A COMPARISON OF NO-TILL WINTER WHEAT RESPONSE TO SEED-PLACED AND BROADCAST NITROGEN FERTILIZER PLACEMENT

J. Brydon and D.B. Fowler
Crop Development Centre
University of Saskatchewan

ABSTRACT

Winter wheat (Triticum aestivum L.) can be successfully overwintered in most regions of the Canadian prairies if it is no-till sown into standing stubble immediately after harvest of the previous crop. Soil nitrogen (N) is usually deficient in this production system and N fertilization is necessary to optimize yield and maintain minimum quality standards. In the present study, the effect of seed-placed (SP), early spring broadcast (BC), and SP/BC combinations of ammonium nitrate fertilizer (AN) on winter survival, grain yield and protein production of winter wheat was investigated in 15 field trials conducted over a wide range of soil types and environmental conditions in Saskatchewan. Ammonium nitrate fertilizer placed in a 20 mm wide band with 'Norstar' winter wheat seed produced average grain yield-N responses for 67 and 101 kg N ha^{-1} treatments that were only 86 and 70% of comparable BC treatments, respectively. Average grain protein yield-N responses for the 67 and 101 kg ha^{-1} SP N treatments were 86 and 73% of comparable BC treatments, respectively. Changes in grain protein concentration due to increased rate of SP N were small. Similar grain and grain protein yield responses for 34 kg N ha^{-1} SP and BC treatments indicated that AN could be seed placed at low rates without reduced N-use efficiency. However, significant reductions in winter survival potential in all trials where differential winterkill occurred suggested that even rates as low as 34 kg N ha^{-1} SP AN should be avoided when cultivars with marginal winter hardiness are utilized.

INTRODUCTION

A high risk of winterkill has restricted the northern expansion of the traditional winter wheat production area of the North American Great Plains. The introduction of a practical snow management system, which utilizes no-till seeding into standing stubble immediately after harvest of the previous crop ("stubbling-in"), has reduced the winterkill risk and provided an opportunity for the expansion of winter wheat production in this region (Fowler, 1983).

Most stubble fields on the Canadian prairies are deficient in plant-available-soil nitrogen (N) and N fertilization is usually necessary to optimize yield (Fowler et al., 1989a) and maintain minimum grain quality standards of winter wheat (Fowler et al., 1989b). However, the no-till requirement of stubbled-in winter wheat has presented problems when many of the traditional N-application methods are employed (Fowler, 1983). For example, the limited time between harvest of the previous crop and seeding, seedbed damage, and stubble breakdown restrict the banding options that are practical. As a result, early spring broadcast application has been the recommended method of applying N fertilizer with the stubbling-in management system. Seed placement of N fertilizer is also an option but concerns over stand damage (Nyborg, 1961; Toews and Soper, 1978) and reduced winter hardiness (Freyman and Kaldy, 1979; Tyler et al., 1981; Grant et al., 1984) have restricted the use of this placement option. Therefore, the objective of this study was to determine the effect of seed-placed ammonium nitrate fertilizer on winter survival, grain yield and protein production of stubbled-in winter wheat produced in Saskatchewan.

MATERIALS AND METHODS

Fifteen N fertilizer field trials were conducted from 1983 to 1986 in Saskatchewan, Canada (Table 1). Nitrogen fertilizer was applied as commercial grade ammonium nitrate placed with the seed at the time of seeding (SP), hand-broadcast (BC) on the soil surface in the early spring before the growth of winter wheat had resumed, or in combinations of both SP and BC. Fertilizer rates were 0,34,67,101 and 135 kg N ha^{-1} applied in the following treatment combinations: 0, 34 SP, 67 SP, 101 SP, 34 BC, 67 BC, 101 BC, 135 BC, 34 SP 34 BC, 34 SP 67 BC, 34 SP 101 BC, 67 SP 34 BC, 67 SP 67 BC, 101 SP 34 BC. Experimental design for all trials was a randomized complete block with four replicates.

With the exception of trial 15, which was seeded into summerfallow, 'Norstar' winter wheat was no-till seeded into standing stubble (Table 1) with a five-row small plot hoe-press drill immediately after harvest of the previous crop (between 24 Aug. and 7 Sept. of each year). Seeding rate was 100 kg ha^{-1}. Row spacing was 200 mm and plots were 5.5 m long. The hoe openers were 20 mm wide and were followed immediately by a packing wheel. Phosphate fertilizer was applied as mono-ammonium phosphate with the seed at rates recommended for each soil type. Elements other than phosphorus and nitrogen were not considered to be limiting. Soil moisture conditions were favorable for rapid germination at all trial locations in all years.

In the early spring of each year, mid-row soil samples to a 60 cm depth were collected (0 to 15, 15 to 30, and 30 to 60 cm increments) from plots in each trial that had not received N fertilizer for nitrate analyses by the Saskatchewan Institute of Pedology, soil testing laboratory. Available NO_3-N

Table 1. Trial location, previous crop, soil characteristics and general growing season environmental conditions for winter wheat ammonium nitrate fertilizer trials in Saskatchewan, 1983-86.

