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OVERCOMING THE ROTATIONAL ANTAGONISM OF CORN
FOLLOWING WHEAT IN HIGH RESIDUE CROPPING
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OVERCOMING THE ROTATIONAL ANTAGONISM OF CORN FOLLOWING WHEAT IN HIGH RESIDUE CROPPING SYSTEMS

By

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ABSTRACT

OVERCOMING THE ROTATIONAL ANTAGONISM OF CORN FOLLOWING WHEAT IN HIGH RESIDUE CROPPING SYSTEMS

By

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Two established methods for increasing the sustainability of production agricultural cropping systems are (i) increasing crop residue levels by reducing tillage and (ii) including a winter annual crop in the rotation. However, many crops following wheat in tillage and reduced tillage systems have reduced grain yields. The objective of this study was to develop management practices to overcome the observed negative yield response in corn (*Zea mays L.*) grain grown following winter wheat (*Triticum aestivum* L.) in no-till, high residue cropping systems. We hypothesized that management practices including using a presidedress nitrogen test (PSNT) and using a PSNT in combination with manure and clover cover crops, or a combination of the two could be used to overcome the rotational wheat antagonism in such cropping systems. The experimental design was a randomized complete block design. Experimental factors were: presence of wheat residue from the previous crop with three levels (no residue, root residue, or root and shoot residue); (2) manure application with two levels (with or without); and, (3) red clover (*Trifolium pretense* L.) with two levels (with or without).

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ABSTRACT

Two established methods for increasing the sustainability of production agricultural cropping systems are (i) increasing crop residue levels by reducing tillage and (ii) including a winter annual crop in the rotation. However, many crops following wheat in tillage and reduced tillage systems have reduced grain yields. The objective of this study was to develop management practices to overcome the observed negative yield response in corn (*Zea mays L.*) grain grown following winter wheat (*Triticum aestivum* L.) in no-till, high residue cropping systems. We hypothesized that management practices including using a presidedress nitrogen test (PSNT) and using a PSNT in combination with manure and clover cover crops, or a combination of the two could be used to overcome the rotational wheat antagonism in such cropping systems. The experimental design was a randomized complete block design. Experimental factors were: presence of wheat residue from the previous crop with three levels (no residue, root residue, or root and shoot residue); (2) manure application with two levels (with or without); and, (3) red clover (*Trifolium pretense* L.) with two levels (with or without). Data were collected in 2003, 2004, and 2005. In all years the presence of winter wheat residue decreased soil temperature, increased soil moisture, and decreased chlorophyll content in corn leaves and plant height in the early stages of corn development. Winter wheat residue decreased the amount of plant available N, and increased grain moisture and test weight of corn grain at harvest. Emergence and population of corn in 2003 and 2005 were reduced. A PSNT nitrogen strategy was effective in maintaining corn grain yields in wheat residue systems equivalent to no-wheat residue systems in 4 of 6 site years. Similar results were obtained for PSNT plus clover cover crop and PSNT plus manure plus clover cover crop

N management systems. Using PSNT and manure system equalized high wheat residue yields to no-wheat residue in 6 of 6 site years.

CHAPTER 1

EFFECT OF WINTER WHEAT CROP RESIDUE ON NO-TILL CORN GROWTH AND DEVELOPMENT

ABSTRACT

Two established methods for increasing the sustainability of production agricultural cropping systems are (i) increasing crop residue levels by reducing tillage and (ii) including a winter annual crop in the rotation. However, many crops following wheat in tillage and reduced tillage systems have reduced grain yields. The objective of this study was to evaluate the effect of winter wheat (*Triticum aestivum* L.) crop residue on the growth and development of no-till corn (*Zea mays L.*).

The experimental design was a randomized complete block design. Treatments consisted of no-till systems with three levels of winter wheat residue (no wheat residue, wheat root residue only, and wheat root and shoot residue). Data were collected in 2003, 2004, and 2005. Measurements included corn grain yield, grain moisture and test weight of corn at harvest, plant growth characteristics (emergence, plant height, time of tasseling (VT stage), chlorophyll content), presidedress nitrogen test (PSNT), and soil moisture and temperature taken weekly during the spring and early summer. In all years, the presence of winter wheat residue above and below ground decreased soil temperature, increased soil moisture, and decreased chlorophyll content in corn leaves and plant height in the early stages of corn development. VT stage of corn was delayed for about 1 week in residue systems. Winter wheat residue decreased the amount of plant available N and

increased grain moisture and test weight of corn grain at harvest. Emergence and population of corn in 2003 and 2005 were reduced.

INTRODUCTION

High residue cropping systems such as no-till and reduced-till systems contribute significantly to the sustainability of production agriculture. No-till and reduced-till farmers in the United States occupy 21 million ha of land, about 38% of the United States cropland (Conserv. Technol. Inf. Cent, 2000). These systems reduce soil erosion and run-off and increase the percolation of rainfall (Cavigelli, 1998). Additionally, soil organic C levels are increased, leading to improved soil nutrient holding capacity and structure (Tisdall and Oades, 1982). Maintenance of soil organic matter has long been recognized as a strategy to reduce soil degradation in agricultural systems.

Soil structure is an important property that mediates many soil physical and biological processes and controls soil organic matter decomposition (van Veen and Kuikman, 1990). Soil aggregates are the basic units of soil structure and are composed of primary particles and binding agents (Edwards and Bremner, 1967; Tisdall and Oades, 1982; Haynes et al., 1991). Soil organic matter is a major binding agent that stabilizes soil aggregates (Haynes et al., 1991).

The amount and turnover of soil organic matter can be altered by different management practices. Cultivation affects soil structure by destroying soil aggregates, resulting in loss of soil organic matter (Tisdall and Oades, 1982; Elliott, 1986; Angers et al., 1992). Incorporation of plant residues in soil affects the soil microclimate and increases plant residue contact with soil, increasing the rate of residue decomposition and organic matter transformation (Beare et al., 1992; Cambardella and Elliott, 1993; Paustian et al., 1997). Tillage enhances decomposition of organic matter by mixing plant residues into the soil, increasing aeration, and enhancing dry-wet and freeze-thaw cycles (Paustian et al., 1997). Also, tillage disrupts soil aggregation and exposes physically protected organic material (Blevins and Frye, 1993; Beare et al., 1994b). In contrast, no-till systems reduce soil mixing and soil disturbance, allowing soil organic matter accumulation (Blevins and Frye, 1993). Many studies have shown that no-till farming improves soil aggregation and aggregate stability (Beare et al., 1994b; Six et al., 1999). Mycorrhizal fungi, which are promoted by no-till systems, contribute to formation and stabilization of macroaggregates (Tisdall and Oades, 1982; O'Halloran et al., 1986; Beare and Bruce, 1993). Also, no-till significantly increases soil total C and N levels, water-stable aggregates, and labile C and N associated with macroaggregates, compared with conventional tillage (Mikha and Rice, 2004).

Michigan growers increased winter wheat production from 214,650 ha in 2002 to 255,150 ha in 2004, a 20% increase (Michigan Agricultural Statistics Service, 2004). Winter wheat is generally grown in rotation with corn and soybean. The growth cycle of soybeans makes winter wheat a logical fallow crop in the rotation, which is usually planted right after soybean harvest. Growers typically follow wheat with corn. There are many advantages of including a winter annual crop such as winter wheat in a cropping system. Sanchez et al. (2001a) reported that N mineralization was increased in a diverse cropping system including wheat in the rotation. In addition, pest cycles can be disrupted with the inclusion of a winter annual crop (Cavigelli, 2000). Wicks et al. (1995) reported reduced weed emergence when no-till corn was planted into winter wheat residue. Copeland et al. (1997) estimated a 10% corn grain yield increase when corn was rotated with wheat.

The agronomic and environmental advantages of reduced-tillage, high residue cropping systems have been well documented (Cavigelli et al., 1998, Sanchez, 2001b). Despite many advantages, there are also negative impacts associated with high residue systems. One such negative impact is a corn-wheat antagonism that results in lower corn grain yield following wheat (Beuerlein and Houdashelt, 1997). Similar reports that corn following wheat in the crop rotation seems to have reduced grain yields came from no-till and reduced-till growers in the Great Lakes Region (K.Thelen, personal communication).

Cox et al. (1990) noted that cool conditions in May in years with less than normal growing degree days may result in poorer emergence under reduced tillage because high residue inhibits soil warming and delays corn emergence in northern latitudes. Also, Drury et al. (2003), in a four-year study in a winter wheat- corn-soybean rotation with and without red clover, reported different emergence rates of corn in different tillage systems. In no-till systems corn emergence rates were slower compared with conventional tillage over 3 years. However, despite low emergence rates, final plant stands were not significantly different between treatments in some years. Also, emergence of corn depended on time of planting (early or late) and spring weather conditions (wet or dry, cool or warm).

Beuerlein and Houdashelt's (1997) results contradict the notion that cooler soil temperature in the spring, because of the presence of wheat residue, is the only cause of corn-wheat antagonism. In a study, they grew wheat adjacent to bare soil plots. After harvesting the wheat, they removed the above ground wheat residue and transferred it to the bare soil plots without disturbing the soil. The following spring, corn was planted into the crops. Interestingly, the removal of the above ground wheat residue did not overcome the corn yield antagonism.

One other possible cause of corn/winter wheat antagonism is allelopathy. Allelopathy results from plant-plant and plant- microorganism interactions mediated by several secondary metabolites released to the environment from the donor plant. These secondary metabolites or allelochemicals stimulate or inhibit the growth of plants and microorganisms by acting directly on some essential biological processes (respiration, photosynthesis, membrane permeability, cellular division, and protein synthesis) or indirectly on soil microorganisms, interfering with the establishment of some bacterial-plant or fungi-plant symbiosis (Golovko, 1999).

Winter wheat is an active allelopathic plant. The allelopathic nature of wheat residue has been demonstrated in fields where residues are mulched on the soil surface (Krupa, 1982). Winter wheat straw significantly inhibits emergence, seedling growth, and dry matter accumulation of various weeds (Wu et al., 2000). The release of allelochemicals of different chemical classes from wheat has been well documented. These include tannins, cyanogenic glycosides, several flavonoids, and phenolic acids such as ferulic, p-coumaric, syringic, vanilic, and p-hydroxybenzoic acids (Einhellig, 1995).

The main sources of phenolic compounds in soil are root exudates of allelopathically active plants, products of decomposition of root residues, and intermediate products of humus transformations (guayacol, quayacol-hydroxyphenol, and others) (Golovko, 1999). Soil toxicity depends not only on root excretions, but also on decomposition of residue. Krupa (1982) reported that residue from winter wheat significantly decreased productivity of corn in an Alfisol soil under moldboard tillage systems. In winter wheat residue, he found five phenolcarboxilic acids: phenolic, ferulic, coumaric, vanilic, and caffeic. The same acids were also found in the soil in high concentrations. Lower yields resulted from accumulation of soil nitrophenols, which, after addition of fertilizers, turned into aminophenols and stimulated plant growth (Golovko, 1984).

During cool, wet springs in Ohio, farmers and researchers often noticed that no till corn planted into wheat residue does not grow as rapidly as corn planted with conventional tillage. Thomison (1995) explained that under cool soil conditions and no-till farming practices winter wheat residues concentrated near the soil surface break down more slowly and tie up N longer than when residue is incorporated, making N less available for crop growth. This slow decomposition can be attributed to the high C-N ratio of wheat residue and environmental conditions. Another biological process that may also contribute to the slow growth of corn following wheat involves the production and release of phytotoxins from decomposing wheat residues. The allelopathic effects of wheat straw on corn growth may be related to either anaerobic production of microbial byproducts using wheat residue as a C source and/or direct release of organic compounds from the decomposing residue. Cool temperature, anaerobic conditions, and low pH increase leaching of amino acids and carbohydrates from the plant roots. Anaerobic conditions contribute to exudation of alcoholic substances that are toxic to plants (Christiansen et al., 1970).

Phytotoxic strains of microorganisms produce more than 45% of the common pool of soil phenolic compounds. Among the microorganisms that most actively produce polyphenols are: *Pseudomonas rubigenosa*, *Bacillus rusticus,and Fusarium solani* (Golovko, 1999). Other researchers (Dill-Macky and Jones, 2000) cited increased substrate for disease, such as *Fusarium graminearum*, as a potential concern to long term rotations including winter wheat.

Rice (1984) most vividly showed the relationship between the allelopathy and microbial activities that determine plant available N in soils. He found that active allelopathic compounds inhibit N fixation by free-living and symbiotic microorganisms. These compounds influence nitrification, but do not influence denitrification processes.

Allelopathy is also of agricultural importance because of the phenomenon of autotoxicity. The negative impact of wheat autotoxicity on agricultural production systems has been reported when wheat straws are retained on the soil surface for conservation farming purposes (Wu et al., 2001).

Greenhouse studies have shown that toxins and bacteria from decaying residue affect growth of new plants (Krupa, 1982). In the field, it is difficult to separate allelopathic effects from soil temperature effects. Further, many researchers believe that the toxic effect is most likely to occur when corn follows corn, rye, or winter wheat and when residue is on or near the soil surface in the row area.

Our objective was to verify the reported antagonism of winter wheat residue on no-till corn growth and development.

MATERIAL AND METHODS

Experimental site and data collection

We conducted the research at the Michigan State University Agronomy Farm, in East Lansing, MI. The experiment was established on soybean-winter wheat-corn cropping systems from 2001 through 2005 with three cycles. The first cycle included plots planted to soybeans in 2001, winter wheat in fall 2001, and corn in 2003. The second cycle included plots planted to soybeans in 2002, winter wheat in 2002, and corn in 2004. A similar third cycle was implemented with soybeans and wheat planted in 2003 and with corn planted in 2005. Treatments with no wheat residue had a second year of soybean substituted for wheat in the second year of each cycle.

The first cycle was established on a Capac loam soil (Fine loamy, mixed, mesic Typic Hapladulfs). The second and third cycles were established on Colwood (Fine loamy, mixed, mesic Typic Haplaquolls) - Brookston (Fine loamy, mixed, mesic Typic Argiaquolls) loam soils.

The experiment was a randomized complete block design with treatments consisting of three levels of winter wheat residue (no wheat residue, wheat residue above and below ground, and wheat residue below ground only). In the first cycle, the experiment had four replications. Plots were 14.0 m long and 6.1 m wide. In the second and third cycles the treatments were replicated eight times. Plots were 9.1 m long and 6.1 m wide. Distance between rows of planted corn was 76 cm.

In the second year of the experimental cycle, soybean (Dekalb 23-51) was planted on 5 May 2002, 19 April 2003, and 29 May 2004 (rate of planting was 444,600 seeds ha^{-}

^{1}) for treatments having neither above or below ground wheat residue. Soybean was harvested on 28 September 2002, 13 October 2003, and 20 December 2004. At planting time, liquid starter fertilizer 6-24-6 (28 kg ha^{-1}) was added, providing 1.7 kg N ha^{-1} similar to local common production practices. Yields of soybean were not significantly different between plots ($p>0.05$). In 2002 soybean yielded 3.59 Mg ha^{-1}, in 2003 2.25 Mg ha^{-1}, and in 2004 3.26 Mg ha^{-1}.

Winter wheat (Harus) was planted in the fall of 2001, 2002, and 2003. In the following spring, at green up, wheat plots received 246 kg ha^{-1}of granular urea (46-0-0). Winter wheat yielded an average of 5.65 Mg ha^{-1} in 2002, 7.65 Mg ha^{-1} in 2003, and 4.95 Mg ha^{-1} in 2004 with no yield significant differences between plots. After harvest the remaining wheat straw was about 30 cm tall. The remaining residue was returned to the plots with below and above ground wheat residue and removed from treatments having below ground wheat residue only. The amount of straw left in the treatments with wheat root and shoot residue (WRSR) was 10.73, 7.39, and 9.63 Mg ha^{-1} in 2003, 2004, and 2005, respectively, with no significant differences between plots. The highest amount of wheat residue left in the plots was from the first cycle (2001-2003).

An early maturity corn variety DKC44-46 (YieldGard Corn Borer/Roundup Ready, Residue Proven, 94-day relative maturity) was planted into plots by a customized John Deere no-till planter. Corn was planted at a target population of 69,000 plants ha^{-1} on 30 April 2003, 29 May 2004, and 19 April 2005 and harvested on 16 October 2003, 22 October 2004, and 27 September 2005. In 2003 and 2005, starter fertilizer 6-24-24 was placed in furrow and in row (269 kg ha^{-1}), providing 16 kg N ha^{-1}. In 2004 starter fertilizer 19-19-19 was added (140 kg ha $^{-1}$), providing 26.6 kg N ha $^{-1}$.

Based on PSNT results, on 25 June 2003, 15 July 2004, and 20 June 2005, we applied N to every plot (based on yield goal of 8.8 Mg ha^{-1}). The soil samples for the PSNT test were taken from a depth of 0-30 cm on 17 June 2003, 7 July 2004, and 7 June 2005. Soil pH, nitrate, and phosphorus levels were determined from separate soil samples obtained each spring. The average pH values based on all the plots were 6.1 and 5.6 (1:1 soil/water), in 2003 and 2004, respectively. The average phosphorus values were 97.5 and 107 kg ha^{-1} (Bray P_1), respectively. Treatments had no significant effect on either pH or phosphorus. Potassium content was not measured but assumed sufficient based on soil test data obtained prior to the experiments.

In the early spring and early summer of 2004 and 2005, soil temperature measurements were taken weekly at a depth of 10 cm. In the early spring of 2003, soil temperature was measured at a depth of 20 cm at the early sampling dates and then from a depth 10 cm for the later sampling dates. Soil moisture was measured using a Trime–FM3 moisture meter with a P3 probe (Mesa Systems Co. Framingham, MA) at a depth of 0-15 cm.

Changes in soil temperature or moisture values of wheat root residue (WRR) treatments and WRSR as compared to the control no wheat residue (NWR) treatments were expressed as a ratio between soil temperature or moisture values measured in WRR and WRSR plots and the average soil temperature or moisture value from the NWR plots, and are called Δ temperature or Δ moisture.

To monitor corn development, we recorded emergence, postemergence stand count, time of tasseling (VT stage), and stalk lodging. Corn height was measured at the V9 stage until VT stage every week. Chlorophyll content of the uppermost corn leaf that had formed a collar was measured weekly using a SPAD-502 meter (Specialty Products Agricultural Division, Minolta Co. LTD, Japan) in 2004 and 2005, when corn was at the V6 stage until VT stage.

Growing degree days (GDD) were calculated as GDD = $[(T_{max}+T_{min})/2]-10$, where T_{max} and T_{min} are the daily maximum and minimum temperatures (°C), respectively. If T_{max} was greater than 30 °C, then we set T_{max} to be equal to 30 °C. If T_{min} was less than 10 °C, then we set T_{min} to be equal to 10 °C.

Two center rows of corn from each plot were machine harvested. Moisture content, test weight, and field weight of corn were measured by a Grain Gage™ and HarvestMasterSystem™ (Juniper Systems, Inc., Logan, UT) mounted on a plot combine. Grain yield was reported at 15.0 % moisture content. Grain test weight is reported at harvest moisture.

Percent of soil surface cover by wheat residue was determined using digital images. In WRSR treatments the soil was covered by winter wheat residue at a level of 72.6 % and in WRR treatments at a level of 57.5 % with no differences between plots.

Data analysis

Analysis of variance was performed to test significance of the factors and their interactions. Statistical analyses were conducted using the PROC MIXED procedure in SAS (SAS Inc., 2002). Normality of the residuals and homogeneity of variances were evaluated. When the variances were not homogeneous, the REPEATED /GROUP option of PROC MIXED was used. When the F-test showed a significant treatment effect we conducted mean separations using Fisher protected t-tests (P=0.05).

RESULTS

Weather conditions of 2003-2005 growing seasons

The 2003 growing season had persistently cool temperatures, delayed crop growth, and abnormal dryness during the later half of the season (Table 1.1). The spring of 2003 was cooler than normal and cooler than the 2004 spring season. Although, the amount of precipitation was above normal in May 2003, the overall 2003 growing season had below normal precipitation. In contrast, the 2004 growing season had above normal precipitation. Because of the very wet and cool spring of 2004, corn was planted one month later than in 2003. In both 2003 and 2004, during the 5-month May-September period, growing degree day accumulations were below normal. The 2003 growing season accumulated fewer growing degree day units than 2004. In 2005 both growing degree days and precipitation were close to the 30-years norms. Temperatures in May 2005 were below average. However, the temperatures during the rest of the 2005 growing season were above the 30 – year average for the East Lansing area.

Effect of wheat residue on soil temperature

Wheat residue affected soil temperature. In 2003, WRSR treatments had significantly lower soil temperatures compared to NWR and WRR treatments in all studied dates (Figure1.1). The exception was 8 May when soil temperatures in WRSR treatments were not different from soil temperatures in NWR treatments. Soil temperatures in NWR and WRR treatments were not significantly different in all studied dates.

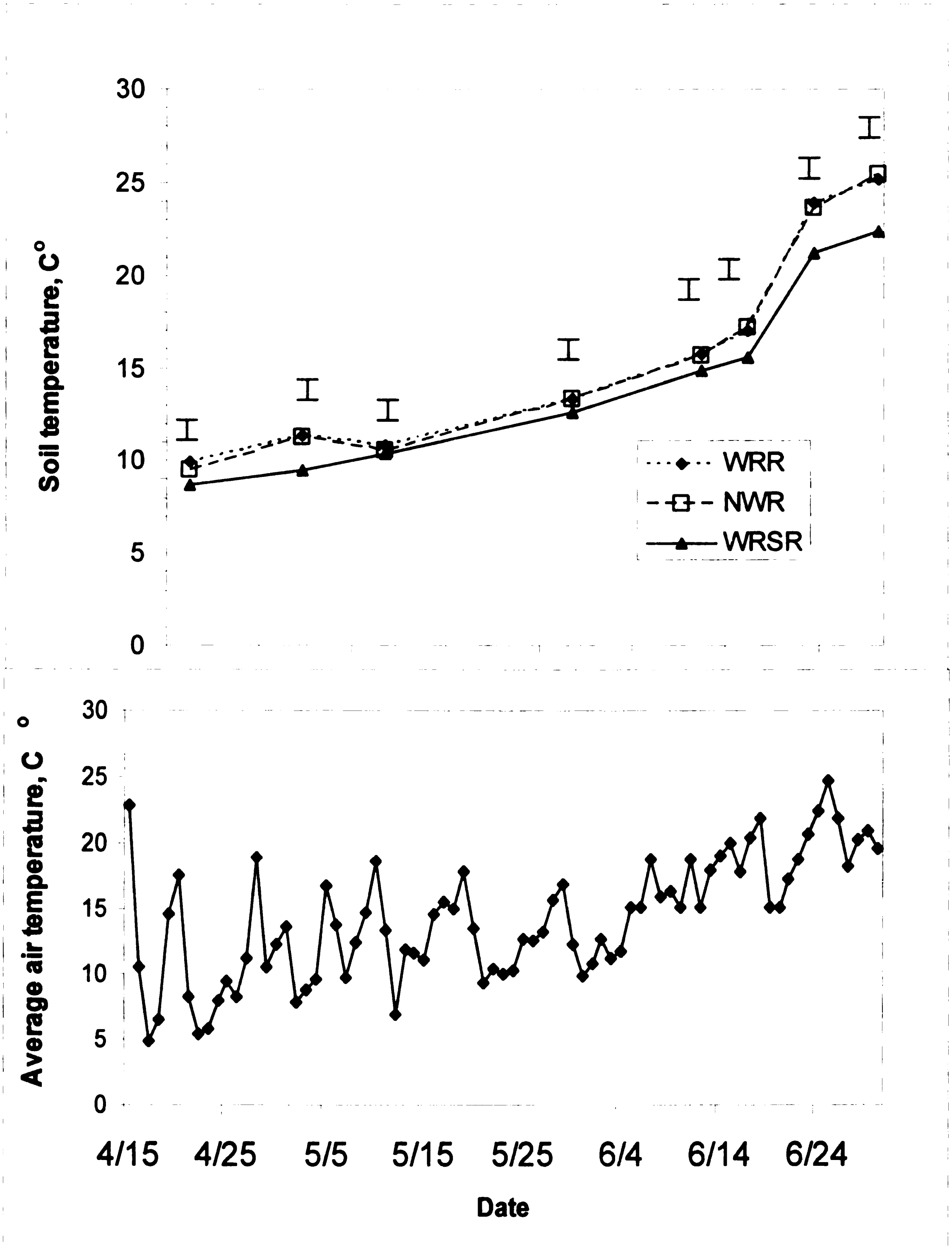
Table 1.1. Monthly precipitation, temperature, and growing degree days at East Lansing, MI during the 2003- 2005 seasons (Data courtesy of MSU Agricultural Weather Office).

Precipitation (mm)	2003		2004		2005		Norma
	OBS	DEV	OBS	DEV	OBS	DEV	
May	100.8	31.5	265.2	195.9	33.2	-36.1	69.3
June	47.8	-42.2	78.2	-11.7	108.7	18.8	89.9
July	45.9	-30.7	96.5	19.8	116.3	39.6	76.7
August	32.3	-46.9	81.0	1.8	16.3	-62.9	79.2
September	45.7	-17.8	25.9	-37.6	76.7	13.2	63.5
Total	272.5	-106.1	546.8	168.2	351.2	-27.4	378.6
Growing Degree Days (°C)							
May	140	-48	193	5	96.5	-91.5	188
June	247	-47	264	-30	349.9	55.9	294
July	334	-22	330	-26	354.3	-1.7	356
August	340	8	274	-58	348.3	16.3	332
September	217	-15	264	32	241.7	9.7	232
Total	1278	-124	1325	-77	1390.7	-11.3	
Mean Temperature (°C)							
May	12.2	-2.2	14.8	0.6	11.9	-2.3	14.2
June	17.5	-2.0	18.4	-1.1	22.1	2.6	19.5
July	20.5	-1.3	20.7	-1.1	22.1	0.3	21.8
August	20.9	0.1	18.6	-2.0	21.9	1.1	20.8
September	15.9	-0.7	18.6	2.0	18.5	1.9	16.6

OBS-Total observed DEV- Deviation of observed from normal

*- 1951-1980 means for East Lansing area

Figure 1.1. Treatment effects on soil temperature, and average air temperatures in 2003.



In 2004, WRSR treatments had significantly lower soil temperatures than NWR and WRR treatments in all studied dates. Soil temperatures in NWR and WRR treatments were not different on 5 of 8 studied dates (Figure 1.2). The 23 and 29 April dates represent the beginning of the sampling period and 21 June the last sampling date. This suggests that soils were uniformly cool and warm at the beginning and at the end of the sampling period respectively and that treatments had more of an effect on soil temperature during the transitional soil warm-up phase.

