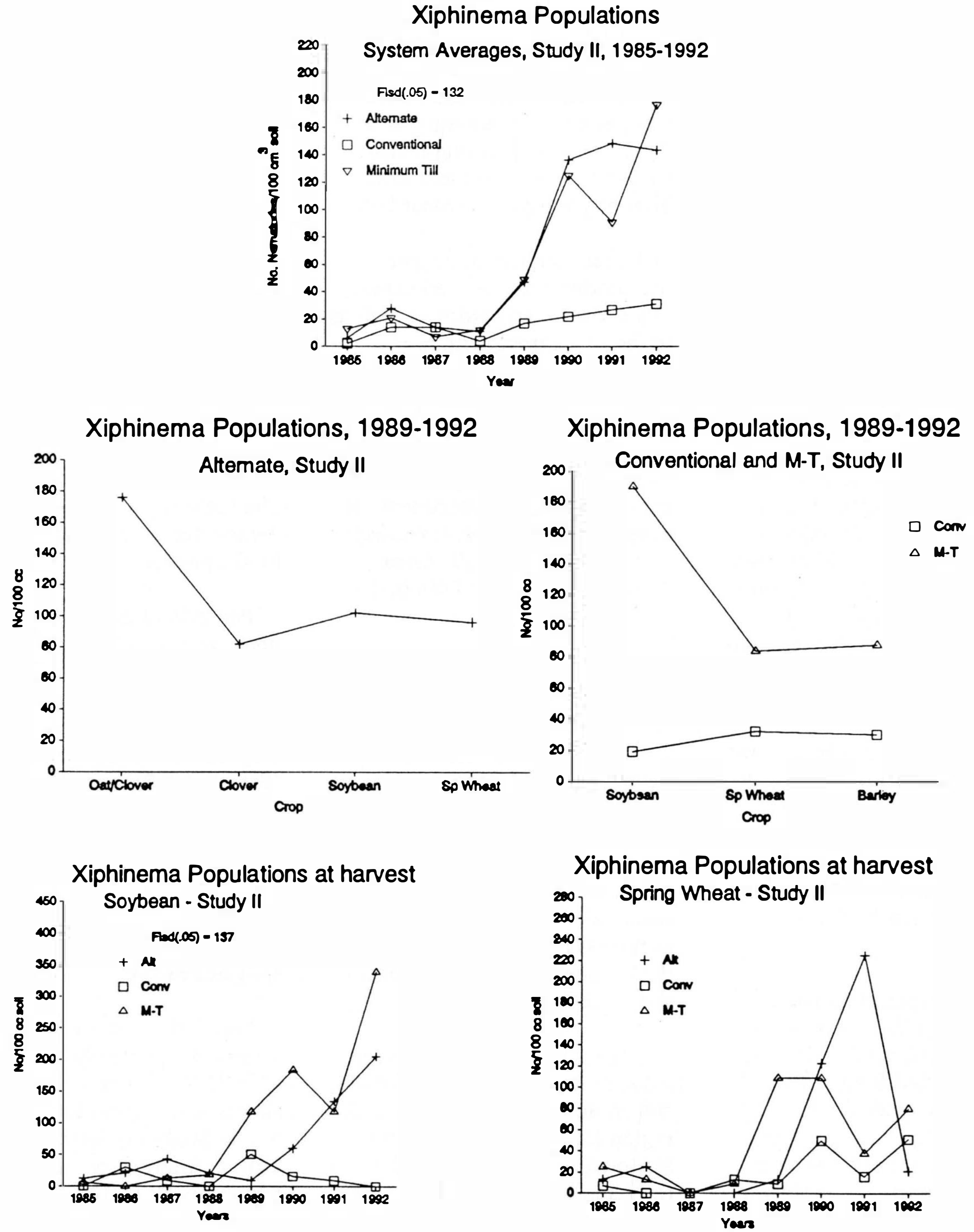
**Figure 7. *Xiphenema* (dagger nematode) populations in Study I.**



were highest in oats/clover (Fig 8). In the M-T system, numbers were highest in soybeans, and populations in the Conv system were low in all crops. A mold-board plow was used frequently in the Conv system and was probably responsible for the low dagger nematode populations.

Populations in soybeans were low in the early years of the study, but they increased significantly in the Alt and M-T systems in later years (Fig 8). Populations in the Conv system remained low throughout the study period. In spring wheat, numbers were gen-

**Figure 8. *Xiphenema* (dagger nematode) populations in Study II.**



erally highest in the Alt and M-T systems in the later years; however, numbers declined substantially in the Alt system in 1992.

### *Xiphinema* Greenhouse Experiments

Populations of dagger nematodes in the Alt, R-T, and M-T systems had reached levels in the later years of the studies that could reduce plant growth. To test this, several greenhouse experiments were conducted to measure the effect of *Xiphinema* on growth of corn and soybeans.

In the first experiment, soil was removed from several plots with high populations of *Xiphinema* in fall 1990. The soil was thoroughly mixed, and half was steamed to eliminate nematodes. Equal amounts of soil were placed in 6-inch plastic pots and seeded with corn or soybeans. Each of the four treatments (check-corn, check-soybean, steamed-soil corn, and steamed-soil soybean) was replicated four times. Plants were thinned to one per pot after emergence and, 2 months later, were removed and total dry weight was measured. Numbers of *Xiphinema* were also determined.

Corn growth was reduced 16% in the nematode-infested soil. No growth reduction occurred in soybeans. Populations of *Xiphinema* on corn nearly tripled over the course of the experiment but remained nearly constant on soybeans.

A second experiment was conducted in fall 1992. Soil infested with high populations of *Xiphinema* was collected from plots and was thoroughly mixed. To eliminate nematodes, half of the soil was spread in a thin layer on a greenhouse bench and rapidly air-dried. This technique provided excellent control of plant parasitic nematodes but did not substantially alter other soil properties, as occurred with steaming in the first experiment. (In the author's experience, steamed soil is often difficult to uniformly moisten.) Equal volumes of soil were placed in plastic pots, seeded with either corn or soybeans, and each of the four treatments (air-dry, corn or soybeans; *Xiphinema* infested, corn or soybeans) was replicated four times. Plants were thinned to one per pot after emergence, and 2 months after planting nematodes were extracted and total plant dry weight was recorded.

Initial numbers of dagger nematodes in the second experiment were nearly twice as high as in the first experiment, and growth of both corn and soybean was significantly reduced. *Xiphinema* populations again nearly tripled on corn, increasing from 2,800 to 7,300 per pot at the conclusion of the experiment. No dagger nematodes were recovered from the air-dried soil. Corn growth was reduced 24% in the infested soil.

Nematode populations on soybeans did not increase over the experiment, but soybean growth was reduced 32%. The failure of *Xiphinema* to increase on soybeans was probably a function of the high initial populations and the small amount of soybean root material available to support this nematode. The dry weight of corn roots was nearly 10 times greater than soybean roots at the conclusion of the experiment.

Dagger nematodes have been associated with damage to alfalfa, clover, and shelterbelt trees in this region (Malek and Smolik 1975, Norton 1965, 1967). Based on results in these preliminary greenhouse experiments, it appears that this nematode is also capable of causing significant damage to corn and soybeans.

The consistently low dagger nematode populations in the Conv systems compared to Alt and reduced-till suggests that occasional use of a moldboard plow, perhaps once every 4 or 5 years, might disrupt population increases of this nematode and thereby prevent significant damage to crops.

### Pin nematodes

Populations of *Paratylenchus* (pin nematodes) did not differ substantially between systems in Study I except in 1992 when numbers increased in the Alt system (Fig 9). In Study II, pin nematode numbers did not change substantially over the course of the study in the Conv and M-T systems but were significantly higher in the Alt system the last 3 years. The highest populations of pin nematodes occurred in soybeans in all systems.

*Paratylenchus* is a very tiny nematode, and low populations probably do not reduce plant growth. However, high populations have been associated with crop damage in South Dakota (Smolik 1987), and the populations in soybeans in these studies warrant further investigation.

### Predaceous and Microbial Feeding Nematodes and Oligochaetes

Populations of predaceous nematodes generally increased over the study period and were significantly higher in the Alt system in Study I in later years (Fig 10). In Study II, populations were highest in Alt and M-T systems.

**Figure 9.** ***Paratylenchus*** **(pin nematode) populations in Study I and II.**

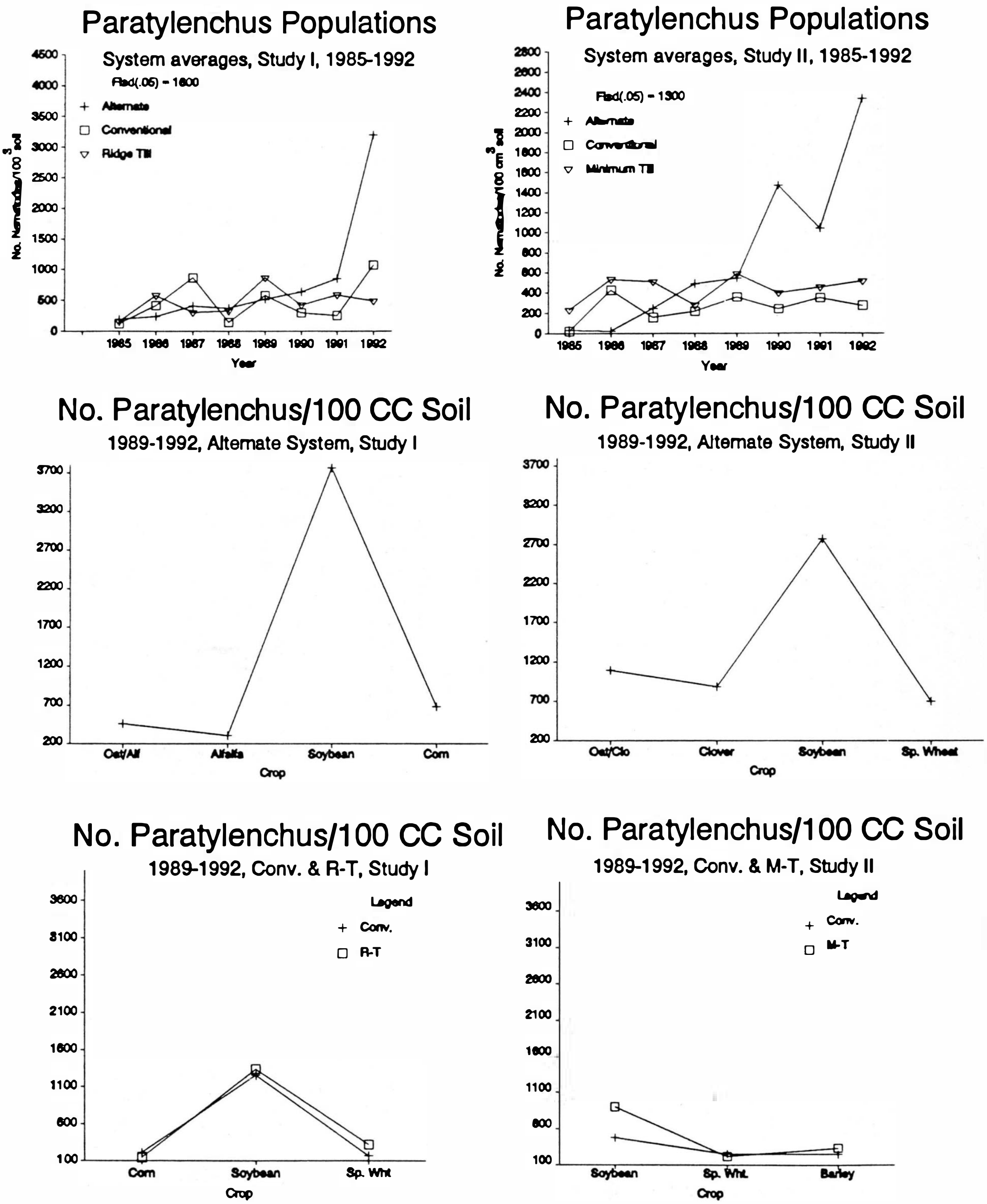
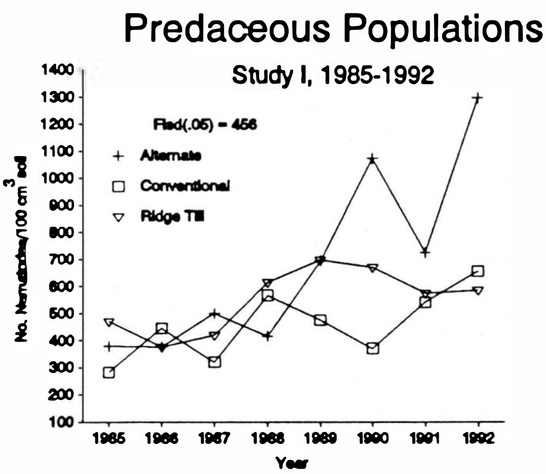
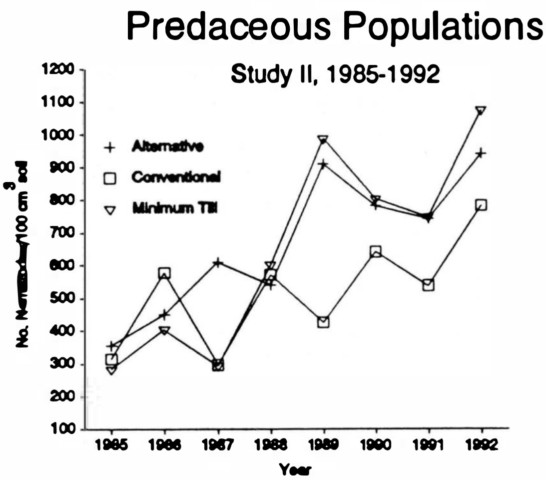
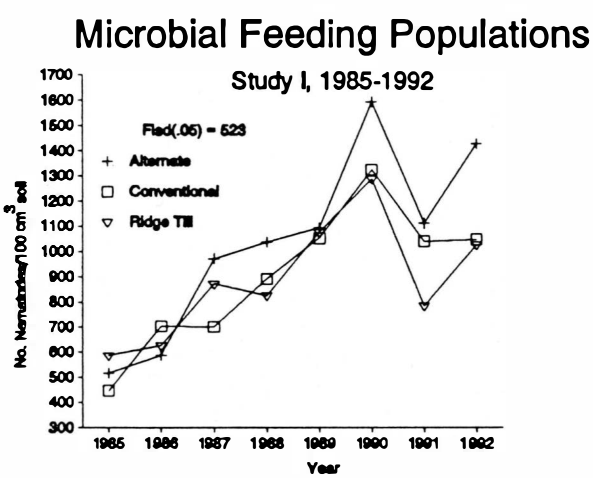
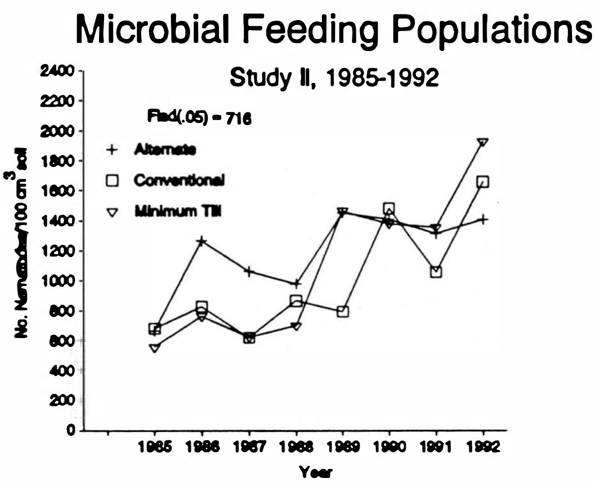