Trial	Year	Previous crop[†]	Classification[‡]	Texture[‡]	NO_3N in early spring (kg N ha^{-}	Growing season environmental conditions[¶]
1. Clair	1983-84	Barley	Udic Haploboroll	L	29	Good
2. Outlook	1983-84	Rapeseed	Typic Haploboroll	FSCL	111	Irrigation
3. Paddockwood	1983-84	Rapeseed	Entic Udic Haploboroll	L	36	Good
4. Saskatoon	1983-84	Rapeseed	Vertic Haploboroll	C	103	Poor
5. Clair	1984-85	Rapeseed	Udic Haploboroll	CL	42	Good
6. Outlook	1984-85	Rapeseed	Typic Haploboroll	L	90	Irrigation
7. Paddockwood	1984-85	Rapeseed	Entic Udic Haploboroll	L	38	Winterkilled
8. Saskatoon	1984-85	Rapeseed	Vertic Haploboroll	CL	99	Winterkilled
9. Carlyle	1985-86	Mustard	Typic Haploboroll	L	73	Good
10. Clair	1985-86	Barley	Udic Haploboroll	L	47	Average
11. Handel	1985-86	Spring wheat	Typic Haploboroll	L	100	Poor
12. Indian Head	1985-86	Barley	Udic Haploboroll	C	44	Average
13. Maidstone	1985-86	Spring wheat	Udic Haploboroll	L	55	Poor
14. Paddockwood	1985-86	Rapeseed	Boralfic Argiboroll	L	46	Poor
15. Porcupine Plain	1985-86	Summerfallow	Boralfic Argiboroll	CL	311	Average

[†]Barley (_Hordeum_ _vulgare_ L.), Rapeseed (_Brassica_ _campestris_ L.), Mustard (_Sinapsis_ _alba_ L.), Spring wheat (_Triticum_ _aestivum_ L.).

[‡]Soil Survey Staff (1975)

[§]Amount of N in the 0-60 cm soil layer of unfertilized plots.

[¶]Good - Above average rainfall that was well distributed during the growing season. Moisture r es adequate to cope with wind and heat stress experienced.
Average - No extended dry periods. Heat and/or wind stress may have been yield reducing facto Average growing season rainfall for this area is 208 to 278 mm.
Poor - Periodic drought combined with heat and/or wind stress.
Winterkill - Trial abandoned in the spring due to winter damage.

concentrations were determined colorimetrically by auto analyzer using cadmium reduction (Technicon Industrial Method #100-70W, Technicon Instrument Corp., Tarrytown, N.Y.). Only estimates of NO_3-N were utilized because field trials in Alberta and Saskatchewan have demonstrated that the relationship between grain yield or protein concentration and mineral N (NO_3-N plus NH_4-N) is no better than for NO_3-N) alone (Nuttall et al., 1971; Malhi et al., 1985). Soil and fertilizer N were considered to be equally plant-available. Therefore, total available N was calculated as the sum of soil NO_3-N to 60 cm depth, as estimated from the soil test, and added fertilizer N (Heapy et al., 1976; Zentner and Read, 1977; France and Thornley, 1984; Bole and Dubetz, 1986).

Soil was moist to at least 60 cm depth in the spring in all trials. General environmental conditions were monitored throughout the growing season (Table 1).

In May of each spring, after allowing time for new growth, estimates were made of the area within each plot that had suffered complete winterkill of plants (WKA) at each location (Fowler et al., 1976). Percent survival was determined as follows: % survival = 100 - 100 WKA/total plot area. These values were then utilized to calculate a Field Survival Index (FSI) for each treatment. The FSI was developed as a measure of the relative winter hardiness of wheat cultivars (Fowler and Gusta, 1979). For example, the cultivars Norstar, 'Sundance', 'Norwin', and 'Winalta' have FSI of 514, 494, 470, and 463, respectively. The procedure for determining FSI has been detailed in other publications (Fowler and Gusta, 1979; Fowler et al., 1983). Differences in FSI of cultivars represent the average percent difference expected in field survival, eg., Norstar versus Norwin = 514-470 = 44% difference in expected winter survival potential. The FSI has also been utilized to express the effects of shortfalls in a management practice on winter survival potential (Fowler, 1982). In the present study, the predetermined FSI for Norstar was utilized as the value for each fertilizer treatment that did not receive seed-placed ammonium nitrate. Then, utilizing only plots that had partial winterkill, i.e., $\geq$ 5% to $\leq$ 95% survival, and the FSI for BC treatments, estimates were made of the FSI for each SP N treatment.

Grain yield (90 g H_2O kg^{-1} dry grain) was determined from a 5.0 m long and 0.6 m wide sample that was harvested from each plot at maturity. Grain protein concentration and protein yield (grain yield x protein concentration) were determined for each plot in each trial. Protein concentrations were determined from Kjeldahl N (N x 5.7) or by the Udy dye method (Udy, 1971). Kjeldahl analyses were utilized to standardize protein concentrations in each trial analyzed by the Udy dye method.

