NITROGEN FERTILIZATION FOR MAXIMUM ECONOMIC YIELD OF STUBBLED-IN WINTER WHEAT

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INTRODUCTION

Maintenance of a snow cover during the winter is necessary for successful winter wheat production in most areas of the Canadian prairies outside of southwestern Alberta. Direct seeding into standing stubble (no-till or stubbling-in) has proven to be the most reliable method of accomplishing this objective. The success of the stubbling-in management system is best demonstrated by the increase in Saskatchewan's winter wheat production from less than 2,000 acres harvested in 1972 to 860,000 and 805,000 acres harvested in 1985 and 1986, respectively. The potential for stubbled-in winter wheat is further emphasized when one considers that winter stresses as severe as those experienced in 1984-85 are expected to occur only once in 30 to 50 years in this region (Fowler and Entz, 1986). However, in spite of these promising results, many producers have had difficulties in inserting winter wheat into their rotations. These management problems, combined with low market prices, have resulted in a decrease in Saskatchewan's winter wheat production to 350,000 acres harvested in 1987.

Nitrogen (N) fertilizer application is one of the several steps in the stubbled-in production system that has created problems for winter wheat producers. Most stubble fields are deficient in available soil N and it is common to find residual plant available soil N levels of less than 30 kg/ha. Therefore, responses to added N are usually very dramatic making N fertilizer a highly profitable input. The large N requirements of stubbled-in winter wheat also makes N fertilizer a major cost factor, often exceeding 50% of the variable input costs (Rutherford and Fowler, 1983). Consequently, N fertilization has an important influence on both the income and expense columns of the winter wheat balance sheet (Fowler, 1986). Variables such as fertilizer formulation, time and method of application, fertilizer, equipment and labor availability, possible N losses after application, and regional weather patterns also have an influence on the level of returns from N fertilization. The objective of this paper was to assess the relative importance of these variables in determining the Maximum Economic Yield of stubbled-in winter wheat produced in Saskatchewan.

RULE 1: A comprehensive management package is necessary to obtain maximum economic N fertilizer response.

Winter survival and a healthy, vigorous stand the following spring are prerequisites to obtaining economic fertilizer response with winter wheat. The winter survival potential of the hardiest winter wheat cultivars is not sufficient to ensure overwintering in Saskatchewan without snowcover protection (Fowler, 1983). Consequently, strict attention must be paid to management factors that maximize the winter hardiness potential of the winter wheat crop and maintain a uniform snowcover during the coldest part of the winter. No amount of N fertilizer will salvage a crop that has been winterkilled or severely winter damaged.

In addition, any management factor that limits the yield potential of a crop that survives the winter will also result in reduced N fertilizer response and lower Maximum Economic Yields. In the stubbling-in production system, the most important management decisions are made before winter wheat seeding moves into high gear. For example, correcting phosphate deficiencies and seeding at the optimum date have a large influence on the degree of success that can be achieved in the production of stubbled-in winter wheat. Many western Canadian soils are phosphate deficient and field trials have indicated that correcting these deficiencies results in an improved ability to recover from winter damage, higher yields and earlier maturity. Optimum seeding dates range from the last week in August in the northern part of the agricultural region to the end of the first week in September in the southeast. There is some leeway in both directions, but seeding too early or too late will increase the risk of winter damage and reduce yield potential. Seeding too late also usually results in later maturity and an increased risk of rust damage. Successful winter wheat producers will plan their rotations to ensure that standing stubble is available for seeding into at the optimum date.

RULE 2: Post-harvest operations that reduce the snowtrapping potential of a stubble field or dry out the seedbed must be avoided.

Height and density of stand determine the snowtrapping potential of a stubble field and any post harvest operation, including fertilizer banding, that breaks down the stubble will increase the risk of winter damage. Soil moisture in stubble fields is also often limiting for germination and establishment of winter wheat. When soil moisture is poor, a fall banding operation prior to seeding may result in additional moisture loss and poor seed germination. Excessive tillage associated with fertilizer banding during the seeding operation can also create similar problems.

RULE 3: Keep the winter wheat production system as simple and straightforward as possible.

In its simplest form stubbled-in winter wheat production involves seeding directly into standing stubble with a no-till drill the last week in August, first week in September. Phosphate fertilizer, if required, should be applied with the seed. Winter annual weeds are sprayed for in the late fall or early spring. Nitrogen fertilizer should be applied by early spring at the latest. The crop is then harvested. While only minor changes appear to be required to accommodate winter wheat on a farm geared for spring crops, many producers have run into problems inserting winter wheat into their rotations. Most Saskatchewan farmers are not experienced in either the production of a crop with a winter growth habit or the no-till production system. Consequently, the production scheme for stubbled-in winter wheat presents a major change in management philosophy for most farmers. Unfortunately, this production system is often too simple for modern hi-tech agriculture and many of the production problems with winter wheat can be directly attributed to a tendency to make some of these operations overly complicated.

Most of the problems that producers have with the stubbling-in production system are associated with the seeding operation. Winter wheat is seeded in late August or early September. This often results in a conflict with harvesting of late-season, spring sown crops. Time means money during harvest and winter wheat seeding. Too much experimentation or excessive labor demands at this busy period are a sure formula for disaster. Forward planning and the postponement of operations that could be completed at a later date help to reduce these conflicts ensuring priority can be given to essential production steps, such as getting the seed into the ground properly at the optimum date.

Interest in fertilizer banding drills has accompanied the growth of winter wheat. While the concept of banding urea, and urea based fertilizers, during the seeding operation has merit in that N losses with urea are reduced, it does add an extra variable that most producers have little experience with. Also of concern is the observation that, compared to conventional no-till drill openers, some types of banding drill openers increase the horsepower requirement per unit width of drill by 2 to 3 times, depending upon soil characteristics (Collins et al., 1988). This means that drill size has to be reduced by 1/2 to 2/3's, or tractor horsepower has to be increased by 2 to 3 times when the seeding of winter wheat is accompanied by N fertilizer banding with certain openers. However, in addition to reducing urea losses, N banding as part of the seeding operation eliminates the extra trip over the field that is required when N is broadcast or banded as a separate operation. As a result, based on Saskatchewan Department of Agriculture suggested labor and rental rates for 1987, the cost per acre is not much different for N banding as part of the seeding operation compared to seeding and broadcasting N as separate operations (Collins et al., 1988). This study indicated that the value placed on labor during seeding and harvest compared to early spring would often be a major factor in determining profitability of these two seeding and N fertilizer application systems. Clearly, the producer is left with a number of options and the need to prioritize seeding decisions so that winter wheat can be integrated into their total crop production package with the objective of maximizing economic yield for all crops produced.

<u>RULE 4: Seed placement must receive priority over fertilizer placement</u>.

