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MONITORING THE WEATHER AT FIVE WINTER WHEAT EXPERIMENTAL FIELD SITES*

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ABSTRACT

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Weather monitoring equipment was set up at 5 winter wheat experimental field sites ranging from Lethbridge, Alberta, Canada, to Lubbock, Texas, U.S.A. Uniform weather-measurement techniques were employed at all locations for the following weather variables: wind speed and direction; solar radiation; air temperature and relative humidity; soil temperature and precipitation. Weather data for the Nebraska and Kansas locations were automatically retrieved via daily computer telecommunication. Data from the remaining locations were retrieved at the end of each growing season. Data from 2 growing seasons show wide differences in the environmental conditions among the study locations. Near-real-time data collection required less quality control because the daily eavesdropping on the station resulted in less sensor down time.

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INTRODUCTION

Wheat responds strongly to a number of weather variables. Because winter wheat is planted in the fall and matures the following summer, its emergence, early growth, dormancy, re-emergence and subsequent development are presumably a complex integral of the weather during a 9–10-month period. Researchers conducting field studies of wheat must monitor weather adequately from planting to harvest, in order to view treatment effects in the light of the weather.

The phenological growth scales in common use have been corelated by Bauer et al. (1983). The phenological development of wheat is accelerated with warmer temperature and slowed by cool temperatures (Nuttonson, 1955). Growing degree days – the accumulation of air temperatures in excess of a base temperature – are used to estimate the effect of temperature on phenological development of wheat. Air temperature is thereby a fundamental weather variable requiring measurement.

Low temperature also determines the length of the freeze-free season over the major wheat-growing regions of the world. Since it is planted in the fall, winter wheat spans parts of 2 freeze-free seasons. With sufficient decrease of air and soil temperatures in the fall, winter wheat will become dormant. Dormancy does not provide complete protection however, when air temperatures fall below $-20°C$ the crop may be damaged unless protected by snow (Percival, 1921). Certain genotypes must fulfill a vernalization requirement before completing their ontogeny.

The soil-moisture status in the wheat-crop root zone also has profound effects on growth and development. Well-watered plants may not develop as rapidly as moderately water-stressed plants (Angus and Moncur, 1977), while severely-stressed plants are actually delayed in development compared with their well-watered counterparts. Precipitation and evapotranspiration obviously affect the moisture available in the root zone. Solar radiation, wind speed, relative humidity and air temperature are weather variables commonly used to estimate potential evapotranspiration (Rosenberg et al., 1983). These variables then, need to be measured in order to characterize the environment affecting wheat growth.

In addition, winter wheat is subject to the influence of snow mold during dormancy (Tindall, 1986). This influence is strongest when temperatures under the snow are relatively warm. Emergence is affected by soil temperature (Lindstrom et al., 1976) and moisture, generally decreasing as temperature approaches the freezing point. Weather also plays a role in the development of wheat powdery mildew (Merchan and Kranz, 1986) and wheat rust (Fogliani and Caffarri, 1986). For more extensive reviews of the agrometeorology of wheat, the reader is referred to Treidl (1978) and Kirkham and Kanemasu (1983).

Effects of weather on winter wheat all argue for a strong monitoring program to document the state of the environment during field studies. This paper presents a summary of weather conditions at 5 locations in the North American Great Plains during the course of a 2-year experiment. It is intended to assist the reader in evaluating the information presented in the companion papers.

MATERIALS AND METHODS

The site descriptions and measurement methodologies employed in the experiments are discussed in a companion paper (Reginato, 1987).

Automated weather monitoring was desired at each of the sites to efficiently collect the data necessary to make a quantitative assessment of environmental conditions. A data logger, complete with an array of sensors, was installed for this purpose at each of the locations. The equipment used is listed in Table 1. Initial plans called for daily telephone communications between the central computer and each location. This near-real-time linkage was only accomplished between the data archival headquarters in Lincoln, Nebraska and the Tryon, Nebraska and Manhattan, Kansas sites. Hourly data from these sites were quality controlled on a daily basis. Telephone links were not installed at the remaining locations, however data were observed and daily measurements were later forwarded to the central location.

TABLE 1

Hardware for the AWDN computer and an AWDN station[a]

Central office	Station
IBM PC-AT	Campbell CR21X (or CR10) micrologger
monochrome monitor	CM10 tripod
20 MB hard disk	022UDS large enclosure
1.2 MB floppy disk	T107B thermistor
360 KB floppy disk	T/RH207 Thermistor/RH probe
Epson FX-80 printer	014A Met One wind sensor
2-20MB Bernoulli	024A Met One wind vane
cartridge system	019 Cross arm
Microcom AX2400 modem	015 Pyranometer mount
Campbell PC201 card	LI200S Li-Cor silicon pyranometer
Campbell PC203 power-up box	LI2003S Li-Cor base and level
HP-7470A plotter	RG2501 Sierra tipping bucket (1 mm) raingage
	DC103A Answer modem
	PCRC-11 1% RH chip
	41002-3 Gill radiation shield
	Assorted hardware

[a]Mention of manufacturer's name does not imply endorsement of a product over those offered by other manufacturers but is merely provided for the convenience of the reader.