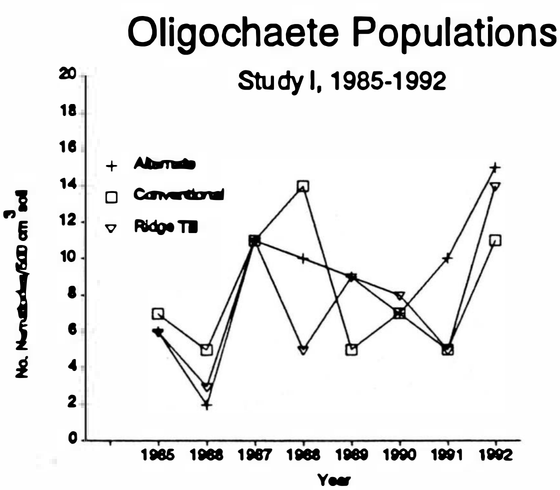
**Figure 10. Predaceous and microbial feeding nematode and Oligochaete populations in Study I and II.**

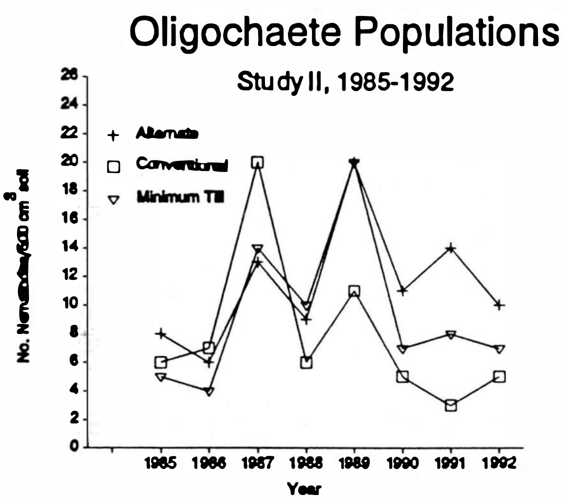


Predaceous nematodes feed on soil animals, including other nematodes, and probably provide some biological control. However, some members in this group are omnivorous and also consume plant material. This group of nematodes has received comparatively little research effort and, because of their substantial soil populations, deserve increased investigation.

Microbial feeding nematodes are generally considered beneficial because they aid in decomposition of organic matter and nutrient cycling. In Study I, populations of microbial feeders increased substantially over the study and were higher in the Alt system in most years (Fig 10). In Study II, populations also increased but were not consistently different between systems.

Oligochaetes are small earthworms; they too aid in decomposition of organic matter. Populations were highly variable across the years of the studies, and in Study I there were no consistent differences between systems (Fig 10). Oligochaete numbers in Study II were higher in the Alt and M-T systems from 1988-1992.

Larger earthworms were occasionally detected in the soil samples, but numbers were low in all years and were not influenced by system. Results indicate the difficulty in substantially influencing earthworm numbers through specific management practices.

## Plant Diseases and Soil Microbes

J.D. Smolik and G.W. Buchenau

Plant pathologists in cooperation with plant breeders have developed crop cultivars with very good resistance to some previously devastating diseases, such as wheat stem rust; however, many other plant diseases pose a continuing threat to the productivity of our farming systems.

Levels of common root rot (*Cochliobolus sativus*) were consistently higher in the R-T spring wheat compared to Conv in Study I. Root rot was also higher in M-T spring wheat in Study II in the later years of the study. Rust was moderately severe on oats in both studies in 1986 and probably contributed to lower yields. In 1987, excessive soil moisture delayed planting of the M-T barley by 2 weeks, and levels of barley yellow dwarf virus (BYDV) were substantially higher in the M-T barley than in Conv. Yield of M-T barley in 1987 was significantly lower than Conv (Fig 2), and BYDV was likely a contributing factor. Infection levels of BYDV in barley were also high in 1988 but were not different between systems.

There were no significant foliar disease problems in 1989. Stem rust developed in both Conv and M-T barley late in the 1990 growing season, and yield loss was estimated at 10%. The extended period of warm, moist weather that accompanied heading of the spring wheat and barley crops in 1991 resulted in severe infection levels of Fusarium head scab. Yields of both crops were reduced 50 to 85% compared to the previous year. Foliar disease problems were minimal in 1992. Overall, foliar disease problems in similar crops did not differ substantially between systems in most years of the study.

Populations of soil microbes were also measured in several years of the studies. In some instances, populations of fluorescent Pseudomonads, *Fusarium* spp., *Pythium* spp., and total fungi were significantly different between systems or crops. However, the data were highly variable, and no consistent differences from year to year were detected. All of the systems in these studies contained three or four different crops in the various rotations, which would have provided a variety of food sources for soil microbes. This diversity of food sources in all the systems may account for the lack of consistent differences in microbe populations between systems.

Farming systems can affect crop yields through their influence on various soil microorganisms which either cause root disease or inhibit the growth of root disease causing agents, thereby controlling these diseases "biologically." This characteristic of certain soils has been termed "suppressiveness" to certain diseases. Disease suppressiveness was measured in the later years of the studies. Although there were occasional significant differences in suppressiveness between systems, the differences were not consistent between years.

## Insect Populations

J.D. Smolik

In general, insects were not a significant problem in most years of the studies. The clover weevil (*Hypera punctata*) appeared to cause some damage to sweet clover, but adequate clover stands were achieved in all years. Grasshopper populations were occasionally high, particularly in drier years, but they were primarily confined to the grassed alleyways. In several years of the studies, malathion was applied to the alleyways early in the season for grasshopper control.

The diversity of crops in all the systems and the absence of monocultures and short-cycle (2-yr) rotations aided in avoiding some of the more common insect pests such as corn rootworms.

This is not to suggest that these systems were free of all insect problems. BYDV, an insect-vectored virus, was a serious problem in some years of the studies.

## Mycorrhizae

D.H. Rickerl and S. Ananth*

Mycorrhizal fungi infect plant roots and can improve P uptake. In most agricultural soils, tillage, P fertilizer, pesticide use, and fallow or monocrop tend to decrease the infection and its benefits.

Mycorrhizal infection levels and spore counts were obtained over the growing season in 1989 and 1990 in both studies. Infection levels in corn increased early in the season, but 10 weeks after planting they declined. There were no consistent differences in infection levels in corn between systems in Study I. Infection levels in soybeans in Study I were higher in the R-T system in 1989 but were not different in 1990. Infection levels tended to drop after ridging and then recover.

Mycorrhizal fungi form resting spores which survive in the soil and can germinate to infect future crops. Mycorrhizal spore populations were highest in the 18-36-inch soil depths, but were not influenced by system or crop. Overall, mycorrhizal infection appeared to be influenced more by soil moisture than by system.

In Study II, mycorrhizal infection levels in spring wheat and soybean were not consistently different between systems in either 1989 or 1990. Infection levels in spring wheat were very high only 3 weeks after planting. Infection levels in soybeans were highest 5 to 9 weeks after planting. As was noted in Study I, spore populations were highest in the 18-36-inch soil depths, and were not affected by system or crop.

## Soil Water Content

D.H. Rickerl and J.D. Smolik

Precipitation is probably the dominant influence on productivity in most crop production systems in South Dakota, and maintenance of adequate levels of soil moisture is essential to the success of a farming system.

Fall soil moisture was recorded in Study I from 1987 to 1992 and in Study II from 1987 to 1991. In most years, soil cores were removed from each plot to a depth of 24 inches, subdivided into 0-6 and 6-24-inch increments, and soil water content measured gravimetrically. In 1987, soil water content in Study II was measured to a depth of 48 inches.

In Study I, soil moisture contents in the 0-6-inch soil layer averaged over all crops in a system were not significantly different between systems (Fig 11). In the 6-24-inch soil depth, moisture content was not consistently different between systems but tended to be lower in the Alt system.

The lowest fall soil moisture levels were measured in 1989, following the year when growing season precipitation was lowest (Fig 1). More than half of the limited precipitation in 1988 came in August and September, too late to be used by most crops, but it was reflected in fall soil moisture measurements.

The average soil moistures associated with the various crops in the systems in Study I over a 6-year period (1987-1992) are also compared in Fig 11. In the Alt system, soil moisture was lowest in the oat/alfalfa plots, which might be expected since these were the only plots that contained actively growing plants at the time of sampling. Fall soil moisture levels recovered substantially following incorporation of alfalfa and were similar to those following soybeans. Treating alfalfa as a biennial appears to have allowed adequate soil moisture recharge for subsequent soybean growth, and it may have partially addressed some of the soil moisture concerns regarding the inclusion of alfalfa in cropping systems (Taylor *et al* 1992).

In the Conv system, the highest soil moisture levels in the 0-6-inch layer occurred following soybeans, whereas the highest levels in the R-T system were measured following corn (Fig 11). The pattern of moisture levels in the 6-24-inch layer following the various crops was similar for both Conv and R-T systems, being highest following soybeans, intermediate for spring wheat, and lowest following corn. For all crops and systems in Study I (Fig 11), the highest average soil moisture levels in the 0-6-inch

