Fertilization and Erosion on a New Highway

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•IN early 1961 a research project was established at the Engineering Experiment Station of the Ohio State University (1). The site of this project was a 33-mile section of Interstate 71 running north and slightly east of Columbus, Ohio. This roadway is a 4-lane divided highway constructed to standards of the Interstate System. Within the 33 miles there are some 890 acres of median, side slopes, drainage channels and back slopes. A typical section of the roadway would show a 300-ft right-of-way with two 39-ft wide pavements separated by a 74-ft median. Soils in the area traversed are glacial tills composed of unsorted and non-stratified mixtures of clay, silt, sand and coarser fragments. All of the alignment is over ground moraine except for a short stretch through the Powell end moraine where most of the cut sections in the project are located. The roadway traverses some of the poorer farm land in the state. Topography is generally level with some sections of rolling terrain.

A major concern for highway systems is the establishment of an adequate turf on the roadside. This need includes the prevention of erosion as well as an obviously improved appearance. Unfortunately, a pleasing roadside cannot be understood in terms of dollars; erosion, however, results in increased maintenance costs which are clear when gullies must be filled and drainage systems unclogged. Before this, however, wheel alignments may be distorted and axles, mower-blades, etc., broken in traversing hidden erosion channels. Mowing and other maintenance patterns may be changed to less efficient ones and the obscure costs from operator fatigue and of shortened equipment life can accumulate unnoticed. A major objective of this research was to determine the effects of post-construction fertilization on the turf in this 30-mile section of Interstate highway.

Construction of the highway was completed on June 30, 1960. Seeding, fertilization and mulching of the roadside was completed under Ohio Department of Highway's specifications between August and October 1960, and this project began the following spring. The construction fertilization was 20 lb/1,000 sq ft (870 lb/acre) of 12-12-12; this is the treatment recommended by the HRB Committee on Roadside Development (2). Straw mulching was at the rate of 2 tons per acre. The specified seeding rate was 3 lb/1,000 sq ft of a mixture of Kentucky 31 fescue, Kentucky bluegrass, alsike clover and redtop. This seeding rate has been discussed by Davis (3) and others.

COVER

After the road was opened and before detailed planning of the research phases, preliminary soil fertility samples were taken and tested. Based on the analysis of these tests a detailed sampling and testing program was undertaken. In this program 53 soil samples were taken at about ½-mile intervals along the roadway. Each sample was a composite of 32 cores taken in 2 lines, 16 cores per line, with cores equally spaced between right-of-way fences. The top lines were spaced 330 ft apart and each core represented a depth of 3 in. In addition to these, 31 composite samples were similarly taken in the interchanges. Tests on these samples were performed by the University's Soil Testing Laboratory. For reference, the test procedures used are the same as those followed by the state testing labs of Iowa, Wisconsin, North and South Dakota, Pennsylvania and Michigan. Summary results of tests on these 84

Paper sponsored by Committee on Roadside Development.

TABLE 1

PRELIMINARY TESTS

Item	Average	High	Low
Organic matter, %	2.0	4.0	1.0
pH	7.2	7.8	6.1
Phosphorus, lb/acre	16.4	100	1
Potassium, lb/acre	210	360	160
Lime deficit, lb/acre	0	2	0

TABLE 2

INITIAL FERTILITY

Organic Matter (%)	pH	Phosphorus (lb/acre)	Potassium (lb/acre)	Lime Deficit (tons/acre)
(a) Cut				
2.0[a]	7.5	5	222	0
-[b]	7.5	9	228	0
-[b]	7.5	9	216	0
-[b]	7.6	11	222	0
-[b]	7.6	8	222	0
(b) Fill				
1.5[a]	7.1	8	180	0
-[b]	7.5	8	192	0
-[b]	7.5	8	234	0
(c) Level				
2.5[a]	7.3	36	234	0
2.0[a]	7.2	30	174	0
-[b]	7.2	86	276	0
-[b]	7.2	43	244	0
-[b]	7.4	62	222	0
-[b]	7.4	26	222	0

[a]From the preliminary tests.
[b]Subsequent samples, 18 core per sample.

samples are given in Table 1 in which phosphorus and potassium are expressed in elemental pounds, lime deficit is expressed in tons per acre of agricultural ground limestone (TNP 90), and organic matter in percent of original dry weight. Five samples showed a lime deficit of two tons per acre.

These results indicated a high pH level and no need for additional lime (4, 5). Potassium in nearly all samples was at a level considered satisfactory for the growth of grasses. The tests for phosphorus, however, showed a large range, from high to low, and in several samples the levels were considered critical. Information on soil types and the low organic contents indicated that these soils would be low in nitrogen releasing ability. General observation of the turf and previous experience also indicated that the application of nitrogen was probably essential to grass growth and that phosphorus could have a marked effect.

Design Experiment

Based on the fertility levels shown in the soil tests an experiment was designed to determine the effect of post-construction applications of nitrogen and phosphorus on the existing turf. For this experiment three location conditions, or sections, were selected to evaluate the effect of various applications. These conditions were (a) a cut section; (b) a fill section; and (c) a level section. Initial fertility test results in these sections (Table 2) show, with the exception of the pH levels in cut and the phosphorus levels in cut and fill, that these results are similar to the overall averages for the 33-mi project.

The three sections (cut, fill and level) were utilized in small plots to test 25 combinations of nitrogen and phosphorus in each section (Table 3). The 100 and 300 lb/acre treatments of nitrogen and the 150 and 500 lb/acre treatments of phosphorus were designed to be obtained in two equal split treatments within a calendar year; e.g., two 50 lb/acre treatments of nitrogen in 1961 to give a 100 lb/acre treatment of nitrogen in the first year. Treatments were applied for 1½ years. Phosphorus applications were in the granular form of superphosphates containing 45 percent phosphate and treatments are expressed in pounds of phosphate (P_2O_5). Nitrogen applications were in the granular form of ammonium nitrate (NH_4NO_3) containing 33.5 percent nitrogen and treatments are expressed in pounds of nitrogen. In the construction fertilization, some 103 lb/acre each of N, P_2O_5 and K_2O were applied. The theoretical conversion of application rates to test rates involves division of P_2O_5 by 2.3 for phosphorus and division of K_2O by 1.2 for potassium.

At each location, test plots were installed for each of these combination treatments. Each test plot representing a treatment was repeated or replicated for a total of four like plots for each treatment in each section; i.e., a total of 100 test plots in each of the cut, fill and level sections. Each test plot was 6 ft wide and extended across the entire right-of-way. This gave three placement variables: east side, west side and median. The 100 plots in each section were arrayed in random order, 25 at a time, by use of a table of random numbers. This randomizing was done four times for one

TABLE 3

DESIGN TREATMENTS (lb/acre)

Phosphorus (P_2O_5)	Nitrogen				
	0	50	100[a]	150	300[a]
0	0, 0	50, 0	100, 0	150, 0	300, 0
75	0, 75	50, 75	100, 75	150, 75	300, 75
150a	0, 150	50, 150	100, 150	150, 150	300, 150
250	0, 250	50, 250	100, 250	150, 250	300, 250
500[a]	0, 500	50, 500	100, 500	150, 500	300, 500

[a]Split treatment.

section and the relative positioning of plots in all sections was the same. The design of this experiment gives the following variables:

1. Three locations along the highway (cut, fill, level);
2. Three placements (median, east and west sides);
3. Five nitrogen levels; and
4. Five phosphorus levels.

These variables were present in all combinations, each (N, P) level repeated for a total of four times.

Fertilizer was applied to the test plots using a 36-in. hand spreader. The spreader was calibrated by weighing the fertilizer spread over a ground-cloth on level ground; settings were not varied for slopes. On the high slopes it was necessary to pull the spreader with a tractor through a block-and-tackle arrangement. Figure 1 shows this arrangement for the first application on the west side of the cut section. The photograph was taken about June 22, 1961, and shows the condition of the turf at the start of research. Figure 2 shows a portion of the east slope at the same location that fall. The dark stripes identify those plots receiving nitrogen applications. Table 4 gives the dates of fertilizer applications in the three sections.

Observations

Observations were made in each plot to evaluate the results of the fertilizer applications. Each "reading" or estimate was made within a 10-in.-square frame. The frame was divided by thin wires into 25 squares, each representing 4 percent of the

Figure 1. First fertilizer application, west side, cut section, June 1961.

area within the frame. Readings were made by placing the frame on the turf and recording the data given in Table 5.

