RESPONSE OF WINTER WHEAT AND RYE TO NITROGEN FERTILIZATION

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This study summarizes the results of thirty-one station years of replicated winter wheat and rye nitrogen fertilizer trials which were conducted in Saskatchewan during the period 1973 to 1984. The use of nitrogen fertilizer on winter wheat and rye resulted in significant grain and protein yield increases in all trials except those with exceptionally high residual nitrogen levels or those which experienced severe late season drought. Although the pattern of nitrogen response was similar, winter rye significantly outyielded winter wheat in 80 percent of the trials.

A 5-fold increase in winter wheat yield for irrigation compared to conditions of extreme drought clearly demonstrated the interdependence of nitrogen and water in determining yield. Rye was more efficient in its utilization of fertilizer nitrogen with the result that it consistently produced more protein per hectare than wheat. However, when environmental factors such as moisture became limiting, the response to increased levels of nitrogen quickly diminished to near zero for both species.

The general nitrogen response curves for protein concentration (%) were similar for wheat and rye. After an initial lag, protein concentrations increased rapidly with increases in available soil nitrogen, even under favorable growing conditions. However, the response curve turned up at lower nitrogen levels and tailed off at higher protein concentrations under poor compared to good growing conditions.

The nitrogen fertilizer net return break-even point was approx. 100, 125 and 145 kg/ha total available nitrogen for wheat produced under poor, average and good environmental conditions. These nitrogen levels will produce wheat with slightly less than 11% protein suggesting that with the present price structure, and the absence of protein classification in the grading system, there is little monetary incentive to fertilize for higher protein concentration. The same general principles should guide nitrogen fertilizer usage on winter rye.

INTRODUCTION

Winter cereals are not major crops in Saskatchewan. However, in the last few years there has been a greater acceptance of the potential for producing winter wheat in this province. In 1985, this increased interest translated into 340,000 ha harvested in spite of a winter which was 1 in 30 in severity. This increase, from less than 1000 ha harvested in 1973, has been a direct result of the adoption of snow management systems which maintain soil temperature at levels above those critical for overwintering wheat seedlings. The most effective method of snow-trapping has been direct seeding into standing stubble from a previous crop. Most stubble fields are deficient in available nitrogen (N) and, therefore, considerable attention has been focused on N fertilization of winter wheat.

Rye production has traditionally been confined to lighter, less productive soils where erosion and summer drought are problems. The risks associated with production on these soils are high and there has not been a large incentive to add extra costs in the form of fertilizers.

The importance of N fertilization in management packages designed to maximize the yield potential of winter wheat and rye has been well documented. Fowler and Hamm (1979) reported average yield increases of 64% for the first 34 kg/ha N added for winter wheat and rye produced on Yorkton association soils with less than 55 kg/ha available soil N. Fowler (1983) also emphasized the mitigating effect of available soil moisture on winter wheat yield responses to added fertilizer N. Subsequent reports (Rennie et al. 1984, Campbell et al. 1984, Foster and Austenson 1985) have further established that large winter wheat yield increases can be achieved by the proper application of N fertilizer.

The importance of eliminating N deficiencies in winter cereal production are easily demonstrated. However, characterizing these responses for purposes of prediction has been more difficult, largely because of the limited data base. This report summarizes data from 31 station years of replicated trials in which the effect of nitrogen fertilization on winter wheat and rye grain yield, hectoliter weight, 1000-kernel weight, protein concentration and protein yield was measured.

MATERIALS AND METHODS

A total of 31 trials were conducted during the period 1974 to 1984 (Table 1). Trial sites were located throughout all but the southwest corner of the agriculture region of Saskatchewan. This provided for a broad sample of soil types (Table 1).

Experimental design for trials that included both winter wheat and rye (Table 1) was a split plot with species the main plots and nitrogen (N) rates the sub plots. Experimental design for trials that included only winter wheat was a randomized complete block. N treatments were replicated from 3 to 12 times in each trial. With one exception (Table 1), trials were direct seeded into standing stubble from a previous crop. Trials were seeded with a small plot hoe-press drill or a commercial minimum tillage drill. Each plot was 5.5 m long and 1.2 m wide. Seeding date was between 24 Aug. and 7 Sept. of each year. Phosphate fertilizer (11-55-0 or 11-48-0) was applied with the seed at rates recommended for each soil type. Available N estimates for each site were corrected to include N applied as mono-ammonium phosphate.

Soil samples were taken at each site in the late fall and early spring for nutrient analyses. Available N levels in the surface 60 cm of early spring samples have been utilized in this report. Soil and fertilizer N were considered to be equally available to the plant. Therefore, total available N has been reported as the sum of the available N in the surface 60 cm as estimated from the soil test plus added fertilizer N. Available soil N for each site is indicated by the start-point of each response curve reported in Fig. 1 to 2. Nitrogen fertilizer was added as early spring broadcast ammonium nitrate (34-0-0) at 0,34,67,101,202 and 303 kg N/ha, the last two rates being

Table 1. Test site, environment and cultivar description.

Location	Year	Soil			Environmental[+] conditions	Previous crop	Cultivar Utilized	
		Zone	Association	Texture			Wheat	Rye
1. Clair	1974-75	Thick black	Yorkton	Loam	Average	Summerfallow	'Sundance'	'Frontier'
2. Clair	1975-76	Thick black	Yorkton	Loam	Average	Rapeseed	Sundance	'Cougar'
3. Clair	1976-77	Thick black	Yorkton	Loam	Average	Rapeseed	Sundance	Cougar
4. Clair	1976-77	Thick black	Yorkton	Loam	Good[1]	Rapeseed	Sundance	Cougar
5. Clair	1976-77	Thick black	Yorkton	Loam	Average	Rapeseed	Sundance	Cougar
6. Saskatoon	1976-77	Dark brown	Sutherland	Silty Clay Loam	Average[2]	Rapeseed	Sundance	Cougar
7. Saskatoon	1976-77	Dark brown	Sutherland	Silty Clay Loam	Poor	Rapeseed	Sundance	Cougar
8. Clair	1977-78	Thick black	Yorkton	Loam	Good	Barley	Sundance	Cougar
9. Clair	1977-78	Thick black	Yorkton	Loam	Good	Barley	Sundance	Cougar
10. Saltcoats	1981-82	Thick black	Yorkton	Loam	Average	Barley	'Norstar'	'Puma'
11. Kipling	1981-82	Dark brown	Weyburn	Loam	Poor	Winter wheat	Norstar	Puma
12. Saskatoon	1977-78	Dark brown	Sutherland	Silty Clay Loam	Poor	Rapeseed	Sundance	Cougar
13. Langbank	1981-82	Dark brown	Weyburn	Loam	Poor	Winter wheat	Norstar	Puma
14. Carnduff	1981-82	Thin black	Oxbow	Loam	Poor	Durum wheat	Norstar	Puma
15. Saskatoon	1981-82	Dark brown	Sutherland	Heavy Clay	Good[2]	Barley	Norstar	Puma
16. Wynyard	1981-82	Thick black	Oxbow	Loam	Good	Spring wheat	Norstar	Puma
17. Clair	1982-83	Thick black	Yorkton	Loam	Poor	Winter wheat	Norstar	
18. Kindersley	1982-83	Brown	Sceptre	Clay Loam	Poor	Winter wheat	Norstar	
19. Watrous	1982-83	Dark brown	Weyburn	Loam	Poor	Winter wheat	Norstar	
20. Meadow Lake	1982-83	Thick black	Meadow Lake	Clay	Poor	Rapeseed	Norstar	Puma
21. Kelvington	1982-83	Thick black	Yorkton	Loam	Fair	Barley	Norstar	Puma
22. Nipawin	1982-83	Gray black	Shellbrook	Fine Sandy Loam	Average	Rapeseed	Norstar	Puma
23. Paddockwood	1982-83	Gray black	Pelly	Loam	Average	Rapeseed	Norstar	Puma
24. Outlook	1983-84	Dark brown	Bradwell	Fine Sandy Clay Loam	Irrigation	Rapeseed	Norstar	
25. Clair	1983-84	Thick black	Yorkton	Loam	Good	Barley	Norstar	
26. Clair	1983-84	Thick black	Yorkton	Loam	Good	Rapeseed	Norstar	
27. Paddockwood	1983-84	Gray black	Paddockwood	Loam	Good	Rapeseed	Norstar	
28. Saskatoon	1983-84	Dark brown	Sutherland	Clay	Poor	Rapeseed	Norstar	
29. Saskatoon	1983-84	Dark brown	Sutherland	Clay	Poor	Rapeseed	Norstar	
30. Strasbourg	1983-84	Dark brown	Weyburn	Loam	Poor	Winter wheat	Norstar	
31. Watrous	1983-84	Dark brown	Weyburn	Clay Loam	Poor	Winter wheat	Norstar	

[+] Irrigation - Approx. 65 cm total growing season moisture.
Good - Above average rainfall which was well distributed during the growing season. Moisture reserves adequate to cope with wind and heat stress experienced.
Average - No extended dry periods. Heat and(or) wind stress may have been yield reducing factors.
Poor - Periodic drought combined with heat and(or) wind stress.

