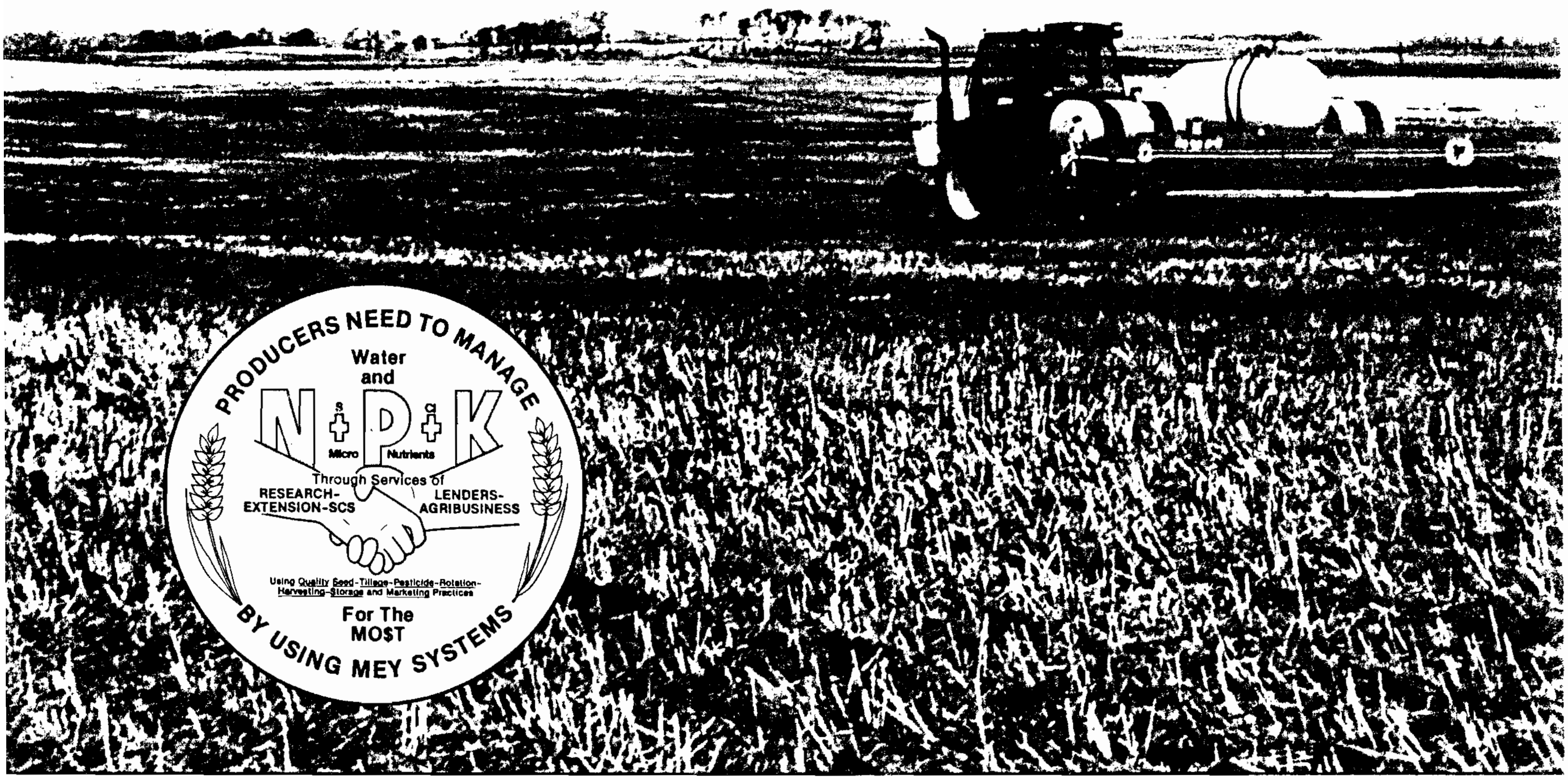
A Regional Workshop
Prairie Provinces on Implementing Maximum Economic Wheat Yield Systems (IMEWYS)