Figure 2. East side, cut section, fall 1961.

TABLE 4

APPLICATION AND READOUT DATES

Application	Readout	Cut	Fill	Level
		(a) 1961		
First	-	June 20-23	June 27-29	June 13-20
-	First	July 13-27	July 31-Aug. 10	July 13-Aug. 1
-	Second	Aug. 11-18	Aug. 28-Sept. 6	Aug. 21-28
Second[a]	-	Sept. 5-6	Sept. 8-11	Sept. 7
-	Third	Sept. 18-20	Sept. 21-23	Sept. 11-18
-	Fourth	Oct. 12-26	Oct. 26-Nov. 7	Oct. 3-20
-	-	(Nov. and Dec.; test cores taken in selected plots)		
		(b) 1962		
Second-third[a]	-	June 13-14	June 15-16	June 11-12
-	Fifth	Oct. 19-Nov. 8	Oct. 26-Nov. 15	Oct. 2-19
		(c) 1963		
-	Sixth	June 14-24	June 24-28	June 10-14
		(d) 1964		
-	Seventh	July 2-8	July 14-29	July 9-13

[a]For split applications only.

TABLE 5

DATA RECORDED IN EACH READING

1. Readout No. (1 through ?)
2. Location (cut, fill or level)
3. Placement (median, east or west side)
4. Plot No. (1 through 100)
5. Reading (1 through 4)
6. Percent bare area
7. Percent fescue
8. Percent blue grass
9. Percent clover
10. Percent other (redtop and weeds)
11. Color symbol (good, fair or poor)
12. Grass height (range in inches)
13. Erosion symbol (yes or no, from observation of whole plot)

Readings were made in each plot—4 each in the median and the 2 sides for a total of 12 readings in each plot across the right-of-way. With 100 plots per section and three sections this made a total of 3,600 readings for one "readout." (This program was different the first year when 5 readings were made on the two sides—the change was for accuracy and processing convenience.)

The four readings per plot in each placement was equi-spaced in that portion of the plot. In reading along a plot the frame was placed roughly on the plot-centerline. When the frame fell on turf obviously different, as on completely bare area or when covered by mulch from mowing, the reading location was advanced. Plots were located by reference points on the side fence and pavements. Four readouts were made in 1961 and one each in 1962, 1963, and 1964. Table 4 gives the readout dates in relation to the fertilizer applications.

Fertility Check Tests

Soil test cores were taken in selected plots in November and December 1961, some two months after the September fertilizer applications (see Table 4). These cores were taken to determine the effect of applications on test fertility levels. Samples were taken under the following plan:

1. All control plots, (0, 0) treatment;
2. All plots treated with nitrogen only;
3. All plots treated with phosphorous only; and
4. All plots treated with 150 lb/acre of nitrogen and with phosphorus.

In this program some 290 composite samples (12 to 24 cores) were taken and tested. As had been concluded from the preliminary testing, the test results for these samples verified that lime and potassium were not needed. Of particular interest were the results of the tests for phosphorus.

Normally phosphorus levels in soil are divided into low, medium and high ranges. For this investigation the medium range was further subdivided into low-, mid- and high-medium ranges for a clearer understanding of the test results. Table 6 gives the phosphorus test results by the number of samples testing within these ranges.

Aside from showing that the overall effect of the phosphorus treatments was to raise the phosphorus levels as expected (6), these results confirm that the choice of test sections was good. In the non-phosphorus treated cut-section plots, the tests show a uniformly low level of phos-

TABLE 6

PHOSPHORUS IN FERTILITY CHECK TESTS

Phosphorus (lb/acre)	Number of Samples		
	All no P	All no N Except (0, 0)	All (150, P) Except (150, 0)
(a) Cut			
Low (0-10)	56	0	1
Low-Medium (11-18)	7	1	3
Mid-medium (18-26)	1	6	2
High-medium (27-35)	0	7	0
High (35+)	0	12	2
(b) Fill			
Low (0-10)	39	3	2
Low-medium (11-18)	11	8	1
Mid-medium (18-26)	4	1	2
High-medium (27-35)	2	6	0
High (35+)	1	10	3
(c) Level			
Low (0-10)	5	0	0
Low-medium (11-18)	11	0	0
Mid-medium (18-26)	11	1	0
High-medium (27-35)	9	0	0
High (35+)	27	27	8

phorus with 90 percent of the tests falling in that category and the remaining 10 percent essentially in the low-medium range. Similarly, in the fill section 87 percent fall in the low and low-medium categories with the remainder scattered. In the level section the trend of these numbers reverses: 8 percent of the non-phosphorus treatment tests were in the low range, and 25 percent were in the low and low-medium categories. In this section a particularly high plant response to phosphorus would not be expected. Height of slope averages about 20 ft in the cut, 9 ft in the fill, and 3 ft in the level section (in which the pavements are on a shallow fill). Soil fertility levels would be expected to be roughly inverse to the height of cut or fill and these test results are in agreement with this rather broad generalization.

Limited data on the variable of placement (median, east or west sides) were obtained in this sampling and testing program. Samples across the cut section were completely consistent. Samples from the fill section suggested contradictory trends; e.g., the (50, 0) plot-tests showed the east side and median alike in phosphorus levels with the west side low; the (150-0) plot samples showed the reverse. It was concluded that this variation represented the statistics of a normal sampling problem. Data in the level section were scattered; however, there was a trend for the median tests to be somewhat lower in phosphorus levels than either of the sides. A side question in this sampling program was the effect of varying the number of cores per sample from 12 to 24. No obvious benefit was noted from the increased number of cores.

These data are rearranged in Table 7 to show the average phosphorus test levels at the end of 1961 as a function of applied fertilizer. Table 8 gives the test data on pH, summarized by number of samples.

Processing of Readout Data

The readout data from the small plots were transferred to punch cards for machine processing using the IBM-7094 computer. The data for each year were processed and analyzed separately. In the first year there were four readouts and there was one in each of the following three years. Summarizing, within any one readout the following experimental plan was present:

1. Three locations (cut, fill, level).
2. Three placements (east, median, west).
3. Five nitrogen levels (0, 50, 100, 150, 300).
4. Five phosphorus levels (0, 75, 150, 250, 500).

A. The above present in all combinations.

B. Nitrogen-phosphorus combinations repeated four times; the design anticipated four blocks.

C. Within any location-readout-placement-nitrogen-phosphorus combination, multiple readings were taken. In the first year these varied from 0 (missing plot) to 8 but the majority were 4 or 5. There were four in the succeeding years.

TABLE 7

AVERAGE PHOSPHORUS TEST LEVELS

Phosphorus Application (lb/acre)	Average Phosphorus Test Levels at End of 1961: No Nitrogen	150 Lb/Acre of Nitrogen
(a) Cut		
0	8 (5)	7 (28)
75	25 (2)	10 (2)
150[a]	36 (2)	27 (2)
250	39 (10)	20 (2)
500[a]	61 (2)	43 (2)
(b) Fill		
0	8 (3)	7 (29)
75	35 (2)	43 (2)
150[a]	30 (12)	56 (2)
250	41 + (12)	48 (2)
500[a]	26 (2)	12 (2)
(c) Level		
0	47 (6)	32 (30)
75	86 (2)	64 (2)
150[a]	86 + (12)	72 (2)
250	96 + (12)	100 + (2)
500[a]	100 + (2)	100 + (2)

Notes: Numbers in parentheses indicate number of samples; plus signs indicate that one or more samples showed over 100 lb/acre, the maximum test value.
[a]Split treatments.

TABLE 8

pH TEST DATA

Section	Range	Below 7.0	Above 6.9
Cut	7.3 to 7.8	0	99
Fill	6.5 to 7.8	6	87
Level	6.2 to 8.0	12	87

The recorded range of heights measured in each plot placement were added and divided by two to obtain an average height. All other individual observations from a single plot placement were summed and counted. This sum was divided by the number of observations and an average obtained. The basic unit for analysis was the average reading within a single plot. In the first and second years the number of observations varied. (While the use of averages based on unequal observations is not considered strictly polite behavior in statistical circles, its initial use here was dictated by practicality and the use of averages in the first two years should not seriously bias the interpretation of these data.) This procedure gives a single average from four repetitions of 75 placement-nitrogen-phosphorus plots in each reading-location combination. Each readout-location combination was treated as a separate experiment.