In 2005, soil temperatures in WRSR treatments were significantly lower than soil temperatures in NWR and WRR treatments on all dates (Figure 1.3). Also, NWR treatments had significantly higher soil temperatures than WRR treatments on 5 of 6 dates. On 10 May there were no differences between NWR and WRR treatments.

Effect of wheat residue on soil moisture

Wheat residue affected soil moisture. In 2003, WRSR treatments had significantly higher soil moisture levels on all sampling dates compared to NWR and WRR treatments (Figure 1.4). The exception is 28 May 2003 when treatments were not different. Also, soil moistures in WRSR and NWR treatments were not different on 14 May, 16 June, and 18 June. Soil moistures in NWR and WRR treatments were not significantly different on most dates.

In 2004, WRSR treatments had significantly higher soil moistures compared to NWR and WRR treatments (Figure 1.5). Soil moistures in NWR and WRR treatments were not different on all dates.

Figure 1.2. Treatment effects on soil temperature, and average air temperatures in 2004.

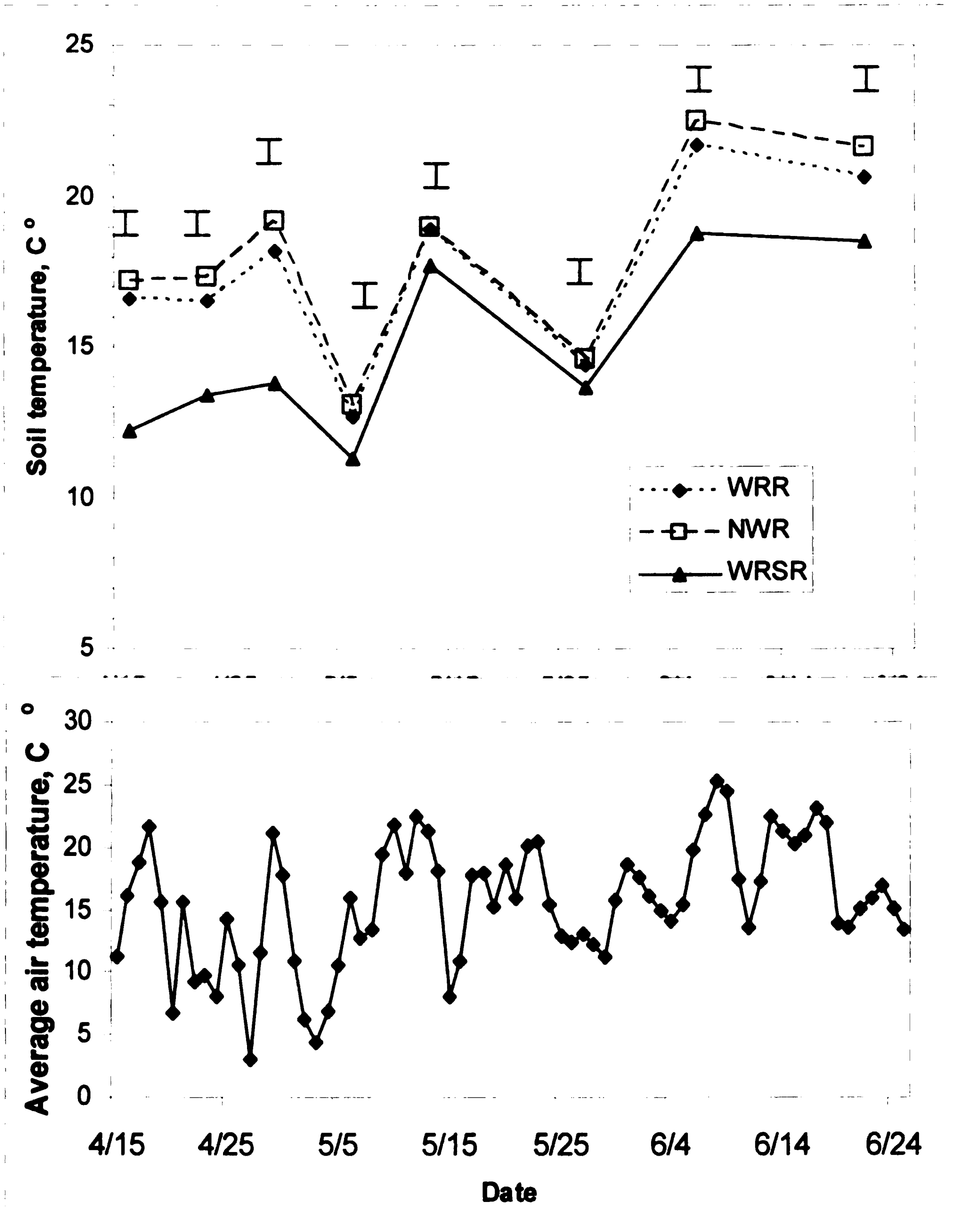


Figure 1.3. Treatment effects on soil temperature, and average air temperatures in 2005.

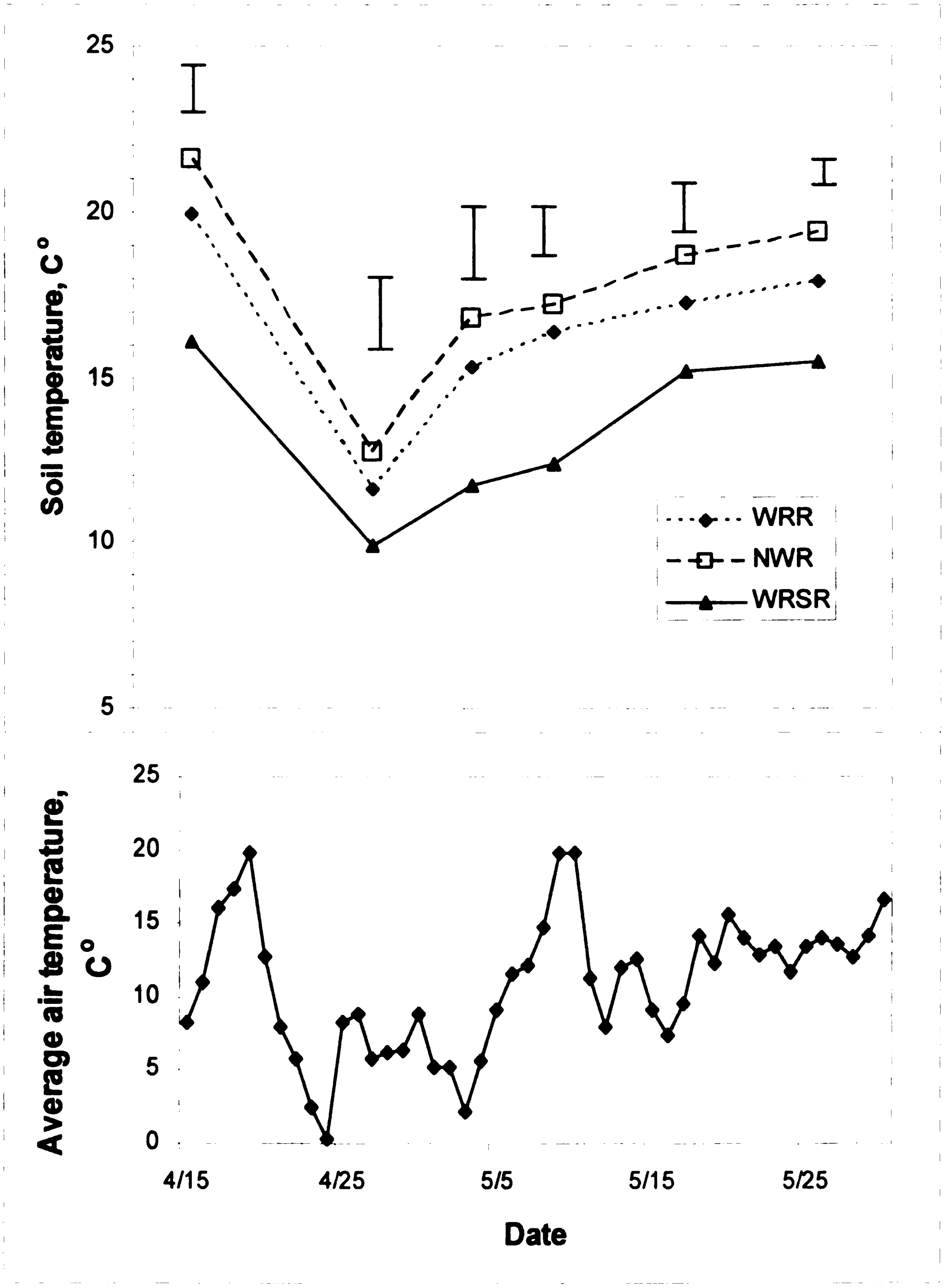


Figure 1.4. Treatment effects on soil moisture, and precipitation in 2003.

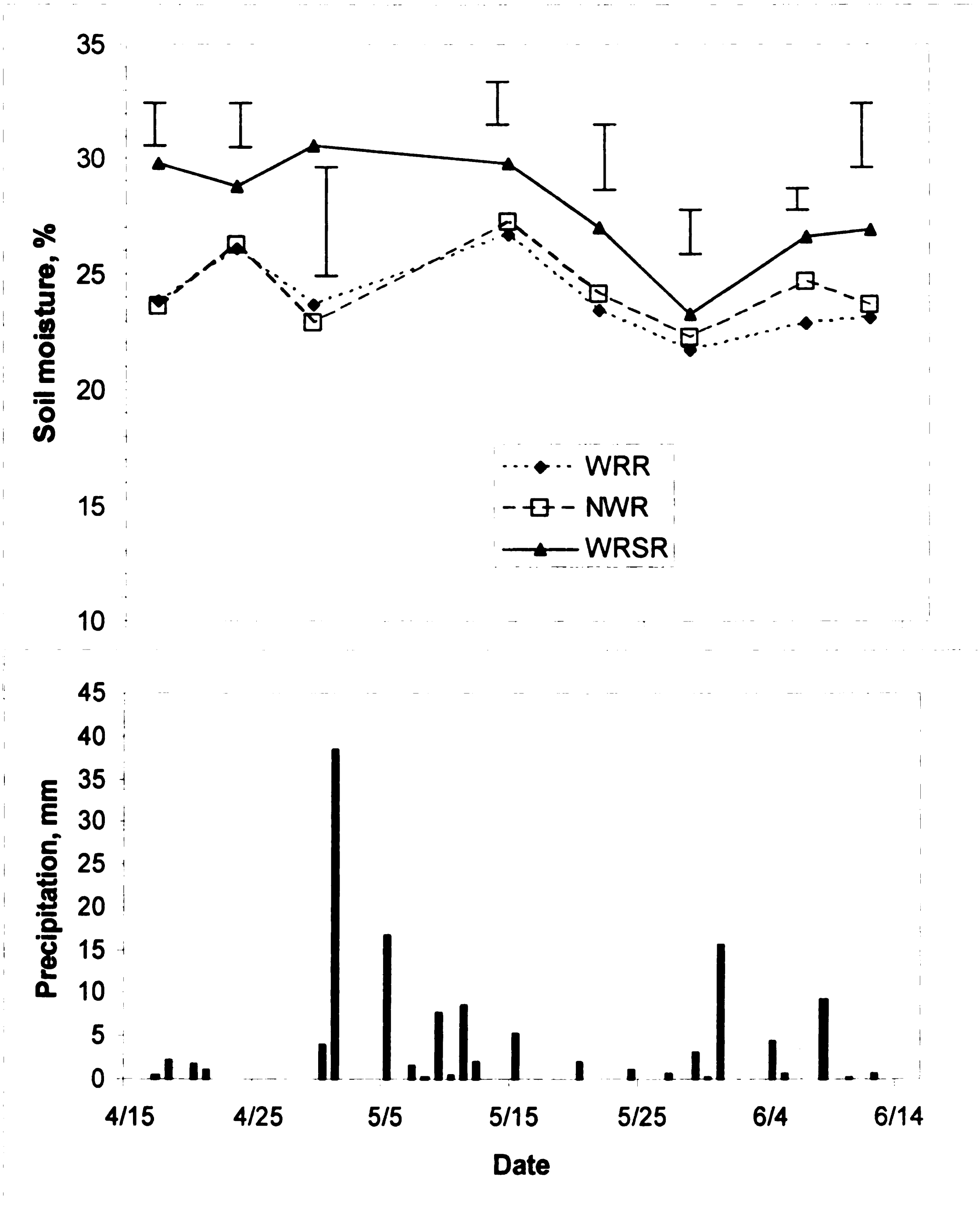
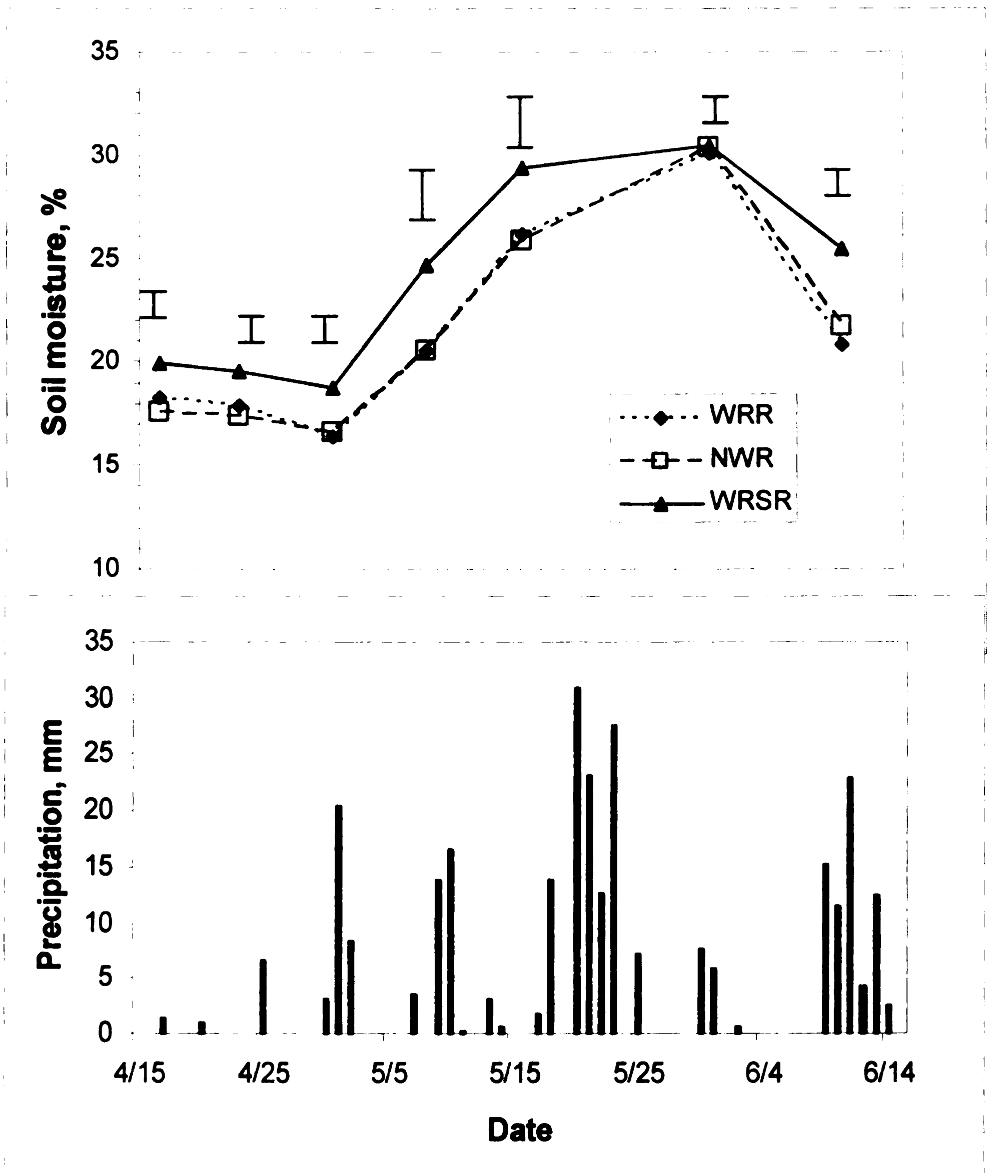


Figure 1.5. Treatment effects on soil moisture, and precipitation in 2004.



In 2005, WRSR treatments had significantly higher soil moistures compared to NWR and WRR treatments on all dates (Figure 1.6). Soil moisture in NWR and WRR treatments were not different on all dates. The exception was 18 May when WRSR and WRR treatments were not different. NWR and WRR treatments were also not different on this date.

In all three years, the values of Δ temperature and Δ moisture from WRR and WRSR treatments were significantly negatively correlated ($p<0.05$). Lower Δ temperature values corresponded to higher Δ moisture, and higher Δ temperature values were observed in drier soil (Figures 1.7, 1.8, and 1.9).

Both Δ temperature and Δ moisture were strongly related to percent of residue cover (Figures 1.10 and 1.11). Higher residue cover corresponded to lower soil temperature and higher soil moisture.

The observed cooler temperatures and higher moistures at higher residue cover are consistent with other observations. Researchers (TeKrony et al., 1989) and growers have speculated that corn grain yield antagonism may be attributable to cooler soil temperature in the spring from the wheat residue. Lund et al. (1993) associated the reduced yield of no-till, continuous corn with the greater crop residue and cooler soil temperature in the spring (2.7 ^{o}C lower). Wilhelm and Wortmann (2004) concluded that the advantage of moldboard tillage over no-till for corn yield was greatest in years with low spring temperatures. Tillage may be preferred for soils that are slow to warm or when early planting is preferred.

Figure 1.6. Treatment effects on soil moisture, and precipitation in 2005.

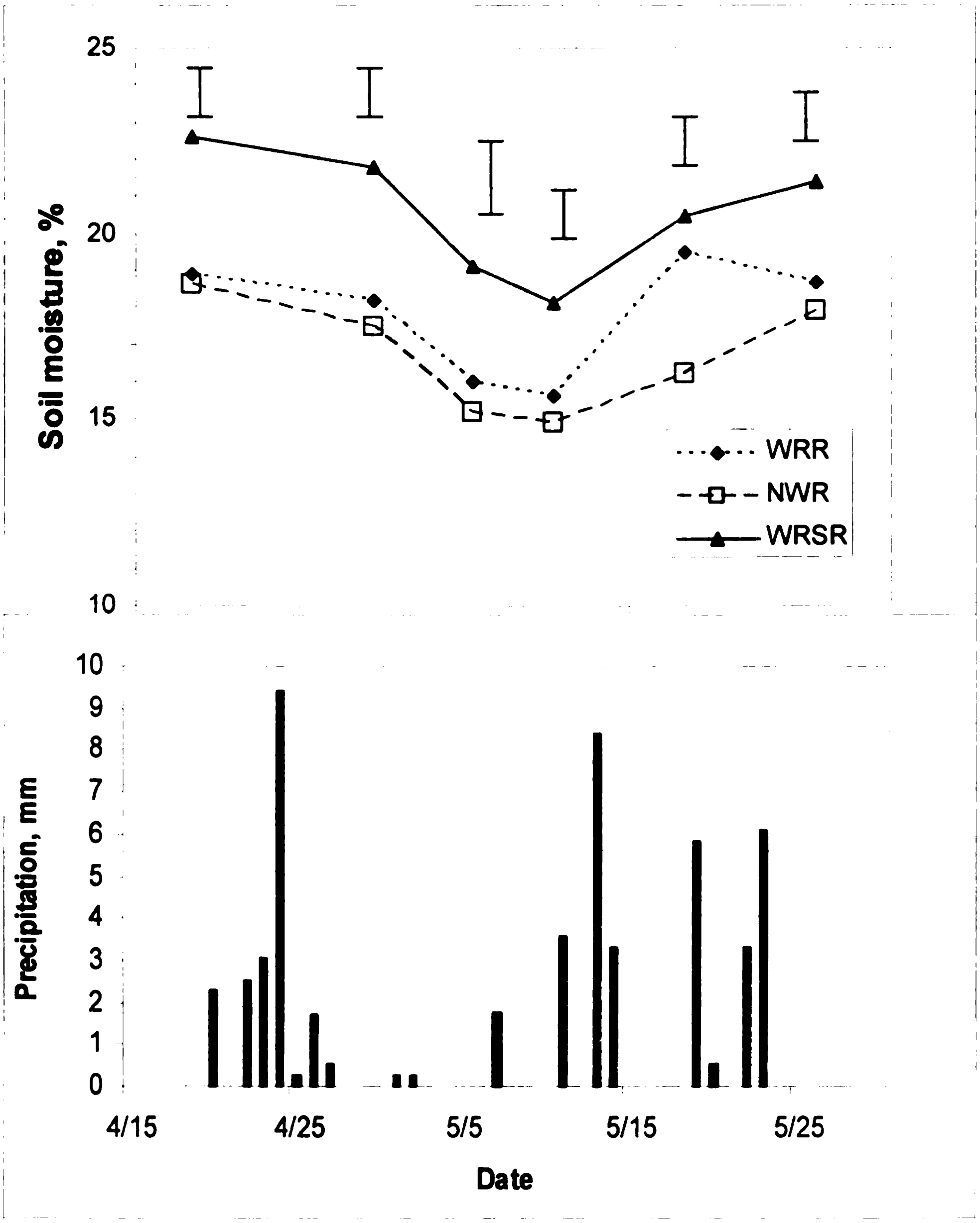


Figure 1.7. Relationship between Δ soil temperature and Δ soil moisture in 2003.

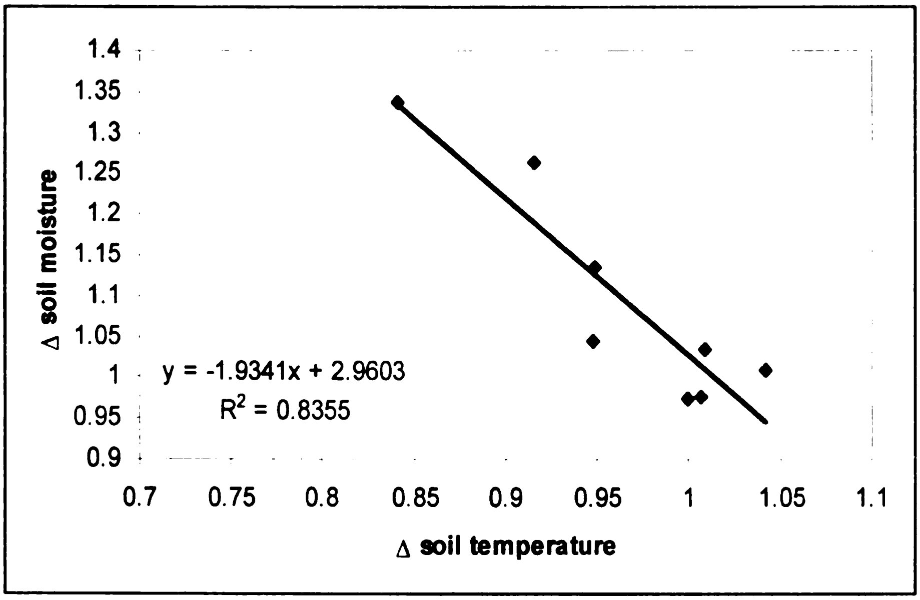


Figure 1.8. Relationship between Δ soil temperature and Δ soil moisture in 2004.

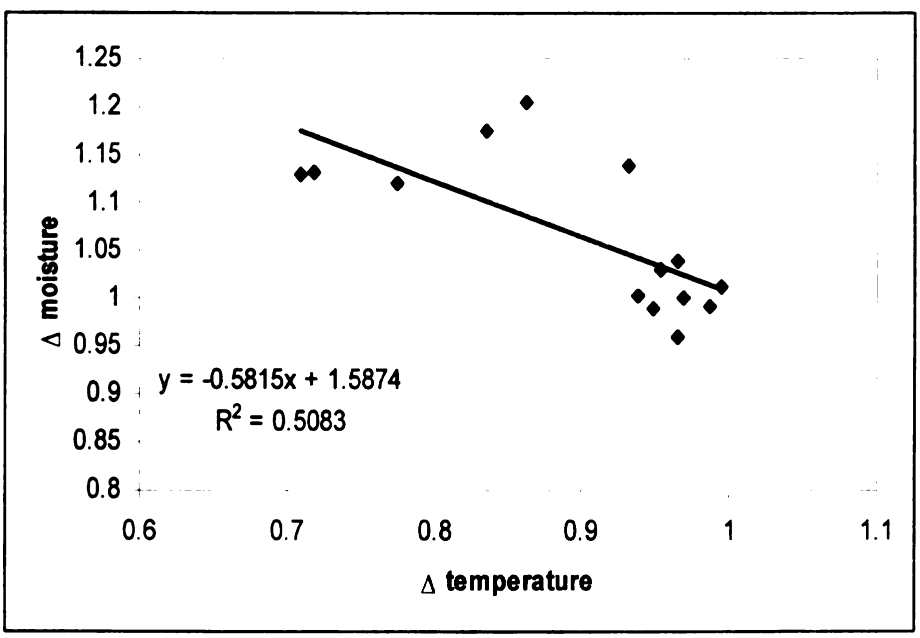


Figure 1.9. Relationship between Δ soil temperature and Δ soil moisture in 2005.

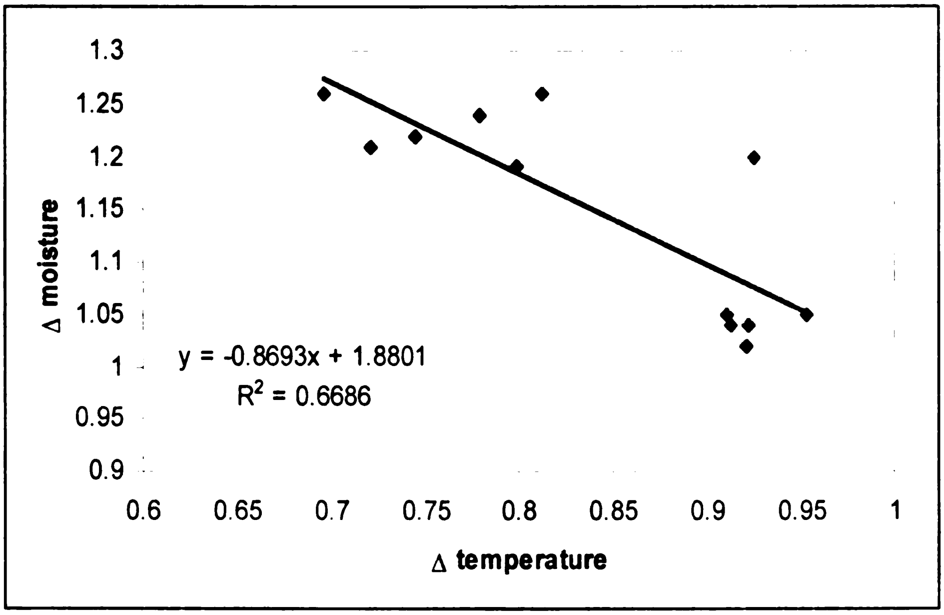


Figure 1.10. Relationship between percents of soil surface covered by wheat residues and Δ soil temperatures in 2005.