A Hands-On Workshop For

IMPLEMENTING MAXIMUM ECONOMIC YIELD (MEY) SYSTEMS



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PHOSPHORUS MANAGEMENT FOR MEWY AND QUALITY[1]

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INTRODUCTION

Many of the soils in the Northern Great Plains are deficient in plant-available phosphorus (P). Therefore, wheat yields are generally increased by P fertilization on soils testing "very low" and "low" in sodium bicarbonate extractable P. Accurately assessing the level of available P in the soil and determining the quantity of P fertilizer to apply to alleviate any P deficiency becomes very important. Obtaining maximum economic wheat yields (MEWY) will require adequate amounts of plant-available P. In addition, the current emphasis on the need for higher fertilizer rates to optimize grain yields necessitates that the short- and long-term economic impact of these fertilizer applications be evaluated. Farmers today are under severe economic pressure. Their costs of production have tended to inflate while commodity prices have tended to decrease. The current management emphasis for farmers is on increasing the efficiency of inputs. A good balance of plant nutrients is essential for obtaining optimum economic yields. Soil test information is essential for making accurate fertilizer recommendations. Accurate fertilizer recommendations can help farmers achieve the required nutrient balance without overinvesting or underinvesting in fertilizer.

The purpose of this paper is to examine: a) the relationship between soil test P level and the yield potential of wheat; b) the balance required in N and P fertilization to optimize wheat yields; and c) the economics of fertilizing for optimum wheat yields. Several long-term P fertility studies have been conducted in the northern Great Plains and served as the source of information for the relationships developed in this paper.

SOIL TEST P vs. WHEAT YIELD POTENTIAL

Spring Wheat-Fallow Cropping System

The relationship between soil test P and relative yield potential shown in Figure 1 was developed from the data of Black (1982) and Halvorson and Black (1985). Yield data from only the P treatments receiving 40 and 80 lb N/acre each crop year were used in this analysis in order to eliminate N deficiency as a variable. This study was conducted on a glacial till, Williams

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loam soil and provided a range in soil test P values from 5.4 to 40.2 ppm collected over a period of 12 years. A hyperbolic function provided the best fit line (r = 0.92) to this data:

$$Y = 110.5 + (-282.8/X)$$

where Y = relative yield potential (%) and X = soil test P level (ppm) in the 0 to 6 inch soil depth. Using this relationship, a soil test P level of 26.9 ppm in the 0 to 6 inch soil depth would be needed to obtain 100% of the yield potential. This is considerably higher than most soil testing laboratories would use for making P fertilizer recommendations. Soil test calibration data from the South Dakota State University Plant Science Department supports this soil test level (personnel communication with Dr. Paul Fixen, Plant Science Dept., SDSU). Their soil test calibration data shows that a soil test level of about 25 ppm P is needed to achieve 100% yield potential when using a Mitscherlich function to evaluate the relative yield data as a function of soil test P compared to a critical level of 13.8 ppm P at 89% relative yield potential for wheat when using the Cate-Nelson approach.

When using the Cate-Nelson Graphical Method (Nelson and Anderson, 1977) to determine a critical soil test level, a value of 16 ppm P was estimated to be needed to obtain a 93% relative yield potential (Figure 2). This value is in close agreement with many of the University Soil Testing Laboratories located in the Great Plains. Using the hyperbolic function given above, a soil test level of 16 ppm would have an estimated 93% yield potential. Therefore, both methods for interpreting a critical soil test P value are in close agreement for the wheat-fallow system.