Analyses of variance were conducted to determine the significance of treatment differences within each fertilizer trial. An inverse polynomial equation with a modification for yield depression at high N levels (France and Thornley, 1984) was used to describe the relationship between available N and both grain and grain protein yield. Use of this function to describe N response curves of grain and grain protein yield has been elaborated on in earlier publications (Fowler et al., 1989a; b). The inverse polynomial equation takes the form:

$$Y = \frac{\underline{u}N}{N + \underline{u}/\underline{e}} (1 - N/\underline{s}), \qquad [1]$$

where Y = predicted grain or protein yield (kg ha^{-1})

N = total available N (kg N ha^{-1})

$\underline{s}$ = a measure of yield sensitivity to high N levels (large $\underline{s}$ indicates less sensitivity)
$\underline{u}$ = upper limit of yield achieved in the absence of sensitivity to high levels of N (kg ha^{-1})
$\underline{e}$ = maximum N use efficiency at low levels of N (kg yield kg N^{-1})

Non-linear regression procedures outlined by the SAS Institute (1985) were used to provide least-squares estimates of the regression coefficients $\underline{u}$, $\underline{e}$ and $\underline{s}$. In most cases, limited data prevented the statistical program from converging on reasonable estimates of all three coefficients. In these instances, $\underline{s}$ was held constant at the value (903 for grain and 949 for grain protein yield) determined in earlier studies (Fowler et al., 1989 a; b) and $\underline{u}$ and $\underline{e}$ were successfully estimated.

The Gompertz equation was employed to describe the relationship between protein concentration and available N. Use of this function to describe the protein concentration-N response curve has been detailed in an earlier publication (Fowler et al., 1989b).

The Gompertz equation takes the form:

$$P = \underline{M} + \underline{A} \exp [-\underline{B} \exp (-\underline{KN})] \quad [2]$$

where P = predicted protein concentration (g protein kg^{-1} dry grain)
$\underline{M}$ = minimum protein concentration (g protein kg^{-1} dry grain)
$\underline{M}$ + $\underline{A}$ = asymptotic protein concentration achieved at high N levels
$\underline{B}$ = determines N level at which protein concentration reaches $\underline{M}$ + 0.5$\underline{A}$
$\underline{K}$ = coefficient that determines the rate P increases to $\underline{M}$ + $\underline{A}$.
$\underline{N}$ = total available N (kg ha^{-1}).

The coefficients $\underline{K}$ and $\underline{M}$ were held constant at 0.0230 and 95.4, respectively (Fowler et al., 1989b). Non-linear regression procedures outlined by the SAS Institute (1985) were used to provide least-squares estimates of the coefficients $\underline{A}$ and $\underline{B}$.

RESULTS AND DISCUSSION

A wide range of soil types and climatic conditions were represented in the 15 site-years considered in this study (Table 1). These large differences in environmental conditions were reflected in significant ($P \leq 0.05$) differences due to trial location for winter survival, grain yield, grain protein yield, and grain protein concentration.

While not considered to be as great a problem as with urea, winter wheat stand reductions have been noted with seed-placed ammonium nitrate (Brage et al., 1960; Olson and Dreier, 1956), especially under poor soil moisture conditions during germination. In the present study, moisture conditions were favorable for germination in all trials and the only stand reductions observed were due to winterkill. There was complete winterkill of the Saskatoon trial (trial 8) and severe winter damage to all treatments in the Paddockwood trial (trial 7) in 1984-85. Both these trials were abandoned after winter survival had been determined int he spring. Winterkill was also observed at Clair (trial 5) and Outlook (trial 6) in 1984-85 and Handel (trial 11 and Maidstone (trial 13) in 1985-86. In these trials, stand reduction averaged less than 15 percent in treatments that did not receive seed-placed N. Seed-placed N treatments sustained significantly ($P \leq 0.01$) more winter damage and level of winterkill was directly related to the amount of seed-placed N applied (Fig. 1). The absence of a significant location by treatment interaction for FSI in a combined analyses of variance of data from these trials indicated that the effect of seed-placed N in reducing winter hardiness was similar for all locations. The FSI units (%) used to measure these shortcomings are the same as for cultivar FSI. Therefore, the consequences of suboptimal management can be determined for a cultivar by simple subtraction. For example, 101 kg ha^{-1} ammonium nitrate N banded in the seed row would, on average, reduce the FSI of the winter-hardy cultivar Norstar (514-48 = 466) to approximately that of the less winter-hardy cultivars Norwin (470) and Winalta (463) without seed-placed N (Fig. 1). In other words, the winter hardiness advantage of Norstar over Norwin and Winalta would be completely eliminated by the placement of 101 kg ha^{-1} ammonium nitrate N with Norstar seed.

Previous studies have demonstrated a strong positive relationship between grain and grain protein yield (Fowler et al. 1989b). This relationship was also evident in the present study and similar N rate response patterns were observed for grain and grain protein yield. Early spring broadcast ammonium nitrate fertilizer applications gave significant ($P \leq 0.05$) N rate responses for grain yield in ten and grain protein yield in eleven of thirteen trials. Residual soil N was exceptionally high in trial 15 and a severe late season drought limited grain and grain protein yield responses to added N in trial 4. A late season drought restricted grain yield and resulted in small, but significant ($P \leq 0.05$), grain protein yield-N responses in trial 13.

The inverse polynomial function (Eq.[1]) outlined by France and Thornley (1984) provided an excellent description of the grain (Table 2, Fig. 2) and grain protein (Table 3, Fig. 3) yield-N response patterns observed for early spring broadcast ammonium nitrate fertilizer in these trials. Average reductions in sums of squares due to model were 99.8% for both grain and grain protein yield. The grain (Fig. 2) and grain protein (Fig. 3) yield-N response curves for these trials demonstrated the large interaction between plant available N and environmental conditions, especially moisture, in determining yield (Ramig and Rhoades, 1963; Fowler et al., 1989a). Poor yield-N responses were observed under dry, high stress conditions, while larger N responses occurred under more favorable growing conditions (Fig. 2 and 3).

