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# Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota

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## Abstract

Because the adoption of conservation tillage requires long-term evaluation, the effect of tillage and residue management on corn (*Zea mays* L.) grain and stover yields was studied for 13 seasons in east central Minnesota. Three primary tillage methods (no-till (NT), fall chisel plow (CH), fall moldboard plow (MB)) and two residue management schemes (residue removal versus residue returned) were combined in a factorial design experiment on a Haplic Chernozem silt loam soil in Minnesota. No significant effects on grain yield were seen due to tillage treatments in 9 out of 13 years. The NT treatment resulted in lower yields than CH and MB treatments in years 6 and 7, and lower than the MB in year 8, indicating a gradual decrease in yield over time with continuous use of NT. There were differences due to residue management in 8 out of 13 years. The residue-returned treatments contributed about 1 Mg ha$^{-1}$ greater yields in intermediate level dry years such as years 3 and 6, which had cumulative growing season precipitation 20 and 30% below the 9-year average, respectively. In excessively dry or long-term-average years, residues resulted in little yield difference between treatments. The most pronounced effects of residues were with the CH treatment for which yields were greater in 8 out of 13 years. The ratio of grain to total dry matter yield averaged 0.56 and did not vary with time or between treatments. These results apply primarily to soils wherein the total water storage capacity and accumulated rainfall are insufficient to supply optimum available water to the crop throughout the growing season. Under conditions with deeper soils or in either wetter or drier climates, the results may differ considerably. Published by Elsevier Science B.V.

*Keywords:* No-tillage; Moldboard-tillage; Chisel-tillage; Nitrogen; Harvest index; Water deficit; *Zea mays* L.; Minnesota; Haplic Chernozem

## 1. Introduction

The effect of tillage and crop residue management on corn (*Zea mays* L.) yield has been studied extensively over many years. Much of the research has involved short-term studies that suggest what would occur over the course of 1 or 2 years (Cassel et al., 1995), but fell short of indicating what might happen under long-term continuing management practices. Short-term studies also do not account for variable weather conditions over extended periods. Tillage and residue management variations create a complex association of soil and surface conditions that both directly and indirectly influence the performance of a crop such as corn. For example, crop residue coverage has been observed to decrease yields because of poor weed control, excessively wet and cold soils, and poor seed placement and stand (Swan et al., 1994). On the plus

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side, residues are credited with improving yields through retention of essential nutrients, protection from raindrop induced crusting (Blevins et al., 1983), and soil water conservation (Doran et al., 1984). Under most midwestern USA cornbelt conditions, the benefits and risks of residues vary depending on seasonal climatic conditions. These benefits and risks often change with time as management practices are continued year after year (Griffith et al., 1988). Only long-term studies can assess management options over a wide variety of climatic inputs. By continuing treatments over a long period, soils approach equilibrium conditions based on a particular management scheme. The objectives of this 13-year study were to provide information on: (1) the effect of tillage and residue management on corn biomass and grain production, and (2) to assess the time course of treatment effects.

## 2. Materials and methods

### 2.1. Experimental site

A long-term field experiment was established in 1980 on a Waukegan silt loam (Typic Hapludoll) at the University of Minnesota Agricultural Experiment Station located at Rosemount, MN (Gupta et al., 1983; Clay et al., 1989; Clapp et al., 2000). The soil is a Haplic Chernozem (FAO) of about 60–90 cm depth overlaying neutral to calcareous outwash gravels and sands. The somewhat shallow soil depth is typical of glaciated regions and is often observed to limit yields through water stress. The climate of the region is characterized by approximately 60 cm of annual precipitation balanced by 60 cm of evapotranspirational demand. The average accumulated growing degree days are approximately 1000 providing an adequate season for 100–105 maturity-day rated corn varieties.