Annual Cropping Systems

Data from Halvorson and Black (1985), Wagar et al. (1986), Bailey et al. (1977), Read et al. (1977), Ridley and Tayakepisuthe (1974), and Alessi and Power (1980) were used in developing the relationship between soil test P and relative yield potential shown in Figure 3. Soil textures ranged from clay loams to sandy loams. A good range in soil test values (1.8 to 66.5 ppm P) with corresponding yields was obtained. A hyperbolic function gave the best fit line (r = 0.83) to the soil test P vs. relative yield data plotted in Figure 3. The equation was:

$$Y = [X/(1.845 + 0.911*X)]*100$$

where Y = relative yield potential (%) and X = soil test P level (ppm) in the 0 to 6 inch soil depth. The four data points that are circled were excluded from the regression analysis because they tended to move the regression line to much to the right. A

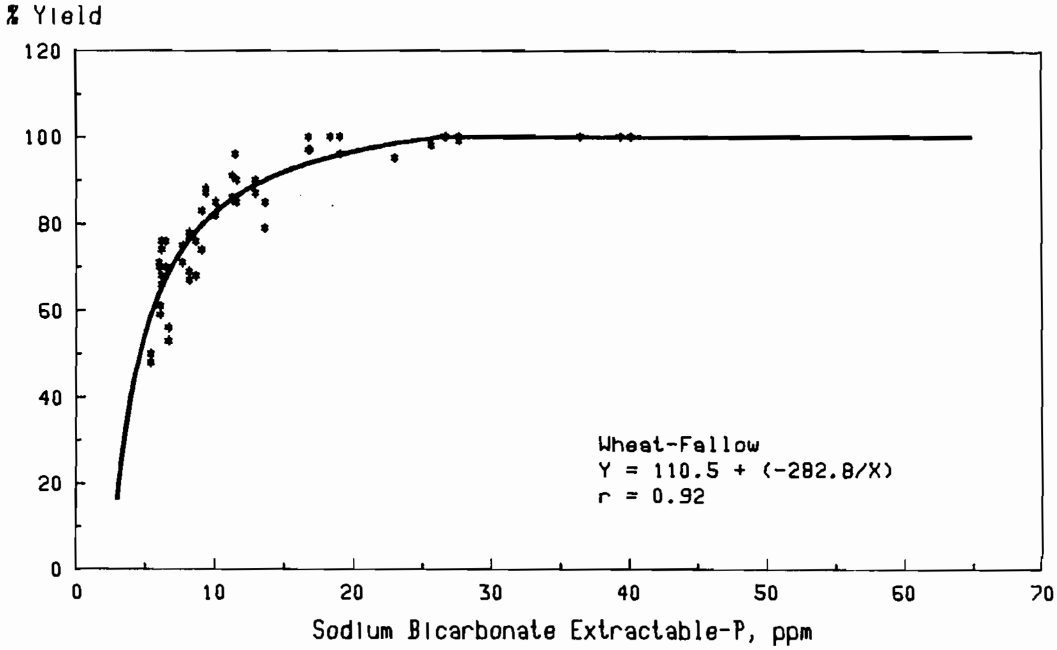

Figure 1. Relative yield potential as a function of soil test P level in a wheat-fallow system expressed as a hyperbolic function.