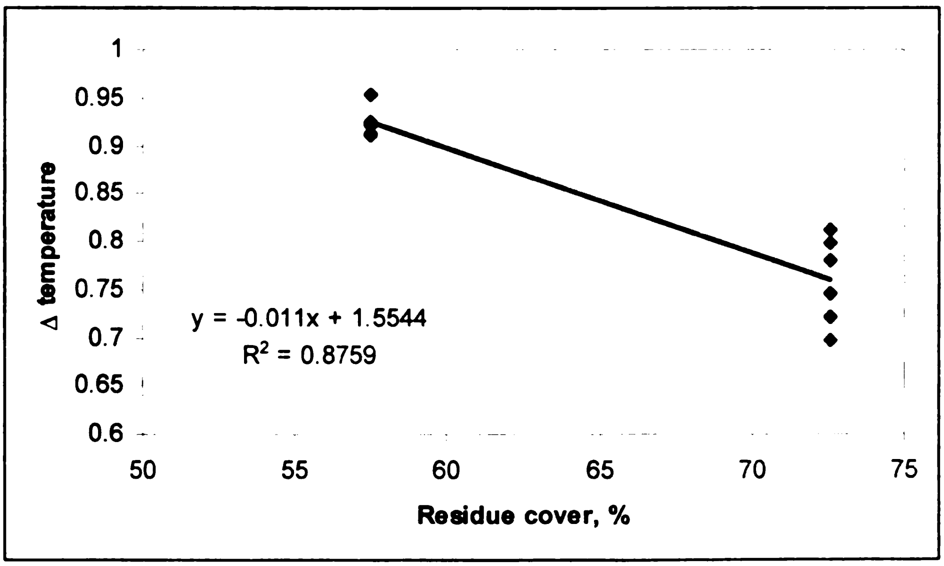
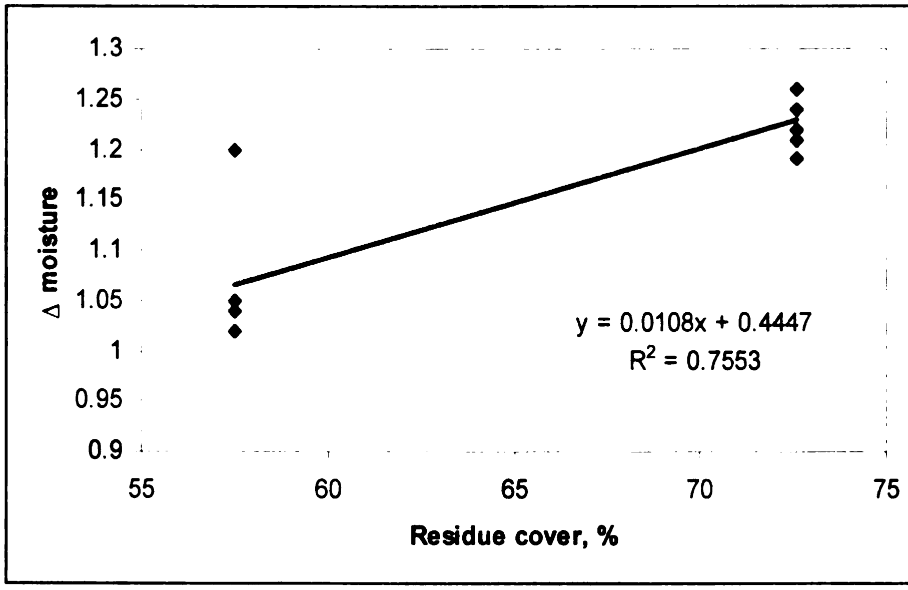


Figure 1.11. Relationship between soil surfaces covered by wheat residues and Δ soil moistures in 2005.



Effect of wheat residue on date of corn emergence

In 2003 and 2005, in WRSR treatments corn emerged significantly later than in NWR and WRR treatments (Table 1.2). There was a difference between NWR and WRR treatments. The negative effect of wheat residue on corn emergence can be related to the relatively early planting of corn (17 April and 30 April). Soil temperatures in WRSR treatments were lower compared to NWR and WRR treatments, explaining the delayed corn emergence. Also, the early cool spring of 2005 delayed corn emergence. In both 2003 and 2005, corn emergence was significantly negatively correlated with Δ soil temperature ($p<0.05$) (Figures 1.12 and 1.13). These results are consistent with many reports of reduced emergence and yields under no-till compared with conventional till farming, especially in humid and cool temperate climates (Fortin and Pierce, 1991).

Table 1.2. Treatment effects on corn emergence, population, and time of tasseling.

Treatment	2003	2004	2005	2003	2004	2005	2003	2004	2005
	Emergence (date)			Population (plants ha^{-1})			VT stage (date)		
WRR	5/25 b†	6/10 a	5/20 b	66297 b	62827 a	62505 b	7/27 a	8/4 a	7/15 b
NWR	5/19 a	6/10 a	5/15 a	67863 b	59705 a	64962 b	7/24 a	8/4 a	7/12 a
WRSR	5/29 c	6/10 a	5/25 c	62674 a	65455 a	57383 a	7/30 b	8/10 b	7/18 c

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, P<0.05).

In 2004, because of the very wet and cool spring, corn was planted relatively late (29 May). Higher soil temperatures observed in late May and early June promoted germination of corn, thus potentially being the reason for the same corn emergence time in all treatments in that year. There was no significant relationship between the date of corn emerged in 2004 and Δ soil temperature.

Figure. 1.12. Relationship between date of corn emerged and Δ soil temperature in 2003.

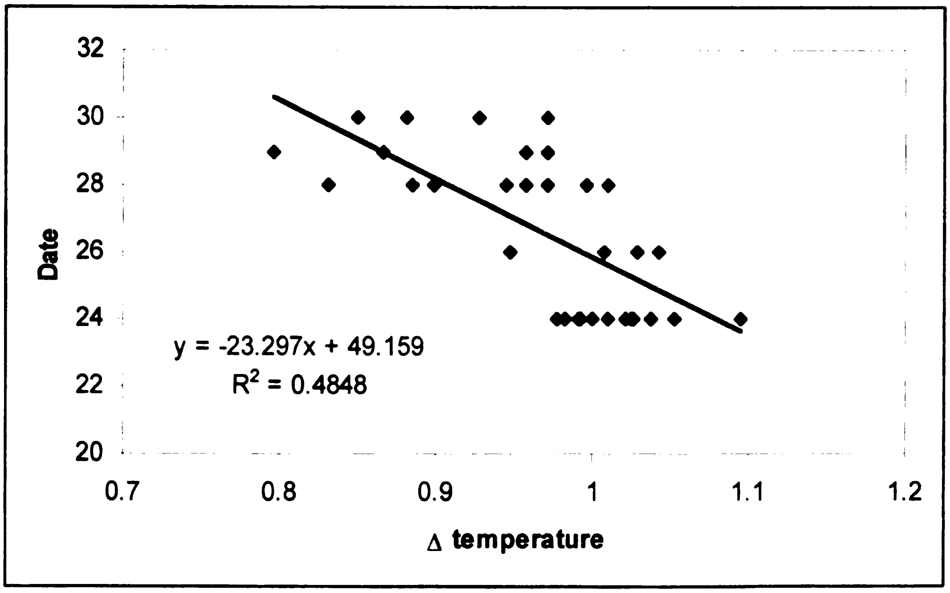


Figure 1.4. Treatment effects on soil moisture, and precipitation in 2003.

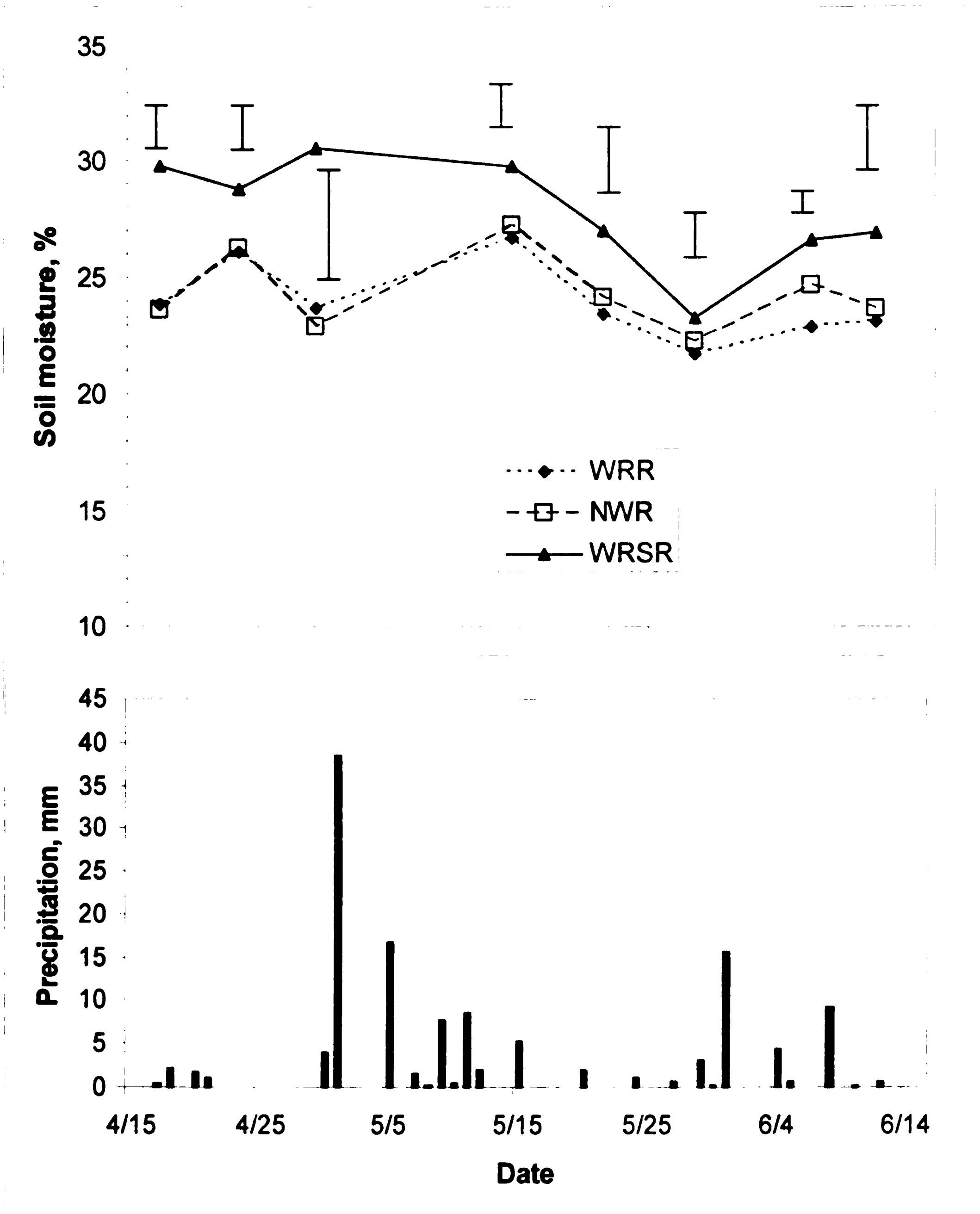
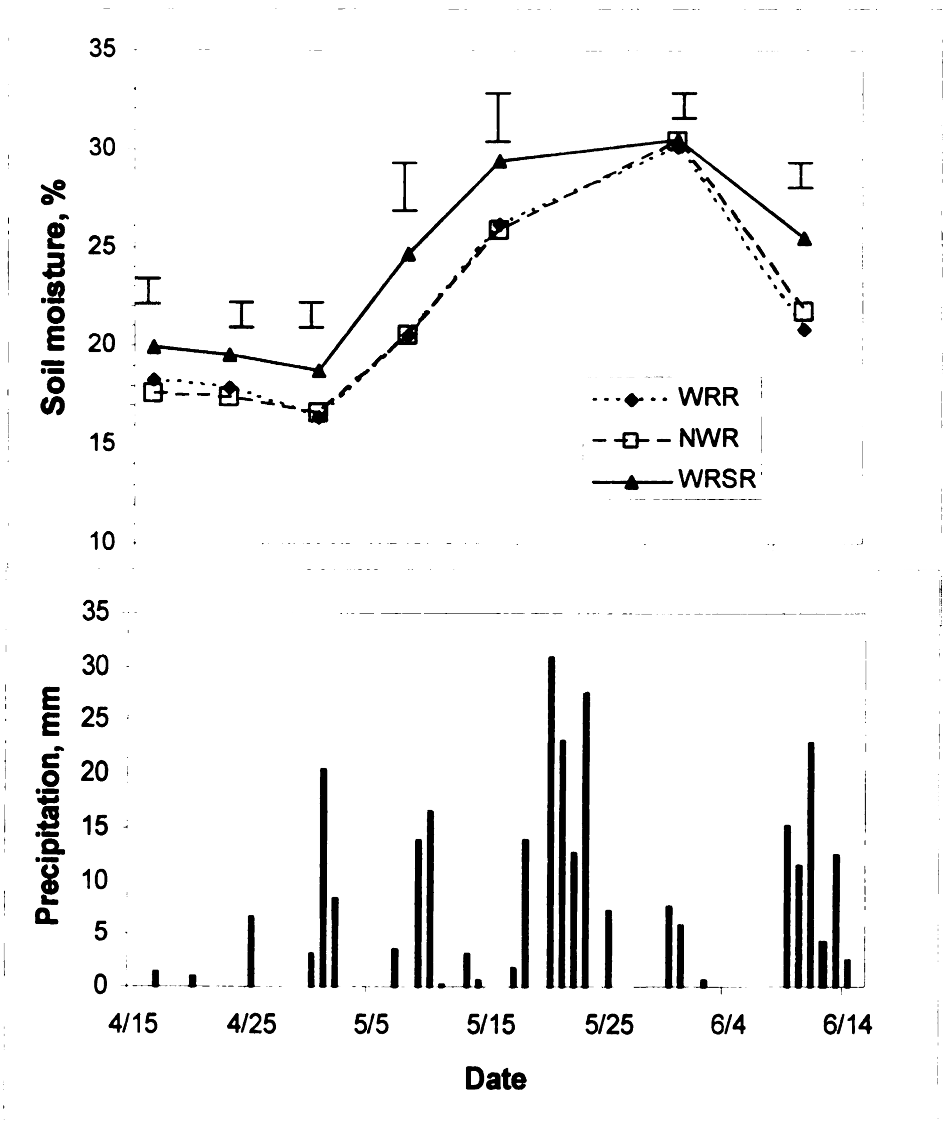


Figure 1.5. Treatment effects on soil moisture, and precipitation in 2004.



In 2005, WRSR treatments had significantly higher soil moistures compared to NWR and WRR treatments on all dates (Figure 1.6). Soil moisture in NWR and WRR treatments were not different on all dates. The exception was 18 May when WRSR and WRR treatments were not different. NWR and WRR treatments were also not different on this date.

In all three years, the values of Δ temperature and Δ moisture from WRR and WRSR treatments were significantly negatively correlated ($p<0.05$). Lower Δ temperature values corresponded to higher Δ moisture, and higher Δ temperature values were observed in drier soil (Figures 1.7, 1.8, and 1.9).

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The observed cooler temperatures and higher moistures at higher residue cover are consistent with other observations. Researchers (TeKrony et al., 1989) and growers have speculated that corn grain yield antagonism may be attributable to cooler soil temperature in the spring from the wheat residue. Lund et al. (1993) associated the reduced yield of no-till, continuous corn with the greater crop residue and cooler soil temperature in the spring (2.7 °C lower). Wilhelm and Wortmann (2004) concluded that the advantage of moldboard tillage over no-till for corn yield was greatest in years with low spring temperatures. Tillage may be preferred for soils that are slow to warm or when early planting is preferred.

Figure 1.6. Treatment effects on soil moisture, and precipitation in 2005.

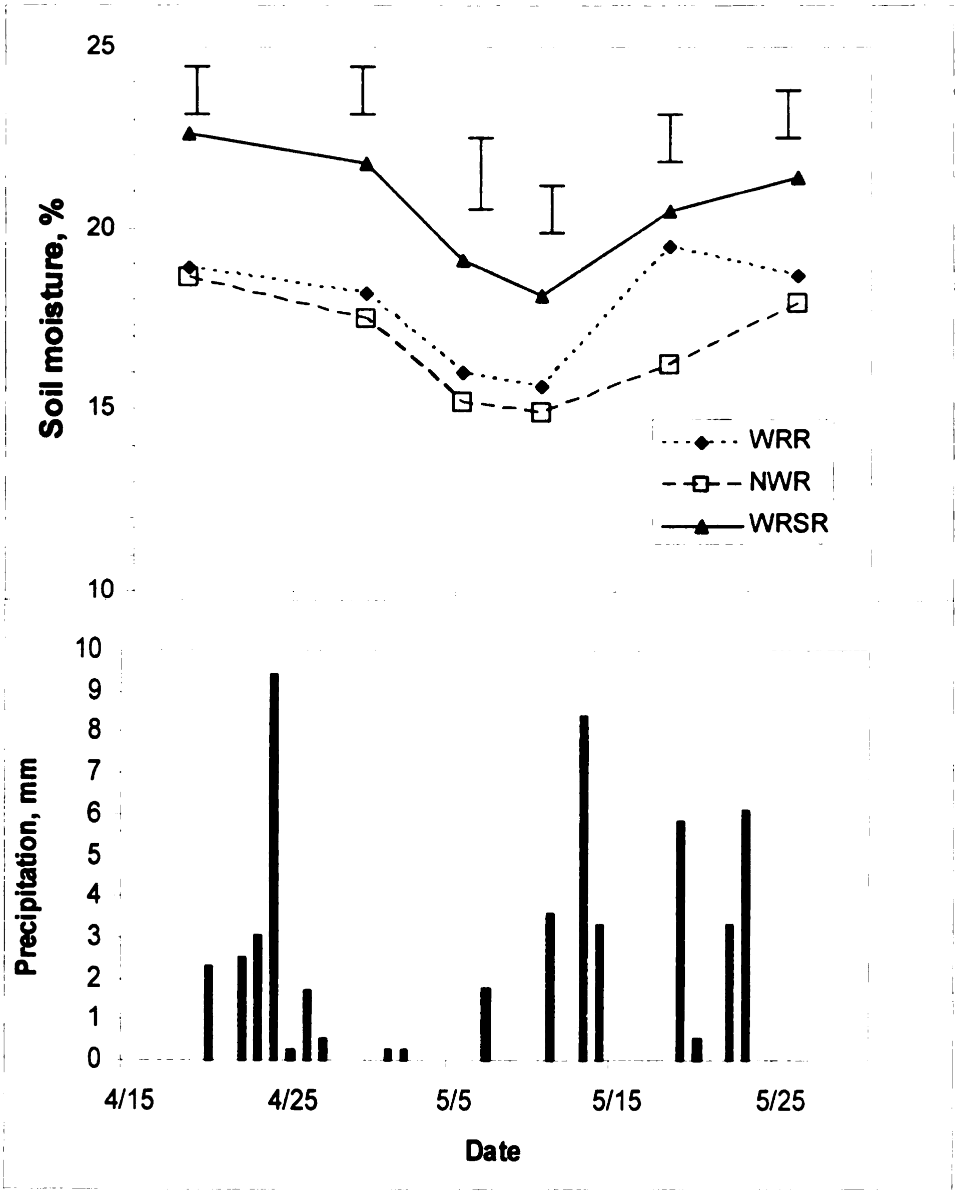


Figure 1.7. Relationship between Δ soil temperature and Δ soil moisture in 2003.

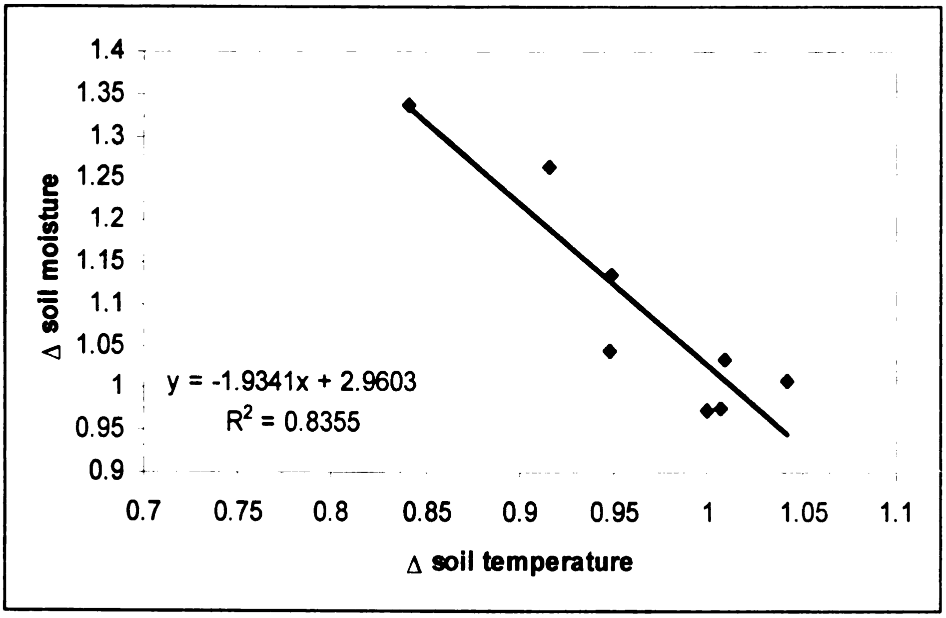


Figure 1.8. Relationship between Δ soil temperature and Δ soil moisture in 2004.

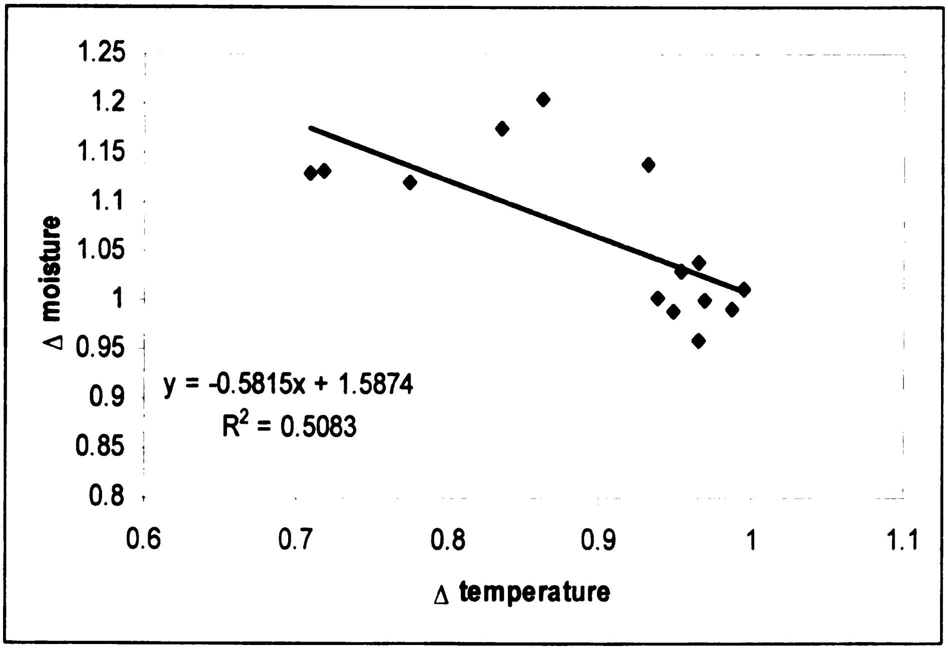


Figure 1.9. Relationship between Δ soil temperature and Δ soil moisture in 2005.

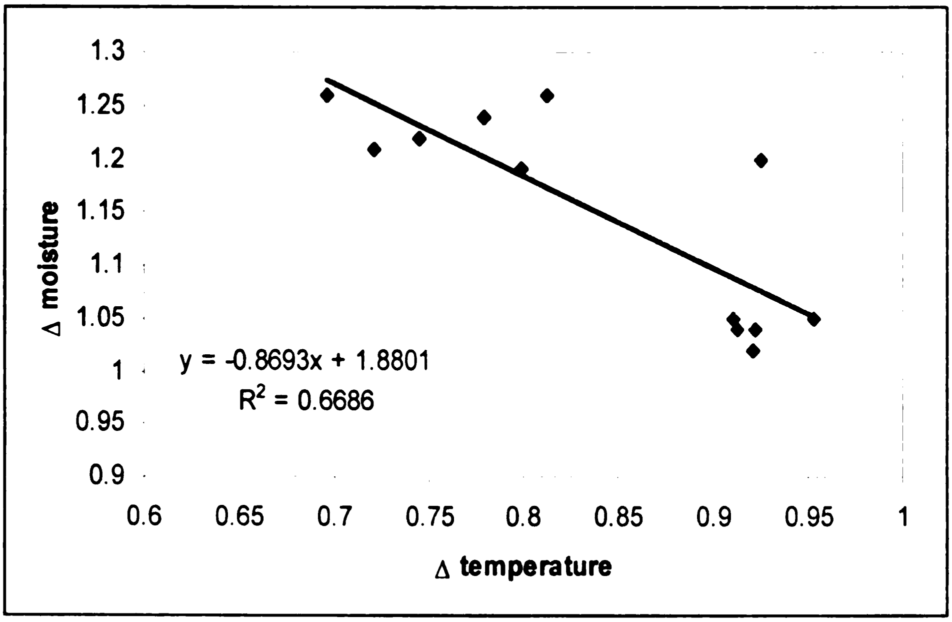


Figure 1.10. Relationship between percents of soil surface covered by wheat residues and Δ soil temperatures in 2005.