### 2.2. Tillage-residue experiment

The experiment consisted of six tillage and residue treatments, each on a randomly allocated block measuring 18 m wide and 50 m long. Three tillage treatments: fall moldboard plow (MB), fall chisel plow (CH), and no-till (NT) were randomly combined with two residue management schemes (corn stover residue returned or removed) forming six unique treatments. Three nitrogen (N) treatments (0, 100, and 200 kg N ha$^{-1}$ applied broadcast just before planting) were randomly assigned to three split plots of each tillage-residue treatment block. Prior to year 4, the 100 kg N ha$^{-1}$ treatment had been 200 kg N ha$^{-1}$ with the N application split one-half at planting and one-half at "lay by" (approximately July 1). Each tillage-residue-N rate-treatment was split into four plots to derive an error term related to field measurement.

The NT treatment plots were not tilled at any time during the study. Both MB and CH treatment plots were consistently fall tilled with a single pass at about 17–20 cm depth. In the spring of each year, corn was planted without additional tillage. No secondary tillage, including cultivation, was performed on plots of any treatment. A fluted (wave shaped) coulter running in front of the seed openers caused the only soil disturbance other than primary tillage. This coulter was also used to plant corn in NT plots, which resulted in a very narrow (approximately 5 cm) and shallow (approximately 5–7 cm) disturbed zone.

For no-residue treatments, all corn residue was removed from the plot using a silage chopper. This technique did not remove the base of the corn stalk (approximately 15 cm high), some leaves and brace roots. The residue on the residue-returned treatment plots consisted of all plant material, except grain. This material was left standing after combine harvest and was stalk chopped just prior to tillage.

Plots of all treatments were planted with Pioneer[1] 3780, 105-day hybrid seed corn in approximately the second week of May. From 60 000 to 75 000 seeds ha$^{-1}$ were planted in 75 cm rows at a depth of 3–4 cm. A John Deere Max-Merge (see Footnote 1) planter with fluted coulters was used to plant the seed 15 cm to the side of the previous years row, which was alternated to the opposite side the following year.

Phosphorus (P) and potassium (K) fertilizer was broadcast applied to the blocks in the initial year

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[1] Names are necessary to report factually on data; however the USDA-ARS neither guarantees nor warrants the standard of the product, and the use of the name by the USDA-ARS implies no approval of the product to the exclusion of others that may also be suitable.

before planting at the rates of 171 kg P ha$^{-1}$ and 246 kg K ha$^{-1}$, respectively. Soil test samples of 10 composited probes at 0–15 and 15–30 cm depth were taken in the fall of each year to determine soil fertility levels. Standard soil test analyses were performed by the soil testing service at the University of Minnesota. No further P or K were applied during the course of this experiment. Nitrogen fertilizer in the form of ammonium sulfate was applied broadcast according to N treatment in the spring of each year just before, or soon after planting. Annual soil tests monitored the pH status in plots of each treatment. In 1985, half the plots receiving 200 kg N ha$^{-1}$ received lime to correct the falling pH. Thereafter, yields are reported only for the limed plots where pH remained at 6 or above.

Herbicides were used primarily to control foxtail (*Setaria fabaria* Herrm.) and wild proso millet (*Panicum miliaceum* L.). Atrazine and oil were applied post-emergence broadcast at a rate of 2.8 kg ai ha$^{-1}$ in the first 2 years and was combined with alachlor at the rate of 2.8 kg ha$^{-1}$ in the next 4 years. Plots of all treatments had alachlor alone applied for pre-emergence broadcast at rates of 2.8–3.3 kg ai ha$^{-1}$ for all other years. To control wild proso millet, pendimethalin plus cyanazine was broadcast before the fourth leaf stage of the corn at rates of 1.1 and 1.7 kg ai ha$^{-1}$, respectively. This application was carried out for years 6–8. Corn root worm insecticide (Counter (see Footnote 1), Amaze, Thimet, Lorsban, or Force) was banded over the row at recommended rates each year at planting time. A variety of insecticides were used in rotation to avoid resistance buildup.

### 2.3. Crop measurement

Corn on all plots was harvested shortly after physiological maturity near the end of September. A sample for yield was harvested from the center 6.1 m of the middle two rows of each plot. The ears on all plants were hand picked and weighed. Ten ears were randomly selected to form a subsample that was dried at 60°C to determine water content. Grain and stover yields are reported on a dry weight basis. The relationship between grain and total yield is expressed as a harvest index (HI) defined as grain yield divided by the total dry matter yield (Prihar and Stewart, 1990).

