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FERTILIZATION OF WHEAT, CORN, AND GRASS-LEGUME MIXTURE GROWN ON RECLAIMED SPOILBANKS

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Interpretive Summary

The efficacy of phosphorus and nitrogen soil tests developed for undisturbed soils in North Dakota to predict deficiency of these nutrients and the related corrective measures using commercial fertilizers was evaluated on reclaimed sites with three crops over a 2-year period. Yield responses of wheat, corn, and grass-legume to application of phosphorus and nitrogen fertilizers confirmed a deficiency or sufficiency of each nutrient. The nutrient status predictive capability of the soil tests is considered suitable for reclaimed sites. Rate of nutrient application to correct the deficiency, however, may require adjustment from those utilized for undisturbed sites.

Foreword

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The chemical characteristics of soil and spoil materials were determined in the laboratory of Fred W. Schroer at North Dakota State University. The authors express their appreciation for his contribution. Appreciation is expressed also to Baukol-Noonan Coal Company, Consolidation Coal Company and Knife River Coal Company for their cooperation in providing site and services.

Fertilization of Wheat, Corn, and Grass-Legume Mixture Grown on Reclaimed Spoilbanks

Armand Bauer, Paul Nyren, George Reichman, Glendon Gee, and John Gilley

Reclamation of lands stripmined for coal in North Dakota will involve growing some type of vegetation. Major plant-types that are presently grown on undisturbed soils will be grown on reclaimed lands, and include grasses and annual agronomic crops, the former occupying more land area than the latter. Woody species will also be involved, but in comparison with the other two plant types, the area will be very small. Reclamation laws require removing and stockpiling soil materials suitable for plant growth before the stripping operation, and then eventually replacing these soil materials over spoils after mining and levelling. Some physical properties of soil materials, like macrostructure and bulk density, are altered somewhat during stripping, stockpiling, and replacement, though not necessarily to the detriment of productivity. The chemical properties, however, seem to be unaffected, and the characteristics of undisturbed soils are retained (Gee and Bauer, 1976). Thus, most of the soil chemical factors limiting crop production before disturbance could be expected to limit production on "reclaimed" land.

During the stripping process soil materials are removed in two stages, separating the A horizon (zone of maximum organic matter) from soil horizons lower in organic matter content. The materials are replaced so that the highest organic matter is at the surface. The thickness of soil materials replaced over spoils varies with location, and depends in part upon amount available. Maximum thickness required by law is 5 feet, which is within the range of rooting depth of major grasses and annual agronomic crops (Bauer and Young, 1969; Power 1970).

Two factors limiting crop production on undisturbed soils are inadequate fertility and low available water supply. While little can be done to increase the annual water supply in dryland agriculture, fertility status of plant rooting media can be altered by several means, including application of commercial fertilizers. Nitrogen (N), phosphorus (P), and potassium (K) deficiencies in undisturbed soils in the coal-mining areas of North Dakota and their correction with fertilizers have been documented (Bauer **et al.**, 1966; Bauer and Zubriski, 1958). Soil tests have been developed (Bauer **et al.**, 1966; Bauer **et al.**, 1967) to predict the indigenous fertility status of undisturbed soils and, if soils are deficient, the fertilizer rate needed to correct the deficiency (Wagner **et al.**, 1974).

Trials were conducted with three crops in 1975 and 1976 on levelled spoils to determine the effect of N and P fertilization on crop yields, to estimate depth of water extraction by the crop grown, to evaluate crop water use efficiency at these sites, and to determine whether the P and N soil tests used on undisturbed soils to predict the "available" P and N status and the corrective measures, are useful on reclaimed lands.

Previous work

Nitrogen and P in forms available to plants were determined (Sandoval **et al.**, 1973) to be deficient in spoils of the Fort Union groups (the geological formation in which the coal in North Dakota is found). While P seems to be universally deficient, freshly exposed shales frequently contain exchangeable ammonium (NH_4^+) (Power **et al.**, 1974) in quantities comparable to the quantity of nitrate nitrogen (NO_3-N) found in an equal thickness of the upper foot of fallowed soils in North Dakota (Bauer **et al.**, 1966). After exposure of the shales to weathering, some of the exchangeable NH_4^+ is converted to NO_3-N. Depending upon plant N needs and the quantity of NH_4^+ present, available N may not be deficient in recently exposed spoils. However, older spoils usually are devoid of available N because they lack organic N from which plant-available inorganic N can be mineralized.

Plant nutrient deficiencies are common in soils of the Northern Great Plains. Deficiencies have been reported for all soil-derived essential elements, except for molybdenum (Mo) and chlorine (Cl). However, the degree and extent of nutrient deficiency varies greatly and depends upon factors like soil properties and characteristics, past and present soil management practices, plant species grown, crop yield, and climatic conditions during the growing season. In terms of areal extent and degree of deficiency, P and N are of greatest concern. These two nutrients can be deficient in soils varying widely in texture and organic matter content (Bauer **et al.**, 1966; Bauer and Zubriski, 1958). Potassium deficiency, perhaps of next greatest concern in terms of areal extent, occurs primarily in coarse and moderately coarse textured soils of low cation exchange capacity, although Skogley (1976) obtained grain yield increases from fertilizer K application on soils considered high in exchangeable K. Compared with P and N, areal extent of K deficiency is relatively small in North Dakota.

Sulfur (S) deficiency is most often found on coarse-textured, well-drained, low organic matter soils (Beaton, Tisdale and Platou, 1971) or areas where erosion has exposed the soil parent material. In terms of areal extent, however, S deficiencies are even less prevalent than K. Micronutrient deficiencies, zinc (Zn), copper (Cu), boron (B), iron (Fe), and manganese (Mn) have been reported (Berger, 1962), but these invariably occur on only a limited portion of a field, and are very minor in areal extent.

Depth of water extraction by crops depends upon factors like the depth to which available water extends in the soil, prevailing climatic conditions, nutrient supply, and the crop type. Bauer and Young (1969) showed that water removal by spring wheat, based on gravimetric samples at seeding and harvest, extended as deep as 5 feet, but only the upper 3 feet of soil was depleted of available water. These studies showed that some available water remained below the 3-foot depth at harvest, regardless of the amount of growing season rainfall received. Bond, Power, and Willis (1971) reported that changes in soil water content under wheat extended to 36 inches in 1967 and to 48 inches the next year.

Corn of 85-day relative maturity grown on dryland at Mandan, North Dakota extracted soil water to about the 36-inch depth; no changes in soil water content were measured at 48 inches (Alessi and Power, 1976). Holt and Van Doren (1961), in western Minnesota, measured water content changes to the fifth foot after corn tasseling.

