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INFLUENCE OF WATER AND NITROGEN LEVELS ON CANOPY TEMPERATURES OF WINTER WHEAT GROWN IN THE NORTH AMERICAN GREAT PLAINS*,**

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ABSTRACT

Blad, B.L., Bauer, A., Hatfield, J.L., Kanemasu, E.T., Major, D.J., Reginato, R.J. and Hubbard, K.J., 1988. Influence of water and nitrogen levels on canopy temperatures of winter wheat grown in the North American Great Plains. Agric. For. Meteorol., 44: 159–173.

Canopy temperatures of winter wheat were measured with infrared thermometers in 1985 and 1986 at five locations in the North American Great Plains. These measurements were made to determine the occurrence and severity of water stress resulting from different water treatments

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and to evaluate the influence of nitrogen (N) fertilization on canopy temperatures. Study results suggest that water stress occurred at locations in the northern and southern Great Plains in both 1985 and 1986, but not at the mid-Plains locations. The influence of N fertilization on canopy temperature was not consistent among locations nor even between years at the same location. At Mandan, ND, the level of N fertilization had a significant impact on the canopy temperature in both years while at Lethbridge, Canada, it had no effect in either year. At the other locations, the level of N fertilization influenced the canopy temperature in one year, but not the other. In some locations, there was an apparent cultivar effect on the canopy temperature. Colt, as indicated by canopy temperature data, did not grow as well at the northern and southern locations as it did at the mid-Plains locations. Colt was developed in the mid-Plains environment, which may explain its better performance at the mid-Plains locations.

INTRODUCTION

Transpiration is a primary mechanism for maintaining plants below injurious or lethal temperatures, thereby allowing plant biochemical reactions to proceed at a high rate. When soil water is limiting and plants become stressed, stomata partially or completely close, transpiration decreases and plant temperature increases. Jackson (1982) provided a review of the literature from the mid-19th century through about 1982 describing relationships between transpiration and leaf and canopy temperature.

Accurate hand-held infrared thermometers now available allow for routine measurements of canopy temperature. Monteith and Szeicz (1962), Tanner (1963) and Fuchs and Tanner (1966) were among the first scientists to suggest the use of infrared thermometers to measure canopy temperature. Since that early work, many articles relating canopy temperature to the plant water status of various crops have been published (e.g., see Idso et al., 1977; Jackson et al., 1977, 1981; Ehrler et al., 1978; Gardner et al., 1981, Howell et al., 1986). It has been well established that water stress causes an increase in plant temperature. The degree of stress can be related to the magnitude of the temperature increase if other environmental factors such as net radiation, vapor pressure deficit, windspeed and air temperature are taken into account.

The effect of the nutrient supply on plant temperature has not been studied extensively. Blad et al. (1980) reported that the canopy temperature of corn (*Zea mays* L.) increased by $\sim 1\,^{\circ}C$ when available nitrogen (N) was severely limiting; moderately limiting N conditions had no effect on canopy temperature. Hegde (1986) observed the canopy temperature of onions (*Allium cepa* L.) at three N levels (0, 80 and 160 kg ha^{-1}). They found that the lowest canopy temperature was coincident with the highest rate of N. However, on many days canopy temperature differences between the 80 and 160 kg N ha^{-1} levels were not significant.

Here, we address one of the project goals outlined in the first paper of this series (Reginato et al., 1988), i.e., to assess the crop condition of wheat (*Tri-*

ticum aestivum L.) utilizing measurements of emitted radiation. More specifically, the objectives of this study were: (1) to determine from canopy temperature measurements the occurrence and severity of water stress resulting from different water treatments at the five selected experimental locations in the North American Great Plains; (2) to determine the degree to which the level of N fertilization affects canopy temperatures.

MATERIALS AND METHODS

Details of the experimental design are given in Reginato et al. (1988). Hence, only a brief description of pertinent information related to canopy temperature is given here. Canopy temperatures of winter wheat were measured with hand-held infrared thermometers. A minimum of six readings were taken facing east and west at oblique angles and 12 readings were made facing south using a nadir view. (At Lethbridge, only nadir-view readings were taken in 1986.) Measurements were made between 1230 and 1430 CST, whenever possible. On certain days, measurements were made throughout the day. Data were taken only when clouds did not obscure the sun. Canopy temperature data were collected on at least two replications of each water and N treatment in 1985 and 1986 from two wheat cultivars: Colt, grown at all locations, and a locally adapted cultivar. The locations were Lubbock, TX; Manhattan, KS; Sandhills Agricultural Laboratory (SAL) near Tryon, NE; Mandan, ND; Lethbridge, Alberta, Canada. The three water treatment levels were: full irrigation, rain fed and 50% of full irrigation. The four N treatments were: ~50–60, 100, 160 and 240 kg N ha^{-1}.