Data loggers were programmed to record weather variables on hourly and daily frequencies from readings that were made each minute. This system of data collection has been employed in the High Plains (Hubbard et al., 1983). For this study, software was designed to archive the data in the required format. The Automated Weather Data Network (AWDN) served as the near-real-time data collection point. Hardware at the data archival headquarters is listed in Table 1. Quality control consisted of the following.

(1) Dealing with calibration peculiarities. Setting night-time values of hourly solar radiation to zero. Setting relative humidity values that exceed 100% to 100.

(2) Checking solar radiation output against sunrise and sunset times to identify any possible errors in the data logger time.

(3) Comparing data for a given variable against assigned upper and lower limits and when found to be outside the threshold values, flagging the data and/or setting the data to the threshold.

(4) Flagging those occasions when a measured variable remains constant and determining the cause (sensor malfunction or constant environment at the site).

(5) Estimating missing data from surrounding automated weather data stations by weighted inverse distance interpolation.

Missing solar radiation values were estimated in a similar fashion to the method employed by Hodges et al. (1985). A ratio was formed between calculated extra-terrestrial and maximum observed solar radiation during measured periods and this ratio was extrapolated to missing periods for calculating the solar radiation.

Where possible, data were compared with measurements taken at nearby National Weather Service (NWS) stations or Environment Canada stations. Normal values of temperature and precipitation were compared with the weather conditions observed during the course of the experiment to assess the representativeness of the study period.

RESULTS

To view the weather data in the light of its impact during growth and development, it is important to keep in mind the planting and ripening dates from the growth history records for this study (see Table 2). The Lubbock, Texas, crop was planted last but was the first to ripen in both years. Northern locations were the first planted and the last to ripen.

Figures 1–5 show monthly accumulated values of measured precipitation and average monthly temperature for sites from Lethbridge, Alberta, Canada, to Lubbock, Texas, respectively. Long-term normals and measured values at nearby official stations are also shown. The locations of the sites used for this comparison are listed in Table 3.

TABLE 2

Approximate growing seasons at each experimental site. Day number from 1 January in parentheses

Site	1984-1985		1985-1986	
	Planting date	Ripening date	Planting date	Ripening date
Lethbridge, Canada	9/14 (257)	7/23 (204)	9/04 (247)	7/06 (191)
Mandan, ND	9/19 (262)	7/22 (203)	9/22 (266)	7/20 (201)
Sandhills Ag Lab, NE	9/13 (256)	6/26 (177)	9/06 (249)	6/30 (181)
Manhattan, KS	9/22 (266)	5/31 (151)	9/20 (267)	5/31 (151)
Lubbock, TX	11/02 (306)	5/30 (150)	11/15 (319)	5/30 (150)

Air temperature was near or above normal during the period of rapid wheat growth at all 5 sites in both the 1984–1985 and 1985–1986 growing seasons. This can be seen by examining the (c) and (d) portions of Figs. 1–5. A few locations experienced below normal temperatures during the period November–December 1985. Monthly values of temperature at the AWDN stations compared well with nearby official stations.

Precipitation at Lethbridge, Canada (see Fig. 1(a), (b)) was generally above normal in the fall season for both years. May, June and July precipitation in 1985 was well below normal levels (less than 10% of normal in June 1985). Temperature (see Fig. 1(c), (d)) was near normal in both seasons, but temperatures in December and January of 1985–1986 were significantly above normal. No major differences were noted between the experimental site and the official weather station.

In Mandan, North Dakota (see Fig. 2(a), (b)), the first growing season was marked by high precipitation (over 200% of normal) in May, followed by less than normal amounts in June and July. The summer of 1986 was unusually wet for Mandan. Average temperatures (see Fig. 2(c), (d)) were near normal with the exception, that March of both years was warmer than usual. Good agreement was observed between the official weather station and the study site.

At the Sandhills Agricultural Laboratory in Nebraska (see Fig. 3(a), (b)) the precipitation was noticeably low in April and June 1985 and again in May 1986. Precipitation was high in September 1985 and in April 1986. Average temperatures (see Fig. 3(c), (d)) were near to slightly above normal for the spring and summer months. A nearby official NWS station substantiated these temperature changes. Monthly precipitation at the study site differed by as much as 20–40 mm from the official station.