The winter wheat plots that received seed-placed (SP) N were severely winter damaged and were not harvested in trials 5,6,11 and 13. Fertilizer responses were not observed for any treatments in trials 4 and 5. In the remaining trials, treatments receiving 67 and 101 kg ha^{-1} SP N (101 SP, 67 SP 34 BC, 67 SP 67 BC, 101 SP 34 BC) did not produce as large a grain (Table 5) or grain protein (Table 6) yield-N response as comparable spring broadcast (BC) N treatments (101 BC, 135 BC). The one exception to this generalization occurred for the 67 kg ha^{-1} SP N treatment (67 SP 34 BC, 67 SP 67 BC) in trial 10. In contrast split N applications that included 34 kg SP N ha^{-1} (34 SP 67 BC, 34 SP 101 BC) usually performed as well as comparable BC N treatments. A combined analyses of variance, which considered only the 101 and 135 kg ha^{-1} total N treatments for these seven locations (Table 5 and 6), demonstrated a significant ($P \leq 0.05$) SP N rate by location interaction for both grain and grain protein yield indicating that the effect of SP N was not constant over environments. However, as indicated earlier, SP treatments never produced significantly higher grain or grain protein yields than comparable BC treatments (Table 5 and 6). Average grain yield-N responses for the 67 and 101 kg ha^{-1} SP N treatments were only 86 and 70% of comparable BC N treatments, respectively (Table 5). Similarly, average grain protein yield-N responses for the 67 and 101 kg ha^{-1} SP N treatments were 86 and 73% of comparable BC N treatments, respectively (Table 6).

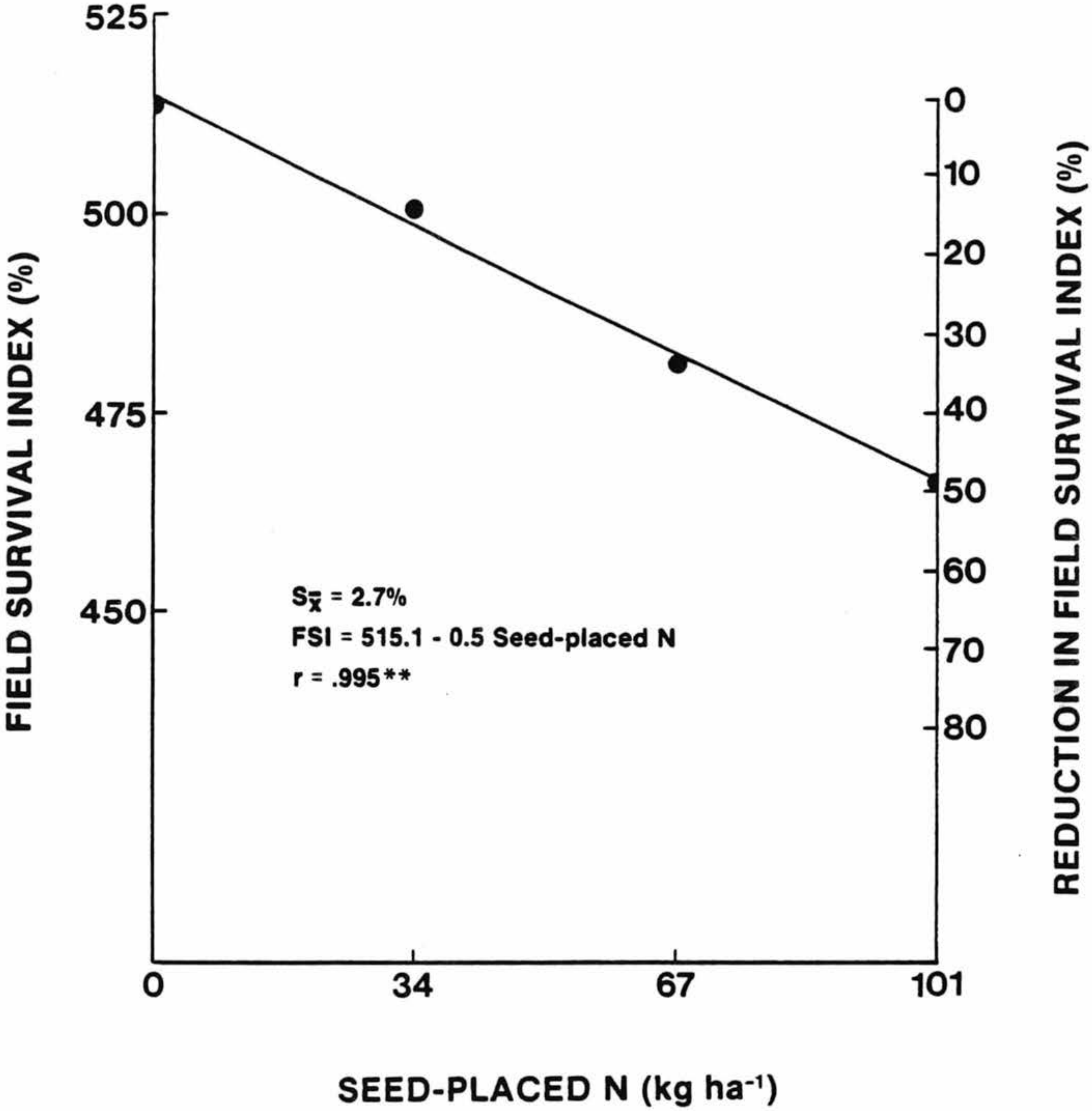

Fig. 1. Influence of seed-placed ammonium nitrate fertilizer on Field Survival Index (FSI) of Norstar winter wheat grown in Saskatchewan.