RESULTS AND DISCUSSION

General observations

Data were examined to determine whether statistical differences occurred in canopy temperatures due to cultivar, water treatment or N level (Table 1). An examination of the data reveals the following:

(1) Canopy temperature differences due to cultivar were detected in 1985 at Lubbock, Mandan and Lethbridge, but not at the two mid-Plains locations, Manhattan and SAL. No differences due to cultivar were found at any location in 1986 at the 0.01 level.

(2) Plants experienced water stress at the southern and northern locations during both years, but in the mid-Plains area, only in 1985 at SAL were significant differences in canopy temperature detected for the different irrigation treatments.

(3) N level caused no effect on canopy temperature at the southern-most and northern-most locations in either year. However, there was an apparent

TABLE 1

Statistical significance of canopy temperature differences as a function of cultivar (C), water treatment (I) and nitrogen level (N) for the five North American Great Plains sites in 1985 and 1986

Site	Year	Direction	C	I	N	Comments
Lubbock	1985	Nadir	**	**		
		E	**	**		
		W	**	**		
		E-W avg.	**	**		
	1986	Nadir		**		
		E		**		
		W		**		
		E-W avg.		**		
Manhattan	1985	Nadir			*	2 days of data
		E				
		W			*	
		E-W avg.				
SAL	1985	Nadir		*		
		E		*		
		W		*		
		E-W avg.		*		
	1986	Nadir			**	
		E			**	
		W	*		**	
		E-W avg.			**	
Mandan	1985	Nadir	**	**	**	Data for rain-fed and
		E	**	*	**	full irrigation, 60 and
		W	**	**	**	160 kg N ha^{-1}
		E-W avg.	**	**	**	treatments only
	1986	Nadir		**	**	
		E		*	**	
		W		**	**	
		E-W avg.		**	**	
Lethbridge	1985	Nadir	**	**		
		E	**	**		
		W	**	**		
		E-W avg.	**	**		
	1986	Nadir		**		

*Significant at the 0.05 level of probability.**Significant at the 0.01 level of probability.

influence of N level on canopy temperature at Manhattan and Mandan in 1985, and SAL and Mandan in 1986. Data for Manhattan were unavailable in 1986.

In the sections that follow, we present information from the two experimental seasons and draw some general conclusions about the effect of irrigation and N treatment on the canopy temperatures of the two wheat cultivars grown at each location. Only a few representative figures from the large number of graphs used to analyze the data are presented.

Irrigation effects on canopy temperatures

Lubbock, TX

1985 — The canopy temperature patterns for the two cultivars show that the greatest temperature differences occurred between rain-fed and full-irrigation treatments (Fig. 1). The intermediate irrigation plots fell between the two extremes after the onset of water stress on or about Day 100. After water stress began, as evidenced by the higher temperature of the rain-fed treatment, it continued throughout the remainder of the season. Temperature differences between rain-fed and full irrigated plots were of the order of 3–8 °C. This suggests that the rain-fed plots probably suffered moderate to severe water stress.