Manhattan, Kansas (see Fig. 4(a), (b)) received much above normal precipitation in April 1985 and in May 1986. Temperatures were near normal in both years. Noteworthy precipitation differences between the study site and

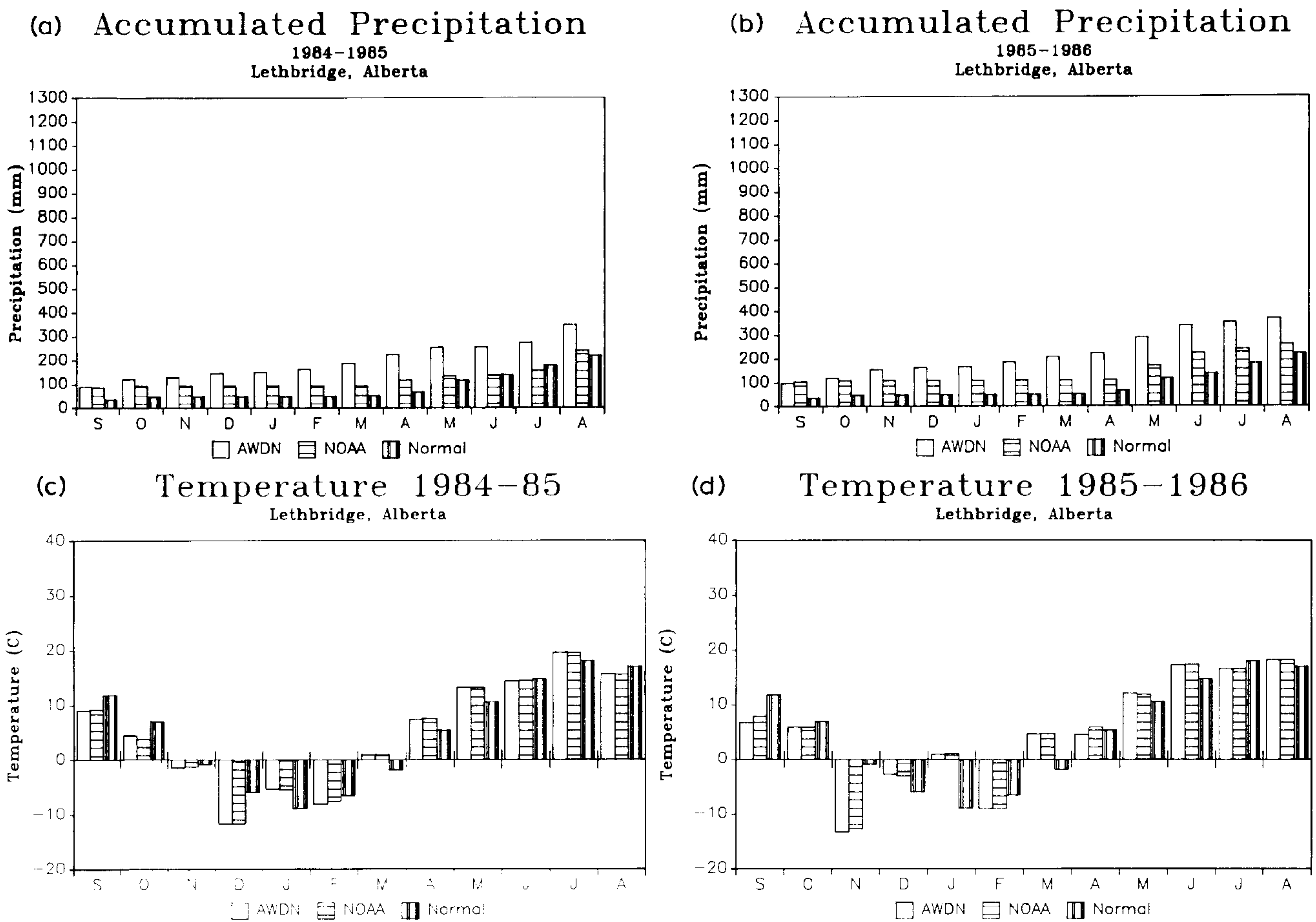

Fig. 1. Comparison between weather at the National Oceanic and Atmospheric Administration (NOAA) station and the Automated Weather Data Network (AWDN) station and normal conditions at Lethbridge, Alberta, Canada. (a) Rainfall 1984–1985; (b) rainfall 1985–1986; (c) (temperature 1984–1985; (d) temperature 1985–1986.