Because of discrepancies in the field layout of the plots, some of the four repetitions of the 75 treatments (placement-nitrogen-phosphorus combinations) were not present (improper applications giving 3 or 5 plots where 4 were designed). To simplify computational procedures a missing plot was replaced by the average of the like-treated plots in that placement and a degree of freedom was subtracted from the error term. In the case of 5 plots, the first 4 were used.

Analysis of Readout Data

Each variable was subjected to the standard analysis of variance. The design presumed was that of treatments (placement-nitrogen-phosphorus) and plots within treatments. Originally the design called for blocks but because of the errors in layout the block effect could not be evaluated without a much more complex computational procedure. On this basis the block effects were included in the error term. The significance of different treatments was ascertained from the "F" test in the analysis of variance tables using the 1 percent level of significance. Those treatments showing significant "F" values were evaluated by Duncan's new multiple range test, again using the 1 percent level of significance.

Principal Findings from Readouts

While all combinations of the 25 fertilizer treatments with the variables given in Table 5 were analyzed, this presentation is restricted to those findings believed to be of most interest. In considering these findings it should be noted that they address the question: Given a newly opened Interstate highway that has been properly seeded, and given an ample application of fertilizer and straw mulch, what is the effect of post-construction fertilization?

The results of this study are summarized in the combined graphs of Figure 3, which show the average turf populations, by section, for:

1. (0, 0) plots (control plots receiving no post-construction fertilization);
2. (50, 0) plots (plots receiving two spring treatments of 50 lb/acre of nitrogen with no phosphorus);
3. (50, 150) plots (plots receiving two spring treatments of nitrogen at 50 lb/acre and two spring and one fall treatment of phosphorus at 75 lb/acre); and
4. (300, 500) plots (plots receiving the maximum fertilization of three (150, 250) treatments in two spring and one fall applications).

These fertilization rates were selected for presentation from the 25 rates investigated because they essentially represent the ranges and the principal findings at the conclusion of four years of observations. In this sense it should be noted that the "best" fertilizer treatment (e.g., for cover the best treatment is that treatment below which there is significantly less cover and above which there is little significant increase in cover) varies with the effect being observed and with the time of observation. It is also noted that this and subsequent use of the word "significant," unless qualified, refers to the results of statistical analyses in which results are significant at the 0.01 level. Table 9 gives this time effect on the best treatment for cover, by year and readout.

In examining the graphs the sequence of applications and readouts should be kept in

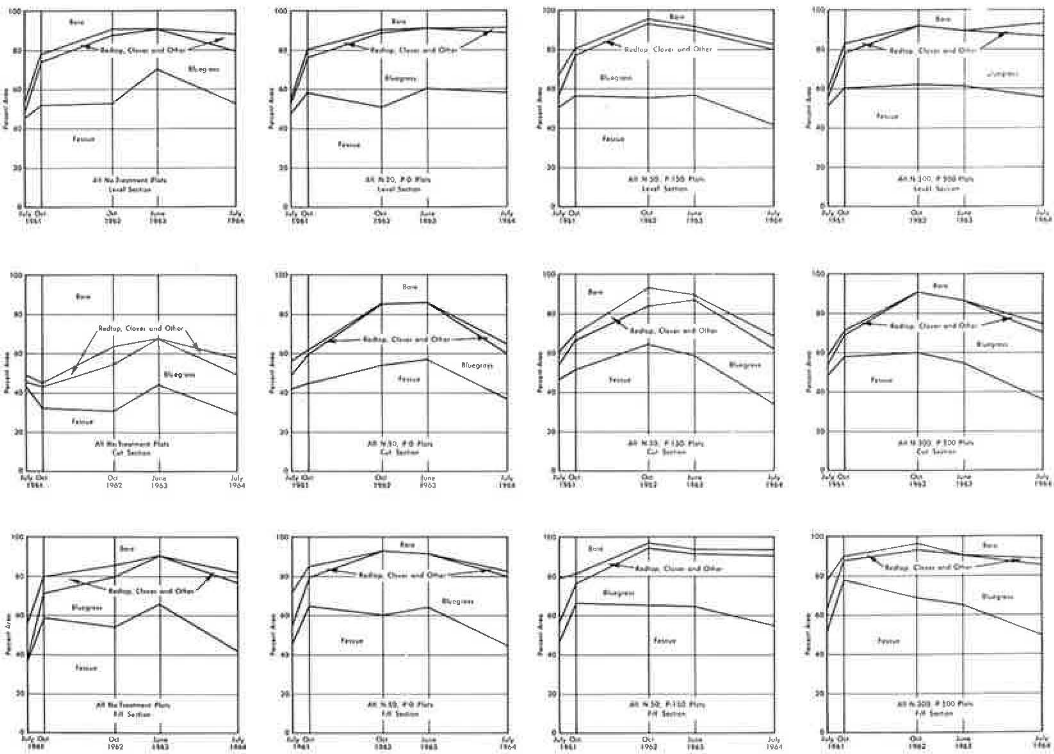

Figure 3. Response of cover with fertilization and time.

TABLE 9

"BEST" TREATMENT FOR COVER

Year and Readout	Nitrogen			Phosphorus		
	Cut	Fill	Level	Cut	Fill	Level
1961 - 1	1x-50 lb/A.	1x-50 lb/A.	0	0	0	0
1961 - 4	1x-50 lb/A.	0	0	0	0	0
1962 - 5	2x-50 lb/A.	0	0	3x-75 lb/A.	0	0
1963 - 6	2x-50 lb/A.	0	0	0	0	0
1964 - 7	1x-50 lb/A.	0	0	3x-75 lb/A.	0	0

mind: the construction seeding, fertilizing and mulching was accomplished in 1960; the first "research" treatment of the plots was in June 1961; the first readout was about one month later and reflects the effect of the first treatment. The second fertilizer application (split treatments only) was in September 1961; the readouts, plotted second on the graph, were made about one month later. The third plotted readings followed the third split-application and the second annual application.

The major effect of fertilization on cover occurred in the first year and in the cut and fill sections. This is shown by the decrease in percent bare area in comparing initial readings in (0, 0) plots to any of those receiving nitrogen in these two sections. Treatment with phosphorus alone had no effect as might be expected for that elapsed time. The second, third and fourth readings indicate that fertilization after the first year had little effect on the amount of cover in the fill section and none in the level section. In effect, fertilization with nitrogen "bought" time in two of the three sections; this effect was most marked in the cut section where control plots did not "catch up"

TABLE 10

ORIGINAL SEEDING

Seed	% of Mixture by Weight	% of Mixture by Seed Count
Ky. 31 fescue	65	15
Ky. bluegrass	25	55
Redtop	5	26
Alsike clover	5	4

with the N-treated plots in four years. In the fill section the control plots essentially caught up with the N-treated plots (or the latter regressed) at the end of the first treatment year; in the level section the differences have never been significant. Of some interest in these data on cover is the absence of an interaction between nitrogen and phosphorus until 1964 and then only in the cut section. This finding is contrary to that expected and no explanation can be advanced. While phosphorus (alone) significantly increased cover on the cut areas observed in 1962, this effect cannot be evaluated in the 1964 observations because of the interaction with nitrogen.

The construction seeding mixture consisted of bluegrass, fescue, redtop and clover. The percentages of these and the corresponding relative number of seeds are given in Table 10.

The relative area covered by each of these species in the plots at the time of the various readouts is shown in Figure 3. The effect of the different fertilizations on the relative cover is not discussed other than to note that the fescue and bluegrass were competitively dominant, with redtop, clover and weeds in all plots and in all sections, and that fertilization accelerated their dominance until about 1964, when the effect of fertilization was wearing off and weeds were becoming more significant. The relative competition of bluegrass with fescue varied with location, placement and time.

In all other observed variables except height, there were significant differences as a result of location (cut, fill or level) and as a result of placement (east, west or median). Height is expected because mowing maintained the grasses between 3 and 7 in. in all sections and readouts were random with respect to the mowings in which clippings were not removed. While these effects are significant statistically, it is believed that the findings shown in Figure 3 and Table 9 are of most importance in the sense of current applicability.

Conclusions on Cover

Based on these data on cover it is concluded for this project that:

1. Post-construction fertilization was of particular significance in increasing cover on the cut section. It was of no significance in the level section and of limited significance in the fill section.
2. The major effect of fertilization was a reduction in the time required to achieve a given level of cover.
3. Phosphorus fertilization did not increase cover in the level and fill sections, and its effect in the cut section was not numerically significant.
4. Nitrogen fertilization had a most significant and continuing effect on cover in the cut section.