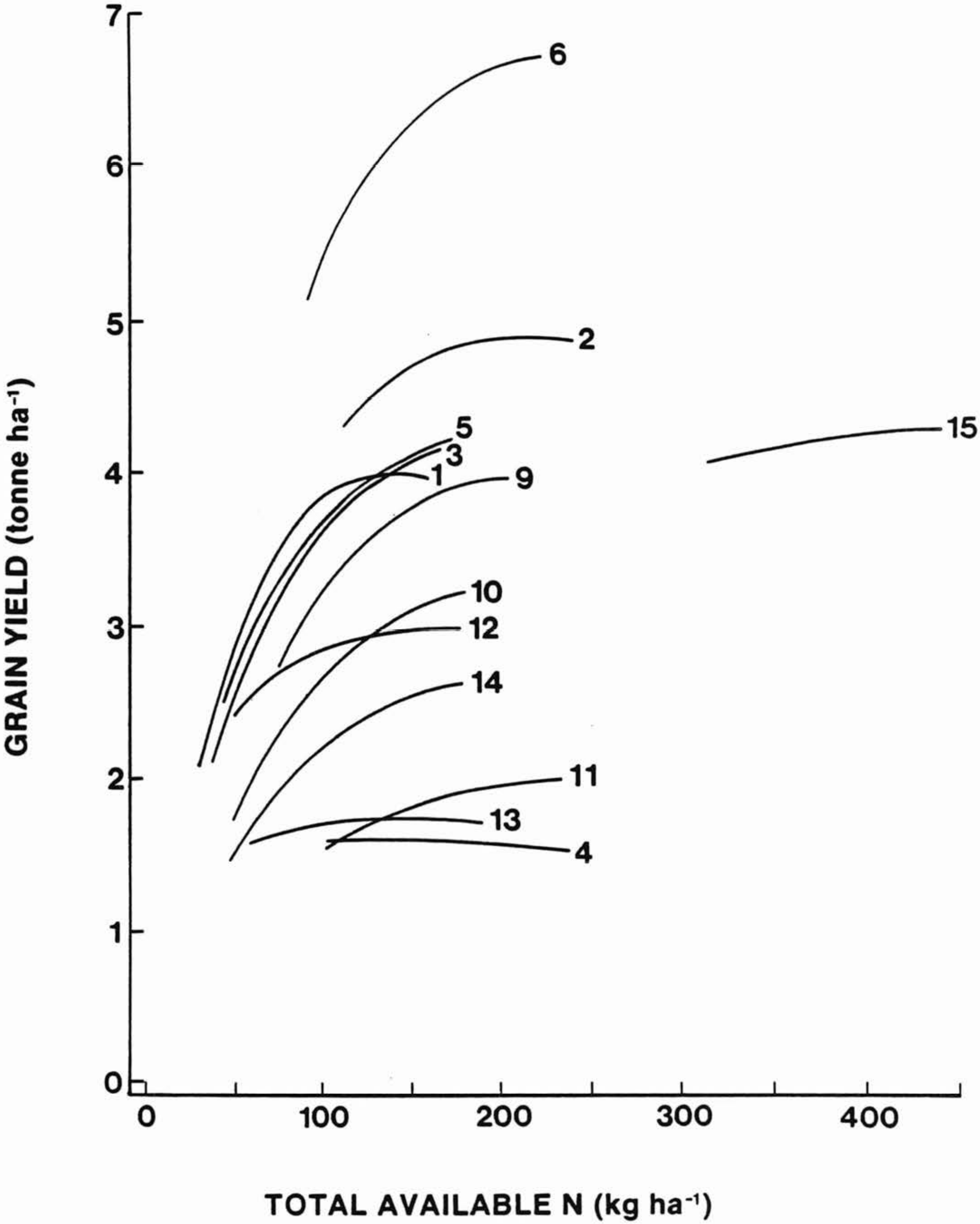

Fig. 2. Norstar winter wheat grain yield response to total available N for early spring broadcast treatments in ammonium nitrate fertilizer trials. See Table 1 for details on trials.