Shallow seeding (approximately 2 cm) into a firm, moist seedbed provides optimum seed placement for stubbled-in winter wheat. Improper seed placement can result in increased winterkill, later maturity and lower yields (Fowler, 1983; Hultgreen et al., 1987; Loeppky et al., 1987). For example, in the severe winterkill winter of 1984-85, a difference in seeding depth of 2 cm compared to 4 cm often meant the difference between a crop and no crop the following spring. Accurate seed placement is often difficult to accomplish (Hultgreen et al., 1987), especially when drill openers create considerable soil disturbance and seeding is followed by a rain or other factor resulting in furrow cave-in. It is also important to remember that straw and chaff can present obstacles to proper seed placement with the stubbling-in production system. Most successful winter wheat producers invest in the equipment necessary to provide for chopping of straw and uniform spreading of straw and chaff to facilitate their seeding operations thereby maximizing the opportunity for uniform stand establishment and winter survival. In addition, when selecting seeding equipment, they will remember that trash clearance and seed placement should not be sacrificed for fertilizer placement.

RULE 5: Growing season weather conditions have a large influence on winter wheat N response.

Differences in environmental conditions produced a ten-fold difference in the maximum grain yield observed in forty winter wheat N fertilizer trials conducted in Saskatchewan between 1974 and 1986 (Fowler et al., 1987). Nine years of trials at Clair in the Black soil zone (Figure 1) and seven years of trials at Saskatoon in the Dark Brown soil zone (Figure 2) were selected for further analyses in the present study. The N response curves for these trials indicated that the N use-efficiency for grain yield was highest for the initial increment of N. After the initial increment of N, the N-use efficiency gradually decreased, reaching zero when maximum yield was achieved and then becoming negative at excessively high N rates, i.e., there was a loss in grain yield for N added beyond that required for maximum yield. It was also obvious that, at N levels less than those required for maximum yield, the N-use efficiency for each increment of added N was larger and the N requirement for maximum yield was higher under environmental conditions favouring higher potential yield.

At both Clair and Saskatoon, environmental conditions were responsible for approximately a 3-fold difference in maximum yield observed for the least compared to the most productive years (Figures 1 and 2). Approximately 100 kg/ha additional fertilizer was required to produce this 3-fold yield increase at both locations. This observation emphasizes the extreme difficulty in determining fertilizer requirements for winter wheat. Because fertilizer N responses are extremely dependent upon growing season weather conditions, N recommendations are only going to be as good as our ability to predict the weather.

The influence of environmental conditions on stubbled-in winter wheat grain yield has been studied in detail in Saskatchewan (Entz and Fowler, 1988). Evaporation during the two week period immediately prior to heading, root zone extractable soil water at anthesis and evaporation during the last two weeks in July were found to be the primary environmental factors determining grain yield in these studies.

Evaporation rates during the growing season generally gradually increase from May to July and then drop off quickly in August in Saskatchewan (Fowler and Entz, 1986). On average, evaporation rates increase from southwest to the north in the agricultural region of Saskatchewan (Figure 3). Consequently, one would expect that maximum potential grain yield and N fertilizer requirements would increase in a similar manner. As expected, a comparison

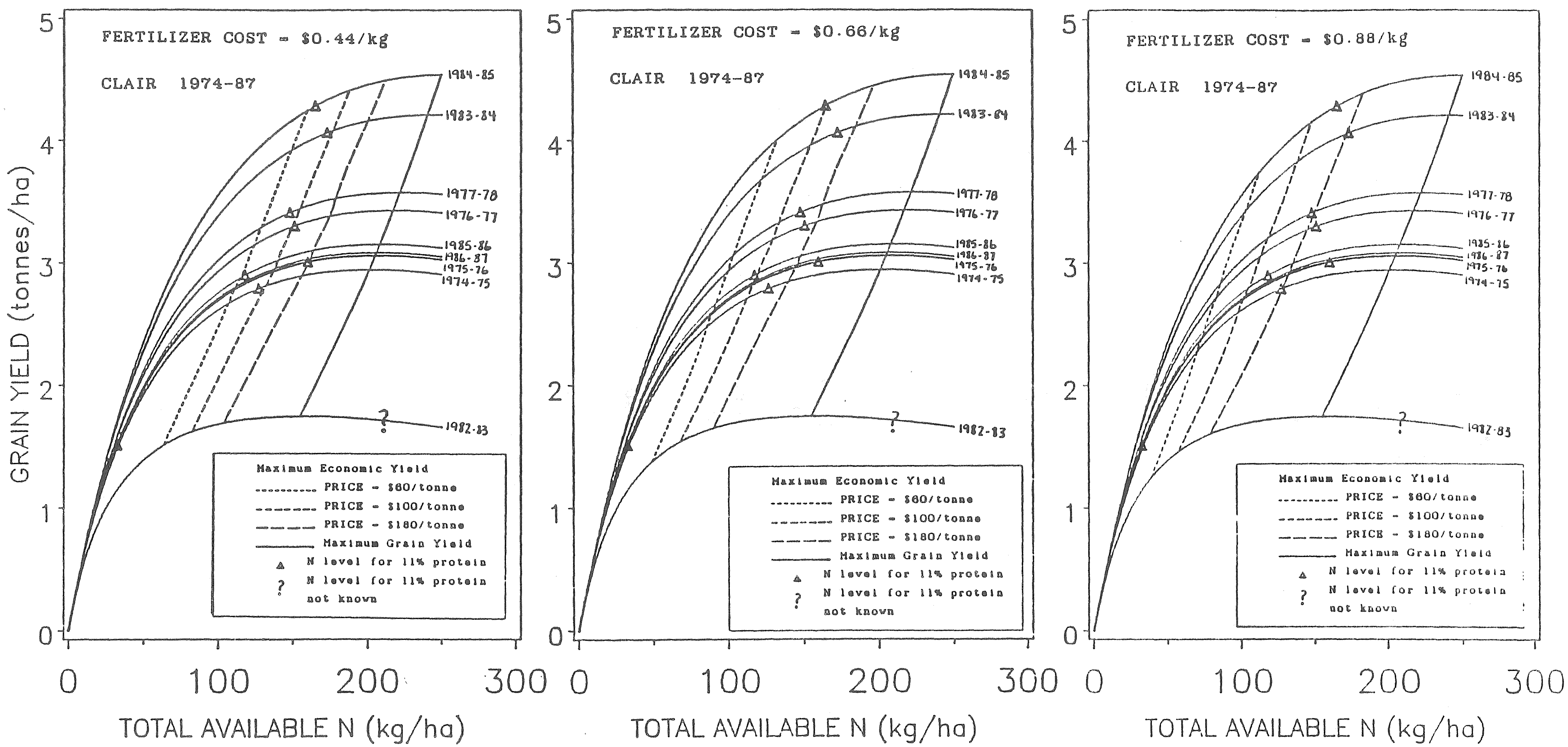

Figure 1. Grain yield response to total available N for nine years of fertilizer trials at Clair, Saskatchewan.

