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Corn stubble height and residue placement in the northern US Corn Belt II. Spring microclimate and wheat development

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Abstract

Crop residue management systems are yet needed in the northern Corn Belt of the USA that hasten sowing and early establishment of crops in the spring. This study was conducted to investigate the effect of corn stubble height and residue placement on the soil microclimate and associated development of wheat in early spring. Treatments were established after corn harvest in the autumn of 1993–1995 and included 60 cm stubble, 30 cm stubble, 30 cm stubble with adjacent interrows devoid of and covered with prostrate residue (30 cm stubble with banded residue), 0 cm stubble, and 0 cm stubble without prostrate residue. Five rows of wheat were sown by hand into one corn interrow on 12 April 1994, 3 April 1995, and 24 April 1996. Leaf development on the main stem was assessed twice weekly until late May. Net and reflected global radiation, soil temperature, and soil water content were measured in each treatment throughout the spring. Vegetative development of wheat was hastened in soils with little residue cover (0 cm stubble without residue treatment and the bare interrow of the 30 cm with banded residue treatment). Averaged across years, the phyllochron ranged from 75 °C day per leaf for treatments with little residue cover to 92 °C day per leaf for the residue interrow of the 30 cm stubble with banded residue treatment. Vegetative development in treatments with little residue cover was hastened by soil temperatures that were at least 1 °C higher throughout spring than those of the residue interrow of the 30 cm stubble with banded residue treatment. The 0 cm stubble without residue treatment was warmer because of a smaller albedo (at least 0.03) and greater net radiation (at least 0.5 MJ m^{-2} per day) compared with all other treatments. Little difference in soil water content was found among treatments, although treatments with little residue cover were wetter in two of the three springs. Based on the results of this study, one can conclude that soils with little residue cover or that have taller stubble on the surface will absorb more radiation and thereby enhance soil warming and early development of plants in the northern Corn Belt of the USA. Published by Elsevier Science B.V.

Keywords: Soil temperature; Albedo; Radiation; Thermal time; Haun stage; Phyllochron

1. Introduction

Management of crop residue following harvest in autumn can impact runoff and soil erosion during snowmelt and spring thaw in cold regions. Runoff and erosion during spring thaw in the northern Corn Belt of the USA, for example, were, respectively, reduced by 20 and 70% when corn residue was retained on rather than removed from the soil surface prior to autumn tillage (Sharratt et al., 2000). In addition, soil loss during spring snowmelt on the Canadian prairies was reduced by 50% when crop stubble was maintained on rather than removed

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from the soil surface during winter (Chanasyk and Woytowich, 1987).

Crop residue management systems that are sustainable must both protect the soil and water resource as well as optimize the soil microclimate for establishment of crops in spring. Establishment of crops in early spring is critical to the viability of the farming system in cold regions. In the northern Corn Belt, corn is typically sown after the soil profile has completely thawed, which occurs in late April or early May (Sharratt, 2002). Buaha et al. (1995) and Lauer (1996), however, found that corn yield is reduced by as much as 2% per day as sowing is delayed beyond about 1 May in Wisconsin and Minnesota. A limited opportunity, therefore, exists to sow corn after complete thaw without affecting yield.

The microclimate of soil in spring is affected by the presence of crop residue on the soil surface. Crop residue influences the transmission of radiation, heat, and water between the soil surface and atmosphere (Bristow et al., 1986). The transmission of radiation, heat, and water is generally dampened between the soil and atmosphere with an increase in the percent cover and amount of crop residue that lay on the soil surface. Managing residue to maximize soil warming and drying is especially challenging in the northern Corn Belt where cold and wet soils can delay sowing and early plant growth (Gupta et al., 1990).

Despite the importance of crop residue in altering the soil microclimate, more information is needed concerning the impact of corn residue management on soil warming and drying during the spring in the northern US Corn Belt. The height of crop stubble can influence the soil microclimate. Cutforth and McConkey (1997) found that global radiation, wind speed, and evaporative flux at the soil surface could be modified by the height of wheat stubble on the Canadian prairies. In addition, Sharratt and Flerchinger (1995) found that barley stubble height affected the rapidity of soil thawing and drying in the spring in the sub-arctic more so than altering other residue physical characteristics. In the northern Corn Belt, Sharratt (2002) found that winter snow cover was modified by corn stubble height. He found that enhanced snow cover on soils with taller stubble reduced frost penetration and hastened thawing of the profile during the spring. Therefore, differences in the winter microclimate will likely influence soil water and temperature at the time of sowing in the spring.