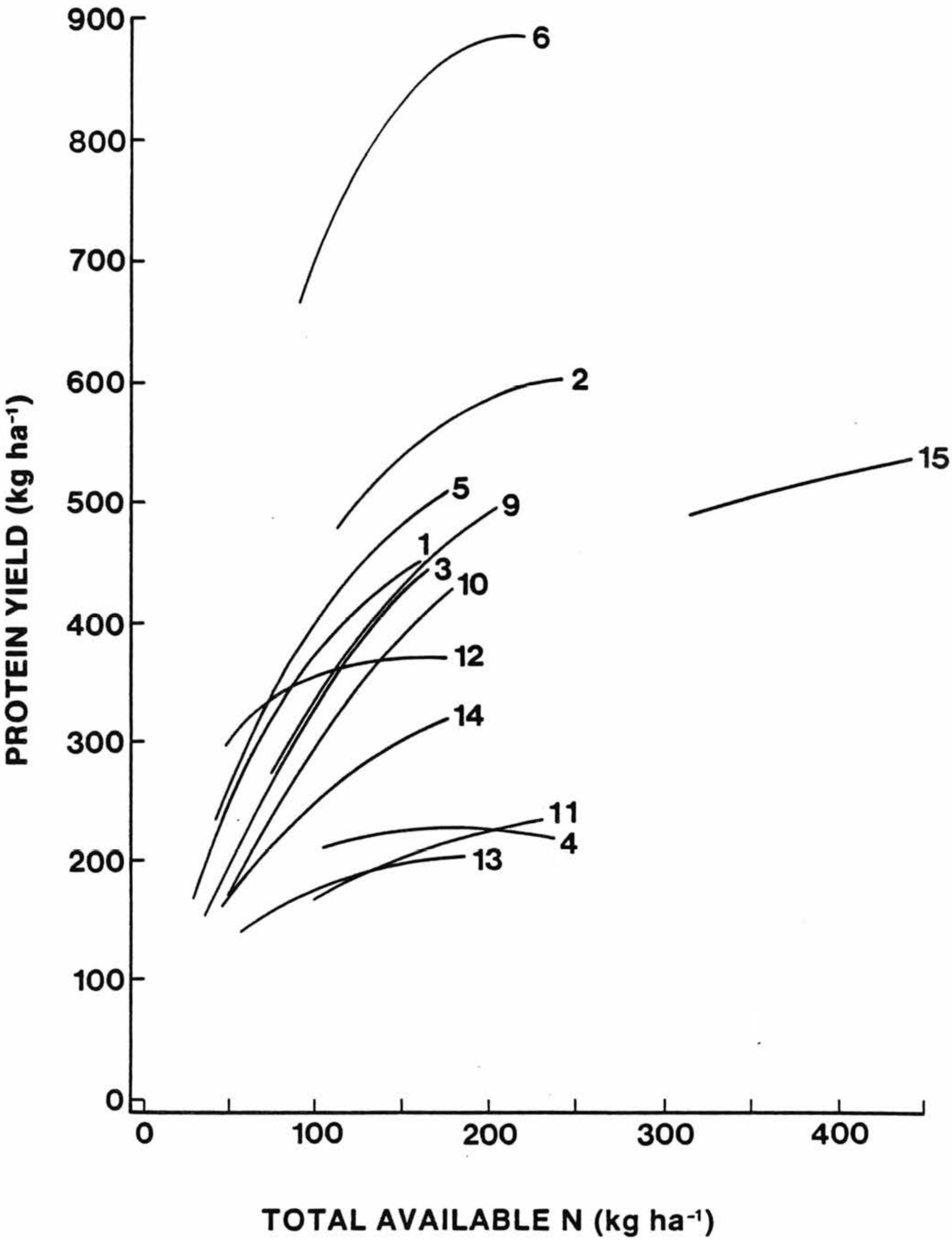

Fig. 3. Norstar winter wheat grain protein yield response to total available N for early spring broadcast treatments in ammonium nitrate fertilizer trials. See Table 1 for details on trials.

Table 2. Estimated regression coefficients (Eq.[1]) for grain yield-N response of Norstar winter wheat for early spring broadcast treatments in ammonium nitrate fertilizer trials. See Table 1 for details on each trial and Fig. 2 for response curves.

Trial	u	e	s
1	9379	98.9	485
2	10800	84.1	765
3	8302	80.6	846
4	2375	72.6	885
5	6235	102.9	1822
6	15199	101.6	839
9	12634	56.6	587
10	8083	50.7	717
11	4574	28.1	903
12	3875	144.0	1658
13	2458	92.6	903
14	5521	46.8	849
15	9629	33.2	1646

Table 3. Estimated regression coefficients (Eq.[1]) for grain protein yield-N response of Norstar winter wheat for early spring broadcast treatments in ammonium nitrate fertilizer trials. See Table 1 for details on each trial and Fig. 3 for response curves.

Trial	u	e	s
1	803	7.5	2667
2	1767	7.3	755
3	1138	5.0	2165
4	533	4.7	601
5	988	7.5	1706
6	3209	11.5	587
9	1106	5.2	2463
10	1186	4.3	2463
11	404	3.1	2463
12	488	17.7	1454
13	344	4.6	1127
14	573	4.9	2463
15	931	4.1	3507

Table 4. Estimated regression coefficients (Eq. [2]) for grain protein concentration-N response of Norstar winter wheat for early spring broadcast treatments in ammonium nitrate fertilizer trials. See Table 1 for details on each trial and Fig. 4 for response curves.