EROSION

The range in variables in the design of the fertilizer experiments made it possible to evaluate effects other than those anticipated. Principal among these other effects is exposure to erosion as a function of geometry, aspect, etc. Completely bare areas developed on parts of all sections at the end of four years. Eroded areas requiring maintenance developed in one of the three sections. Interaction of fertilization with erosion is clear.

East Cut Slope

Bare area and erosion developed in plots on the east side of the cut section and are developing at a slower rate on the west side. Figure 1 indicates the condition of the turf at the start of the project.

Figures 2 and 4 show the development of bare area with time. Figure 2 shows the slope at the end of one year of fertilizer applications. In this photograph Plot No. 99 (300, 0) is the last dark stripe on the right hand side. Plot No. 100 (0, 75) consists of the next 6 ft to the right of Plot 99. In these photographs, the ground is dry and nitrogen-treated plots show as dark stripes. Figure 4 shows the same plots in March 1962 when the ground was wet. Plot 99 appears as a dark stripe that extends about halfway up the slope; here dark stripes represent bare gound and the light toned upper part of Plot 99 is grass (the triangular pattern of grass at the bottom of slope in Plot 100 is better seen in Fig. 5). Based on these and detailed color photographs, it is clear that completely bare area developed in these plots in the winter of 1961-1962. This was the first winter after the application of additional fertilizer; the second year after construction and cover was increasing.

Figures 4 and 5 show that bare area increased very little the next winter (1962-1963) and that the grasses were not capable of recouping the loss of cover in the intervening time. Figure 5 was taken in May 1963; Figure 6 is another photograph of selected plots taken in May 1963. The bare areas and the turf below the bare areas show that erosion had not become a problem as of that date in the plots on the east side.

Figure 7 taken in May, 1964 shows that erosion occurred in the winter of 1963-64, as is clearly seen by comparing Figures 6 and 7.

Summarizing, this series of photographs shows the following:

1. Completely bare areas developed in these plots in the winter of 1961-1962.
2. The amount of bare area did not significantly increase in the winter of 1962-1963 nor did erosion in the form of gullies develop at that time.
3. Erosion did develop in the winter of 1963-1964.

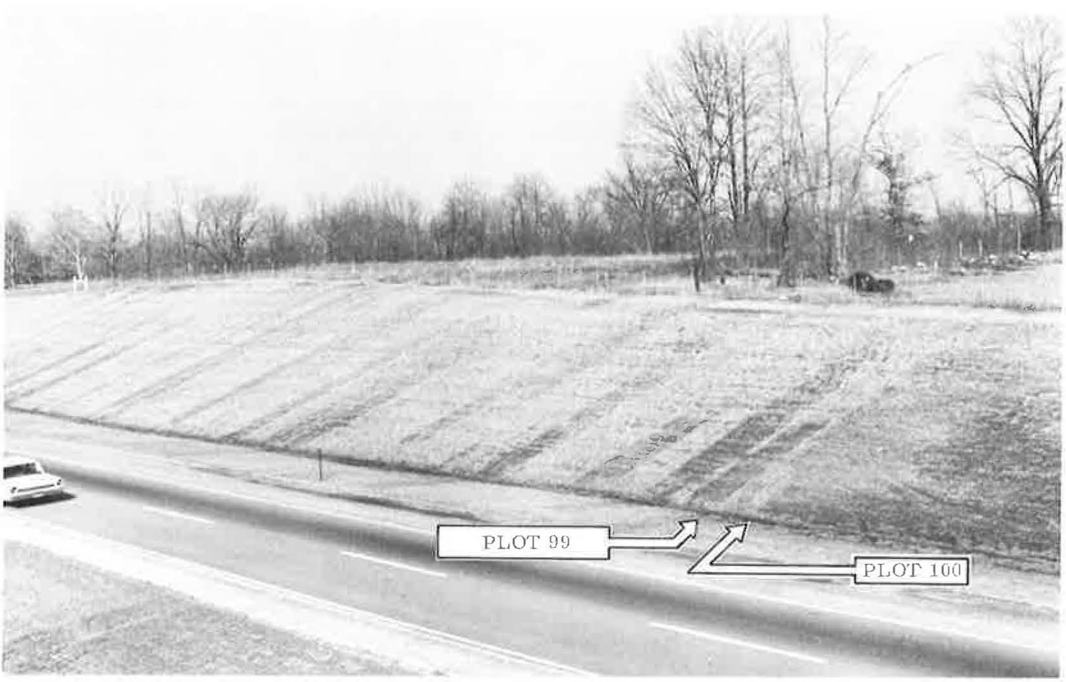

Figure 4. East side of cut section, March 1962.

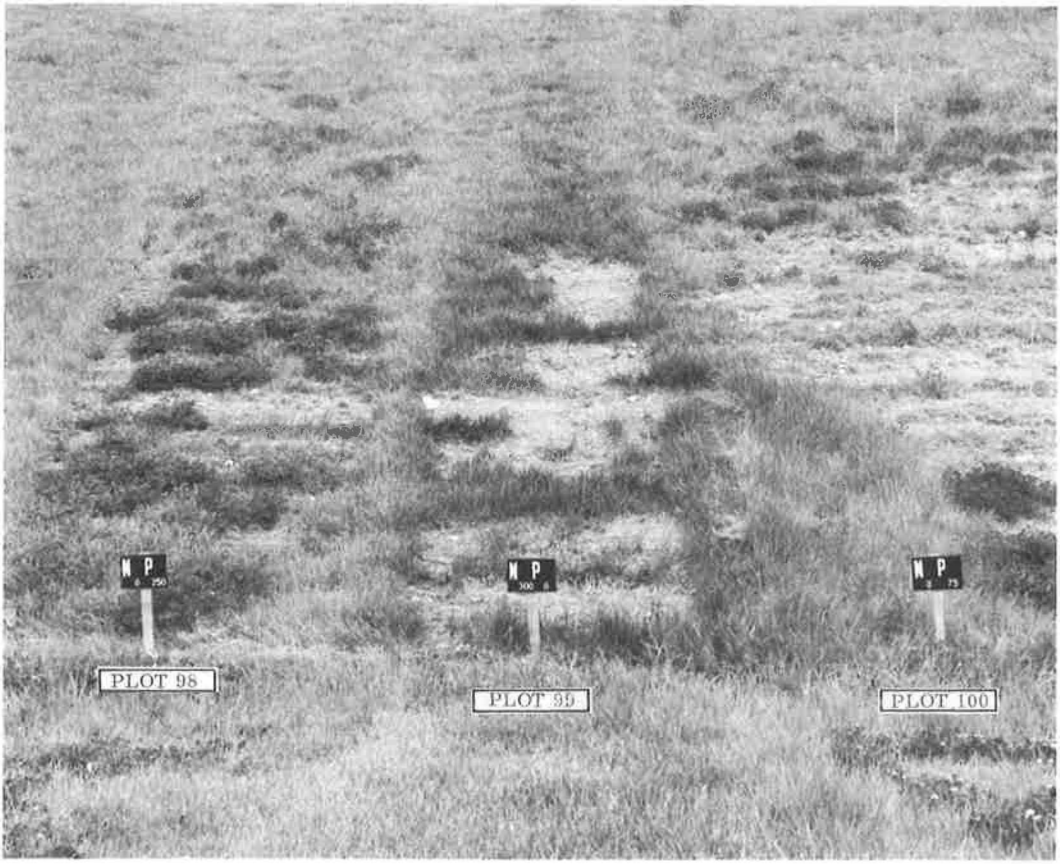

Figure 5. East side of cut section, March 1963.

Susceptibility to erosion is greatly increased with the development of completely bare area. The cumulative effect of rainfall is shown in Figures 7 and 8 and the effect of individual rainfall is shown in Figures 9 and 10. Figure 8 shows the effect on Plot 99 of ten rainfalls accumulating 9.09 in. with a range of 0.09 in. to 2.11 in. Figures 9 and 10 bracket one rainfall of 2.6 in. in a 24-hr period. The bare area visible in these figures is in two contiguous (0, 0) plots.

This series of photographs shows the development of completely bare area and erosion on the east slope of the cut section. These photographs, particularly Figure 6, suggest an interaction between nitrogen and phosphorus–an interaction that did not appear until the fourth year in the cover-readout data (Figure 3).