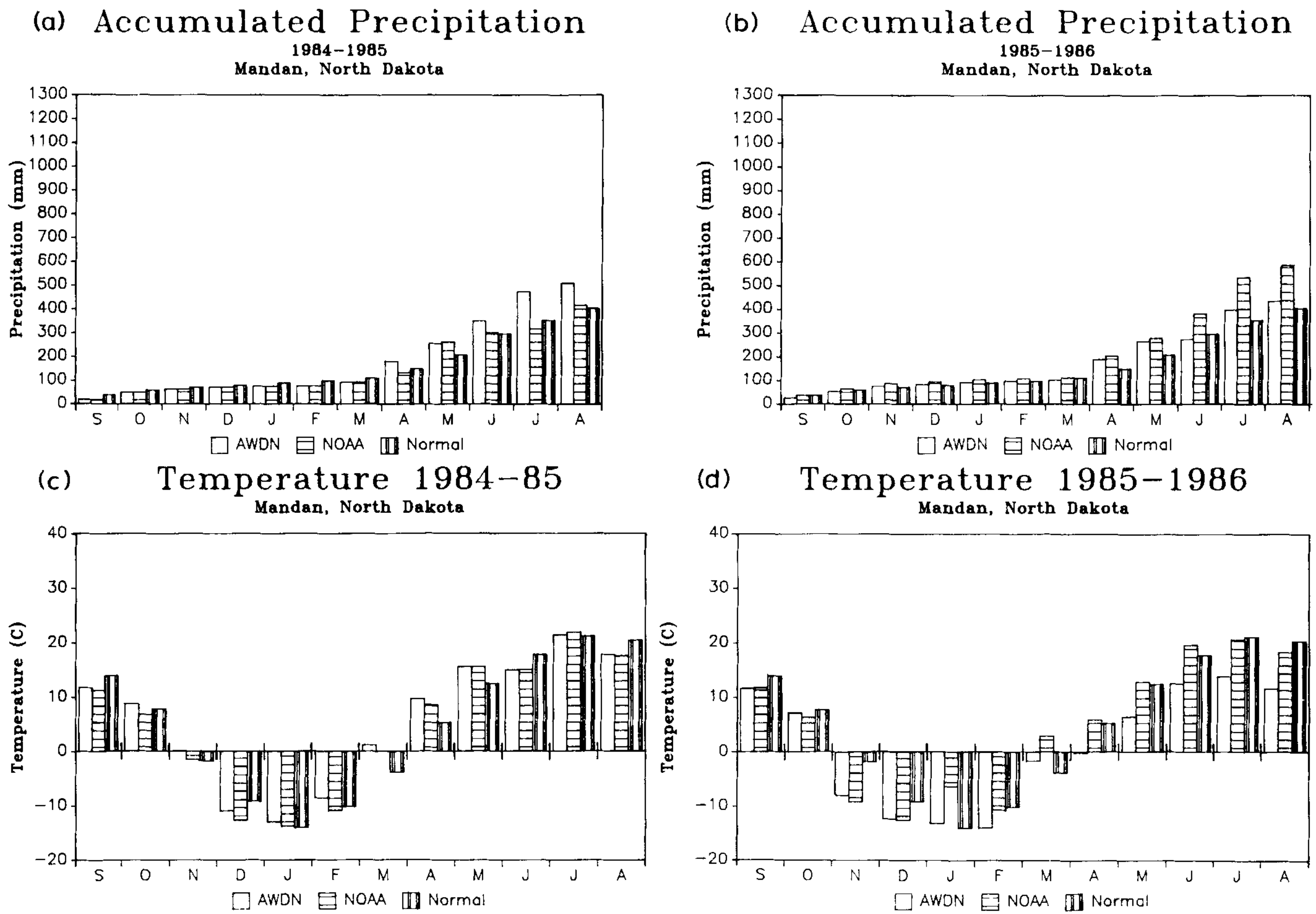

Fig. 2. As in Fig. 1, except data from Mandan, North Dakota.