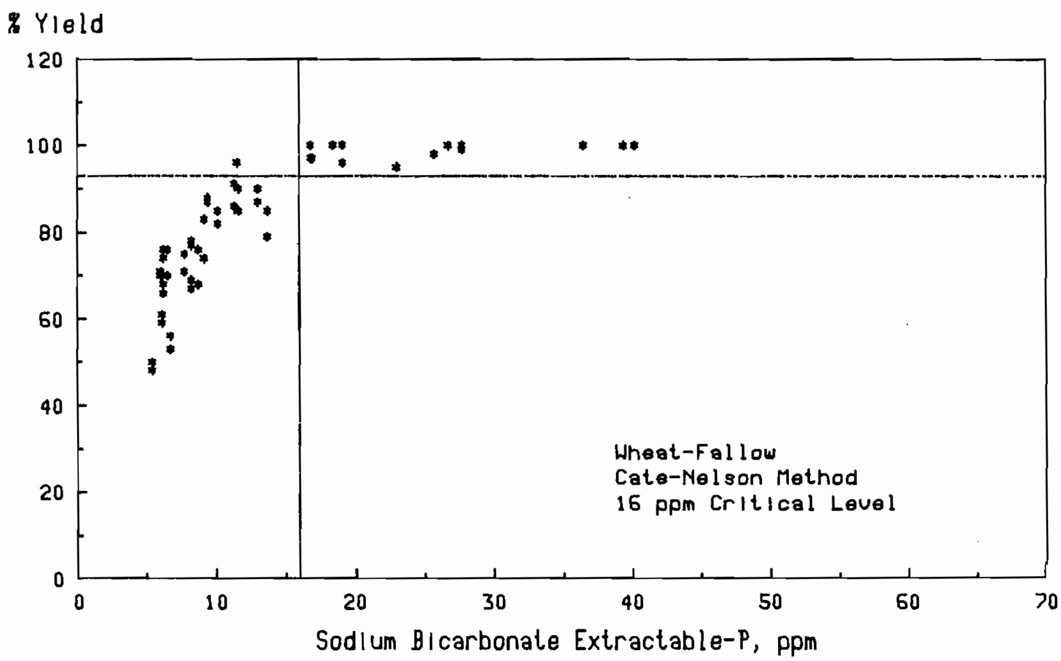

Figure 2. Use of the Cate-Nelson Graphical method to estimate a critical soil test level for P in a wheat-fallow system.

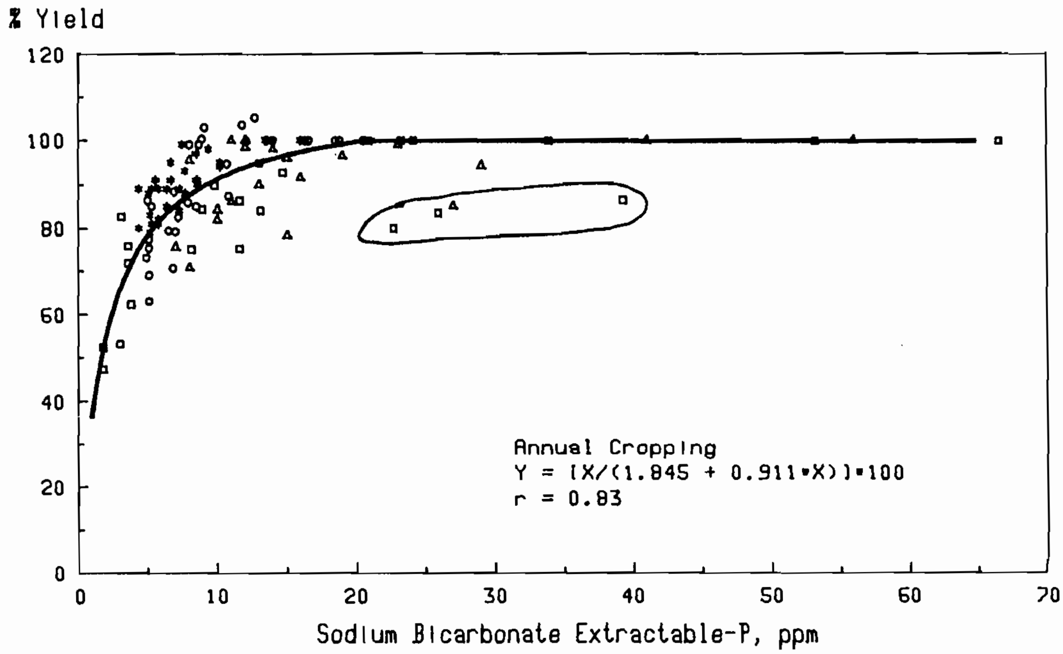

Figure 3. Relative yield potential as a function of soil test P level in an annual cropping system expressed as a hyperbolic function.