Nitrogen-Phosphorus Interaction

In May 1964, a detailed survey was made of each of the 100 plots on the east cut slope. Photographs of each plot were taken in standard camera-slope geometry with 2-ft square cardboard strips placed beside bare areas just off the plot (Fig. 9). The square feet of bare area was then estimated using a planimeter standardized on the cardboard squares. Because of the differences in measured bare area for like-treated plots, these estimates were checked as closely as possible by measuring the bare area on the ground with a meter stick. With few exceptions the data obtained by the two methods were the same. The measurements for each plot are given in Table 11.

These data conclusively show an interaction between nitrogen and phosphorus. All zero nitrogen treatments and all zero phosphorus treatments resulted in the develop-

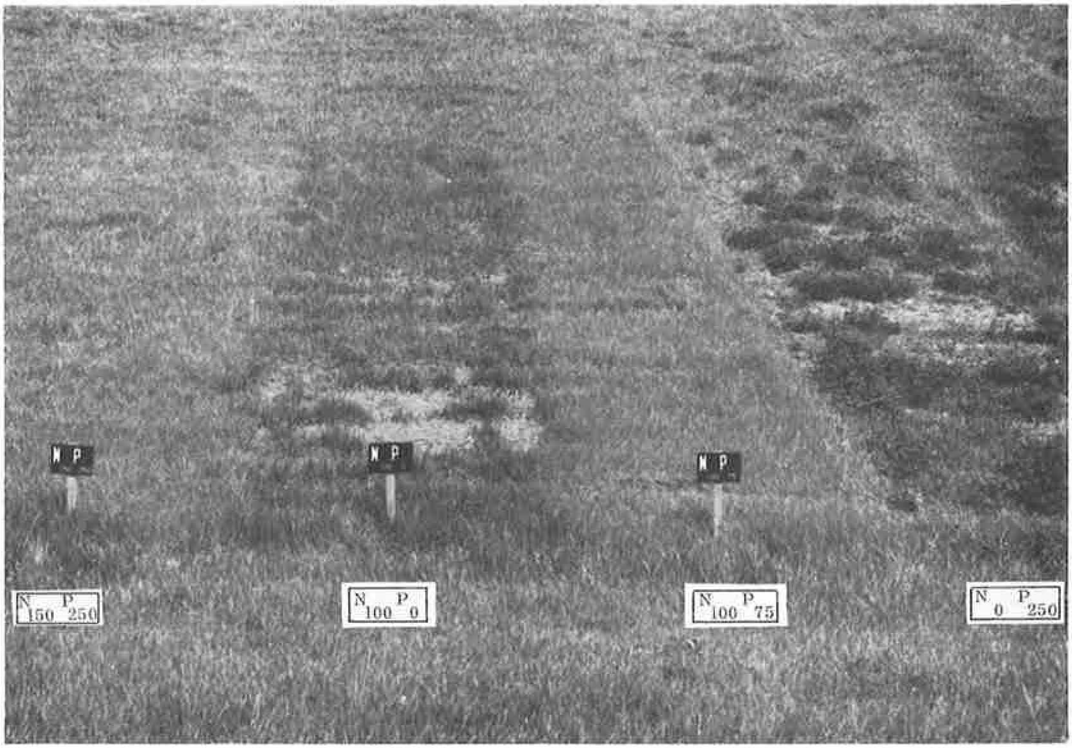

Figure 6. East side of cut section, May 1963.

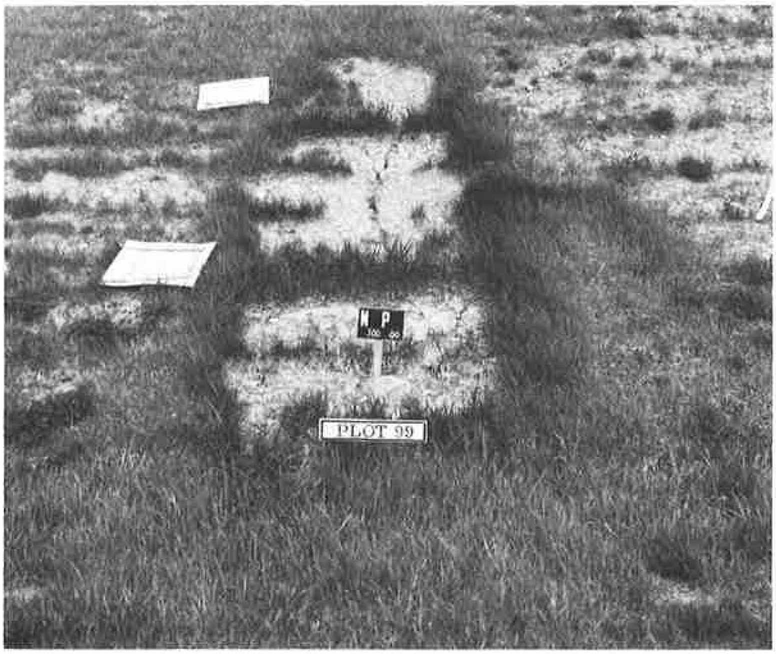

Figure 7. East side of cut section, May 1964.

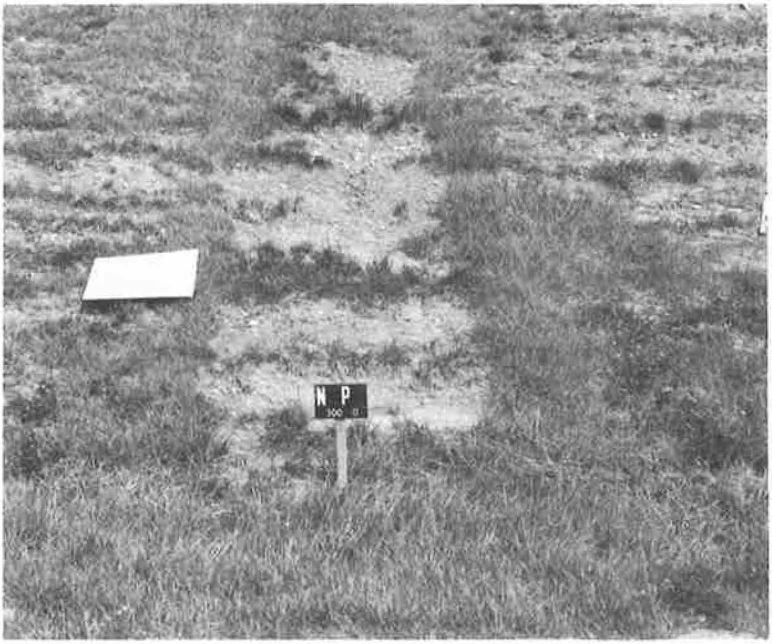

Figure 8. East side of cut section, July 1964.

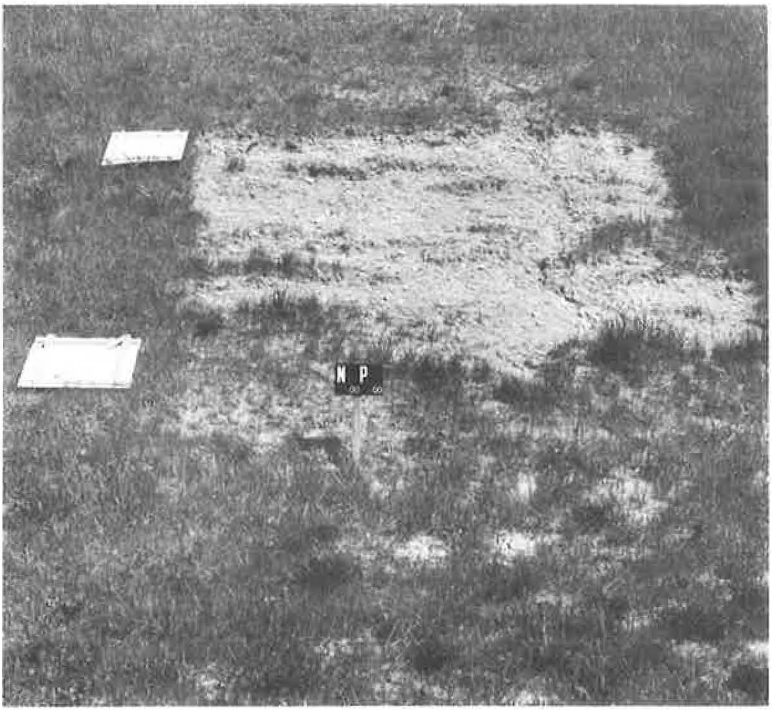

Figure 9. East side of cut section, May 1964 (two contiguous 0, 0 plots).