Crop residue management systems are yet needed in the northern US Corn Belt that hasten sowing and early establishment of crops in the spring. Corn stubble height can be altered at the time of harvest in the autumn and may be a strategy for enhancing soil warming and drying in the spring. The purpose of this study was to assess the effect of corn stubble height and residue placement in the autumn on the soil microclimate and associated development of wheat in the early spring in the northern Corn Belt.

2. Materials and methods

This study was conducted to assess the soil microclimate in early spring of various corn residue management treatments near Morris, MN (45°N, 95°W). Morris is located at the northern edge of the US Corn Belt where corn (*Zea mays* L.) is grown continuously or in rotation with wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr.). The study site is typified by a sub-humid climate with a mean annual air temperature of 5.5 °C and annual precipitation of 600 mm. The experimental procedure has been discussed in greater detail in a previous paper (Sharratt, 2002).

2.1. Experimental design

Treatments were established in triplicate in the autumn of 1993 through 1995 on a Barnes loam (Haploboroll in the USDA classification and Chernozem in the FAO classification). Corn was sown in 76 cm rows in the spring and harvested in the autumn using a combine that cut corn stalks at 60 cm above the soil surface. The combine was equipped with a straw chopper that chopped and uniformly spread the harvested residue onto the soil surface. Corn residue treatments were then established after harvest and included: (1) *60 cm stubble*. This treatment remained unaltered following harvest and was characterized by 60 cm tall stubble with residue that lay prostrate on the soil surface; (2) *30 cm stubble*. Corn stalks that remained standing after harvest were cut 30 cm above the soil surface using a combine; (3) *30 cm stubble with banded residue*. Similar to the 30 cm stubble treatment, except that loose residue that lay prostrate on the soil surface of alternating interrows was placed into adjacent interrows. Adjacent interrows were, therefore, devoid of (bare) and covered with residue; (4) *0 cm stubble*. Corn stalks that remained standing after harvest were cut near the soil surface using a combine; (5) *0 cm stubble without residue*. Similar to the 0 cm stubble treatment, except that all residue was removed from the soil surface by raking.

Corn residue characteristics were assessed in the spring following snowmelt (Sharratt, 2002). Averaged across years, stubble height was 57 cm for the 60 cm stubble treatment, 30 cm for the 30 cm stubble treatments, and 8 cm for the 0 cm stubble treatments. Percent residue cover was about 85 for the 60, 30, and 0 cm stubble treatments, 70 for the 30 cm stubble with banded residue treatment, and 30 for the 0 cm stubble without residue treatment. Total biomass of corn stubble and residue was 980 g m^{-2} on all treatments except the 0 cm stubble without residue treatment. Biomass of the latter treatment was about 100 g m^{-2}.

2.2. Development of spring wheat and soil microclimate

Wheat (Pioneer 2375) was sown by hand in the spring after the soil thawed and dried sufficiently to support foot traffic. Wheat was sown on 12 April 1994, 3 April 1995, and 24 April 1996. At the time of sowing, the soil profile on the 30 and 60 cm stubble treatments was completely thawed. On these dates, however, the soil was frozen below 30 cm on the 0 cm stubble treatments. Those treatments with residue that lay prostrate on the soil surface necessitated removing corn residue from one interrow to facilitate the planting of wheat. One interrow was sown to wheat in each plot; however, two adjacent interrows were sown to wheat in the 30 cm stubble with banded residue treatment. Two seeds were dropped into 10 mm deep holes (created using a 5 mm diameter stainless steel tube) after which the holes were filled with air dry soil. Holes were located every 50 mm along a 1 m long row. Wheat row spacing was 0.18 m with five rows of wheat sown within one interrow. Corn residue was returned to those interrows that necessitated removal of the residue for sowing. After emergence, wheat was thinned to one seedling per hole to achieve an equivalent plant population of 1.1×10^6 plants ha^{-1}. Wheat was then fertilized by hand at a rate of 100 kg N ha^{-1}. Twenty plants in each plot were identified and monitored twice weekly for development of leaves on the main stem using the Haun scale (Haun, 1973). The Haun scale represents the number of fully expanded leaves plus the ratio of the length of the elongating leaf to that of the previous leaf. Wheat development was assessed until late May, at this time the apex of the main stem was near or had emerged from the soil surface. Thereafter, development of small grains is less dependent of soil temperature (Hay, 1978).