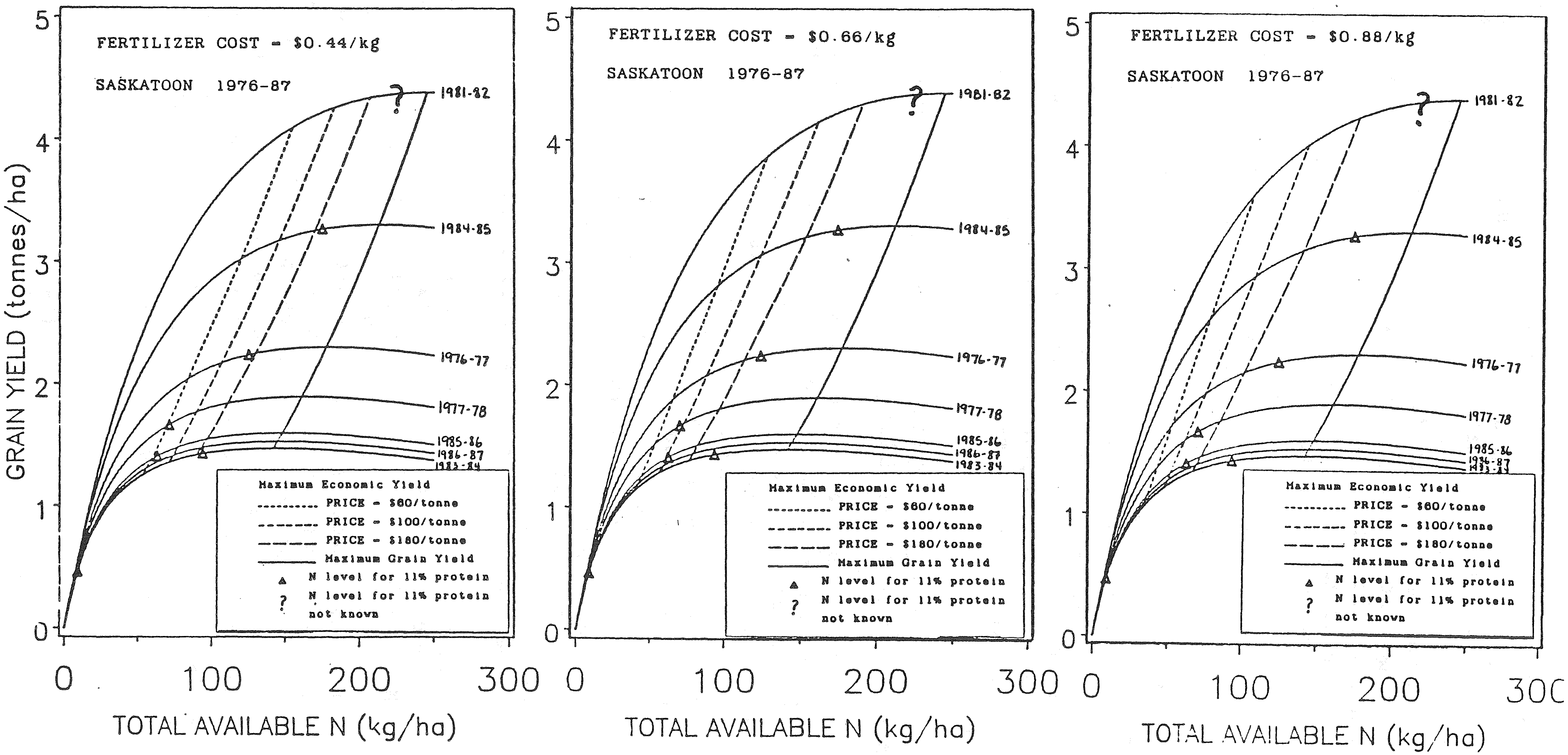

Figure 2. Grain yield response to total available N for seven years of fertilizer trials at Saskatoon, Saskatchewan.

of dryland N fertilizer responses for Clair and Saskatoon in the present study demonstrated the greater average potential as one moves from the Dark Brown to the Black soil zone (Figures 1 and 2).

The growth and development of winter wheat is normally 10 days to two weeks ahead of spring wheat and therefore coincides more favorably with the mean temperature and precipitation patterns experienced in Saskatchewan (Figures 4 and 5). However, stubbled-in winter wheat is by definition a stubble crop making it highly dependent upon precipitation that occurs between the harvest of the previous crop and pre-heading, the critical period for moisture availability. Snow trapped in the standing stubble provides additional spring moisture that can be especially valuable to crop production following dry years (Steppuhn, 1981). Consequently, moisture availability from fall rains and the snow trap can provide useful guides to decisions on N fertilizer rates. However, field studies (Entz and Fowler, 1988) have demonstrated that soil water reserves only contribute approximately 20% to the total annual evapotranspiration indicating that, unless irrigation water is available, the yield potential of stubbled-in winter wheat is very dependent upon growing season rainfall. These studies also demonstrated that stubbled-in winter wheat exhausts most of its available soil water reserves by anthesis making later season growth even more dependent upon rainfall. Because N fertilizer has to be applied by early spring at the latest, this strong influence of growing season rainfall makes it extremely difficult to accurately predict N requirements for maximum economic yield of stubbled-in winter wheat.

<u>RULE 6: Grain and fertilizer prices have a large influence in determining maximum economic yield of winter wheat</u>.

The last few years have seen dramatic reductions in grain prices, especially for winter wheat where the price of #1 CWRW fell from $194/tonne in 1981/82 to $89/tonne in 1987/88 (basis Thunder Bay). Because N-use efficiency gradually decreases with increases in total available N, price changes do not have a straight line influence on the "break-even" N fertilizer rates. In the present study, the influence of grain price, fertilizer price and N response on maximum economic yield were investigated using data from nine and seven years of fertilizer trials at Clair and Saskatoon, respectively. Economic N levels, defined as the N level at which the marginal cost equals the marginal return, were determined by the procedure outlined by France and Thornley (1984). In the discussion of this analyses we have taken the optimistic view that, at present, prices have nearly bottomed out and we will see gradual increases in the future.