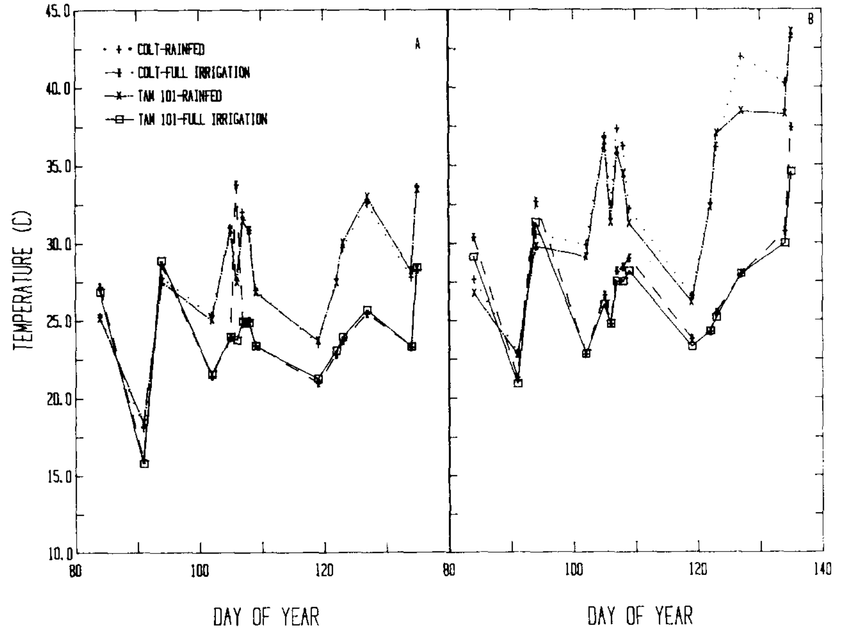

Fig. 1. Canopy temperatures of rain-fed and fully irrigated Colt and TAM 101 winter wheat cultivars at Lubbock, TX, in 1985. Data are averages of measurements made from east- and west-facing views (A) and nadir view (B).

The canopy temperature viewed from the nadir showed even greater temperature differences of 10–15 °C, due to the contribution of emitted radiation from the hot, dry soils of the rain-fed treatment (Fig. 1). Canopy temperatures viewed from nadir were always slightly warmer than those of the E–W average with maximum differences as great as 10 °C. This suggests that complete canopy cover was not achieved. No differences in canopy temperature between the two cultivars were detectable.

1986 – By the start of canopy temperature measurements on Day 105, the rain-fed plots were ~8 °C warmer than the fully irrigated plots (Fig. 2). The nadir-view temperature differences were often 10–15 °C. The rain-fed wheat continued under stress for the remainder of the season. Temperature differences between the two irrigation treatments were greater in 1986 than in 1985. Maximum temperatures measured with the E–W and nadir-view angles were also higher. This suggests that water stress conditions in Lubbock in 1986 were more severe than they had been in 1985. This conclusion is supported by the analysis of precipitation data at Lubbock by Hubbard et al. (1988). They report that precipitation was below normal in the spring and summer of 1986, but near normal in 1985. Also, as reported by Major et al. (1988), there was an infestation of Russian leaf mites at Lubbock in 1986. This infestation could have put the wheat under greater stress than can be explained by the lack of

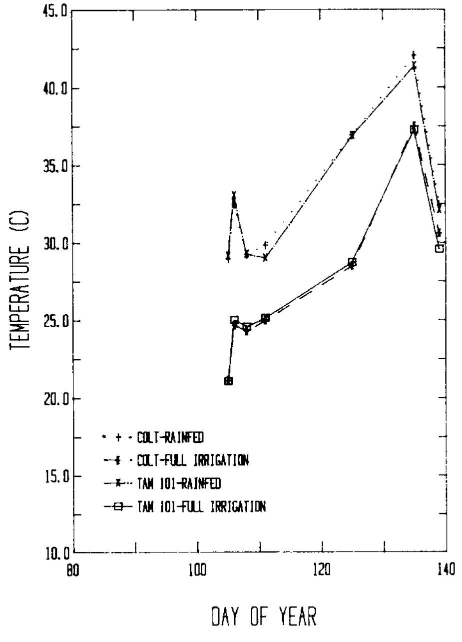

Fig. 2. Canopy temperatures of rain-fed and fully irrigated Colt and TAM 101 winter wheat cultivars at Lubbock, TX, in 1986. Data are averages of measurements made from east- and west-facing views.

soil water alone. The Colt cultivar had slightly higher temperatures than the locally adapted TAM 101 cultivar.

Manhattan, KS

1985 — The rain-fed treatments experienced only minimal water stress at Manhattan during the period of measurement, which extended from ~Day 120 to Day 140. The temperature response of the Colt and Newton cultivars under both dry land and full-irrigation treatments was almost identical and no consistent pattern of treatment differences was observed.

Sandhills Agricultural Laboratory (SAL), NE

1985 — Starting at ~Day 120, the rain-fed treatment exhibited a higher temperature than the fully irrigated treatment. Differences were never greater than ~1–2 °C and most of the time the rain-fed plots were no more than 0.5–1.0 °C warmer using the E–W average. This suggested minimal water stress on the rain-fed plots during 1985. Data collection ceased on Day 185. After Day 150, the nadir-viewed rain-fed treatments became 2–3 °C warmer than the irrigated treatments due to energy emitted from the warm, dry soil. No differences in the canopy temperature between the Colt and Brule cultivars were detected.