### 2.4. Meteorological measurements

Rainfall, air temperatures, pan evaporation, and other meteorological characteristics were measured at the experimental site or at a nearby weather station. Crop water demand balanced against rainfall is summarized and expressed as potential water deficit (PWD) defined as

$$\text{PWD} = \text{rainfall} - (0.8 \times \text{pan evaporation}) \qquad (1)$$

wherein rainfall is measured daily and pan evaporation is either measured directly or approximated from temperature data. The PWD was computed daily and accumulated over the season to reflect water supply; PWD is positive if rainfall exceeds the evaporative demand and negative when demand exceeds rainfall. This is one method of expressing the depletion of stored soil water reserves. Large negative values indicate very dry soils wherein crop stress would be likely.

### 2.5. Statistical methods

The experiment was treated as a three by two factorial. Statistical analysis (standard ANOVA) was carried out separately on each year's data. A least significant difference (LSD) allowed residue-return versus no-residue mean comparisons within each tillage treatment. For purposes of comparing residue treatments with sufficient plant nutrients, data for the zero N plots were not included and for those 100 and 200 kg N ha$^{-1}$ plots were averaged because they were not significantly different. Variations due to tillage or N treatments were not always significant, but were consistent over time so that accumulated or average annual yields became the best indication of tillage and N effects. The average annual stover yields and standard deviations were computed by standard procedures.

## 3. Results and discussion

### 3.1. Tillage and nitrogen treatment effects

During the first 5 years of this study no trends were observed due to tillage or N rates (Fig. 1). The CH treatments appeared to have lower yields than either