As expected, as price per tonne of wheat increased the amount of N fertilizer required to reach the economic N level also increased (Figures 1 and 2). Because N-use efficiency is greater under more favorable growing conditions, a larger increase in N rate was required to obtain the full benefit of price increases in seasons with high compared to low yield potentials. There was a direct benefit, e.g., increasing the price from $60 to $180 per tonne increases the returns by 3 times, and an indirect benefit of grain price increases, e.g., a return from higher N fertilizer levels can also be captured. For example, at Clair in 1984-85. With the price of N at $0.44/kg the economic N level of 160 kg/ha produced a yield of 4.3 tonnes/ha and a return of $258/ha when wheat was $60/tonne. With the price of N at $0.44/kg the economic N level of 212 kg/ha produced a yield of 4.5 tonnes/ha

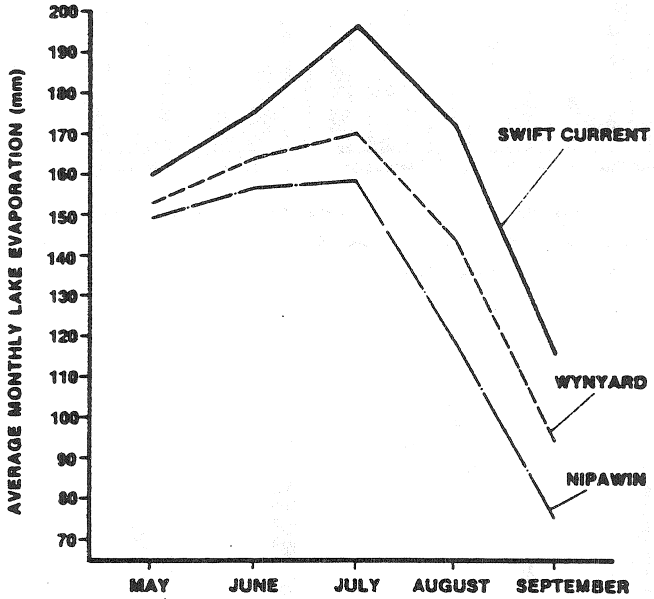

Figure 3. Calculated Monthly Lake Evaporation (mm) for Swift Current, Wynyard and Nipawin, Saskatchewan.
Source: Canadian Climate Normals Vol. 9 Environment Canada. Atmospheric Environment Service.

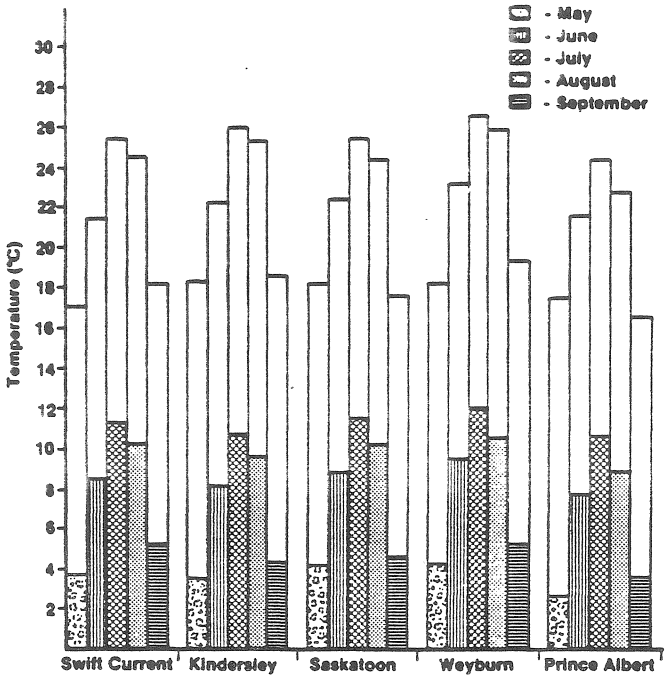

Figure 4. Monthly high (open) and low (shaded) average temperatures at selected stations in Saskatchewan,1951-80 (form Guide to Farm Practice in Saskatchewan, 1984).

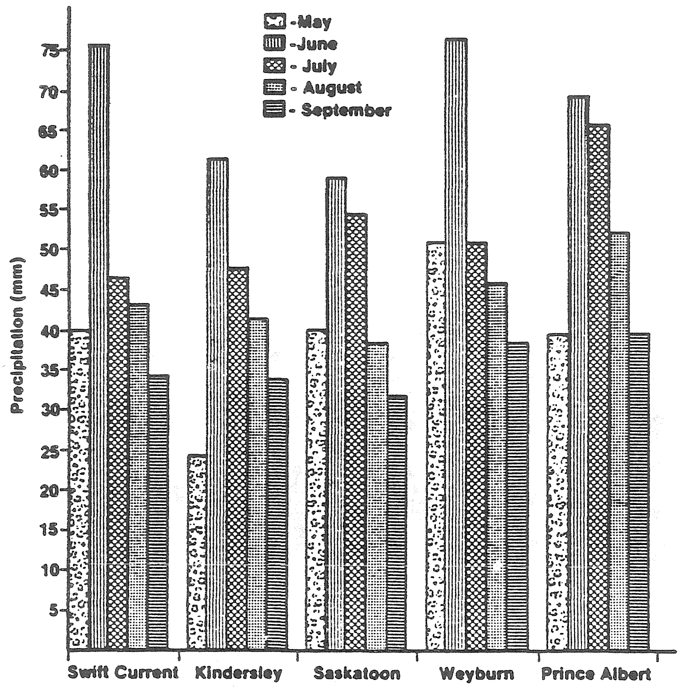

Figure 5. Mean Monthly Precipitation at selected stations in Saskatchewan, 1951-80 (from Guide to Farm Practice in Saskatchewan, 1984)

and a return of $810/ha when wheat was $180/tonne. Therefore, a 3-fold price increase resulted in a potential 3.14-fold increase in gross returns (assuming the fertilizer requirement for maximum economic yield could be accurately predicted) thus providing an extra incentive to risk a higher investment in N when grain prices are high.

Expected return on investment also has large influence on maximum N fertilizer rates recommended. The Saskatchewan soil testing laboratory bases their recommendations on a return of at least $0.50 on every dollar spent on N fertilizer. When compared to the "break-even" N rates in our examples at Clair and Saskatoon (Figures 6 and 7) this change resulted in a reduction in recommended N fertilizer rates by 25 to 50 kg/ha. Lower recommended N rates have the effect of reducing risk and ensuring recovery of miscellaneous costs, such as N fertilizer carrying costs from time of application to sale of the grain. However, balanced against these factors is a reduction in the opportunity to fully exploit the potential N response in a favorable growing season. Once again, the Saskatchewan soil testing laboratory tries to accommodate both the optimistic and the pessimistic producer by providing recommendations for at least three moisture scenarios thereby allowing each farmer the opportunity to decide upon which growing season environmental conditions they wish to bet.