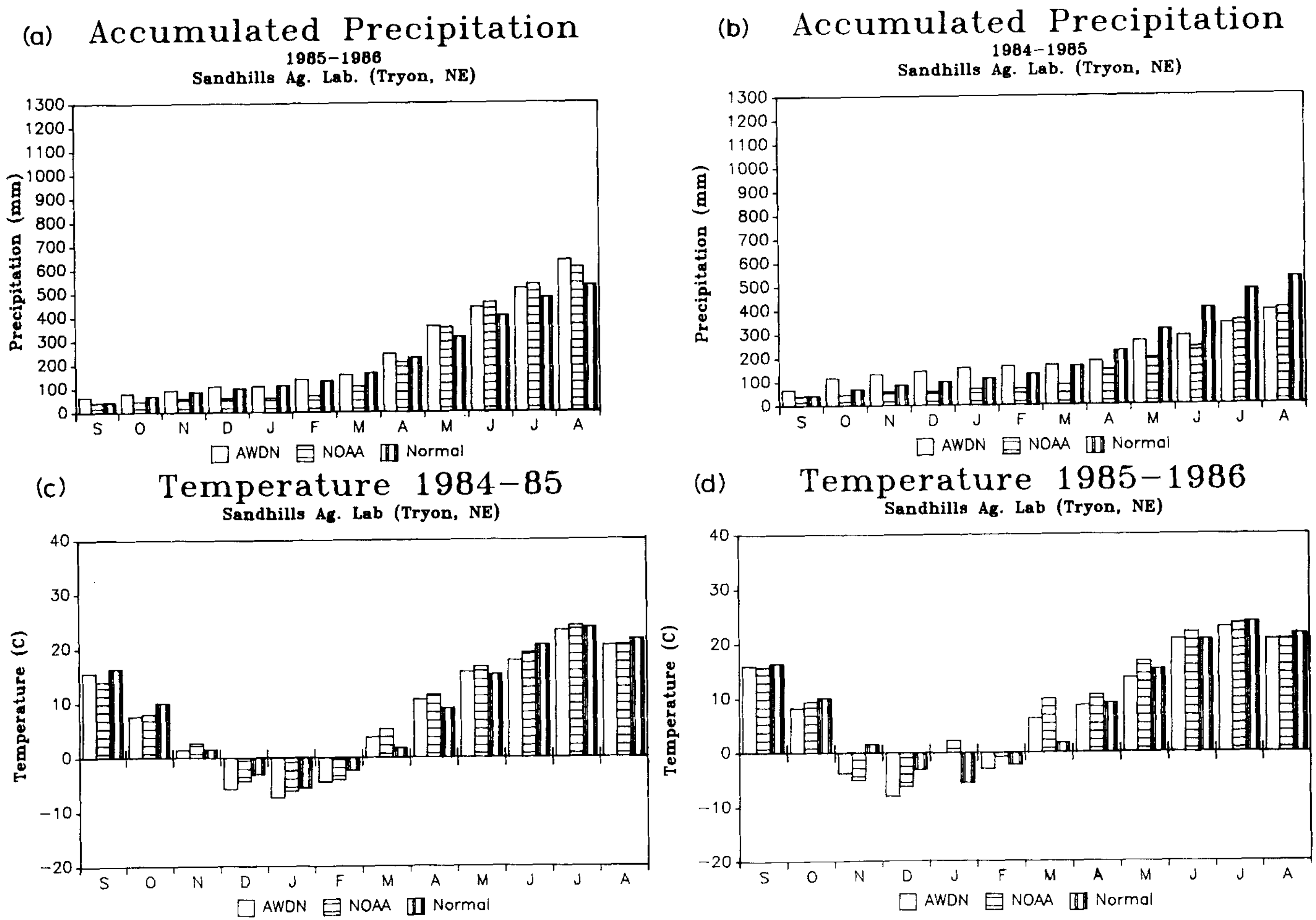

Fig. 3. As in Fig. 1, except data from Sandhills Agricultural Laboratory, Nebraska.