[1] Three test sites in the Clair area, one of which caught the edge of a heavy thunderstorm in early July.

[2] Normal rainfall supplemented by a single irrigation (5 cm) in late June.

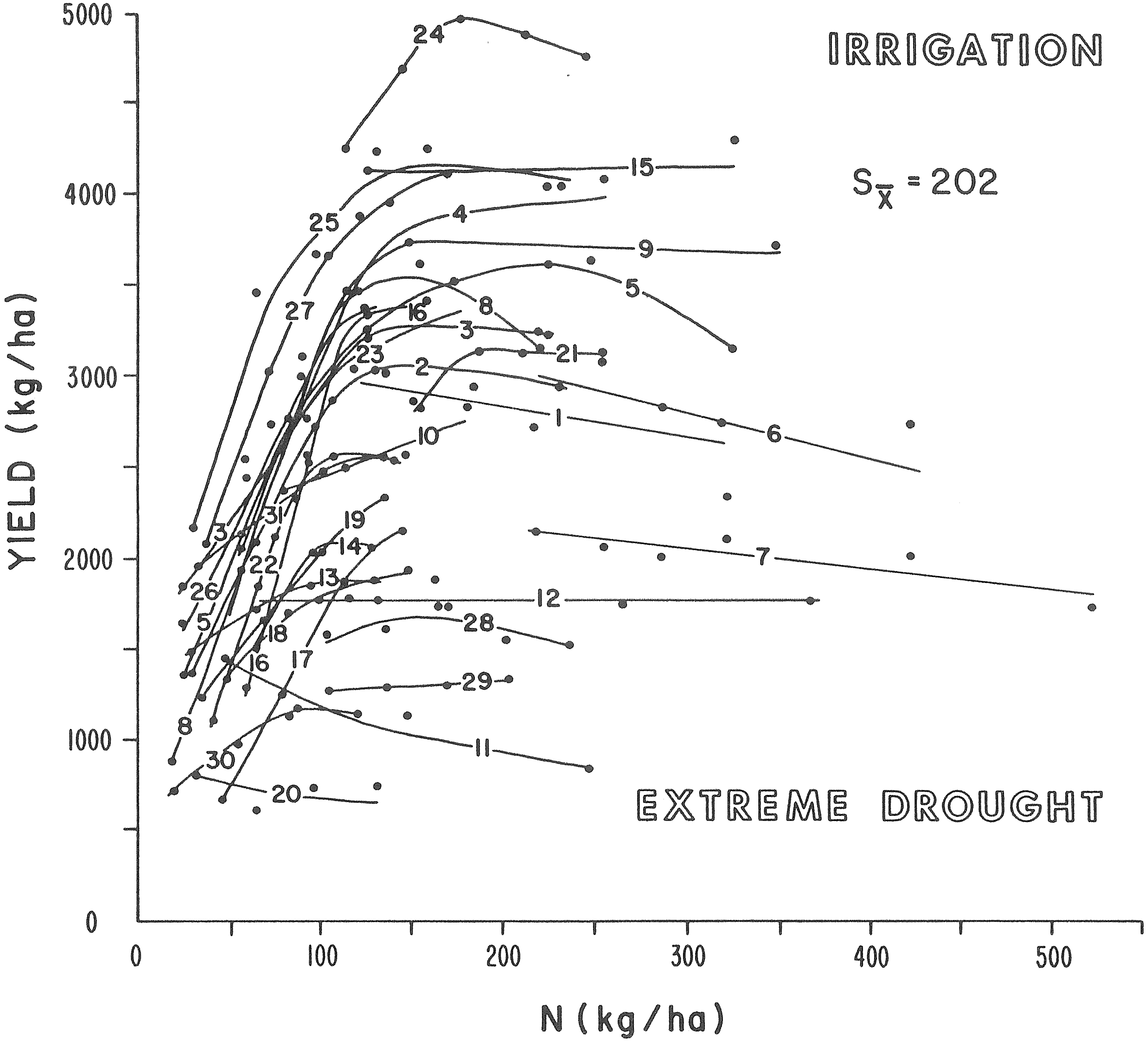

Figure 1 Relationship between available nitrogen (N) and winter wheat grain yield.

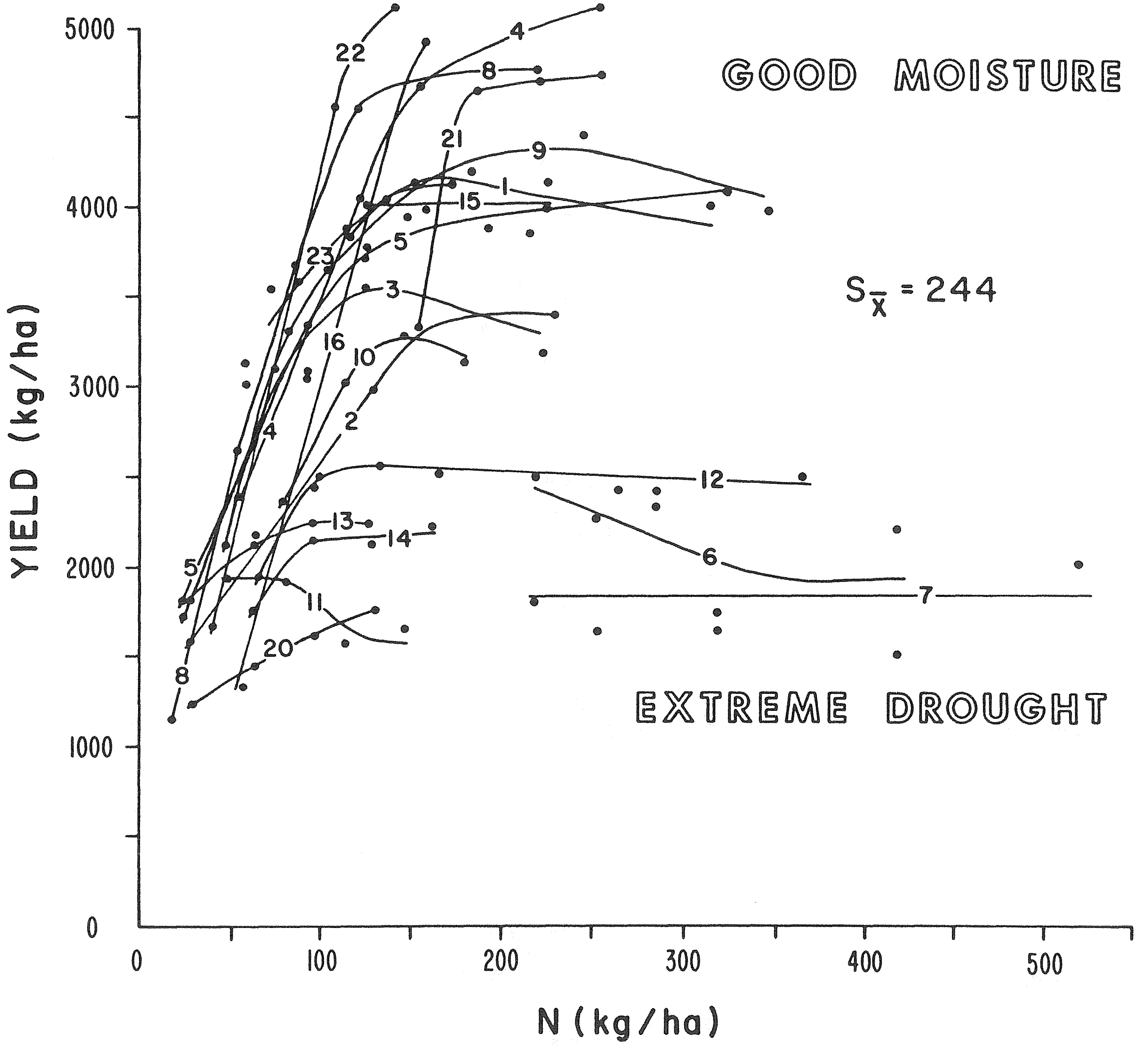

Figure 2 Relationship between available nitrogen (N) and winter rye grain yield.

optional. Soil was moist to a depth of at least 60 cm in the spring at all sites. Environmental conditions were monitored during the growing season.

