No-till Seeded Winter Wheat: Influence of Date of Nitrogen Application on the Seasonal Pattern of Crop Growth and Water Use

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Abstract

An experiment was carried out to determine the influence of fertilizer N timing on the early season crop development and water use (ET) of no-till seeded winter wheat (Triticum aestivum L.). Ammonium nitrate N was surface broadcast either as early as possible (early), split between 2/3 early and 1/3 at the beginning of stem elongation (split), and 3 weeks after early (late), at rates of 0, 67, 134, and 202 kg N ha^{-1}. Early and split-N application increased the early season plant development over late-N as recorded by tiller number and leaf area production. The development and maintenance of a larger leaf area with N fertilization in 1987 resulted in increased grain yields. However, high evaporative demand prior to anthesis in 1988 resulted in the 'collapse' of early season leaf and tiller responses. A positive correlation ($r=0.82^{**}$) was recorded between leaf stomatal conductance (g_l) and leaf relative water content, illustrating the importance of tissue water content in maintaining high photosynthetic activity. While added N increased pre-anthesis g_l over the unfertilized check, the opposite response was recorded during the post-anthesis grain filling period. Increasing fertilizer N rate increased seasonal ET at 2 of the 8 trials by increasing post-anthesis ET over the unfertilized check. High pre-anthesis evaporative demand reduced season long ET to 159 mm in 1988, 59% of the 218 mm recorded in 1987. Soil water contributed 16% of total ET in 1987 and 30% in 1988. The bulk of this soil water was taken up pre-anthesis, with 98% of post-anthesis ET coming from rainfall.

Introduction

The development of a practical snow management system, which involves no-till seeding into standing stubble of the previous crop (stubbling-in), has reduced the risk of winterkill and permitted expansion of the winter wheat (Triticum aestivum L.) production area on the Canadian prairies. While no-till seeding maintains the standing stubble necessary to trap an insulating layer of snow during the winter, the recrop environment is usually deficient in plant available nitrogen (N). Correction of this N deficiency is necessary before optimum grain yield and acceptable grain quality can be produced (Fowler et al., 1989a;b).

Winter wheat produced on the Canadian prairies resumes growth in late-April, flowers approximately the third week of June, and is normally harvested in mid-August. The long-term growing season conditions of this region are more moist in May and June, and hot and dry in July (deJong and Steppuhun, 1983). The 32 to 42% yield advantage observed for winter over spring wheat in this region has been attributed to its more efficient early-season water use, and the generally cooler, wetter conditions during the critical booting to flowering development stages (Entz and Fowler, 1990). Therefore, it is important that N fertilizer be positionally available to the winter wheat prior to early season plant demands.

The interaction of N fertilizer additions with environmental and soil water conditions can result in a wide range of crop responses. It has been reported that the maximum yield potential of winter wheat is established early in the growing season with the number of potential tillers, spikelets per spike, and florets per spikelet determined in a matter of a few weeks in the spring (Peterman, 1983). However, subsequent water, nutrient, and temperature stresses affect the final harvested yield. Consequently, an understanding of the interactions of N fertilizer responses and seasonal environmental stresses is a prerequisite to the development of management packages designed to produce maximum economic yields.

The objective of this study was to determine the influence fertilizer N application timing had on the early season crop development and water use of no-till seeded winter wheat in Saskatchewan.

Materials and Methods

Eight field trials were established in farmer seeded fields of winter wheat (cv. Norstar) in 1987 and 1988 in the Dark Brown, and Black soil zones in Saskatchewan (Table 1). Field selection was based on overwinter survival and use of monoammonium phosphate fertilizer seed placed at recommended rates. All nutrients other than N and phosphorus were not considered to be limiting.

In the early spring of each year, mid-row soil samples to a 60 cm depth were collected (0-15, 15-30, and 30-60 cm increments) from the experimental area prior to fertilizer application. Soil samples were air dried and submitted to the Saskatchewan Institute of Pedology, soil testing laboratory where nitrate-N concentrations were determined colorimetrically by autoanalyzer using cadmium reduction (Technicon Industrial method #100-70W, Technicon Instrument Corp., Tarrytown, N.Y.). Only estimates of nitrate-N were utilized because field trials in Alberta and Saskatchewan have demonstrated that the relationship between grain yield or protein concentration and mineral N (nitrate plus ammonium) is no better than for nitrate-N alone (Nuttall et al., 1971; Malhi et al., 1985). Soil and fertilizer N were considered to be equally plant-available. Total available N is the sum of spring soil test nitrate-N to 60 cm depth plus added fertilizer N (Heapy et al., 1976; Zentner and Read, 1977; Bole and Dubetz, 1986).

The variables N rate and time of N application were evaluated using a four replicate split-plot experimental design. The N rates used were 0, 67, 134, and 202 kg N ha^{-1} as ammonium nitrate hand broadcast on the surface. The N application times were as early as possible after spring thaw (early), split between 67% early and the remaining 33% at Zadoks growth stage (ZGS)30 (split), and three weeks after early (late) (Table 1). In 1987 time of N application was used as the main plots and N rates as the subplots. In 1988 N rates were the main plots and N application time the subplot. This change in the arrangement of main and subplots between the two years was to increase the precision of estimating the effect of N application time on crop response. As a result of this change in design, data from different years were not combined in any of the statistical analysis carried out. At the East Sutherland location in 1988 a split-split-plot design was employed with water as the main plot, N rate as the subplot, and time of N application as the sub-subplot. Irrigation water totalling 100 mm was applied in units of 25 mm on May 3 and 16, and June 3 and 16. In the presentation of data this trial was divided into dryland (Trial 7) and irrigated (Trial 8).

Daily minimum and maximum air temperatures and 24 hour rainfall was collected at the Clair and Hagen trials in 1987, and the Dafoe and Hagen trials in 1988 using a field data logger (Campbell Scientific Model CR-21, Logan, Ut.). Weather data for the East Sutherland and Watrous trials in 1987 and East Sutherland in 1988 were obtained from the local Environment Canada meteorological stations. Class A pan evaporation was also obtained from the closest weather recording station (furthest distance 65 km). Growing degree days were calculated from daily minimum and maximum air temperatures, using a base temperature of 5°C.

Soil water was measured using the neutron scattering method (Model 3300; Troxler laboratories; Triangle Park, N.C.) at the 10 to 30, 30 to 50, 50 to 70, 70 to 90, and 90 to 110 cm soil depths. The neutron access tubes were located in the center of each plot. Surface soil water (0 to 10 cm) was determined gravimetrically, and converted to a volumetric basis using soil bulk density. Soil water was measured every two weeks from the beginning of May through to the day of harvest. Evapotranspiration (ET) was calculated from the addition of rainfall to soil water extraction during each two week period through the season.

Above ground dry matter samples were collected at the same time that soil water was measured (every two weeks) by cutting two 1 m sections of row at ground level. Sampling stage was recorded using the Zadoks growth stage (ZGS) scale (see Appendix 1). Samples were dried and weighed to determine dry matter yield. Leaf area samples were collected on a weekly basis up until anthesis

Table 1. Test location, previous crop, soil characteristics, and time of N fertilizer application for Norstar winter wheat in 1987 and 1988 crop development trials.