Soil water extraction by native mixed grasses at Mandan (Power, 1970) apparently did not extend appreciably below 2 feet, because the soil was seldom wet below that depth. When water was applied in the fall to wet the soil profile to 6 feet, native grasses fertilized with 160 pounds N per acre removed water from the 5 to 6-foot soil depth, but unfertilized grasses removed water only to the 4 to 5-foot depth.

Depth of soil-water depletion by alfalfa was shown by Haas and Willis (1971) to be related to depth of wetting. Changes in water content on level bench terraces were measured as deep as 8 feet when water was available to that depth.

Water use efficiency is a function of climate and cultural practices, as well as the plant part on which yield is measured. Bauer et al. (1966) in North Dakota showed that spring wheat, grown on P-deficient fallowed soils, produced about 137 pounds grain per acre per inch of water as compared with 182 where adequate P was applied. In trials in South Dakota (private communication with Earl P. Adams), hard red spring wheat water use efficiency ranged from 76 to 95 pounds grain per acre per inch of water. The difference between states is attributed to differences in aspects of climate affecting water evaporation rate.

Corn silage yields (dry matter) at Mandan, North Dakota varied with amount of available water during the growing season; water-use efficiency also varied and ranged from 273 to 408 pounds per acre per inch of water lost in evapotranspiration (Alessi and Power, 1967).

Water use efficiency of brome-alfalfa grown near Upham, North Dakota ranged from 52 to 290 pounds per acre per inch of water depending upon N fertilization rate and irrigation treatment (Holmen **et al.**, 1961). Water use efficiency of irrigated alfalfa at Oakes, North Dakota, ranged from about 360 to 840 pounds per acre per inch of water, depending upon year and harvest date (Bauer **et al.**, 1974). Whitman and Wolters (1967) reported mixed prairie grasses production ranged from 201 to 336 pounds dry matter per acre per inch of water during the major growth period of 3 years.

Procedure

Field trials were conducted in 1975 and 1976 at three mine sites to measure the effect of fertilizer P and N on production and water use efficiency of two annual crops and an established stand of grass-legume mixture. Samples of the plant rooting medium and spoil were analyzed for plant nutrient status by the North Dakota State University (NDSU) Soil Testing Laboratory. The soil test information is presented in Table 1.

Trials with wheat and corn were established at Consolidation Coal Company and the Knife River Coal Company mines. At Consolidation, the spoil was levelled to about 9 per cent slope during autumn-winter 1973-74 and covered with 2 feet of stockpiled "topsoil" (a mixture of A and B horizon) during the 1974 summer season, as required by the 1973 North Dakota reclamation law. At Knife River, the research plots were established on soil-covered spoil levelled to about 1 per cent slope in the autumn of 1974. Four thicknesses of "topsoil", 2, 6, 12 and 24 inches were placed over the spoil immediately before seeding in late May, 1975.

The trial to evaluate the fertility needs for sustained grass-legume production was initiated at the Baukol-Noonan Coal Company mine in autumn 1974. The site area had been levelled and seeded to a mixture of alfalfa, sweetclover, crested wheatgrass, intermediate wheatgrass, and smooth brome in the spring of 1973 by the coal company. No topsoil was placed over the spoil. The area had been mined before reclamation laws required such a treatment.

Soil water was measured with a neutron scattering meter (Stone, Kirkham, and Read, 1955) in all three trials both years. Metal conduit tubes were installed to 9 feet in selected plots. These plots are identified in the tables in which water data are shown.

Consolidation site

In spring 1975, fertilizer P (0-46-0) was broadcast and disked in at rates of 0 and 40 pounds P per acre on both the wheat and corn. At seeding, 0 and 11 pounds P per acre were banded in the row with Waldron wheat seed and 0 and 16 pounds P per acre were banded 2 inches to the side and 2 inches below the High-n-Dry corn (85-day relative maturity). The banded P was placed at right angles direction to the broadcast P, providing a factorial of P application method.

Table 1. Nitrogen and phosphorus concentrations and soil test ratings of rooting media at research sites, based on North Dakota State University Soil Testing Laboratory standards.

Site, crop, year	Nitrogen† ppm§	Nitrogen† rating	Phosphorus‡ ppm§	Phosphorus‡ rating
Consolidation, wheat, 1975	19	high	7	low
Consolidation, wheat, 1976	22	high	8.5	low-medium
Consolidation, corn, 1975	19	high	7	low
Consolidation, corn, 1976	11	medium	7	low
Knife River, wheat, 1975	2.5	low	7.5	low
Knife River, wheat, 1976	26	high	10.5	medium
Knife River, corn, 1975	2.5	low	7.5	low
Knife River, corn, 1976	24	high	5	very low
Baukol-Noonan, grass-legume, 1975	3.3	very low	9	low-medium
Baukol-Noonan, grass-legume, 1976	1.8	very low	8.5	low-medium

†Water-soluble nitrate-nitrogen to 2 feet (Young **et al.**, 1967; NCR-13 Soil Testing Committee, 1975).
‡Sodium bicarbonate soluble P to 6 inches (Olson **et al.**, 1954).
§Concentration is in parts per million (ppm).

Fertilizer N (34-0-0) at 0, 20, 40 and 60 pounds per acre was broadcast at right angles to direction of the broadcast P, to wheat immediately after seeding, and at 0, 30, 60 and 90 pounds N per acre to corn immediately after planting. Each treatment of all combinations of broadcast P, band-applied P, and broadcast N was replicated four times. Plots were 6.5 feet wide and 24 feet long. Wheat was seeded in 7-inch spaced rows at a rate equivalent to about 1 million viable seeds per acre (about 1.5 bushels per acre). Corn was planted in 36-inch spaced rows, and after emergence thinned to a final population of 16,000 plants per acre. In 1975 only, corn received 2 pounds Zn per acre by planter attachment from disodium zinc ethylene-diamine tetra-acetic acid ($Na_2ZnEDTA$).

In 1976, wheat was seeded on the 1975 corn plots, and corn was planted in the 1975 wheat plots. No fertilizer P was broadcast in 1976, but banded P and broadcast N were applied at the 1975 rates to the same plots.

Wheat was harvested with a small plot combine. Straw yields were measured in 1975 only. Corn ears were picked by hand and then the stover was hand-harvested.

Knife River site

Fertilizer P (0-46-0) was broadcast at rates of 0, 30, and 90 pounds P per acre on levelled spoil in 1975 immediately before placement of variable thicknesses of topsoil. Fertilizer P was band-applied to wheat and corn at rates of 0, 10, and 30 pounds P per acre. Each combination of topsoil thickness, broadcast P at the spoil:soil interface and banded P was replicated four times. Each plot was 6 feet wide and 24 feet long. Waldron wheat and High-n-Dry corn were seeded and planted, respectively, with the same equipment and at the same rates as those used at the Consolidation Coal Company site. Fertilizer N (34-0-0) was broadcast uniformly at rates of 80 pounds N per acre to wheat and 100 pounds N per acre to corn. Corn in 1975 only, received 2 pounds Zn per acre as at the Consolidation site.