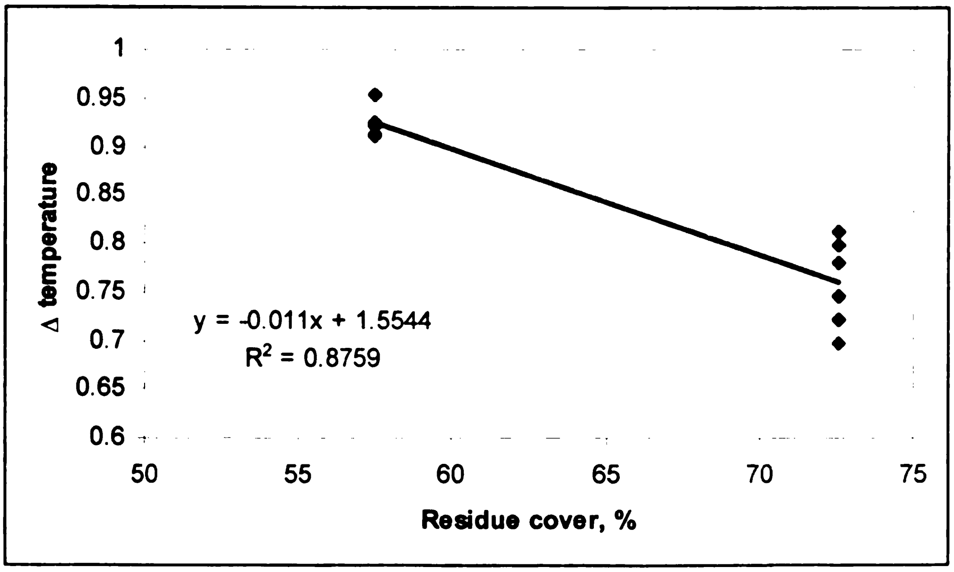
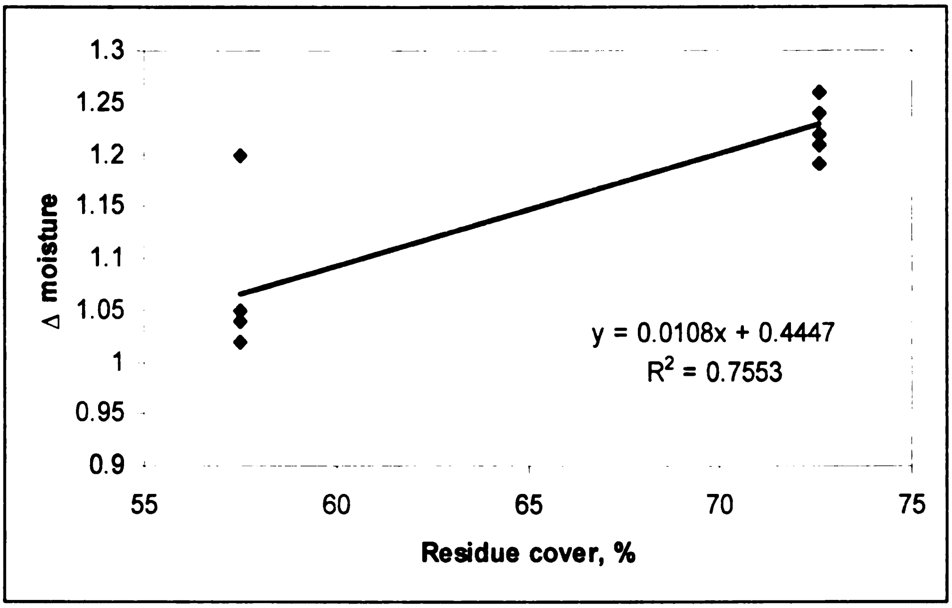


Figure 1.11. Relationship between soil surfaces covered by wheat residues and Δ soil moistures in 2005.



Effect of wheat residue on date of corn emergence

In 2003 and 2005, in WRSR treatments corn emerged significantly later than in NWR and WRR treatments (Table 1.2). There was a difference between NWR and WRR treatments. The negative effect of wheat residue on corn emergence can be related to the relatively early planting of corn (17 April and 30 April). Soil temperatures in WRSR treatments were lower compared to NWR and WRR treatments, explaining the delayed corn emergence. Also, the early cool spring of 2005 delayed corn emergence. In both 2003 and 2005, corn emergence was significantly negatively correlated with Δ soil temperature ($p<0.05$) (Figures 1.12 and 1.13). These results are consistent with many reports of reduced emergence and yields under no-till compared with conventional till farming, especially in humid and cool temperate climates (Fortin and Pierce, 1991).

Table 1.2. Treatment effects on corn emergence, population, and time of tasseling.

Treatment	2003	2004	2005	2003	2004	2005	2003	2004	2005
	Emergence (date)			Population (plants ha^{-1})			VT stage (date)		
WRR	5/25 b†	6/10 a	5/20 b	66297 b	62827 a	62505 b	7/27 a	8/4 a	7/15 b
NWR	5/19 a	6/10 a	5/15 a	67863 b	59705 a	64962 b	7/24 a	8/4 a	7/12 a
WRSR	5/29 c	6/10 a	5/25 c	62674 a	65455 a	57383 a	7/30 b	8/10 b	7/18 c

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$).

In 2004, because of the very wet and cool spring, corn was planted relatively late (29 May). Higher soil temperatures observed in late May and early June promoted germination of corn, thus potentially being the reason for the same corn emergence time in all treatments in that year. There was no significant relationship between the date of corn emerged in 2004 and Δ soil temperature.

Figure. 1.12. Relationship between date of corn emerged and Δ soil temperature in 2003.

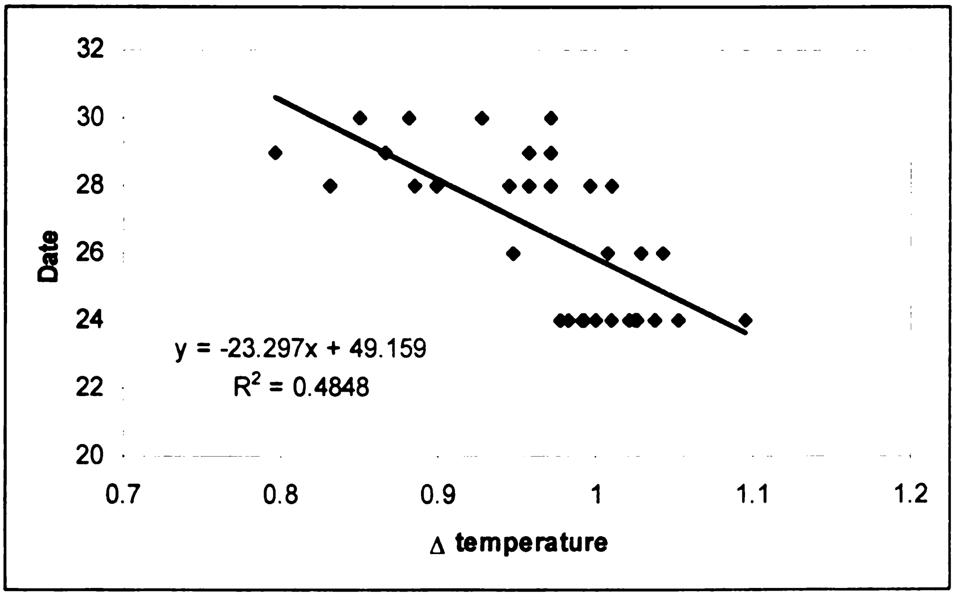
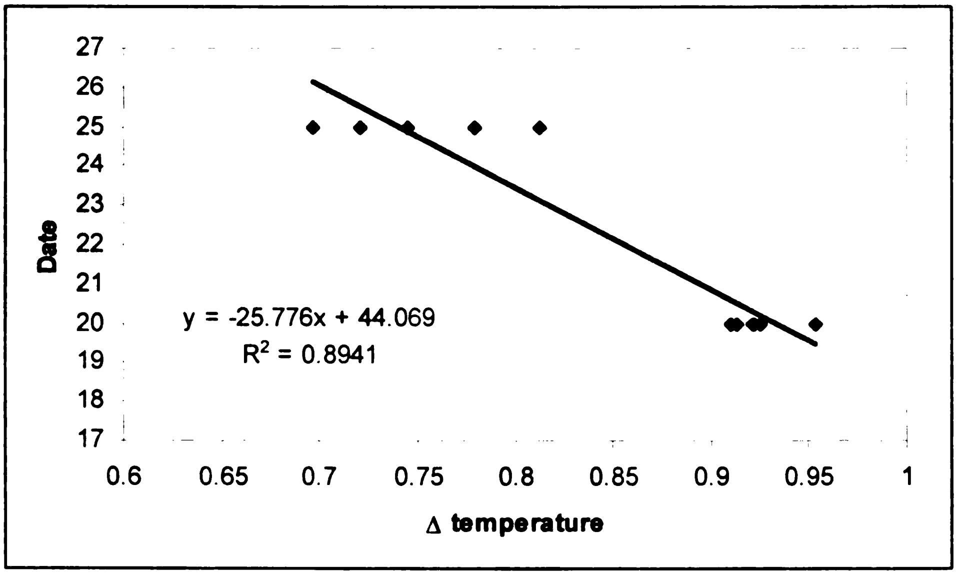


Figure 1.13. Relationship between date of corn emerged and Δ soil temperature in 2005.



Effect of wheat residue on stand population of corn

In 2003 and 2005, WRSR treatments had lower corn plant stands than NWR and WRR treatments, likely due to the delayed corn emergence and cooler soil temperatures (Table 1.2). The corn population trends resemble those observed with date of emergence. NWR and WRR treatments were not different. In both 2003 and 2005, soil temperature affected corn stand population with higher values observed in plots with larger Δ temperature values (temperature relative to NWR plots) (Figures 1.14 and 1.15). This is consistent with findings of Katsvairo and Cox (2000) who recorded that corn densities were less under reduced tillage compared to moldboard plow systems when corn followed corn or wheat/red clover.

In 2004 there were no differences in corn plant stands between WRSR, WRR, and NWR treatments. The lack of a treatment effect on 2004 corn plant stands is likely due to the relatively late planting date of corn and higher soil temperatures.

Figure 1.14. Relationship between Δ temperatures and stand population of corn in 2003 (data for individual plots are shown).

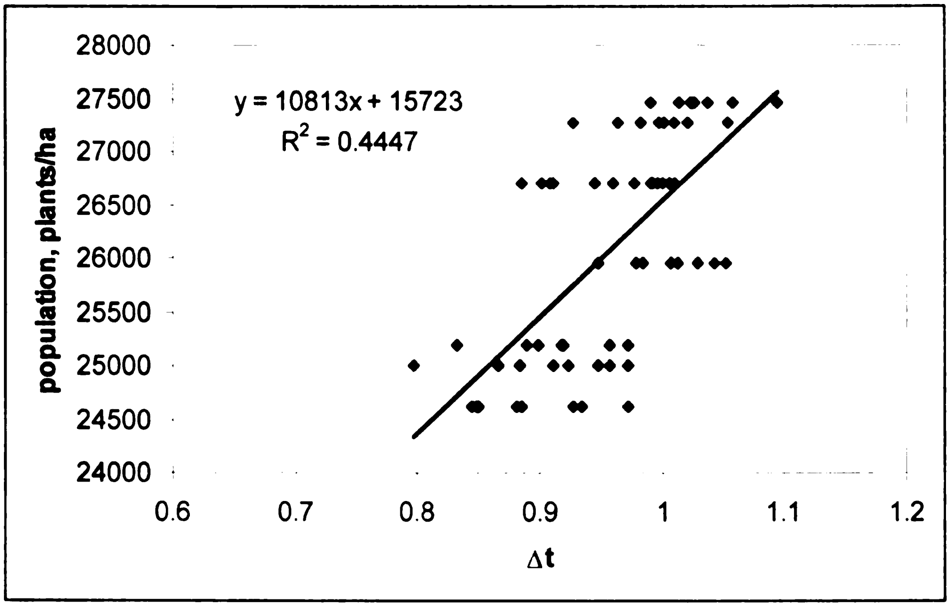
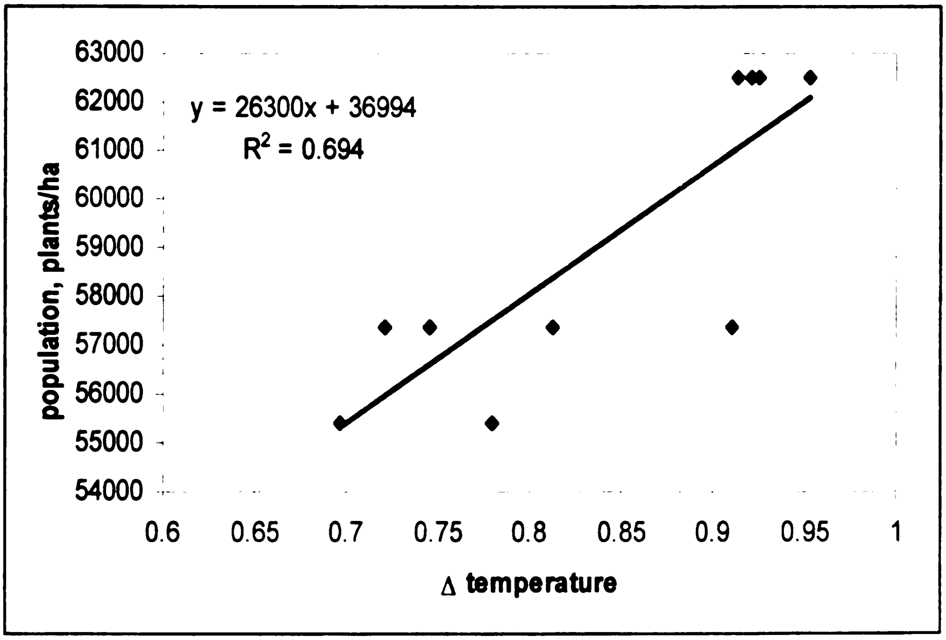


Figure 1.15. Relationship between Δ temperatures and corn stand populations in 2005.



Effect of wheat residue on corn date of tasseling

In all years, corn tasselling was delayed in WRSR treatments as compared with NWR and WRR treatments (Table 1.2) likely due to lower soil temperatures, delayed emergence, and lower amounts of plant available N (Table 1.3).

Table 1.3. Effect of treatments on the soil pre-sidedr6ess nitrogen test (PSNT) (kg ha^{-1}) results and on the total amounts of nitrogen added to the soil as a fertilizer (kg ha^{-1}).

Treatment	PSNT			Added N		
	2003	2004	2005	2003	2004	2005
WRR	69.5 b†	108.5 a	29.2 a	101	58	145
NWR	92.5 b	161.5 b	83.2 b	101	31	90
WRSR	43.7 a	87.8 a	29.6 a	134	105	145

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

In 2004, despite a lack of differences in corn emergence and relatively high soil temperatures, corn tasselling was significantly delayed in WRSR treatments as compared with NWR and WRR treatments. The delay in corn reaching the VT stage may be attributable to the lower soil nitrate levels measured in WRSR treatments (Table 1.3). The wheat residue results in microbial immobilization of N because of the very high C:N ratio of the wheat residue (80:1) and also possible allelopathy effects. Rice (1984) reported that high soil temperature promoted fixing of soil residual N by soil microorganisms increasing their populations. Rice also found that active allelopathic compounds from wheat residue inhibit N fixation by free-living and symbiotic microorganisms. These compounds influence nitrification, but do not influence denitrification processes.

In 2003 and 2004, in WRR treatments tasselling of corn was not delayed and WRR treatments were not different from NWR treatments. In 2005, a delay in reaching VT stage was observed for WRR treatments. This delay in reaching VT stage can be related to microbial immobilization of N, because of high C: N ratio of wheat root residue, and/or allelopathy effect (Krupa, 1982, Rice, 1984).

Effect of wheat residue on corn height

The presence of wheat residues affected corn height. In 2003, corn plants in WRSR and WRR treatments were shorter compared with NWR treatments in all dates (Table 1.4). Corn heights in WRSR and WRR treatments were not significantly different.

Table 1.4. Effect of treatments on height of corn (m) during the 2003-2005 growing seasons.

Treatment	2003			2004			2005		
	9-July	15-July	22-July	20-July	28-July	4-Aug.	20-June	27-June	5-July
WRR	1.14 a†	1.50 ab	1.86 a	0.91 b	1.43 b	2.00 a	0.72 b	0.90 b	1.29 b
NWR	1.36 b	1.75 b	2.17 b	0.95 b	1.43 b	1.96 a	0.85 c	1.17 c	1.55 c
WRSR	1.03 a	1.40 a	1.85 a	0.67 a	0.98 a	1.84 a	0.55 a	0.76 a	1.11 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

In 2004, corn plants in WRSR treatments were shorter compared with heights in NWR and WRR treatments in the early stages of corn development. Corn heights in NWR and WWR treatments were not significantly different. Around VT stage (4 August) heights in all three treatments equalized. During the earlier stages of corn development plant height was found to be positively related ($p<0.05$) to chlorophyll leaf content with taller plants having higher chlorophyll contents (Figures 1.16 and 1.17). Higher plant heights ($p<0.05$) were also correlated with soil nitrate levels (Figure 1.18).

Figure 1.16. Relationship between corn heights and leaf chlorophyll contents on 28 July 2004.

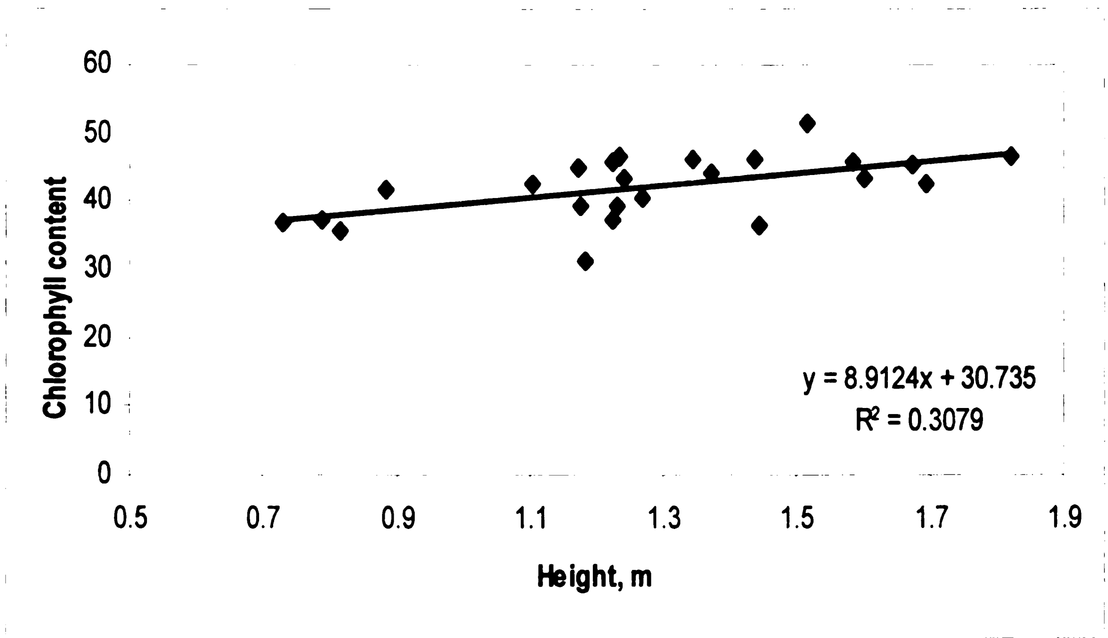


Figure 1.17. Relationship between corn heights and leaf chlorophyll contents on 2 August 2004.

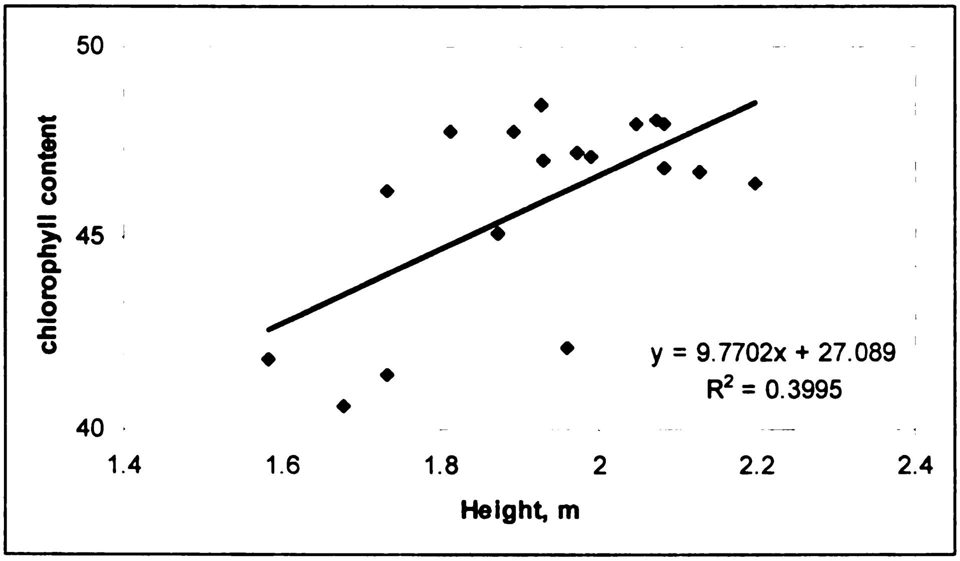
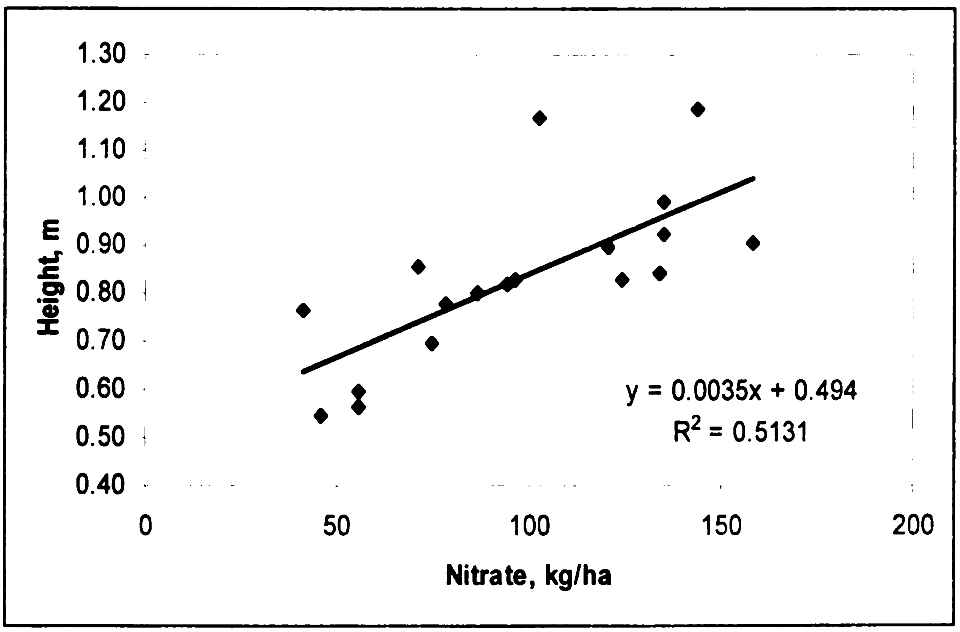


Figure 1.18. Relationship between corn height and PSNT result on 20 July 2004.



In 2005, WRSR treatments had shorter plants than NWR and WRR treatments at all sampling dates. Furthermore, the heights of plants in NWR and WWR treatments were significantly different, with NWR treatments having taller plants than WRR treatments. In two earlier sampling dates (21 and 28 June), the heights of corn were positively correlated to chlorophyll content (Figures 1.19 and 1.20). However, the correlation between plant height and chlorophyll content did not continue beyond the 28 June sampling date. As in 2004, higher plant height ($p<0.05$) was observed in plots with higher nitrate levels (Figure 1.21).

Figure 1.19. Relationship between corn heights and leaf chlorophyll contents on 21 June 2005.

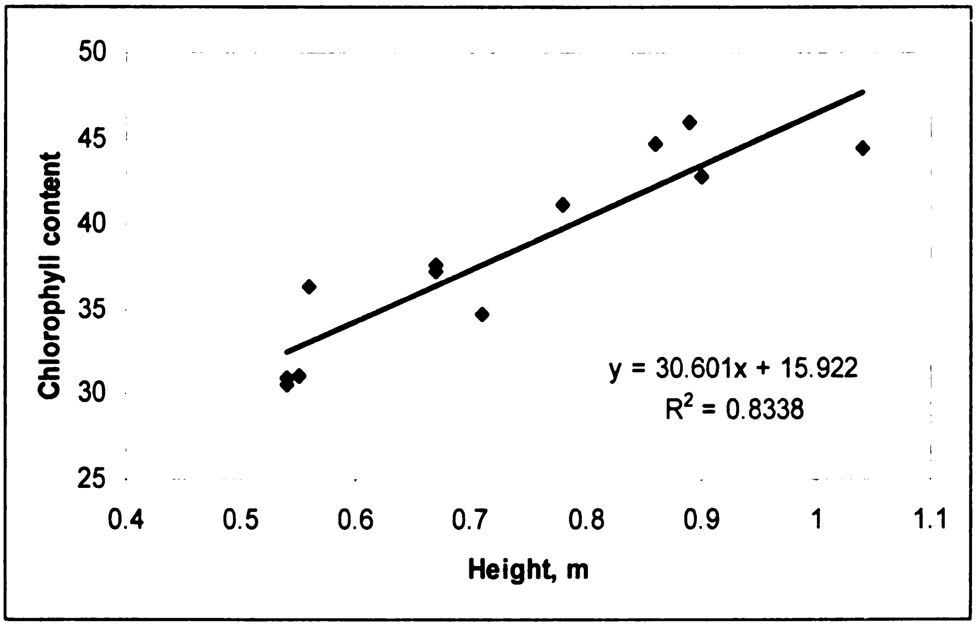


Figure 1.20. Relationship between corn heights and chlorophyll contents on 28 June 2005.