The soil microclimate of corn residue treatments was assessed throughout the early spring. Soil water was measured thrice weekly by neutron attenuation and time domain reflectometry (TDR). Soil water was assessed at 0.3 m depth intervals to 2.1 m in all plots using a neutron probe. In addition, soil water was measured at depths of 0.15 and 0.5 m in one replication by TDR. Net and reflected global radiation and soil temperature were measured every 60 s and data recorded hourly by a data logger. A net radiometer (measures the difference between incoming and outgoing all wave radiation) and pyranometer were suspended from a boom mounted 1 m above the soil surface in one replication of each treatment. The pyranometers were inverted to assess reflected global radiation. Radiometers were field-calibrated each year; radiometric comparisons were made with new factory-calibrated sensors over a uniform soil surface for several days following the study. Soil temperatures were measured in all plots with thermocouples installed at depths of 0, 0.01, 0.05, and 0.10 m below the soil surface. A thin layer of soil was sprinkled on the thermocouples located on the soil surface. Three thermocouples were wired in parallel for acquiring a spatially-averaged temperature at each depth. Air temperature, global radiation, wind speed, and precipitation were measured at the experimental site.

Thermal time was computed as the cumulative difference between the daily temperature and base temperature (0 °C in this study) from the time of planting or over some specified time interval. Daily temperature was determined by averaging hourly air or soil temperature data. Air temperatures were used in the thermal time computation to assess wheat development. Soil temperatures were used in the computation for characterizing the soil thermal regime.

Wheat development and microclimate were compared among residue treatments using an analysis of variance (Gomez and Gomez, 1984). In the event that treatment effects were significant ($P \leq 0.1$), means were compared using least significant difference.

3. Results and discussion

The spring (April–May) of 1994 was generally warmer and wetter than normal. Air temperatures in May were more than 2 °C higher than the 100 year average of 13 °C, while precipitation in April was 8.5 cm above the average of 5.5 cm. The spring of 1995 was cooler than normal (average daily air temperature in April was 3 °C below normal), while the spring of 1996 was cooler and drier than normal. In April 1996, air temperatures were 3 °C below the 100 year average of 6 °C and precipitation was 4 cm below the 100 year average. The spring of 1995 was cloudy compared with the previous or following spring; insolation in successive years beginning in 1994 was 18.1, 12.4, and 16.6 MJ m^{-2} per day.

3.1. Development of spring wheat

Early development of wheat is largely dependent on the thermal regime of the soil. Soil water and global radiation, however, also influence wheat growth and development (Ritchie, 1991). Therefore, in this study, the development of wheat was assessed to differentiate the integrated microclimate of corn residue treatments. In all years, vegetative development of wheat was hastened in soils with little residue cover (0 cm stubble without residue treatment and the bare interrow of the 30 cm stubble with banded residue treatment). At the time of or near tillering, for example, wheat grown in soils with little residue cover had at least 0.6 more leaves than wheat grown in the residue interrow of the 30 cm stubble with banded residue treatment and at least 0.3 more leaves than wheat grown in the 0 cm stubble and 30 cm stubble treatments (Table 1). In addition, vegetative development of wheat in most years was hastened in soils with little residue cover as compared with wheat grown in 60 cm stubble. Wheat development was similar for the 0, 30, and 60 cm stubble treatments during all years, except in 1995 when wheat development was accelerated by the 60 cm stubble treatment as compared with the 0 cm stubble treatment.

Table 1
Main stem Haun stage of spring wheat (near tillering) grown under various corn residue treatments during the spring of 1994–1996 near Morris, MN

Residue treatment	Haun stage[a]		
	1994	1995	1996
0 cm stubble, no residue	3.3	3.6	3.5
0 cm stubble	2.8	3.0	2.8
30 cm stubble	2.6	3.2	2.8
30 cm stubble, band			
Residue interrow	2.7	2.9	2.6
Bare interrow	3.4	3.9	3.6
60 cm stubble	2.8	3.5	2.8
LSD ($P \leq 0.10$)	0.4	0.4	0.2

[a] Planted on 12 April, 3 April, and 24 April; staged on 13 May, 19 May, and 23 May in successive years using the Haun scale (Haun, 1973).