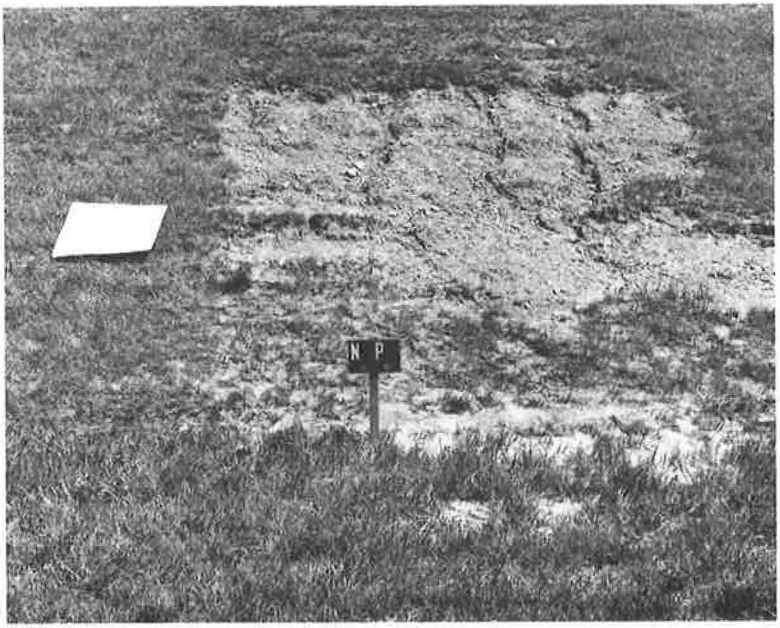

Figure 10. East side, cut section, August 1964 (after 2.6-in. rainfall).

TABLE 11

FERTILIZER TREATMENT VS ERODED AREA (Square Feet, East Side, Cut Slope)

Nitrogen (lb/acre) / Phosphorus (lb/acre)	0	50, Spring '61 50, Spring '62	50, Spring and 50, Fall '61 50, Spring '62	150, Spring '61 150, Spring '62	150, Spring and 150, Fall '61 150, Spring '62
0	54	0	35	8	20
	54	0	17	0	27
	83	32	62	14	missing plot
	156	24	0	60	83
				0	
Avg.	87	14	29	18	43
75, Spring '61 75, Spring '62	89	0	0	0	0
	32	0	0	0	0
	0	0	0	0	0
	36	0	0	0	0
Avg.	39	0	0	0	0
75, Spring & 75, Fall '61 75, Spring '62	12	0	0	0	0
	4	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Avg.	4	0	0	0	0
250, Spring '61 250, Spring '62	65	0	0	0	0
	0	0	0	0	0
	16	0	0	0	0
	0	missing plot	0	0	missing plot
	24				
Avg.	21	0	0	0	0
250, Spring & 250 Fall '61 250, Spring '62	11	9	0	0	0
	18	0	0	0	0
	8	0	0	0	0
	0	0	0	0	0
Avg.	9	2	0	0	0

ment of bare area (37 plots, 10 random exceptions). Treatment with a combination of nitrogen and phosphorus prevented the development of bare area (63 plots, 1 exception). This relationship was remarkably clear in May 1964. Referring to Figure 5 where the (300, 0) plot touches (0, P) plots on each side, at each edge where the phosphorus-only plots touch the nitrogen-only plot there is a strip of surviving grass showing the interaction of the two fertilizers. The other photographs, particularly Figures 6 and 9, show the sharp plot delineations.

Plots showing bare area were not consistent within replicates of like-treatments as shown in the table—excepting the (0, 0) treatment. Neither do the average amounts of bare area between treatments show any particular trend. The data have been studied for location-effect (position along slope), as given in Table 12. This table shows those east-side cut plots that were treated with zero N or/and zero P as they are arrayed from north to south. Bare area, with zero treatment, was as likely to occur anywhere along the slope.

Correlation with Cover

There is no correlation between the incidence of bare area and the average amount of cover estimated in the readouts on cover. This observation is supported by three principal points:

1. Treatment with phosphorus had no significant effect on cover in any of the 1961 readouts. This was the time prior to the development of completely bare area and means that the amount of cover on nitrogen treated plots was the same with or without phosphorus when the grasses became dormant. However, completely bare area developed in all nitrogen treatments without phosphorus.
2. There were significant differences in amount of cover between nitrogen treatments. Despite these differences in cover completely bare area developed only if phosphorus was missing in the treatment.
3. There is no level of cover below which completely bare area developed, and above which it did not. Cover readouts made on the slope showing erosion are used for this comparison. The cover readout data is given in Table 13 and does not include the completely bare area shown in the photographs. This table shows the percent bare area in each of the 100 plots for the first and fourth readouts in 1961 (before the development of completely bare area), and in the 1962 and 1963 readouts (after this development). Also shown are the averages for like treatments. Plot No. 100, (0, 75) is missing in the readouts. If the July 1961 readout averages are examined (with the criterion that the lowest percent bare area in any zero-treated plot constitutes a thresh-

TABLE 12

COMPLETELY BARE AREA VS LOCATION ALONG EAST CUT SLOPE
(All zero-treated plots, May 1964)

Plot	Bare Area?	Plot	Bare Area?	Plot	Bare Area?
Adjoining	yes	34	no	73	yes
1	no	38	no	74	no
4	yes	42	no	78	yes
7	yes	44	yes	82	no
8	yes	48	yes	84	yes
12	yes	50	yes	85	no
17	yes	51	yes	89	yes
21	yes	56	yes	93	no
23	yes	59	yes	96	no
24	yes	60	yes	98	yes
25	yes	63	yes	99	yes
29	yes	66	yes	100	yes
33	yes	70	no	Adjoining	yes

TABLE 13

PERCENT BARE AREA
(Cut Slope, East Side, 1961-1963)

Phosphorus (lb/acre) \ Nitrogen (lb/acre)	Zero				50, Spring '61 50, Spring '62				50, Spring '61 50, Fall '61 50, Spring '62				150, Spring '61 150, Spring '62				150, Spring '61 150, Fall '61 150, Spring '62			
	7/61 Readout	10/61 Readout	10/62 Readout	6/63 Readout	7/61 Readout	10/61 Readout	10/62 Readout	6/63 Readout	7/61 Readout	10/61 Readout	10/62 Readout	6/63 Readout	7/61 Readout	10/61 Readout	10/62 Readout	6/63 Readout	7/61 Readout	10/61 Readout	10/62 Readout	6/63 Readout
Zero	60	85	47	34	37	24	8	5	53	19	15	23	59	42	13	9	45	34	8	9
	70	53	34	19	32	20	14	8	34	15	9	8	46	33	13	5	51	23	14	19
	60	44	21	10	45	35	10	9	42	16	8	14	51	48	14	10		Missing Plot		
	51	52	34	14	58	14	10	6	32	26	15	5	59	8	6	6	50	9	15	10
													43	38	6	8				
Avg.	60	59	34	19	43	23	11	7	40	19	12	13	52	34	10	8	49	22	12	13
75, Spring '61	77	61	29	8	52	42	17	10	52	38	10	10	41	28	5	9	60	25	5	15
75, Spring '62	65	42	38	11	43	18	13	8	44	18	9	11	57	16	5	0	51	18	6	11
	47	27	13	6	32	8	9	4	20	15	5	3	23	5	3	4	58	11	3	8
		Missing Plot			46	12	13	5	30	2	7	5	42	8	12	10	45	12	6	4
																	43	9	3	6
Avg.	63	43	27	8	43	20	13	7	37	18	8	7	41	14	6	6	51	15	5	9
75, Spring '61	73	51	28	11	56	17	10	8	33	6	8	8	59	20	4	13	24	11	8	11
75, Fall '61	74	26	25	9	52	29	11	6	50	16	4	5	35	26	6	9	53	12	6	9
75, Spring '62	65	25	12	9	33	22	12	6	40	11	9	4	53	3	7	3	40	15	6	5
	66	23	12	8	34	19	9	13	34	11	8	5	33	4	2	4	55	15	9	10
Avg.	70	31	19	9	44	22	11	8	39	11	7	6	45	16	5	7	43	13	7	9
250, Spring '61	70	63	17	5	29	11	7	6	39	17	10	4	60	7	2	9	40	8	8	11
250, Spring '62	74	29	17	8	27	11	6	8	40	22	5	6	48	32	9	20	38	17	5	8
	57	45	25	18	42	3	12	4	24	6	7	4	24	19	5	20	36	5	3	6
	70	25	12	11		Missing Plot			43	8	7	5	29	4	8	3		Missing Plot		
	58	10	20	9																
Avg.	66	34	18	10	33	8	8	6	37	13	7	5	40	16	6	13	38	10	5	8
250, Spring '61	70	40	16	8	60	40	19	10	29	40	16	8	38	26	4	4	45	4	3	9
250, Fall '61	67	40	26	10	39	39	9	8	34	37	12	6	34	19	5	6	57	29	9	9
250, Spring '62	58	20	20	4	19	7	8	1	17	5	9	8	19	4	7	4	24	5	5	11
	67	17	11	5	35	20	13	4	24	3	6	4	35	9	4	4	45	3	10	4
Avg.	66	29	18	7	38	27	12	6	26	21	11	7	32	15	5	5	43	10	7	8

old, at or above which completely bare area will develop and below which it will not) four of the sixteen non-eroded plots are exceptions; this difference is too large to be ignored. Dicarding the individual plots having zero N or zero P and no completely bare area does not improve the comparison and actually makes it less favorable (five exceptions). Data from other readout dates show the same trend and more exceptions.