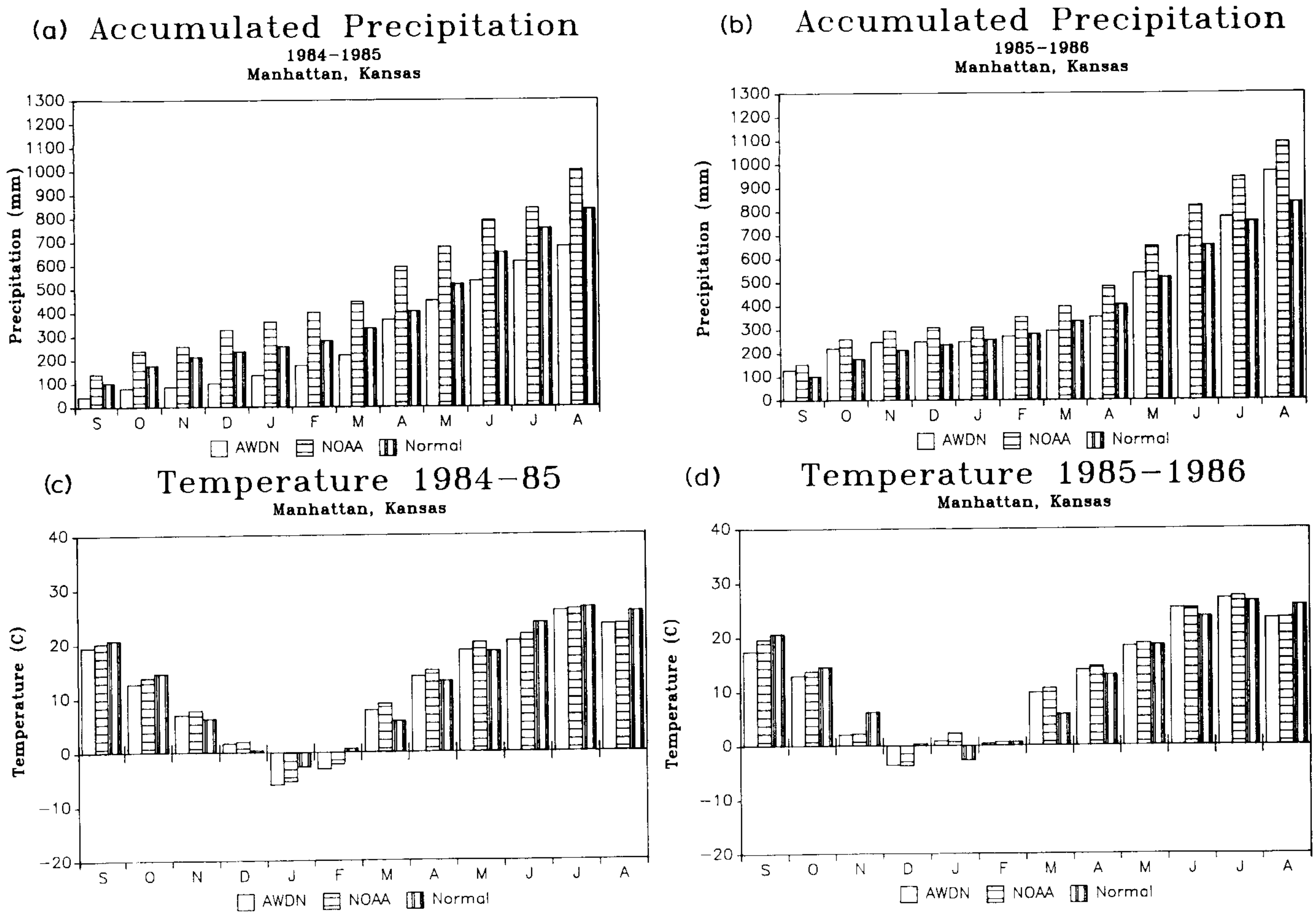

Fig. 4. As in Fig. 1, except data from Manhattan, Kansas.

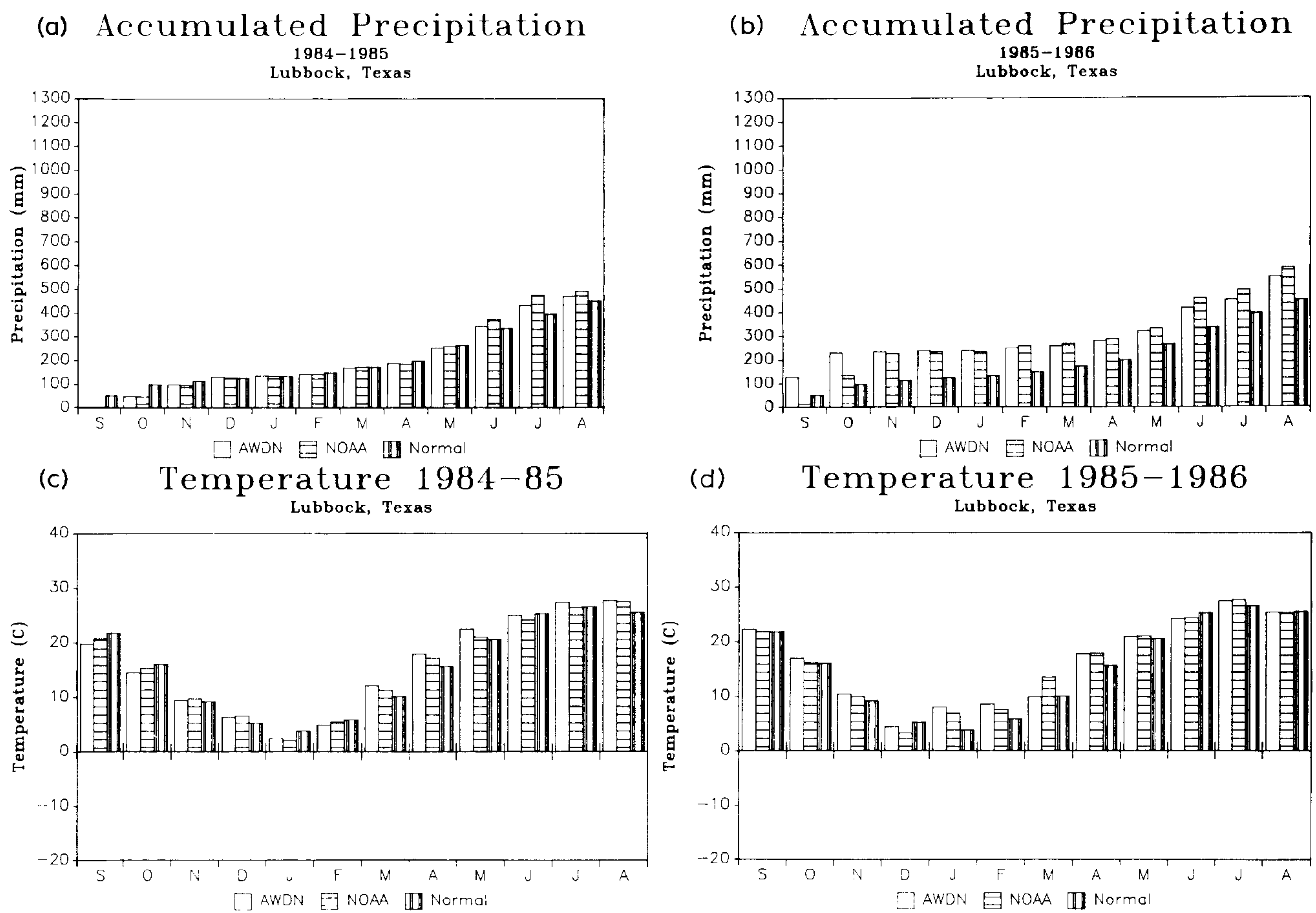

Fig. 5. As in Fig. 1, except data from Lubbock, Texas.