RESULTS AND DISCUSSION

Yield

The addition of nitrogen fertilizer resulted in significant yield increases for both winter wheat and rye in all trials except those with exceptionally high residual soil nitrogen levels or those which experienced severe late season drought (Fig. 1 and 2). The absence of a significant species by nitrogen rate interaction for all trials except Wynyard 1981/82 and Nipawin 1982/83 indicated that the yield response to added nitrogen was similar for wheat and rye (Fig. 3). However, although the pattern of nitrogen response was similar, winter rye significantly outyielded winter wheat in 16 out of 20 trials. Yield differences between the two species were not significantly different in the remaining four trials.

The potential for yield increases through the use of inorganic nitrogen fertilizers has been recognized for over a century. However, predicting this response so that net farm returns can be maximized still presents a challenge. Part of the difficulty in predicting nitrogen response lies in the fact that biological systems are influenced by many environmental factors. The nitrogen cycle itself is strongly modified by the environment with the result that available soil nitrogen is not a constant. Consequently, soil tests only estimate nitrogen availability during the cropping season. Part of the variability in the population of curves presented in this study arises from the difficulty in establishing the influence of residual nitrogen, i.e., where should the fertilizer nitrogen response curve be positioned relative to the residual soil nitrogen response curve. This background noise can be avoided to some extent in individual experiments by only considering the added nitrogen part of the response curve. However, for purposes of prediction, the complete response curve must be considered if for no other reason than to establish optimum economic response levels.

Characterization of nitrogen response curves also presents a difficult mathematical problem which is often ignored. Several equations provide a good fit to the data reported in this study. However, characterization of the region where the nitrogen response rapidly drops off to near zero has not been satisfactory and the problem is still receiving attention. Therefore, for purposes of this report, the data points for all treatments are given and general trends are recognized in positioning of response curves. These observations indicate that where yield responses to nitrogen occur, they are large. However, when other environmental factors such as moisture become limiting, the response to increased levels of nitrogen quickly diminishes to near zero.

Moisture availability is one environmental factor influencing nitrogen response that stood out clearly above the background noise in this study. The importance of soil moisture in maximizing nitrogen responses has also been recognized for years. However, we often tend to de-emphasize this relationship in our pursuits of ever-increasing yields. With the recent publicity that has been given to Intensive Cereal Management (ICM) systems imported from high moisture regions this relationship must be re-emphasized. The 5-fold difference in winter wheat yield (Fig. 1), for irrigation compared

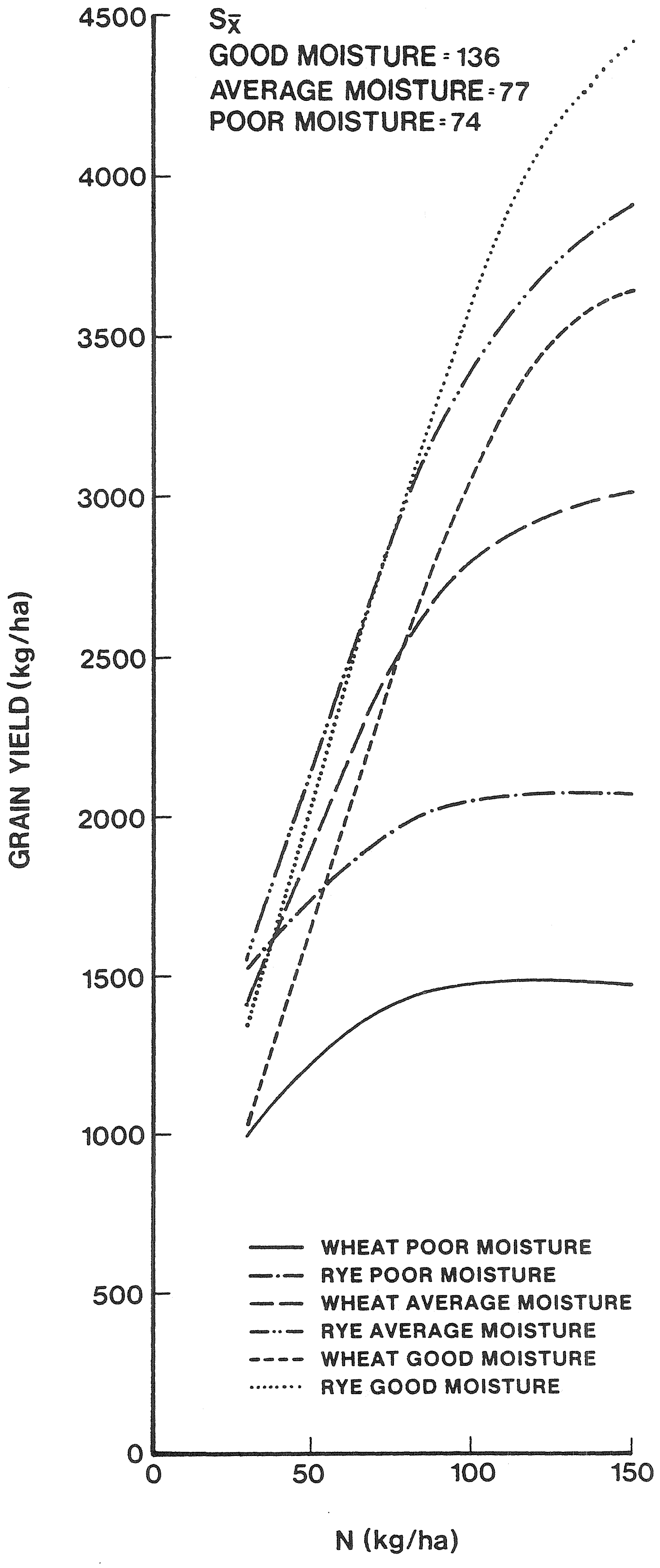

Fig. 3 Relationship between available nitrogen (N) and winter wheat and rye grain yield for poor, average and good moisture conditions.

to conditions of extreme drought, observed in this study clearly demonstrates the interdependence of nitrogen and water in determining yield.

The environmental conditions experienced by the trials reported on in this study have been divided into four groups (Table 1) to permit further analyses of the data collected. For the most part, these groupings reflect differences in total growing season moisture availability and distribution. The importance of moisture distribution over the growing season should not be under-emphasized because, without exception, the worst yielding trials in this study were victims of mid- or late-season droughts which would not have been predicted on the basis of spring moisture reserves. Mean performance for good, average and poor environmental (moisture) conditions highlight the general trends in nitrogen response (Fig. 3 and 4). As observed earlier, the superior yielding ability of winter rye compared to wheat was consistent over most environments (Fig. 3). For both species, rates of yield increase with added nitrogen were slower and maximum yields attained were lower with less favorable environments (Fig. 3 and 4).

Heading Date, Maturity, Height, Hectoliter Weight and Kernel Size

Increasing nitrogen fertilizer rate did not have a significant influence on these characters in many of the trials reported. Maximum differences resulting from increased nitrogen rates for any one trial were a one day delay in heading, a four day delay in maturity, a two kilogram reduction in hectoliter weight and a nine gram reduction in 1000-kernel weight. Less directional responses were observed for height with increases up to 25 cm, reductions to 8 cm, and no significant effects being observed in different trials.