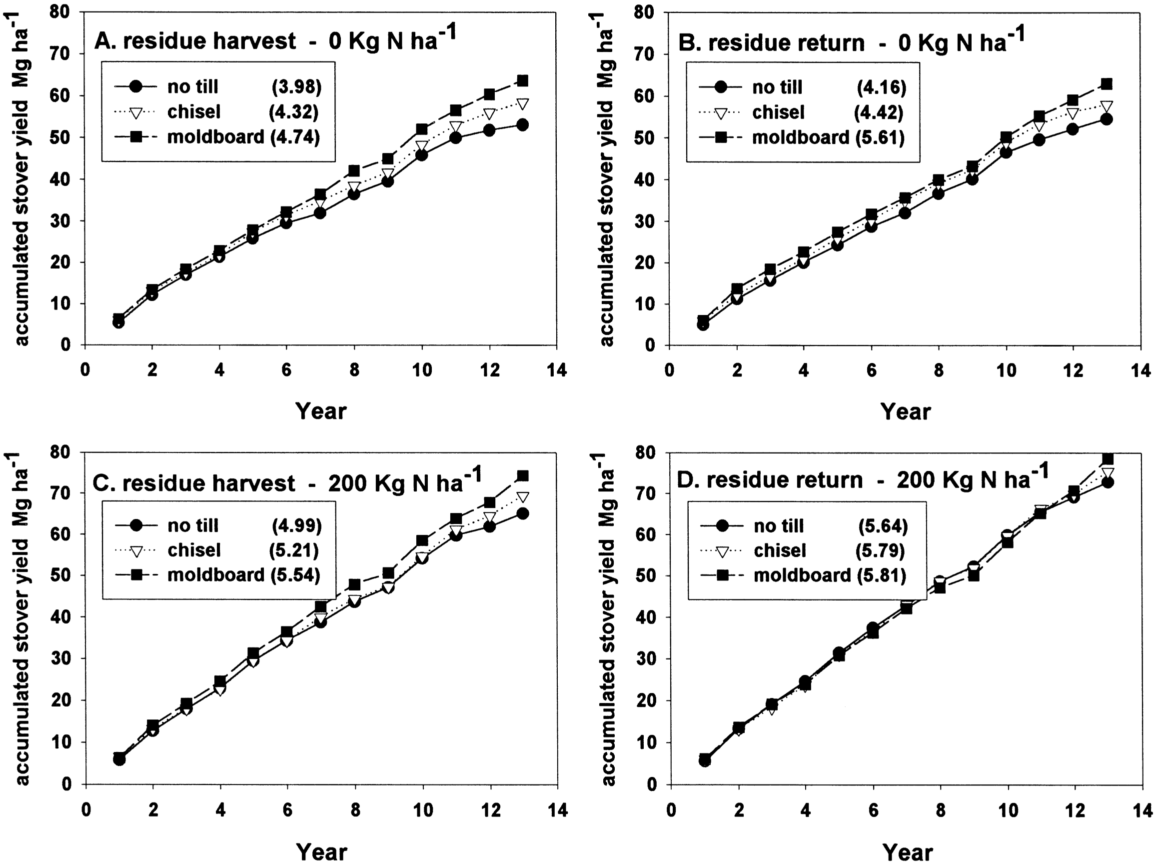

Fig. 1. Accumulated stover yields for each tillage, residue, and N-rate treatment over 13 years. The average annual yields are shown in the legend. The standard deviation did not vary significantly between treatments with the pooled value equal to 1.45 Mg ha$^{-1}$ per year.

MB or NT treatments; however, yields were not significantly different even at the 10% level. Yield differences began to appear after 5 years and continued through year 13. After year 5, the MB treatment resulted in significantly greater yields than the NT treatments, with CH resulting in yields intermediate between the two. The 13-year accumulated stover yields varied from 55 Mg ha$^{-1}$ with NT without N fertilizer or residue to 75 Mg ha$^{-1}$ with MB with N and residue (Fig. 1). Griffith et al. (1988) found similar results in a 12-year study conducted on a Chalmers silty clay loam in central Indiana. In that study yields with NT were consistently lower than with MB after the first 4 years of the study. Griffith et al. (1988) concluded that these differences with time were likely related to soil fertility, unlike our field study where soil tests indicated that soil fertility was not limiting. Blevins et al. (1983), in a 10-year study conducted in Kentucky on a Maury silt loam, reported decreasing corn yields with time under unlimed NT conditions, as soil acidity increased due to the buildup of organic C and N near the soil surface. In contrast, our declining pH was corrected to about 6.0 by the additions of lime at year 6 so that the pH impact on nutrients and yields was minimized.

Tillage effects on corn yield are greatly dependent on climate and soil type. Results varied with MB yields being greater than with NT (Iragavarapu and Randall, 1995), to yields being greater with NT than with MB (Griffith et al., 1988). Chisel treatments in most cases resulted in intermediate yields as compared with those of NT and MB. In areas experiencing lower soil temperatures, like those generally found throughout the northern cornbelt or on poorly drained soils in the central cornbelt, MB treatments usually resulted in greater yields than those in NT (Iragavarapu and Randall, 1995). This has been attributed to slow early growth under NT caused by soil temperatures under surface residues being 1–4°C cooler than those of bare soil (Griffith et al., 1973; Imholte and Carter, 1987; Iragavarapu and Randall, 1995).

On well-drained soils of the central cornbelt or on most soils in the southern cornbelt, NT usually results in equal or greater corn yields under continuous corn than MB; however, Griffith et al. (1988) report NT versus MB corn yields on a poorly drained Clermont silt loam that were very different from those on a poorly drained Chalmers soil. Yields under no till on the Chalmers soil were consistently lower than under moldboard plowing after 4 years of continuous tillage treatments. At the Clermont soil site yields under no till were lower than plowing for the first 3 years but equaled or exceeded yields under moldboard plowing thereafter. Yields with NT on a well-drained Wooster soil in Ohio were significantly greater over a 23-year period than with tilled treatments using MB for primary tillage (Dick et al., 1986a,b). They also reported, however, for a similar study conducted on poorly drained Hoytville soil also in Ohio that yields with NT were consistently lower than with tilled treatments under continuous corn. These effects may be related more to the surface residues that were the consequence of tillage, rather than directly from tillage (Gupta et al., 1983).