1986 — Canopy temperature measurements began on Day 120 and continued until Day 190. In neither the nadir view nor the E–W average view angle was there any evidence of water stress, as reflected by the canopy temperature measurements, until ~Day 170. From then until Day 190, temperature differences were <2 °C. There was a slight tendency for the nadir-viewed temperature of the Colt cultivar to be slightly greater than that of the Brule cultivar. No differences were observed between cultivars using the E–W average data. Only minimal water stress occurred in 1986.

Mandan, ND

1985 — Beginning on Day 155, the rain-fed treatment of the Colt and Norstar cultivars became warmer than the fully irrigated treatment and, with few exceptions, remained warmer for the remainder of the season. Temperature differences between the two treatments were as great as 5–6 °C (Fig. 3). This suggests moderate to severe water stress on the rainfed plots, particularly for the Colt cultivar. There was a strong influence of cultivar on the canopy temperature (Fig. 3). In general, Colt was several degrees warmer than Norstar. On several occasions, temperatures of the Norstar rain-fed wheat were cooler than fully irrigated Colt wheat (see the period, Day 180–200). These differences may have been caused by a significant reduction, due to winter kill, in the plant population of the Colt compared to Norstar. Plant populations were 51 and 164 plants m^{-2} for Colt and Norstar, respectively. The nadir-view val-

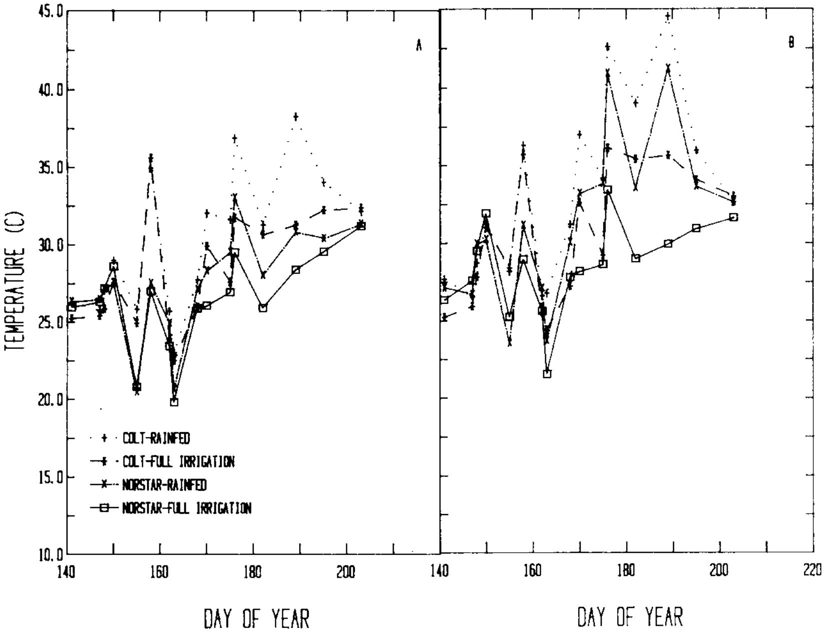

Fig. 3. Canopy temperatures of rain-fed and fully irrigated Colt and Norstar winter wheat cultivars at Mandan, ND, in 1985. Data are averages of measurements made from east- and west-facing views (A) and nadir view (B).

ues were 1–2°C higher than the E–W view for the fully irrigated plots, while the rain-fed plots were often 5–10°C higher (Fig. 3).

1986 — Water stress began in the rain-fed plots by ~Day 160 and continued until ~Day 200. Temperature differences were <5°C, suggesting less stress and a shorter duration of stress in 1986 as compared to 1985. These findings are corroborated by rainfall data for Mandan reported by Hubbard et al. (1988), which show that the amount of precipitation received during the summer growing season of 1986 was greater than that received in 1985. Even though the rainfall in 1986 was considerably above normal, the canopy temperature data suggest that water stress was still present.

As in 1985, Colt had higher temperatures than Norstar. These temperature differences were as much as 2–3°C. Plant populations were lower for Colt (161 plants m^{-2}) than for Norstar (198 plants m^{-2}), but it is uncertain as to whether or not the temperature differences can be attributed to these population differences.