In 1976, wheat was seeded on the 1975 corn plots and corn was planted on 1975 wheat plots. No P was broadcast in 1976. Plots that received either 10 or 30 pounds P per acre as a band application in 1975 received the identical amount in 1976.

Samples for yield estimates were made in the same manner as at the Consolidation sites.

Baukol-Noonan site

Fertilizer P (0-46-0) was broadcast in October 1974 at rates of 0, 5, 15, 45 and 135 pounds P per acre. Each P treatment was divided into three subplots to which fertilizer N (34-0-0) was broadcast in the spring of 1975 at rates of 30, 60, and 120 pounds N per acre. Each subplot was 6 feet wide and 25 feet long, replicated four times. Phosphorus was again applied at the same rates to the same plots in autumn of 1975 and N at the same rates to the same subplots in spring of 1976.

Tissue samples were taken in August for yield estimates.

On October 23, 1975, 1.5-inch diameter core samples, 1 per plot from 4 replications of each of two fertilizer treatments, were removed to determine grass-legume root distribution. One set of the plots sampled received 30 pounds per acre fertilizer N and no fertilizer P, and the second set received 120 and 135 pounds per acre of N and P, respectively. Samples were taken at 6-inch increments from the surface 1 foot and at 1-foot increments thereafter to 5 feet.

Results

Wheat at Consolidation site

A summary of variance sources and their significance of the measurements made on the wheat plant is presented in Appendix Table 1. Both straw and grain yields were affected by fertilizer application but test weight was not. Main stems plus tillers per head and kernels per head were affected by broadcast P only.

The effect of fertilizers on grain yield in 1975 and 1976 is shown by data presented in Table 2 for the N x P broadcast interaction.

Table 2. Effect of broadcast fertilizer nitrogen and phosphorus on wheat grain yield on spoil covered with 2 feet of soil material, Consolidation Coal Company, 1975 and 1976.

1975 Nitrogen (N)	1975 Phosphorus (P), lbs/ac: 0	1975 Phosphorus (P), lbs/ac: 40	1976 Nitrogen (N)	1976 Phosphorus (P), lbs/ac: 0	1976 Phosphorus (P), lbs/ac: 40
lbs/ac	bu/ac	bu/ac	lbs/ac	bu/ac	bu/ac
0	13.3 bc[†]	17.8 e	0	17.1 ab	15.5 a
20	12.8 ab	16.9 de	30	18.1 ab	17.5 ab
40	14.3 c	16.5 de	60	16.6 ab	19.0 b
60	11.5 a	16.2 d	90	15.2 a	19.1 b

[†]Values followed by the same letter in an experiment, do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Vegetative growth response to P, observed visually, were very pronounced.

Grain yields in 1975 were increased by fertilizer P, but not by N (Table 2). The fertility status, "low" in P and "high" in N (Table 1), was predicted by soil tests used at the NDSU Soil Testing Laboratory. Grain yields in 1976 were more erratic than in 1975. Yields in 1976 were lower when no N plus 40 pounds per acre P were broadcast than when 60 or 90 pounds N plus 40 pounds P were broadcast. Soil test ratings in 1976 were "low-medium" in P and "high" in N.

Grain yields in 1975 were increased 3.7 bushels per acre by banded P and 5.9 bushels by P broadcast at 40 pounds per acre (Table 3). Bauer **et al.** (1966) reported that average wheat grain increase was 4.2 bushels per acre from 11 pounds banded P per acre in 37 trials conducted on soils testing "low" in P.

Table 3. Effect of fertilizer phosphorus placement on wheat grain yield in 1975, Consolidation Coal Company.

Broadcast phosphorus (P)	Banded phosphorus (P), lbs/ac: 0	Banded phosphorus (P), lbs/ac: 11
lbs/ac	bu/ac	bu/ac
0	10.9 a[†]	14.6 b
40	16.8 c	17.3 c

[†]Values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Grain yield increases from P resulted primarily from an increase in 2.2 kernels per head (Table 4).

Fertilizer P increased the number of culms (main stem plus tillers) by July 9, but fewer culms in the

Table 4. Effect of broadcast fertilizer phosphorus on number of wheat culms, head to culm ratio, and number of kernels per head, Consolidation Coal Company, 1975.

Broadcast phosphorus (P)	Culms†	Head/culm‡	Kernels/head
lbs/ac	no/9 ft^2	no/9 ft^2	no.
0	311 a§	0.71 b	18.3 a
40	425 b	0.64 a	20.5 b

†The main stems plus tillers on July 9.
‡On August 11, heads were counted on the same 9-square-feet area that culms were counted on July 9.
§Column values followed by the same letter do not differ significantly at the 95% level, according to Duncan's multiple range test.

plots receiving P produced heads than those on the no P plots.

Straw yield responses to fertilizer P and N rates in 1975 were similar to those of grain yield (Tables 5 and 6). Banded P increased straw yields, but broadcast P increased yields more. Fertilizer N applied at 60 pounds per acre decreased straw yields, like it did grain yields.

Table 5. Effect of fertilizer phosphorus placement on straw yield in 1975, Consolidation Coal Company.

Broadcast phosphorus (P)	Banded phosphorus (P), lbs/ac	
	0	11
lbs/ac	lbs/ac	
0	1206 a†	1680 b
40	2199 c	2278 c

†Values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Table 6. Effect of fertilizer nitrogen and phosphorus on straw yield in 1975, Consolidation Coal Company.

Nitrogen (N)	Broadcast phosphorus (P), lbs/ac		
lbs/ac	0	40	Mean
	lbs/ac		
0	1353 a†	2351 c	1852 b‡
20	1575 a	2299 bc	1937 c
40	1443 a	2331 bc	1837 b
60	1399 a	2074 b	1736 a

†Values followed by the same letter within the first 2 columns do not differ significantly at the 95% probability level according to Duncan's multiple range test.
‡Values followed by the same letter in this column do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

The total soil water contents and the water content changes in the rooting medium during the growing season are shown by data presented in Table 7 for two fertilizer N rates in both years.

Total soil water content did not decrease below the 4-foot depth either year. While apparently the amount of soil water withdrawn in 1975 from the zero N plots was more than from the 40-pound per acre N plots, variability among replications was large, which may account for the difference. No explanation can be given for what appears to be an increase in water content at some depths on August 5 as compared with April 27. Variability in water holding capacity likely is greater at these disturbed sites than in undisturbed soils because bulk density varies more.

Table 7. Total soil water content and the difference in the amount at seeding and harvest under wheat grown at two soil fertility levels, 1975 and 1976, at Consolidation Coal Company.

