THE EFFECT OF VARIABLE AND UNIFORM N-FERTILIZER APPLICATION RATES ON GRAIN YIELD

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One of the main objectives of soil fertility research is to develop techniques for identifying and correcting field nutrient deficiencies through fertilization. Recently, there appears to be considerable interest in the concept of varying the application rate within a given field to match the changing levels of soil fertility. The method requires appropriate technology for easily identifying areas of different fertility status and equipment for automatically varying the application rate. These aspects are under commercial development by several private companies in Saskatoon, some specifically created for this purpose (Coxworth et al. 1984).

In Saskatchewan, soil fertility status within a given field is closely associated with topography which accounts for most of the local variability in soil profile thickness (Joel 1933). In addition, erosion and tillage translocation of soil from the knoll and upper slope positions, and subsequent deposition in lower slopes will result in varying depths of topsoil. Application of more fertilizer to the upper slopes is viewed as a practical method of offsetting these differences in fertility status. Since fertilizer response (yield gains over check) should be higher in soils with low inherent fertility, the variable application should increase fertilizer use efficiency (yield gain over check per kg fertilizer added) and thus profits.

The objectives of this paper is to examine field N fertility response under varying topography and test the validity of the variable rate application concept. The paper will mainly deal with wheat yield response under stubble, however a summary of previous experiments dealing with response of wheat under fallow will also be given.

MATERIALS AND METHODS

During the 1964 to 1966 growing season a total of 14 stubble field plots each with 8 to 10 subplots at selected slope positions were seeded to wheat in the Dark Brown and Black soil zones. A summary of the different fertilizer N treatment strips (2.5 m x 800 m) is given in Table 1. Each of the treatments was included at each slope positions. Grain yield was determined at each treatment for each slope position by taking 2 m^2 samples.

Composite soil samples were taken from each slope position to a depth of 60 cm for soil test N determination (kg NO_3^--N/ha). Neutron probe access tubes were installed at each of the slope positions. Soil water measurements were made at the time of seeding and at harvest. Precipitation was measured during the growing season by on site total catchment rain gauges which were monitored throughout the growing season. Crop water use (WU) during the growing season was calculated as:

$$WU = P + \Delta S \qquad [1]$$

where P = growing season precipitation (cm), and ΔS = change in soil water storage (cm) to a depth of 120 cm between spring and harvest. The neutron access tube was placed in the intermediate N treatment (approximately 40 kg N/ha), thus the WU represents an average value of the total water available for crop growth at each slope position.

Fertilizer N response curves were estimated for each of the slope positions by fitting the response equation,

$$Y = A + B \cdot N_A - C \cdot N_A^2 \qquad [2]$$

where Y = yield in kg/ha, N_A = applied N fertilizer kg N/ha, and A, B, and C are regression coefficients. The response Equation [2] was chosen since yield increases from fertilizers usually follow some kind of decreasing increment function such that each successive unit of fertilizer added produces less yield increase than its predecessor. In addition the equation can account for yield decreases at a given water content due to over fertilization which is important in situations where water is a limiting factor (Viets, 1962; Power, 1983).

The slope (first derivative) of the yield response Equation [2] is given by

$$\frac{\partial Y}{\partial N_A} = B - 2 \cdot C \cdot N_A \qquad [3]$$

The slope of the response curve (Equation [3]) is a maximum when N_A = 0 and is equal to the B coefficient. Thus the B coefficient represents the change in yield (from check yield) for the first kg of fertilizer added and has the units kg grain/kg N added. In soils which are deficient in N, the value of B will be positive and will represent the maximum fertilizer use efficiency for the conditions at that site.

The response curve reaches a maximum yield when the slope of the response curve ($\partial Y/\partial N_A$) equals zero (i.e. no yield increase for addition of further fertilizer N). The applied nitrogen fertilizer at maximum yield (N_{max}) is thus given by

$$N_{max} = \frac{B}{2C} \qquad [4]$$

or

$$C = \frac{B}{2*N_{max}} \qquad [5]$$

Thus C is related to the maximum fertilizer use efficiency (B) and to the N fertilizer rate which gives maximum yield.