Lethbridge, Canada

1985 — Canopy temperatures for the rain-fed treatments of both cultivars became warmer than the fully irrigated treatments on ~Day 170 and continued to be warmer through Day 200, when measurements ceased (Fig. 4). Tem-

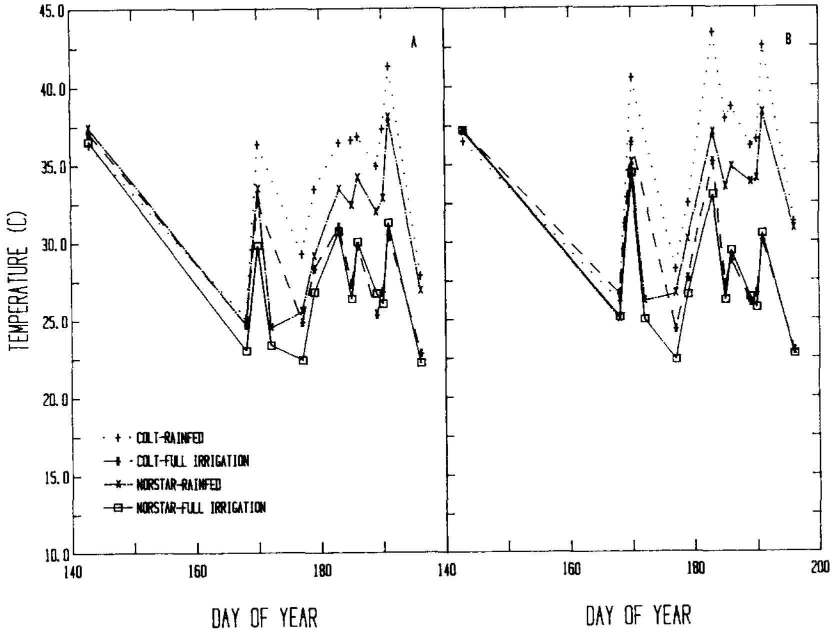

Fig. 4. Canopy temperatures of rain-fed and fully irrigated Colt and Norstar winter wheat cultivars at Lethbridge, Canada, in 1985. Data are averages of measurements made from east- and west-facing views (A) and nadir view (B).

perature differences between the rain-fed and irrigated treatments were as great as 10°C for the E–W average of Colt, although differences for Norstar were never more than ~5°C. Although fully irrigated Norstar tended to be cooler than fully irrigated Colt until ~Day 180, no temperature differences between the two cultivars were observed after that date. The magnitude of the temperature differences between the rain-fed and full-irrigation plots for Colt, as compared to Norstar, suggest that Colt was subject to greater water stress. Perhaps the temperature differences reflect differing physiological responses by each cultivar for dealing with stress. The nadir-view data exhibited very similar patterns to the E–W average data, but the magnitude of the temperature differences between the rain-fed and irrigated plots, as might be expected, was a few degrees greater (Fig. 4).

1986 — When canopy temperature collection began on Day 150, the rain-fed plots of both cultivars were already ~2°C higher than the irrigated plots. The rain-fed plots tended to remain warmer throughout the measurement period, with a maximum difference of ~7–8°C on Day 180, when the last measurements were made. Although Colt was warmer than Norstar, differences were smaller than in 1985 and were never >1–2°C.

Nitrogen treatment effects on canopy temperature

Lubbock, TX

1985 — Temperature differences in E–W average data between the 60 and 160 kg N ha^{-1} levels for both the Colt and TAM 101 cultivars were negligible (Fig. 5). However, for the nadir view, temperatures of the 60 kg N ha^{-1} treatments were slightly warmer than those of the 160 kg N ha^{-1} treatment (Fig. 5). This probably reflects the influence of increased crop cover and reduced exposure of the soil surface to the nadir view of the infrared thermometer as the amount of N was increased.