Nitrogen (N)	Date	Soil depth (ft) 0-1	1-2	2-3	3-4	4-5
lbs/ac	mo/day/yr	in. water†				
0	5/28/75	4.15	4.73	4.59	3.94	3.74
	7/15/75	3.82	4.44	3.77	3.46	3.72
	Difference	0.33	.29	.82	.48	.02
40	5/28/75	4.19	4.94	4.56	3.95	3.54
	7/15/75	3.75	5.01	4.15	3.72	3.70
	Difference	.44	—	.41	.23	—
0	4/27/76	3.97	4.20	3.77	2.98	3.10
	8/5/76	2.00	4.07	4.23	3.53	3.80
	Difference	1.97	.13	—	—	—
40	4/27/76	3.94	4.01	3.62	3.37	2.64
	8/5/76	2.07	3.68	4.18	4.04	3.12
	Difference	1.87	.33	—	—	—

†Average of 4 holes per treatment. The access tubes were placed in plots receiving 40 pounds broadcast P per acre and 11 pounds per acre banded.

Wheat at Knife River site

A summary of variance sources and their significance for measurements made on the wheat plant is presented in Appendix Table 2. Fertilizer P and topsoil thickness affected grain yield both years, and straw yield in 1975.

Grain yields were increased by fertilizer P in 1975, even though yields were less than 4 bushels per acre (Table 8) because of a very limited water supply. The stockpiled topsoil placed on the spoil shortly before seeding was dry. Rainfall received after seeding in June 1975 (Appendix Table 3) was equal to the 61-year average, but July rainfall was below the long-term average.

Fertilizer P also increased grain yield in 1976 (Table 9); in both years the P soil test rating was "low" (Table 1) by NDSU Soil Testing Laboratory standards. Grain yield responses obtained from 10 pounds per acre of banded P in 1976 were as large as those from the 30 or 90 pounds per acre P broadcast in 1975 at the soil:spoil interface.

Wheat grain yields in 1976 were largest when 6 inches or more of topsoil were placed on levelled spoils (Table 10).

The larger grain (Table 8) and straw yields (Table 11) associated with topsoil thickness in 1975 are attributed to a combination of higher plant population on June 23, more main stems plus tillers on July

Table 8. Effect of banded fertilizer phosphorus and topsoil thickness on wheat grain yield in 1975, Knife River Coal Company.

Topsoil thickness	Phosphorus (P), lbs/ac			
in	0	10	30	Mean
	bu/ac			
2	1.5 ab†	2.0 abc	1.5 ab	1.7 a§
6	1.4 a	2.7 cde	2.2 ab	2.1 ab
12	2.3 bcd	3.3 ef	3.8 f	3.1 bc
24	3.1 def	3.9 f	3.8 f	3.6 c
Mean	2.1 a‡	3.0 b	2.8 b	

†Values followed by the same letter within the first three columns, but not including the last row of mean values, do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
‡Mean values followed by the same letter in this row do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
§Column values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Table 9. Effect of fertilizer phosphorus placement interaction on wheat grain yield in 1976, Knife River Coal Company.

Broadcast phosphorus (P)	Banded phosphorus (P), lbs/ac		
	0	10	30
lbs/ac	bu/ac		
0	11.7 a†	13.8 bc	14.2 bc
30	13.4 abc	13.3 abc	14.4 bc
90	14.8 c	14.2 bc	12.5 ab

†Numbers followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Table 10. Effect of topsoil thickness on wheat grain yield in 1976, Knife River Coal Company.

Topsoil thickness	Grain yield
in	bu/ac†
2	11.2 a
6	13.7 b
12	14.1 b
24	15.3 b

†Values followed by the same letter in this column do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

14, more kernels per head, and an increase in 1000-kernel weight (Table 12) on the thicker topsoil plots. The larger grain yields due to fertilizer P application were associated with higher population on June 23, more main stems plus tillers on July 14, and higher kernel weight (Table 13). The amount of water removed from 6, 12, and 24-inch topsoiled plots was larger than that removed from the 2-inch thick topsoil plots (Table 14), which may account for the difference in grain yield.

Table 11. Effect of banded fertilizer phosphorus and topsoil thickness on 1975 wheat straw yield, Knife River Coal Company.

Topsoil thickness	Banded phosphorus (P), lbs/ac			
	0	10	30	Mean
in	lbs/ac			
2	442 a†	511 a	515 a	489 a‡
6	428 a	692 b	521 a	547 a
12	679 b	1051 d	755 b	828 b
24	921 c	1059 d	1073 d	1017 b
Mean	617 a§	828 c	716 b	

†Values followed by the same letter in the first three columns, but not including the last row of mean values, do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
‡Column values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
§Row values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Table 12. Effect of topsoil thickness on wheat plant population, main stem plus tillers, kernels per head and 1000-kernel weight in 1975, Knife River Coal Company.

Topsoil thickness	Population June 23	Main stems plus tillers July 14	Kernels/ head	1000-kernel weight
in	no plants/ 9 ft^2	no/9 ft^2	no	g‡
2	174 a	243 a	3.5 a	23.1 a
6	177 a	263 a	3.8 a	23.9 ab
12	172 a	273 ab	5.5 b	25.0 b
24	209 b	314 b	5.4 b	25.1 b

†Column values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
‡Grams. An ounce, English system, equals 28.35 grams.

Table 13. Effect of broadcast fertilizer phosphorus on wheat plant population, main stems plus tillers, and 1000-kernel weight in 1975, Knife River Coal Company.

Broadcast phosphorus (P)	Population June 23	Main stems plus tillers July 14	1000-kernel weight
lbs/ac	no plants/9 ft^2	no/9 ft^2	g
0	163 a†	248 a	23.7 a
30	200 c	288 b	24.4 b
90	186 b	283 b	24.7 b

†Column values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

The total soil water content and the water content change in the rooting medium from seeding to harvest are shown by data presented in Table 14.

The largest change in water content occurred in the surface 1 foot of the rooting medium in both years. This likely reflected the presence at seeding of a larger quantity of available water in the upper than lower depths, and reflected the zone of maximum root activity. In 1975, a significant change in water content (<.10 inches) did not occur below

Table 14. Total water content and the difference in the amount from seeding and harvest under wheat grown on four topsoil thicknesses in 1975 and 1976, Knife River Coal Company.