### 3.2. Residue treatments

When yearly yield data resulting from residue-returned or -removed treatments are compared, differences across all tillage systems seemed to correspond to the amount of growing season precipitation (Fig. 2). In years with near average or only a small deficit in the growing season precipitation (Fig. 3, years 2, 4, 5, and 8), yield differences between residue treatments were not significant (Fig. 2). In drier than average years (Fig. 3, years 1, 3, 6, 9 and 10) yield separation between residue treatments was much more apparent, with yields under returned-residues treatments exceeding those with no-residue by 22% on the average (Fig. 2). These differences were significant at the 0.1 level, except for years 6 and 10, which were significant only at the 0.2 level.

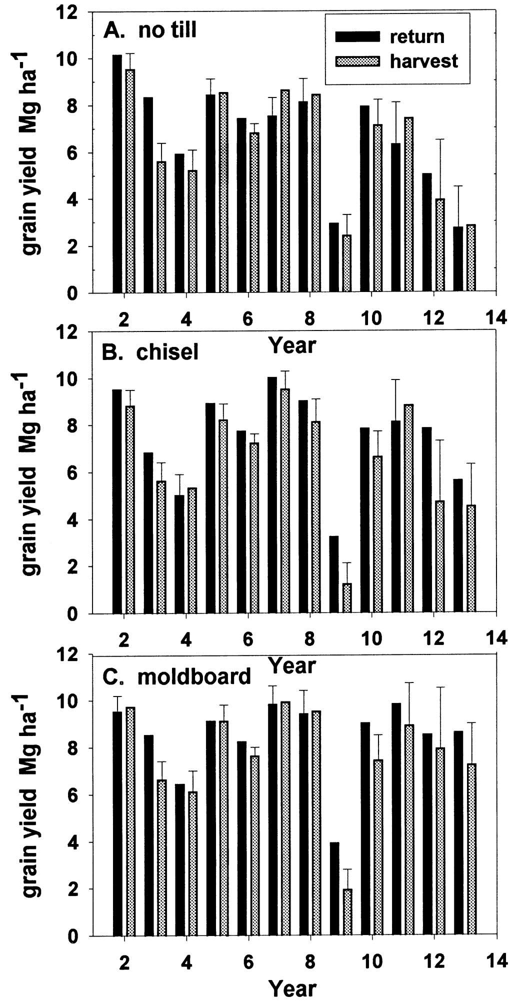

Fig. 2. Corn grain yields for residue-returned and residue removal conditions under the 200 kg N ha$^{-1}$ rate treatments for three tillage systems and for each of the 12 years. The difference between pairs of values (residue versus no-residue), which exceed the error bar, indicates results that are significantly different at the 0.10 level of probability. The LSD for each paired treatment is shown as the error bar.

The differences in water demand balanced against rainfall show dramatic differences during the 13 years of this experiment (Fig. 4). The dry years (3, 6, 9, 10 and 12) had consistently greater water deficits (more negative PWD), with PWD near the end of the growing season ranging from −20 to −70. Years 9 was a record dry year and little corn was produced regardless of treatment. In average to wetter years, PWD

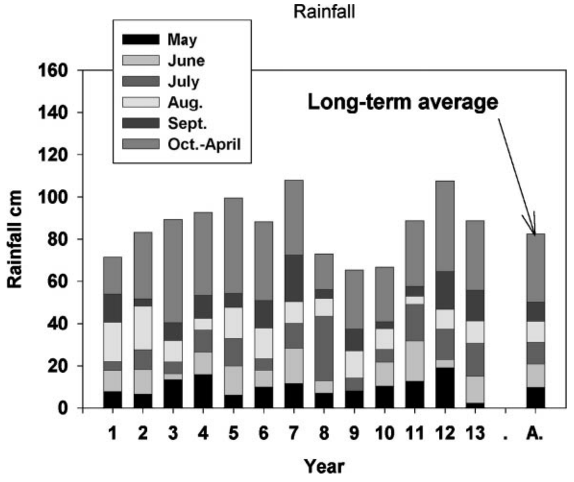

Fig. 3. Monthly and yearly total precipitation. Each bar segment represents the total precipitation for a month or the remainder of the year in the case of the top segment. The entire bar represents the total annual precipitation. A long-term average bar is also shown for comparison.