Protein Yield

Cereal protein contains approx. 17.5% nitrogen. This nitrogen is obtained from the soil. Therefore, available soil nitrogen can be expected to have a direct influence on grain protein yield. In this study, the nitrogen response curves for winter wheat and rye grain protein yield (Fig. 5 and 6) were similar to those for total grain yield (Fig. 1 and 2). The addition of nitrogen fertilizer resulted in significant grain protein yield increases in all trials except those with exceptionally high residual soil nitrogen levels or those that experienced extreme late season droughts (Fig. 5 and 6). The protein yield curves usually broke off abruptly at high available soil nitrogen levels and there is good evidence to suggest that soil moisture was the major factor limiting nitrogen uptake under these conditions. The environmental effect on protein yield was not as large under conditions of very low available soil nitrogen (Fig. 7 and 8). Larger differences were observed in the slope of the nitrogen response curve for protein yield when available soil nitrogen levels ranged up to 100, 125 and 145 kg/ha for poor, average and good environmental conditions respectively for wheat. The relationship between fertilizer nitrogen and grain protein nitrogen was very strong up to these levels of available soil nitrogen. In fact, pooled correlation coefficients indicated that 99 (r=.993) and 96 (r=.977) percent of the variability in grain protein nitrogen yield could be explained by variability in the amount of added fertilizer nitrogen for wheat and rye respectively. In this range 4.7, 2.8 and 2.3 kg of fertilizer nitrogen were required to produce one kg of wheat grain protein nitrogen under poor, average

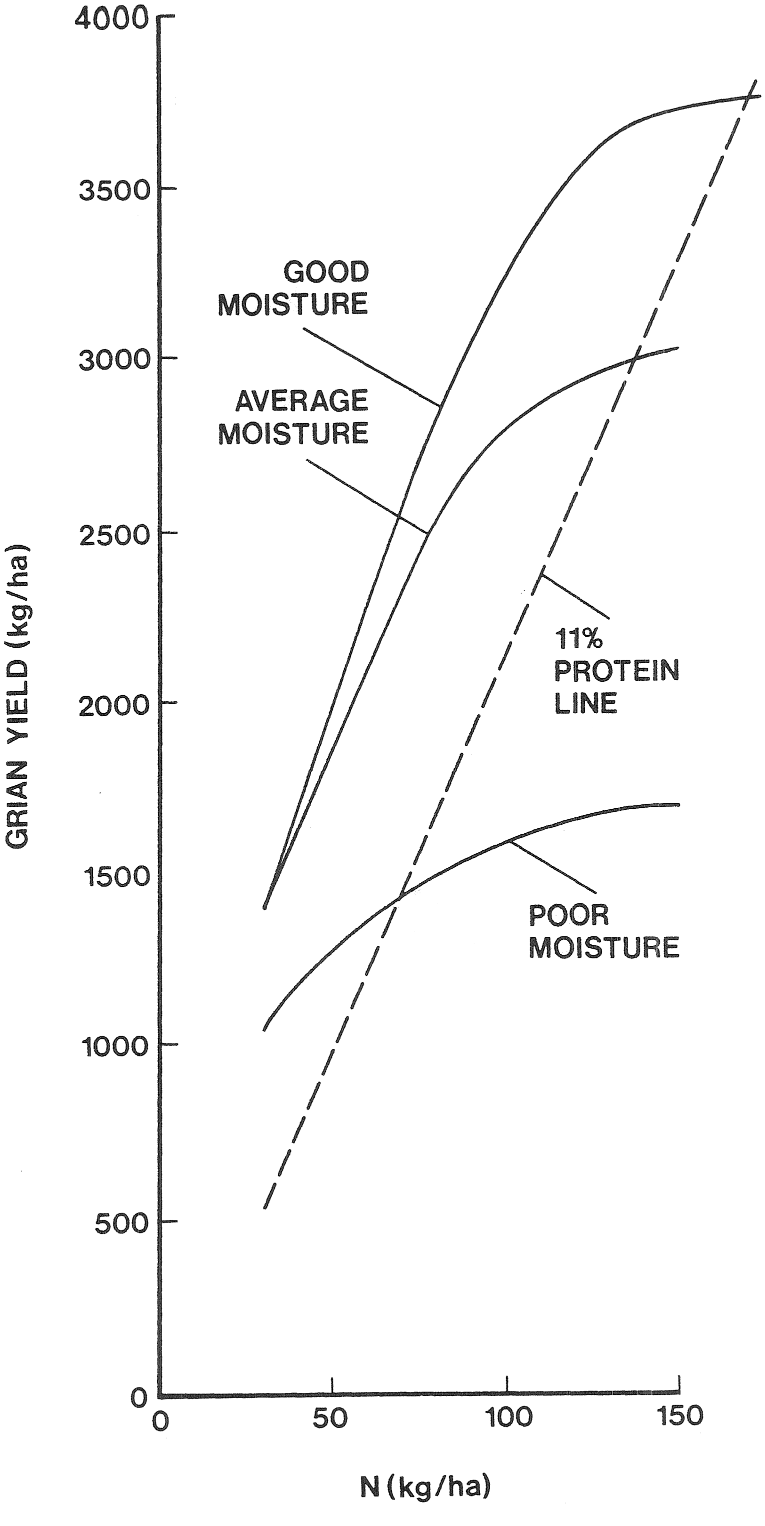

Fig. 4 Relationship between available nitrogen (N) and winter wheat grain yield for poor, average and good moisture conditions. Protein concentrations of greater than 11% are expected to the right of the 11% protein line.

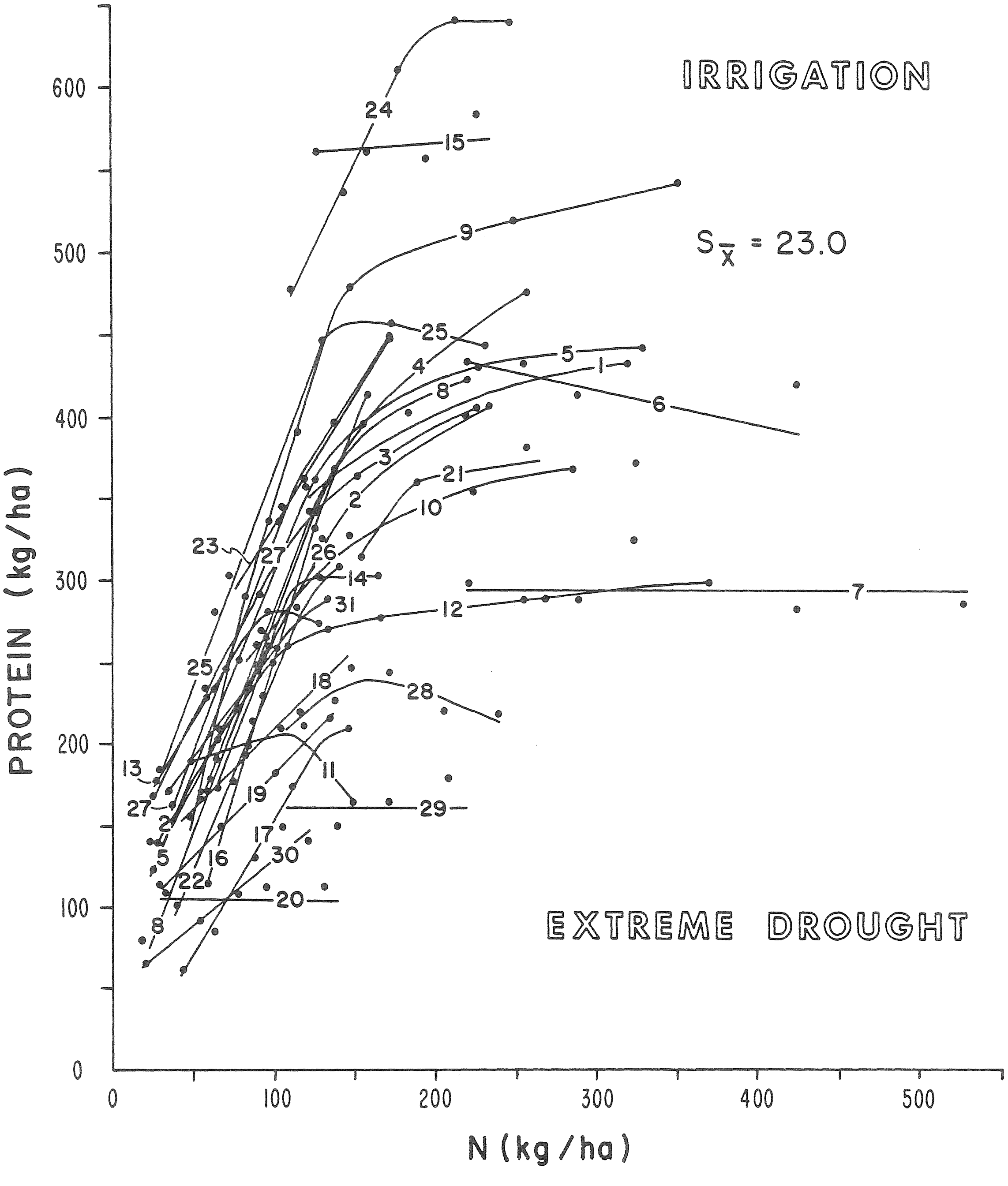

Figure 5 Relationship between available nitrogen (N) and winter wheat grain protein yield.