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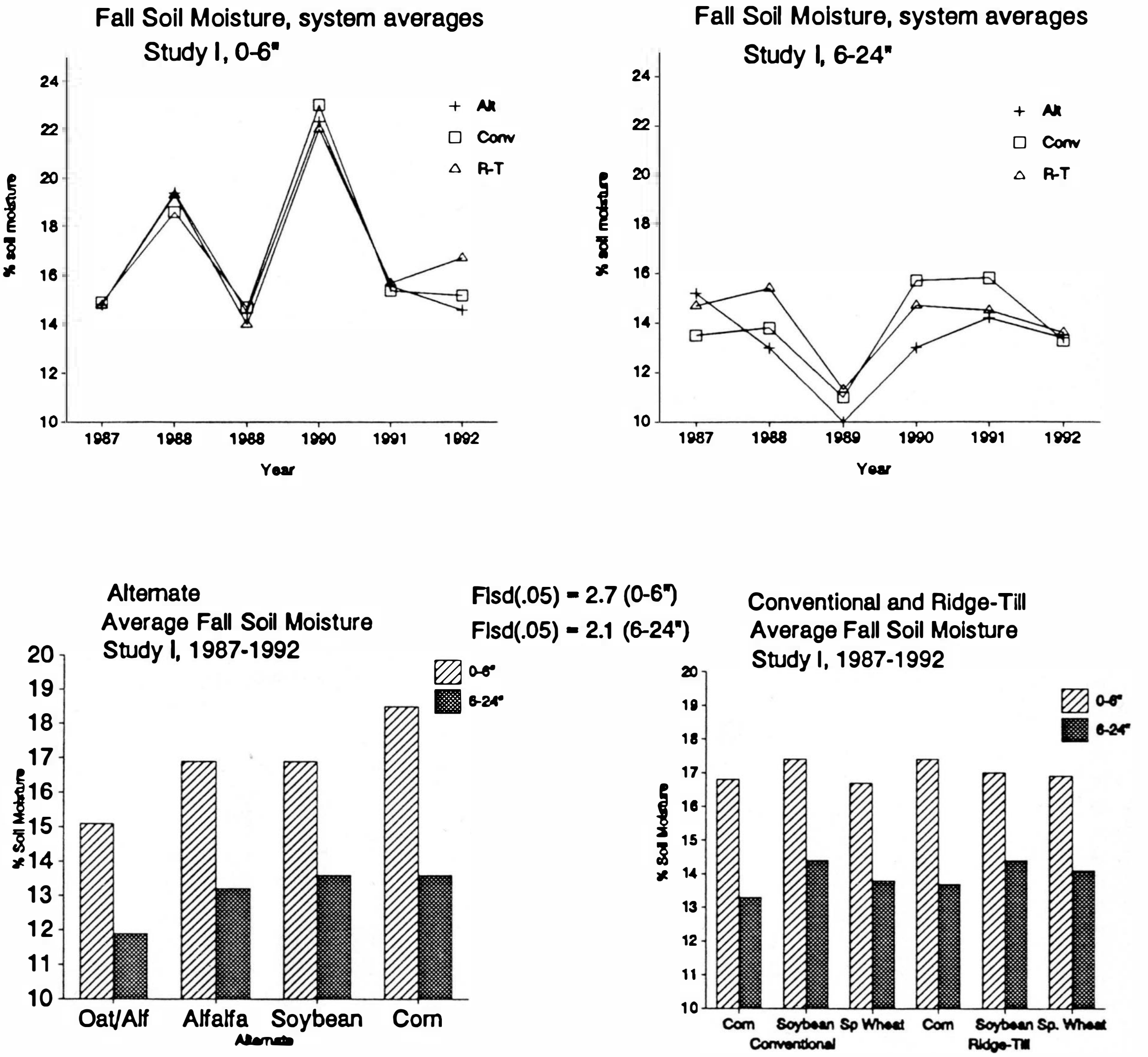
* Seeth Ananth was a graduate research assistant in the Plant Science Department, SDSU.

**Figure 11. Fall soil moisture in Study I.**



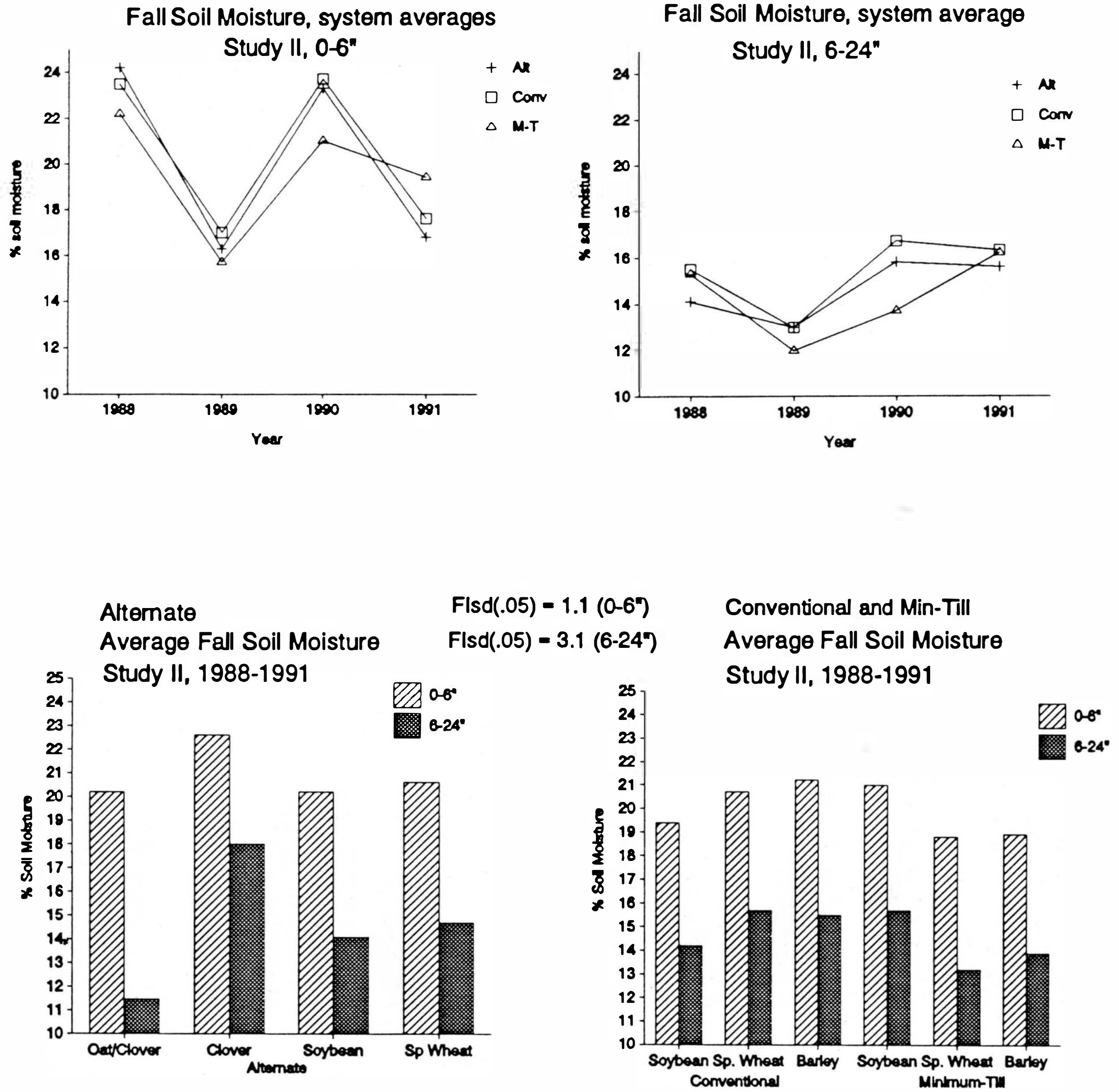

layer averaged over the 1987-1992 period occurred in the Alt system following corn. In the 6-24-inch layer, the highest average soil moisture levels followed soybean in the Conv and R-T systems.

Soil moisture in the 0-6 and 6-24-inch depths in Study II, averaged over all crops in a system, was not significantly different between systems (Fig 12). Soil moisture was measured to a depth of 48 inches in 1987 in 12-inch increments, and moisture content was highest in the clover, 1 bar vs. 15 bar in other crops (R. Kohl, unpubl). Soil moistures in the 0-6-inch depth in all systems were comparatively high in 1988.

Soil moisture averaged over a 4-year period (1988-1991) in both the 0-6 and 6-24-inch soil depths was significantly higher following clover in the Alt system (Fig 12). Clover was incorporated in early to mid-July in most years, thereby allowing a greater opportunity for soil moisture recharge than with the other crops.

The lowest soil moisture in the Alt system was in oats overseeded with clover, which was similar to the moisture relationships in oats overseeded with alfalfa (Fig 11). In the Conv system, average soil moisture in the 0-6-inch depth

## Figure 12. Fall soil moisture in Study II.




was highest following barley and in the M-T system was highest following soybeans. In the 6-24-inch depth, soil moisture in the Conv system was highest following spring wheat, and in the M-T system was the highest following soybeans.

The cropping systems in Study II, emphasizing small grains, were designed to require less moisture than the systems in Study I. In most years, fall soil moisture at both sampling depths was numerically higher in Study II than in Study I.

One of the frequently stated advantages of reduced-till systems is their ability to conserve soil moisture. Comparing soil moisture in the R-T and M-T systems to those in the Conv did not indicate any significant advantage for the reduced-till systems over the study period.

The absence of a moisture advantage may have been due to the lack of intense tillage in any of the systems; for example, soybeans were never fall-tilled. The greater amount of surface residues associated with reduced till systems can improve snow catch and thereby increase soil moisture; however, snow cover was light in most years of the studies. Treating alfalfa as a biennial appeared to reduce the potentially negative effects of long-term alfalfa stands on soil moisture reserves. Also, the inclusion of clover (green manure) in the Alt system in Study II substantially improved the overall average soil moisture relationships in that system and may have been partly responsible for the more stable production in this system compared to Conv and M-T (Table 7).

## Surface Residues and Soil Erosion Estimates

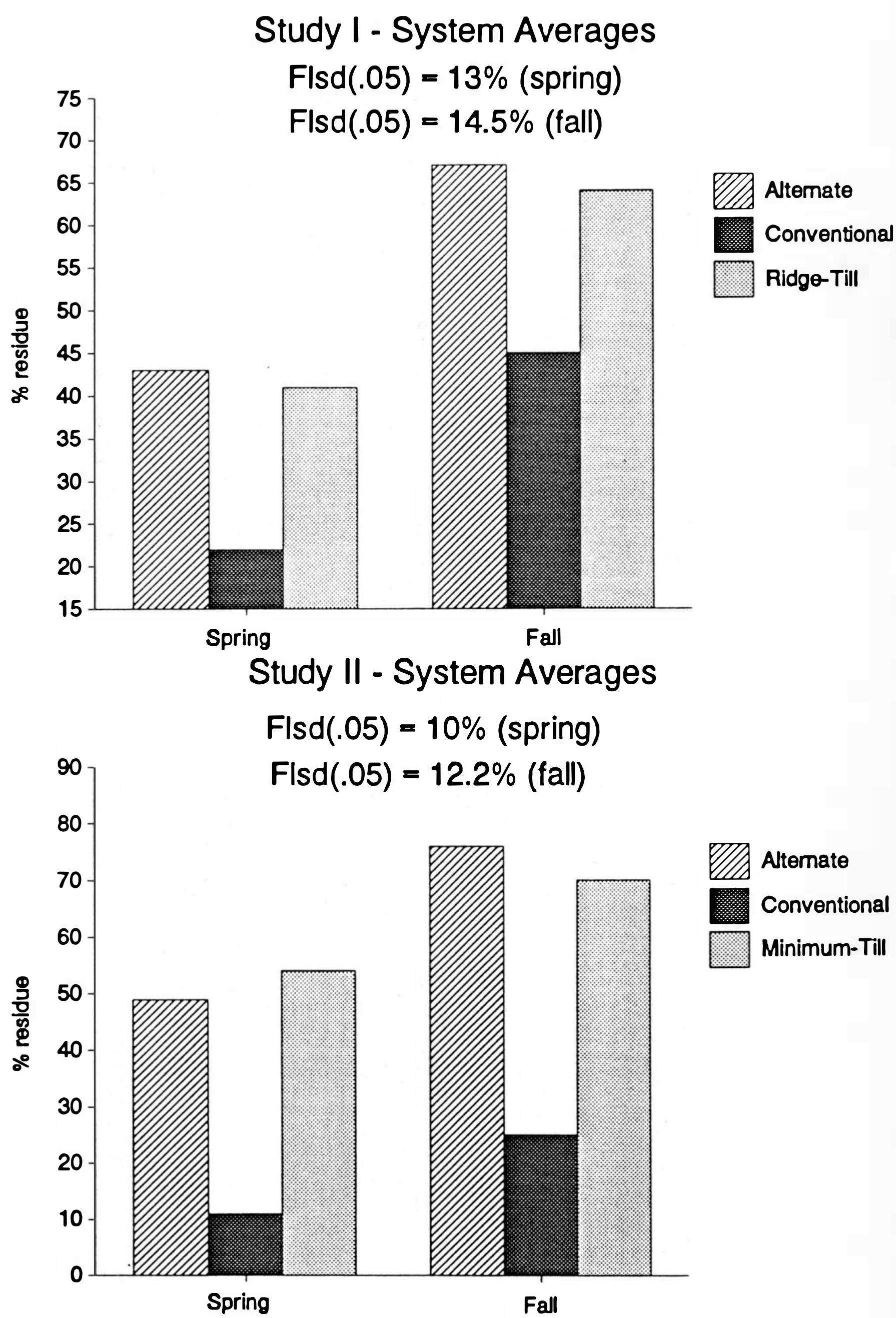
D. H. Rickerl, T.A. Machacek, and J.D. Smolik

Soil erosion is a continuing threat to the long-term productivity of farming systems, and current federal programs place a great deal of emphasis on limiting soil losses. One of the methods for limiting soil erosion is retention of adequate levels of crop residues on the soil surface. Fall surface residues help to insulate the soil, reduce wind erosion, and aid in trapping snow. Spring residues protect the soil surface from wind and water erosion during the period between planting and establishment of the crop canopy. Present soil conservation compliance regulations for highly erodible land require 30% surface residue cover after planting.

Surface residues were measured using Soil Conservation Service procedures (line-intersect method) at four random locations in each plot. Plant residues measured included both crops and weeds.

Surface residues in Study I, averaged over all crops in a system from 1990-1992, were highest in the Alt system (Fig 13). Residues were also high in R-T; both of these systems exceeded 30% residue cover in spring after planting and after tillage in the fall. Residues in the Conv system exceeded 30% in the fall, but postplant spring residues did not.