With most farm chemicals, such as herbicides, rates cannot be modified without compromising the performance of the chemical. Consequently, rate cutting is usually not an economic option for farmers faced with increases in the price of farm chemicals. However, not only is N fertilizer rate cutting an option, it is a requirement if maximum economic yield is to be achieved following a N fertilizer price increase (Figures 1 and 2). For example, an increase in the price of fertilizer N from $0.44/kg to $0.88/kg when wheat was $100/tonne would have reduced the economic N level by 39 kg/ha at Clair in 1983-84. This 39 kg/ha reduction in fertilizer N would have resulted in 0.25 tonne/ha less wheat or a $25/ha reduction is net returns. However, this reduction was accompanied by a N fertilizer saving of $34.32/ha giving a net return that was $9.32/ha greater than if the N fertilizer reduction had not been made.

RULE 7: High N rates are necessary to maintain grain quality.

Cereal protein contains approximately 17.5% N. Because N is obtained from the soil, plant-available soil N also has a direct influence on grain protein yield. The ratio of grain protein yield to total grain yield determines grain protein concentration (% protein). Consequently, the influence that N fertilizer has on this ratio determines its influence on grain protein concentration.

The following general grain yield, grain protein yield and grain protein concentration N response patterns have been identified for winter wheat grown in Saskatchewan (Brydon and Fowler, 1988). There is a minimum N level for plant growth that results in a constant ratio of total grain yield to grain protein yield and a minimum grain protein concentration of approximately 8.2% protein. Consequently, when conditions are favorable for growth, the correction of severe N stress by the addition of fertilizer N produces a lag phase (Fowler et al., 1987) in the protein concentration N response curves. Once genotypic (Darroch and Fowler, 1988) or other environmental (Brydon and Fowler, 1988) factors become limiting to growth and subsequent yield

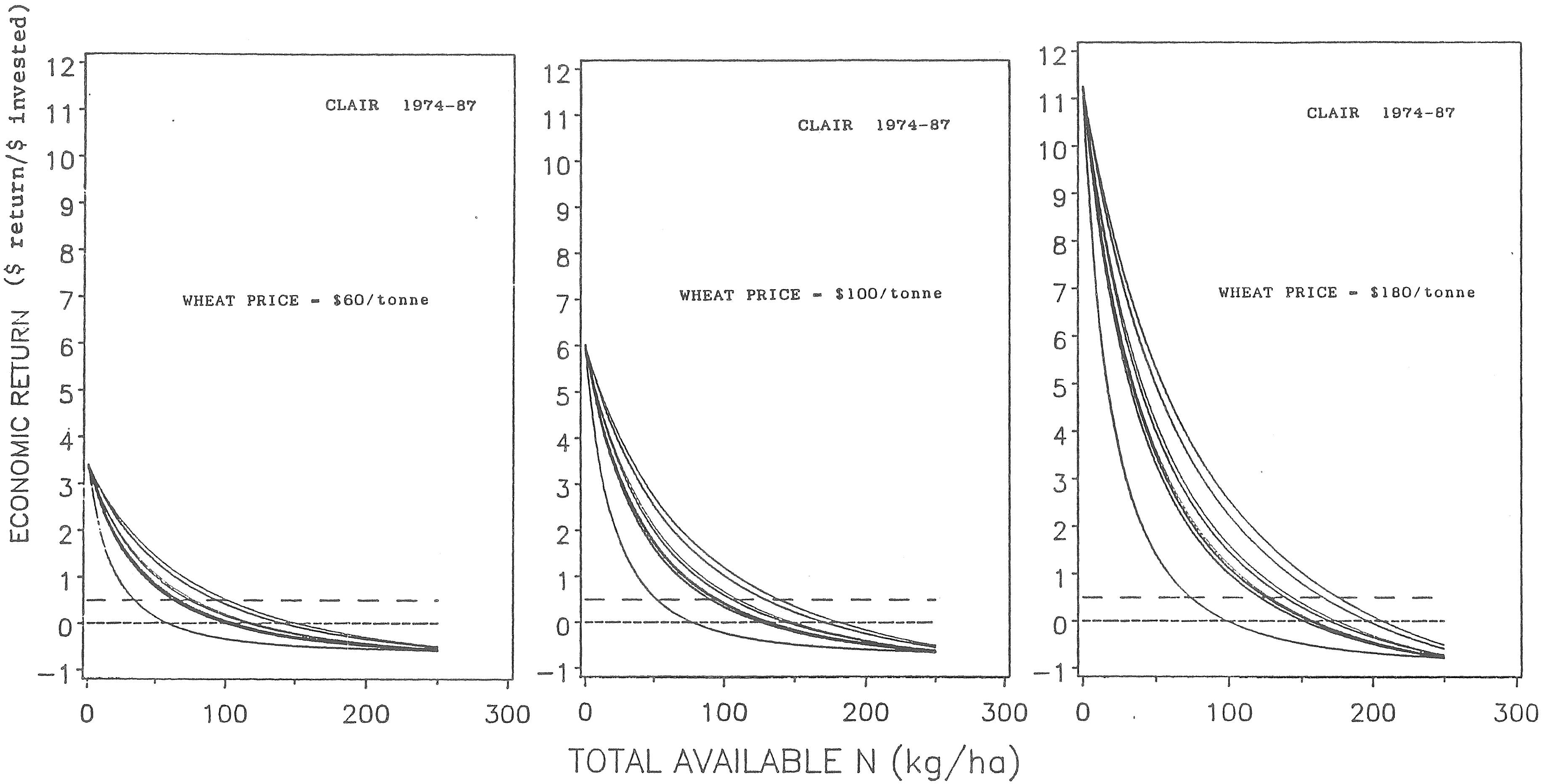

Figure 6. Return on investment in fertilizer N (cost = $0.50/kg N) for nine crop years at Clair, Saskatchewan. See Figure 1 for crop years.