Trial	Year	Previous Crop†	Soil: Classification‡	Soil: Texture§	Soil: NO_3-N in¶ early spring (kg ha^{-1})	Time of N application (day/month): Early	Split	Late
1. Clair	1986-87	Barley	Yorkton# Black Chernozem	L	29	20/4	20/4:19/5	13/5
2. Hagen	1986-87	Rapeseed	Blaine Lake Black Chernozem	L	40	21/4	21/4:31/5	12/5
3. Kernen	1986-87	Barley	Sutherland Dark Brown Chernozem	C	77	16/4	16/4:29/5	11/5
4. Watrous	1986-87	Barley	Weyburn Dark Brown Chernozem	CL	24	17/4	17/4:29/5	14/5
5. Dafoe	1987-88	Barley	Weyburn Dark Brown Chernozem	L	18	13/4	13/4:25/4	10/5
6. Hagen	1987-88	Rapeseed	Blaine Lake Black Chernozem	L	47	21/4	21/4:26/4	13/5
7&8. East Sutherland	1987-88	Rapeseed	Elstow Dark Brown Chernozem	C	40	14/4	14/4:28/4	11/5

† Barley (Hordeum vulgare L.), Rapeseed (Brassica campestris L.).

‡ Canadian Soil Survey Committee, Subcommittee on Soil Classification, 1978.

§ L-loam, C-clay.

¶ Amount of NO_3-N in the 0 to 60 cm soil layer of unfertilized plots in the spring.

Soils survey report No. 12 (Mitchell, Moss and Clayton, 1944).

from a 0.093 m^2 (1 ft^2) area at Clair and Hagen in 1987, and all trials in 1988. Green leaf area was determined using the Lambda LI3000 leaf area meter and a LI3050A conveyor belt assembly (Li-Cor Inc., Lincoln, Ne.). Green leaves were dried separately from stems and senesced leaves. Leaf area index (LAI) was calculated by dividing cm^2 of green leaf surface area by the cm^2 of sample area. In 1988 tiller numbers were determined from weekly counts on two adjacent 0.5 m sections of row from the beginning of stem elongation (ZGS30) to harvest, when spike counts were taken.

Leaf relative water content (RWC) samples were collected on a weekly basis from the beginning of sampling up until flag leaf senescence. Leaf samples were always collected between 1000 and 1200 hours. The upper-most fully developed leaf was cut from the plant using a scalpel, loosely rolled, and then sealed in preweighed screw top vials for transport to the laboratory. On return to the laboratory, vials were weighed and leaf fresh weight determined. The leaves were then hydrated in test tubes containing distilled water (Turner, 1981). After 24 hours in a dark cupboard the leaves were blotted dry and reweighed to determine their turgid weight. The leaves were then returned to the empty test tubes, oven dried at 80°C for 48 hours, and reweighed to determine their dry weight. RWC (%) was calculated as follows:

$$\text{RWC} = (\text{fresh wt} - \text{dry wt}) / (\text{turgid wt} - \text{dry wt}) * 100 \qquad [1]$$

Leaf stomatal conductance (g_l) was measured by sampling the abaxial surface of three leaves from each plot using the LI-1600 Steady State Porometer (Li-Cor Inc., Lincoln, Ne.). Cuvette humidity was set at ambient levels in the crop canopy prior to taking g_l readings and was never changed while measurements were being made within each replicate. Readings were always taken between 1000 and 1200 hours.

Data from each trial were analyzed using a split-plot analysis of variance (SAS Institute, 1985). Where analysis was conducted for samples collected over time, or for trials combined within a year, homogeneity of error variance was checked using the Fmax test (Rohlf and Sokal, 1969). Simple correlations were used to determine the relationship among and between variables measured. Forward stepwise regression analysis (SAS Institute, 1985) was used to determine those factors which had the greatest influence on the response of dependent variables.

Results and Discussion

Environmental Conditions

Environmental conditions in both 1987 and 1988 were characterized by above average air temperatures and below average rainfall in May and June. Trial locations in this study were selected and established in mid- to late-April with the goal of initiating sampling in early May. The sampling schedule was limited to a two week cycle because of the number of trial locations included. Three two week development periods (DP) were sampled both before and after anthesis in 1987 (Table 2). However, high air temperatures in late-May and early-June resulted in only two DP prior to anthesis in 1988. Considerable difficulty was encountered in the determination of crop stage in 1988 due to head emergence, with kernels already formed, from the side rather than the tip of the boot. There was limited stem elongation after head emergence. While there was little variation in environmental conditions during DP1 in either 1987 or 1988, the increased air temperatures and low rainfall in DP2 in 1988 doubled daily pan evaporation rate and growing degree day accumulation. This resulted in the pre-anthesis period that was at least 10 days shorter and a 34% reduction in the number of days from spring green-up to harvest (ZGS92) (mean for 1987 was 91 days, while only 60 days in 1988).

Dry Matter Accumulation and Evapotranspiration

Dry matter accumulation patterns for all eight trials are illustrated in Figures 1 and 2. In Trials 2,3,4, and 5, dry matter accumulation followed a characteristic sigmoid pattern over the growing season (Lal et al., 1978; Gregory et al., 1979; Karlen and Whitney, 1980). Dry matter increased up to the early milk stage (ZGS73) in Trials 2,3, and 4, after which it levelled off or showed a decline immediately prior to harvest. In Trial 1 in 1987, and Trials 6,7, and 8 in 1988, dry matter

Table 2. Environmental conditions during each development period, pre-, post-anthesis, and the growing season at 1987 and 1988 crop development trial locations.