Finding no correlation between cover and the development of bare area is also supported by later developments in other placements and sections. Root weights from samples of each treatment in each section also failed to correlate, probably because of the limited number of samples.

West Cut Slope

Completely bare area is developing in the same location (bottom third) along the west slope of the cut section. Its development along this slope has been much more gradual than on the east slope. After four years on zero-treated plots, bare area is perhaps just a bit beyond the stage that the east slope reached in the winter of 1961-1962. In September 1964, 35 of the 37 zero-treated plots, and 7 of 63 of the combined-treated plots on the west side had developed completely bare area. In the two slopes this difference must be a function of differences in exposure, probably as related to aspect.

TABLE 14

EAST AND WEST SLOPES

Plot No.	Average Slope (%)	Vertical Height (ft)
(a) Cut Section Slopes		
East side of road:		
1 (N)	34	14.9
20	32	14.9
40	35	17.8
60	35	22.1
80	32	20.1
100 (S)	37	17.0
Avg.	34	17.8
West side of road:		
1 (N)	27	15.6
20	39	23.7
40	42	24.8
60	40	25.0
80	35	24.3
100 (S)	49	21.2
Avg.	39	22.4
(b) Fill Section Slopes		
East side of road:		
1	26	9.6
33	27	9.3
67	27	9.4
100	21	9.5
Avg.	25	9.5
West side of road:		
1	26	8.4
33	30	9.5
67	24	8.8
100	23	8.8
Avg.	26	8.9

Relative Exposures

The east slope faces west and its inclination and alignment expose it to the nearly full brunt of the summer sun. In addition, the prevailing wind is from the southwest. This relatively more favorable aspect consistently resulted in a slightly higher level of cover on the west slope than on the east slope at any readout date. Both slopes were increasing in cover at the time of the development of completely bare areas on the east slope. Relative exposures between east and west slopes as related to height and degree of slope were slightly more severe on the west side as sectioned in Table 14, and summarized in Figure 11.

Exposure as related to contributory runoff was initially more severe on about the middle third of the west slope. This contributory runoff was diverted by a ditch constructed in August 1961, but before this erosion of all cover on that portion of the top-of-slope had occurred (the area involved is shown in Figure 1). In this part of the west slope the upper portion has never recovered from the initial erosion although the lower three-fourths, or more, were apparently not affected.

Contributory runoff is present in the south end of the east slope (past about plot 60). The north end, where the shortest slopes are located (about plots 1 to 20), has always been protected by a ditch installed or eroded in the original construction. The data on the east cut slope show that a 50 percent variation in slope height

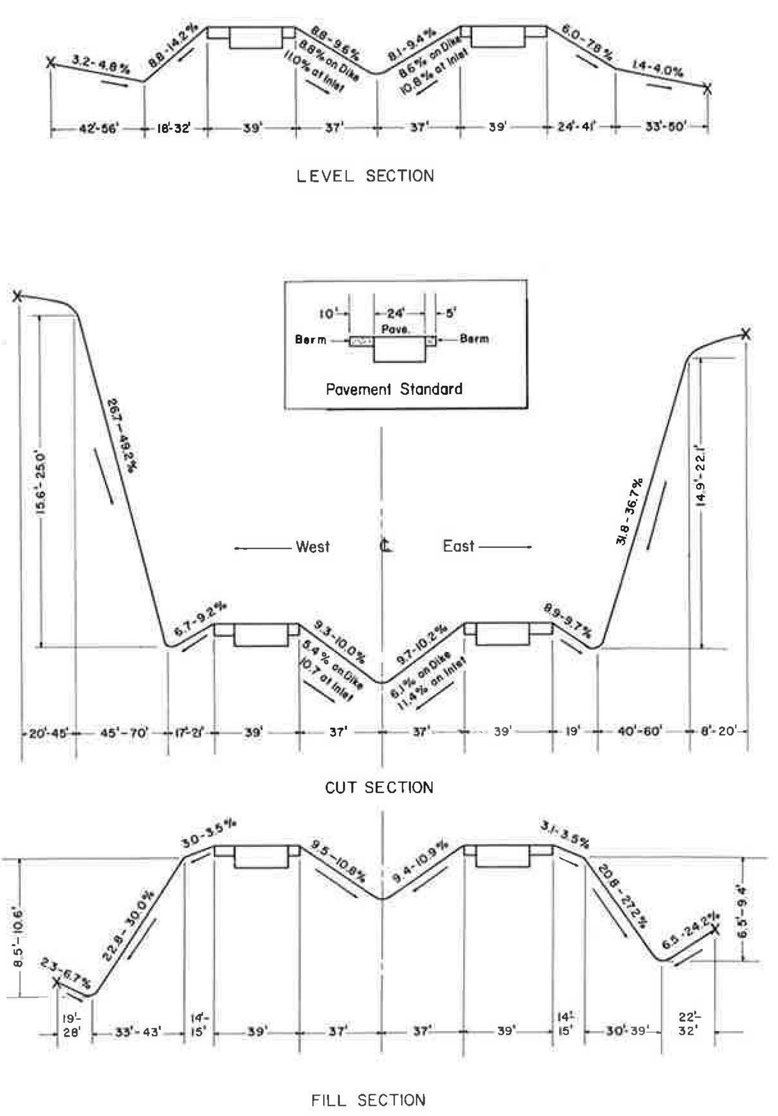

Figure 11. Range in cross-sections, all fertilizer plots.

(or length) did not affect the development of erosion. This is consistent with findings reported by Carreker (7).

Other Exposure Conditions

Table 15 gives rainfall data for the time since before the roadway was seeded. These data are from Weather Bureau records taken at Port Columbus about 12 air-miles from the cut section. Rainfall at the cut section was measured during the above-freezing months except in 1962 when this time was misjudged and all miniature gages burst. The trend of the data at the cut section, at Port Columbus and at the Weather Bureau's Delaware station (11 air-miles from the cut section in the oposite direction) is about the same. It may be that the turf was in a relatively weakened condition entering the winter of 1961-1962 as a result of the preceding dry conditions (August and September 1961) and this resulted in the development of bare area on the more exposed east cut slope. Rainfall prior to the winter of 1962-1963 was somewhat better and

TABLE 15

MONTHLY RAINFALL IN INCHES

Month	1931 to 1960 Average	Monthly Deviations				
		1960	1961	1962	1963	1964
Jan.	2.94	-0.63	-2.29	0.01	-1.77	-1.12
Feb.	2.27	0.22	0.63	1.15	-1.30	-0.69
March	3.43	-2.32	1.40	-0.73	3.98	6.16
April	3.44	-1.84	1.14	-2.16	-0.22	2.92
May	3.97	1.85	-1.07	-1.69	-2.39	-2.02
June	4.33	-1.86	-0.84	-1.90	-2.91	1.38
July	3.85	0.69	0.76	-0.34	-1.03	-
Aug.	3.21	-0.73	-0.48	-0.55	-0.81	-
Sept.	2.91	-2.08	-1.86	-0.97	-2.14	-
Oct.	2.18	0.37	-1.00	-0.05	-2.00	-
Nov.	2.76	-1.26	0.63	0.44	-1.70	-
Dec.	2.49	-0.87	-0.07	-0.58	-1.49	-

little erosion developed in plots subject to erosion at that time (Figs. 4 and 5). Rainfall prior to the winter of 1963-1964 was again relatively low and some erosion developed in plots so subject (Figs. 5 and 7).