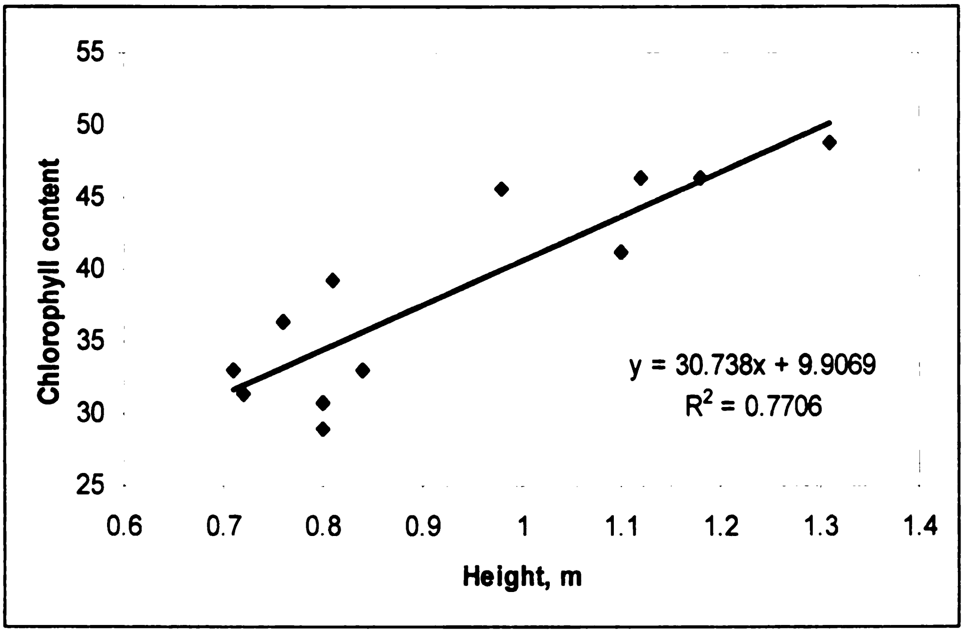
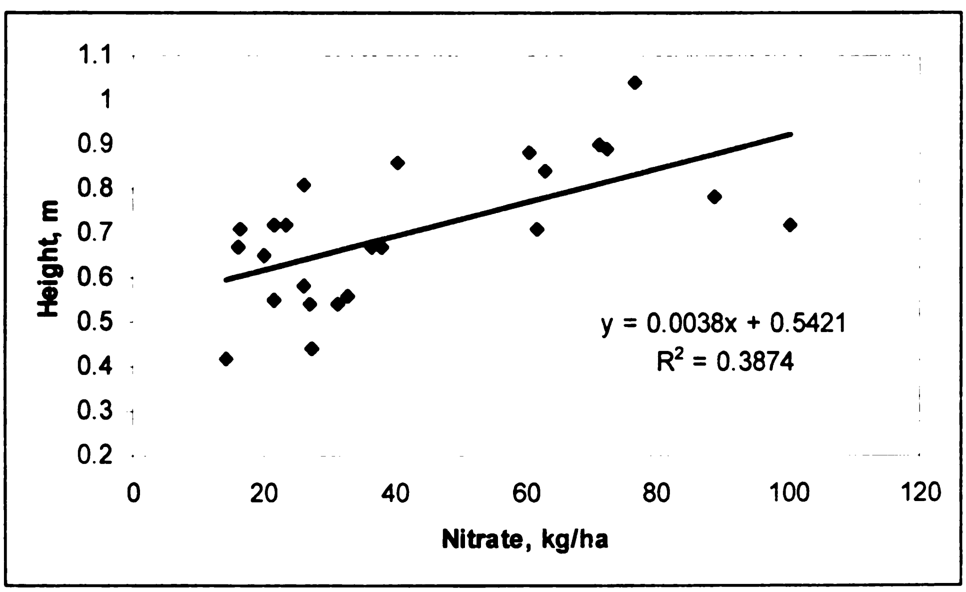


Figure 1.21. Relationship between corn height and PSNT result on 20 July 2005.



Effect of wheat residue on chlorophyll content in corn leaves

In 2004 and 2005, in the early to mid-stages of corn development, WRSR treatments had significantly lower leaf chlorophyll contents compared with NWR and WRR treatments (Table 1.5).

Table 1.5. Effect of treatments on the amount of chlorophyll in corn leaves observed during the 2004 and 2005 growing seasons.

Treatment	2004				2005		
	8-July	15-July	26-July	2-Aug	21-June	28-June	5-July
WRR	40.4 b†	42.2 b	43.3 b	46.4 a	38.6 b	37.4 ab	45.6 a
NWR	42.0 b	45.2 b	44.9 b	45.3 a	43.6 c	45.5 b	47.2 a
WRSR	33.3 a	36.9 a	37.8 a	46.0 a	32.3 a	32.4 a	46.6 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$).

In 2004, in NWR and WRR treatments chlorophyll contents were similar prior to the VT stage. But, in 2005, chlorophyll contents in WRR and NWR treatments were different, especially before added N which was side-dressed according to PSNT results. However, by August 2 and July 5, just prior to tasseling, the amount of chlorophyll was found to be similar in all treatments, likely due to different N application rates based on PSNT results. Variability in soil nitrate levels between treatments is likely a primary reason for the observed differences in chlorophyll content. Soil nitrate and corn leaf chlorophyll were found to be positively correlated ($p<0.05$) at early stages of corn development (8 July 2004 and 21 June 2005) (Figures 1.22 and 1.23).

Figure 1.22. Relationship between soil nitrate levels and leaf chlorophyll content on 8 July 2004.

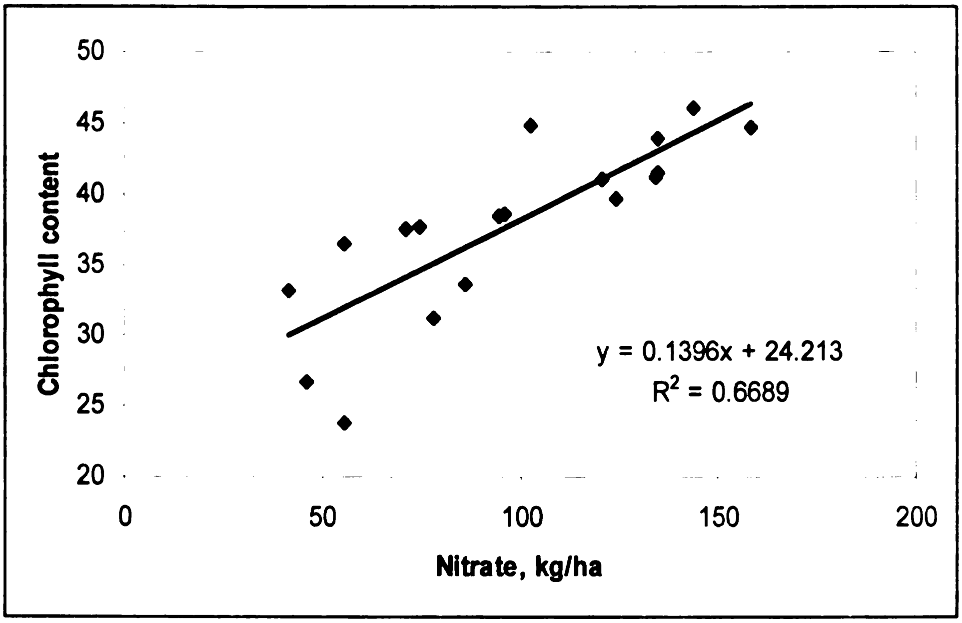
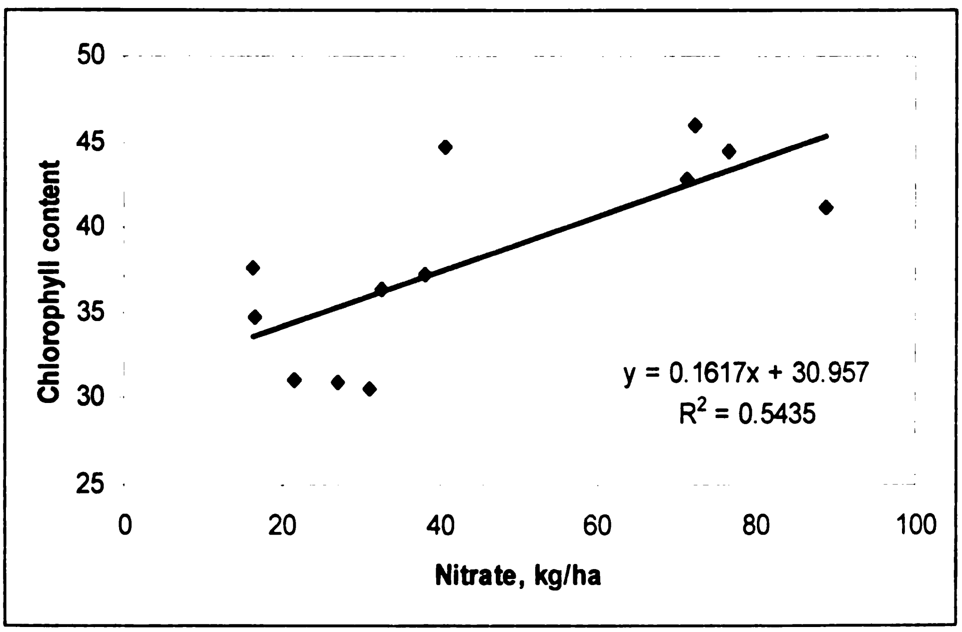


Figure 1.23. Relationship between soil nitrate levels and leaf chlorophyll content on 21 June 2005.



Effect of wheat residue on PSNT results

In all three years, PSNT levels were the highest in NWR treatments compared to WRSR and WRR treatments (Table1.3). The soil in NWR treatments warmed faster compared with the other treatments, thus the rate of N mineralization was probably higher in the early spring. In addition, the NWR soil had higher amounts of residual N due to soybean being the previous crop. Also, low plant available N in WRSR and WRR treatments can be explained by microbial immobilization of N because of the very high C:N ratio of wheat residue (80:1). However, in 2003, WRR and NWR treatments PSNT levels were not different.

Generally, relatively lower amounts of plant available nitrate were in the soil in 2003 and 2005 compared to 2004. The higher soil nitrate levels in 2004 are likely due to a later PSNT sampling date.

Effect of wheat residue on corn grain moisture, test weight and yield

Wheat residue affected corn grain moisture. In all years, WRSR treatments had significantly higher grain moisture at harvest than NWR and WRR treatments (Table 1.6). This is likely due to delayed emergence observed in 2003 and 2005 and delayed time of tasseling in all three years. NWR and WRR treatments were not different in all years.

In 2003 and 2005, WRSR treatments had significantly lower test weights at harvest than NWR and WRR treatments (Table 1.6). This is likely due to the higher grain moisture levels, delayed emergence (2003 and 2005), delayed tasseling, and lower amounts of soil plant available N resulting from microbial N immobilization. In 2004, the test weights in all treatments were lower than usual, possibly due to late planting date and higher than usual grain moisture at harvest. There were no differences between the test weights of the three treatments.

Despite late emergence, delayed VT stage, and lower amount of plant available N in WRSR treatments than in WRR and NWR treatments, in 2003 and 2004, yields of corn in all treatments were not different (Table 1.6). The lack of a yield effect is likely due to different rates of added N according to PSNT results. The WRSR treatments had the highest amounts of added nitrogen in all years. In 2005, corn grain yields in WRSR and WRR treatments were not different, but both were less than the grain yields from NWR treatments. Yields in WRSR and WRR treatments were close to the planned yield goal (8.8 Mg ha^{-1}).

Table 1.6. Treatment effects on corn grain moisture at harvest, test weight, and yield.

Treatment	Grain moisture (%)			Test weight (kg m^{-3})			Yield (Mg ha^{-1})		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
WRR	19.8 a†	28.6 a	18.1 a	708.5 b	608.2 a	722.0 b	6.90 a	8.79 a	9.01 a
NWR	19.5 a	28.0 a	17.9 a	711.9 b	615.2 a	732.7 c	8.64 a	8.62 a	9.99 b
WRSR	25.4 b	32.4 b	20.2 b	679.1 a	612.9 a	708.1 a	8.71 a	8.57 a	8.27 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, P<0.05)

SUMMARY

In all years, WRSR treatments had decreased soil temperatures and increased soil moisture levels compared to NWR and WRR treatments. In 2003 and 2005, when corn was planted early, WRSR treatments delayed emergence and reduced the corn populations compared to NWR and WRR treatments. In each year, the time to reach VT stage was lengthened for the WRSR treatments. In all years, WRSR treatments had significantly lower plant heights, especially in early growth stages. In the early stages of development (prior to sidedress N application), corn leaves in WRSR treatments had significantly lower chlorophyll content. In WRSR and WRR treatments the amount of plant available N as determined by the PSNT results was decreased compared to NWR treatments. In all years, WRSR treatments had higher grain moisture at harvest. In 2003 and 2005, corn in WRSR treatments had lower test weights compared to NWR and WRR treatments. In 2003 and 2004, yields in WRSR, WRR, and NWR were not significantly different. In 2005, WRR and NWR treatments had higher grain yield than the targeted N-based yield goal. WRSR treatments were not different from WRR treatments and yielded similar to the targeted yield goal.

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CHAPTER 2

NITROGEN MANAGEMENT STRATEGIES FOR OVERCOMING THE WHEAT RESIDUE ANTAGONISM OF NO-TILL CORN

ABSTRACT

Two established methods for increasing the sustainability of production agricultural cropping systems are (i) increasing crop residue levels by reducing tillage and (ii) including a winter annual crop in the rotation. However, many crops following wheat in tillage and reduced tillage systems have reduced grain yields. The objective of this study was to develop management practices to overcome the observed negative yield response in corn (*Zea mays L.*) grain grown following winter wheat (*Triticum aestivum* L.) in no-till, high residue cropping systems. We hypothesized that management practices including using a presidedress nitrogen test (PSNT) and using a PSNT in combination with manure and clover cover crops, or combination of the two could be used to overcome the rotational wheat antagonism in such cropping systems. The experimental design was a randomized complete block design. Experimental factors were: presence of wheat residue from the previous crop with three levels (no residue, root residue, or root and shoot residue); (2) manure application with two levels (with or without); and, (3) red clover (*Trifolium pretense* L.) with two levels (with or without). Data were collected in 2003, 2004, and 2005. Measurements included corn grain yield, grain moisture and test weight of corn at harvest, plant growth characteristics (emergence, plant height, time of tasseling (VT stage), chlorophyll content), PSNT, and soil moisture and temperature

taken weekly during the spring and early summer. In all years the presence of winter wheat residue decreased soil temperature, increased soil moisture, and decreased chlorophyll content in corn leaves and plant height in the early stages of corn development. VT stage of corn was delayed for about 1 week in residue systems. Winter wheat residue decreased the amount of plant available N, and increased grain moisture and test weight of corn grain at harvest. Emergence and population of corn in 2003 and 2005 were reduced. A PSNT nitrogen strategy was effective in maintaining corn grain yields in wheat residue systems equivalent to no-wheat residue systems in 4 of 6 site years. Similar results were obtained for PSNT plus clover cover crop and PSNT plus manure plus clover cover crop N management systems. Using PSNT and manure system equalized high wheat residue yields to no-wheat residue in 6 of 6site years.

INTRODUCTION

High residue cropping systems such as no-till and reduced-till systems contribute significantly to the sustainability of production agriculture. No-till and reduced-till farmers in the United States occupy 21 million ha of land, about 38% of the United States cropland (Conserv. Technol. Inf. Cent, 2000). These systems reduce soil erosion and run-off and increase the percolation of rainfall (Cavigelli, 1998). Additionally, soil organic C levels are increased, leading to improved soil nutrient holding capacity and structure (Tisdall and Oades, 1982). Maintenance of soil organic matter has long been recognized as a strategy to reduce soil degradation in agricultural systems. No-till, manure additions, and planting legume cover crops are management practices that can increase soil organic matter content and improve soil structure.

Soil structure is an important property that mediates many soil physical and biological processes and controls soil organic matter decomposition (van Veen and Kuikman, 1990). Soil aggregates are the basic units of soil structure and are composed of primary particles and binding agents (Edwards and Bremmer, 1967; Tisdall and Oades, 1982; Haynes et al., 1991). Soil organic matter is a major binding agent that stabilizes soil aggregates (Haynes et al., 1991).

The amount and turnover of soil organic matter can be altered by different management practices. Cultivation affects soil structure by destroying soil aggregates, resulting in loss of soil organic matter (Tisdall and Oades, 1982; Elliott, 1986; Angers et al., 1992). Incorporation of plant residues in soil affects the soil microclimate and increases plant residue contact with soil, increasing the rate of residue decomposition and organic matter transformation (Beare et al., 1992; Cambardella and Elliott, 1993; Paustian et al.,1997). Tillage enhances decomposition of organic matter by mixing plant residues into the soil, increasing aeration, and enhancing dry-wet and freeze-thaw cycles (Paustian et al., 1997). Also, tillage disrupts soil aggregation and exposes physically protected organic material (Blevins and Frye, 1993; Beare et al., 1994b). In contrast, no-till systems reduce soil mixing and soil disturbance, allowing soil organic matter accumulation (Blevins and Frye, 1993). Many studies have shown that no-till farming improves soil aggregation and aggregate stability (Beare et al., 1994b; Six et al., 1999). Mycorrhizal fungi, which are promoted by no-till systems, contribute to formation and stabilization of macroaggregates (Tisdall and Oades, 1982; O'Halloran et al., 1986; Beare and Bruce, 1993). Also, no-till significantly increases soil total C and N levels, water-stable aggregates, and labile C and N associated with macroaggregates, compared with conventional tillage (Mikha and Rice, 2004).

Application of manure is another management practice that can improve the nutrient status of the soil and increase soil organic matter (Rochette and Gregorich, 1998). Aoyama et al. (1999) observed an increase in soil organic matter with addition of manure and consequently the formation of shaking-resistant macroaggregates (250-1000 μm diam). Mikha and Rice (2004) concluded that manure significantly increased total soil C and N levels through improved formation of water- stable aggregates and increased aggregate-associated C and N. In general, it has been observed that the combination of a high residue cropping system, such as no-till, with manure application significantly improves soil aggregation and aggregate-associated C and N compared with conventional tillage.

However, manure application in a no-till system has certain disadvantages. Surface manure application may not be as efficient as incorporation of manure because of N loss (volatilization of ammonia and runoff) or nutrient stratification. Still, many studies have reported that net N mineralization from manure is often similar in no-till and conventional tillage systems. Eghball (2000) reported that 11% of the organic N applied the previous fall was mineralized from composted beef cattle manure; N mineralization was similar in no-till and conventional tillage systems even though the compost was surface-applied in no-till. Eghball and Power (1999a) reported similar corn grain yields in no-till and conventional tillage systems with beef manure in 3 of 4 years in Nebraska. In the fourth year, a no-till system yielded less than conventional tillage with compost application. They concluded that surface application of beef manure did not result in significant N loss. N requirements for no-till versus conventional tillage systems may differ. Stecker et al. (1995) found that no-till corn following soybeans on poorly drained soils required 17 kg ha^{-1} more fertilizer N for maximum corn yield than a chisel-disk system and 45 kg ha^{-1} more N for maximum profit.

Michigan growers increased winter wheat production from 214,650 ha in 2002 to 255,150 ha in 2004; a 20% increase (Michigan Agricultural Statistics Service, 2004). Winter wheat is generally grown in rotation with corn and soybeans. The growth cycle of soybeans makes winter wheat a logically fallow crop in the rotation, which is usually planted right after soybean harvest. Growers typically follow the wheat with corn. There are many advantages of including a winter annual crop such as winter wheat in a cropping system. Sanchez et al. (2001a) reported that N mineralization was increased in a diverse cropping system including wheat in the rotation. In addition, pest cycles can be disrupted with the inclusion of a winter annual crop (Cavigelli, 2000). Wicks et al. (1995) reported reduced weed emergence when no-till corn was planted into winter wheat residue. Copeland et al. (1997) estimated a 10% corn grain yield increase when corn was rotated with wheat.

Including a legume cover crop in a cropping system can reduce soil erosion (Smith et al., 1987), increase water infiltration (McVay et al., 1989), improve soil tilth (Marten and Touchton, 1983), contribute biologically fixed N (Heichel et al., 1985), and increase yield of subsequent crops (Baldock et al., 1981). Red clover underseeded in cereals can provide large amounts of plant biomass and fix N in the nodules, providing the equivalent of 90-125 kg ha^{-1} of N to the following crop (Bruulsema and Christie, 1987). Dou et al. (1995) reported that mineralized N concentrations from red clover that had been seeded into wheat peaked about four weeks after planting of the following corn crop, and that grain yield in corn was similar to those obtained where fertilizer N was applied without legume N. In Wisconsin, Mallory and Posner (1994) found that overseeding red clover into wheat increased yields of corn grown the following year. In Ontario, Raimbault and Vyn (1991) found similar results. Furthermore, red clover may be effective in cool temperate climates for increasing microbial biomass (Drury et al., 1991), accelerating the decomposition of surface crop residues (Drury et al., 1999), and tying up residual soil N after grain harvest (Ditsch et al., 1993). Other advantages attributed to legume cover crops include improved soil structure and increased soil organic matter content (Bruce et al., 1990), increased water penetration (Benoit et al., 1962), weed suppression (Worsham, 1991), and increased beneficial insect populations (Roberts and Cartwright, 1991).

Despite many advantages of planting legume cover crops, non-legume crops following a legume do not always show yield increases. Under certain conditions, legume cover crops actually can have a negative effect upon a subsequent crop. Under water-limiting conditions, corn crops following a legume cover crop exhibited reduced emergence (Holderbaum et al., 1990) and reduced grain yield (Touchton and Whitwell, 1984; Hesterman et al., 1992). The likely cause of this negative effect was depletion of soil moisture content by the actively growing legume (Ebalhar et al., 1984; Badarrudin and Meyer, 1990).

Herbicide burn down or plow down of a cover crop two weeks before planting a subsequent crop (Hargrove and Frye, 1987; Munawar et al., 1990) may minimize the risk of yield loss from cover crop induced soil water deficit. Munavar et al. (1990) found timing of killing cover crops had no effect on soil water content at the time of no-tillage corn planting. Timing of legume cover crop desiccation or incorporation may be an effective technique for managing green manure water use. When water is plentiful, cover crops could be allowed to grow until planting of the subsequent crop. Under water surplus conditions, cover crop spring growth may actually reduce soil water content, potentially reducing leaching of nitrate and allowing earlier field operations (McCracken et al., 1988).

The agronomic and environmental advantages of reduced-tillage, high residue cropping systems have been well documented (Cavigelli, 1998, Sanchez, 2001b). Despite many advantages, there are also negative impacts associated with high residue systems. One such negative impact is a corn-wheat antagonism that results in lower corn grain yield following wheat (Beuerlein and Houdashelt, 1997). Similar reports that corn following wheat in the crop rotation seems to have reduced grain yields came from no-till and reduced-till growers in the Great Lakes Region (K.Thelen, personal communication).

Researchers (Tekrony, 1989) and growers have speculated that corn grain yield antagonism may be attributable to cooler soil temperature in the spring from the wheat residue. There are many reports of reduced corn emergence and yields under no-till compared with conventional till farming, especially in humid and cool temperate climates (Fortin and Pierce, 1991). Lund et al. (1993) associated the reduced yield of no-till, continuous corn with the greater crop residue and cooler soil temperature in the spring (2.7^{o}C lower). Wilhelm and Wortmann (2004) concluded that the advantage of moldboard tillage over no-till for corn yield was greatest in years with low spring temperatures. Tillage may be preferred for soils that are slow to warm or when early planting is preferred. Katsvairo and Cox (2000) recorded that corn densities were less under reduced tillage compared to moldboard plow systems when corn followed corn or wheat/red clover. Cox et al. (1990) noted that cool conditions in May in years with less than normal growing degree days may result in poorer emergence under reduced tillage because high residue inhibits soil warming and delays corn emergence in northern latitudes. Also, Drury et al. (2003), in a four-year study in a winter wheat- corn-soybean rotation with and without red clover, reported different emergence rates of corn in different tillage systems. In no-till systems corn emergence rates were slower compared with conventional tillage over 3 years. However, despite low emergence rates, final plant stands were not significantly different between treatments in some years. Also, emergence of corn depended on time of planting (early or late) and spring weather conditions (wet or dry, cool or warm).

Beuerlein and Houdashelt's (1997) results contradict the notion that cooler soil temperature in the spring, because of the presence of wheat residue, is the only cause of corn-wheat antagonism. In a study, they grew wheat adjacent to bare soil plots. After harvesting the wheat, they removed the above ground wheat residue and transferred it to the bare soil plots without disturbing the soil. The following spring, corn was planted into the crops. Interestingly, the removal of the above ground wheat residue did not overcome the corn yield antagonism.

During cool, wet springs in Ohio, farmers and researchers often noticed that no till corn planted into wheat residue does not grow as rapidly as corn planted with conventional tillage. Thomison (1995) explained that under cool soil conditions and no-till farming practices winter wheat residues concentrated near the soil surface break down more slowly and tie up N longer than when residue is incorporated, making N less available for crop growth. This slow decomposition can be attributed to the high C-N ratio of wheat residue and environmental conditions. Another biological process that may also contribute to the slow growth of corn following wheat involves the production and release of phytotoxins from decomposing wheat residues. The allelopathic effects of wheat straw on corn growth may be related to either anaerobic production of microbial byproducts using wheat residue as a C source and/or direct release of organic compounds from the decomposing residue. Cool temperature, anaerobic conditions, and low pH increase leaching of amino acids and carbohydrates from the plant roots. Anaerobic conditions contribute to exudation of alcoholic substances that are toxic to plants (Christiansen et al., 1970).

Nitrogen fertilizers are important for corn production, but there is concern that large amounts of fertilizers may have adverse effect on ground water quality (Blackmer, 1987). It is very difficult to determine the appropriate rate of N fertilizer application, especially considering the possibility for N loses by leaching and denitrification before the crop can utilize the fertilizer. The pre-sidedress soil nitrate test (PSNT) based on the quantity of nitrate that is present in the soil at that time, a decision is made on how much more N fertilizer should be applied. The PSNT has potential for detecting the amounts of available N released from organic N sources, such as legume crop residues, manure, and soil organic matter, as well as any residual nitrate in the surface foot of soil (Silva, 1998). There are situation when PSNT has not been accurate as desired, like leaching of nitrate from the surface before the PSNT sampling date but large amounts still remained in the root zone, heavy rainfall which can cause leaching of nitrate out of the root zone, and cool wet conditions early in the season with low mineralization of organic N followed after PSNT sampling by conditions that promote N mineralization.

Our objective was to develop management practices to overcome the observed negative yield response in corn grain grown following winter wheat in no-till, high residue cropping systems. We hypothesized that a PSNT nitrogen management system alone or combined with legume cover crops and manure compost soil amendments could be used to overcome the rotational wheat antagonism in reduced tillage, high residue cropping systems.

MATERIAL AND METHODS

Experimental site and data collection

We conducted the research at the Michigan State University Agronomy Farm, in East Lansing, MI. The experiment was established on soybean-winter wheat-corn cropping systems from 2001 through 2005 with three cycles. The first cycle included plots that were planted to soybeans in 2001, winter wheat in fall 2001, and corn in 2003. The second cycle included plots that were planted to soybeans in 2002, winter wheat in 2002, and corn in 2004. A similar third cycle was implemented with soybeans and wheat planted in 2003 and with corn planted in 2005. The treatments with no winter wheat residue had a second year of soybean substituted for wheat in the second year of each cycle.