Topsoil thickness	Date	Soil depth (ft) 0-1	1-2	2-3	3-4	4-5
in	mo/day/yr			in. water†		
2	6/13/75	4.70	5.04	4.92	4.60	4.31
	8/04/75	3.88	5.16	4.85	4.51	4.56
Difference		.82	—	.07	.09	—
6	6/13/75	4.31	4.65	4.81	4.69	4.39
	8/04/75	2.91	4.74	4.80	4.60	4.43
Difference		1.40	—	0.01	.09	—
12	6/13/75	3.67	4.61	4.97	4.81	4.50
	8/04/75	2.38	4.57	4.97	4.87	4.48
Difference		1.29	.04	—	—	.02
24	6/13/75	3.10	2.96	4.87	4.62	4.22
	8/04/75	1.27	2.34	4.78	4.55	4.24
Difference		1.83	.62	.09	.07	—
2	4/29/76	4.86	5.12	4.60	4.48	4.38
	8/03/76	3.01	4.56	4.34	4.52	4.38
Difference		1.85	.56	.26	—	—
6	4/29/76	4.61	4.38	4.69	4.64	4.27
	8/01/76	2.62	3.64	4.46	4.41	4.10
Difference		1.99	.74	.23	.21	.17
12	4/29/76	4.06	3.86	4.18	4.62	4.23
	8/03/76	1.86	3.00	3.96	4.35	4.10
Difference		2.20	.86	.22	.27	.13
24	4/29/76	3.35	3.95	4.25	4.25	4.20
	8/03/76	1.68	2.72	4.05	4.13	4.13
Difference		1.67	1.23	.20	.12	.07

†Average of four holes per treatment. The access tubes were placed in plots receiving 90 pounds per acre P broadcast at the soil:spoil interface and 30 pounds per acre banded.

the 2-foot depth for any topsoil thickness, while in 1976 changes larger than 0.20 inch occurred to at least the 3-foot depth in all treatments, and to the 4-foot depth in the 6- and 12-inch thicknesses. The greater depth of withdrawal in 1976, equated to root extension, is reflected in larger grain yields.

Corn at Consolidation site

A summary of the significance of variance sources is presented in Appendix Table 4. Corn grain and silage yields were affected by fertilizer P in both years, but N influenced silage yield only in 1975. Phosphorus affected the growth rate in 1975, as evidenced from its effect on height and leaf number.

The effect of banded P on number of leaves and height, as well as on grain yield, is shown by data presented in Table 15.

Growth stage was advanced by banded fertilizer P as shown by height and number of leaves per plant on given dates. However, while height differences, resulting from P fertilizer, persisted between July 11 and August 11, the difference in number of leaves did not.

Grain yields were very low (Table 15) because of limited rainfall, especially in July and August (Appendix Table 3).

Table 15. Effect of banded fertilizer phosphorus rate on corn height, number of leaves at several dates, and grain yield in 1975, Consolidation Coal Company.

Parameter	Date	Phosphorus (P) rate (lbs/ac) 0	16
	mo/day		
Height (in)	7/11	25.5 a†	30.4 b
Height (in)	7/29	37.3 a	43.4 b
Height (in)	8/11	42.4 a	45.3 b
Leaves (no/plant)	7/11	8.8 a	10.1 b
Leaves (no/plant)	8/11	12.1 b	11.6 a
Yield (bu/ac)‡		9.1 a	11.7 b

†Row values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
‡At 15.5 % water content.

Although fertilizer P advanced the stage of growth, silage yield was not increased by the band application in 1975, but yield was maintained at a higher level by the broadcast fertilizer P when 60 or 80 pounds per acre fertilizer N were applied. Silage yields were increased by banded P in 1976 (Table 16).

Table 16. Effect of broadcast application of fertilizer nitrogen and phosphorus on corn silage yield in 1975 and banded phosphorus in 1976, Consolidation Coal Company.

1975				1976	
Nitrogen (N)	Broadcast, lbs/ac phosphorus (P) 0	40	Mean	Banded phosphorus (P)	Yield
lbs/ac	tons/ac†			lbs/ac	tons/ac
0	4.2 bc‡	4.4 bc	4.3 a§	0	2.9 a§
30	4.8 c	4.8 c	4.8 b	16	3.0 b
60	3.9 ab	4.5 c	4.2 a		
80	3.6 a	4.9 c	4.3 a		

†At 70% water content.
‡Values followed by the same letter within the first two columns do not differ significantly at the 95% probability level, according to Duncan's multiple range test.
§Column values followed by the same letter do not differ significantly at the 95% probability level, according to Duncan's multiple range test.

Height and leaf number on a given date and yield response to fertilizer P showed evidence of P deficiency. The P soil test rating was "low" in both years (Table 1).

The N soil test rating was "high" in 1975 and "medium" in 1976 (Table 1) at the Consolidation corn sites. Silage yields were not increased by N fertilization either year. In 1975, corn silage yields were lower when 80 pounds per acre of fertilizer N were applied than when no N was applied, without addition of fertilizer P. Yields in 1976 were lower than in 1975 because of more limited water supply.

Total soil water content and the change in water content in the rooting medium from planting to harvest are shown by data presented in Table 17 for both years.

Table 17. Total soil water content and the difference in the amount at planting and harvest for corn grown at two fertility levels in 1975 and 1976, Consolidation Coal Company.

		Soil depth (ft)				
Nitrogen (N)	Date	0-1	1-2	2-3	3-4	4-5
lbs/ac	mo/day/yr			in. water†		
0	5/28/75	4.03	4.33	4.40	4.28	3.88
	8/12/75	2.77	4.17	4.35	4.25	4.09
Difference		1.26	.16	.05	.03	—
60	5/28/75	4.04	4.52	4.59	4.19	3.62
	8/12/75	2.35	4.50	4.22	3.88	4.11
Difference		1.69	.02	.37	.31	—
0	5/20/76	3.51	4.12	3.97	3.54	3.45
	9/01/76	1.76	3.40	4.06	3.65	3.53
Difference		1.55	.72	—	—	—
40	5/20/76	3.61	3.94	4.39	4.08	3.86
	9/01/76	1.84	3.43	4.42	4.16	3.92
Difference		1.77	.51	—	—	—

†Average of four holes per treatment. The access tubes were placed in plots receiving 40 pounds per acre P broadcast and 16 pounds per acre P banded.

Water content changed most in the surface 1 foot of the rooting medium; water content changes larger than 0.15 inches were limited to the surface 2 feet in three of the four treatments. If changes in water content are equated with root extension, these data (Table 17) suggest that corn roots penetrated about as deeply as did wheat roots (Table 7).

Corn at Knife River site

A summary of variance sources and their significance is presented in Appendix Table 5. Both topsoil thickness and fertilizer P affected the performance of corn in both years. Because of mechanical problems at planting, banded P was not properly placed in 1976.

Table 18. Effect of banded phosphorus rates on corn height and number of leaves on two dates, and on grain and silage yield in 1975, Knife River Coal Company.

		Phosphorus (P), lbs/ac		
Parameter	Date	0	10	30
	mo/day			
Height (in)	7/24	21.4 a§	22.9 b	26.9 c
Height (in)	8/05	27.0 a	28.1 b	31.5 c
Leaves (no)	7/24	9.8 a	10.2 a	11.0 b
Leaves (no)	8/05	12.0 a	12.4 b	12.5 b
Grain yield (bu/ac)†		1.4 a	2.7 b	2.8 b
Silage yield (tons/ac)‡		1.4 a	1.8 b	1.9 b

† At 15.5% water content
‡ At 70% water content
§ Row values followed by the same letter do not differ at the 95% probability level, according to Duncan's multiple range test.