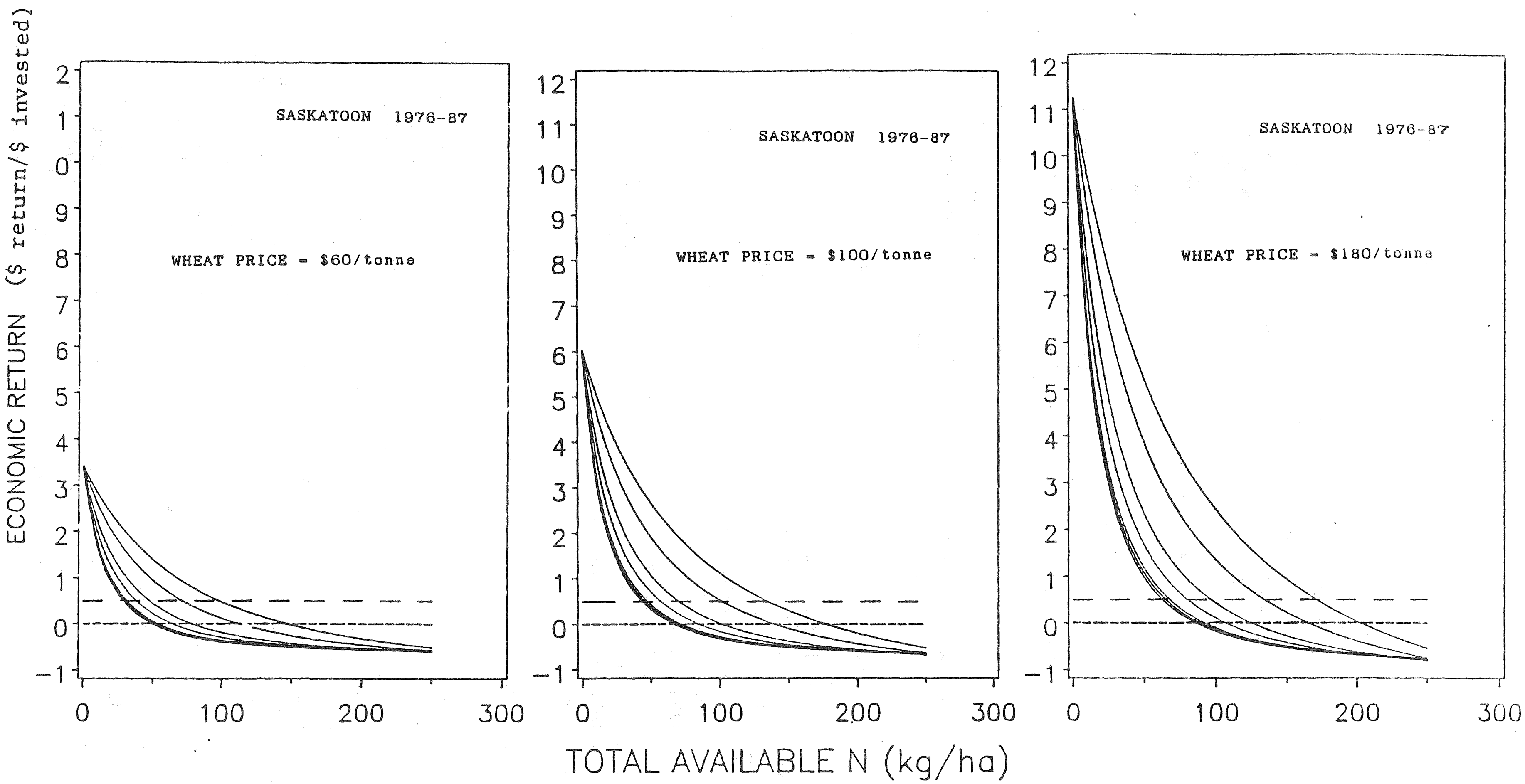

Figure 7. Return on investment in fertilizer N (cost = $0.50/kg N) for seven crop years at Saskatoon, Saskatchewan. See Figure 2 for crop years.

increases, excess N is utilized mainly for grain protein production and the protein concentration N response curve enters an increase phase (Fowler et al., 1987.). Under average to good environmental conditions in Saskatchewan, the maximum N requirements of the winter wheat plant can be expected to have been met when the grain protein concentration N response curve reaches approximately 12.5% (Brydon and Fowler, 1988). The protein concentration N response curve will reach a maximum near this level unless spring environmental conditions favorable for plant growth and N uptake are followed by extreme drought that severely limits grain yield. Maximum protein concentrations ranging from 14.5% to 20% have been observed for Norstar winter wheat produced under these conditions (Brydon and Fowler, 1988).

It is clear from the above observations that, because most stubble fields are deficient in plant-available soil N, N fertilization is also required to maintain grain protein concentration at an acceptable level (Fowler, 1983). Low protein concentration (less than 11 percent) is reflected in a high frequency of "piebald", "yellow berry" or "starchy kernels" in a sample. If the frequency of piebald kernels is high, a sample will be degraded to No. 3 CWRW, which presently sells for the same price as feed wheat. Therefore, grain quality can become an important consideration in determining N fertilization rates required for Maximum Economic Yield.

Identification of the N levels required for 11% protein at our example locations, Clair and Saskatoon, demonstrated that both reductions in grain price and increases in fertilizer price can shift the economic N rate curves below the N levels required for 11% grain protein concentration (Figures 1 and 2). Consequently, market opportunities and penalties for low protein concentration, i.e., degrading to feed wheat prices, or premiums for high protein concentration should receive attention when determining N fertilizer requirements for Maximum Economic Yield of winter wheat. Of even greater concern is the fact that current N fertilizer levels used by most Saskatchewan farmers are below the economic N levels identified in these studies further emphasizing the potential quality problem that exists with stubbled-in winter wheat.

<u>RULE 8: Date of N fertilization can have a large influence on N-use efficiency</u>.

Date of N fertilizer application has been shown to have a significant influence on total grain yield, grain protein yield and grain protein concentration of stubbled-in winter wheat produced in Saskatchewan (Brydon and Fowler, 1988; Johnston and Fowler, 1988). Reduced grain yield, grain protein yield, and protein concentration, attributed primarily to denitrification losses and immobilization, have been observed with fall broadcast N fertilizer in the northeastern part of the agricultural region of Saskatchewan. These N losses were associated with cool, damp weather conditions in early May. Large grain yield losses (Figure 8) were also observed with late spring (late May, early June) N fertilizer applications. In this instance, poor grain yields were attributed to the fertilizer N not being positionally available until after N became severely limiting to plant growth. A stranding of fertilizer N at the soil surface, due to dry conditions following early spring application, also had a similar effect. Comparatively larger increases in grain protein yield with delayed N availability often resulted in higher grain protein concentration, but this did not ensure that an 11% protein concentration would be achieved at economic N levels (Figure 8).