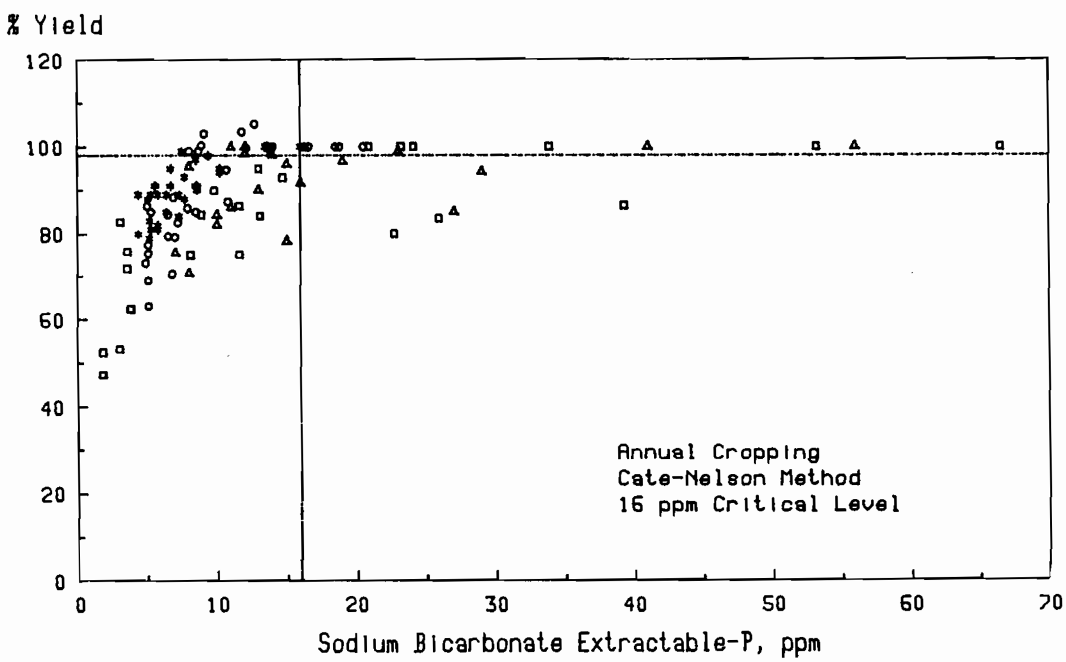

Figure 4. Use of the Cate-Nelson Graphical method to estimate a critical soil test level for P in an annual cropping system.

soil test level of 20.6 ppm would be needed to obtain 100% of the yield potential. This is slightly less than the 26.9 ppm P level needed for maximum yield potential in the wheat-fallow system. This should probably be expected since yields under recrop conditions are generally slightly lower than those obtained with a wheat-fallow system. Soil water supply under annual cropping conditions may be slightly less than with wheat-fallow, which may account for the slightly lower yields with annual cropping when N has been adequately supplied. Thus with a lower yield level, the need for P is slightly less. North Dakota State University (Dahnke et al. 1985) makes P fertilizer recommendations for wheat based on soil test value and expected yield level, with more P fertilizer being recommended for increasing yield level.

The Cate-Nelson Graphical Method was also used to estimate a critical soil test P level for the annual cropping system (Figure 4). A critical level of 16 ppm P with a 98% yield potential was estimated using this method. This is the same critical level estimated for the wheat-fallow system (Figure 2) with a yield potential of only 93%. Thus is would appear that a higher level of available P would be needed in a crop-fallow system to attain maximum yield potential than in an annual cropping system.

The Cate-Nelson approach estimates a soil test P level of at least 16 ppm is needed to obtain optimum wheat yields in either the wheat-fallow or annual cropping systems. This agrees with the original work of Olsen et al. (1954) in developing the sodium bicarbonate soil test. They also found that when the soil test level reached about 18 ppm P, no responses to fertilizer P were obtained. The data presented in Figures 1 and 3 shows that to attain maximum wheat yield potentials, soil test P levels above 20 ppm may be required.