The effect of banded P on growth stage and grain and silage yields in 1975 is shown by data presented in Table 18.

Fertilizer P advanced the stage of growth of corn. On a given date, height was greater with each increment P application. The number of leaves differed between the 10- and 30-pound per acre P rate on July 24, and not on August 5, but the number of leaves between the 0 and 30-pound per acre rate differed on both dates. Both grain and silage yields were increased by the 10-pound per acre P rate, indicating a P deficiency (Table 18). Yields were increased even though less than 3 bushels grain per acre were produced. The P soil test rating was "low" as determined by the NDSU Soil Testing Laboratory (Table 1).

Grain and silage yields in 1975, and silage yields in 1976 were increased for corn grown on topsoil of varying thicknesses (Table 19).

Table 19. Effect of topsoil thickness on corn grain and silage yield in 1975, and silage yield in 1976, Knife River Coal Company.

		Topsoil thickness (in)			
Parameter	Year	2	6	12	24
Grain (bu/ac)†	1975	0.5 a§	1.0 a	2.0 a	5.8 b
Silage (tons/ac)‡	1975	1.0 a	1.3 ab	1.8 b	2.7 c
Silage (tons/ac)	1976	1.7 a	2.3 b	2.9 c	4.2 d

† At 15.5% water
‡ At 70% water
§ Row values followed by the same letter do not differ at the 95% probability level, according to Duncan's multiple range test.

Silage yields increased as thickness of topsoil increased (Table 19) and were directly related to the amount of water depleted from the surface 2 feet of the rooting media (Table 20) between planting and harvest. This is added evidence that water supply was a severely limiting factor in these studies and emphasizes the need to manage "reclaimed" areas to store as much non-growing season precipitation as possible.

Assuming that depth of water depletion approximates depth of root extension, the data in Table 20 suggest that roots did not penetrate the spoil material in 1975, but that they did in 1976, although the chemical characteristics of the spoil were initially the same (Appendix Table 6). The data suggest also that roots likely did not extend below 3 feet in 1976.

Grass-legume mixture at Baukol-Noonan site

A summary of variance sources and their significance on yield is shown in Appendix Table 7. Fertilizer N affected yield but not fertilizer P. Yield data are presented in Table 21.

Table 20. Total soil water content and the difference in the amount from planting and harvest under corn grown on four topsoil thicknesses in 1975 and 1976, Knife River Coal Company.

Topsoil thickness	Date	Soil depth (ft) 0-1	1-2	2-3	3-4	4-5
in	mo/day/yr			in. water†		
2	6/13/75	4.45	4.94	4.66	4.17	4.02
	8/04/75	4.18	5.11	4.62	4.18	4.03
Difference		.27	—	.04	—	—
6	6/13/75	4.00	4.09	4.36	4.40	4.00
	8/04/75	3.15	4.06	4.38	4.48	4.06
Difference		.85	.03	—	—	—
12	6/13/75	3.69	3.74	3.68	3.85	3.63
	8/04/75	2.39	3.74	3.75	3.87	3.66
Difference		1.30	—	—	—	—
24	6/13/75	3.49	3.96	4.30	4.15	4.11
	8/04/75	2.47	3.55	4.40	4.17	4.05
Difference		1.02	.41	—	—	.06
2	5/21/76	4.85	5.10	4.91	4.47	4.40
	9/03/76	4.26	4.82	4.77	4.34	4.15
Difference		.59	.28	.14	.13	.25
6	5/21/76	4.26	4.86	4.90	4.74	4.37
	9/03/76	3.37	4.63	4.73	4.66	4.37
Difference		.89	.23	.17	.08	—
12	5/21/76	3.76	4.89	5.06	4.98	4.80
	9/03/76	2.74	4.63	4.92	4.84	4.54
Difference		1.02	.26	.14	.14	.26
24	5/21/76	2.74	3.72	4.76	4.64	4.02
	9/03/76	1.35	2.94	4.68	4.52	3.99
Difference		1.39	.78	.08	.12	.03

†Average of four holes per treatment. The access tubes were placed in plots receiving 90 pounds fertilizer P per acre at the soil:spoil interface and 30 pounds per acre banded.

Table 21. Effect of fertilizer nitrogen rate on grass-legume dry matter yields in 1975 and 1976, Baukol-Noonan Coal Company.

Nitrogen (N)	Year 1975	1976
lbs/ac	tons/ac	
30	0.6 a†	1.0 a
60	0.6 a	1.2 b
120	0.8 b	1.3 c

†Column values followed by the same letter do not differ at the 95% probability level, according to Duncan's multiple range test.

Fertilizer N increased dry matter yield both years. In both years the highest yield was obtained with the largest N rate applied. In both years, the soil N test level was "very low", as determined by soil test standards (Table 1). However, yields were not increased by fertilizer P even though the P soil test level was "low-medium". Grasses frequently do not respond to P fertilization on unmined sites, unless the P soil test rating is "very low".

Data of root concentration to 5 feet are presented in Table 22.

Table 22. Air-dry weight of grass-legume roots, October 23, 1975, Baukol-Noonan Coal Company.

Depth	Fertilizer rate 30+0+0†	120+135+0
ft	g/core	
0-.5	2.69‡	2.50
.5-1	0.41	.55
1-2	0.43	.26
2-3	0.20	.16
3-4	0.27	.16
4-5	0.52	.11

† Refers to 30 pounds nitrogen (N), 0 pounds phosphorus (P), and 0 pounds potassium (K) applied as fertilizer.

‡Each value is a mean of four cores; each core was 1.5 inches in diameter.

While roots extended to at least 5 feet, about 60% of the measured mass was in the surface 6 inches, and more than 75% in the surface 2 feet. The rooting medium, apparently, did not restrict plant root penetration, and provided a favorable chemical environment (Appendix Table 6).

Total soil water content to 6 feet at four dates and the change between May 17 and August 1 are shown by data presented in Table 23.

Table 23. Total soil water content to 6 feet at four dates and the difference in content between May 17 and August 1 under a grass-legume mixture in 1975, Baukol-Noonan Coal Company.

Date	Soil depth (ft) 0-1	1-2	2-3	3-4	4-5	5-6
mo/day			in. water			
5/17	4.69†	4.57	4.63	4.36	4.36	4.42
6/17	4.38	4.41	4.41	4.11	4.13	4.23
7/15	2.12	3.63	4.18	4.14	4.13	4.27
8/01	2.00	3.15	4.05	3.85	3.97	4.15
Differ.‡	2.69	1.42	0.58	0.51	0.39	0.27

†Each value is a mean of 16 holes. All plots received 60 pounds fertilizer N per acre.

‡Change from May 17 to August 1.