	1987				1988		
Trial	1†	2	3	4	5	6	7+8
Development Period #1							
ZGS‡	30-32	12-21	21-30	21-30	23-31	23-31	23-31
Days	14	14	18	14	15	13	16
Mean air temp (°C)	12.3	12.0	13.4	13.5	13.5	16.3	16.3
Growing degree days	102.2	98.1	151.4	118.5	127.9	180.3	181.5
Rainfall (mm)	8.2	20.7	3.8	6.9	35.6	25.4	5.7
Pan evap§(mm d^{-1})	8.7	8.6	8.4	8.3	9.2	9.0	9.3
Development Period #2							
ZGS	32-45	21-30	30-31	30-43	31-65	31-65	31-65
Days	15	13	10	14	13	13	13
Mean air temp (°C)	13.2	13.7	15.7	14.3	21.8	23.6	23.3
Growing degree days	123.6	113.4	107.4	130.1	218.0	275.5	237.3
Rainfall (mm)	34.2	36.8	29.6	26.2	0	0	8.5
Pan evap(mm d^{-1})	6.2	5.3	6.0	6.1	13.7	12.5	13.0
Development Period #3							
ZGS	45-65	30-65	31-65	43-65	65-80	65-71	65-75
Days	12	16	15	13	14	14	14
Mean air temp (°C)	16.8	17.4	18.6	19.3	19.9	18.7	19.1
Growing degree days	142.1	198.0	203.5	186.4	209.2	248.2	197.2
Rainfall (mm)	6.0	26.7	1.8	6.5	7.6	10.2	11.6
Pan evap(mm d^{-1})	8.4	9.0	9.7	9.3	10.5	9.3	11.2
Development Period #4							
ZGS	65-73	65-73	65-75	65-77	80-92	71-83	75-92
Days	14	14	15	16	11	12	21
Mean air temp (°C)	18.8	18.5	19.2	17.5	20.2	19.8	19.8
Growing degree days	192.6	188.7	213.2	199.7	197.2	229.6	192.8
Rainfall (mm)	9.2	53.3	18.0	43.2	0	20.3	43.1
Pan evap(mm d^{-1})	9.4	7.5	8.0	7.5	12.1	8.3	5.6
Development Period #5							
ZGS	73-83	73-83	75-83	77-85	-	83-92	-
Days	15	14	12	12	-	11	-
Mean air temp (°C)	15.7	15.8	16.3	16.9	-	18.3	-
Growing degree days	160.1	150.7	135.6	143.1	-	189.6	-
Rainfall (mm)	52.0	50.8	9.7	57.5	-	49.5	-
Pan evap(mm d^{-1})	6.2	5.3	6.4	7.0	-	6.6	-
Development Period #6							
ZGS	83-92	83-92	83-92	85-92	-	-	-
Days	29	22	17	15	-	-	-
Mean air temp (°C)	17.3	18.0	19.3	18.0	-	-	-
Growing degree days	357.5	285.4	243.1	194.5	-	-	-
Rainfall (mm)	49.6	86.4	14.7	70.9	-	-	-
Pan evap(mm d^{-1})	5.9	4.8	7.3	5.9	-	-	-
Preanthesis Period							
Days	41	43	43	41	28	26	29
Growing degree days	368	409	462	435	346	456	419
Rainfall (mm)	48.4	84.2	35.2	39.6	35.6	25.4	14.2
Pan evap(mm d^{-1})	7.7	7.7	8.3	7.9	11.0	10.8	11.0
Post-anthesis Period							
Days	58	50	44	43	25	37	35
Growing degree days	710	625	592	537	406	667	508
Rainfall (mm)	110.8	190.5	42.4	171.6	7.6	80.6	54.7
Pan evap(mm d^{-1})	6.8	5.7	7.3	6.8	6.9	8.4	10.2
Growing Season							
Days	99	93	87	84	53	63	64
Growing degree days	1078	1034	1054	927	752	1123	927
Rainfall (mm)	159	275	78	211	44	106	69
Pan evap(mm d^{-1})	7.2	6.6	7.8	7.3	11.1	9.3	10.5

†Trials - see Table 3.2 for details on individual trials.
‡ZGS-Zadoks Growth Stage (see appendix 1).
§Pan evaporation - from the nearest Environment Canada recording station (max. 65 km).

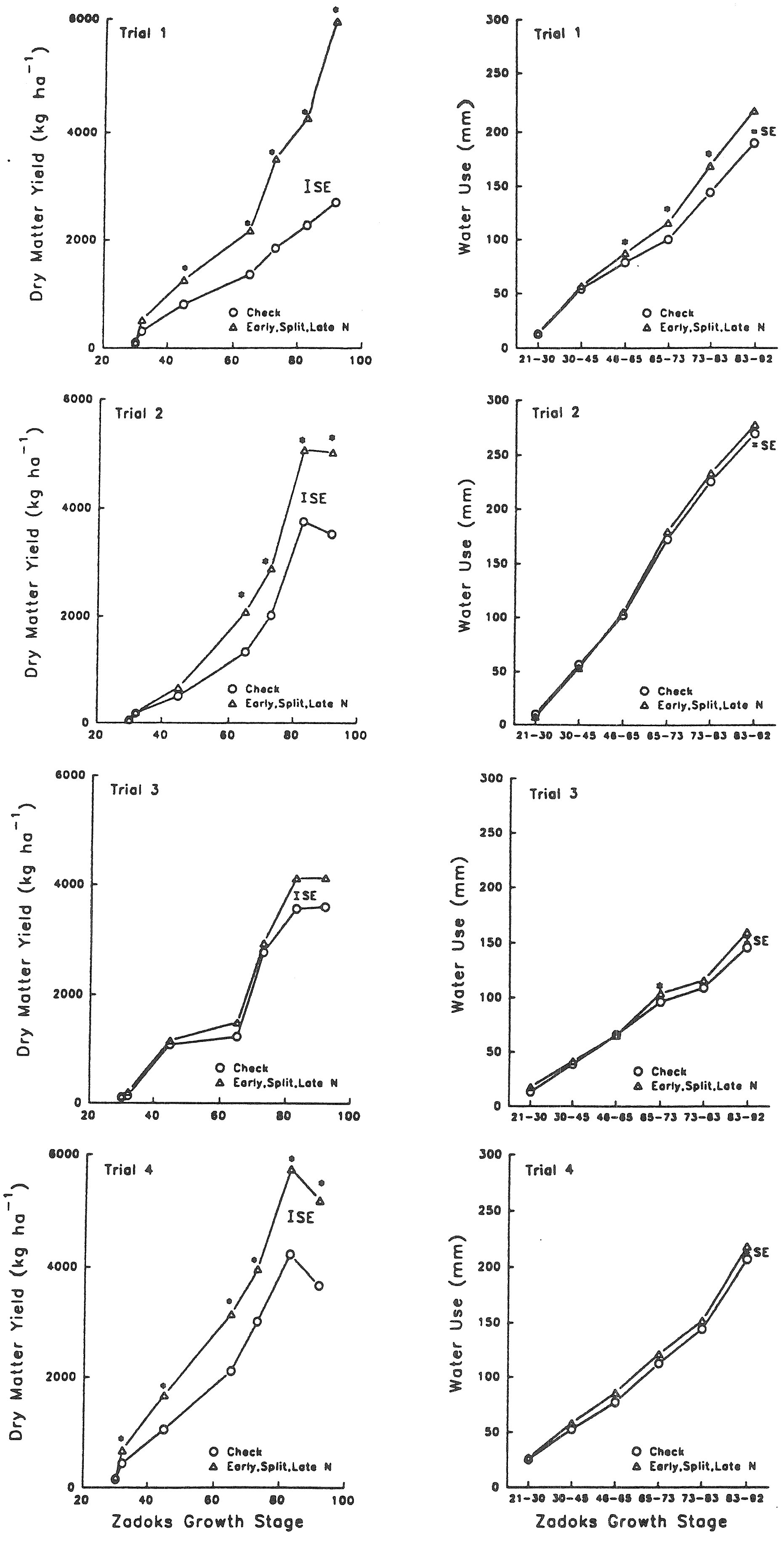

Figure 1. Evapotranspiration (ET) and dry matter production for no-till Norstar winter wheat in 1987 crop development trials. See Table 1 for details on individual trials. (*-indicates significant ($P<0.05$) N rate response).