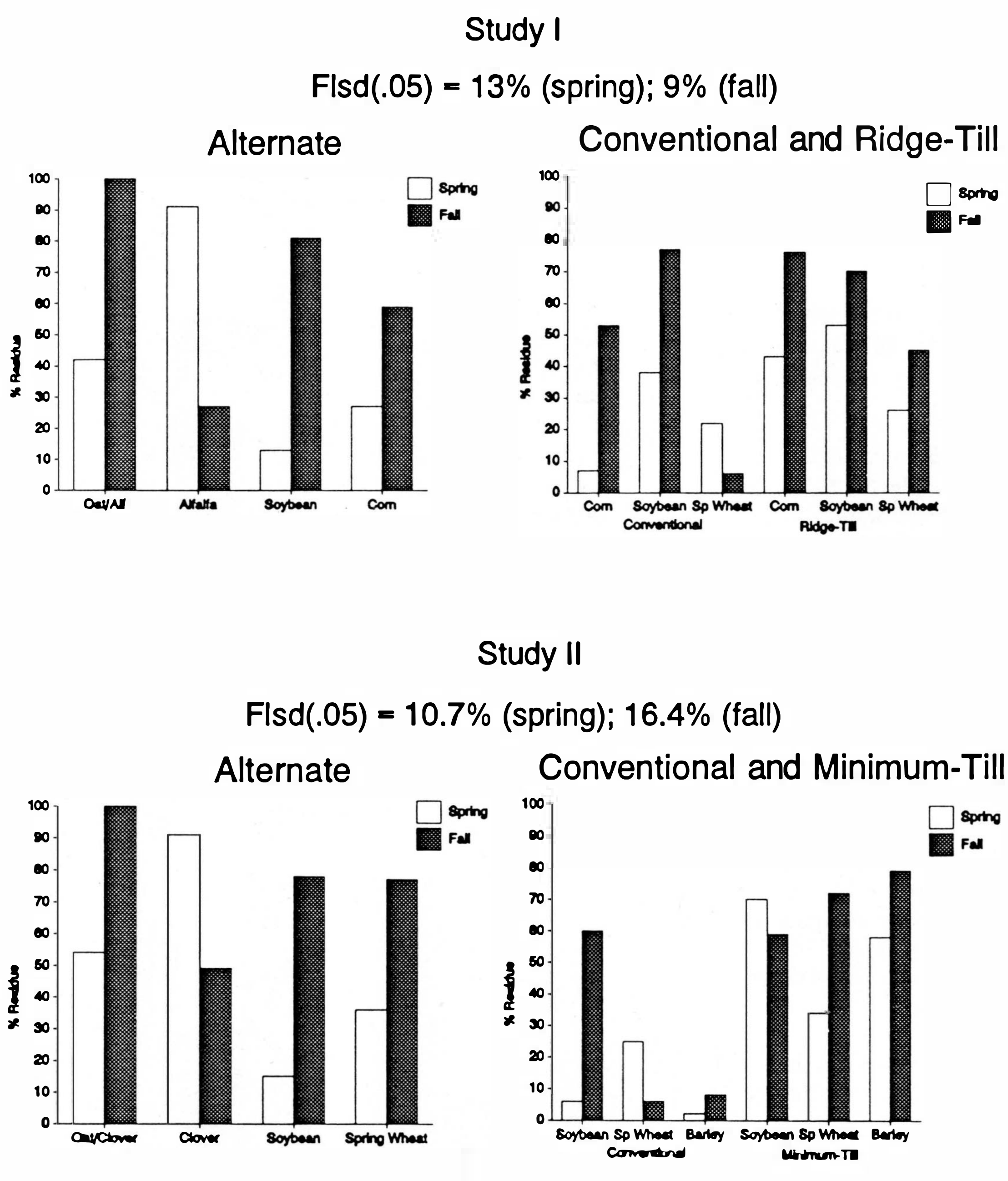
**Figure 13. Surface residues averaged over all crops in a system (1990-1992), Study I and II.**



In Study II, spring residues were highest in the M-T system, and fall residues were highest in Alt. Both the Alt and M-T systems provided very good protection of the soil surface. The Conv system in Study II did not meet 30% residue cover in either the spring or fall. Overall, surface residues in the Conv systems were significantly lower than the Alt and reduced-till systems.

Surface residues associated with the various crops in the systems in Study I over the last 3 years of the studies are compared in Fig 14. In the Alt system, the highest residues were associated with alfalfa, and fall residues were also high following soybeans and corn. Postplant spring residues were lowest in soybeans. In the Conv system, fall residues were highest following soybeans and lowest following spring wheat which had been fall plowed.

**Figure 14. Average surface residues associated with the various crops in Study I and II (1990-1992).**



Residue covers based on line intersects are often high for soybeans but do not account for the mass of the residue or its degradation rate. Therefore, residue counts for soybeans change rapidly from fall to spring, and crops following soybeans often had low postplant residue cover.

Spring residues in the Conv system were lowest in corn. All crops in the R-T system exceeded 30% residue cover in both spring and fall except for postplant residues in spring wheat.

In Study II, all crops in the Alt system exceeded 30% residue cover except soybeans in the spring (Fig 14). The Conv system in Study II provided very poor soil surface protection except for soybeans in the fall. All crops in the M-T system exceeded 30% residue cover in both spring and fall.

Overall, information in Figs 13 and 14 indicates that Alt systems can provide soil surface protection equal to that achieved in more conventional types of reduced-till.

### Soil Erosion Estimates

Soil erosion on a field-scale basis was estimated for systems in Study I and II using the Universal Soil Loss Equation (USLE), the surface residue (Figs 13 and 14), and tillage data in Tables 1 and 2. Wind erosion estimates were negligible in all systems, due primarily to soil type. Using the moldboard plow in the Conv systems resulted in the highest estimated water erosion (1.4 to 1.7 ton/A). The absence of a forage legume in the Conv system rotations also increased the potential erosion.

Soil erosion estimates in the Alt systems were approximately half those of the Conv systems and just slightly higher than the R-T and M-T systems. There was no difference in the estimated soil erosion rates between R-T and M-T. Erosion estimates in all the systems were well below the 5 ton/acre "T" value, due primarily to the gentle slopes (0-2%) in the study area.

## Nutrient Relationships

D.H. Rickerl and J.D. Smolik

The farming systems compared in these studies utilized substantially different approaches for supplying nutrients to crops. Nutrients in the Conv and reduced-till systems were primarily fossil-fuel based (conversion of natural gas to nitrogen fertilizer); nutrients in the Alt systems were primarily legume-based (alfalfa in Study I and clover in Study II). Commercial fertilizer was applied in the Conv, R-T, and M-T systems based on soil tests and yield goals.

The Alt system in Study I relied primarily on the forage legume (alfalfa), supplemented by moderate applications of feedlot manure following oat harvest (Table 1), to meet crop nutrient needs. In Study II, crop nutrients in the Alt system were supplied primarily by the unharvested clover (green manure). Soils in the study area and in much of South Dakota are naturally high in their K-supplying ability, and soil test levels of K remained moderate to high over the study period.

Average nutrient removal from the various systems each year on a whole-farm basis (540 tillable acres) is compared in Table 24. Nutrient removal was based on data in Tables 4, 5, and 6 and on tissue analyses for each cutting of the alfalfa. For example, N removal by corn in the Conv system was 14,772 bu (Table 5) X 56 lb/bu (test wt) X 0.845 (conversion to dry wt) X 0.015 (% N) = 10,485 lb.

The greatest removal of N, P, and K occurred in the Alt system in Study I, which might be expected since, in terms of crop mass removed, it was also the most productive (Fig 4). The lowest nutrient removal occurred in the Alt system in Study II, due to the lower production in this system (Table 6) and the return of clover to the system.

Nutrients supplied to the systems through fertilizer applications, livestock manure, soybeans, alfalfa, and clover are listed in Table 25. The nutrient contributions for clover (green manure) are based on tissue analyses for each cutting and on a 30 lb/A N credit for roots and crowns.

N is often the most limiting nutrient in crop production, and maintenance of adequate N levels is essential to the success of a farming system. In Study I the greatest apparent disparity between total N removal and total N supplied occurred in the Alt system in Study I (Tables 24 and 25). However, most of the N removed in this system was in alfalfa hay, and a major proportion of the N would have been supplied by the alfalfa through fixation of atmospheric nitrogen.

The N removed by non-leguminous crops is also listed in Table 24. Based on N supplied (Table 25), it appears that all of the systems in both studies had adequate N supplies.

Through the addition of livestock manure, the Alt system in Study I returned approximately 80% of the P removed compared to only 7-8% returned in the Conv and R-T systems. The manure applications also returned a substantial proportion of the K removed. In Study II the nutrients supplied through clover (green manure) exceeded both N and K removal, and equaled approximately 29% of the P removed (Tables 24 and 25). The Conv and M-T systems in Study II, through applications of P fertilizer, returned only 11-12% of the P removed.

### Nitrate-N Relationships and Soil Test Results

Soil samples were obtained each year after fall tillage, except in 1986, when samples were collected the following spring prior to planting. Four to six cores were removed to a depth of 24 inches from each plot, subdivided into 0-6 and 6-24-inch increments, and pooled by increment. In 1992 (the last year of the study), plots were sampled to 48 inches in Study I. Samples were submitted to the SDSU Soil Testing Laboratory for analyses.

Fall soil test $NO_3$-N levels associated with the various crops in Study I and II, averaged over a 4-year period (1989-1992), are compared in Fig 15. In Study I, levels of $NO_3$-N in the 0-24-inch profile in the Alt system did not exceed 45 lb and varied by approximately 3X across the crops in the rotation.

Levels of $NO_3$-N in the Conv and R-T systems were significantly higher than in the Alt system for all crops except R-T soybeans, and the variability in $NO_3$-N levels across crops in the Conv and R-T systems was less than 2X.

Levels of $NO_3$-N in the Alt system in Study II varied substantially across crops (7X), whereas levels in the Conv and M-T were less variable (<2X). The levels of $NO_3$-N were consistently higher in the Conv systems compared to R-T and M-T, even though the reduced-till systems had received more N fertilizer (Table 25) and also had lower crop yields (Figs 1 and 2) and therefore had less N removal (Table 24) in the later years of the studies.

Levels of plant-available N can influence weed populations (Callaway 1992), and the variability in nitrate-N in the Alt systems may be a part of the "rotation-effect" that enhances the ability of these systems to maintain adequate levels of weed control without the use of herbicides. Weeds are at a competitive disadvantage in these systems because of the sequence of crops relative to high levels of plant-available N.

For example, in the Alt system in Study II, the rotation begins with oats overseeded with clover. Oats are competitive with weeds and also utilize much of the N remaining after the spring wheat crop. Clover is a legume and is

**Table 24. Nutrients removed from the systems each year (average of 1986-1992), whole-farm basis (540A).**

| System | Crop | N | | P | K |
|---|---|---|---|---|---|
| | | | lbs | | |
| **STUDY I** | | | | | |
| Alternate | Corn | 6,641 | | 1,264 | 2,198 |
| | Soybean | 11,260 | | 987 | 3,089 |
| | Oats | 3,626 | | 764 | 897 |
| | Alfalfa | 35,868 | | 2,911 | 26,263 |
| | Total: | 57,395 | (10,267)[a] | 5,926 | 32,447 |
| Conventional | Corn | 10,485 | | 1,992 | 3,495 |
| | Soybean | 14,038 | | 1,283 | 4,109 |
| | Sp. Wheat | 9,114 | | 1,268 | 1,614 |
| | Total: | 33,637 | (19,599)[a] | 4,543 | 9,218 |
| Ridge-Till | Corn | 10,379 | | 1,828 | 3,281 |
| | Soybean | 12,296 | | 1,028 | 3,491 |
| | Sp. Wheat | 7,928 | | 1,051 | 1,423 |
| | Total: | 30,603 | (18,307)[a] | 3,907 | 8,195 |
| **STUDY II** | | | | | |
| Alternate | Soybean | 13,323 | | 1,138 | 3,649 |
| | Sp. Wheat | 7,433 | | 1,086 | 1,405 |
| | Oats | 4,003 | | 851 | 990 |
| | Total: | 24,759 | (11,436)[a] | 3,075 | 6,044 |
| Conventional | Soybean | 14,995 | | 1,287 | 4,450 |
| | Sp. Wheat | 9,326 | | 1,227 | 1,604 |
| | Barley | 8,776 | | 1,444 | 2,301 |
| | Total: | 33,097 | (18,102)[a] | 3,958 | 8,355 |
| Minimum-Till | Soybean | 13,994 | | 1,172 | 3,923 |
| | Sp. Wheat | 9,255 | | 1,203 | 1,587 |
| | Barley | 7,099 | | 1,190 | 1,844 |
| | Total: | 30,348 | (16,353)[a] | 3,565 | 7,354 |

[a] Figure in parenthesis is the amount of N removed by non-leguminous crops.