fluctuated around the long-term average occasionally reaching −25, but seldom continuing the downward trend observed during the dry year (year 9). Year 8 is included as an average year since early dry conditions, similar to year 9, continued only through day 200 when mid-season rains provided drought relief. This relief came at a critical time as yields in year 8 were considerably better than year 9. Doran et al. (1984), in a study conducted in eastern Nebraska on a Crete-Butler silty clay loam, showed that complete removal of residue resulted in a 21–24% reduction in grain yield of NT corn. This was partially attributed to decreased soil water storage. In a continuation of the same study, Wilhelm et al. (1986) reported similar results. Van Doren and Triplett (1973) in Ohio also reported the water saving advantages of residues.

In a wet year (year 7), returned-residues incorporated with tillage treatments (either CH or MB) resulted in higher yields than no-residue treatments,-while the residue removal treatment resulted in greater yield than the surface residue treatment with no-till (Fig. 2). Swan et al. (1987) stated that in-row surface cover can greatly affect the rate of early corn development due to soil temperatures. They added that, in years with lower soil temperatures and with little water stress, high residue cover delayed silking, increased grain moisture content, and decreased yields. This likely was the primary explanation for yield differences seen in year 7 in our study although soil temperatures were not measured.

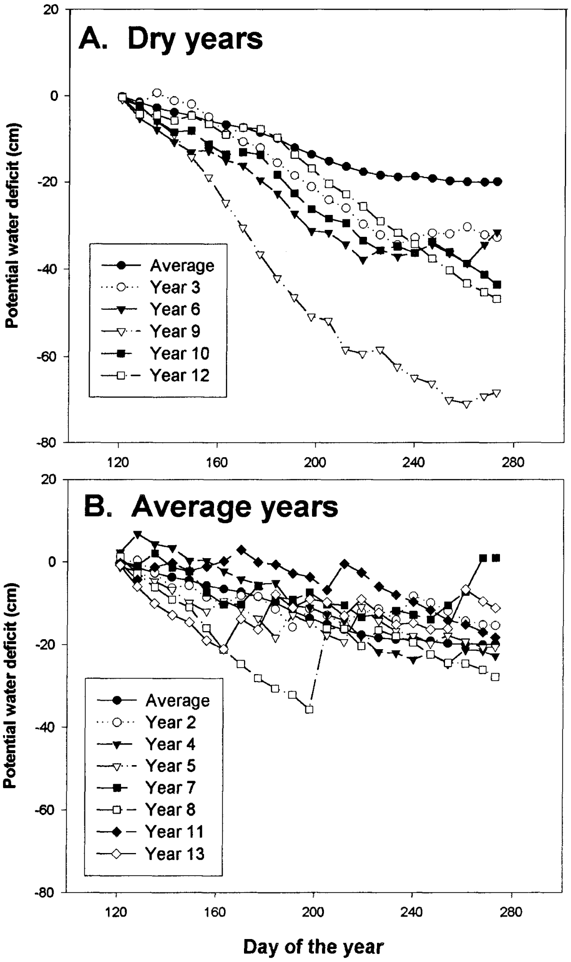

Fig. 4. The PWD for years 1–13. Dry years are shown separate (Fig. 4A) from the average or wetter years (Fig. 4B). Negative values indicate a shortage of rainfall to meet the potential water demands of the crop.

In dry years, returned-residues often resulted in significantly higher yields, but the difference was tillage treatment dependent (Fig. 2). In 8 out of 12 years, including all of the dry years, a grain yield advantage due to residue presence occurred with the CH treatment. These yield differences ranged from 0.5 to 1.0 Mg ha$^{-1}$. With MB, these differences were apparent in only 4 of the 12 years and were not apparent in every dry year. Moldboard plowing leaves little surface residue cover to minimize evaporative water losses. In contrast, with NT the differences were significant in only 3 of the 12 years although residue surface coverage was nearly complete. The general decline in yields with NT compared to those with CH or MB and a greatly increased data variability resulted in no significance differences in yields between residue treatments with the NT treatment.