Total soil-water content at all depths decreased with the advance in growing season, but the greatest decrease from May 17 to August 1 occurred in the surface 1 foot and changes during this period decreased as depth increased (Table 23). These data support those of Table 22 on root distribution. The change in water content decreased with each depth increment. Of the 5.86 inches of water depleted to the 6-foot depth, 70% was removed from the surface 2 feet.

Like in 1975, the change in water content from spring to autumn in 1976 under a grass-legume mixture was greatest in the surface 1 foot and decreased as depth increased to 5 feet (Table 24). Of the 4.82 inches of water depleted over the period about 72% was removed from the surface 2 feet.

Water use efficiency

Water-use efficiency (yield per unit area per unit amount of water lost) was calculated for the three crops grown at the three research sites. The data are presented in Table 25. It was assumed in making these calculations that no runoff occurred during the growing season and no water was lost in drainage below the sampling depth.

Table 24. Total soil water content to 5 feet and the difference in water content under a grass-legume mixture on two dates in 1976, Baukol-Noonan Coal Company.

Date	Soil depth (ft)				
mo/day	0-1	1-2	2-3	3-4	4-5
			in. water		
4/28	4.40†	4.16	4.09	3.82	4.02
8/17	2.21	2.89	3.54	3.41	3.62
Difference	2.19	1.27	.55	.41	.40

†Each value is a mean of 16 holes. All plots received 60 pounds fertilizer N per acre.

Water use efficiency was greater for corn silage than wheat grain, within a givên year. Fertilizer N rate had little influence on water-use efficiency, but neither did it increase yields. Water use efficiency of corn silage increased with each increment of topsoil thickness; however, water-use efficiency of wheat grain increased but not at all topsoil thickness increases.

Water-use efficiency of grass-legume was lower in 1975 than in 1976, and was also lower than that of corn silage in both years.

Table 25. Water use efficiency (WUE) of wheat grain, corn silage, and grass-legume forage as affected by fertilizer nitrogen or topsoil thickness in 1975 and 1976 at three research sites.

Site	Year	Crop	Treatment	Growing¶ season rainfall	Soil†† water removed	Dry matter yield	WUE
				in	in	lbs/ac	lbs/ac/in
Consolidation	1975	Wheat grain	0 N†	6.53	1.94	936	111
			40 N		1.08	924	121
	1976	Wheat grain	0 N	8.37	2.10	978	93
			60 N ‡		2.20	1068	101
	1975	Corn silage	0 N	7.04	1.50	2589	303
			60 N		2.39	2497	265
	1976	Corn silage	0 N	8.78	2.27	1909	173
			40 N		2.28	1817	164
Knife River	1975	Wheat grain	2 §	5.92	.98	102	15
			6		1.50	126	17
			12		1.35	186	26
			24		2.61	216	25
	1976	Wheat grain	2	6.82	2.67	672	71
			6		3.34	822	81
			12		3.68	846	81
			24		3.29	918	91
	1975	Corn silage	2	5.91	.31	588	95
			6		.88	788	116
			12		1.30	1076	149
			24		1.49	1642	222
	1976	Corn silage	2	6.59	1.39	1004	126
			6		1.37	1382	174
			12		1.82	1708	203
			24		2.40	2490	277
Baukol-Noonan	1975	Grass-legume	60 N	6.30	5.59	1232	104
	1976	Grass-legume	60 N	9.32	4.82	2321	164

† Soil water was measured in plots receiving 0 and 40 pounds per acre N.

‡ Soil water was measure in plots receiving 0 and 60 pounds per acre N.

§ Soil water was measured in plots with 2, 6, 12, and 24 inches topsoil.

¶ Seeding to harvest, or in the case of grass-legume at Baukol-Noonan, the interval between access tube readings in the spring and at harvest.

†† Difference in soil water content to five feet from seeding to harvest.

Summary and Conclusion

Trials were conducted on levelled spoils to evaluate the effect of P and N fertilization on performance of wheat, corn, and a grass-legume mixture; to determine depth of water withdrawal by these crops; to determine water use efficiency; and to determine if the P and N soil tests used on undisturbed soils to predict the "available" P and N status and the corrective measures are useful for the same purposes on reclaimed lands.

Spring wheat grain yields were increased by fertilizer P banded in the row with the seed or by broadcast either on the surface or at the soil:spoil interface. Straw yields were also increased by the same P treatments. Soil tests predicted a P deficiency, based on the interpretations used for undisturbed soils. Grain yield level was influenced by the amount of available soil water present at seeding.

Wheat grain yields were not increased by fertilizer N. Soil tests, based on interpretations used for undisturbed soils, correctly predicted an adequate fertility status.

Corn silage yields were increased by fertilizer P and its placement. Growth stage was advanced in terms of height and number of leaves per plant on a given date in 1975, when P was banded 2 inches to the side and 2 inches below the seed, but yields were not increased by this placement. However, broadcast P increased silage yields. In 1976, banded P increased yields. Phosphorus soil test rating was "low" in both years.

The N soil test rating was "high" in 1975 and "medium" in 1976, but silage yields were not increased either year. Silage yields in 1975 were lower when 80 pounds per acre fertilizer N were applied, without addition of fertilizer P, than when no N was applied. Where fertilizer P was applied silage yields did not differ among N rates.

As topsoil thickness increased both wheat grain and corn silage yield increased, but only corn silage yield in 1976 significantly increased with each increment of soil thickness. Water depletion from seeding to harvest was least from the 2-inch topsoil thickness. The 2-inch soil treatment consistently produced the smallest yield.

Grass-legume dry matter yield was increased by fertilizer N on spoils rated "very low" in available N by soil test. Fertilizer P did not increase yields even though the P soil test rating was "low-medium".

The depth from which soil water was withdrawn by spring wheat and corn did not exceed 4 feet, and was often less than 2 feet. In all cases, soil water content changed most between seeding and harvest in the surface 1 foot of the rooting medium.

Soil water content of the grass-legume rooting medium changed to at least the 5-foot depth between early spring and the August harvest. Of the water content change to 5 feet, 70% or more was removed from the surface 2 feet. Roots, removed in soil cores in October, 1975 (seeded spring 1973), were found to at least 5 feet, but more than 75% of the air-dry root mass was in the surface 2 feet of rooting medium.

Water-use efficiency varied with years. For wheat grain it ranged from 15 to 121 pounds per acre per inch of water, corn silage (dry matter) from 95 to 303, and grass-legume from 104 to 164.

Application of N and P fertilizers increased crop yields when nutrients were deficient, as predicted by soil tests currently used in North Dakota. Exceptions occurred when yields were severely restricted by water supply, or as was the case on the grass-legume mixture, where responses occur infrequently on undisturbed soils at the same P test level as the medium on which the trial was conducted.