**Table 25 . Nutrients supplied to the systems each year (average of 1986-1992), whole-farm basis (540A)[a].**

| STUDY I | | N | P | K |
|---|---|---|---|---|
| System | Source | | lbs | |
| Alternate | Livestock Manure | 14,520 | 4,800 | 16,693 |
| | Alfalfa | 28,575 | | |
| | Soybean | 3,381 | | |
| | Total: | 46,476 | | |
| Conventional | Fertilizer | 21,780 | 330 | 0 |
| | Soybean | 4,373 | | |
| | Total: | 26,153 | | |
| Ridge-till | Fertilizer | 24,518 | 330 | 0 |
| | Soybean | 3,757 | | |
| | Total: | 28,275 | | |
| **STUDY II** | | | | |
| Alternate | Clover (green manure) | 14,756 | 877 | 8,039 |
| | Soybean | 3,994 | | |
| | Total: | 18,750 | | |
| Conventional | Fertilizer | 13,152 | 420 | 0 |
| | Soybean | 4,633 | | |
| | Total: | 17,785 | | |
| Minimum-Till | Fertilizer | 18,555 | 420 | 0 |
| | Soybean | 4,222 | | |
| | Total: | 22,777 | | |

[a] Soybean N credit based on 1 lb N/bu, alfalfa roots and crowns = 225 lb N/A, clover roots and crowns = 30 lb N/A (R. Gelderman, SDSU soil testing, pers comm).
Note: Feeding all corn and alfalfa produced in Alt system (Study I) to ruminant livestock would produce approximately 90% of the manure applied (J. Wagner, SDSU, pers comm).

able to meet its own N requirements and thus is also competitive with weeds. In the second year of the rotation the established clover outgrows weeds early in the season. The clover crop is mowed and partially incorporated in early summer (green manure), and by fall N levels have substantially increased. The fallow period following incorporation of the clover also aids in weed control. The soybean crop in the third year of the rotation no doubt utilizes some of the N produced by the clover, but it also produces N, and levels of $NO_3$-N remain moderately high. The fourth crop in the rotation has high N requirements, and N levels drop substantially following spring wheat. Spring wheat is also competitive with weeds (Table 22). The rotation resumes with oats/clover and a subsequent increase in N levels (Fig 15).

In contrast to the Alt system, the N levels in the Conv and M-T systems remain at moderate to high levels across all crops in the rotations. These N levels, coupled with less weed competitive crops, may provide conditions more conducive for weed growth (Callaway 1992), which in turn leads to the need for continuing herbicide applications.

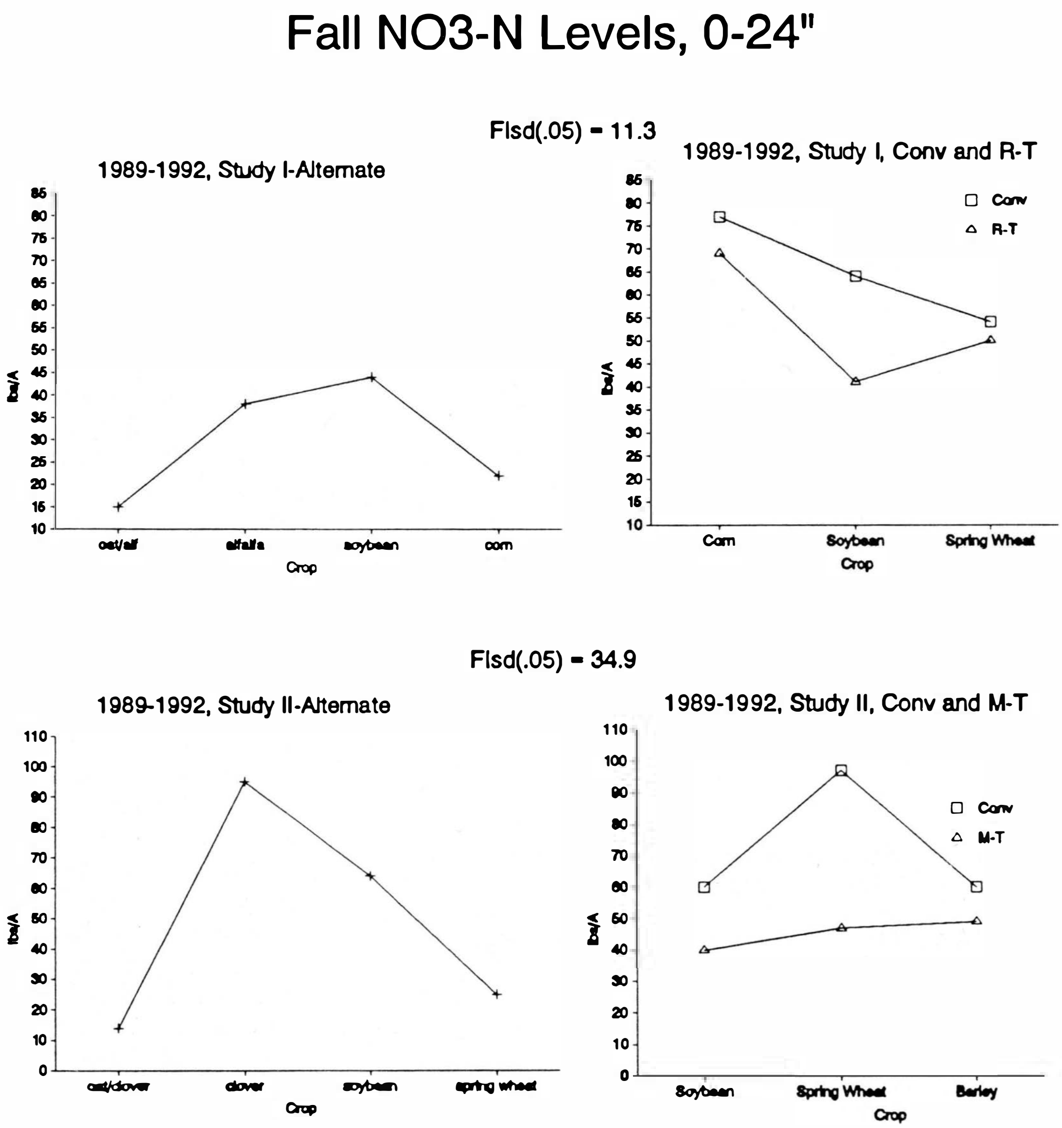
The accumulation of nitrate-N in agricultural soils is of growing concern because of its ability to leach and potentially pollute groundwater. In 1992, 8 years after initiation of the study, levels of $NO_3$-N to a depth of 4 feet in the Conv and R-T systems in Study I were approximately two to three times higher than in the Alt system (Table 26).

The distribution of N also differed considerably. In the Alt system, N was distributed approximately 50:50 between the 0-24 and 24-48-inch depths, while in the Conv and R-T systems the distribution was approximately 40:60 with the majority of the N below 2 feet.

The high $NO_3$-N levels deeper in the soil profile in the Conv and R-T systems are an area of concern for both economic and environmental reasons and apparently are a result of fertilizer applications in excess of crop use. Residual $NO_3$-N following the poor 1992 corn crop in the Conv and R-T systems might have been expected. Corn in these two systems was fertilized for a 120 bu/A yield goal, and only about half of that was obtained. However, residual $NO_3$-N was also high following spring wheat, particularly in the Conv system (Table 26), even though Conv spring wheat yield exceeded the yield goal by 18%.

The mass balance information in Tables 24 and 25 (N removed vs. N supplied) indicates more N was removed from all of the systems than was supplied, yet $NO_3$-N levels were significantly higher in the Conv and R-T systems compared to the Alt (Table 26). It appears that we underestimated the N supplied through such processes as N fixation by soybeans and decomposition of

**Figure 15. Fall soil test nitrate-N levels in Study I and II, 1989-1992.**




organic matter and thus overestimated the N requirements of corn and spring wheat in the Conv and R-T systems.

Other factors that may have contributed to the higher $NO_3$-N levels in the Conv and R-T systems was the form in which N was supplied. Nitrogen in the Alt systems was supplied in an organic form and probably would have been released more slowly (Papendick *et al* 1987), and therefore it would have been less susceptible to leaching than the more soluble N supplied in the Conv and R-T systems. The absence of a deep-rooted crop, such as alfalfa, in the Conv and R-T rotations also may have contributed to an increase of N deeper in the soil profile.

The R-T system had more N fertilizer applied than the Conv (Table 25) but was less productive in the later years of the study (Fig 4). Thus, higher $NO_3$-N levels might have been expected in the R-T system compared to Conv, not the reverse (Table 26). It is possible that N was denitrified or moved below the 48-inch depth, since reduced-till systems can increase denitrification (Rice and Smith 1982) and nitrate leaching (Rickerl et al unpubl).

## Organic Matter

Soil organic matter is a major reservoir of nutrients for crops. For example, 1% organic matter in the 0-6-inch soil layer contains approximately 1,400 lb N/A.

Organic matter levels increased substantially over the first several years of the studies, declined significantly following the 1988 drought, and in Study I again increased to near their previous highs (Fig 16). In Study II, organic matter levels increased from 1989 to 1990 but did not reach previous highest levels.

Alternative and reduced-till systems have been reported to increase soil organic matter (Reganold 1988, Karlen *et al* 1992); however, in Study I there were no significant differences between systems (Fig 16). In Study II, organic matter levels were generally greater in the Alt and M-T systems compared to the Conv system (Fig 16).

The moldboard plow buries most of the surface crop residues and speeds decomposition of organic matter. The more extensive use of a moldboard plow in the Conv system in Study II (Table 2) may explain the lower organic matter levels in this system. Overall, no system seemed to offer a consistent trend or advantage in organic matter accumulation.

### Phosphorus

System averages of soil test P levels for years 1985-1992 are shown in the upper portion of Figure 17. Initial soil test values in fall 1985 were in the high to medium range. P applications were of feedlot manure in the Alt system in Study I (Table 25) and P fertilizer at recommended rates in the Conv, M-T, and R-T systems in spring 1988 and 1989.

Regardless of P application, soil test P levels declined initially, lev-

**Table 26. $NO_3$-N levels in Study I, Fall 1992**

| | | lbs $NO_3$-N/Depth | | | | |
|---|---|---|---|---|---|---|
| System | Crop | 0-6" | 6-24" | 24-36" | 36-48" | Total N 0-48" |
| Alternate | Oat/Alf | 2.1[a] | 6.5 | 6.3 | 11.0 | 25.8 |
| | Alfalfa | 12.5 | 15.7 | 6.9 | 7.4 | 42.4 |
| | Soybean | 13.7 | 32.4 | 16.4 | 14.4 | 76.9 |
| | Corn | 6.7 | 14.3 | 20.4 | 19.6 | 61.0 |
| | System Avg: | 8.8 | 17.2 | 12.5 | 13.1 | 51.5 |
| Conventional | Corn | 18.1 | 70.7 | 31.5 | 45.4 | 165.7 |
| | Soybean | 6.3 | 28.4 | 46.8 | 52.2 | 133.6 |
| | Sp. Wheat | 13.3 | 33.2 | 48.1 | 40.3 | 134.9 |
| | System Avg: | 12.6 | 44.1 | 42.1 | 46.0 | 144.7 |
| Ridge-Till | Corn | 17.3 | 33.5 | 22.9 | 24.3 | 97.9 |
| | Soybean | 6.7 | 28.9 | 38.0 | 41.8 | 115.3 |
| | Sp. Wheat | 13.4 | 23.5 | 24.7 | 25.6 | 87.1 |
| | System Avg: | 12.5 | 28.6 | 28.5 | 30.6 | 100.1 |
| | $Flsd_{.05}$ = | 5.2 | 12.4 | 14.6 | 21.2 | 41.6 |

[a] Average of four replications.