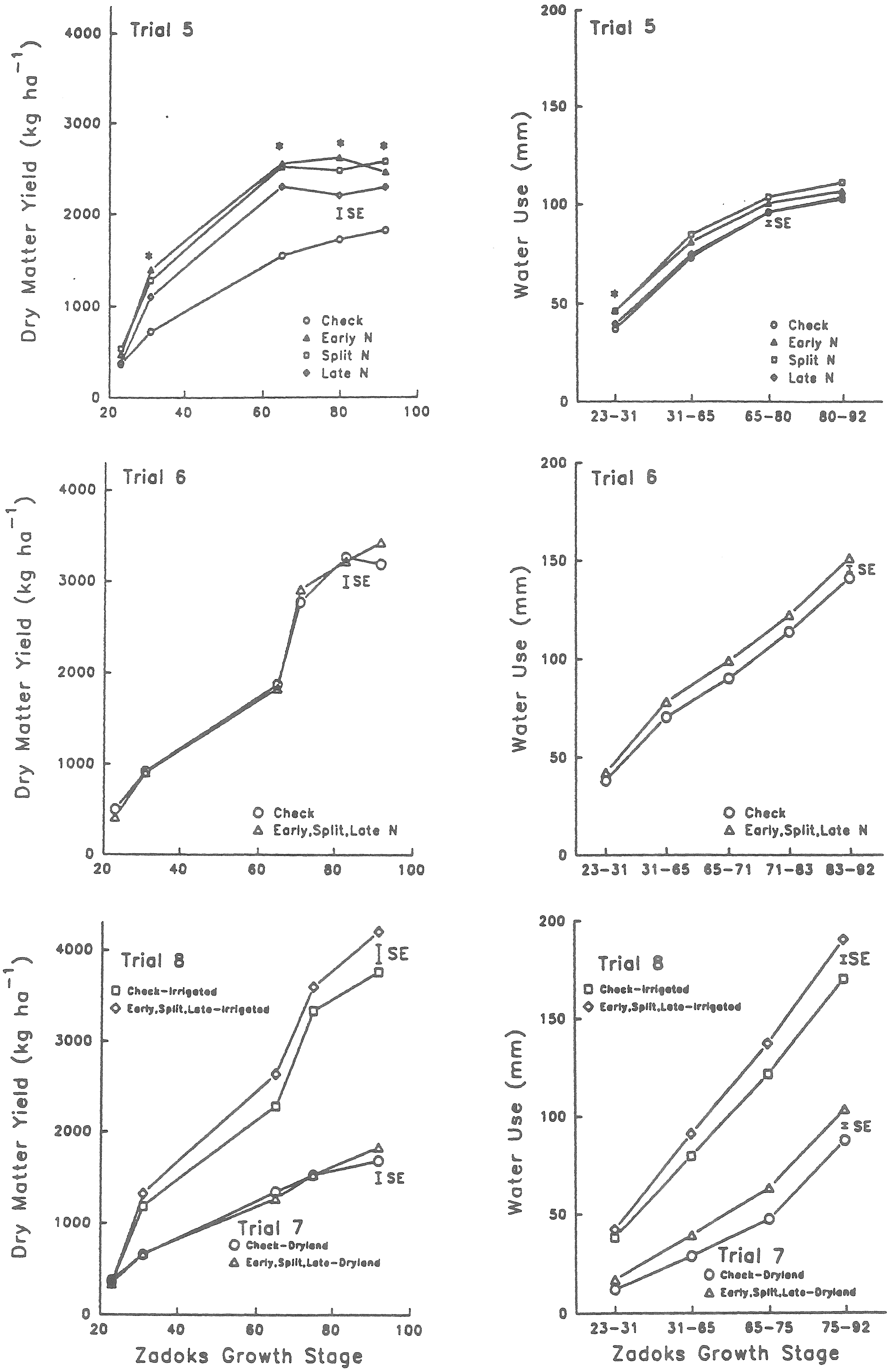

Figure 2. Evapotranspiration (ET) and dry matter production for no-till Norstar winter wheat in 1988 crop development trials. See Table 1 for details on individual trials. (*-indicates significant ($P < 0.05$) N rate response).

accumulated through to harvest. Similar increases in dry matter through to harvest have been reported for winter wheat by Harper et al. (1987) and Darroch and Fowler (1990). The dry matter accumulation through to harvest in Trial 1 is a reflection of an abundant supply of post-anthesis rainfall (Table 2). In 1988, the rapid senescence of plants under the high evaporative demand conditions experienced impaired the characteristic redistribution of biomass from accumulated dry matter to grain yield at maturity as illustrated by the absence of a pre-harvest plateau in dry matter response.

Added fertilizer N significantly ($P<0.05$) increased dry matter accumulation in Trials 1,2,4, and 8, both during the growing season and at harvest (Fig. 1 and 2). In Trials 3,6, and 7, spring soil residual nitrate-N levels were in excess of those required under the environmental conditions experienced (Table 1).

Compared to late-N application, early and split-N application significantly ($P<0.05$) increased dry matter yield at ZGS 23, 31, and 65 in Trial 5 (Fig. 2). With split-N treatments 67% of the total N rate was applied as early treatments, while the remaining 33% was applied at ZGS30 (Table 1). The similar response recorded for early and split-N treatments indicates that 67% of the full N rate was sufficient to meet crop requirements in this trial. Correction of the low soil residual nitrate-N levels in Trial 5 (18 kg N ha^{-1}) were required to optimize early season crop response to fertilizer N. No other significant ($P<0.05$) dry matter responses were recorded for time of N application.

Evapotranspiration

The seasonal pattern of evapotranspiration (ET) for each trial is illustrated in Figures 1 and 2. Unlike dry matter, ET showed a progressive increase through to harvest. Added fertilizer N significantly ($P<0.05$) increased ET from ZGS46 to ZGS83 in Trial 1, from ZGS65 to ZGS73 in Trial 3, and from ZGS23 to ZGS31 in Trial 5. The only time of N application response was in Trial 5, where early and split-N had significantly ($P<0.05$) higher crop water use than late-N application and the unfertilized check during DP1. Season-long ET ranged from a low of 75 mm at Trial 7 to 277 mm at Trial 2. Mean seasonal ET was 216 mm in 1987 and 128 mm in 1988. Previous studies have reported mean seasonal ET values of 245 mm (Hatfield et al., 1988) and 233 mm (Entz and Fowler, 1989) for well fertilized dryland winter wheat.