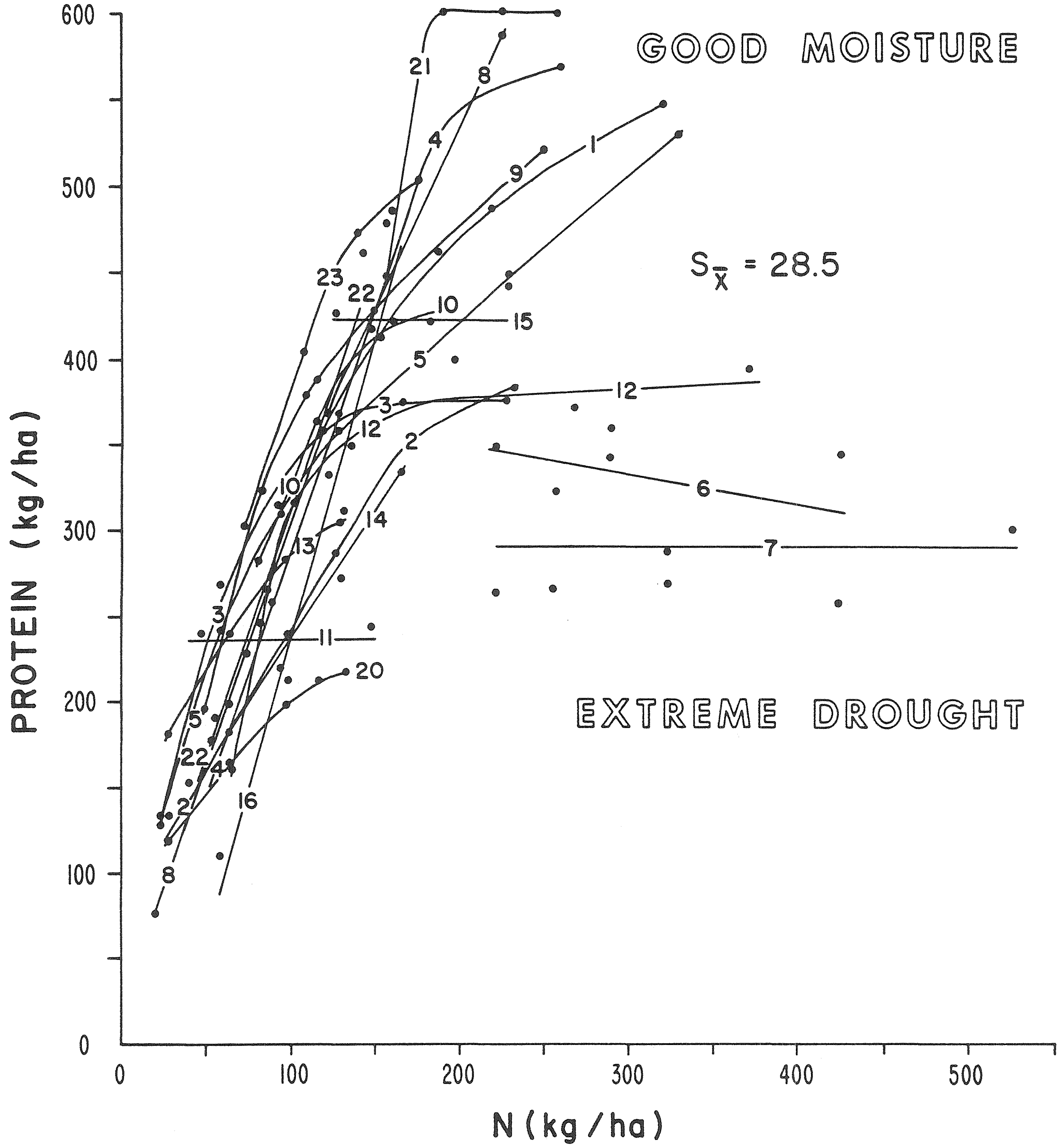

Figure 6 Relationship between availble nitrogen (N) and winter rye grain protein yield.

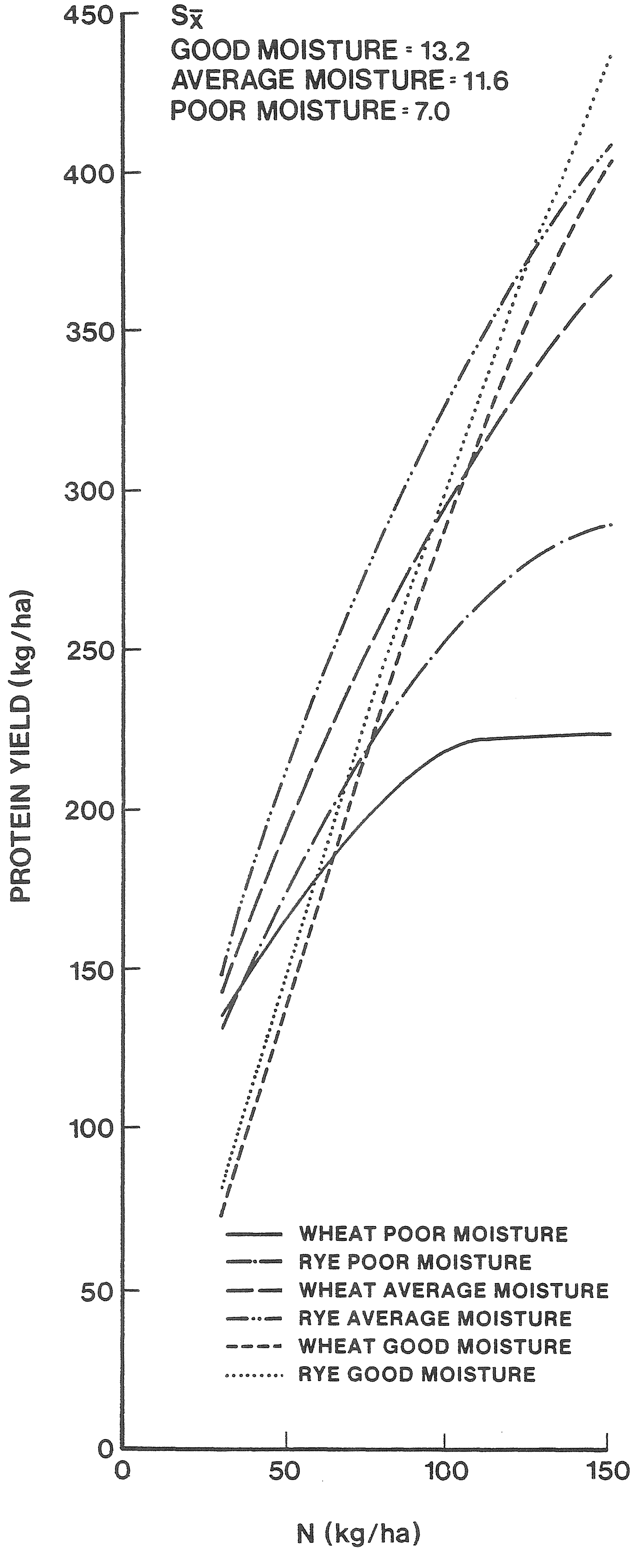

Fig. 7 Relationship between available nitrogen (N) and winter wheat and rye grain yield for poor, average and good moisture conditions.