Trial	A	B
1	N/A †	14.7
2	48.3	9.1
3	N/A †	25.2
4	63.6	2.8
5	36.3	3.3
6	50.1	0.5
9	44.0	11.8
10	68.5	9.2
11	30.0	3.7
12	40.2	0.1
13	38.4	8.2
14	32.9	0.8
15	40.9	N/A ‡

† Maximum N rates were not high enough to provide an estimate of A
‡ High residual soil N did not allow for an accurate estimate of B

Table 5. Winter wheat grain yield response to seed-placed ammonium nitrate fertilizer. Mean yield for 101 (101 BC, 34 SP 67 BC, 67 SP 34 BC, 101 SP) and 135 (135 BC, 34 SP 101 BC, 67 SP 67 BC, 101 SP 34 BC) kg ha^{-1} total N treatments for trials with significant grain yield-N responses and no measurable winter damage. See Table 1 and Fig. 2 for details on each trial.

Trial	Seed-placed N (kg ha^{-1})			
	0	34	67	101
	- - - - - - - - - - kg ha^{-1} - - - - - - - - - -			
1	3984a†	3940a	3634b	3756b
2	4920ab	5004a	4798bc	4594c
3	4052a	3946ab	3873b	3489c
9	4037a	4155a	3819ab	3643b
10	3041ab	3257a	3316a	2842b
12	3059a	2870ab	2720bc	2601c
14	2558a	2527a	2206b	2020b
$\bar{X}$	3664a	3671a	3480b	3278c
ΔY‡ (kg ha^{-1})	1277	1284	1093	891
ΔY (%)	100	101	86	70

† Within trials, means followed by the same letter are not significantly different at the 0.05 level of probability as tested by a Duncan's New Multiple Range Test.
‡ ΔY = Yield of N treatment - yield of unfertilized check. Mean yield of unfertilized check treatment = 2387 kg ha^{-1}.

Table 6. Winter wheat grain protein yield response to seed-placed ammonium nitrate fertilizer. Mean yield for 101 (101 BC, 34 SP 67 BC, 67 SP 34 BC, 101 SP) and 135 (135 BC, 34 SP 101 BC, 67 SP 67 BC, 101 SP 34 BC) kg ha^{-1} total N treatments for trials with significant grain yield-N responses and no measurable winter damage. See Table 1 and Fig. 3 for details on each trial.

Trial	Seed-placed N (kg ha^{-1})			
	0	34	67	101
	------------- kg ha^{-1} -------------			
1	446a †	452a	424a	445a
2	638a	639a	609ab	591b
3	431a	417a	416a	381b
9	516a	519a	474ab	442b
10	425a	428a	436a	368b
12	382a	359ab	343bc	320c
14	315a	295a	255b	226b
$\bar{X}$	450a	444a	422b	396c
ΔY‡(kg ha^{-1})	200	194	172	146
ΔY (%)	100	97	86	73

†Within trials, means followed by the same letter are not significantly different at the 0.05 level of probability as tested by a Duncan's New Multiple Range Test.

‡ΔY = Protein yield of N treatment-protein yield of unfertilized check. Mean protein yield of unfertilized check treatment = 250 kg ha^{-1}.

Table 7. Winter wheat grain protein concentration response to seed-placed ammonium nitrate fertilizer. Mean protein concentration for 101 (101 BC, 34 SP 67 BC, 67 SP 34 BC, 101 SP) and 135 (135 BC, 34 SP 101 BC, 67 SP 67 BC, 101 SP 34 BC) kg ha^{-1} total N treatments with significant grain yield-N responses and no measurable winter damage. See Table 1 and Fig. 4 for details on each trial.

Trial	Seed-placed N (kg ha^{-1})			
	0	34	67	101
	------ g protein kg^{-1} dry grain ------			
1	121a †	124ab	126b	128b
2	140a	138a	137a	139a
3	115a	114a	116a	118a
9	138a	135ab	134ab	131b
10	151a	142b	142b	140b
12	135a	135a	136a	133a
14	133a	126b	125b	121b
$\bar{X}$	133a	131a	131a	130a

†Within trials, means followed by the same letter are not significantly different at the 0.05 level of probability as tested by a Duncan's New Multiple Range Test.