A similar pattern of ET was recorded for all 1987 trials, with 40% of the season long ET occurring pre-anthesis. Rainfall accounted for 61% of pre-anthesis ET and 98% post-anthesis ET. The high post-anthesis rainfall in Trials 2 and 4 (Table 2) actually resulted in a net increase in post-anthesis soil water. Daily ET rates ranged from a low of less than 1.0 mm d^{-1} during GP1 to a maximum of 2.46 to 5.21 mm d^{-1} during the growth period when highest rainfall was recorded (Table 2). Unlike previous reports of increases in ET from emergence to anthesis (Brown, 1971; Campbell et al., 1977), highest daily ET rates were always a function of rainfall events in the 1987 trials. While greater variability was observed among trials in 1988, mean pre-anthesis ET represented 55% of season long crop water use. This was similar to the results of Bauer et al.(1989) and Entz and Fowler (1989) who reported season long ET for winter wheat was equally divided between pre- and post-anthesis periods. However, present results differ in that mean pre-anthesis ET was only 78 mm, less than 50% of that recorded in previous studies (Bauer et al., 1989; Entz and Fowler, 1989). Rainfall accounted for 49 and 97% of pre- and post-anthesis ET in 1988, respectively. Seasonal ET derived from stored soil water was 16% in 1987 and 30% in 1988.

The significant ($P<0.05$) increase in ET for post-anthesis growth periods in Trials 1 and 3 resulted in added N increasing season long ET over the unfertilized check (Fig. 1). In both of these trials, increased ET was a reflection of N fertilized treatments using more post-anthesis rainfall than the unfertilized check. The increased ET recorded during DP1 in Trial 5 did not influence the season long crop water use (Fig. 2). The absence of differences in seasonal ET in Trials 2,4,6,7, and 8 indicates similar crop water use patterns for both the fertilized and unfertilized treatments. There are several reports in the literature of added N increasing total soil water extraction over the unfertilized check (Ramig and Rhodes, 1963; Brown, 1971; Singh et al., 1975). However, there are also reports of no difference in crop water use with N fertilizer additions under dryland recrop conditions, where all the available soil water is extracted by the crop (Warder et al., 1963; Campbell et al., 1977). The high level of post-anthesis ET derived from rainfall in this experiment (98% in 1987 and 97% in 1988) leads to the conclusion that available soil water was extracted before anthesis with post-anthesis grain filling dependent on subsequent rainfall events.

Seasonal Pattern of Tiller Production and Senescence

The seasonal pattern of tiller production and senescence was monitored in 1988 trials. Fertilizer N additions significantly ($P < 0.05$) increased tillers in Trials 5,6, and 8 (Fig. 3). In all three trials, the highest N rate (202 kg N ha^{-1}) produced the highest tiller number. Early and split-N application resulted in higher tiller numbers than late-N application at the first two sampling dates in Trial 5, and the first three sampling dates in Trial 8 (Fig. 4). In both Trials 5 and 8, a three week delay in N application (late-N) resulted in lower initial tiller numbers than were observed with early and split-N application dates. At no time did late-N produce a maximum tiller number achieved with early or split-N application. Mclaren (1981) and Darwinkel (1983) have also reported that early-N application promotes the development of higher order tillers, which have the potential to contribute more to grain yield than late-formed tillers (Ishag and Taha, 1974; Darwinkel et al., 1977). The similar initial tiller numbers for early and split-N treatments indicates that early application of 67% of the full N rate (split-N) was sufficient to meet the N requirements for tiller production of the crop in this experiment.

The high evaporative demand created by the elevated air temperatures during DP2 (ZGS30 to ZGS65) in 1988 resulted in a rapid reduction in tiller numbers (Fig. 3 and 4). These observations indicate that tiller senescence is an escape mechanism for plants exposed to high evaporative demand. Aspinall et al. (1964) reported that a reduction in tillers per plant is the primary response of cereals to soil moisture stress. The highest tiller loss occurred in Trial 5 of the present study, where 58 tillers m^{-2} d^{-1} senesced during the seven days between ZGS40 and ZGS55. These observations are consistent with past reports that high air temperatures shorten the vegetative and tiller developmental phase of cereals (Campbell and Read, 1968; Ishag and Taha, 1974; Frank and Bauer, 1982). No significant ($P > 0.05$) difference was recorded in spike number at harvest in Trials 5,7, and 8 indicating that the negative effect of high evaporative demand during stem elongation on tillering was greater for N fertilized treatments with the result that the early season N induced increases in tiller number were lost. Campbell and Davidson (1979) have also reported that under abundant N supply high air temperatures (>25°C) reduced tiller numbers to a greater extent than low temperature.

Maximum tiller numbers were established prior to the beginning of sampling in this experiment. The adjustment in tiller numbers to compensate for adverse environmental conditions leads to the conclusion that a high tillering capacity is desirable for environments characterized by erratic precipitation patterns (Hsu and Walton, 1971). Therefore, early correction of N deficiencies are critical for the establishment of high tiller numbers and subsequent maximum spike production. The supplemental addition of 100 mm of irrigation water in Trial 8 improved surface soil water content, increasing maximum tiller number by 21% (Fig. 3) and harvest spike number by 80% over Trial 7. This supports the conclusion of Day and Intalap (1970) that removing water stress during stem elongation increases harvest spike number by reducing tiller senescence.

Leaf Area, Relative Water Content, and Leaf Conductance

Leaf area index (LAI) and plant water status parameters, leaf relative water content (RWC) and leaf stomatal conductance (g_l), were monitored during the growing season to determine crop response to changes in environmental conditions and N treatment. Environmental conditions varied considerably between 1987 and 1988 (Table 2). Leaf area developed slowly under the cool, dry conditions in the spring of 1987 in Trials 1 and 2 (Fig. 5). However, once established, leaf area was

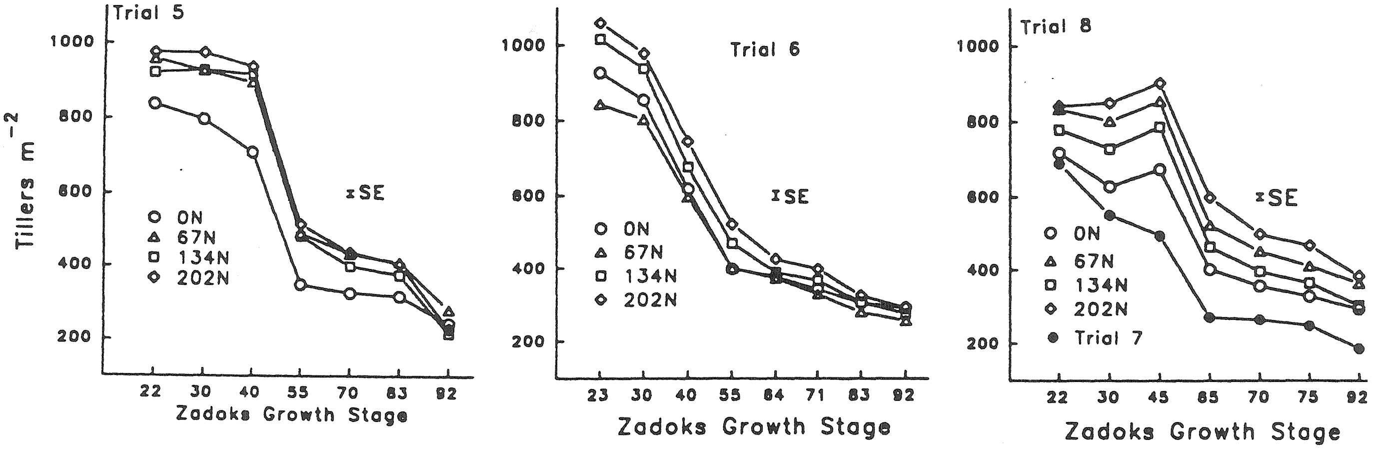

Figure 3. Seasonal pattern of tiller production and senescence in response to N rate for 1988 crop development trials. See Table 1 for details on individual trial locations.