The rapid development of wheat in soils with little residue cover (0 cm stubble without residue treatment and bare interrow of the 30 cm stubble with banded residue treatment) is illustrated by the data in Fig. 1. Slope estimates of the relationship between Haun stage and thermal time from planting were greater for soils with little residue cover than for the residue interrow of the 30 cm stubble with banded residue treatment in all years (Table 2). These slope estimates suggested that, at the projected time of the appearance of the sixth leaf in soils with little residue cover, wheat in the residue interrow of the 30 cm stubble with banded residue treatment lagged one leaf behind in development. Differences in development beyond the six leaf stage would not be entirely related to soil temperature, but influenced by air temperature as the main stem apex emerges from the soil (Hay, 1978).

The phyllochron (thermal time required between elongation of successive main stem leaves) of wheat grown in all treatments increased during successive years. Averaged across treatments, the phyllochron was 77, 81, and 90 °C day per leaf in succeeding years. The lengthening of the phyllochron did not correspond with progressively warmer springs across years; the phyllochron typically increases with air temperature (Cao and Moss, 1989). Sharratt (1999), however, found that larger temperature contrasts between emergence and vegetative development can result in larger

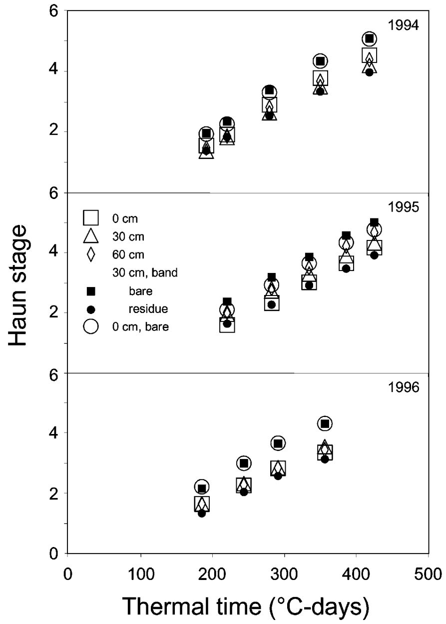

Fig. 1. Haun stage of leaves on the main stem of wheat as a function of thermal time from planting. Wheat was grown in soil having variable height corn stubble (0, 30, and 60 cm) and with and without (bare) prostrate residue on the surface during the spring of 1994–1996 near Morris, MN.

phyllochrons of field-grown small grains. Indeed, air temperatures from sowing to emergence (sowing to emergence required about 13 days in 1994, 28 days in 1995, and 16 days in 1996) averaged 9.5, 3.5 and 6.5 °C, while temperatures from emergence to Haun stage 4.0 averaged 9.5, 12.0, and 13.5 °C during successive years. The mean air temperature from sowing to Haun stage 4.0 was 9.5, 7.0, and 10.0 °C in subsequent years. Thus, the lengthening of the phyllochron across years in this study was because of higher temperatures from sowing to Haun stage 4.0 as well as to larger temperature contrasts between emergence and vegetative development.

The phyllochron of wheat grown in the residue interrow of the 30 cm stubble with banded residue treatment was greater than wheat grown in soils with little residue cover. Averaged across years, the thermal time required for the elongation of one leaf was 92 °C day for wheat grown in the residue interrow of the 30 cm stubble with banded residue treatment and 75 °C day for wheat grown in soils with little residue cover.