N AND P FERTILIZATION EFFECTS ON GRAIN YIELD AND QUALITY

Grain yield and protein data were collected from 1967 to 1983 from 11 crops of a N and P fertilizer study conducted on a glacial till Williams loam soil near Culbertson, MT (Black, 1982; Halvorson and Black, 1985a and 1985b). After the 6th crop in a crop-fallow sequence, the plots were annually cropped through 1983. Although safflower and barley were grown during the annual cropping phase of the study, they had yields in terms of pounds/acre equivalent to wheat. Therefore, to keep the analysis in wheat equivalents, the yields of safflower and barley were calculated based on 60 lb/bu grain test weight. However, only the protein data from the wheat crops are discussed in this paper.

Ammonium nitrate (34-0-0) was applied broadcast each crop year (0, 40, and 80 lb N/acre) as main plots in a split-plot design, except to the 7th and 8th crops which were safflower and barley, respectively. By the end of the 6th crop-fallow cycle, residual NO_3-N had accumulated in the root zone of the 40 and 80 lb N/acre fertilizer treatments (Halvorson and Black, 1985c), and therefore, no additional N was applied to the 7th and 8th crops. Fertilizer P was applied only once, at initiation of each plot series in 1967 or 1968. The fertilizer P (0, 20, 40, 80, and 160 lb P/acre) was broadcast and incorporated with a disk to a depth of about 3 inches. All other tillage operations during the study were performed to a depth of 2 to 3 inches.

The average cumulative grain yield increase over that of the no fertilizer treatment (check plot) for the 11 crops is shown in Table 1. The treatment with the greatest cumulative yield above that of the check was the single application of 160 lb P/acre plus the addition of 80 lb N/acre each crop year. Following the 6th crop, the cumulative yields for the zero N plots showed little change and tended to decrease slightly during the annual cropping phase of this study. Note, that adding N fertilizer without P did not significantly increase grain yields during the crop-fallow phase of the study. However, N fertilizer alone did increase grain yields during the annual cropping phase of the study. Although adding P fertilizer without N increased grain yields above that of the check plot, the increase was not as great as when both N and P fertilizer were added (a positive N-P interaction).

Table 1. Wheat grain yield of the check treatment each crop year and cumulative yield above check with each additional crop year for the various N and P treatments.

Treatment		Crop year										
N	P	1	2	3	4	5	6	7	8	9	10	11
lb/acre		Check yield, bu/acre										
0	0	31	18	35	23	32	20	17	32	24	18	15
		Cumulative yield above check, bu/acre										
0	0	0	0	0	0	0	0	0	0	0	0	0
0	20	6	7	8	9	14	16	17	16	17	16	14
0	40	7	12	16	18	25	27	31	30	30	29	28
0	80	8	13	19	22	32	38	42	40	41	39	38
0	160	10	18	27	31	41	48	52	51	53	49	50
40	0	-2	-1	1	1	6	4	10	7	12	23	28
40	20	7	14	15	15	23	23	33	34	40	52	56
40	40	12	20	26	30	44	50	59	59	65	78	86
40	80	12	24	36	45	65	79	88	91	98	112	119
40	160	13	27	39	48	70	87	96	100	110	125	133
80	0	-2	-0	1	0	8	7	17	17	21	33	42
80	20	7	11	15	15	26	28	38	38	43	55	61
80	40	10	18	28	31	46	53	63	65	70	84	93
80	80	11	25	38	45	64	77	86	86	93	109	118
80	160	12	27	42	50	69	89	100	103	114	132	142

The effects of the various N and P fertilizer treatments on grain protein of the wheat crops grown from 1967 to 1983 are shown in Table 2. Note that without any N fertilizer applied, the protein concentration of the grain decreased as the rate of the one-time P fertilizer application increased. Adding 40 lb N/acre each crop year increased the concentration of protein in the grain, however, a slight decrease in protein was still noticeable as the rate of P application increased. Increasing the rate of N fertilization to 80 lb N/acre resulted in further improvement in grain protein and generally maintained the same protein level at all P levels with the exception of the highest P application rate.

Table 2. Average grain protein concentration of the wheat crops for the various N and P treatments.