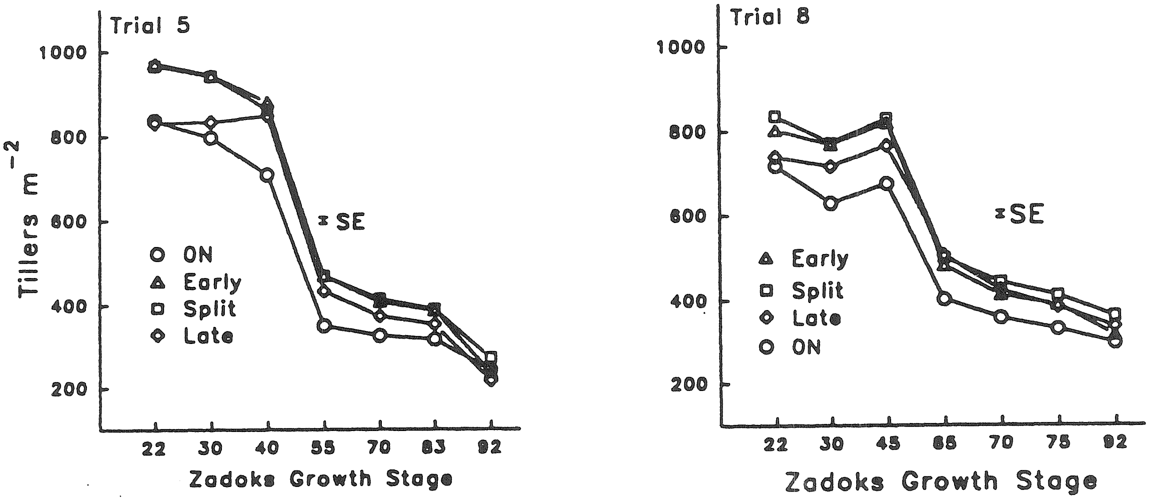

Figure 4. Seasonal pattern of tiller production and senescence in response to N time for 1988 crop development trials. See Table 1 for details on individual trial locations.

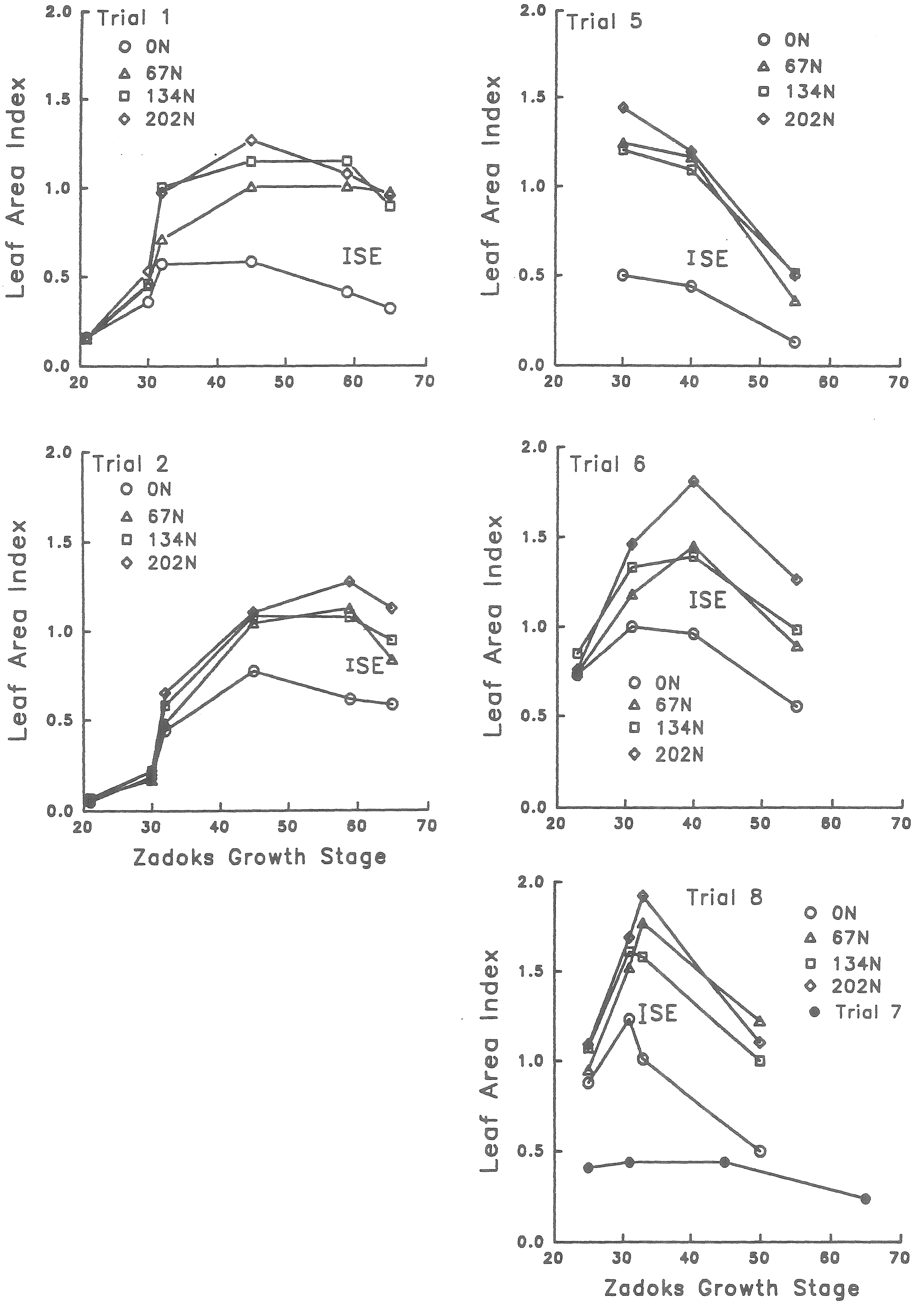

Figure 5. Seasonal pattern of LAI response to N rate at 1987 and 1988 crop development trials. See Table 1 for details on individual trial locations

maintained up until anthesis. In Trials 5,6, and 8 in 1988 increased rainfall during DP1 resulted in a rapid increase in LAI. In these trials high air temperatures during stem elongation in 1988 increased evaporative demand, resulting in rapid leaf senescence and declining LAI prior to anthesis. Morgan (1988) reported that the development and maintenance of a larger photosynthetic surface was the major factor in increasing the growth and yield of fertilized compared to unfertilized wheat. The collapse of LAI during stem elongation in 1988 prevented the increased leaf area with added N from being translated into increased grain yield.