3.2. Soil microclimate

3.2.1. Soil temperature

Hastening of development in treatments with little residue cover (0 cm stubble without residue treatment and bare interrow of the 30 cm stubble with banded residue treatment) was in part due to higher soil temperatures. This is exemplified by the differences in soil temperature on clear days each spring (Fig. 2). Daytime soil temperatures were highest for soils with little residue cover and lowest for the residue interrow of the 30 cm stubble with banded residue treatment. For those clear days illustrated in Fig. 2, the range in daytime temperatures near the soil surface among treatments exceeded 5 °C on 15 April 1994, 7 °C on

Table 2
Slope estimates of the relationship between Haun stage and thermal time for spring wheat grown under various corn residue treatments during the spring of 1994–1996 near Morris, MN

Residue treatment	Slope estimate[a,b]		
	1994 (leaf °C per day)	1995 (leaf °C per day)	1996 (leaf °C per day)
0 cm stubble, no residue	0.0144 ab	0.0133 ab	0.0123 ab
0 cm stubble	0.0132 bc	0.0126 bc	0.0102 c
30 cm stubble	0.0124 bc	0.0115 bc	0.0112 bc
30 cm stubble, band			
Residue interrow	0.0113 c	0.0111 c	0.0103 c
Bare interrow	0.0141 ab	0.0130 ab	0.0126 ab
60 cm stubble	0.0128 bc	0.0131 bc	0.0106 bc

[a] Based on data presented in Fig. 1.
[b] Means followed by the same letter are not significantly different at $P \leq 0.10$.

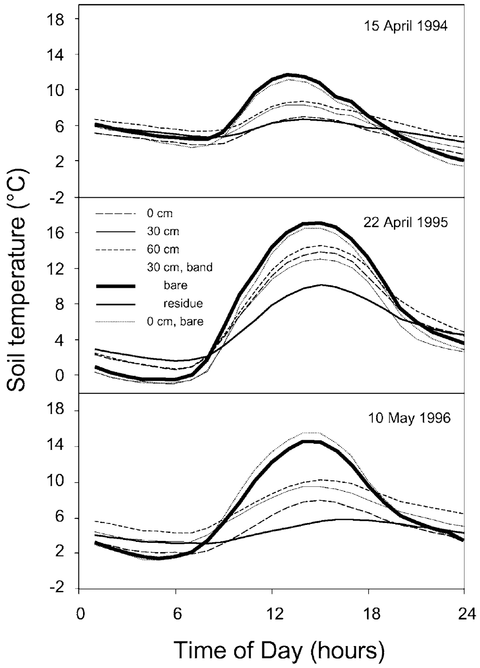

Fig. 2. Temperature at 1 cm depth in a soil having variable height corn stubble (0, 30, and 60 cm) and with and without (bare) prostrate residue on the surface. Data were collected on a clear day each spring from 1994 to 1996 near Morris, MN.

22 April 1995, and 10 °C on 10 May 1996. Differences in nighttime soil temperatures were not consistent among treatments, although temperatures were often highest for the 60 cm stubble treatment (Fig. 2). Thus, on clear days, the lower daytime and higher nighttime temperature of soils with 60 cm stubble resulted in similar daily temperatures as compared with soils with little residue cover.

Differences in soil thermal time were also observed among treatments during spring thaw and early season warming (15 April–10 May). These dates correspond to the ablation of snow cover and initiation of irreversible thawing of the soil profile by mid-April (Sharratt, 2002), while sowing in the northern Corn Belt typically occurs in early May. Thermal time generally increased with an increase in stubble height or decrease in residue cover (Table 3). Thermal time was smallest for soil in the residue interrow of the 30 cm stubble with banded residue treatment, except during the spring of 1994 and 1995 when thermal time of soil in the 0 cm stubble treatment equaled that of the residue interrow. Thermal time was greatest for soils with little residue cover or for soil in the 60 cm stubble treatment. The 0 cm stubble without residue and 60 cm stubble treatments, however, were not consistently the warmest across years. Across all years, thermal time was greater for soils with little residue cover and in the 60 cm stubble treatment than for soils in the 0 cm stubble treatment and in the residue interrow of the 30 cm stubble with banded residue treatment.

Table 3
Soil thermal time for various corn residue treatments from 15 April to 10 May of 1994–1996 near Morris, MN

Treatment	Thermal time[a,c]		
	1994 (°C day)	1995[b] (°C day)	1996[b] (°C day)
0 cm stubble, no residue	207 d	198 c	145 c
0 cm stubble	173 ab	175 a	85 b
30 cm stubble	180 bc	191 b	101 b
30 cm stubble, band			
Residue interrow	167 a	175 a	64 a
Bare interrow	213 d	205 d	146 c
60 cm stubble	185 c	201 cd	144 c

[a] Thermal time at 1 cm depth.
[b] Missing 15–20 April 1995 and 15–22 April 1996.
[c] Means followed by the same letter are not significantly different at $P \leq 0.10$.