The first cycle was established on a Capac loam soil (fine loamy, mixed, mesic Typic Hapladulfs). The second and third cycles were established on Colwood (fine loamy, mixed, mesic Typic Haplaquolls) - Brookston (fine loamy, mixed, mesic Typic Argiaquolls) loam soils.

The experiment was a randomized complete block design with treatments consisting of four nitrogen management practices: 1) PSNT; 2) PSNT with clover; 3) PSNT with manure; 4) PSNT with clover and manure. Treatments were imposed on three levels of wheat residue: no wheat residue (NWR), wheat residue from roots and shoots (WRSR), and wheat residue from roots only (WRR).

In the first cycle, the experiment had four replications. Plots were 14 m long and 6.1 m wide. In the second and third cycles the treatments were replicated eight times.

Plots were 9.1 m long and 6.1 m wide. Distance between rows of planted corn was 76 cm.

Winter wheat (Harus) was planted in the fall of 2001, 2002, and 2003. In the following springs, at green up, wheat plots received 246 kg ha^{-1} of granular urea (46-0-0). Winter wheat yielded an average of 5.65 ton ha^{-1} in 2002, 7.65 ton ha^{-1} in 2003, and 4.95 ton ha^{-1} in 2004 with no differences between plots. After harvest of winter wheat, the height of the remaining wheat straw was about 30 cm. The remaining residue was returned to the plots having below and above ground wheat residue (WRSR) and removed from treatments having below ground wheat residue only (WRR). The amount of straw left in the treatments with wheat residue above and below ground was not significantly different between treatments in any year. The highest amount of wheat residue left in the plots was from the first cycle (2001-2003).

In the second year of the experimental cycle, soybean (Dekalb 23-51) was planted on 5 May 2002, 19 April 2003, and 29 May 2004 (rate of planting was 444,600 seeds ha^{-1}) for treatments having neither above or below ground wheat residue. Soybean was harvested on 28 September 2002, 13 October 2003, and 20 December 2004. At planting time, liquid starter fertilizer 6-24-6 (28 kg ha^{-1}) was added, providing 1.7 kg N ha^{-1} similar to local common production practices. Yields of soybean were not significantly different between plots ($p>0.05$). In 2002 soybean yielded 3.59 ton ha^{-1}, in 2003 2.25 ton ha^{-1}, and in 2004 3.26 ton ha^{-1}.

In the first and second cycles, manure was applied by broadcast method in the late fall following wheat and soybean harvest in 2002 (86.3 Mg ha^{-1}) and in 2003 (81.5 Mg ha^{-1}). In the third cycle, manure was applied in the early spring 2005 (105.5 Mg ha^{-1}) due to inclement fall weather. The manure was obtained from the Michigan State University Dairy Farm, in East Lansing, MI.

Red clover (22.4 kg ha^{-1}) was frost seeded by hand into the plots where wheat was growing on 14 March 2002, 24 March 2003, and 30 March 2004. In 2005, the average biomass of clover before herbicide burndown was 2 Mg ha^{-1} and there was no significant difference in clover biomass between the treatments. In 2003 and 2004, the clover stand was poor, two to three times less than that in 2005. Glyphosate (2.34 L ha^{-1} with 2.04 kg 100^{-1} L of ammonium sulfate) was used to burn down clover and weeds, 7-10 days before planting of corn in 2003 and 2004. In 2005, due to spring manure application and having a goal of early planting of corn, clover was sprayed with glyphosate after planting of corn on 22 April. Because clover was not killed completely, it was sprayed the second time on 5 May 2005. In all years, glyphosate was applied after corn emergence to control weeds, prior to applying nitrogen according to PSNT recommendations.

An early maturity corn variety DKC44-46 (YieldGard Corn Borer/Roundup Ready, Residue Proven, 94-day relative maturity) was planted into plots by a customized John Deere no-till planter. Corn was planted at a target population of 69,000 plants ha^{-1} on 30 April 2003, 29 May 2004, and 19 April 2005 and harvested on 16 October 2003, 22 October 2004, and 27 September 2005. In 2003 and 2005, starter fertilizer 6-24-24 was placed in furrow and in row (269 kg ha^{-1}), providing 16 kg N ha^{-1}. In 2004 starter fertilizer 19-19-19 was added (140 kg ha^{-1}), providing 26.6 kg N ha^{-1}.

Based on PSNT results, on 25 June 2003, 15 July 2004, and 20 June 2005, we applied N to every plot (based on yield goal of 8.8 Mg ha^{-1}). The soil samples for the PSNT test were taken from a depth of 0-30 cm on 17 June 2003, 7 July 2004, and 7 June

2005. In addition, soil was resampled in the fall and evaluated for residual N. Also, soil pH, nitrate, and phosphorus levels were determined from separate soil samples obtained each spring. The average pH values based on all the plots were 6.1 and 5.6 (1:1 soil/water), in 2003 and 2004, respectively. The average phosphorus values were 97.5 and 107 kg ha^{-1} (Bray P_1), respectively. Treatments did not have a significant effect on either pH or phosphorus. Potassium content was not measured but assumed to be sufficient based on soil test data obtained prior to experiment establishment.

In the early spring and early summer of 2004 and 2005, soil temperature measurements were taken weekly at a depth of 10 cm. In the early spring of 2003, soil temperature was measured at a depth of 20 cm and then from depth 10 cm. Soil moisture was also measured using a Trime – FM3 moisture meter with a P3 probe (Mesa Systems Co. Framingham, MA) at a depth of 0-15 cm.

Changes in soil temperature or moisture values of treatments WRR and WRSR as compared to the control NWR treatments were expressed as a ratio between soil temperature or moisture values measured at WRR and WRSR plots and the average soil temperature or moisture value from the NWR plots, and are called Δ temperature or Δ moisture.

To monitor corn development, we recorded emergence, postemergence stand count, time of tasseling (VT stage), and stalk lodging. Plant height was measured when corn was at the V9 stage until VT stage every week. Chlorophyll content of the uppermost leaf of corn that had formed a collar was measured weekly using a SPAD-502 meter (Specialty Products Agricultural Division, Minolta Co. LTD, Japan) in 2004 and 2005, when corn was at the V6 stage until VT stage.

Two center rows of corn from each plot were machine harvested. Moisture content, test weight, and field weight of corn were measured by a Grain Gage^{tm} and HarvestMasterSystem^{tm} (Juniper Systems, Inc., Logan, UT) mounted on a plot combine. Grain yield was reported at 15.0 % moisture content. Grain test weight is reported at harvest moisture.

Percent of soil surface cover by manure, residue and clover was determined using digital imagery.

Data analysis

SPAD (leaf chlorophyll) data was fitted with a logistic growth curve model:

$$SPAD = \frac{k}{1 + ((k + n_0)/n_0)e^{-rN}}$$

where N is the NO_3 level, k describes the SPAD reading as N approaches infinity, n_0 is the SPAD reading at zero N, and r is the rate of increase.

Statistical analyses were conducted using the PROC MIXED procedure in SAS (SAS Inc., 2002). Normality of the residuals and homogeneity of variances were evaluated. When the variances were not homogeneous, the REPEATED /GROUP option of PROC MIXED was used. When the F-test showed a significant treatment effect we conducted mean separations using Fisher protected t-tests (P=0.05).

RESULTS

Effect of clover on soil temperature

In 2003, in WRSR treatments without manure, clover did not affect soil temperature in all studied dates compared to treatments without clover (Figure 2.1). In treatments with manure, clover did not affect soil temperatures on 6 of 8 dates. On 11 and 30 June, soil temperatures in these treatments were significantly higher when clover was present compared to treatments without clover. The observed increases in soil temperature on these later sampling dates may be due to the increased soil biological activity associated with the presence of the decomposing clover roots. In WRR treatments without manure, clover significantly decreased soil temperature on 5 of 8 dates. The cooler soil temperatures with the presence of the clover residue appear to be associated with the earlier sampling dates, suggesting that the clover residue effectively insulated the soil delaying warm-up. In treatments with manure, the effect of clover on soil temperature was not significant in all studied dates, suggesting that the soil insulating effect of the manure masked that effect of the clover residue.

In 2004, in WRSR treatments with and without manure, clover did not affect soil temperature on 6 of 8 dates (Figure 2.2). But, on 13 May, treatments with and without manure had significantly lower soil temperatures and, on 29 April treatments with manure had significantly higher soil temperatures compared to treatments without clover.

Figure 2.1. 2003 means of soil temperature (°C).

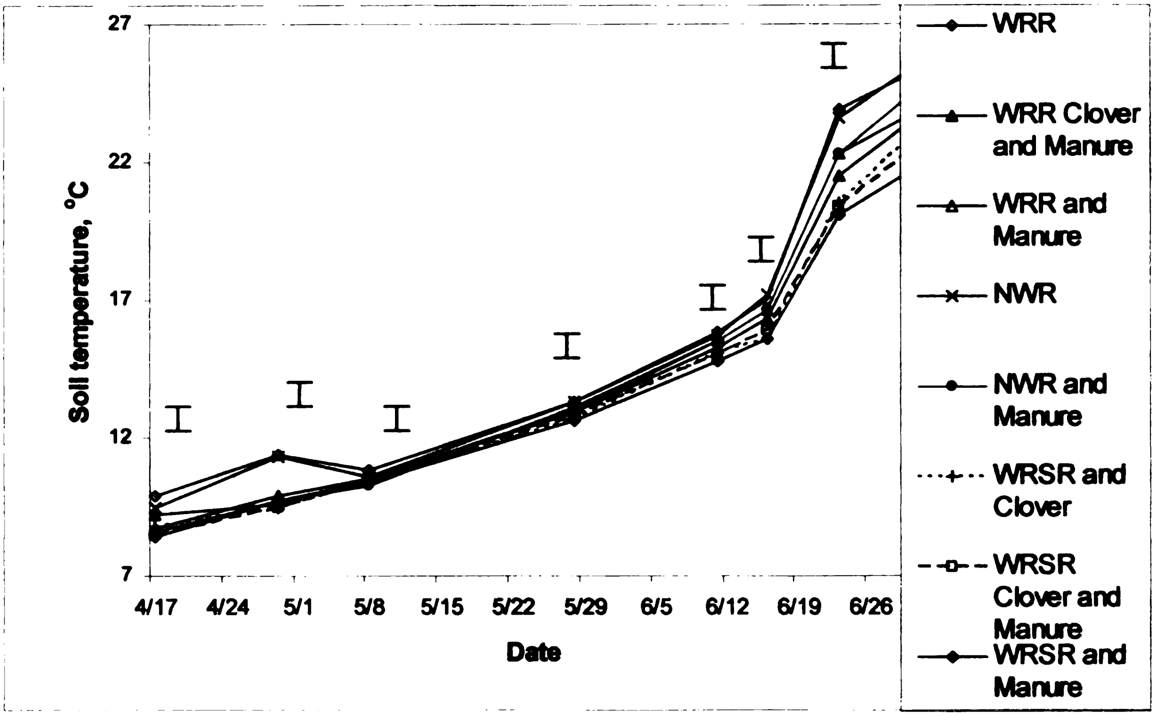
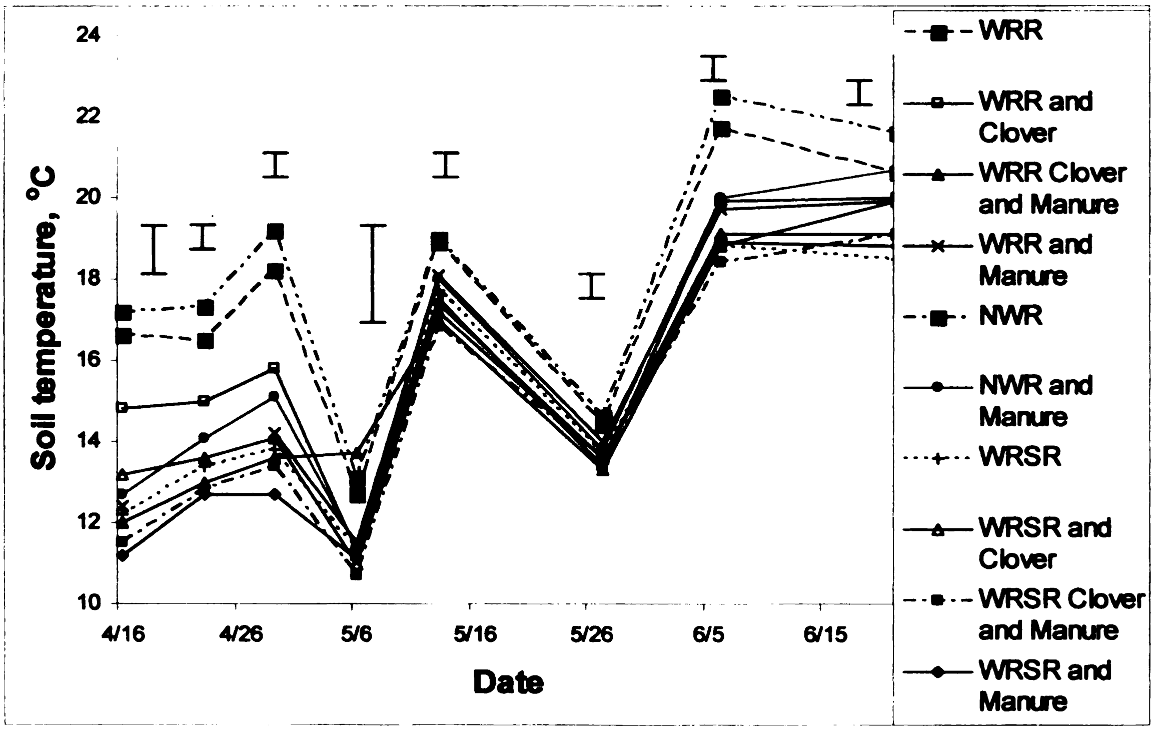


Figure 2.2. 2004 means of soil temperature (°C).



In WRR treatments without manure, clover significantly reduced soil temperatures on 6 of 8 studied dates compared to treatments without clover. On 6 May and 21 June, there were not significant differences between treatments. In WRR treatments with manure, clover significantly reduced soil temperature on 4 of 8 dates. On 16 April, 6 May, 6 June, and 21 June, clover did not have an effect on soil temperatures compared to treatments without clover. The 16 April date represents the beginning of the sampling period and 6 June and 21 June are the last two sampling dates. This suggests that soils were uniformly cool and warm at the beginning and the end of the sampling period, respectively, and that treatments had more of an effect on soil temperature during the transitional soil warm-up phase.

In 2005, clover again affected soil temperature (Figure 2.3). Soil temperature was strongly related to percent of clover cover (Figure.2.4 and Table 2.1). Higher clover cover corresponded to lower soil temperature. In WRSR treatments with and without manure, clover significantly reduced soil temperature on all but one sampled date compared to treatments without clover. This is likely due to the heavy 2005 clover stand and the cooler 2005 air temperatures resulting in an enhanced insulating effect from the clover residue. In WRR treatments with and without manure, clover significantly decreased soil temperatures in all but one date (18 May) compared to treatments without clover.

Figure 2.3. 2005 means of soil temperature (°C).

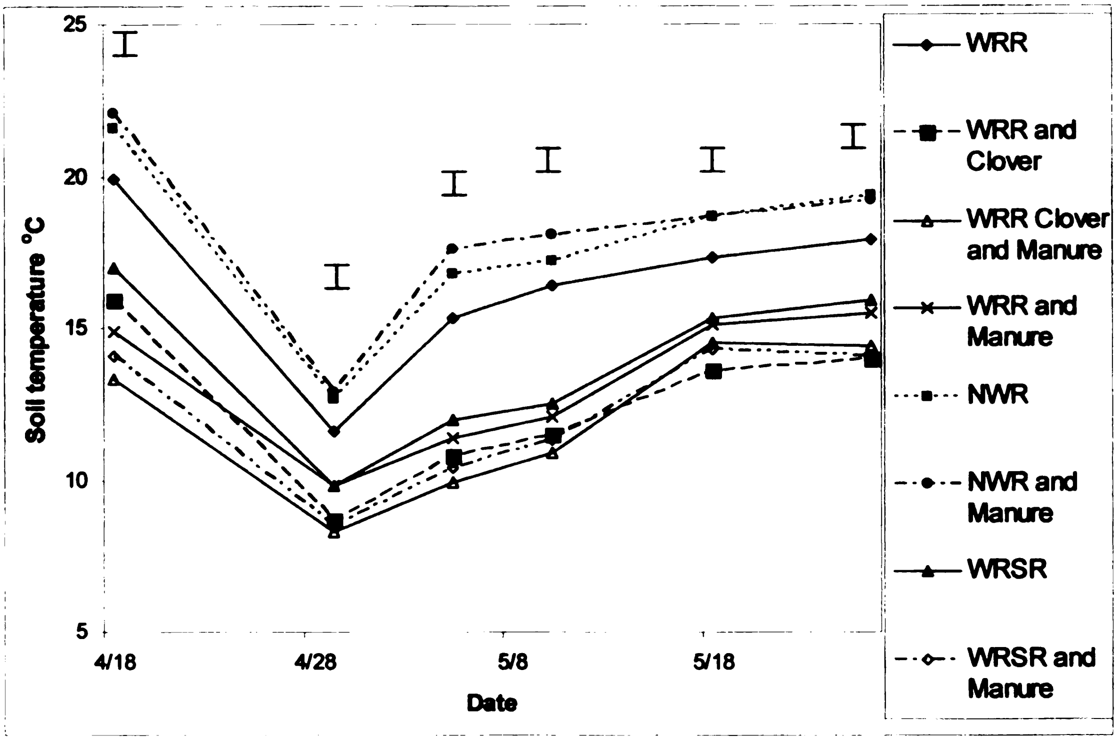


Table 2.1. Average percent of soil surface cover by manure, residue, and clover in 2005 treatments.

Treatment	Manure	Residue	Clover	Total
WRR	-	57.5	-	57.5
WRR and Clover	-	22.3	70.6	92.9
WRR Clover and Manure	45.6	20.6	27.9	94.1
WRR and Manure	54.0	40.9	-	94.9
NWR	-	22.9	-	22.9
NWR and Manure	80.5	15.1	-	95.6
WRSR	-	72.6	-	72.6
WRSR and Clover	-	26.2	53.4	79.6
WRSR Clover and Manure	64.2	13.4	19.1	96.7
WRSR and Manure	50.5	45.2	-	95.7

Figure 2.4. Relationship between percent of soil covered by clover and soil temperatures.

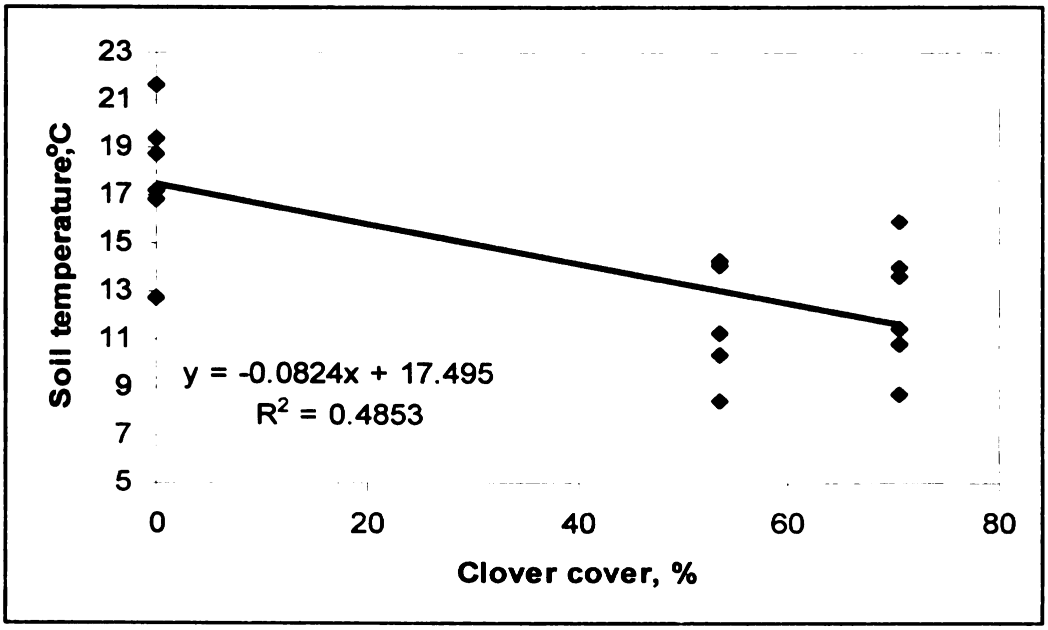


Table 2.2. Summary of clover and manure effects on soil temperature.

Treatment	2003	2004	2005
Effect of clover			
WRSR without manure	8 of 8 no effect	6 of 8 no effect	5 of 6 decreased
WRSR with manure	6 of 8 no effect	6 of 8 no effect	5 of 6 decreased
WRR without manure	5 of 8 decreased	6 of 8 decreased	5 of 6 decreased
WRR with manure	8 of 8 no effect	4 of 8 decreased	5 of 6 decreased
Effect of manure			
WRSR without clover	6 of 8 no effect	6 of 8 no effect	6 of 6 decreased
WRSR with clover	6 of 8 no effect	6 of 8 no effect	4 of 6 decreased
NWR	6 of 8 decreased	7 of 8 decreased	6 of 6 decreased
WRR without clover	7 of 8 decreased	7 of 8 decreased	6 of 6 decreased
WRR with clover	8 of 8 no effect	5 of 8 decreased	3 of 6 decreased

Summarizing the effect of clover on soil temperature (Table 2.2), in 2003 and 2004, in WRSR treatments with and without manure, clover did not affect soil temperature. But, in 2005, clover significantly decreased soil temperature in these treatments. In 2005, clover stands were two to three times graeter than in 2003 and 2004. In all years, in WRR treatments with and without manure, clover significantly decreased soil temperatures on most studied dates. The fact that clover residue decreased soil temperatures in WRR treatments and not in WRSR treatments in 2003 and 2004 is attributable to the insulating value of the above ground wheat residue. When the above ground wheat residue was present the addition of clover residue provided only a negligible additional insulating effect not sufficient to further reduce soil temperature. Without the masking effect of the above ground wheat residue, the clover residue effect on soil temperature in WRR treatments was measurable. The exception was 2003 WRR treatments with manure, where the effect of clover on soil temperature was not significant. However, in 2003, in the early dates, soil temperature was measured at 20 cm which may have been too deep to be sensitive to the temperature change imposed by the clover residue.

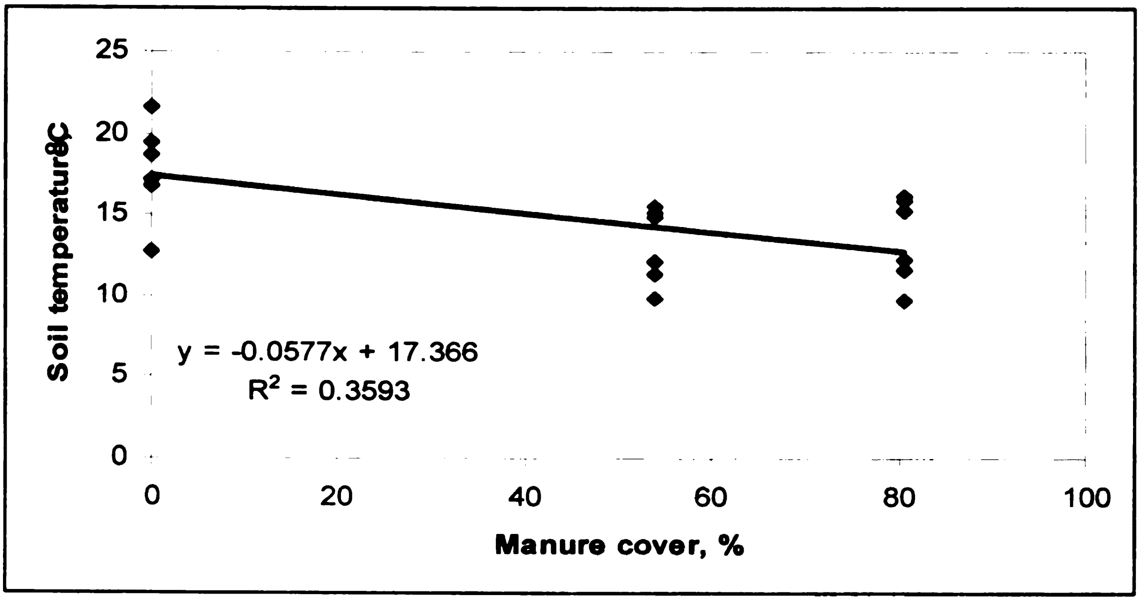
Effect of manure on soil temperature

In 2003, in WRSR treatments with and without clover, manure had no effect on soil temperatures on 6 of 8 studied dates (Figure 2.1). On 11 and 30 June, in treatments without clover, manure significantly decreased soil temperatures. In NWR treatments, manure significantly decreased soil temperatures on 6 of 8 dates compared to treatments without manure. On May 28 and June 23, there was no effect of manure. In WRR treatments without clover, manure significantly decreased soil temperatures on 7 of 8 studied dates compared to treatments without manure. On 23 June, manure did not affect soil temperatures in these treatments. In WRR treatments with clover, manure had no effect on soil temperatures in all studied dates. Clover had already significantly lowered soil temperature on these treatments. The addition of manure to the clover residue plus wheat root residue provided insufficient increased insulating value to further significantly decrease soil temperature.

In 2004, in WRSR treatments with and without clover, manure did not affect soil temperatures on 6 of 8 dates (Figure 2.2). In the early season (16 April and 29 April), in treatments with clover, manure significantly decreased soil temperatures compared to treatments without manure. In NWR treatments, manure significantly decreased soil temperatures on 7 out of 8 dates. In WRR treatments without clover, manure significantly decreased soil temperatures on 7 of 8 studied dates compared to treatments without manure. In WRR treatments with clover, especially in the early season, manure significantly decreased soil temperature on 5 of 8 dates compared to treatments without manure. On 6 May, 27 May, and 21 June, there was no effect of manure on soil temperature.

In 2005, manure affected soil temperature (Figure 2.3). Soil temperature was strongly related to percent of manure cover (Figure 2.5).

Figure 2.5. Relationship between percent of soil cover by manure and soil temperature in 2005.