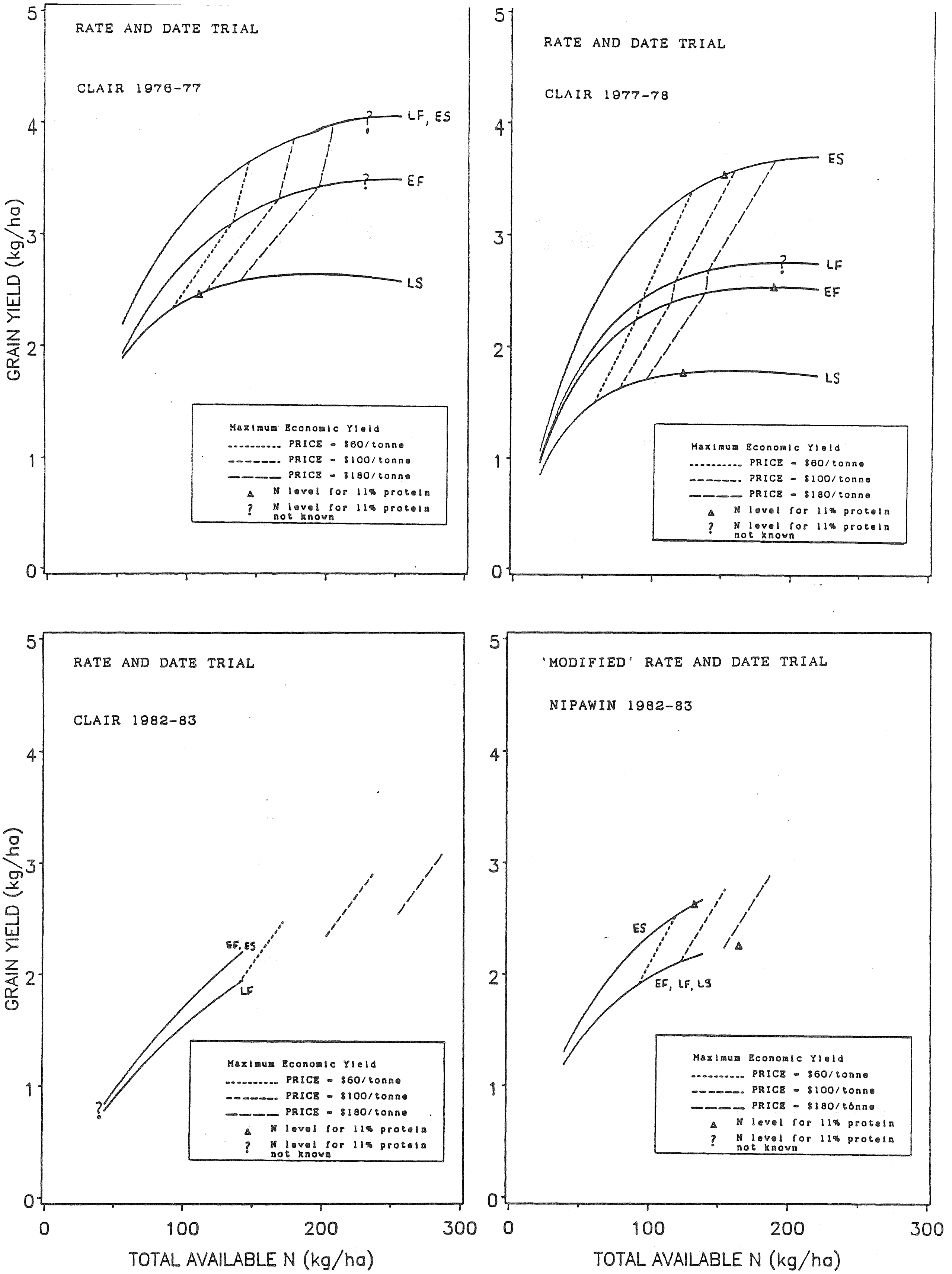

Figure 8. Grain yield response to total available N for trials where significant differences due to date of N application were observed. Approximate dates of N application: LS - June 1, ES - May 1, LF - Oct. 7, EF - Sept. 1. N cost = $0.50/kg.

The size of the yield losses observed in these studies demonstrate the need to pay close attention to date of broadcast N application when fertilizing for Maximum Economic Yield (Table 1). Application at suboptimal

Table 1. Examples of economic losses attributable to date of fertilizer application. Estimates based on wheat at $100/tonne and fertilizer at $0.50/kg N.

Location	Approximate Date of Application (day/mon)	Relative Returns † at Economic N Rate ($/ha)
Clair 1976-77	7/10, 1/5	(387.40)
	1/9	-55.40
	1/6	-139.70
Clair 1977-78	1/5	(359.40)
	7/10	-100.80
	1/9	-119.90
	1/6	-196.70
Clair 1982-83	1/9, 1/5	(289.90)
	7/10	-55.90
Nipawin 1982-83	1/5	(276.10)
	1/9, 7/10, 1/6	-64.90

† Maximum return/ha ($/ha) is given for the application date producing the highest returns at each location. Reduction in returns from this maximum are given for the remaining application dates.

dates resulted in reduced N-use efficiency and a reduction in the N rate at which Maximum Economic Yield occurred (Figure 8). Economic losses were more predictable and much larger for late spring N applications (Table 1) emphasizing the importance of early spring application; or, when cool, damp spring conditions are unlikely, late fall N application.

RULE 9: Ammonium nitrate is the preferred N source of seed placement. Risk of winter damage is increased when N is seed placed.

The response of winter wheat to seed placed N is dependent upon the N source, row spacing and opener type. Drill row spacing and opener type determine the concentration of fertilizer in the row and immediately adjacent to the seed. For instance, moving from a 15 to 30 cm row spacing has the effect of doubling the fertilizer concentration in each row while a disc opener places the fertilizer in a narrower band than a broad hoe opener.

Urea (46-0-0) and ammonium nitrate (34-0-0) are the two most common N forms that are seedplaced. Urea has become the main form of granular fertilizer N and many fertilizer distributors have little interest in stocking ammonium nitrate. Field trials (Johnston and Fowler, 1987) have indicated that, when placed in the seed row, both urea and ammonium nitrate will reduce seedling number and size. However, the effect of urea was more insidious and yield performance was often significantly lower than with ammonium nitrate. Placing urea a minimum of 2.5 cm from the seed row minimized seedling damage.

Increased damage to winter wheat stands has been observed for seedplaced N treatments following high stress winters (Table 2).

Table 2. Effect of seed placed N fertilizer on winter survival. Row spacing = 20 cm.

N added (kg/ha)	Subtract (FSI) †
0	0
34	18
67	24
101	25

† Field Survival Index units

The reduction in winter survival potential with 34 kg/ha seedplaced N was equivalent to the difference in winter hardiness potential between Norstar

(FSI=514) and Sundance (FSI=496) winter wheat cultivars (514-496=18). In other words, the winter survival advantage of Norstar over Sundance would be completely eliminated if 34 kg/ha N was seedplaced with Norstar. The use of high rates of fertilizer P_2O_5 did not counteract the effect that seed row banded N had in reducing winter hardiness. In the absence of winterkill, a yield advantage was not observed with seedplaced compared to early spring broadcast ammonium nitrate in any of the above trials.

RULE 10: N losses with urea are variable, but can be large. Time of application and placement are important considerations in minimizing urea N losses.

Significant N losses have been reported for surface applied urea (46-0-0), esp. when broadcast on snow. These losses arise primarily through ammonia volatilization that results when hydrolysis occurs before the urea moves into the soil (Harapiak et al., 1986).