1986 — The patterns in 1986 were different from those observed in 1985. There was a clear effect of N level on canopy temperature. The 160 kg N ha^{-1} treatments of both cultivars were ~2–3°C cooler than the 60 kg N ha^{-1} treatments (Fig. 6). Data showing the effect of the four N levels on the nadir-view canopy temperatures of the Colt cultivar are presented in Fig. 7. The general, although not always consistent, pattern was such that the highest canopy temperature occurred at the lowest N level (60 kg N ha^{-1}) and the coolest temperature at the highest level of N (240 kg N ha^{-1}). As shown in Fig. 7, however, there was no consistent difference between the E–W average canopy temper-

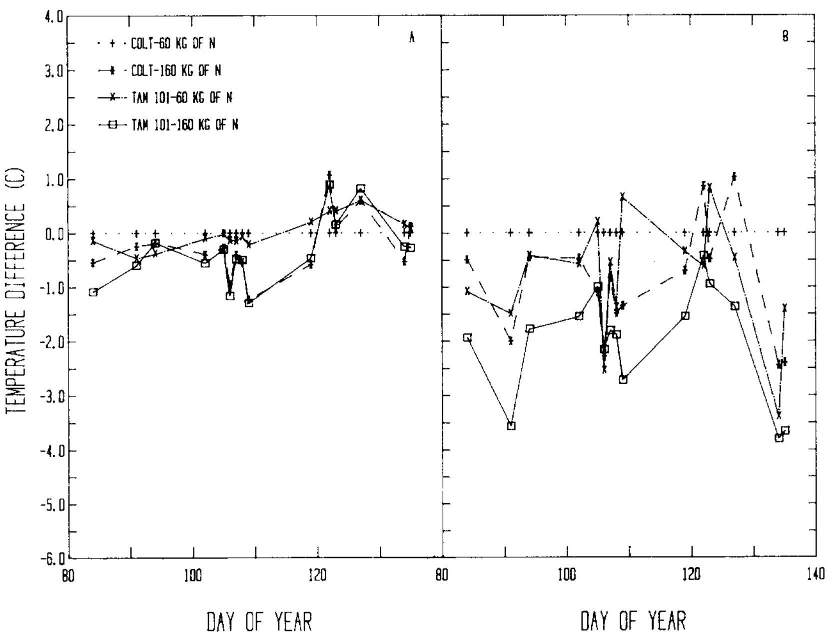

Fig. 5. Canopy temperature differences between 60 and 160 kg N ha^{-1} plots of Colt and TAM 101 winter wheat cultivars at Lubbock, TX, in 1985. Temperature differences are computed using the 60 kg N ha^{-1} data for the Colt cultivar as the standard. Data are averages of measurements from east- and west-facing views (A) and nadir view (B).

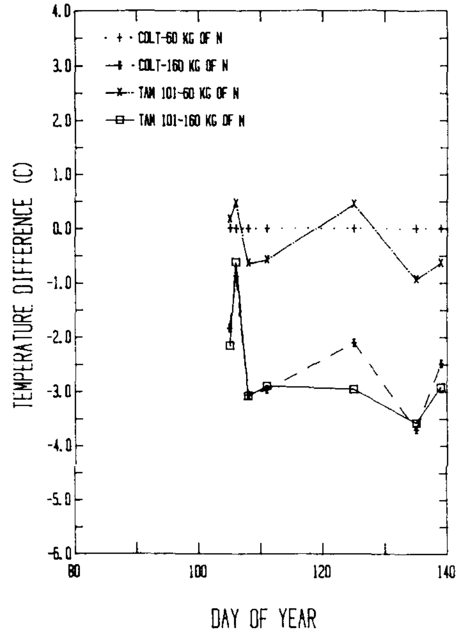

Fig. 6. Canopy temperature differences between 60 and 160 kg N ha^{-1} plots of Colt and TAM 101 winter wheat cultivars at Lubbock, TX, in 1986. Temperature differences are computed using the 60 kg N ha^{-1} data for the Colt cultivar as the standard. Data are averages of measurements from east- and west-facing views.