Soil test interpretations of the rate of fertilizer application needed to correct a deficiency may depend on the kind and thickness of plant rooting medium present on the spoil surface. When plant rooting media consist of soil materials from the solum (A + B horizons), fertilizer application rates are expected to be equal to those required for undisturbed soils of equal deficiency and yield potential. But as the thickness of organic matter-containing plant rooting medium decreases, application rates to correct a given deficiency level are expected to be higher, assuming all other factors affecting the potential yield level of the crop grown remain constant.

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Appendix Table 1. Summary of variance sources and their significance for parameters of wheat grain in 1975 and 1976 and straw in 1975 at Consolidation Coal Company.

Parameter	Variance source						
	P_B†	P_D‡	P_B xP_D	N§	NxP_B	NxP_D	NxP_B xP_D
Grain yield, 1975	ns¶	**††	6.7§§	**	*‡‡	**	ns
Grain yield, 1976	ns	ns	ns	ns	*	ns	
Test weight, 1975	ns	ns	ns	ns	ns	ns	ns
Test weight, 1976	ns	ns	ns	ns	ns	ns	ns
Straw yield, 1975	ns	**	6.7§§	**	*	**	**
Culms¶¶, 1975	ns	ns	ns	ns	ns	ns	ns
Heads, 1975	ns	ns	ns	ns	ns	ns	ns
Kernels/head, 1975	*	ns	ns	ns	ns	ns	ns
Culms/head, 1975	*	ns	ns	ns	ns	ns	ns
1000 Kernel, 1975	ns	ns	ns	*	ns	ns	ns

†Refers to broadcast fertilizer P
‡Refers to banded fertilizer P
§Refers to broadcast fertilizer N
¶Not significant
††Significant at the 1% probability level
‡‡Significant at the 5% probability level
§§Significant at the 6.7% probability level
¶¶Main stem plus tillers (plant stems)

Appendix Table 2. Summary of variance sources and their significance for parameters of wheat grain in 1975 and 1976 and straw in 1975 at Knife River Coal Company.

Parameter	Variance source						
	Soil (S)†	P_B‡	SxP_B	P_D§	P_B xP_D	P_D xS	P_B xP_D xS
Grain yield, 1975	*††	ns¶	ns	**‡‡	ns	**	ns
Grain yield, 1976	**	ns	ns	ns	*	ns	ns
Test weight, 1975	ns	ns	ns	ns	ns	ns	ns
Test weight, 1976	*	**	ns	ns	ns	ns	ns
Straw yield, 1975	**	**	*	**	ns	**	**
Culms, 6/23/75	ns	*	ns	ns	*	ns	ns
Culms, 7/14/75	*	**	ns	**	ns	**	ns
Heads, 8/13/75	ns	ns	ns	ns	ns	ns	ns
Kernels/head, 1975	*	ns	ns	ns	ns	ns	ns
1000 kernel, 1975	*	**	ns	**	**	ns	**

†Refers to topsoil thickness
‡Refers to broadcast fertilizer P
§Refers to banded fertilizer P
¶Not significant
††Significant at the 5% probability level
‡‡Significant at the 1% probability level

Appendix Table 3. Growing season rainfall in 1975 and 1976 recorded at Center and Beulah, North Dakota.†

Month	Year			
	1975		1976	
	Site			
	Center‡	Beulah	Center	Beulah
	in			
April	4.88	4.67	3.46	2.86
May	1.95	2.69	0.87	0.68
June	3.97	3.79	6.51	5.23
July	1.41	1.19	0.99	0.91
August	0.98	0.99	0.98	0.17

†Climatological Data, U.S. Department of Commerce, NOAA, Environmental Data Service.
‡The Center weather station is about 2 miles from the Baukol-Noonan Coal Company research site and 9 miles from Consolidation Coal Company research site.
The Beulah weather station is about 2 miles north of the Knife River Coal Company research site.

Appendix Table 4. Summary of the significance of variance sources and their significance for parameters of corn in 1975 and 1976 at Consolidation Coal Company.

Parameter	Variance source						
	P_B†	P_D‡	$P_B xP_D$	N§	NxP_B	NxP_B	$NxP_D xP_D$
Grain yield, 1975	ns¶	**‡‡	**	**	**	ns	**
Silage yield, 1975	ns	ns	ns	*	*	ns	ns
Silage yield, 1976	ns	**	ns	ns	ns	ns	ns
Height, 7/11/75	*††	**	**	ns	ns	ns	ns
Height, 7/29/75	ns	**	*	ns	ns	ns	ns
Height, 8/11/75	ns	**	ns	ns	ns	ns	ns
Leaves, 7/11/75	**	**	*	ns	ns	ns	ns
Leaves, 7/29/75	**	ns	ns	ns	ns	ns	ns
Leaves, 8/11/75	ns	*	ns	ns	ns	ns	ns

† Refers to broadcast fertilizer P
‡ Refers to banded fertilizer P
§ Refers to broadcast fertilizer N
¶ Not significant
††Significant at the 5% probability level
‡‡Significant at the 1% probability level

Appendix Table 5. Summary of variance sources and their significance for parameters of corn in 1975 and 1976 at Knife River Coal Company.

Parameter	Variance source						
	Soil(S)†	P‡	$P_B xS$	P_D§	$P_B xP_D$	P xS	$P_B xP_D xS$
Grain yield, 1975	**‡‡	ns¶	ns	*††	ns	ns	ns
Silage yield, 1975	**	ns	ns	**	ns	ns	ns
Silage yield, 1976	**	ns	**	—§§	—	—	—
Height, 7/24/75	**	**	**	**	ns	ns	ns
Height, 8/5/75	**	*	ns	**	ns	ns	ns
Leaves, 7/24/75	**	ns	ns	**	ns	ns	ns
Leaves, 8/5/75	**	ns	ns	*	ns	ns	ns

† Refers to topsoil thickness
‡ Refers to broadcast fertilizer P
§ Refers to banded fertilizer P
¶ Not significant
††Significant at the 5% probability level
‡‡Significant at the 1% probability level
§§Mechanical problems prevented proper placement of banded fertilizer P

Appendix Table 6. Chemical characteristics of soil and spoil materials at the research sites.

Parameter	Site		
	Consolidation	Knife River	Baukol-Noonan
Soil pH†	7.5	7.8	—
Soil EC‡	1	1	—
Spoil EC	4-6	5-6	3
Spoil SAR§	6-10	7-14	1

† On saturation extract.
‡ Electrical conductivity in mmhos/cm
§ Sodium adsorption ratio.

Appendix Table 7. Summary of the significance of variance sources for parameters of grass-legume mixture in 1975 and 1976 at Baukol-Noonan Coal Company.

Parameter	Variance source		
	Phosphorus (P)	Nitrogen (N)	PxN
Yield, 1975	ns†	**‡	ns
Yield, 1976	ns	**	ns

† Not significant.
‡ Significant at the 1% probability level.

RM-3-78-180