TABLE 3

Stations used in comparing precipitation and temperature data

Experimental Site	Comparison Station
Lethbridge, Alberta, Canada	Lethbridge, Alberta, Canada
Mandan, North Dakota	Mandan, North Dakota
Sandhills Agricultural Laboratory, Nebraska	Tryon, Nebraska
Manhattan, Kansas	Manhattan, Kansas
Lubbock, Texas	Lubbock, Texas

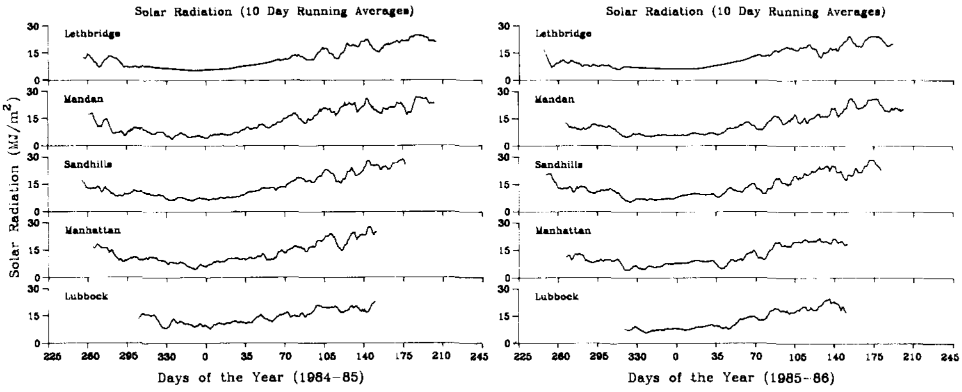

Fig. 6. Solar radiation at: Lethbridge, Alberta, Canada; Mandan, North Dakota; Sandhills Agricultural Laboratory, Nebraska; Manhattan, Kansas; and Lubbock, Texas for: (a) 1984–1985; (b) 1985–1986.

the official station occurred in September–December 1984 and again in August 1985. Precipitation is known to be extremely variable so this does not necessarily indicate that one of the stations is in error.

At Lubbock, Texas, precipitation was near normal in spring and summer of 1985 and below normal for the same period in 1986 with the exception of June. Temperatures were near normal for both years. Good agreement was found between the temperature and precipitation records at the study site and at the nearby official weather station.

All sites exhibit an interior continental rainfall pattern, peaking in summer and reaching a low point in winter. Of all the sites, Manhattan would normally receive the greatest amount of precipitation and it would occur largely in the months April, May and June. This was the case for the study period.

The data for solar radiation, vapor pressure deficit, wind run and soil temperature (at 10 cm) are presented in Figs. 6–9. The data have been arbitrarily restricted to the period from planting to ripening. The data presented are 10-day averages, plotted daily on the date at the end of the 10-day period. These

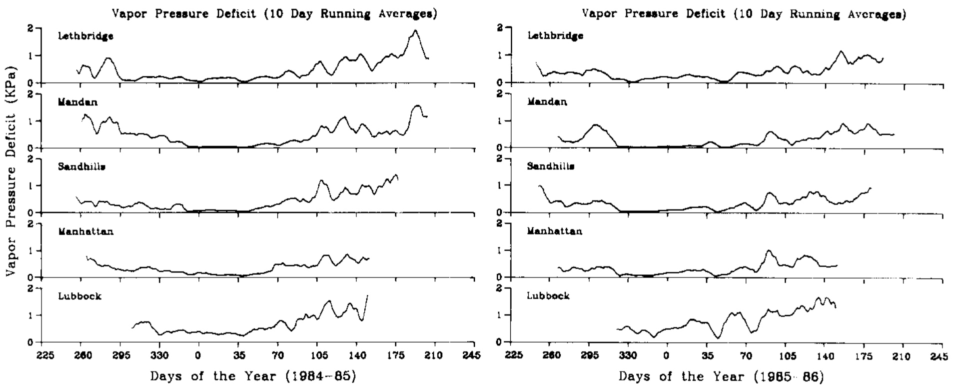

Fig. 7. Vapor pressure deficit at: Lethbridge, Alberta, Canada; Mandan, North Dakota; Sandhills Agricultural Laboratory, Nebraska; Manhattan, Kansas; and Lubbock, Texas for: (a) 1984–1985; (b) 1985–1986.