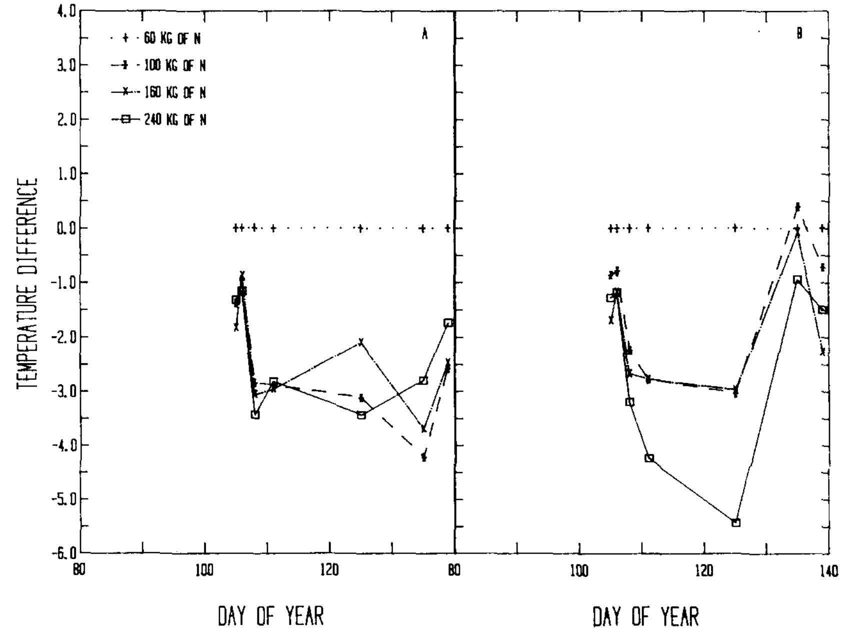

Fig. 7. Canopy temperature differences between 60, 100, 160 and 240 kg N ha^{-1} plots of Colt winter wheat at Lubbock, TX, in 1986. Temperature differences are computed using the 60 kg N ha^{-1} data for the Colt cultivar as the standard. Data are averages of measurements from east- and west-facing views (A) and nadir view (B).

atures of the three highest levels of N for Colt. This was also true for TAM 101.

Manhattan, KS

1985 — The E–W average temperatures of the 60 kg N ha^{-1} treatments of both the Colt and Newton cultivars were warmer than those at the 160 kg N ha^{-1} level. Temperature differences were not more than $\sim 1°C$. For the nadir view, the temperature differences increased to $\sim 2°C$. Both cultivars behaved identically. The 240 kg N ha^{-1} treatment always had slightly cooler temperatures than did the other N treatments.

Sandhills Agricultural Laboratory (SAL), NE

1985 — About Day 110, the 60 kg N ha^{-1} plots of both the Colt and Brule cultivars were 1–2°C warmer than the 160 kg N ha^{-1} plots for both the nadir and E–W average views. By Day 130, these differences disappeared and no differences were observed for the remainder of the measurement period. There was no tendency for one cultivar to be warmer than the other at any of the N levels or at any of the view angles.

1986 — Temperature patterns in 1986 were quite different from those observed in 1985. The 60 kg N ha^{-1} plots of both Brule and Colt were always 1–5°C higher than the 160 kg N ha^{-1} plots for all view angles. The 240 kg N ha^{-1} plots of both cultivars were coolest, while temperatures of the 100 and 160 kg N ha^{-1} plots were intermediate between the 60 and 240 kg N ha^{-1} plots. Poorer plant stands in 1986, due to weed competition, may help to explain some of these differences.

Mandan, ND

1985 — A general trend existed throughout the measurement period for the 60 kg N ha^{-1} plots to be 1–10°C warmer than the 160 kg N ha^{-1} plots. This was observed for all view angles, but was most pronounced at the nadir-view angle. In most instances, the 160 kg N ha^{-1} plots of Colt were warmer than the 60 kg N ha^{-1} plots of Norstar.

1986 — The patterns observed were similar to those of 1985, but temperature differences between the N treatments were larger in 1986. The cultivar effect was not as pronounced as it had been in 1985, except for a few measurements near the end of the growing season (Fig. 8).

Lethbridge, Canada

1985 — The level of N had no effect on the canopy temperature. The Norstar cultivar was generally cooler than the Colt cultivar, but differences were small and non-significant (Fig. 9).