**Figure 16. Fall soil test organic matter levels, Study I and II.**

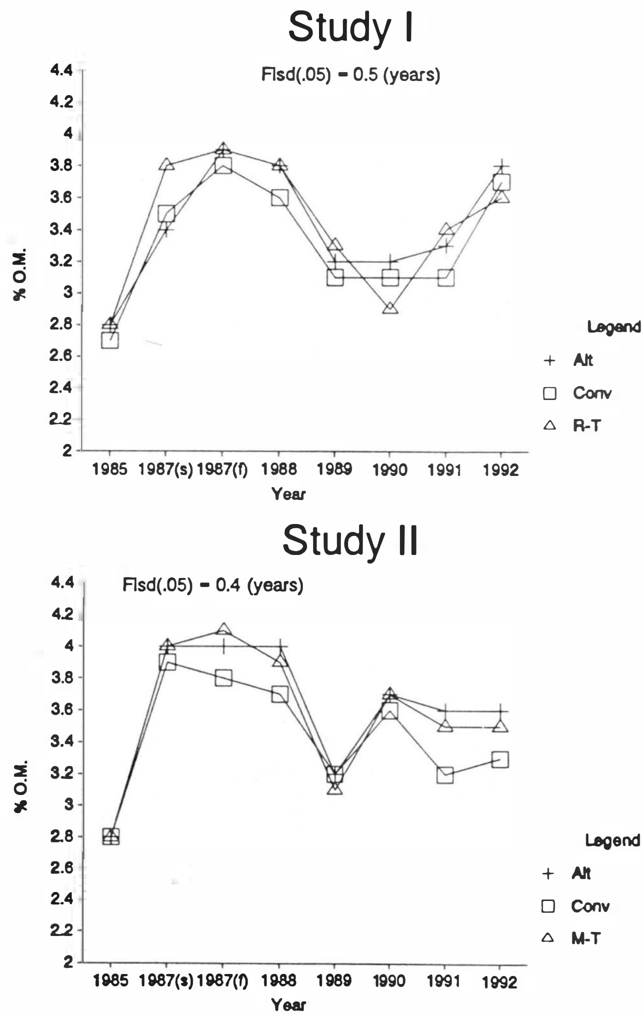
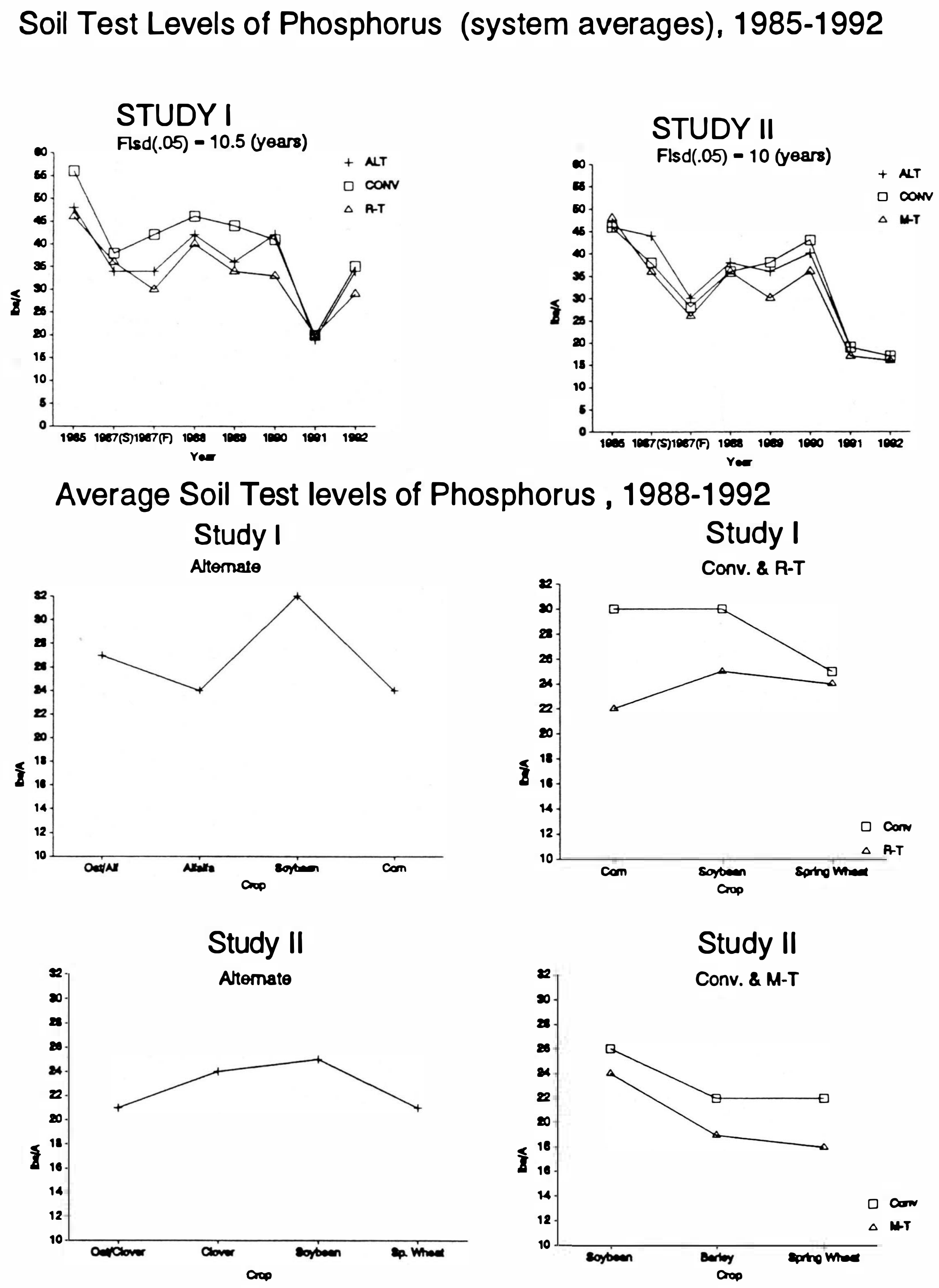


**Figure 17. Fall soil test phosphorus levels in Study I and II.**



eled off for several years, declined markedly in 1991, and in 1992 either recovered somewhat (Study I) or remained low (Study II). There were no apparent reasons for the sharp decrease in soil test P levels from 1990 to 1991. Also, there were no consistent differences in soil test P between systems in Study I even though the Alt system returned, through manure applications, approximately 80% of the P removed, while only 7 to 8% was returned in the Conv and R-T systems (Tables 24 and 25).

The lower half of Figure 17 depicts soil test P levels by crops within systems in Study I and II. Average soil test P levels over a 5-year period were highest following soybeans. The higher P levels following soybeans are worthy of further investigation.

The Alt system produced the greatest fluctuation of soil test P levels in Study I and the least fluctuation in Study II. In both studies, reduced tillage (M-T and R-T) maintained lower soil test levels than the Conv systems. This may have been due to limited mineralization of organic P and supports the conclusions of others (Moschler *et al* 1975) who have found an increased need for P fertilizer in reduced tillage systems.

The results of these studies indicate the inappropriateness of using measurements of plant-available P to determine the long-term ability of a soil to supply crop needs. Organic P levels, mineralization, and immobilization also need to be addressed.

A concern about alternative farming systems was the ability of these systems to supply adequate levels of nutrients, particularly P and K (Taylor *et al* 1992). Soil test levels of K are high in most South Dakota soils, and the SDSU Soil Testing Service rarely recommends K applications; however, the Service commonly recommends application of P fertilizer (R. Gelderman, SDSU, pers comm). Current studies at SDSU are measuring the total amount of P in the 0-6 and 6-24-inch soil profiles in Studies I and II. Preliminary data from Study II indicate that total soil P was not different between systems. The average amount of P in the 0-24-inch soil layer was approximately 5,000 lb/A (J. Doolittle, SDSU, unpubl) The Alt system in Study II did not receive any external sources of P over the 1986-1992 period. Based on rates of P removal in this system (Table 24), the total amount of P in the 0-24-inch soil layer would meet crop needs for approximately 890 years. A more complete analysis of P relationships will be reported in a forthcoming journal article.

## Soybeans Following Alfalfa?

Alfalfa supplies a great deal of N to the Alt system in Study I, so why did soybeans follow alfalfa instead of corn?

There were several reasons. First, the Alt system in Study I was adopted from farmers in the Madison, S.D., area who had found it to be an effective crop rotation system. Second, a moldboard plow was not used to incorporate the alfalfa, and therefore much of the alfalfa residue remained at or near the soil surface where it was slower to decompose and release N. Thus, a substantial amount of the alfalfa-supplied N was available to the corn following the soybeans. Also, avoiding the use of a moldboard plow aided in meeting soil conservation goals. Third, alfalfa may deplete soil moisture reserves and, because soybeans are usually planted later than corn, there was a greater opportunity for spring soil moisture recharge. Fourth, weed populations were often higher in corn than in soybeans. Reversing their order in the rotation may have resulted in increased weed problems.

## Summary

Grassy weed populations in all systems were primarily *Setaria* spp (green and yellow foxtail). Grassy weed numbers in corn were not different among systems in the earlier years of the study, but increased substantially in the last 3 years in the Alt system and in the R-T system in 1992. Grassy weed numbers in soybeans in Study I were not consistently different between systems. In Study II, numbers of grassy weeds in soybeans were highest in the Alt and M-T systems, and numbers in spring wheat were highest in the Alt system in most years.

Populations of annual broadleaved weeds in corn and soybeans in Study I were not substantially different among systems in most years. Annual broadleaved weed numbers in soybeans in Study II were highly variable and were not consistently different among systems. Numbers of annual broadleaved weeds in spring wheat were highest in the last 2 years of the studies in all systems, and the highest numbers occurred in the M-T system.

Populations of perennial weeds, primarily quackgrass and Canada thistle, increased in the reduced-till systems (R-T and M-T) in the later years of the studies.

Soil weed seed densities were higher in the Alt system in Study I than in Conv and R-T but were not correlated with crop yields. Comparisons of soil weed seed densities across years did not indicate weed seeds were increasing in any of the systems.

Mechanical weed control in corn provided good control of foxtail, but early season, in-row weed control provided by a banded herbicide and supplemented by cultivation generally resulted in the highest gross economic returns. Mechanical weed control in soybeans often resulted in levels of weed control, economic returns, and yields equal to or greater than chemical methods. Neither mechanical nor chemical weed control methods in spring wheat increased economic returns in most instances.

Estimated yield loss due to foxtail in corn was highest in the Alt system, and losses from foxtail in soybeans were low in all systems.

Dagger nematode numbers were highest in Alt and reduced-till systems in both studies, particularly in later years. The moldboard plow appeared to be primarily responsible for consistently low populations in the Conv systems. Preliminary greenhouse experiments indicated dagger nematodes may have reduced corn and soybean yields in the Alt and reduced-till systems. Pin nematode numbers were highest in soybeans in all systems. Populations of predaceous and microbial feeding nematodes and Oligochaetes generally did not differ substantially among systems.

Levels of common root rot were higher in the R-T spring wheat compared to the Conv. Barley Yellow Dwarf Virus, Fusarium head scab, and foliar diseases (primarily rusts) all reached damaging levels in some years of the studies in small grain crops, but in most instances disease levels were not different among systems. Populations of various soil microbes were not consistently different among systems.

In general, insects were not a significant problem in any year of the studies. Mycorrhizal infection levels in corn, soybeans, and spring wheat were high in all crops, and appeared to be influenced more by soil moisture than by system.

Fall soil water content in Study I was not substantially different among systems, and was primarily influenced by crop. Treating alfalfa as a biennial in the Alt system in Study I allowed adequate soil moisture recharge for subsequent soybean growth. The inclusion of clover (green manure) in the Alt system rotation in Study II improved the overall soil water relations in that system.

In general, the reduced-till systems did not have higher soil water contents than the Conv systems. The greater emphases on small grains in Study II appeared to improve the overall soil water relations compared to Study I.

Surface residues were highest in the Alt and reduced-till systems and consistently exceeded 30% after spring planting. The estimated rates of soil erosion were lowest in the Alt and reduced-till systems (R-T and M-T) but did not exceed "T" in any of the systems. The low estimated rates of soil erosion in all systems were also influenced by the gentle slopes (0-2%) in the study area.

Comparisons of N removed from the systems to N supplied indicated that all of the systems had adequate N supplies. The levels of nitrate-N based on fall soil tests tended to be highest in the Conv and reduced-till systems, and $NO_3$-N levels were also much less variable between crops in these systems compared to the Alt. The greater variability in plant-available N in the Alt systems may be a portion of the rotation effect that enables these types of systems to suppress weeds without the use of herbicides.

Levels of $NO_3$-N to a depth of 4 ft were significantly higher in the Conv and R-T systems in Study I than in the Alt system. The distribution of $NO_3$-N by depth was also different, and approximately 60% of the $NO_3$-N in the Conv and R-T systems was below 2 ft.

The reduced-till systems in both studies required substantially more N fertilizer than did the Conv systems, but in later years of the studies the reduced-till systems were less productive.

Soil test levels of organic matter varied considerably from year to year. Overall, no system appeared to offer a consistent advantage in organic matter accumulation.

All of the systems removed more P from the systems than they supplied, but the greatest disparity between P removal and return occurred in the Conv and reduced-till systems. Soil test levels of P declined over the study period regardless of system and, in general, were highest following soybeans in all systems. Results demonstrated the inappropriateness of plant-available P measurements to determine the long-term ability of a soil to meet crop P requirements.

# Section D:
# **Economic Relationships**

**T.L. Dobbs***

A relatively brief summary of economic results is contained in this section. Additional economic analyses are reported elsewhere. For example, possible implications for farm size of conversions to alternative systems appear in Dobbs (1993).

Economic results are based upon representative whole-farm analyses. Procedures have been described elsewhere, including annual reports for the Northeast Research Station and Smolik and Dobbs (1991). It was assumed that the representative farms had 540 tillable acres and that they were in the federal farm program each year; therefore, required set-aside acres each year were accounted for in the analyses.

Both market prices and government "deficiency payments" were accounted for in the gross returns calculations. Possible "organic premiums" for products of the alternative systems are not discussed here, though we have considered them in other analyses (Smolik and Dobbs 1991).

Crop prices, government payments, and set-aside requirements were updated each year of the analyses. Input prices were updated periodically, as deemed appropriate. The basic land charge was left constant, however, so that changing land values would not affect the net return comparisons over time. No distinctions were made between operator, family, and hired labor in the cost calculations. All labor except for pure "management" (planning, marketing, etc) was assigned charges, regardless of the source.

After computing costs and returns on whole-farm bases—taking account of the acreage in each system devoted to particular crops and to government set-aside—results were reduced to composite per-acre bases, and they are generally presented that way in this section of the bulletin.

The details of federal farm program payment levels and provisions applicable to these farming systems each year have been described in annual reports for the Northeast Research Station. The principal form of applicable government payment is the "deficiency payment." Deficiency payments for particular crops are based on the difference between "target prices" and the higher of market prices and government "loan rates." The deficiency payments are applied to historical "base yields" on portions of each farm's acreage "bases" for "program crops." Program crops receiving payments in the farming systems we analyzed include corn, wheat, oats, and barley. In return for eligibility to receive deficiency payments, farmers must "set aside" (in non-harvested uses) certain portions of their acreage bases.