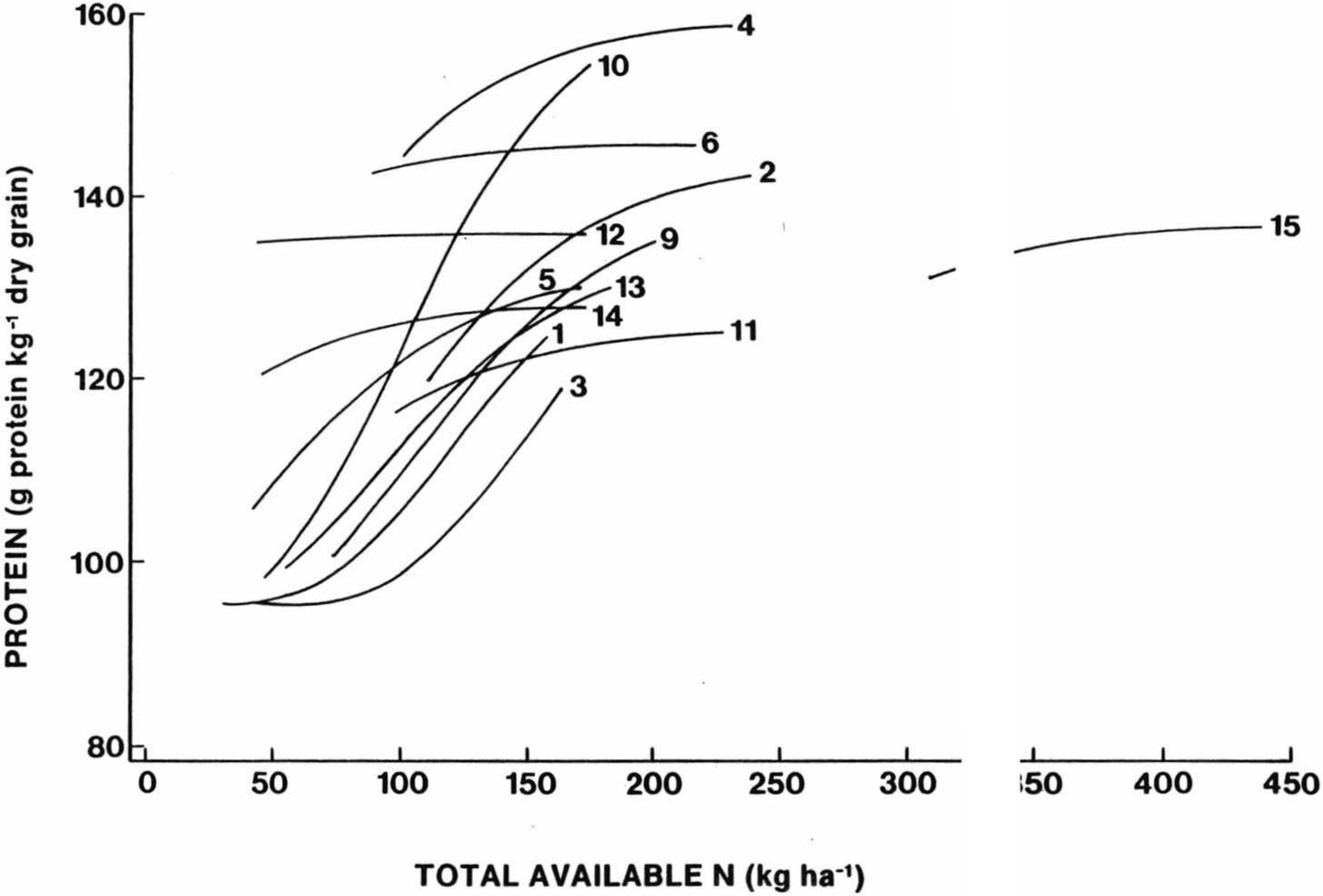

Fig. 4. Norstar winter wheat grain protein concentration response t al
available N for early spring broadcast treatments in ammonium nitrat

Early spring BC ammonium nitrate fertilizer applications resulted in significant ($P \leq 0.05$) protein concentration-N rate responses in eight of thirteen trials. Only trials 6,11,12,14 and 15 did not produce a significant ($P \leq 0.05$) increase in protein concentration with spring BC ammonium nitrate. The Gompertz equation (Eq. [2]) provided an excellent description of the relationship between protein concentration and total plant-available N (Table 4, Fig. 4). Average reduction in sums of squares due to model was 97.4% (minimum 88.0% for trial 3) indicating an excellent fit to the observed data from the trials in this study.

Among the trials that did not sustain winter damage, there was a significant decrease in grain protein concentration as level of SP N increased in trials 9, 10, and 14 (Table 7). In contrast, a significant ($P \leq 0.05$) increase in grain protein concentration was observed as level of SP N increased in trial 1. An analyses of variance that included the 101 and 135 kg ha^{-1} total N treatments for the seven trials with significant fertilizer responses and no measurable winter damage (Table 7) revealed a significant ($P \leq 0.05$) SP N rate by location interaction for grain protein concentration indicating that the effect of SP N was not constant in all environments. However, changes in protein concentration due to increases in the level of SP N were small at all seven locations and only a slight nonsignificant ($P \geq 0.05$) decrease was observed in average protein concentration as level of SP N increased (Table 7). The absence of a large directional change in protein concentration is a reflection of the earlier observation that increases in SP N rate produced decreases of a similar magnitude in both grain and grain protein yield (Table 5 and 6).

Reduced N-use efficiency has been reported for early fall compared to early spring BC ammonium nitrate fertilizer applied to stubbled-in winter wheat in western Canada (Fowler and Brydon, 1989). Results of the present study suggest that placing ammonium nitrate fertilizer with Norstar winter wheat seed in a 20 mm wide band also reduces the N-use efficiency for both grain and grain protein yield at rates above 34 kg N ha^{-1}. However, the reasons for this reduced efficiency are unclear. The relative reduction in both grain and grain protein yield-N responses were similar indicating that timing of N availability was not a factor in this study (Fowler and Brydon, 1989). It is more probable that the SP N was either partially lost over winter or its uptake and utilization by the plant was inhibited relative to spring BC treatments (Harapiak et al., 1986). Similar grain and grain protein yield responses for 34 kg N ha^{-1} SP and BC treatments indicated that ammonium nitrate fertilizer could be seed-placed at low rates without reduced N-use efficiency. However, significant reductions in winter survival potential suggested that even rates as low as 34 kg N ha^{-1} SP ammonium nitrate fertilizer should be avoided when cultivars with marginal winter hardiness levels for a production region are utilized.

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