Losses of urea N, as indicated by significant reductions in grain and grain protein yield relative to comparable ammonium nitrate treatments, have been reported for fall and spring broadcast applications in replicated field trials grown in Saskatchewan (Brydon and Fowler, 1988; Johnston and Fowler, 1988). Economic analyses of the results of these studies indicate that losses from broadcast urea are often very costly (Figure 9, Table 3). However, significant yield reductions were not observed in all trials indicating that specific environmental conditions were required for volatilization losses. This suggests that potential losses with urea are as unpredictable as the weather. Consequently, losses with broadcast urea cannot be corrected for by simply increasing application rates to compensate for average losses.

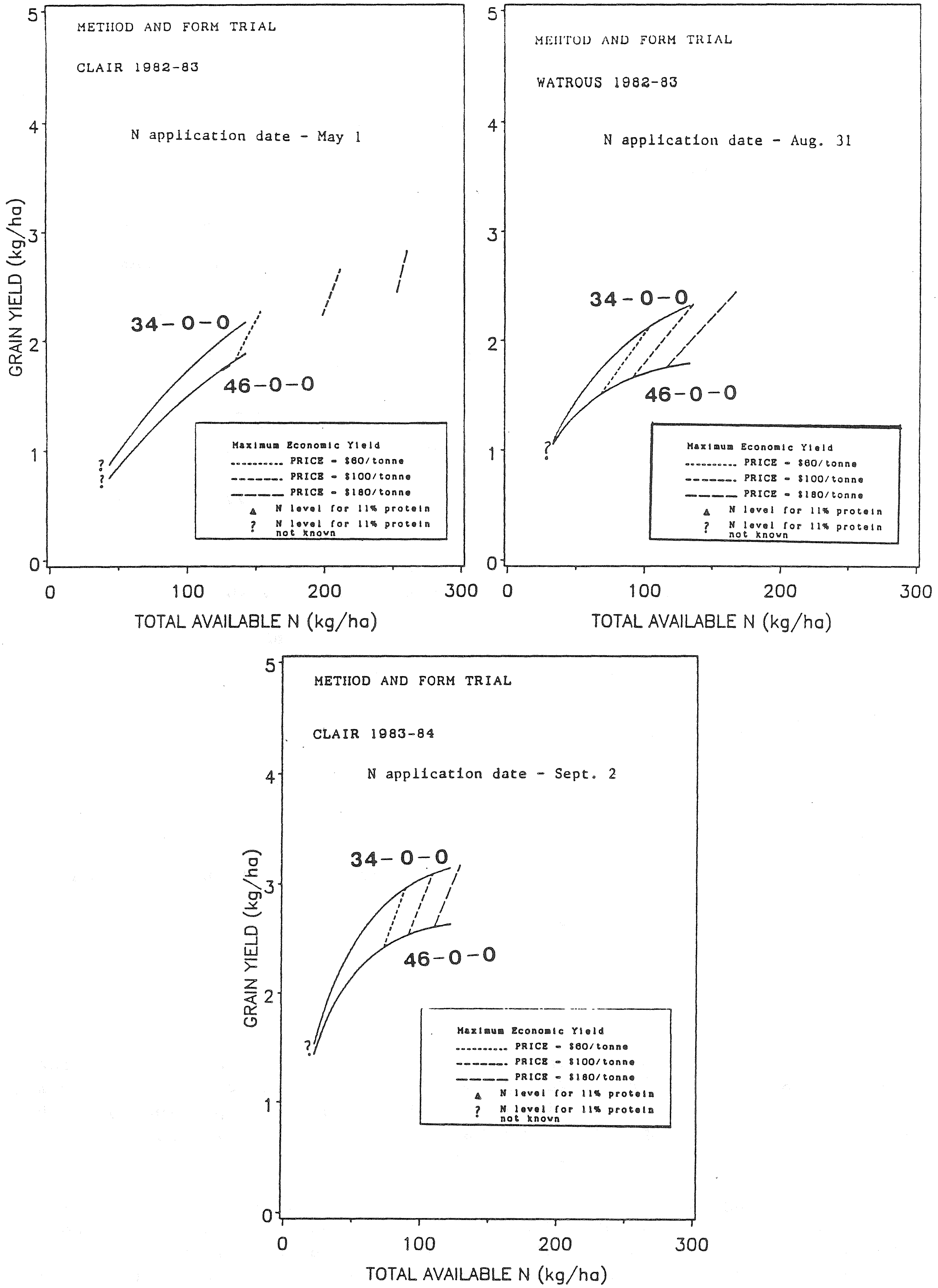

Figure 9. Grain yield response to total available N for trials where significar losses were observed for broadcast urea (46-0-0) compared to ammoniur nitrate (34-0-0). N cost = $0.50/kg.

Table 3. Examples of economic losses for broadcast urea compared with ammonium nitrate. Estimates based on wheat at $100/tonne and fertilizer at $0.50/kg N.

Location	Date of Application (day/mon)	N Form	Relative Returns† at Economic N Rate ($/ha)
Clair 1982-83	1/5	34-0-0	(265.20)
		46-0-0	-41.30
Watrous 1982-83	31/8	34-0-0	(234.40)
		46-0-0	-68.60
Clair 1983-84	2/9	34-0-0	(309.80)
		46-0-0	-55.80

†Return/ha ($/ha) is given for 34-0-0. Reductions in returns are given for 46-0-0 applied at the same time.

Volatilization losses of urea N result in reduced N-use efficiency for yield. As a result, N levels for Maximum Economic Yield are also reduced when volatilization losses occur (Figure 9). This observation provides a further argument against attempting to compensate for potential volatilization losses with broadcast urea by increasing N rates.

Deep banding of N forms that are vulnerable to volatilization losses, e.g., anhydrous ammonia, aqua ammonia and urea, has been the main method of reducing this loss. However, attempts to deep band fertilizer in the stubbled-in production system have exposed the following difficulties: a) Finding time for the seeding of stubbled-in winter wheat is usually difficult enough without adding a fertilizer banding operation prior to seeding. 2) When soil moisture is poor a banding operation prior to seeding may result in additional moisture loss and poor seed germination. 3) Fall banding operations will result in increased stubble breakdown and, hence, reduced snow trapping ability. 4) If banding is done after emergence of the winter wheat there will be damage to the stand. This will result in greater susceptibility to winterkill, delayed maturity and increased weed competition. Spring banding will also result in delayed maturity and increased weed competition. Many of these problems can be avoided if banding is done as part of the seeding operation. However, as indicated earlier, variables such as precision of seed placement, horsepower requirements, seedbed disturbance, labor availability during seeding, time priorities, method of N application for other crops produced, type of drill required to seed other crops produced, ammonium nitrate availability, climatic factors, relative cost of different N forms, etc., must all be assessed before a final decision is made on the purchase of a banding drill. In addition, further studies are required to determine the N-use efficiency of early fall banded urea compared to spring broadcast ammonium nitrate for stubbled-in winter wheat grown under environmental conditions that favor N losses due to denitrification, i.e., cool damp springs.

ACKNOWLEDGMENTS

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