## Direct Costs

Direct costs other than labor for each system are shown over time in Fig 18 and as averages for 1986-1992 in Table 27. A consistent pattern is observed in which direct (cash, operating) costs were lowest every year for the Alt systems in both Study I and II. The absence of purchased chemical fertilizers and herbicides in the Alt systems largely explains this. In both studies, the Conv systems were always intermediate for direct costs, and the reduced till systems (R-T in Study I and M-T in Study II) were always highest.

On average in Study I, direct costs were 38% higher for the Conv system ($62/A) than for the Alt system ($45/A). Average direct costs for the R-T system ($69/A) were 53% higher. Similarly in Study II, the Conv system direct costs ($48/A) were 60% higher and the M-T system direct costs ($59/A) were 97% higher than for the Alt system ($30/A).

## Gross Income

Gross income was highest on average (Table 27) for the Alt system ($153/A) in Study I, followed closely behind by the Conv system ($151/A). Year-to-year variations occurred, however (Fig 19). The Alt system had the highest gross income in 3 out of 7 years during the period 1986-1992. The Alt

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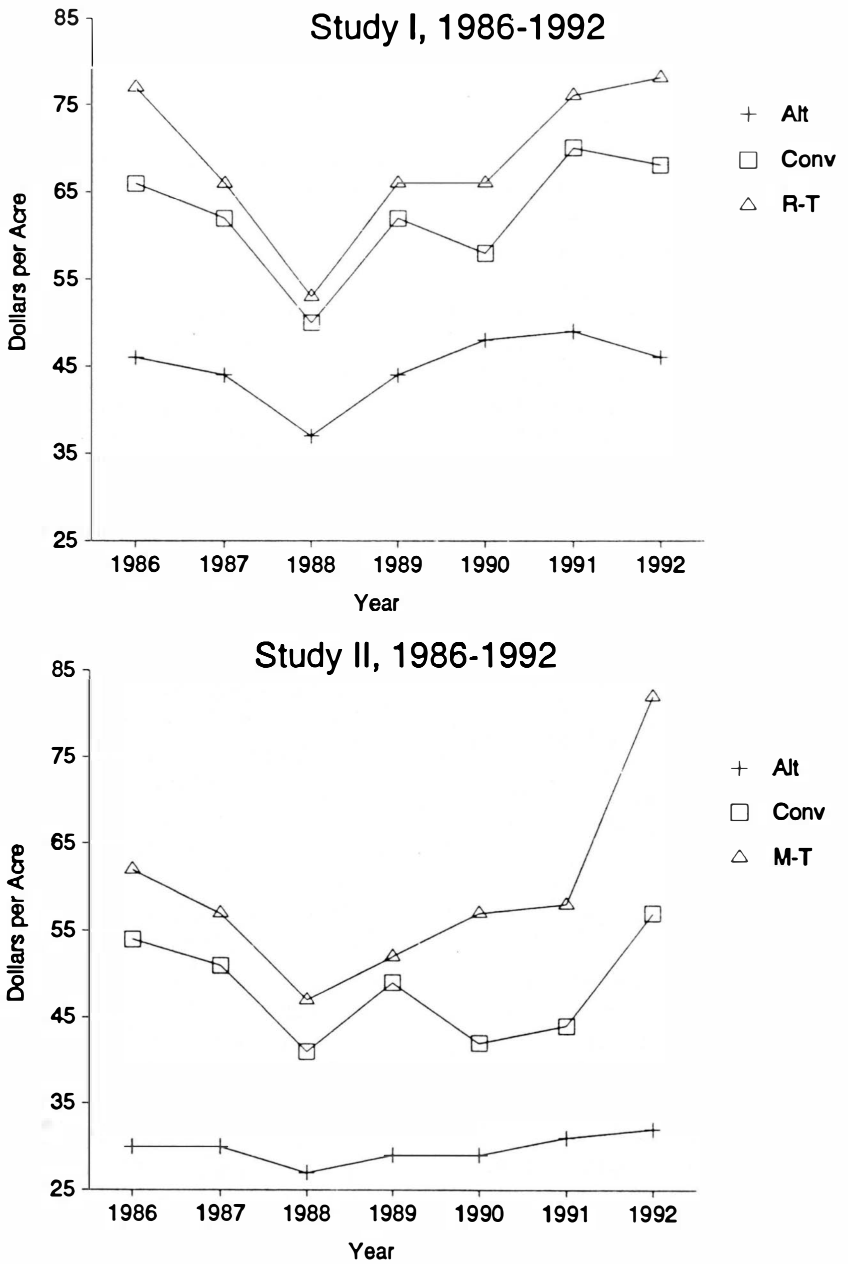
* I am extremely grateful to the research associates and assistants in economics who, over the years, contributed to analyses that led to this summary. Special thanks, in reverse chronological order, go to Lon Henning, who conducted analyses for the 1992 crop year, prepared summary tables and figures for the 1986-92 period, and provided valuable interactions and reviews during the final analyses; David Becker, who conducted analyses for the 1991 crop year; and Clarence Mends, who conducted analyses for the 1986-90 crop years.

**Figure 18. Direct costs other than labor in Study I and II.**




system exhibited the highest gross income during the 1988 severe drought year, as well as in 1991 and 1992. The Conv system had the highest gross income 4 out of 7 years. Gross income showed less variability for the Alt system than for the Conv and R-T systems. Relatively strong alfalfa prices (avg $53/ton) during the study period contributed to the Alt system's high average gross income performance.

The Conv system had the highest average gross income ($127/A) in Study II (Table 27). The Alt system ($101/A) was lowest, on average. The Alt system in Study II had a fourth of its acreage each year devoted to a non-cash, green manure crop (clover); although this acreage counted as government set-aside, it more than met the set-aside requirements. Thus, the fact that the Alt system had more acres in a non-cash use than did the Conv and M-T systems explains at least part of the lower average gross income for the Alt system.

The Conv system in Study II had the highest or equal to the highest gross income in 5 of the 7 years from 1986 to 1992 (Fig 19). In the drought year of 1988, the Alt system had the highest gross income. The Alt system was lowest in gross income in 5 of the other 6 years.

## Net Income

Several measures of net income, averaged over the 7-year study period for each system, are shown in Table 27. The first measure, shown in the third column of data, includes a deduction for all costs (including items like machinery depreciation and interest) except land, labor, and management. The next measure (in the fourth column) includes all costs included in the first measure plus a charge for labor used for crop production. A land charge is included in the final measure (in the fifth column); the final measure is referred to as net income over all costs except management. The land charge is the same for all systems. This final measure constitutes what is often referred to as pure profit or as return to management for planning and risk taking. The same measure is shown in the last column of Table 27, except there it is on a whole-farm (540 crop acres) basis.

The discussion here is based primarily on the net income over all costs except management. On average, the Alt system was the most profitable in Study I. Net income over all costs except management averaged $37/A, compared to $23/A for the Conv system and only $6/A for the R-T system. Average net income was almost identical for the Alt ($12/A) and Conv ($13/A) systems in Study II. The M-T system in Study II actually lost money ($6/A) when all costs, including land, were included. The comparatively poor economic performance of reduced-till systems has been reported in other studies (Martin *et al* 1991, Williams *et al* 1989).

Net income variability over time is shown for each system in Fig 20 (net income over all costs except management is referred to in abbreviated form as "net returns to management"). There was much less variability, from year to year, in the net income of the Alt system in Study I than for the Conv and R-T systems in that study.

The coefficient of variation (CV) for the Alt system was 0.45, compared to 1.38 for the Conv system and 5.17 for the R-T system. The CV measures variability relative to the mean or average for a system. By far the most variability relative to average net income was found in the R-T system.

Relative variability in net income was about the same for the Alt (CV=1.52) and Conv (CV=1.50) systems in Study II. It was highest in that study for the M-T system (CV=-2.74; the negative sign is due to the average net income being negative for the system). The relative variabilities for these systems can be observed in the lower half of Fig 20.

## Role of Alfalfa

It has already been mentioned that relatively strong alfalfa prices contributed to the economic performance of the Alt system in Study I. The question that naturally arises is this: "How would have the Conv and R-T systems of Study I performed, relative to the Alt system, if they had each included the same amount of alfalfa acreage as the Alt system, but if the alfalfa was in a continuous stand rather than in rotation?"

**Table 27. Average economic results in the Farming Systems Studies (1986-1992).**

| | Dollars/Acre | | | | | |
|---|---|---|---|---|---|---|
| | | | Net Income Over | | | |
| System[a] | Direct Costs Other Than Labor | Gross Income | All Costs Except Land Labor, and Management | All Costs Except Land and Management | All Costs Except Management | Whole Farm Net Income Over All Costs Except Management ($)[b] |
| ***Farming Systems Study I*** | | | | | | |
| 1. Alternative (oats-alfalfa-soybeans-corn) | 45 | 153 | 75 | 63 | 37 | 20,139 |
| 2. Conventional (corn-soybeans-s. wheat) | 62 | 151 | 58 | 49 | 23 | 12,328 |
| 3. Ridge Till (corn-soybeans-s. wheat) | 69 | 139 | 41 | 32 | 6 | 3,149 |
| ***Farming Systems Study II*** | | | | | | |
| 1. Alternative (oats-clover-soybeans-s. wheat) | 30 | 101 | 47 | 38 | 12 | 6,443 |
| 2. Conventional (soybeans-s. wheat-barley) | 48 | 127 | 49 | 39 | 13 | 6,803 |
| 3. Minimum Till (soybeans-s.wheat-barley) | 59 | 116 | 29 | 20 | -6 | -3,360 |

[a] Crops are shown in the order in which they occur in each rotation.
[b] For farm with 540 tillable acres.

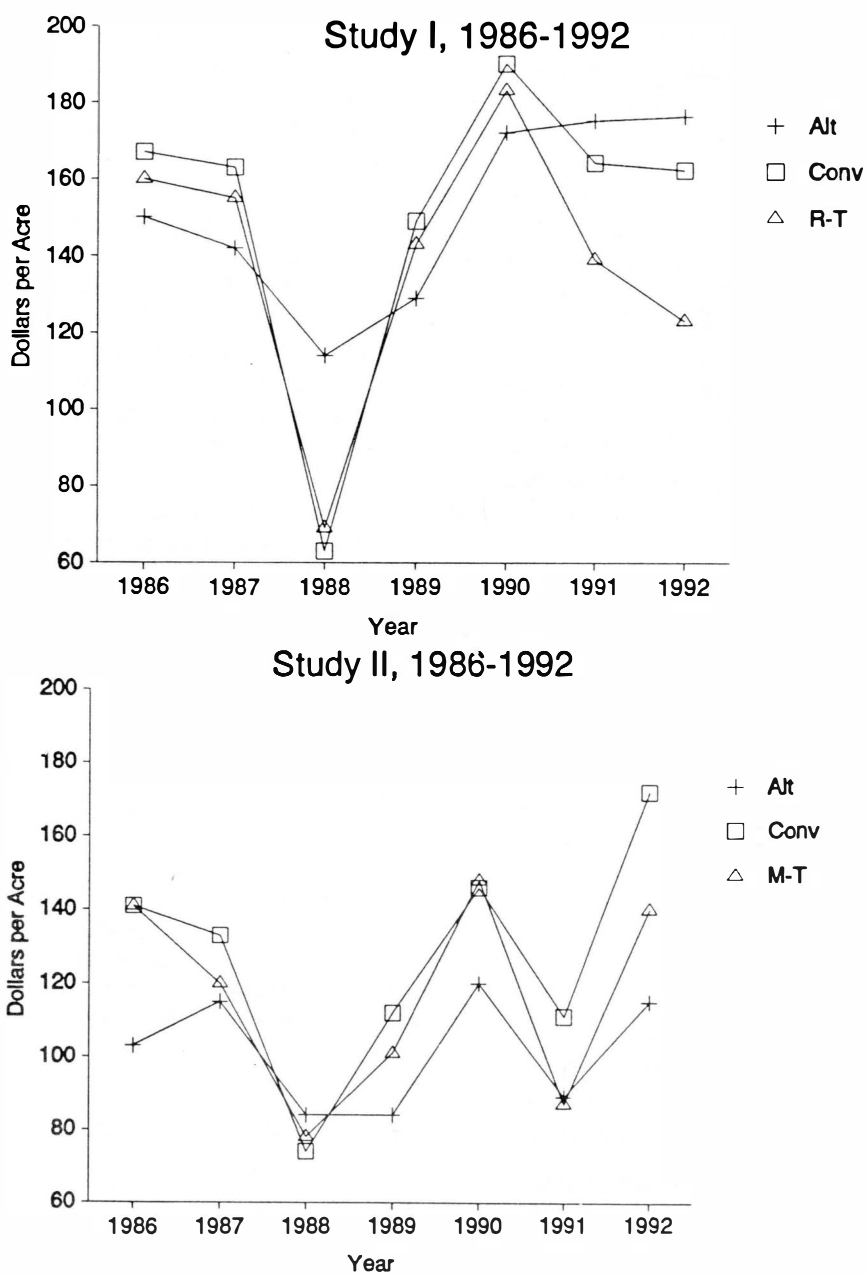
Mends and Dobbs (1991) examined this question using study data through 1989, together with hypothetical data for conventionally grown alfalfa (long-term stands) in the Conv and R-T systems. They found that shifting the same amount of acreage into alfalfa as existed in the Alt system and assuming similar alfalfa yields added an average of $8/A to net income in the Conv system and $9 in the R-T system, over the period 1985-1989. This caused the Conv system to be slightly more profitable than the Alt system (by $3/A) and the R-T system to be just slightly less profitable (by $2/A).