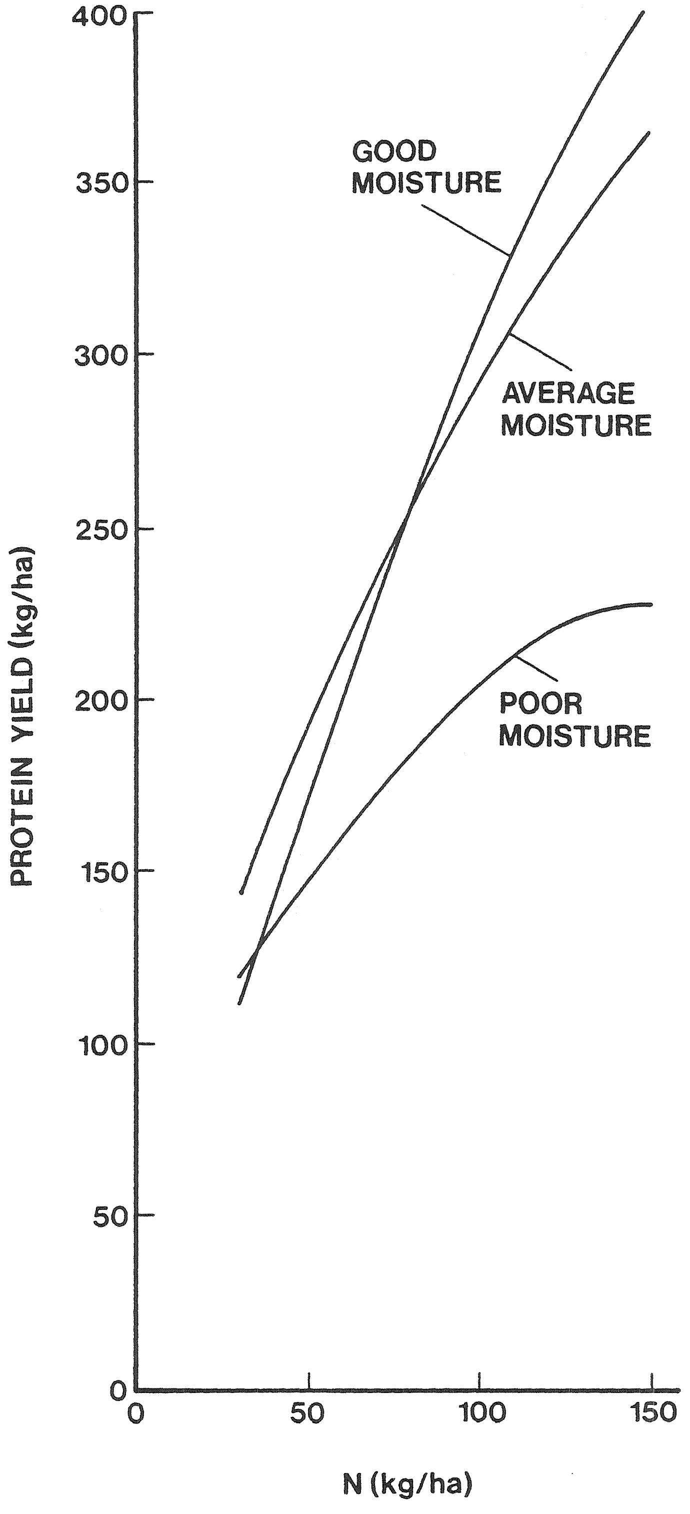

Fig. 8 Relationship between available nitrogen (N) and winter wheat protein yield for poor, average and good moisture conditions.

and good environmental conditions respectively (Fig. 7 and 8). Rye appeared to be more efficient in its utilization of fertilizer nitrogen and required only 3.2, 2.4 and 1.9 kg of fertilizer nitrogen to produce one kg of grain protein nitrogen under these environmental conditions (Fig. 7). This resulted in winter rye consistently producing more protein per hectare than wheat (Fig. 7). The difference between species was especially evident under adverse environmental conditions.

Grain Protein Concentration (%)

Protein concentration is determined by the relationship between grain protein yield and total grain yield. As previously demonstrated, both these variables are strongly dependent upon available soil nitrogen and environmental conditions. Low protein concentrations are usually associated with favorable growing conditions and high yields. However, after an initial lag, protein concentrations in this study increased rapidly with increases in available soil nitrogen, even under favorable growing conditions (Fig. 9 and 10). Under all environments, the protein concentration response curve tailed off at high levels of available soil nitrogen. However, the response curve turned up at lower available soil nitrogen levels and tailed off at higher protein concentrations under poor compared to good growing conditions (Fig. 9 and 10).

The general nitrogen response curves for protein concentrations were similar for winter wheat and rye (Fig. 11). For the same levels of available nitrogen, winter rye consistently produced greater protein and total grain yield than did wheat (Fig. 3 and 7). However, the increases in rye grain yield were greater relative to the increases in protein yield resulting in lower protein concentrations for rye compared to wheat (Fig. 11).

The most rapid period of nitrogen assimilation by the wheat plant occurs prior to anthesis. In contrast, grain carbohydrate synthesis occurs after anthesis. Therefore, mid and late season stress periods have a greater impact on total carbohydrate production than on nitrogen assimilation. As mentioned earlier, summer was the main stress period limiting winter cereal yield for the trials reported. Consequently, protein concentrations should be expected to be higher under the less favorable growing conditions observed in this study (Fig. 11 and 12). Reduced nitrogen utilization efficiency resulting in lower protein yields (Fig. 7 and 8) partially offset the effects of lower carbohydrate production under less favorable growing conditions. However, in spite of this, the net effect in these trials were lower protein concentrations under conditions favorable to growth (Fig. 11 and 12).

Economic Analyses

Snow management through direct seeding into standing stubble has been the main factor allowing for expanded winter wheat production in Saskatchewan. Most stubble fields are deficient in available soil nitrogen (N) and in high production environments it is not uncommon to find soil test results that indicate less than 30 kg/ha available N. The previous crop usually makes a large drain on available N reserves of the soil and N released through stubble decay does not contribute significantly to the available N pool until the next summer. Most of the N demand of the winter wheat crop occurs before the end of June (Fowler 1983 b,c). Therefore, it is not uncommon to see the dramatic

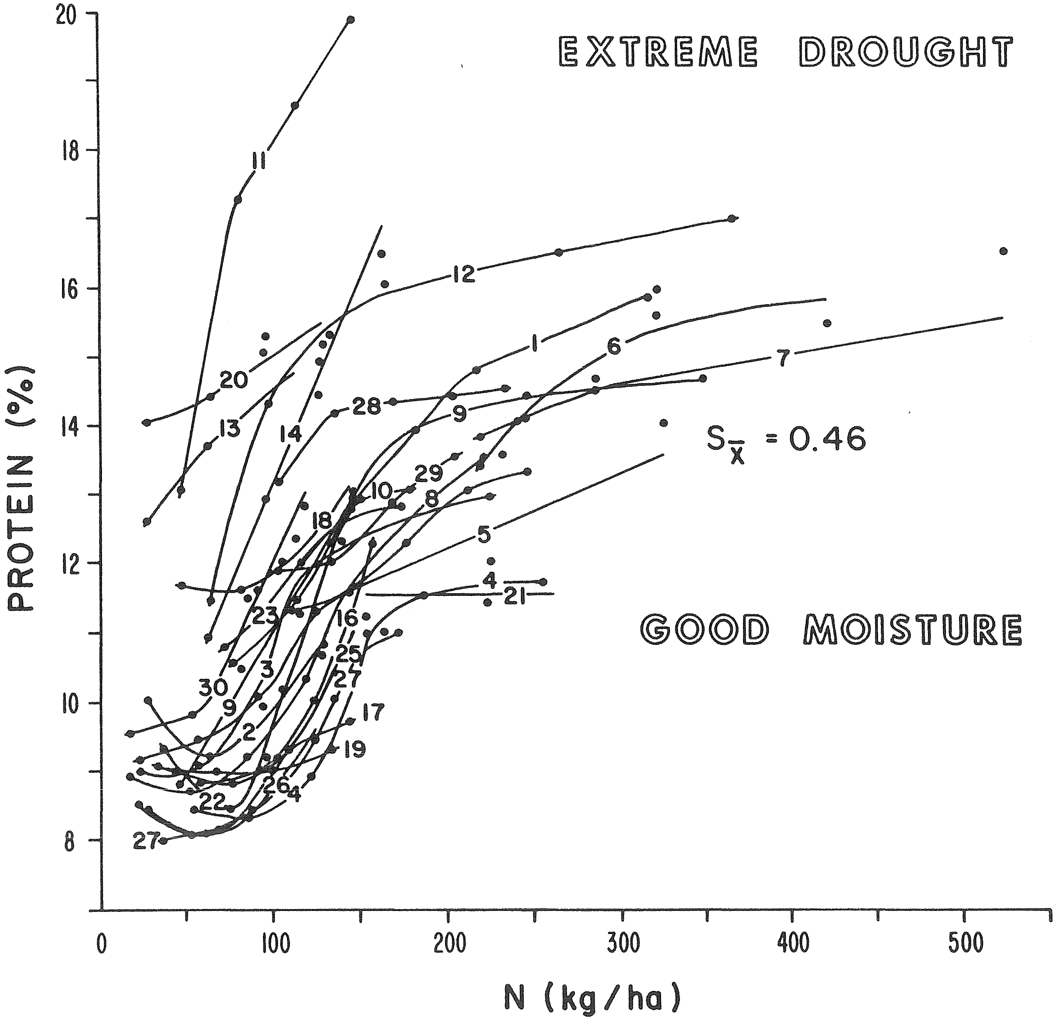

Figure 9 Relationship between available nitrogen (N) and winter wheat protein concentration (8% H_2O).