Higher manure cover corresponded to lower soil temperature. In WRSR treatments without clover, manure significantly decreased soil temperatures in all dates compared to treatments without manure. In WRSR treatments with clover, manure significantly decreased soil temperatures on 4 of 6 dates. In NWR treatments, manure significantly reduced soil temperatures in all sampled dates compared to treatments without manure. In WRR treatments without clover, manure significantly decreased soil temperatures in all dates compared to treatments without manure. In WRR treatments with clover, manure significantly decreased soil temperatures on 3 of 6 studied dates compared to treatments without manure, especially in the early growing season (18 April and 29 April). On 5 May, 10 May, and 26 May, there was no effect of manure in soil temperature for WRR treatments.

Summarizing manure effects on soil temperature (Table 2.2), in 2003 and 2004, in WRSR treatments with and without clover, manure did not affect soil temperatures on the most of the studied dates. In 2005, manure significantly decreased soil temperatures in these treatments. This was likely due to the timing and rate of manure application and cooler than average May temperature in 2005. Prior to the 2003 and 2004 growing seasons, manure was applied in the fall in amounts of 20 Mg ha^{-1} less than the spring application in 2005. There could be some losses of manure, run off, decomposition, mineralization, and other processes that affected soil coverage by manure with the winter applications in 2003 and 2004. In all years, in NWR treatments and WRR treatments without clover, manure significantly decreased soil temperature. In WRR treatments with clover, manure did not affect soil temperature relative to WRR treatments with clover and without manure in 2003 and tended to lower soil temperature in 2004 and 2005.

Effect of treatments on PSNT results

In all three studied years, PSNT levels were the highest in NWR treatments (Table 2.3). The soil in these treatments warmed faster compared with the soil in the other treatments. Thus, rate of mineralization of N was probably higher and the soil had a higher amount of residual N. Also, low plant available N in WRSR treatments can be explained by microbial immobilization of N because of the very high C:N ratio of wheat residue (80:1) and allelopathy effect (Rice 1984). Rice found that active allelopathic compounds inhibit N fixation by free-living and symbiotic microorganisms. These compounds influence nitrification, but do not influence denitrification processes.

Table 2.3. Effect of studied treatments on the soil pre-sidedress nitrogen test (PSNT) (kg ha^{-1}) results and on the total amounts of nitrogen added to the soil as a fertilizer (kg ha^{-1}).

Treatment	PSNT			Added N		
	2003	2004	2005	2003	2004	2005
WRR	69.5 bc†	108.5 bc	29.2 a	101	58	145
WRR and Clover	78.0 cd	134.9 cd	14.3 a	101	31	145
WRR Clover and Manure	54.2 ab	69.9 a	77.2 c	118	112	101
WRR and Manure	57.1 abc	81.9 ab	76.4 bc	118	112	101
NWR	92.5 cd	161.5 d	83.2 cd	101	31	90
NWR and Manure	95.8 d	92.1 abc	95.3 d	101	58	90
WRSR	43.7 a	87.8 ab	29.6 a	134	105	145
WRSR and Clover	50.6 ab	98.5 abc	20.5 a	134	112	145
WRSR Clover and Manure	81.1 cd	65.3 a	94.7 d	101	105	90
WRSR and Manure	47.4 ab	69.8 a	58.7 b	134	129	112

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$

WRR treatments with manure had high rates of N application based on relatively low PSNT levels. The relatively low PSNT N levels found in the manured plots was likely due to a slow rate of mineralization of soil N and slow rate of mineralization of manure N due to lower soil temperatures associated with the manure layer on the soil surface insulating the soil and delaying spring warm up. The soil temperature in these treatments was significantly lower compared with temperature in the rest of the treatments. Also, in 2004 and 2005, the very wet and cool springs further retarded N mineralization and contributed to the low PSNT levels observed in these treatments.

In 2003 and 2004, WRR treatments with and without clover and without manure had high amounts of plant available nitrate that was likely due to higher soil temperatures and a higher rate of mineralization of soil N. In contrast, in 2005, WRR treatments with and without clover and without manure had low amounts of plant available nitrate. In WRR treatments without clover and manure that was likely due to the early 2005 sampling date (7 June), microbial immobilization of N, because of high C:N ratio of wheat root residue, and/or allelopathy effect (Rice, 1984). In WRR treatments with clover and without manure, the low amount of plant available nitrate was likely due to the above factors plus early season N uptake by the clover and low soil temperature (the heavy residue after herbicide burndown clover decreased soil temperature in these treatments) that inhibited rate of mineralization of soil N and nitrogen fixation by clover. Rhizobia influences nodule growth, nitrogen fixation, and the time period when nodules remain active. Rhizobia are mesophiles and most do not grow below 10^{o} C. Azizi et al. (2004) found that the best temperature for nitrogen fixation and nodule formation for annual medics (*Medicago polymorpha* cv. Santiago) at root zone was at 15^{o} C, and 10^{o} C was a thermal critical. Zhang et al. (2002) concluded that soil temperature below 15^{o} C is a limiting factor to soybean nodulation in Canada. Also, after study the effectiveness of strains of Rhizobium, Herdian and Silsbury (2001) found that seeding growth and nodulation were poorer at 10^{o} C than at 15^{o} C or 20^{o} C in faba bean (*Vicia faba L.*) and pea (*Pisum Sativum L.*). Therefore, at the time of the 7 June 2005 PSNT sampling date, the clover was likely an N sink and not an N source.

Generally, relatively lower amounts of plant available nitrate were in the soil in 2003 and 2005 compared to 2004 which is likely due to the late 2004 PSNT sampling date and environmental conditions.

We concluded that, in 2003, in WRSR treatments with manure, clover significantly increased soil nitrate levels. In the rest of treatments, clover did not have any effect on soil nitrate levels. In WRSR treatments with clover, manure significantly increased soil nitrate levels. But in WRR treatments with clover, manure decreased soil nitrate levels which can be related to possible lower spring soil temperature which delayed N mineralization.

In 2004, in all treatments, clover did not affect soil nitrate levels and manure decreased the amount of soil nitrate in WRR treatments with clover.

In 2005, in WRSR treatments with manure, clover significantly increased soil nitrate levels. In the rest of treatments, clover did not have any effect. And, in WRSR and WRR treatments with and without clover, manure significantly increased soil nitrate levels which is likely due the higher amount of plant available N in 2005 manure (Table 2.4). In NWR treatments, manure did not decrease soil nitrate levels as it did in the wheat residue systems. This further supports our conclusions that the relatively cooler soils resulting from the wheat residues delayed manure N mineralization.

In every year, wheat residue affected soil nitrate levels. WRSR treatments with and without clover and manure had significantly lower soil nitrate levels than NWR treatments with and without manure. In 2004 and 2005, WRSR and WRR with and without clover and manure were not different. In 2003, WRR and NWR treatments with and without manure were not different.

Table 2.4. Manure analysis during three years of application.

Parameter	2002		2003		2005	
	kg Mg^{-1}					
Moisture	653.40	-	662.60	-	564.50	-
Solids	254.60	-	245.40	-	343.50	-
Organic Matter (LOI)	no	-	225.81	-	291.19	-
Nitrogen, Total (N)	4.63	2.22*	2.81	1.45*	8.22	3.04*
Nitrogen (NH_4-N)	1.41	1.41*	1.00	1.00*	1.32	1.32*
Nitrogen, Organic	3.22	0.81*	1.81	0.45*	6.90	1.73*
Phosphorus (as P_2O_5)	1.36	1.36*	1.36	1.36*	4.09	4.09*
Potassium (as K_2O)	3.63	1.36*	4.54	4.54*	7.08	7.08*

*- First year availability (source: MWP – 18, Livestock Waste Facilities Handbook, 1993).

Effect of clover and manure on chlorophyll content in corn leaves

In 2004 and 2005, in the early to mid-stages of corn development, WRSR treatments resulted in significantly decreased chlorophyll content in corn leaves compared with other treatments (Figures 2.6 and 2.7). However, by August 2 and July 5, just prior to tasseling, the amount of chlorophyll was found to be similar in all treatments, likely due to different N application rates based on PSNT results (Figure 2.8).

Figure 2.6. Effect of treatments on leaf chlorophyll content in 2004.

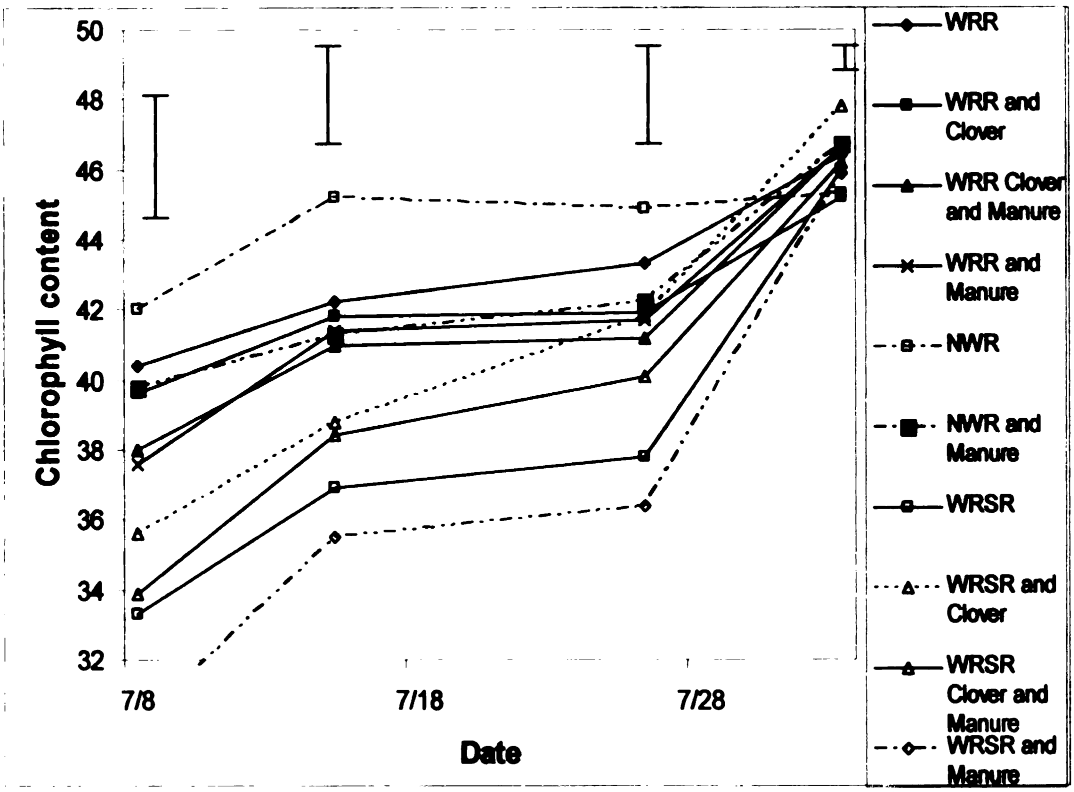


Figure 2.7. Effect of treatments on leaf chlorophyll content in 2005.

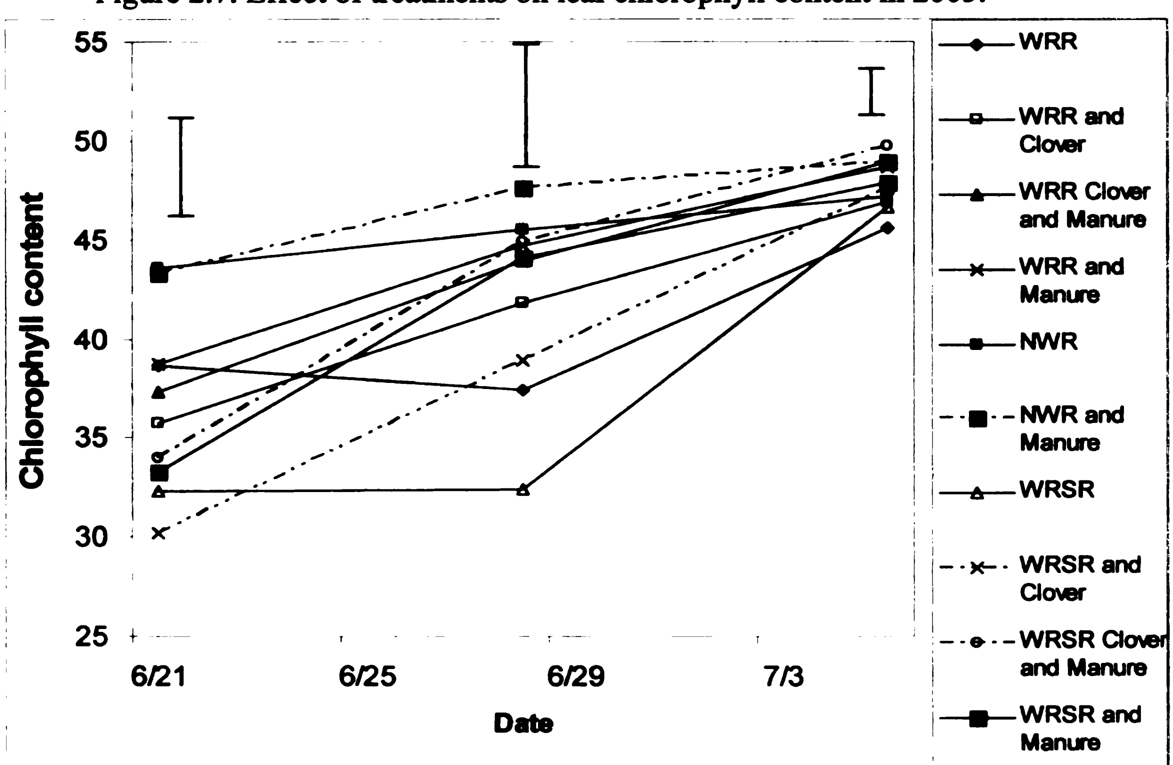
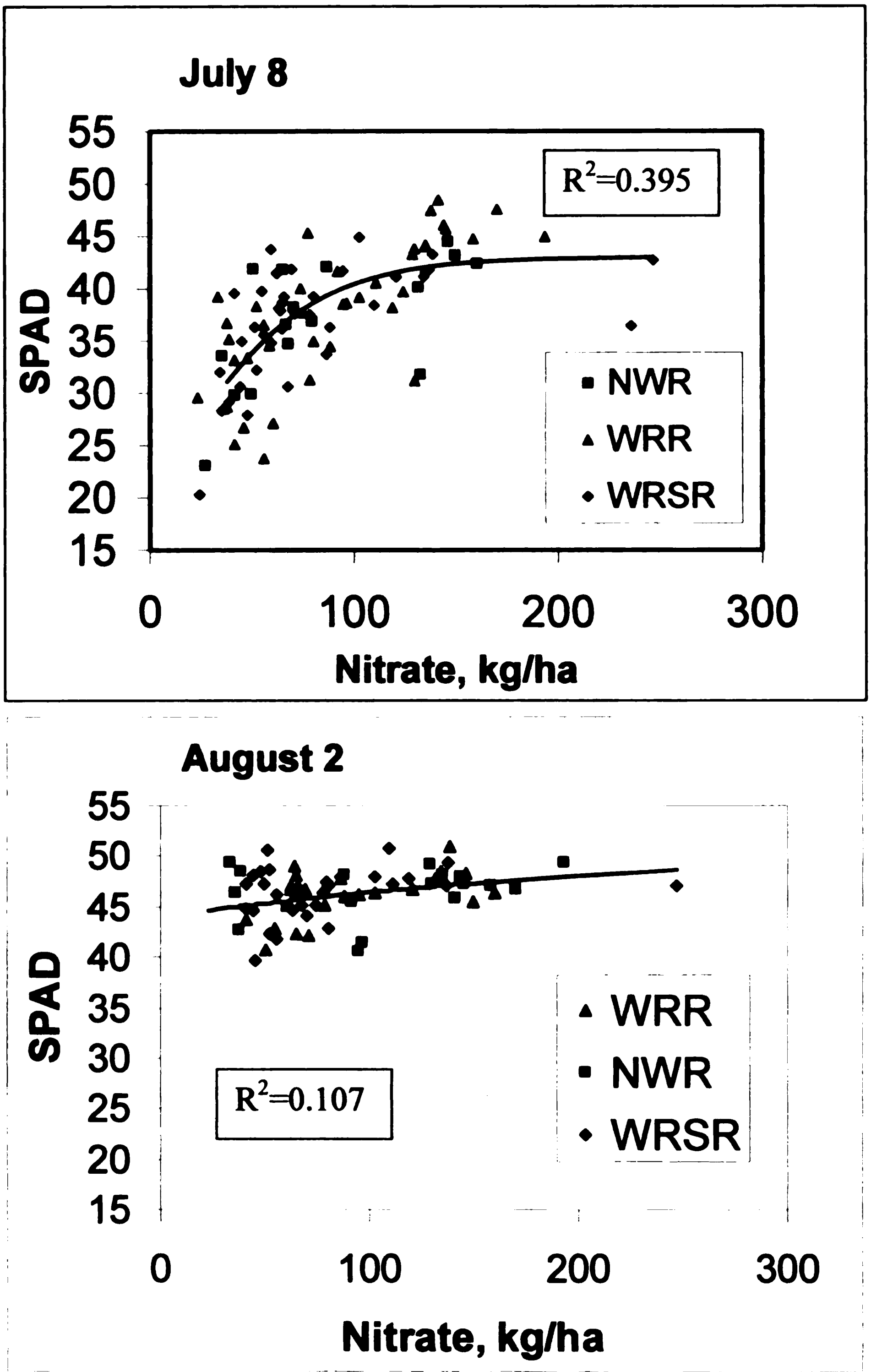


Figure 2.8. 2004 SPAD readings plotted versus soil nitrate levels in 2004.



In 2004, in WRSR and WRR treatments with and without manure, clover did not affect chlorophyll content in corn leaves on 8 July and 15 July. On 26 July, corn leaves, in WRSR treatments with clover and either with or without manure, had significantly higher amounts of chlorophyll than corn leaves in WRSR treatments without clover and with or without manure. This could be explained by either the effect of added N fertilizer and/or N supplying effect of the clover.

In WRSR and WRR treatments with and without clover, manure did not have an effect on chlorophyll content in corn leaves at all studied dates. But, in NWR treatments, manure decreased chlorophyll content of corn leaves in all studied dates. This was likely a result of lower soil temperature and lower rate of mineralization of soil and manure N in the wet and cold growing season of 2004.

In 2005, clover and manure did not affect chlorophyll content in corn leaves on 21 June. On the 28 June and 5 July chlorophyll sampling dates, manure had a significant positive effect on corn chlorophyll levels. This may be attributable to the cold May of 2005 resulting in the PSNT underestimating the N contribution from the manure.

Effect of treatments on corn grain moisture and test weight

In all years, WRSR treatments had significantly higher corn grain moisture at harvest than NWR treatments (Table 2.5). This is likely due to delayed emergence of corn observed in 2003 and 2005 and delayed time of tasseling of corn observed in all three studied years.

In 2003, in WRR treatments without manure, clover significantly increased corn grain moisture. In the rest of the treatments, clover did not have an effect on corn grain moisture. Also, manure did not affect grain moisture of corn in all the treatments. Residue significantly affected corn grain moisture. NWR treatments without manure had significantly lower corn grain moisture than WRSR and WRR treatments without clover and manure.

In 2004, clover and manure did not have any effect on corn grain moisture. Residue was the only factor that increased corn grain moisture. WRSR treatments with and without clover and manure had significantly higher corn grain moisture than NWR and WRR treatments with and without clover and manure. NWR and WRR treatments were not different.

In 2005, clover significantly increased corn grain moisture in WRSR and WRR treatments with and without manure. Also, manure significantly increased corn grain moisture in the all treatments.

Table 2.5. Grain moisture at harvest, test weight, and yield of corn.

Treatment	Grain moisture (%)			Test weight (kg m^{-3})			Yield (Mg ha^{-1})		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
WRR	19.8 a†	28.6 ab	18.1 a	708.5 de	608.2 a	722.0 e	6.90 a	8.79 ab	9.01 bcd
WRR and Clover	23.5 c	29.6 b	23.4 d	692.0 bc	617.5 a	685.6 c	8.35 ab	7.86 a	7.96 a
WRR Clover and Manure	23.2 bc	29.8 b	25.7 f	693.9 bcd	614.8 a	674.0 b	8.23 ab	10.40 d	8.50 abc
WRR and Manure	21.9 abc	29.2 ab	21.9 c	702.1 cde	612.1 a	708.2 d	8.33 ab	10.19 cd	9.74 de
NWR	19.5 a	28.0 a	17.9 a	711.9 ef	615.2 a	732.7 f	8.64 ab	8.62 ab	9.99 e
NWR and Manure	21.0 ab	28.6 ab	21.9 c	717.7 f	617.5 a	710.8 d	9.55 b	8.76 ab	11.37 f
WRSR	25.4 d	32.4 c	20.2 b	679.1 ab	612.9 a	708.1 d	8.71 b	8.57 ab	8.27 ab
WRSR and Clover	22.6 c	31.7 c	24.0 de	690.7 bc	615.3 a	680.8 bc	7.48 a	9.06 abc	8.43 ab
WRSR Clover and Manure	23.6 cd	31.6 c	28.0 g	693.9 bcd	619.7 a	658.9 a	8.15 ab	9.19 bc	8.51 ab
WRSR and Manure	25.1 d	32.3 c	24.8 ef	674.4 a	610.0 a	683.0 bc	7.78 ab	8.23 ab	9.38 cde

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

Wheat residue also increased corn grain moisture. WRSR treatments without clover and manure had significantly higher corn grain moisture than NWR and WRR treatments without clover and manure. NWR and WRR treatments were not different from each other.

In 2003 and 2005, WRSR treatments had significantly lower corn test weight at harvest than NWR treatments (Table 2.5). This is likely due to delayed emergence of corn (2003 and 2005), delayed time of tasseling of corn, and lower amount of soil plant available N that is result of microbial immobilization of N. In 2004, there were no differences between treatments which is likely due to the late planting date of corn and relatively quicker and more consistent emergence patterns.

In 2003, in WRSR treatments with manure and WRR treatments without manure, clover significantly reduced corn test weight. Manure did not have effect on corn test weight. Residue significantly decreased test weight of corn. WRSR treatments without clover and manure had significantly lower corn test weight than NWR and WRR treatments without clover and manure that were not different between each other.

In 2005, in WRSR and WRR treatments with and without manure, clover significantly reduced corn test weight. Also, in all treatments, manure significantly reduced corn test weight. Residue also decreased corn test weight. WRSR, WRR, and NWR treatments without clover and manure were significantly different from each other. And, in WRSR treatments corn had the lowest test weight.

Effect of treatments on corn yields

The treatments can be viewed as four management practices. The first practice consists of N management strategy only with nitrogen application according to PSNT results (Figure 2.9). This management system includes NWR, WRR, and WRSR treatments. PSNT management of the two wheat residue treatments (WRR and WRSR) was effective in two of the three years, 2003 and 2004. But, in 2005, the PSNT management practice was not effective and both WRR and WRSR had lower yields than the NWR treatment.

The second practice consists of N management strategy with nitrogen application according to the PSNT results and clover as a cover crop (Figure 2.10). This management system consists of WRR and Clover and WRSR and Clover treatments. Similar to the first system, the second system was effective in 2003 and 2004. But in 2005 both WRR and Clover and WRSR and Clover treatments had lower yields than NWR.

The third practice consists of N management strategy with nitrogen application according to the PSNT results and manure application (Figure 2.11.). This management system consists of NWR and Manure, WRR and Manure, and WRSR and Manure treatments. This system was effective in all three studied years. In all three years, the yield of WRR and Manure was not significantly lower than the yields of NWR treatments. Also, in all three years, the yields of WRSR and Manure treatments were similar to the yields of NWR treatments.

The fourth practice consists of N management strategy with nitrogen application according to the PSNT results, clover as a cover crop, and manure application (Figure 2.12.). This practice includes WRR Clover and Manure and WRSR Clover and Manure treatments. This system was effective in 2003 and 2004 years, with yields of both WRR Clover and Manure and WRSR Clover and Manure treatments being not lower than the yields of NWR and NWR and Manure treatments. However, the system was not effective in 2005. Yields, in both WRR Clover and Manure and WRSR Clover and Manure treatments, were significantly lower than the yields of NWR and NWR and Manure treatments.

One of the possible reasons that in 2005 the systems were not effective could be much lower corn populations as compared to 2003. In WRR and Clover, WRSR and Clover, and WRR Clover and Manure treatments the corn population in 2005 was more than 20% lower than the population in the control treatment.

Table 2.6. Decrease in corn population (%) compared to NWR (control)

Treatment	2003	2005	Strategy
WRR	2	4	PSNT
WRSR	8	12	
WRR and Manure	6	14	PSNT+ Manure
WRSR and Manure	9	16	
WRR and Clover	3	21	PSNT + Clover
WRSR and Clover	12	22	
WRR Clover and Manure	7	27	PSNT + Clover + Manure

Figure 2.9. Management practice: PSNT.

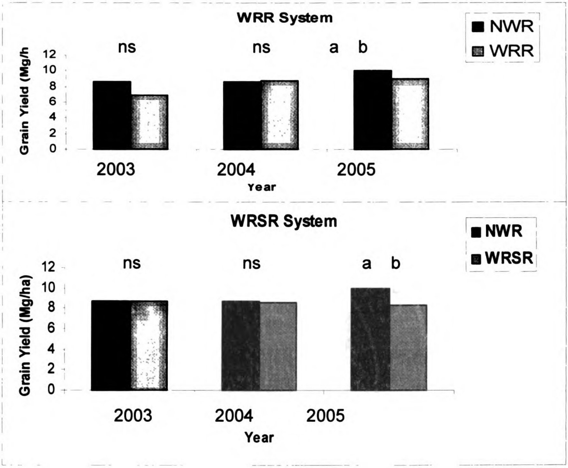


Figure 2.10. Management practice: PSNT and clover cover crop.

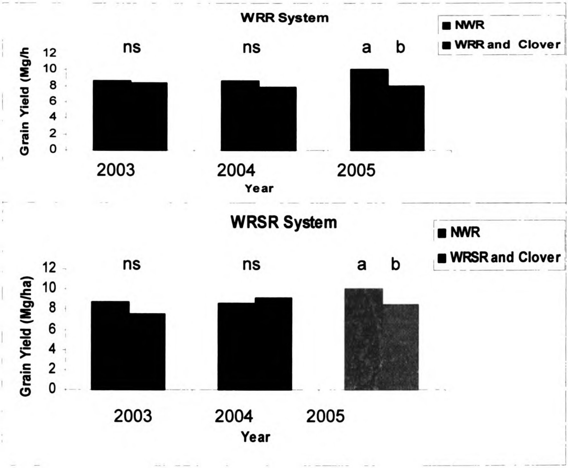


Figure 2.11. Management practice: PSNT and manure.