	Fertilizer P Added, lb P/acre				
N Rate	0	20	40	80	160
lb/acre	----------------------%				-------------------
0	14.5	14.3	14.2	13.9	13.4
40	15.9	15.8	15.5	15.3	15.1
80	16.4	16.4	16.3	16.4	16.0

ECONOMICS OF FERTILIZING FOR OPTIMUM WHEAT YIELDS

The long-term yield and protein data from the study of Black (1982) and Halvorson and Black (1985a) were economically analyzed (Halvorson, Black, Watt, and Leholm, 1986) and are used here to demonstrate the economics of fertilizing for optimum wheat yields. The economic factors considered in this analysis included crop and fertilizer price, fertilizer application costs, protein premiums, federal income taxes, and real interest rates. A grain price of $3.30 was used because this was the average U.S. loan price for hard red spring wheat at the time this economic analysis was conducted. A fertilizer cost of $0.47/lb P and $0.23/lb N with a broadcast application cost of $2.44/acre was used for the first year. All subsequent N fertilizer applications were assumed to be anhydrous ammonia ($0.16/lb N) with an application cost of $4.20/acre. A 6.25% real interest or discount rate was used, which is a 10.25% nominal interest rate minus a 4.00% inflation rate. The discount rate is simply your cost of money above the inflation rate. A tax advantage was calculated assuming a 50% tax bracket for the 1st crop year and a zero percent tax bracket for crop-years 2 through 11. Protein premiums were calculated assuming a zero premium at 12% protein and a $0.46/bu premium at 17% protein with a linear relationship between this protein range, based on a 16-year average of protein premiums paid in North Dakota.

The cumulative net returns above fertilizer costs, discounted at a rate of 6.25% but without any tax credits, are shown in Table 3. Without N fertilization, the 20 and 40 lb P/acre treatments were profitable in crop-yr 1, 80 lb P/acre in crop-yr 2, and 160 lb P/acre in crop-yr 3. The 40 lb N/acre treatment without fertilizer P was not profitable. With 40 lb N/acre each crop year, the 20 and 40 lb P/acre treatments were profitable in crop-yr 1, and the 80 and 160 lb P/acre treatments in crop-yrs 2 and 3, respectively. The 80 lb N/acre treatment without fertilizer P was not profitable. With 80 lb N/acre each crop year, the 40 and 80 lb P/acre treatments were profitable in crop-yr 2 and the 160 lb P/acre treatment in crop-yr 3. The 20 lb P/acre treatment did not become profitable until crop-yr 7 at the 80 lb/acre N rate. These data show that a good balance in both N and P is needed to achieve optimum economic returns. The one-time application of 80 lb P/acre plus 40 lb N/acre each crop year resulted in the highest average estimated net income, $18/acre per crop year above that of the check treatment.

On the assumption that a farmer had a high income situation in one year that extended him into the 50% tax bracket, we calculated an estimated net return with the tax savings. Without N fertilization, all P treatments were profitable the first year except 160 lb P/acre, which became profitable in crop-yr 2. The 40 and 80 lb N/acre treatments without P fertilization did not show a profit at any time. All treatments receiving fertilizer P showed a net profit in crop-yr 1 when 40 or 80 lb N/acre were added each crop year, except for the 160 lb P/acre plus 80 lb N/acre treatment which showed a profit in crop-yr 2. When considering the tax benefit, the 160 lb P/acre plus 40 lb N/acre

Table 3. Cumulative net dollar return above check plot for the various N and P treatments with each additional crop year with a 6.25% discount rate but without tax considerations.