1986 — There was no apparent effect of N level on the canopy temperature in

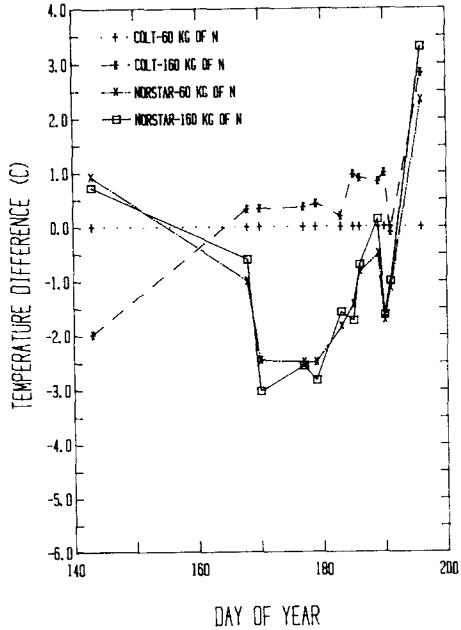

Fig. 8. Canopy temperature differences between 60 and 160 kg N ha^{-1} plots of Colt and Norstar winter wheat cultivars at Mandan, ND, in 1986. Temperature differences are computed using the 60 kg N ha^{-1} data for the Colt cultivar as the standard. Measurements were made at the nadir view.

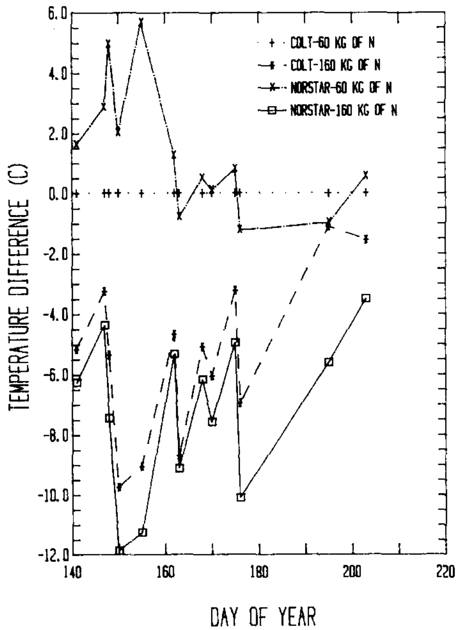

Fig. 9. Canopy temperature differences between 60 and 160 kg N ha^{-1} plots of Colt and Norstar winter wheat cultivars at Lethbridge, Alberta, Canada, in 1985. Temperature differences are computed using the 60 kg N ha^{-1} data for the Colt cultivar as the standard. Data are averages of measurements made from east- and west-facing views.

either cultivar. There was, likewise, no difference in temperature between the two cultivars at the different N levels.

CONCLUSIONS

The results of this study suggest that inadequate rainfall caused the development of water stress in 1985 and 1986 in the northern and southern portions of the North American Great Plains. This conclusion was derived from the observation that rain-fed treatments were generally several degrees warmer than irrigated treatments at Lubbock (TX), Mandan (ND) and Lethbridge, Canada. At the mid-Plains locations of Manhattan, KS, and the Sandhills Agricultural Laboratory (SAL) in NE, the increases in canopy temperature of rain-fed treatments over the irrigation treatments were small, suggesting that water stress was not consequential. This was particularly surprising at the SAL location because of the very sandy soil and low water-holding capacity of the soil. However, a review of weather records at that site showed above average rainfall during the wheat growing season in both years.

The effect of the level of N fertilization on the canopy temperature was not consistent among locations. At Mandan, the nitrogen level had a significant impact during both years of the study. At Lubbock, the 60 kg N ha^{-1} level was slightly warmer in 1985, but only for the nadir view, and in 1986 the lowest N treatment consistently had a higher temperature than did the other N treatments. At SAL, N had an influence in 1986, but not in 1985. Although data were somewhat limited at Manhattan, it appeared that there was some influence of the N level on the canopy temperature in 1985. There was no effect of the N level on the canopy temperature in either 1985 or 1986 at Lethbridge. The reason(s) for the apparent influence of N level on canopy temperatures at the different locations is unclear. It is likely that more vigorous growth of wheat plants at the higher levels of fertilization could help explain some of the differences. More research is needed to explain the influence of N fertilization level on plant temperatures of wheat. Careful attention should be given in such studies to the radiation emitted from the soil.

In some locations, there was evidence that cultivar had an effect on the canopy temperature. Since the Colt cultivar was developed in the mid-Plains environment, it was not too surprising that it did not perform as well at the southern and northern sites where the major effects due to cultivar were observed.

At the northern locations, winter wheat breeding has concentrated on incorporation of increased winter hardiness. The Norstar cultivar developed through that breeding program is tall and leafy. The temperature differences observed for Colt and Norstar suggest that canopy temperature may have considerable value for characterizing morphological differences in winter wheat.

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