3.2.2. Radiation

Soil temperature differences were largely governed by differences in radiation characteristics among residue treatments. This is exemplified by radiation characteristics of treatments on clear days during spring (Fig. 3). Net radiation during the daytime was highest for the 0 cm stubble without residue treatment and declined with 30 cm stubble with banded residue > 60 cm stubble > 30 cm stubble > 0 cm stubble treatment. For those clear days illustrated in Fig. 3, the range in net radiation among treatments at mid-day exceeded 55 W m^{-2} on 15 April 1994, 50 W m^{-2} on 22 April 1995, and 80 W m^{-2} on 10 May 1996. Little difference in net radiation among treatments was observed during the nighttime. The results from this study compare favorably with those of Aase and Siddoway (1980), who found that taller wheat stubble enhanced radiation absorption at mid-day on clear days, while stubble height had little affect on net radiation at night. Aase and Siddoway (1980), how-

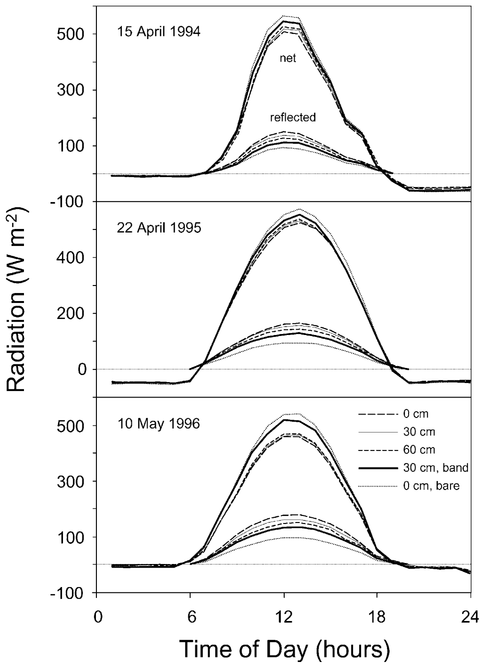

Fig. 3. Net and reflected global radiation over a soil having variable height corn stubble (0, 30, and 60 cm) and with and without (bare) prostrate residue on the surface. Data were collected on a clear day each spring from 1994 to 1996 near Morris, MN.

ever, found that soils having no residue cover absorbed less radiation during the daytime as compared with soils covered with stubble. They also reported little contrast in the albedo of soils with and without stubble. In this study, soils with little residue cover are likely to absorb more radiation than soils with residue cover because of the high contrast in reflectivity between soils with and without residue cover. Reflected global radiation was lowest for the 0 cm stubble without residue treatment and increased with 30 cm stubble with banded residue < 60 cm stubble < 30 cm stubble < 0 cm stubble (Fig. 3). For those clear days illustrated in Fig. 3, the range in reflected global radiation among treatments at mid-day was about 55 W m^{-2} on 15 April 1994, 70 W m^{-2} on 22 April 1995, and 80 W m^{-2} on 10 May 1996.

Seasonal net radiation generally increased with an increase in stubble height or decrease in residue cover (Table 4). Although differences in net radiation were small among the 0, 30, and 60 stubble treatments, net radiation for these treatments increased with stubble height during most years. In addition, net radiation for the 0 cm stubble without residue treatment exceeded that of all other treatments each spring. The greater absorption of radiation by soils with taller stubble or lower residue cover was due in part to the lower reflectivity of these treatments. For example, in all years, the amount of global radiation reflected by the surface was lowest for the 0 cm stubble without residue treatment (Table 4). Reflection of global radiation then increased with the 30 cm stubble with banded residue treatment < 60 cm stubble treatment < 30 cm stubble treatment < 0 cm stubble treatment. Albedo (fraction of incoming global radiation reflected from the surface) of treatments varied little across years and averaged 0.11 for the 0 cm stubble without residue treatment, 0.14 for the 30 cm stubble with banded residue treatment, 0.17 for the 60 cm stubble treatment, 0.18 for the 30 cm stubble treatment, and 0.19 for the 30 cm stubble treatment.