When the applied nitrogen is zero (N_A = 0) the yield is equal to the check yield which according to Equation [2] is equal to the coefficient A. Thus Equation [2] for the N response curve can be rewritten as

$$Y = \text{Predicted check yield} + \text{Maximum N fertility efficiency} * N_A$$

$$- \frac{\text{Maximum N fertility efficiency}}{2 * N_{max}} * N_A^2$$

where A = check yield (kg grain/ha),

B = maximum N fertility efficiency (kg grain/kg N),

C = $B/(2*N_{max})$,

N_{max} = rate of applied N fertilizer to obtain maximum yield.

If you multiply the right hand side of Equation [3] by the ratio of the price of a kg of wheat to the cost of a kg of N, you obtain an equation for the dollar return per dollar invested for the last kg of N fertilizer applied. The equation is:

$$P = (B - 2 \cdot C \cdot N_A) * R \quad [6]$$

where P = dollar return per dollar invested for last kg N added,

R = price of a kg of grain/price of a kg N.

The Saskatchewan Soil Testing Laboratory sets the recommended rate of added fertilizer by setting the value of P at approximately 1.5.

In addition to the fertilizer response trials obtained in 1964 to 1966, field fertility trials where also carried out in 1982 and 1983 as part of the Department of Soil Science FarmLab Program. A total of 11 field plots (4 Dark Brown, 7 Brown soils) were seeded to wheat on stubble with two adjacent N fertility levels (5 kg N, 30 P_2O_5 versus 50 kg N, 30 kg P_2O_5). Paired yield samples were taken at upper, middle and lower slope positions (3 to 4 replications per position) to determine the average yield change from the extra 45 kg N.

RESULTS AND DISCUSSION

A summary of the fertilizer response for the 14 field trials (1964-1966) are given in Table 1. As indicated the maximum fertilizer use efficiency (B) on the lower slope was higher or equal to that on the upper slope in every case except one. The average increase in maximum fertilizer use efficiency of the lower compared to the upper slope (3.9 kg grain per kg N fertilizer) was significant at the 1% probability level. The calculated (Equation [6]) optimum N application rate for a \$1.50 and \$1.00 return per dollar invested for the last kg N added (Table 2) also indicate that more fertilizer should be added to the lower slope positions. It should be realized that the data in this study pertain to Dark Brown and Black soils. A similar response is expected for Brown soils, but not necessarily for fields in more humid areas.

The wheat yield gains over check for addition of an extra 45 kg N, on the Department of Soil Science FarmLab sites (1982-1983) also indicates that fertilizer response was greater on the lower slopes than on the upper slopes. The average additional increase of 340 kg ha^{-1} (approx. 6 bu ac^{-1}) for the lower as compared to the upper slopes was significant at the 1% probability level (Table 3).

The fertilizer responses given in this paper are consistent with the fact that water is one of the more important factors governing productivity on the Prairies. In fact, water is the single most important factor limiting production throughout a major portion of the prairie wheat growing area (Pelton, 1967). In the area where water is the major limiting factor, the variable fertilizer concept must take into account that significantly more water is available in the lower slope positions which would offset the higher soil fertility and give fertilizer responses equal or greater than the upper slope. Thus even though a given fertilizer application may result in a higher percentage yield increase on the upper slopes, the same is not true for the absolute yield increase. A summary of yield response and water use under fallow (Table 4) for different slope positions (1960-1963) has been given by de Jong and Rennie (1967). Their study also shows an increasing response to fertilizer as you move downslope which is related to water use.

The responses given in this paper are in fact the rule rather than the exception. Numerous studies and reviews have concluded that a strong interaction exists between availability of water and fertility (Viets, 1962, 1967). Increased available water not only enhances fertilizer responses by eliminating water as a growth-limiting factor, but in many cases affects nutrient availability and efficiency of utilization (Power, 1983).

Productivity for a given slope position will depend mainly on two limiting factors, fertility and water. The differential response to added fertilizers on upper and lower slopes will depend on the differences in soil fertility (which on average will decrease response in the lower slopes) and the difference in available water (which will increase response in the lower slopes). Initial analysis of the 1964-1966 experiments indicates that the value of B will remain the same if each additional 10-15 kg soil NO_3^--N is accompanied by a 1 cm increase in available soil water. Thus a lower slope with 4 cm more available water than an upper slope can have a soil test N value of 40-60 kg N higher than the upper slope, and still get as good a response to applied N fertilizer.

Successful variable rate application of fertilizers will depend heavily on the ability to detect areas where fertility is the only limiting factor. The semiarid environment over most of the prairie means that water will usually be limited. In areas of higher precipitation, such as the Gray and Dark Gray soil zones, the differences in available water in the lower and upper slopes will not be as important and the variable rate concept may work.