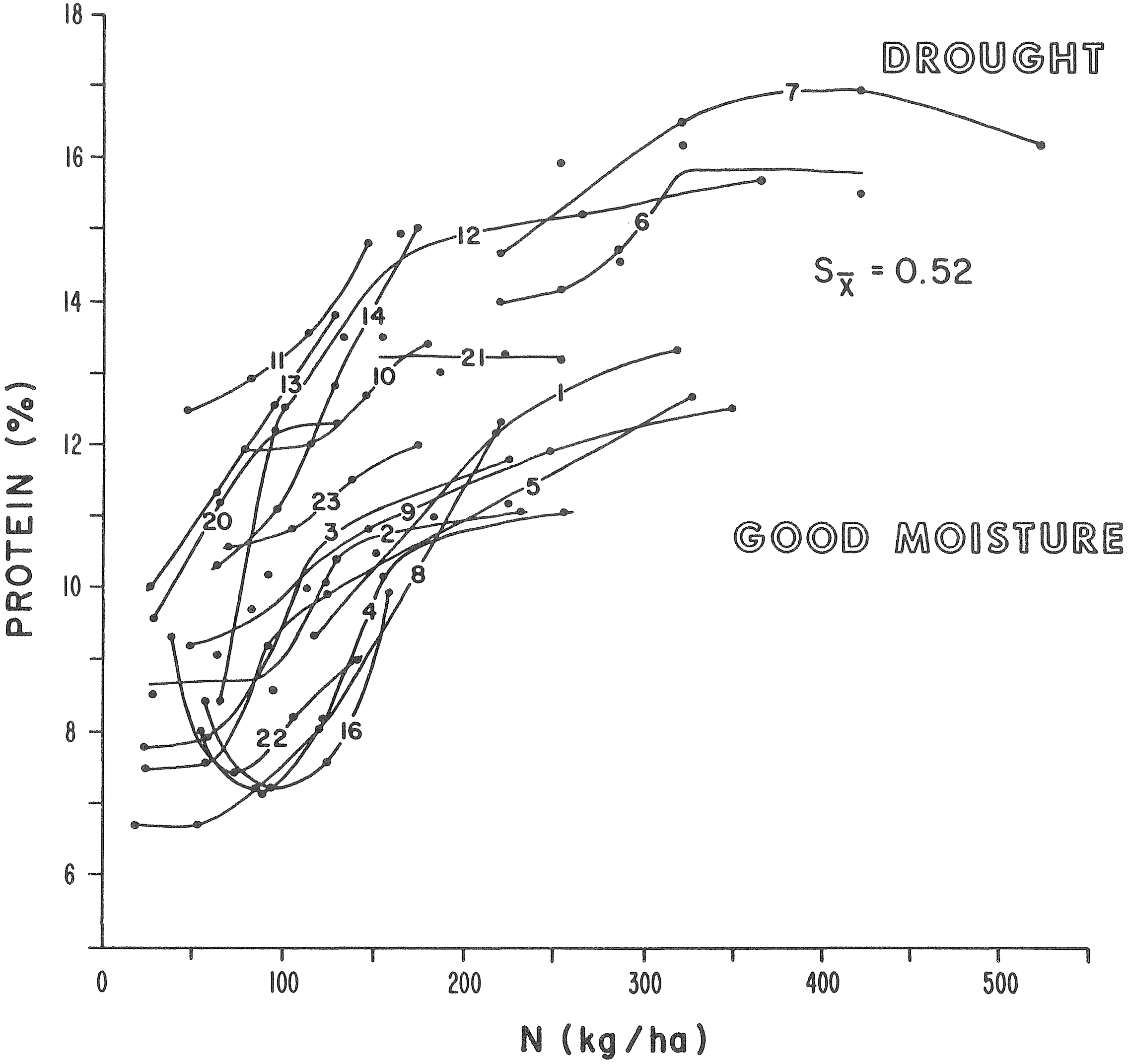

Figure 10 Relationship between available nitrogen (N) and winter rye protein concentration (8% H_2O)

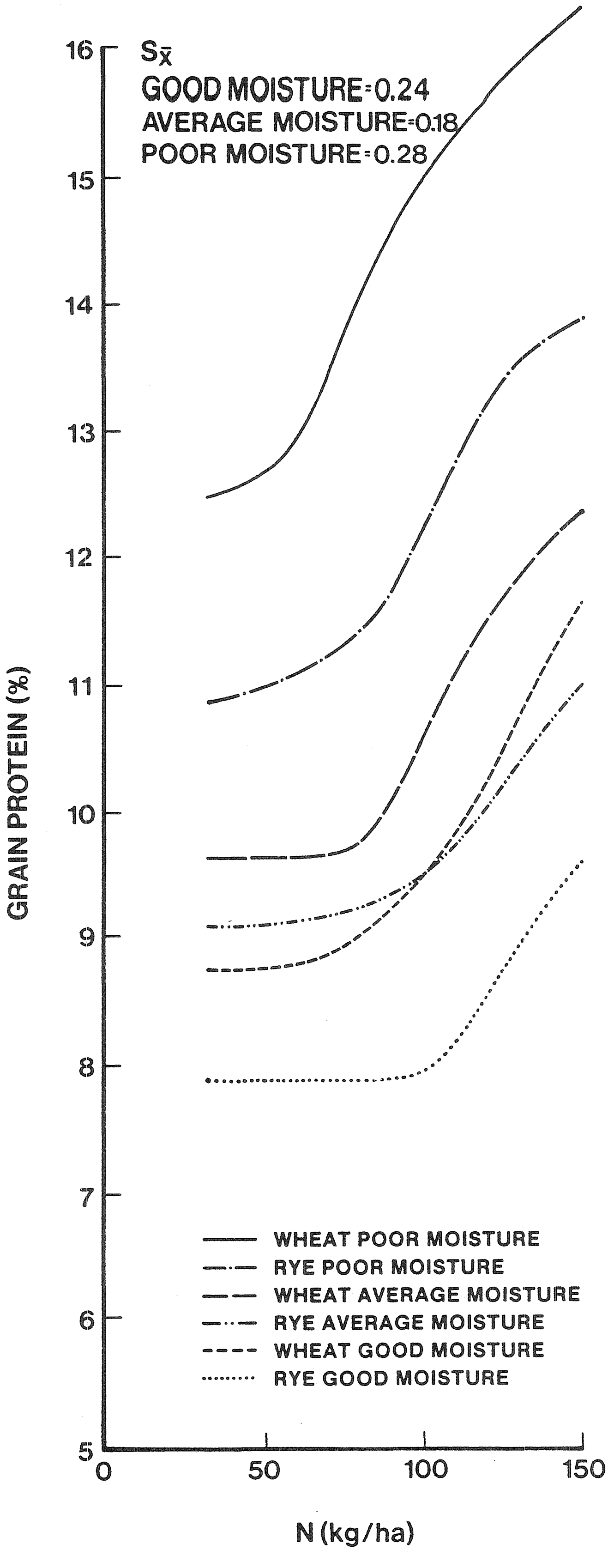

Fig. 11 Relationship between available nitrogen (N) and winter wheat and rye protein concentration (8% H_2O) for poor, average and good moisture conditions.