Longwave radiation emitted from the surface (determined from net and reflected radiation characteristics) was greater for the 0 cm stubble without residue or 30 cm stubble with banded residue treatments. Emitted longwave radiation was least for the

Table 4
Net and reflected-global radiation for various corn residue treatments from 15 April to 10 May of 1994–1996 near Morris, MN

Treatment	Net radiation			Reflected radiation		
	1994 (MJ m^{-2} per day)	1995 (MJ m^{-2} per day)	1996 (MJ m^{-2} per day)	1994 (MJ m^{-2} per day)	1995 (MJ m^{-2} per day)	1996 (MJ m^{-2} per day)
0 cm stubble, no residue	8.3	7.6	8.0	2.1	1.3	1.7
0 cm stubble	7.6	6.9	6.9	3.3	2.4	3.2
30 cm stubble	7.7	7.0	7.0	3.2	2.4	3.1
30 cm stubble, band	8.0	7.0	7.6	2.8	2.0	2.4
60 cm stubble	7.8	7.0	7.1	2.9	2.2	2.9

0 cm stubble treatment across all years. In 1994, differences in emitted longwave radiation of 0.6 MJ m^{-2} per day between the 0 cm stubble treatments indicated a 1.5 °C variation in surface temperatures. This difference corresponds closely with the difference in 1 cm soil temperatures between these two treatments (data in Table 3 indicate a temperature difference of 1.3 °C). In 1995, a difference in emitted longwave radiation of 0.4 MJ m^{-2} per day between the 30 cm stubble with banded residue treatment and 0 cm stubble treatment (the contrast in emitted longwave radiation among treatments was greatest between these two treatments) indicated a 1.3 °C variation in surface temperatures. The magnitude of this difference in surface temperature was not observed at the 1 cm depth; the observed difference in soil temperature between these two treatments was 0.8 °C. In 1996, differences in emitted longwave radiation of 0.3 MJ m^{-2} per day between the 0 cm stubble treatments indicated a 0.8 °C variation in surface temperatures. The observed difference in soil temperature at the 1 cm depth was nearly 3.5 °C between these two treatments.

3.2.3. *Soil water*

Soils were typically wetter during 1995 as compared with the previous and following spring. Although the spring of 1994 was wetter than the spring of 1995, evaporative losses may have been larger during the spring of 1994 because of higher air temperatures and greater insolation. Air temperatures during April and May 1994 were nearly 3 °C higher than during 1995. Although air temperatures were similar during the spring of 1995 and 1996, the spring of 1995 was cloudier and wetter than 1996.

Small differences in soil water content during the spring were found among the corn residue treatments (Fig. 4). These differences, observed at a depth of 15 cm by TDR, were neither persistent throughout the spring nor across years. For example, during May 1994, soil with 60 cm stubble was wetter than soil in the 0 cm stubble without residue treatment. From mid-April to mid-May 1995, the 0 cm stubble without residue treatment was wetter than the 30 cm stubble and 60 cm stubble treatments. In 1996, differential thawing of treatments was apparent from changes in liquid water content measured by TDR. Liquid soil water content in the bare interrow of the 30 cm stubble

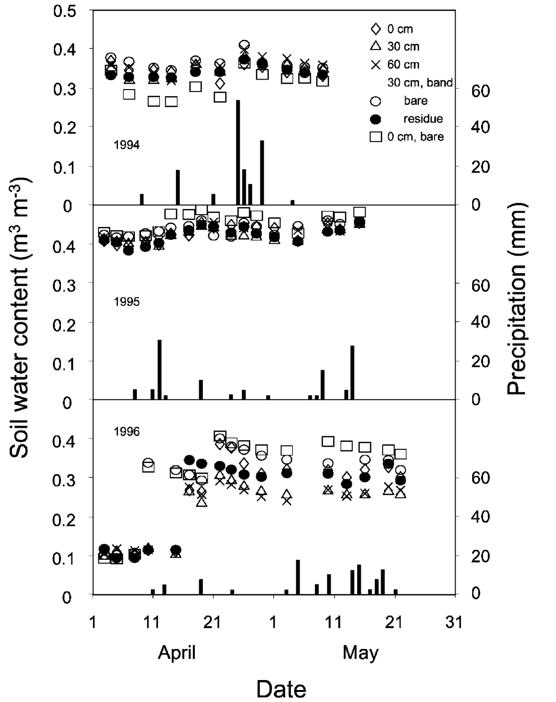

Fig. 4. Water content at 15 cm depth in a soil having variable height corn stubble (0, 30, and 60 cm) and with and without (bare) prostrate residue on the surface. Water content was measured by TDR each spring from 1994 to 1996 near Morris, MN. Daily precipitation noted by the vertical bars.