Treatment		Crop year										
N	P	1	2	3	4	5	6	7	8	9	10	11
lb/acre		$/acre										
0	0	0	0	0	0	0	0	0	0	0	0	0
0	20	8	10	12	17	29	34	36	35	36	34	32
0	40	2	18	30	33	53	58	67	65	65	62	60
0	80	-14	1	20	27	53	68	76	73	75	71	69
0	160	-46	-20	7	17	42	60	69	67	71	65	66
40	0	-17	-23	-30	-39	-32	-45	-31	-37	-34	-17	-14
40	20	4	12	8	-0	12	3	27	29	37	54	54
40	40	8	25	33	34	63	69	88	90	98	116	124
40	80	-9	18	45	59	103	129	149	156	166	187	194
40	160	-43	-11	15	32	80	115	133	142	158	181	189
80	0	-28	-38	-49	-66	-60	-73	-51	-52	-51	-36	-30
80	20	-9	-10	-16	-29	-14	-22	1	2	4	18	21
80	40	-7	3	15	10	37	40	63	67	70	87	95
80	80	-23	4	27	34	68	89	108	109	117	137	144
80	160	-57	-25	3	10	47	83	107	115	131	155	164

treatment had the greatest long-term net profit above that of the check plot with an average net profit of $21/acre per crop year. Using this scenario, the tax savings could contribute greatly to the long-term net profits and make the economic returns to N and P fertilization even more profitable.

The average (16 wheat crops) value of the grain protein per crop year above that of the check treatment is shown in Table 4. Without N fertilization, increasing the rate of P fertilization resulted in a greater net loss per acre because of the lower protein concentration in the grain than that of the check treatment. With N fertilization, the average value of protein per acre increased with increasing rate of P fertilization as a result of an increase in grain yield and protein above that of the check. The 80 lb P/acre plus 80 lb N/acre treatment had the greatest estimated average return per wheat crop ($7.43/acre) due to protein premium. This increase in grain value due to N fertilization can potentially pay for 50 to 75% of the N applied.

Table 4. Average value of the grain protein above that of the check plot per wheat crop for the various N and P treatments.

	Fertilizer P Added, lb P/acre				
N Rate	0	20	40	80	160
lb/acre	----------	----------	$/acre	----------	----------
0	0.00	-0.36	-0.27	-0.51	-1.38
40	3.51	4.06	4.24	4.67	4.96
80	4.70	5.29	6.48	7.43	7.43

PHOSPHORUS FERTILIZATION FOR MEWY

Method and rate of fertilizer P application can greatly affect the response of wheat to P fertilization (Leikam et al.; 1983; Black, 1982; Halvorson and Black, 1985a; Bauer et al., 1970; Wagar et al., 1986; Read et al., 1977; Alessi and Power, 1980). If low rates of fertilizer P are to be applied to soils testing "low" in plant-available P, then banding the fertilizer P below or with the seed is generally more efficient and results in greater yield increases than broadcast P applications. However, if sufficient fertilizer P was to be added to attain maximum wheat yields on a soil testing "low" in P, then method of placement may not be as critical. The recent work of Wagar et al. (1986) supports this theory. They found that a single, broadcast P application of 71 lb P/acre had a greater cumulative yield after 5 years than 18 lb P/acre applied each crop year with the seed. Thus the broadcast treatment produced at or near optimum yields each year whereas the seed place P treatment produced at less than optimum yield potential during the first several years. They also found that a combination of a residual 36 lb P/acre broadcast one time plus 9 lb P/acre applied each crop year with the seed produced near maximum wheat yields. The latter treatment would be desireable from the stand point of spreading the P fertilizer costs out over a longer time frame and still being able to maintain near maximum yield potential.

Based on the studies of Wagar et al. (1986), Read et al. (1977), Jose (1981), and Alessi and Power (1980), I would like to suggest that the following P management system be used to optimize wheat yields in the Great Plains and western U.S.:

a) Broadcast and incorporate sufficient fertilizer P to bring the soil test P level up to 16- to 20-ppm in the 0 to 6 inch soil depth.
b) Apply sufficient fertilizer P by banding, with or below the seed, each crop year thereafter to maintain the soil test P level near 16- to 20-ppm. A broadcast P application would probably produce equal results in a conventional tillage system, but banding would be preferred for reduced tillage systems.

This approach to P fertilization would probably provide the potential for optimum and near maximum wheat yields each crop year. In dry years, a high level of soil P will not hurt yields and in the wet years, a high level of soil P will provide that opportunity to utilize more efficiently the available water supply, providing that N is not limiting.

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