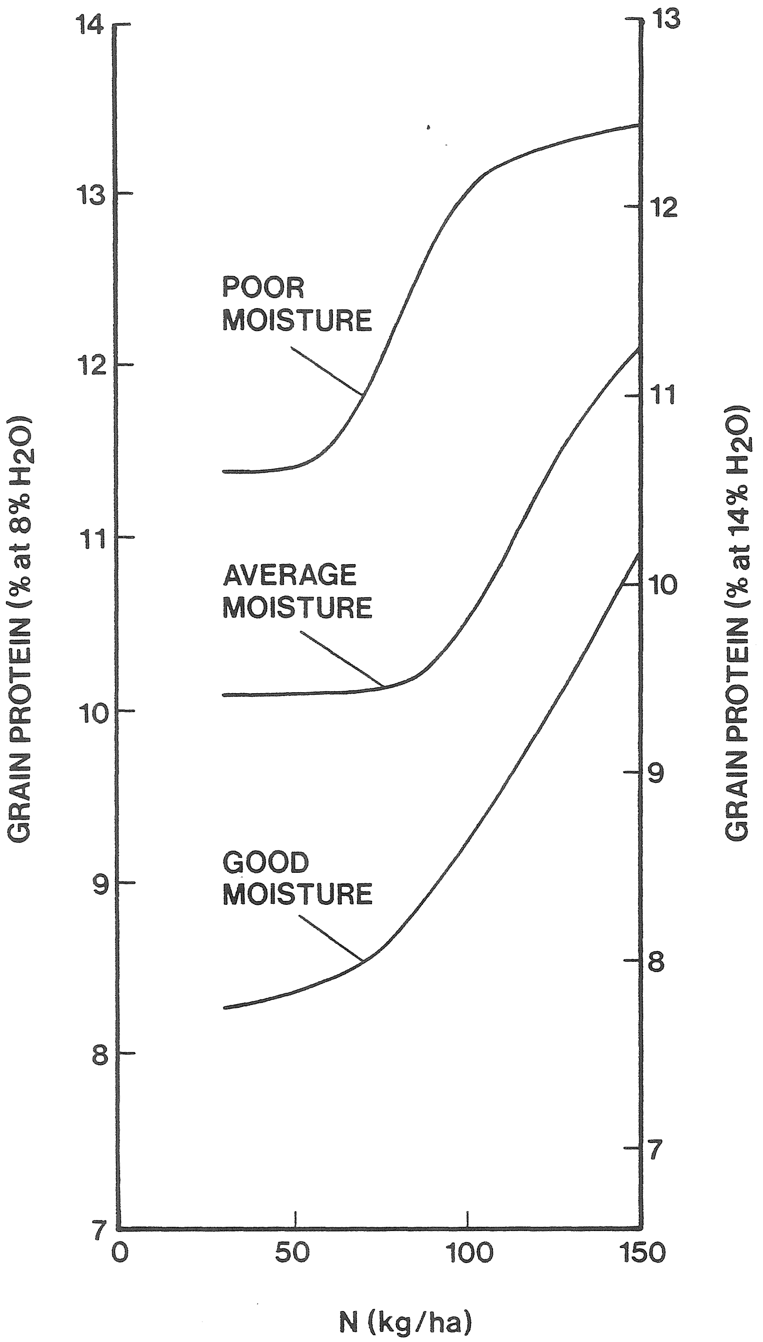

Fig. 12 Relationship between available nitrogen (N) and winter wheat protein concentration (8% H2O) for poor, average and good moisture conditions.

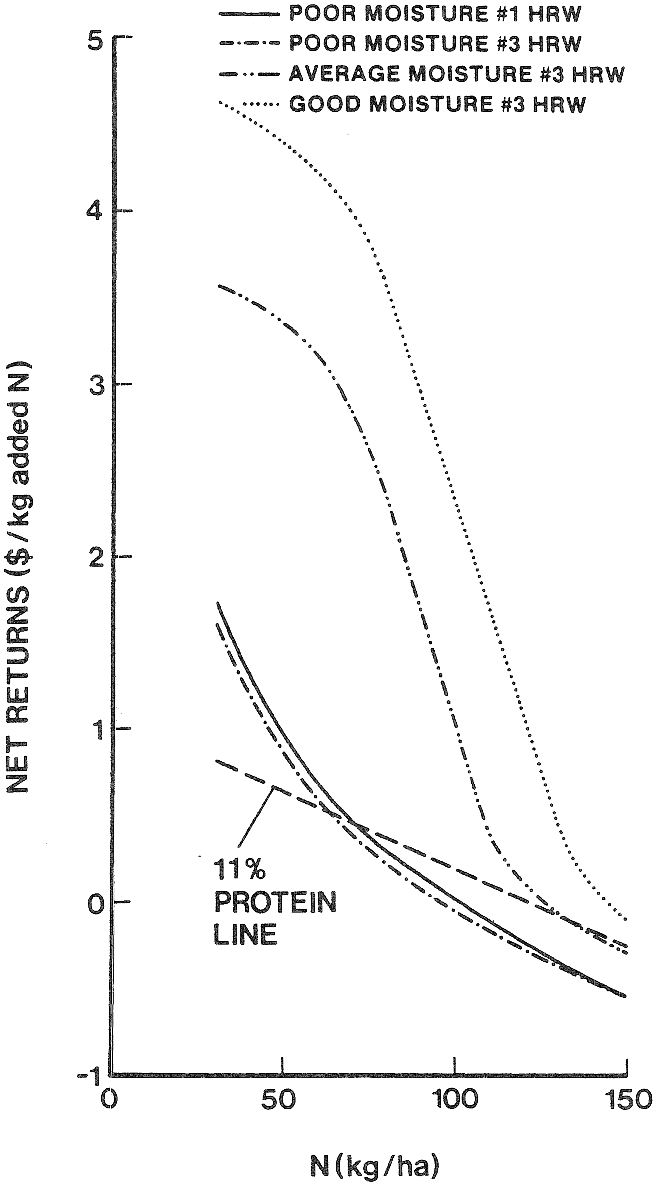

Fig. 13 Net returns expected from each additional kg of nitrogen (N) added for winter wheat grown under poor, average and good moisture conditions. Estimates based on N at 62¢/kg and final 1984-85 Hard Red winter wheat prices of $171.51/t for #1 and $166.51/t for #3. Protein concentrations of greater than 11% are expected below the 11% protein line.

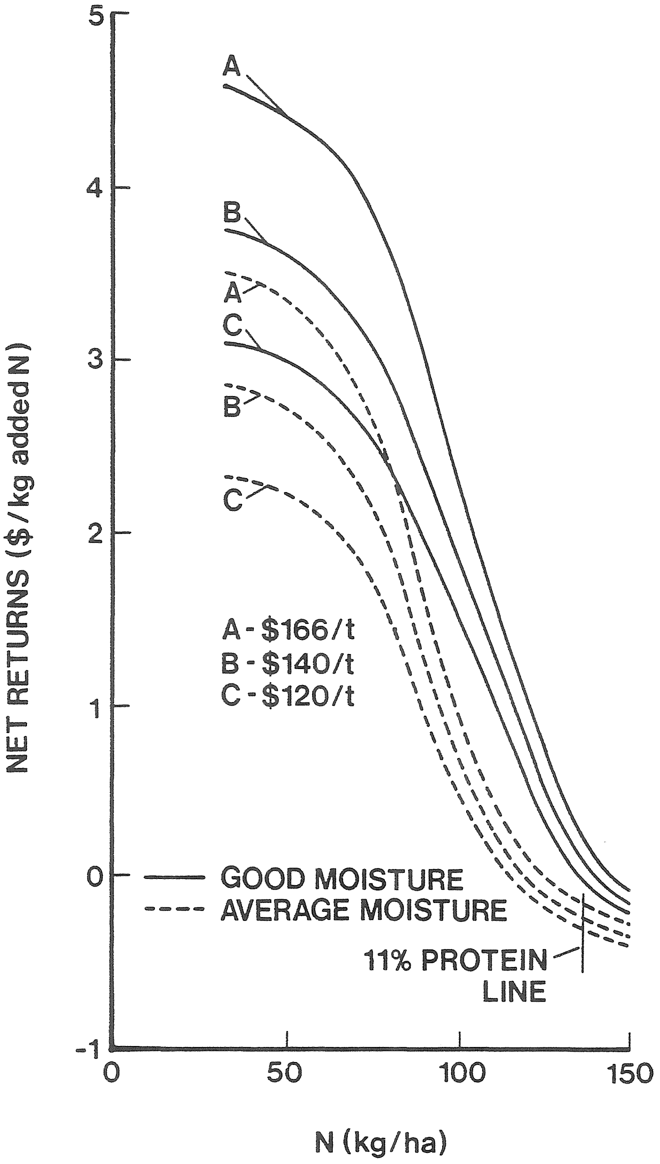

Fig. 14 Net returns expected from each additional kg of nitrogen (N) added for winter wheat grown under average and good moisture conditions. Estimates based on N at 62¢/kg and Hard Red winter wheat prices of $166/t, $140/t and $120/t.

N responses reported in this study. If we utilize these yield responses and 1984-85 fertilizer and final hard red winter wheat prices, we find a break-even point of approx. 100, 125 and 145 kg/ha N for poor, average and good environmental conditions (Fig. 13). At these N levels one would only expect grain protein concentration of greater than 11 percent (at 14% grain moisture) under low moisture environments (Fig. 12). Grain protein concentrations of less than 11 percent are undesirable in the marketplace and high levels of "piebald" or "yellowberry" will result in grade loss to number 3 (Fig. 13). However, with the present price structure and the absence of protein classification in the grading system, there appears to be little monetary incentive to fertilize for higher protein concentration even if one assumed that the farmer netted the total 1984-85 final price for his deliveries. In the event prices dropped further, the largest reductions in net returns from each kg of added N would occur under low available soil N levels. However, the break-even fertilizer level would not shift dramatically (Fig. 14). Consequently, fertilizing with the goal of producing grain of slightly less than 11% protein concentration would make good economic sense even under depressed grain prices.

Winter rye prices tend to be more unstable and less predictable than wheat prices. However, because rye fertilizer response patterns are similar to those of wheat, the same general principles should guide N fertilizer usage. The correction of significant nitrogen deficiencies through the sensible use of fertilizer will increase profits provided the product can be sold.

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