with banded residue treatment and 0 cm stubble without residue treatment increased from about 0.10 m^3 m^{-3} on 8 April to 0.33 m^3 m^{-3} on 10 April. Thaw at the 15 cm depth was not apparent in the other treatments until after 15 April. After thaw, soils with little residue cover were generally wetter than soils with residue cover.

4. Conclusions

Managing corn residue following harvest in the autumn in the northern US Corn Belt can dramatically affect the winter and spring soil microclimate as well as development of crops during the early spring. Soils with little prostrate residue on the surface favored rapid plant development because of higher daytime soil temperatures during spring. In addition, soils with tall stubble favored more rapid plant development than soils with short stubble. Temperatures of soil with little prostrate residue or taller stubble on the surface were elevated as a result of a smaller albedo and greater radiation absorption as compared with soils with residue cover or shorter stubble. Corn residue management influenced early season soil water content, although differences among treatments were not consistent across years. Soils with little residue cover were wetter than soils with residue cover during two of the 3 years of this study.

References

Aase, J.K., Siddoway, F.H., 1980. Stubble height effects on seasonal microclimate, water balance, and plant development of no-till winter wheat. Agric. Meteorol. 21, 1–20.

Bristow, K.L., Campbell, G.S., Papendick, R.I., Elliott, L.F., 1986. Simulation of heat and moisture transfer through a surface residue-soil system. Agric. For. Meteorol. 36, 193–214.

Buaha, G.T., Apland, J., Hicks, D., 1995. A regression analysis of the effects of planting date and variety on corn yields in Minnesota. Department of Applied Economics Staff Paper P95-10, University of Minnesota, 17 pp.

Cao, W., Moss, D.N., 1989. Temperature and daylength interaction on phyllochron in wheat and barley. Crop Sci. 29, 1046–1048.

Chanasyk, D.S., Woytowich, C.P., 1987. Sediment yield as a result of snowmelt runoff in the peace river region. Can. Agric. Eng. 29, 1–6.

Cutforth, H.W., McConkey, B.G., 1997. Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semiarid climate on the Canadian prairies. Can. J. Plant Sci. 77, 359–366.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. Wiley, New York.

Gupta, S.C., Radke, J.K., Swan, J.B., Moncrief, J.F., 1990. Predicting soil temperatures under a ridge-furrow system in the US Corn Belt. Soil Till. Res. 18, 145–165.

Haun, J.R., 1973. Visual quantification of wheat development. Agron. J. 65, 116–119.

Hay, R.K.M., 1978. Seasonal changes in the position of the shoot apex of winter wheat and spring barley in relation to the soil surface. J. Agric. Sci. Camb. 91, 245–248.

Lauer, J.G., 1996. Optimum corn planting dates. Wisconsin Crop Manager 3 (6), 42–43.

Ritchie, J.T., 1991. Wheat phasic development. In: Hanks, J., Ritchie, J.T. (Eds.), Modeling Plant and Soil Systems. ASA Monograph 31. American Society of Agronomy, Madison, WI, pp. 31–54.

Sharratt, B.S., 1999. Thermal requirements for barley maturation and leaf development in interior Alaska. Field Crops Res. 63, 179–184.

Sharratt, B.S., 2002. Corn residue height and placement in the northern US Corn Belt. I. Soil physical environment during winter. Soil Till. Res. 64, 243–252.

Sharratt, B.S., Flerchinger, G.N., 1995. Straw color for altering soil temperature and heat flux in the subarctic. Agron. J. 87, 814–819.

Sharratt, B.S., Lindstrom, M.J., Benoit, G.R., Young, R.A., Wilts, A., 2000. Runoff and soil erosion during spring thaw in the northern US Corn Belt. J. Soil Water Conserv. 55, 487–494.