The general pattern was for g_l to decline as the season progressed, with per unit leaf area g_l highest during the pre-anthesis period when leaf area was also highest. Mean 1988 g_l was 60% of that recorded in 1987, reflecting the increased evaporative demand in 1988. Where significant responses were recorded, added N increased LAI and pre-anthesis g_l, and decreased leaf RWC and post-anthesis g_l. Early season g_l was higher in 1987 than 1988 due to lower initial LAI (Fig. 5). By ZGS30 LAI was between 0 and 0.5 in 1987 and 0.5 and 1.5 in 1988. While LAI developed slower in 1987, it was maintained longer at a higher level than 1988. The highest LAI (1.92) was recorded with the 202 kg N ha^{-1} rate in Trial 8. This is similar to the LAI of 1.25 suggested by Green et al. (1983) to be necessary for complete ground cover and minimum before growth can proceed at a maximum rate. The rapid decline in LAI with high evaporative demand during stem elongation in 1988 is particularly evident in Trial 5 where, due to a delay in sampling until ZGS30, no increase was recorded in LAI (Fig. 5).

Fertilizer N additions increased both LAI (Fig. 5) and unit leaf area g_l (Fig. 6) at ZGS32 in Trials 1 and 2. Similar increases in both pre-anthesis leaf area and g_l have been reported for field grown spring wheat (Morgan, 1988). The increased g_l and LAI response imply a greater photosynthetic activity for the N fertilized treatments. While post-anthesis LAI was not determined in these trials, added N significantly ($P<0.05$) reduced g_l relative to the unfertilized check during ZGS83 in Trial 1, ZGS69 and 83 in Trial 5, and ZGS73 in Trial 8 (Fig. 6). In Trial 1, the reduction on g_l at ZGS83 was in response to the increased level of post-anthesis ET with added fertilizer N (Fig. 1). The unfertilized check plots had lower post-anthesis ET, which increased available soil water and maintained higher leaf RWC and g_l. The negative response of g_l after anthesis in Trials 5 and 8 indicates the development of lower leaf water status (RWC) for N fertilized treatments relative to the unfertilized check (Bradford and Hsiao, 1982). A quadratic regression equation was used to fit the relationship between RWC and g_l (Fig. 7). While g_l increased at the upper range of leaf RWC, it was never lower than 0.2 cm s^{-1} once leaf RWC values dropped below 80%. This supports the findings of Cowan (1984) that stomatal opening shows a strong dependence on plant tissue water content and evaporative demand.

A significant ($P<0.05$) time of N application effect was recorded for LAI in Trials 1,5, and 8 (Fig. 8). Early-N application produced the highest LAI, illustrating that any delay in the correction of a early season N deficiency will result in slower development of a smaller leaf area (Khalifa, 1973; Ellen, 1987). The absence of a N application time by sampling date interaction ($P>0.05$) indicates that the stimulation of leaf area with early applied N was maintained throughout the period that measurements were made.

Summary and Conclusions

The variable growing season weather conditions experienced in semiarid climates like that of the Canadian prairies have a large influence on no-till recrop winter wheat growth and yield response to N fertilization. Growing season environmental conditions and plant-available-N levels also play an important role in determining the efficiencies of N translocation to the seed.

The objective of this experiment was to determine the influence of time of N application on early season plant development and crop water use of no-till seeded winter wheat. Early-N application produced a larger early season plant response than late-N application. There was no difference in plant response to early and split-N application times. Where there were differences in tiller response

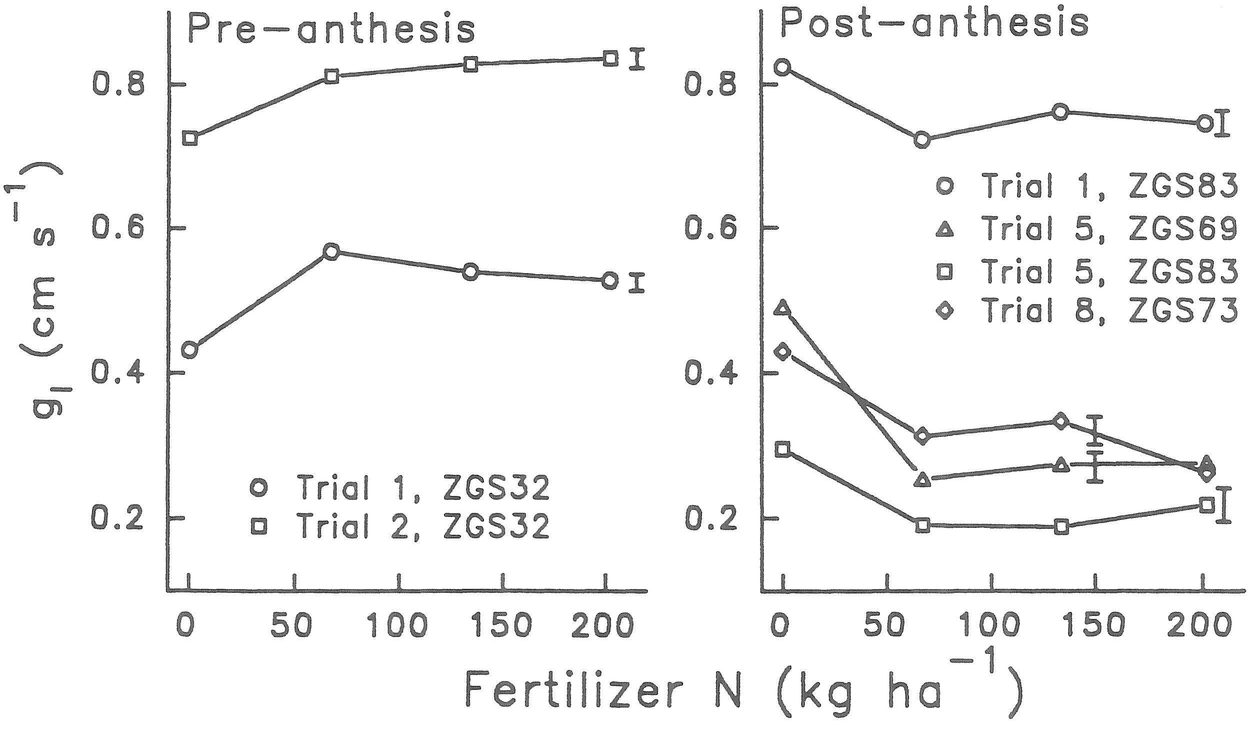

Figure 6. Relationship between leaf conductance (g_l) and N fertilizer rate for Norstar winter wheat at selected trials and growth stages where significant ($P < 0.05$) responses were recorded. See Table 1 for details on individual trials.