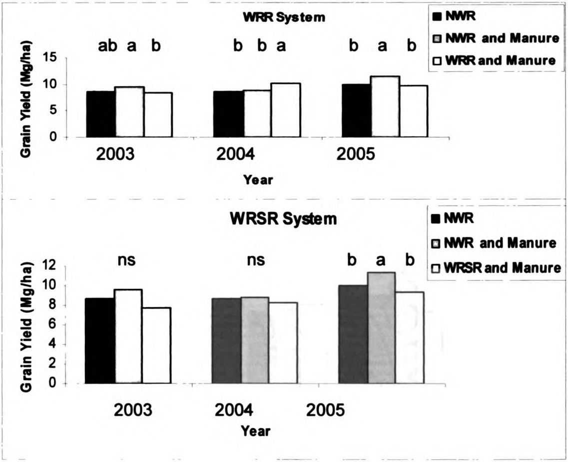
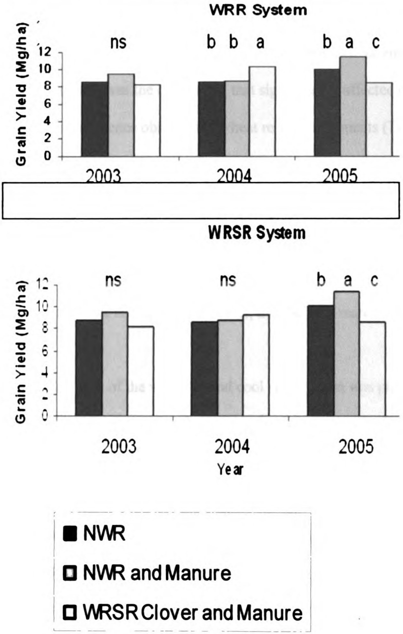


Figure 2.12. Management practice: PSNT, manure, and clover.



N management practices effect corn growth and development

Effect of clover and manure on corn date of emergence

In 2003, residue was the only factor that significantly affected corn emergence, with delayed corn emergence observed in wheat residue treatments (Table 2.6). All WRSR treatments were significantly different in corn emergence compared with NWR and WRR treatments regardless of their manure and clover levels. The negative effect of wheat residue on corn emergence can be related to the relatively early planting of corn (30 April) in 2003. As we discussed earlier, soil temperature in WRSR treatments was lower compared to NWR and WRR treatments, thus being a reason for the delayed corn emergence.

In 2004, because of the very wet and cool spring, corn was planted relatively late (29 May). Higher soil temperatures observed in late May and early June promoted germination of corn, thus potentially being the reason for the same corn emergence time in all treatments in this year.

In 2005, the presence of wheat residue, clover and manure delayed emergence of corn. In all WRSR treatments, NWR treatments with manure, and WRR treatments with clover and manure corn emerged significantly later compared to NWR treatments without manure. In WRSR and WRR treatments with and without manure, clover significantly delayed corn emergence that is likely due to a heavier clover stand in 2005. Heavy clover residue after herbicide burndown insulated soil and prevented it from warming up.

Table 2.7. Emergence, population, and time of tasseling of corn in 2003- 2005 growing seasons.

Treatment	2003	2004	2005	2003	2004	2005	2003	2004	2005
	Emergence (date)			Population (plants ha^{-1})			VT stage (date)		
WRR	5/25 b†	6/10 a	5/20 b	66297 cd	62827 ab	62505 fg	7/27 ab	8/4 ab	7/15 b
WRR and Clover	5/25 b	6/10 a	5/30 fg	65707 bcd	65539 b	51388 bc	7/28 b	8/5 bc	7/22 fg
WRR Clover and Manure	5/25 b	6/10 a	5/30 gh	62827 abc	68913 c	47511 ab	7/30 bc	8/6 bc	7/22 ef
WRR and Manure	5/25 b	6/10 a	5/25 de	64074 abcd	66660 bc	56381 cde	7/28 bc	8/5 abc	7/18 cd
NWR	5/19 a	6/10 a	5/15 a	67863 d	59705 a	64962 g	7/24 a	8/4 a	7/12 a
NWR and Manure	5/23 b	6/10 a	5/24 d	68859 d	63510 b	60616 efg	7/24 a	8/6 c	7/17 cd
WRSR	5/28 c	6/10 a	5/25 e	62674 ab	65455 b	57383 def	7/30 c	8/10 e	7/18 d
WRSR and Clover	5/27 c	6/10 a	5/29 f	59428 a	62296 ab	50932 bc	8/01 c	8/9 de	7/22 fg
WRSR Clover and Manure	5/27 c	6/10 a	5/31 h	59774 a	66381 bc	41953 a	7/31 c	8/8 d	7/23 g
WRSR and Manure	5/29 c	6/10 a	5/30 fg	61997 ab	66381 bc	54708 cd	8/01 c	8/10 e	7/21 e

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

In NWR treatments, WRSR and WRR treatments with and without clover, manure delayed corn emergence compared to NWR treatments without manure. As with the heavy clover residue, the layer of manure acted as an insulator in the early spring season delaying the warm up of the soil. Only, in WRR treatments with clover, manure did not affect corn emergence. Negative influence of manure and clover can be related to spring manure application and high percent of clover standing which, as we stated above, reduced soil temperature.

Effect of clover and manure on corn plant stands and date of tasseling

Generally, in 2003 and 2005, NWR had higher corn plant stands than WRR and WRSR treatments regardless of their manure and clover levels (Table 2.6). In contrast, in 2004, the lowest population of corn had NWR treatments without manure.

In 2003 and 2004, in all treatments, manure and clover did not affect corn population. The exception is 2004 when WRR treatments with clover and manure had higher corn population than treatments without manure. In 2005, clover and manure affected the population of corn. In WRSR and WRR treatments with and without manure, clover significantly reduced corn population. Manure significantly reduced corn population in WRR without clover and WRSR with clover treatments. The corn plant population trends resemble those observed with corn date of emergence.

In 2003, tasselling of corn was significantly delayed in WRSR treatments as compared with NWR treatments, but not significantly different from WRR treatments, regardless of their manure and clover levels (Table 2.6). In 2004, all WRSR treatments were significantly different as compared with the rest of the treatments. In 2005, in

WRSR treatments, NWR and WRR treatments with clover and manure, VT stage of corn was significantly later as compared to NWR treatments with clover and manure.

In 2003, in all treatments, manure and clover did not affect VT stages of corn. In 2004, in WRSR treatments with manure and clover corn had later VT stage. In NWR treatments without clover, presence of manure significantly delayed VT stage of corn. In 2005, in WRSR and WRR treatments with and without manure, presence of clover significantly delayed VT stage of corn. The delay in reaching VT stages of corn may be attributable to the heavy levels of clover residue in 2005 which delayed soil warm up. Also, in WRSR, NWR, and WRR treatments without clover, manure significantly delayed VT stage of corn as compared to treatments without manure.

Effect of clover and manure on height of corn

In 2003, corn plants in WRSR treatments and WRR treatments with and without clover and manure were significantly shorter compared with corn plants in NWR treatments (Figure 2.13).

Figure 2.13. Height of corn in 2003 treatments.

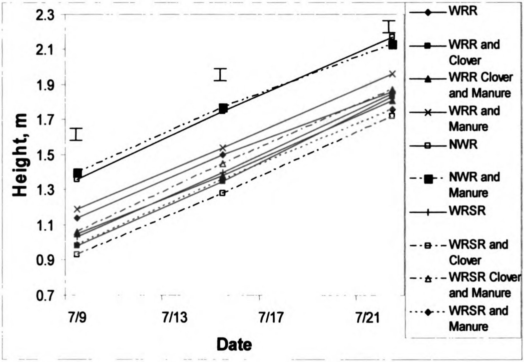
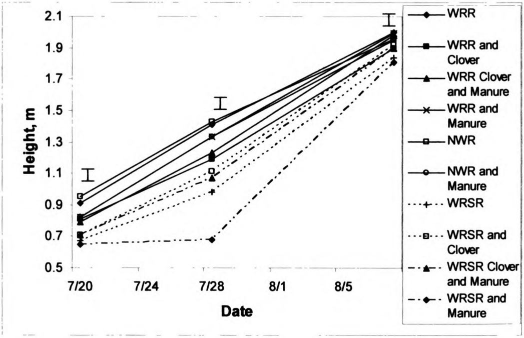


Figure 2.14. Height of corn in 2004 treatments.



In 2004 and 2005, corn height was significantly lower in WRSR treatments with and without clover and manure than in the other treatments, especially in early stages of corn development (Figures 2.14 and 2.15).

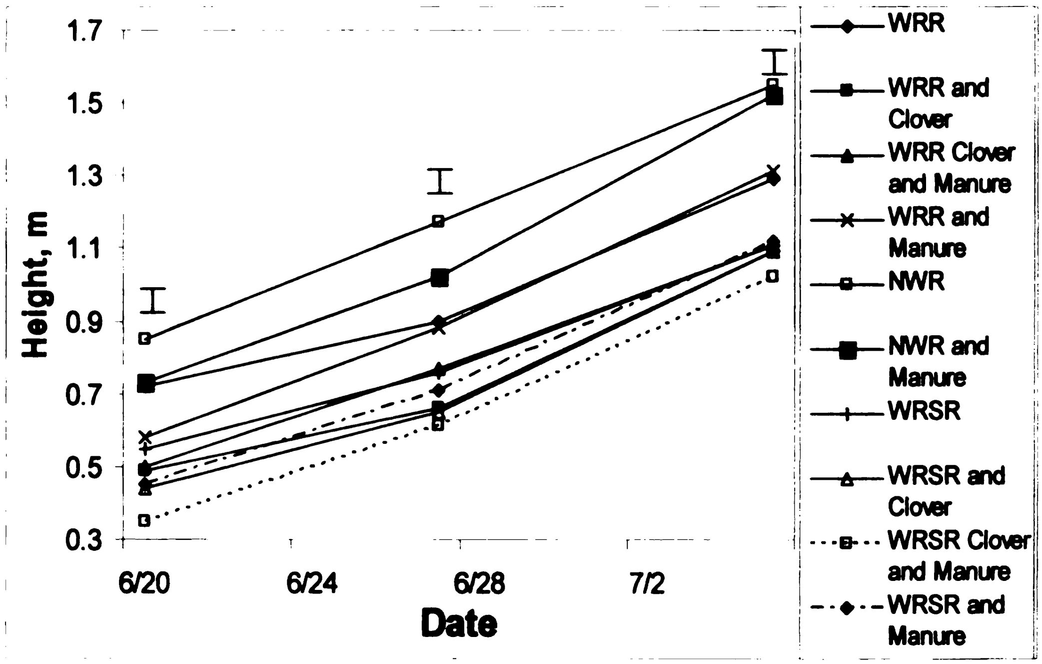
We concluded that, in 2003, manure and clover did not affect height of corn in the all studied treatments that can be related to poor clover stands and fall manure application that barely affected soil temperatures, especially in WRSR and NWR treatments (Table 2.2).

In 2004, in WRSR treatments without manure, clover did not affect height of corn in all studied dates. In WRR treatments without manure, clover significantly reduced height of corn in the early stage of corn development (20 July and 28 July). It can be related to lower soil temperature that was decreased by clover residue that probably affected soil and manure net N mineralization (Table 2.2). In WRR treatments with manure, clover significantly decreased height of corn on 20 July. On the rest of the dates, there were no clover effects. Also, manure affected height of corn. In NWR treatments, manure significantly decreased height of corn on the early dates (20 July and 28 July) that that can be explained by lower soil temperature in the early growing season that probably affected soil and manure net N mineralization. In WRSR treatments with and without clover manure did not affect height of corn in all dates.

In 2005, in WRSR treatments with and without manure, clover significantly decreased height of corn only in the early measured date (20 June). In the rest of the dates there were no effects of clover. In WRR treatments with and without manure, clover significantly decreased height of corn in all dates that is likely due to lower soil temperature that was decreased by clover in the early growing season (Table 2.2).

Manure decreased corn height in WRSR and WRR treatments with and without clover in the early sampling date (20 June).

Figure 2.15. Height of corn in 2005 treatments.



CONCLUSION

Despite decreased soil temperature, later corn emergence, reduced corn populations, delayed VT stage, decreased leaf chlorophyll content and plant height in the early stages of corn development a PSNT nitrogen strategy was effective in maintaining corn grain yields in wheat residue systems equivalent to yields in no-wheat residue systems in 4 of 6 site years. Similar results were obtained for PSNT plus clover cover crop and PSNT plus manure plus clover cover crop N management systems. Using PSNT and manure system equalized high wheat residue corn yields to no-wheat residue in 6 of 6 site years.

Table 2.8. Summary of nitrogen management strategies effectiveness in overcoming wheat residue antagonism on corn grain yield.

	Nitrogen Management Strategy Success Rate (%)			
Residue System	PSNT	PSNT + Clover	PSNT + Manure	PSNT +Clover + Manure
WRR	66	66	100	66
WRSR	66	66	100	66

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Table A 1. 2003 mean volumetric soil moisture values (%).

Treatment	Date								
	17-Apr	23-Apr	29-Apr	14-May	21-May	28-May	6-June	11-June	18-June
WRR	23.8 ab†	26.1 abc	23.7 abc	26.7 a	23.4 a	21.7 ab	22.9 a	23.1 a	20.3 a
WRR and Clover	26.1 bcd	25.1 a	22.2 a	28.8 abc	24.0 ab	20.9 a	23.5 ab	24.0 ab	20.5 ab
WRR Clover and Manure	25.4 abc	25.8 ab	22.5 ab	28.8 abc	26.3 bc	21.8 ab	25.5 bcd	23.0 a	20.4 ab
WRR and Manure	28.2 de	29.2 d	28.8 fg	28.8 abc	25.3 abc	22.4 ab	25.2 abcd	25.3 ab	23.6 de
NWR	23.6 a	26.2 abc	22.9 ab	27.2 abc	24.1 ab	22.3 ab	24.7 abcd	23.7 ab	22.5 abcd
NWR and Manure	28.9 e	27.5 abcd	27.5 ef	26.9 a	24.5 abc	22.7 ab	23.8 abcd	24.6 abcd	22.6 abcd
WRSR	29.8 e	28.8 d	30.6 g	29.8 c	27.0 c	23.3 bc	26.6 d	26.9 d	23.0 cde
WRSR and Clover	27.3 cde	28.9 d	24.7 bcd	29.6 bc	25.9 bc	24.0 bc	26.3 cd	25.7 bcd	22.4 abc
WRSR Clover and Manure	27.9 de	28.1 bcd	25.8 cde	29.0 abc	25.7 abc	22.7 ab	25.0 abcd	24.8 abcd	22.8 bcde
WRSR and Manure	28.6 e	28.2 bcd	26.2 de	28.2 abc	26.1 bc	25.5 c	27.2 d	26.5 cd	25.4 e

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

Table A 2. 2004 mean volumetric soil moisture values (%).

Treatment	Date						
	16-Apr	22-Apr	29-Apr	6- May	13-May	27-May	6-June
WRR	18.3 bc†	17.9 bc	16.4 bc	20.5 a	26.1 a	30.1 a	20.8 a
WRR and Clover	16.8 a	16.4 a	13.8 a	21.2 ab	26.4 a	30.7 ab	24.9 c
WRR Clover and Manure	19.3 cd	19.0 cd	15.4 ab	22.7 bc	27.5 abcd	31.4 ab	24.9 c
WRR and Manure	20.1 de	19.7 d	19.4 de	24.3 cde	26.7 abc	31.4 ab	23.9 bc
NWR	17.6 ab	17.4 ab	16.6 bc	20.5 a	25.8 a	30.4 a	21.7 a
NWR and Manure	21.0 e	20.3 d	20.6 e	24.2 cde	28.3b cde	32.3 b	25.6 c
WRSR	19.9 de	19.5 d	18.8 de	24.7 de	29.4 e	30.5 a	25.5 c
WRSR and Clover	18.2 bc	17.6 bc	17.6 cd	22.8 bcd	26.5 ab	30.7 a	24.2 bc
WRSR Clover and Manure	20.3 de	19.9 d	19.5 e	23.7 cde	27.0 abcd	30.8 ab	25.4 c
WRSR and Manure	20.7 e	20.3 d	19.6 e	24.8 e	28.5 cde	31.0 ab	25.6 c

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, P<0.05)

Table A 3. 2005 mean volumetric soil moisture values (%).

Treatment	18-Apr	29-Apr	5-May	10-May	18-May	26-May
WRR	18.9 a†	18.2 a	16.0 a	15.6 a	19.5 c	18.7 b
WRR and Clover	19.3 a	18.3 a	15.8 a	15.3 a	17.5 b	15.5 a
WRR Clover and Manure	22.3 bc	21.4 bcd	18.9 bc	18.3 bc	22.0 fg	20.3 c
WRR and Manure	21.6 b	20.7 b	18.4 b	17.7 b	24.3 i	24.0 ef
NWR	18.6 a	17.5 a	15.2 a	14.9 a	16.2 a	17.9 b
NWR and Manure	22.4 bcd	20.9 bc	18.9 bc	17.9 b	21.1 def	21.8 d
WRSR	22.6 bcd	21.8 bcd	19.1 bc	18.1 b	20.5 cde	21.4 cd
WRSR and Clover	22.8 bcd	21.5 bcd	18.7 bc	18.0 b	21.5 ef	22.8 def
WRSR Clover and Manure	24.2 cd	22.9 cd	20.5 bc	19.3 bc	24.7 i	24.7 f
WRSR and Manure	24.4 d	23.6 d	21.0 c	20.3 c	23.0 h	24.0 ef

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, P<0.05)

Table A 4. Summary of clover and manure effect on soil moisture.

Treatment	2003	2004	2005
Effect of clover			
WRSR without manure	8 from 9 no effect	4 from 7 decreased	6 from 6 no effect
WRSR with manure	8 from 9 no effect	7 from 7 no effect	5 from 6 no effect
WRR without manure	9 from 9 no effect	4 from 7 no effect	4 from 6 no effect
WRR with manure	6 from 9 no effect	6 from 7 no effect	4 from 6 no effect
Effect of manure			
WRSR without clover	8 from 9 no effect	7 from 7 no effect	3 from 6 no effect
WRSR with clover	9 from 9 no effect	4 from 7 no effect	5 from 6 no effect
NWR	7 from 9 no effect	6 from 7 increased	6 from 6 increased
WRR without clover	4 from 9 increased	5 from 7 increased	6 from 6 increased
WRR with clover	8 from 9 no effect	5 from 7 decreased	3 from 6 increased

Table A.5. 2003 means of soil temperature (^{o}C) in treatments.

Treatment	Date							
	17-Apr	29-Apr	8-May	28-May	11-June	16-June	23-June	30-June
WRR	9.9 e†	11.4 b	10.8 d	13.3 f	15.8 f	17.0 c	23.9 e	25.2 fg
WRR and Clover	9.4 cde	10.0 a	10.5 c	13.0 cd	15.4 cd	16.3 b	21.8 cde	24.5 ef
WRR Clover and Manure	9.2 cd	9.6 a	10.5 c	12.9 cd	15.3 c	16.3 b	21.5 cde	23.5 cd
WRR and Manure	8.7 abc	9.9 a	10.5 bc	13.0 de	15.5 cd	16.6 bc	22.3 de	23.7 d
NWR	9.5 de	11.3 b	10.6 c	13.3 f	15.7 ef	17.2 d	23.6 e	25.4 g
NWR and Manure	8.6 ab	9.7 a	10.3 a	13.1 ef	15.5 cd	16.6 bc	22.3 de	24.5 ef
WRSR	8.7 ab	9.5 a	10.4 ab	12.6 a	14.9 b	15.6 a	21.2 bc	22.4 b
WRSR and Clover	8.8 abc	9.5 a	10.4 ab	12.7 ab	15.1 b	15.6 a	20.5 ab	22.9 bc
WRSR Clover and Manure	8.5 ab	9.5 a	10.4 abc	12.8 ab	15.0 b	15.9 a	20.4 ab	22.4 b
WRSR and Manure	8.4 a	9.7 a	10.4 ab	12.6 ab	14.8 a	15.6 a	20.1 a	21.7 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

Table A.5. 2003 means of soil temperature (^{o}C) in treatments.

Treatment	Date							
	17-Apr	29-Apr	8-May	28-May	11-June	16-June	23-June	30-June
WRR	9.9 e†	11.4 b	10.8 d	13.3 f	15.8 f	17.0 c	23.9 e	25.2 fg
WRR and Clover	9.4 cde	10.0 a	10.5 c	13.0 cd	15.4 cd	16.3 b	21.8 cde	24.5 ef
WRR Clover and Manure	9.2 cd	9.6 a	10.5 c	12.9 cd	15.3 c	16.3 b	21.5 cde	23.5 cd
WRR and Manure	8.7 abc	9.9 a	10.5 bc	13.0 de	15.5 cd	16.6 bc	22.3 de	23.7 d
NWR	9.5 de	11.3 b	10.6 c	13.3 f	15.7 ef	17.2 d	23.6 e	25.4 g
NWR and Manure	8.6 ab	9.7 a	10.3 a	13.1 ef	15.5 cd	16.6 bc	22.3 de	24.5 ef
WRSR	8.7 ab	9.5 a	10.4 ab	12.6 a	14.9 b	15.6 a	21.2 bc	22.4 b
WRSR and Clover	8.8 abc	9.5 a	10.4 ab	12.7 ab	15.1 b	15.6 a	20.5 ab	22.9 bc
WRSR Clover and Manure	8.5 ab	9.5 a	10.4 abc	12.8 ab	15.0 b	15.9 a	20.4 ab	22.4 b
WRSR and Manure	8.4 a	9.7 a	10.4 ab	12.6 ab	14.8 a	15.6 a	20.1 a	21.7 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

Table A.7. 2005 means of soil temperature (^{o}C) in treatments.

Treatment	18-Apr	29-Apr	5-May	10-May	18-May	26-May
WRR	19.9 e†	11.6 d	15.3 e	16.4 e	17.3 f	17.9 e
WRR and Clover	15.9 d	8.7 b	10.8 bc	11.5 bcd	13.6 b	14.0 ab
WRR Clover and Manure	13.3 b	8.3 ab	9.9 ab	10.9 ab	14.5 cd	14.4 bc
WRR and Manure	14.9 c	9.8 c	11.4 cd	12.1 cd	15.1 de	15.5 d
NWR	21.6 f	12.7 e	16.8 f	17.2 e	18.7 g	19.4 f
NWR and Manure	16.1 d	9.7 c	11.6 cd	12.2 cde	15.3 e	15.9 d
WRSR	16.1 d	9.9 c	11.7 d	12.4 d	15.2 de	15.5 d
WRSR and Clover	14.1 bc	8.5 b	10.4 b	11.3 abc	14.3 b	14.1 abc
WRSR Clover and Manure	12.1 a	7.9 a	9.3 a	10.4 a	12.7 a	13.5 a
WRSR and Manure	13.2 b	8.6 b	10.2 b	10.8 ab	13.6 b	14.7 c

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)

Table A 8. Effect of treatments on height of corn (m) during 2003-2005 growing seasons.

Treatment	2003			2004			2005		
	9-July	15-July	22-July	20-July	28-July	8-Aug.	20-June	27-June	5-July
WRR	1.14 b†	1.50 b	1.86 ab	0.91 de	1.41 de	2.00 a	0.72 d	0.90 d	1.29 b
WRR and Clover	0.98 ab	1.35 a	1.83 a	0.81 bc	1.19 bc	1.90 a	0.49 b	0.66 ab	1.09 a
WRR Clover and Manure	1.05 ab	1.38 ab	1.81 a	0.79 bc	1.23 bcd	1.98 a	0.50 bc	0.77 c	1.11 a
WRR and Manure	1.19 bc	1.54 b	1.96 abc	0.82 cd	1.33 cde	1.99 a	0.58 c	0.88 d	1.31 b
NWR	1.36 c	1.75 c	2.17 c	0.95 e	1.43 e	1.96 a	0.85 e	1.17 f	1.55 c
NWR and Manure	1.40 c	1.77 c	2.13 bc	0.82 cd	1.33 cd	1.95 a	0.73 de	1.02 e	1.52 c
WRSR	1.03 ab	1.40 ab	1.85 a	0.67 a	0.98 a	1.84 a	0.55 c	0.76 c	1.11 a
WRSR and Clover	0.93 a	1.28 a	1.72 a	0.71 ab	1.11 ab	1.92 a	0.44 b	0.65 ab	1.09 a
WRSR Clover and Manure	1.06 ab	1.45 ab	1.87 ab	0.71 ab	1.07 ab	1.90 a	0.35 a	0.61 a	1.02 a
WRSR and Manure	0.99 ab	1.36 ab	1.76 a	0.65 a	0.68 a	1.81 a	0.45 b	0.71 bc	1.12 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, P<0.05)

Table A 9. Effect of the treatments on the amount of chlorophyll in corn leaves observed during 2004 and 2005 growing seasons.

Treatment	2004				2005		
	8-July	15-July	26-July	2-Aug	21-June	28-June	5-July
WRR	40.4 ef†	42.2 cd	43.3 def	46.4 a	38.6 cd	37.4 b	45.6 a
WRR and Clover	39.6 def	41.8 bcd	41.9 de	45.2 a	35.7 bc	41.8 bcd	46.9 a
WRR Clover and Manure	38.0 cdef	41.0 bc	41.2 cd	46.6 a	37.3 bc	43.9 cd	48.9 a
WRR and Manure	37.6 cde	41.4 bc	41.7 de	46.6 a	38.7 cd	44.7 de	48.7 a
NWR	42.0 f	45.2 d	44.9 f	45.3 a	43.6 d	45.5 de	47.2 a
NWR and Manure	39.8 de	41.3 bc	42.2 de	46.7 a	43.3 d	47.6 e	48.9 a
WRSR	33.3 ab	36.9 a	37.8 a	46.0 a	32.3 ab	32.4 a	46.6 a
WRSR and Clover	35.6 bcd	38.8 abc	41.8 de	47.8 a	30.2 a	38.9 bc	47.6 a
WRSR Clover and Manure	33.9 abc	38.4 ab	40.1 bcd	46.2 a	34.0 abc	44.9 de	49.7 a
WRSR and Manure	30.2 a	35.5 a	36.4 a	45.9 a	33.3 ab	44.1 cde	47.9 a

†-Means within each column followed by the same letter are not significantly different (Fisher protected LSD, $P<0.05$)