We have updated that "alfalfa analysis" by using what we call normalized crop enterprise and whole-farm budgets for the period 1986-1992. Results somewhat similar to those of the earlier Mends-Dobbs analysis were obtained when comparing the Conv and Alt systems.

Including conventionally grown alfalfa in the crop mix of the Conv system (in the same acreage amounts as in the Alt system), while leaving the Conv system farming practices otherwise unchanged, caused the Conv system of Study I to be slightly more profitable (by $2/A) than the Alt system. Including alfalfa in the crop mix of the R-T system also substantially increased the profitability of that system; however, it still left that system $11/A less profitable than the Alt system.

This analysis is obviously much less firmly grounded in agronomic data than is the rest of the economic analysis, which is based on actual production practices, levels of input use, yields, etc. Also, alfalfa would not have been an integral part of the Conv and R-T rotations as it was in the Alt system, and assuming that yields of

**Figure 19. Gross income in Study I and II.**



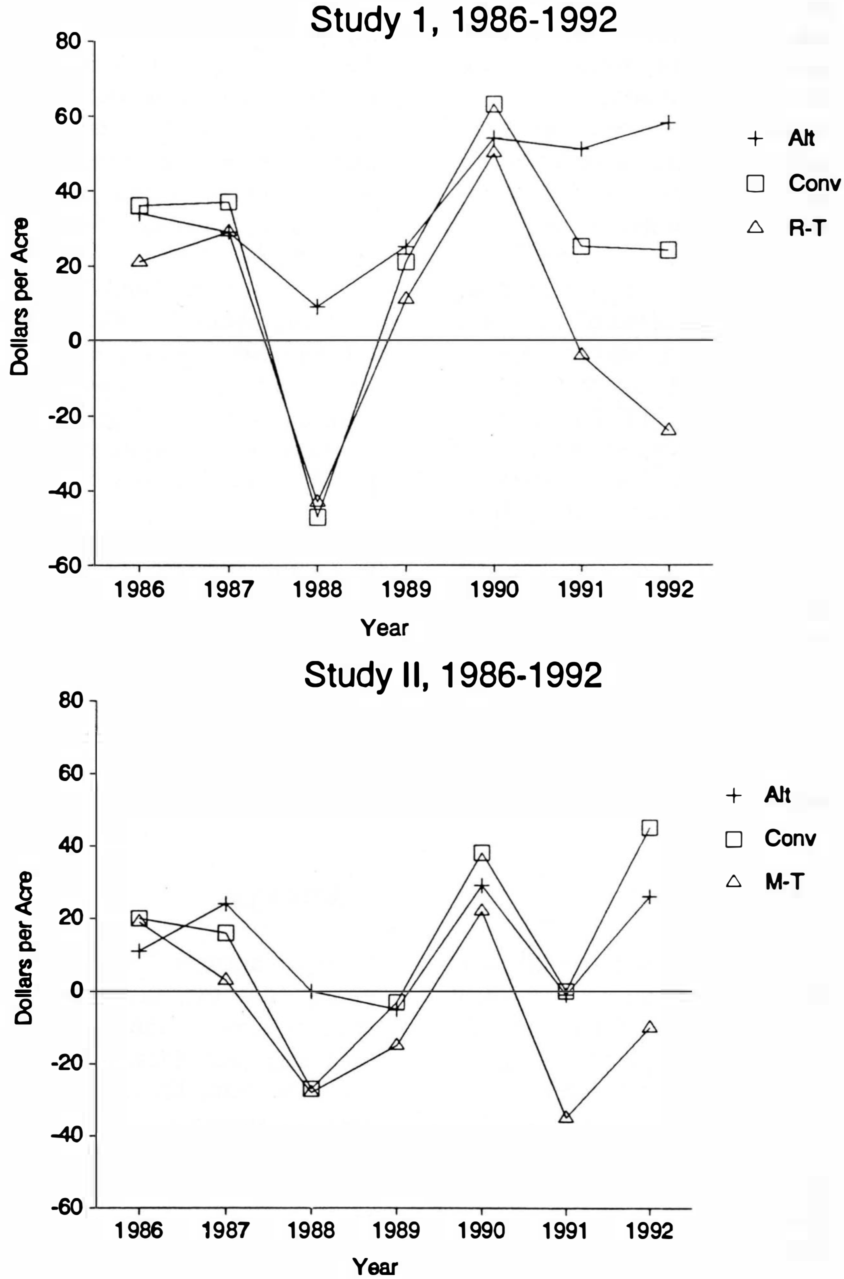

long-term stands would be similar to those of the younger stands in the Alt system probably overestimates yields. Nevertheless, analysis with these normalized and hypothetical budgets does give some notion of the role alfalfa played, or could have played, in the relative economic profitability of systems in Study I during the period 1986-1992. A more detailed discussion about including alfalfa in the Conv and R-T crop mixes appears in Henning and Dobbs (1993).

## Summary

The economic analysis reveals that the Alt systems would have been economically competitive with Conv and reduced tillage (R-T and M-T) systems during 1986-92 in the study area. This is an agroclimatic area in the transition zone between predominantly corn-soybean farming and predominantly wheat farming. We have shown elsewhere (Dobbs *et al* 1992) that relative profitability of systems can differ substantially among agroclimatic areas, with conventional systems tending to be more profitable than alternative systems in corn-soybean areas and some alternative systems tending to be economically competitive with more conventional systems in wheat areas of the Northern Great Plains.

Farm profitability results also depend on market conditions and federal farm program provisions. Even though federal programs tended to favor the crop mixes of the conventional and reduced tillage systems during the study period, the alternative systems were approximately as profitable or more profitable, and they tended to show less year-to-year net income variability.

**Figure 20. Net returns to management in Study I and II.**




## Section E:
## Relative Sustainability of Systems

**J.D. Smolik, T.L. Dobbs, and D.H. Rickerl**

Sustainable agriculture has been the topic of considerable debate and discussion in recent years. The term "sustainable" implies a long-term maintenance of productivity of farming systems without degrading the resource base upon which agriculture depends.

Concerns about the sustainability of our current farming systems arise from a number of different areas, including: increasing rates of soil erosion; pollution of ground and surface waters by agriculture-related activities; excessive reliance on non-renewable energy sources (fossil fuels); response of farming systems to environmental stresses; human health implications of agricultural chemicals; economic stress, including declining numbers of farmers; and continued dependence of farming systems on federal subsidies. The long-term studies reported in this publication, conducted by a multidisciplinary team, are perhaps one of the better approaches for addressing many of the above concerns. Also, the performance of the various systems in these studies relative to the above concerns may provide a measure of the comparative sustainability of the systems.

## Soil Erosion

The Alt and reduced-till (R-T and M-T) systems both provided very good protection of the soil surface. The inclusion of forage legumes in the Alt systems, coupled with selected aspects of reduced tillage, substantially improved surface residue cover in these systems. The Alt and reduced-till systems were the only systems to consistently meet or exceed current conservation compliance regulations for residue cover on highly erodible land, and therefore both of these types of systems should adequately address soil erosion concerns.

## Pollution Potential

Soil cores were removed to a depth of 4 ft in Study I in the last year of the study, and nitrate-N levels were measured. Levels of nitrate-N in the Conv and R-T systems were approximately two to three times higher than in the Alt system. Higher N levels may not necessarily indicate a potential problem if the N is located in the upper layers of the soil profile where it can be readily taken up by crops; however, most of the $NO_3$-N in the Conv and R-T systems was below 2 ft. Results in these studies suggest that the potential for nitrate-N pollution of groundwater is much greater in the Conv and R-T systems compared to the Alt system.

The potential pollution associated with herbicide use, either by movement through soil or as residues on crops, was not measured in these studies. Obviously, eliminating the use of these products, as was done in the Alt systems, would eliminate any possible pollution from these products.

## Energy

Approximately 70% of the energy consumed in regional dryland crop production is for fuel, fertilizers, pesticides, and their transportation. Energy consumed for these inputs in the Alt systems was 68 to 75% less than in the Conv and reduced-till systems. Higher energy consumption accompanied by a proportionately higher productivity might not be an area of concern. However, production in terms of crop mass removed from the systems, or total digestible nutrients (TDN) produced, per unit of energy consumed for the above inputs, was two to six times greater in the Alt systems than in the Conv and reduced-till systems.

Conversion of a portion of the soybean, corn, or spring wheat crops to liquid fuel to counterbalance energy consumed would have reduced production in the Alt systems only 1 to 2% but would have reduced production in the Conv systems 8 to 14%; and in the reduced-till systems production would have been reduced 17 to 21%. Results in these studies indicate Alt systems are very energy efficient and, through bio-fuel production, could compensate for a major proportion of their energy inputs with very little effect on their productivity.

## Environmental Stress

Growing season precipitation had the greatest influence on production in all systems, and climatic events over the study period included the wettest year in the history of the Northeast Station, the fifth driest year and, in the last year of the study, the coolest July temperatures ever recorded in South Dakota.

Plant diseases, primarily Barley Yellow Dwarf Virus and Fusarium head scab, also significantly influenced small grain yields in all systems in some years. In the later years of the studies, weeds and dagger nematodes appeared to influence yields in the Alt and reduced-till systems.

The variability in production in the systems over a long-term period provides a measure of the response of the systems to climatic and biotic stress. Production in the Alt systems in both studies in terms of crop mass removed from the systems was less variable than in the Conv and reduced-till systems. The coefficient of variation (CV) in the Alt systems in both studies was 27% as compared to 33 to 35% in the Conv and reduced-till systems.

The Conv and R-T systems in Study I had similar crops in their rotations as did the Conv and M-T systems in Study II, and the principal difference between the systems was the intensity of tillage. In the earlier years of the studies, production was not substantially different between these systems, but in the last 2 to 3 years production was significantly lower in the reduced-till systems.

The decline in productivity in the reduced-till systems raises questions about their long-term sustainability in this agroclimatic area. Overall, these studies indicated production in the Alt systems is likely to remain more stable over a range of environmental stresses.

## Human Health Implications

Many of the concerns regarding human health are related to pesticide use and the handling of other hazardous materials such as anhydrous ammonia. These concerns were not directly addressed in these studies, but as indicated above in the pollution potential discussion, the most obvious method to eliminate concerns regarding these materials is simply not to use them.

Other potential human health concerns are related to machinery operations. A wider range of crops was included in the Alt systems which indicates they also would include a wider range of machinery operations. This may increase the chances of an accident. However, the types of crops in the Alt systems would spread the workload out over more of the growing season, which likely would reduce the chances of a fatigue-induced accident as can occur in less diverse cropping systems that have shorter time frames for completing particular machine operations.

## Economic Stress

Average net returns to management in Study I were highest for the Alt system. Relative variability in net returns to management was much lower for the Alt system than for the Conv and R-T systems, and net returns were not negative for the Alt system in any year of the 1986-1992 time period. Net returns to management were negative 1 year for the Conv system and 3 years for the R-T system.

In Study II, average net returns to management were nearly equal for Alt and Conv systems. There was also little difference between those two systems in the relative variability of their net returns. The M-T system in that study, however, had much lower and much more variable net returns to management. During the 7-year study period, net returns to management were negative two times for the Alt system, three times for the Conv systems, and four times for the M-T system. On average, returns in the M-T system were inadequate to cover all costs when the charge for land was included.

Overall, the relative economic performance of the Alt systems indicated they have considerable promise in the study area.

The Alt systems also were less dependent on government farm program payments than were the other systems. Average government payments (including deficiency payments and amounts by which loan levels sometimes exceeded marketing period prices) as a percentage of net returns to management were as follows: in Study I—Alt, 34%; Conv, 98%, and R-T, 383%, and in Study II—Alt, 80%; and Conv, 110%. Government payments were nearly as high in absolute terms for the M-T system as for the Conv system, but they were not adequate to produce a positive net return to management, on average, for the M-T system. In light of the continued budget pressure on federal farm programs, those systems most dependent on such programs may not be economically sustainable over time.

## Relative Sustainability

Rating the various systems in regard to sustainability concerns indicates Alt and reduced-till systems would both reduce soil erosion concerns, but the reduced-till systems rate very poorly in regard to all other concerns. The Conv systems were more productive than the reduced-till systems, but they can increase soil erosion, and they are energy inefficient, potentially polluting, and highly variable in production. The Conv and reduced-till systems were also more dependent on government program payments for their profitability than were the Alt systems. The Alt systems rated favorably relative to all concerns and, on the whole, appear to be more sustainable in this agroclimatic area.

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Published in accordance with an act passed in 1881 by the 14th Legislative Assembly, Dakota Territory, establishing the Dakota Agricultural College and with the act of re-organization passed in 1887 by the 17th Legislative Assembly, which established the Agricultural Experiment Station at South Dakota State University. Educational programs and materials offered without regard to age, race, color, religion, sex, handicap, or national origin. An Equal Opportunity Employer.

3M copies printed at a cost of $1.49 each.
AX125 9/93