### *3.3. Harvest index*

The partitioning of biomass between vegetative and grain tissue should be affected by tillage, residues, N, and climate. This partitioning is often expressed as grain dry matter divided by the total harvestable biomass (defined as HI). There is a strong inference for HI to increase with increasing total yields and decreasing crop stresses such as insufficient nutrients and water (Prihar and Stewart, 1990). Our HI data, when computed for every grain and stover pair, indicate HI increasing from lows of about 0.4 toward a plateau of about 0.6 as total yields increased toward 15 Mg ha$^{-1}$ (Fig. 5). This tendency agrees well with previous discussions of HI (Prihar and Stewart, 1990). However, the upper limit envelope procedure defined by Prihar and Stewart (1990) results in HI of 0.73, which is somewhat higher than the 0.60 reported for corn. In this study HI computed for every stover and grain yield pair (Fig. 5) and averaged over all treatments within a year was not significantly different between years, but varied between 0.50 and 0.57. An examination of the treatment effects on HI showed no significant differences. The drought year (year 9) resulted in the highest variability of HI. The standard deviation was 0.111 compared with 0.045 in a long-term average year (year 3). The overall mean HI was 0.56 with a standard deviation of 0.079.

## 4. Conclusions

The continued use of NT over 13 years resulted in a gradual decrease in grain and stover yields after the first 5 years. The effect of the management of residues on corn grain and stover yields did not change over time but rather was affected by the amount of rainfall received during the growing season. The removal of stover in marginally dry years (PWD deficits of 10–30 cm) showed a tendency to result in lower grain yields. These differences were most pronounced with

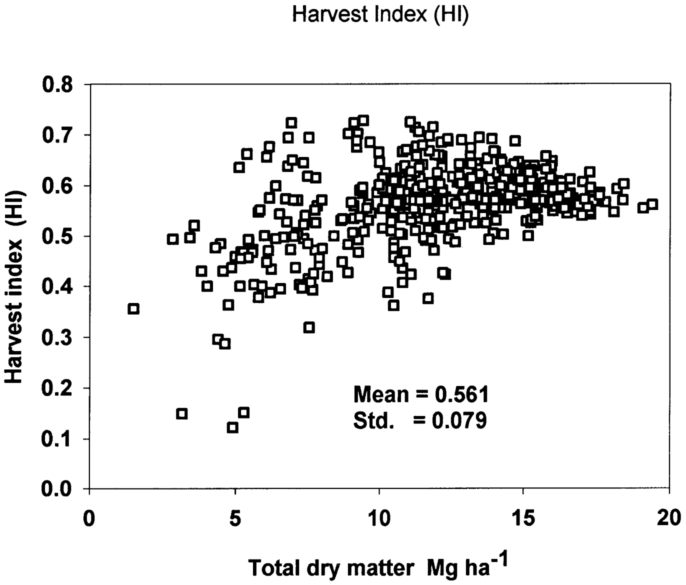

Fig. 5. HI as a function of total dry matter yield for all treatments and years. The overall average and standard deviation for the entire data set are also shown.

the CH treatment for which residue surface coverage is an integral feature of the system and apparently resulted in significantly better use of water, especially in dry years. The advantage of surface residue coverage, however, did not extrapolate in the long term to the higher coverage with NT because yields (even when well fertilized) remained low with time under NT conditions. With NT, the occasional wet and cold soil, which delayed crop establishment as was observed by many previous researchers, resulted in overall lower yields. Although both tillage and residue treatments had small effects on yields, the major impact of yearly growing season rainfall exceeded these differences by many times. Although in our discussion we classified several years as dry (Fig. 4), only one was so dry that the crop almost failed. Several dry years, although resulting in a soil water deficit, apparently had a distribution of rainfall during pollination and silking stages that resulted in reasonable corn yields. It was during these years that the retention of residues with the CH system had the most impact on maintaining higher grain and stover yields. The impact of tillage, residues, and nitrogen fertilizer is expressed equally to both stover and grain yields since HI did not vary significantly between treatments and years. However, when HI data are combined across all treatments and years, impact of stresses such as water deficits is expressed more in grain yields than in stover yields. Our data are consistent with the observations of many disciplines that plant stresses often trigger an increased allocation of resources into reproductive tissue (grain).

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