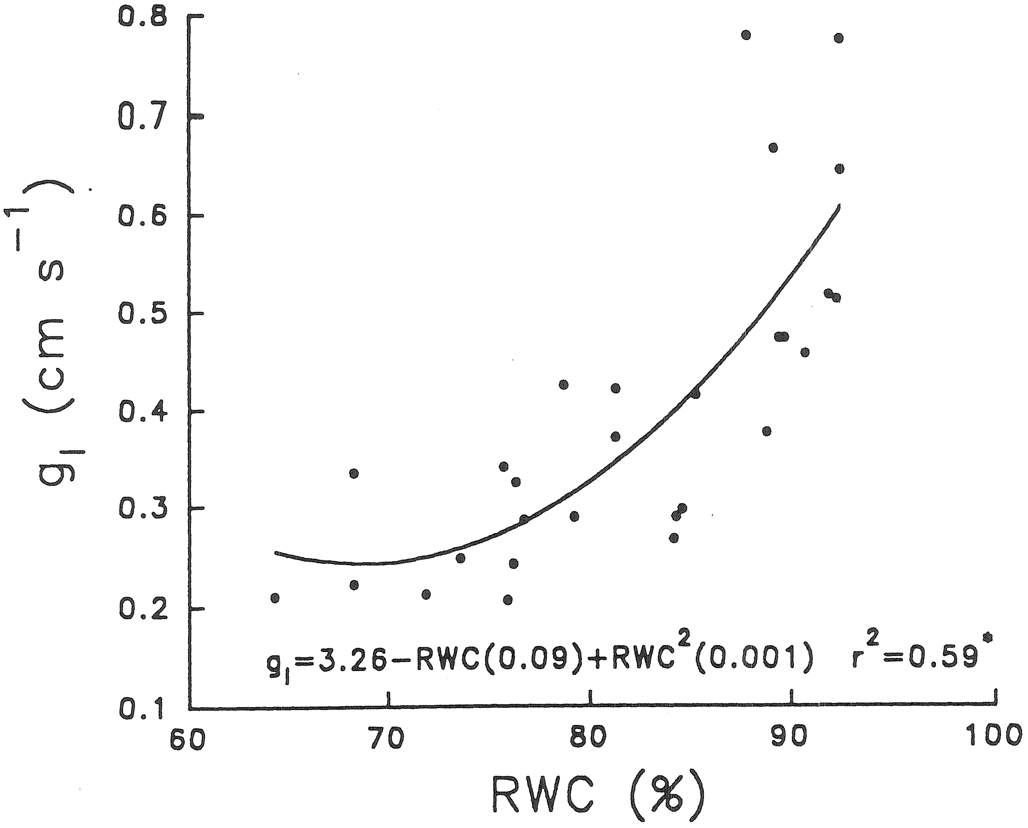

Figure 7. Relationship between leaf conductance (g_l) and leaf RWC in 1987 and 1988 crop development trials. Points represent trial mean values at various growth stages (n=28).

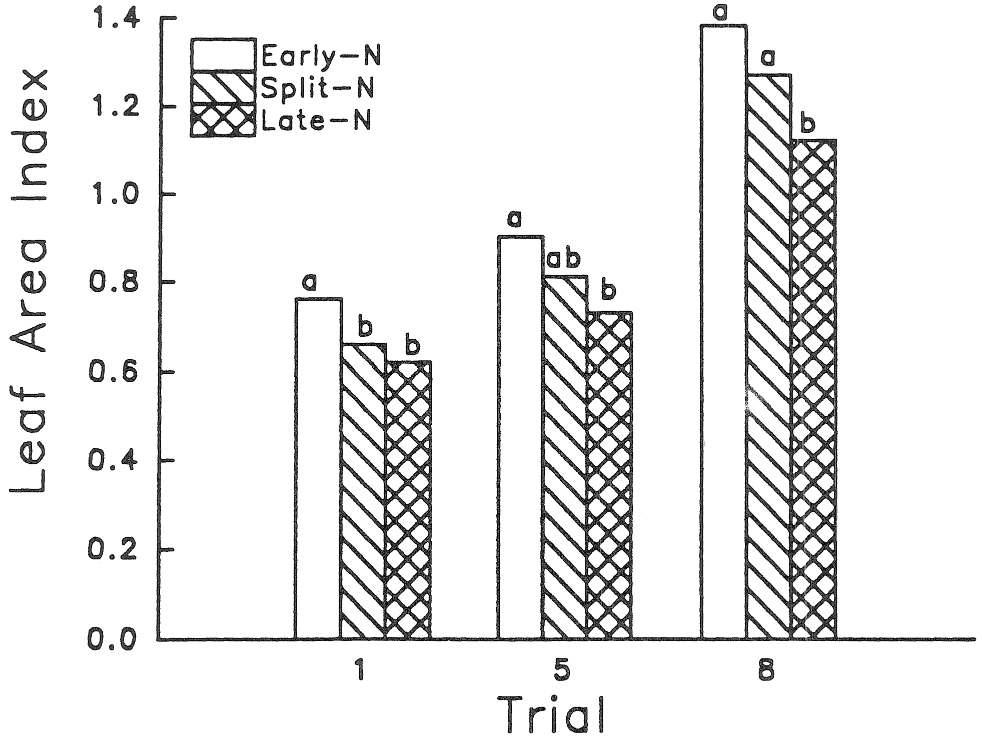

Figure 8. Main effect response to time of N application at 1987 and 1988 crop development trials (see Table 1 for details on individual trial locations).

due to time of N application, delaying N application by 3 weeks (late-N) restricted tiller development. Early-N application was critical for the stimulation of high tiller numbers because maximum tiller number were established prior to the beginning of sampling at ZGS30.

While leaf area developed slowly under the cool, dry conditions in 1987, it was maintained through to anthesis. A rapid initial leaf area response in 1988 was followed by a just as rapid decline during stem elongation. Early- compared to late-N application increased the leaf area in 3 of the 6 trials. Leaf area response to early-N application was maintained throughout the period that samples were collected. Maximum LAI recorded in this study was 1.92.

Added fertilizer N increased pre-anthesis g_l in 1987 trials and decreased post-anthesis g_l in 1987 and 1988 trials. The combined effect of N stimulated increases in pre-anthesis leaf area and g_l in 1987 resulted in an increased grain yield response over the unfertilized check at Trials 1 and 2. There was a strong positive correlation ($r=0.77^{**}$) between g_l and leaf relative water content. This positive relationship indicates that high plant photosynthetic activity is dependent on the maintenance of high tissue water content.

A high evaporative demand during DP2 in 1988 resulted in the pre-anthesis 'collapse' of tiller numbers and leaf area and a reduction in both leaf relative water content and leaf conductance. While N fertilization initially established a higher production potential by increasing tiller number and leaf area, the high stress conditions eliminated this advantage prior to anthesis.

Mean 1988 ET was 128 mm, only 59% of the 216 mm recorded in 1987. On average, 23% of the seasonal ET was derived from soil water with most of this stored soil water being exhausted before anthesis. During the post-anthesis period, 98% of ET came from rainfall. These results indicate that under the recrop conditions used to produce no-till winter wheat in Saskatchewan, early correction of N deficiencies is required to achieve rapid pre-anthesis dry matter accumulation and tiller formation, and to increase and maintain a high leaf area index.

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