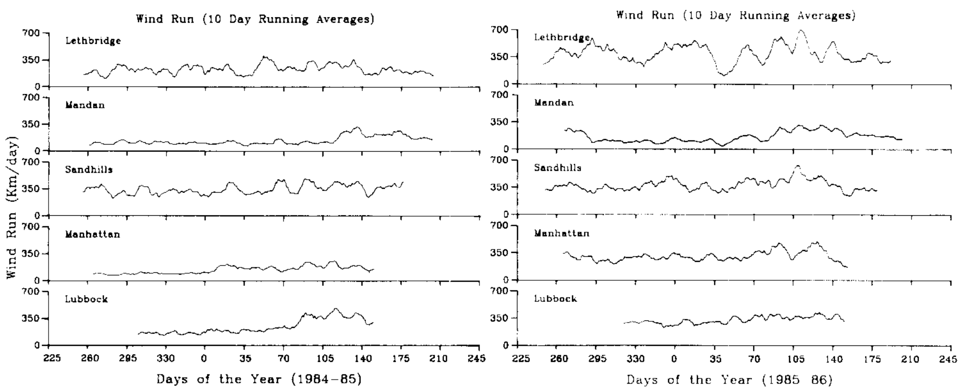

Fig. 8. Wind run at: Lethbridge, Alberta, Canada; Mandan, North Dakota; Sandhills Agricultural Laboratory, Nebraska; Manhattan, Kansas; and Lubbock, Texas for: (a) 1984–1985; (b) 1985–1986.

type of data are not available at nearby official stations so this analysis will compare the data between sites and growing seasons.

It is immediately obvious that the length of growing season varied considerably from site to site, being generally longer at the northern latitudes. For this reason, wheat growing at Lethbridge and Mandan was exposed to as much energy from the sun as wheat growing at Lubbock or Manhattan (see Figs. 6(a), (b)). Incoming solar radiation is an energy source for evapotranspiration. Periods of reduced solar radiation, presumably owing to cloudiness, were observed to occur at different times from site to site and between years.

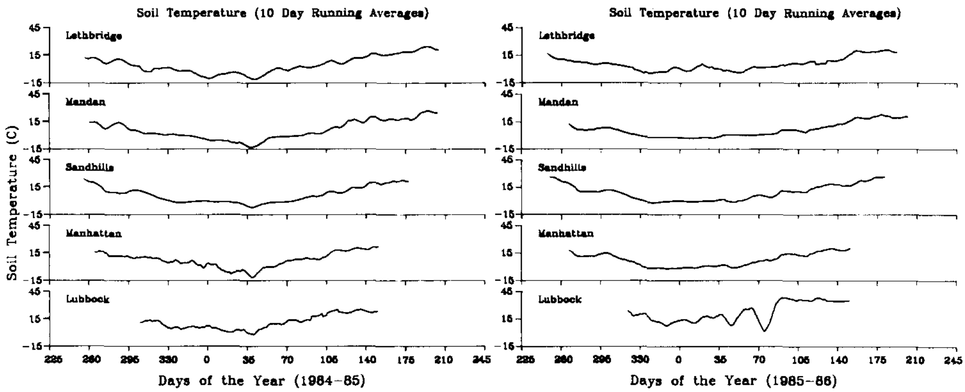

Fig. 9. Soil temperature at: Lethbridge, Alberta, Canada; Mandan, North Dakota; Sandhills Agricultural Laboratory, Nebraska; Manhattan, Kansas; and Lubbock, Texas for: (a) 1984-1985; (b) 1985-1986.

Higher vapor-pressure deficits cause an increase in evapotranspiration from well-watered crops. Vapor-pressure deficit was generally highest at Lubbock, Texas, with the notable exception in 1984–1985 toward the end of the season at both Lethbridge and Mandan (see Fig. 7(a),(b)). Instances where the nominal (1 kPa) value was not exceeded were Manhattan in 1984–1985 and the Sandhills Agricultural Laboratory and Mandan in 1985–1986.

Wind run is important to evapotranspiration owing to the effect of advecting drier and warmer air over a well-watered crop surface. The instances of greatest wind run (Fig. 8(a), (b)) were Lubbock and Sandhills Agricultural Laboratory in 1984–1985 and Lubbock and Lethbridge in 1985–1986.

The duration of soil temperatures below the nominal reference value (15°C) were considerably longer at the northern study sites (see Fig. 9(a), (b)). From year to year the pattern at each site did not seem to vary greatly with the exception of Lubbock where a long time period below 15°C in 1984–1985 was followed by only brief excursions below the same mark in 1985–1986.

CONCLUSIONS

The results of this study demonstrate that it is possible to obtain an accurate record of a wide array of weather variables to describe the growth environment of a crop. This study analyzed winter wheat grown from Lubbock, Texas to Lethbridge, Alberta, Canada.

Fewer quality-control procedures were required for the two stations to which near-real-time linkages were developed because daily eavesdropping allowed faster response to sensor problems.

A preliminary monthly assessment of the temperature data collected, show no extreme excursions from normal at any of the locations. Precipitation data on a monthly basis varied from less than 10% of normal to over 200% above normal. Both variables measured at the study sites agreed well with nearby official stations.

A comparison of solar radiation, vapor-pressure deficit, wind run and soil temperature data from site to site shows obvious differences in the growth environments. These differences were large enough to be considered important factors and deserve further study to determine if they may have affected the experimental outcome from site to site.

ACKNOWLEDGEMENTS

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