CONCLUSION

Measured responses to N fertilizer application indicated that lower slopes had equal or greater yield gains compared to upper slopes over a variety of soils in the Brown, Dark Brown, and Black soil zones. The increased response in the lower slopes was attributed to more available water which offset the higher inherent soil fertility. The results are consistent with previous studies and suggest that the concept of varying the fertilizer application rate in response to only soil fertility levels will not increase the profitability of fertilizer application. Preferentially fertilizing the upper slopes at higher rates would have decreased field yields and returns on fertilizer dollars invested for the soils studied.

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Table 1. Fertility (N) treatments.

Year		
1964	1965	1966
Check	Check	Check
11-48-0 @ 40	11-48-0 @ 40	11-48-0 @ 40
23-23-0 @ 87	23-23-0 @ 87	23-23-0 @ 87
33.5-0-0 @ 120	33.5-0-0 @ 120	33.5-0-0 @ 120
33.5-0-0 @ 240	33.5-0-0 @ 180	33.5-0-0 @ 180
23-23-0 @ 65		
27-14-0 @ 143		

All rates expressed @ kg/ha

Table 2. Effect of slope position on fertilizer use efficiency, predicted optimum N-fertilizer application rate and wheat yield gain over check (1964, 1965, and 1966 growing seasons).

Site #	Soil zone	Soil asociation	Maximum fertilizer use efficiency (B)			Calculated optimum N rate (kg/ha)				Yield gain over check (kg/ha)		
						R* = 1.5		R* = 1.0		R = 1.5		L-U†
			Upper slope	Lower slope	L-U	Upper	Lower	Upper	Lower	Upper	Lower	
1	Brown	Ardill	14.5	16.0	2.5	70	93	82	108	690	1000	
2	Dark Brown	Elstow	3.3	7.6	4.3	0	12	0	20	0	80	
3		Elstow	15.0	22.4	7.4	25	32	29	35	330	450	
4		Elstow	3.2	8.0	4.8	0	8	0	14	0	55	
5		Weyburn	-1.6	0.4	2.0	0	0	0	0	0	0	
6		Weyburn	30.4	34.6	4.2	26	44	28	47	460	890	
7		Sutherland	5.4	5.0	-0.4	0	0	10	10	0	0	
8	Black	Yorkton	12.4	13.1	0.7	20	20	24	24	180	185	
9		Oxbow	34.4	37.6	3.3	35	33	37	34	705	690	
10		Oxbow	-0.8	5.0	5.8	0	0	0	12	0	0	
11		Oxbow	7.5	22.8	15.3	13	27	23	29	85	380	
12		Melfort	7.0	8.6	1.6	17	32	34	49	105	225	
13		Hoey	12.3	7.7	-5.0	23	11	28	19	200	70	
14		Hoey	4.1	12.6	8.5	0	33	8	41	0	300	
	Average				3.9**					195	310	115**

*R = ratio of dollar returned to dollar invested for last kg N-fertilizer added

**Significantly >0 at 5% probability level

†Lower-Upper slope

Table 3. Effect of slope position on yield gains due to applied N-fertilizer (1982-83 growing season).

Soil zone	Soil association		Gain* in wheat yield (over check) kg/ha Slope position Upper	Lower	L-U†
Brown	Ardill		525	500	-25
	Ardill		495	640	145
	Ardill		370	835	465
	Ardill		150	275	125
	Ardill		-410	15	425
	Amulet		1340	1360	20
	Sceptre		1060	1410	350
Dark Brown	Weyburn		740	1710	970
	Weyburn		870	1200	330
	Brooking		-30	940	970
	Keppel		370	350	-20
		Ave.	510	840	340**

*Yield at 50 kg N, 30 kg P_2O_5/ha, yield at 5 kg N, 30 kg P_2O_5/ha

**Significantly >0 at 1% probability level

†Lower-Upper, significant at the 5% level

Table 4. Fallow yields (Weyburn and Elstow soil associations, 1960-1963) (from de Jong and Rennie, 1967).

	Knoll	Upper	Lower	Depression
Yield (kg/ha) Fert.*	1386	1794	1692	1944
Check	1128	1464	1236	1398
Fert. - Check	258	330	456	546
Water use (cm)	21.8	21.5	23.6	26.0

*11-48-0 at 10 kg P ha^{-1}; Check = no fertilizer