Some factor of exposure apparently results in rows or terracing in the turf as shown in the various photographs. The terracing was thought to be the result of the original construction procedures. Interviews with the construction engineers and inspectors revealed, however, that the cut slopes had been disked but that the disking equipment had traveled vertically up and down the slopes rather than along them. Seeding and fertilization were by Hydroseeder and Flowlizer, equipment that did not travel on the slopes. At the top of the slopes seeding and fertilizing was done by hand. Observation of the mowing equipment revealed the probable cause of the terracing. Figure 12 shows a mower "crabbing" into the slope. While the degree of crabbing shown is perhaps slightly exaggerated, the phenomenon is real and results in a row of damaged or scalped turf, particularly in the track of the lower front wheel and when the ground is moist. Flat-bottomed tires do less damage than sharp-edged tires. Level ground minimizes but does not prevent damage because the wheels are "toed in" and some slippage still occurs. On level ground this slippage is about equal for evenly aligned front wheels; on slopes the lower front wheel is at the sharpest attack angle and carries more weight. Turns are most destructive.

Figure 12. Mower "crabbing" on slope.

Another exposure condition common to both cut slopes is the incidence of shrinkage cracks on all parts of the slopes. These cracks, which exhibit a rather large and apparently random pattern (as opposed to small patterned pentagonal cracks in mud) provide natural erosion channels. The fill and level section slopes show shrinkage cracks but not as large, as deep or as numerous as in the cut slopes. One of these cracks can be seen in Figure 7. Another may be seen in Figure 9 just above and to the right of the completely bare area. It is interesting that the turf on those plots receiving both nitrogen and phosphorus is capable of resisting the rather severe exposure conditions that result from these shrinkage movements.

Subsequent Developments

Combination treatments of nitrogen and phosphorus prevented the development of bare area for $2\frac{1}{2}$ years on the east cut slope. The lack of a correlation with cover confirms that an element or function is involved, in addition to fertility, when completely bare area develops. This is the element of exposure to erosion and its function is clearly shown in the photographs by the consistent development of bare area in the bottom one-third of the cut slope and not above or below this area. This area is the weakest point in this slope insofar as preventing erosion with grasses is concerned. It is weakest in an overall or integrated sense and would be expected to be at other slope locations in other soils, geometries, etc. (8). For completely bare area to develop, exposures at some point in time must be greater than the resistance of the turf at that time.

Completely bare area is developing in the fourth year in the combined nitrogen-phosphorus treated plots on the east cut slope. Photographs and observations show that this became observable between May and August, 1964, probably with the 2.6 in. rainfall (9). This is also occurring on the west slope where these developments have apparently proceeded at a slower and more steady pace, i.e., erosion exposure was not as great as on the east slope. Table 16 gives the plot numbers and combined treatments for which completely bare area had developed in the cut section by September 1964. For reference, the bare area in these plots was roughly like that shown for the (0, 250) plot in Figure 5 as opposed to the more uniformly-bare area of the adjoining (300, 0) plot and of the (0, 0) plots in Figure 9.

Bare area is now present in differing degrees in some plots of all sections. Bare area is developed in the median and berm-slopes of the cut section, in the fill section on the east slope and in the level section on the median slopes. Survey of those plots showing this development in September 1964 indicates the same trend found on the east slope of the cut section, i.e., bare area only in zero-N or/and zero-P treated plots. In all of these, the bare area is developing at locations that appear to be points of maximum erosion potential. The development is relatively further advanced in the median and berms of the cut than anywhere in the fill or level sections. In none of these has erosion progressed to the point of representing a maintenance problem as is the case in the cut slopes. In the median of the cut section, the poorest in initial fertility conditions, the asphalt used in anchoring the construction mulch in the drainage swale invert is still present, showing that soil is not washing down and filling the swale even though the opportunity (bare area and runoff) exists. Erosion channels (Figs. 7 and 10) have not yet developed in this or in any placements other than the cut slopes. In the east cut slope erosion is "silting" over the grasses and causing some "kill" at the bottom of slope (Fig. 9).

The sequence of these developments is somewhat involved because of the number of variables, their interactions and of the differing time scales; however, a pattern seems to have emerged in these three sections.

TABLE 16

BARE AREA IN COMBINED TREATMENT PLOTS
(Cut Section, Sept. 1964)

Plot No. East	Plot No. West	Treatment (N, P)	Plot No. East	Plot No. West	Treatment (N, P)
10		(50, 500)		64	(50, 250)
	11	(50, 75)	80		(50, 150)
	18	(300, 150)	92	92	(50, 75)
19		(100, 75)		94	(150, 150)
20		(100, 250)		95	(150, 250)
	39	(50, 150)	97		(100, 75)

Qualitative Interpretation

A qualitative explanation of the developments in these three sections during the first four years can be advanced. Summarizing the original conditions, this roadside was treated by seeding, mulching and fertilizing. Fertility levels of soils were poor to fair. These were present in a variety of aspects on slopes of differing lengths and degrees and with different soil structures as cut and fill. Within these site conditions, exposure to contributory runoff varied, but when present was most nearly in the form of sheet runoff. Rainfall varied between sections and probably within sections as a function of aspect. All combinations of most of these factors were possible but only some appear determinant to the developments observed during these four years.

Bare area first developed on the east slope of the cut section while cover was increasing. This developed as a function of fertilizer and exposure that, in turn, was probably critical as to aspect. In no other slopes were these as severe; no other slopes were affected at this time. Most, but not all, of this slope was affected—showing some localized variations. Cover, if composed of strong and vigorous plants, withstood this exposure; more cover of weaker plants did not. A clear interaction between nitrogen and phosphorus was established.

Subsequently, grass cover reached a maximum and then started decreasing. The amount of cover achieved and the time of the start downward was a function of original fertility and of subsequent fertilization. A decrease in cover reflects a decrease in plant vigor and as this downward trend continued, the condition of criticality of plants vigor vs multi-faceted exposure was approached in the various sections. Meanwhile, erosion channels and silting developed in the east cut slope.

First again to show distress were the surviving plots in the cut section, having always the lowest cover levels and the harshest exposures. Previously unaffected plots in both the east and west slopes showed substantial distress; the median and berms somewhat less. Plant vigor declined with cover and bare area began to develop regardless of added fertilizers. At the same time bare area developed in the level and fill sections as a function of fertilizer and of exposures. This places all sections in phase with the sequences followed in the east and west cut slopes. Similar developments to different time-scales are expected in these sections.

A distinction between bare areas has been noted. The development of a large, continuous, and completely bare area nearly precludes subsequent recovery by the turf. Disconnected and relatively small bare areas may or may not recover and fill in (bluegrass rhizomes, fescue seeding) depending in part on fertility levels and on exposure. These are in turn affected by other variables: all combinations are possible, effects are cumulative, and interactions are expected.

A distinction within erosion has also been noted. The development of completely bare area is believed to be a result, in part, of erosion. The development of completely bare area, however, has not been classified as erosion. Use of this term is restricted to those cases where its development results in a maintenance problem, e.g., a maintenance problem involving cleaning drainage channels, or in the creation of channels which damage or prevent the passage of maintenance equipment. Esthetics are not considered.

Conclusions and Significance

1. Post-construction applications of fertilizers are essential to the prevention of erosion in locations of high erosion potential.
2. Cover per se will not prevent erosion—given an erosion potential that can be controlled by grasses.
3. In areas of initially high potassium and low phosphorus levels, both nitrogen and phosphorus are essential to the production of vigorous grasses for the prevention of erosion.

The findings of this study on fertilization and erosion are believed to be most significant. Site conditions as related to soil types and structures, especially subsoils, are considered representative of roughly the western half of Ohio. In relation to similar fertility levels and the need and benefit of post-construction fertilization on highways these findings are believed representative of the entire state as well as for all locations of similar climate.

For erosion specifically, it cannot be considered that all exposures in the relatively flat median and berm slopes along this roadway have been investigated in the same sense and degree that they have been for the steeper cut slopes. The paved area is a major source of runoff to these gentle slopes, as well as to relatively shallow fills, such as the one investigated. Erosion on these slopes appears to be the result of localized concentrations of runoff. These concentrations seem to be random in distribution, and perhaps, in cause: guardrail posts can serve as concentration points, vehicles leaving the pavement can create furrows, snow-removal salts and concentrations of herbicides can wash down and create others. There were only four, 6-ft wide plots of like treatment in each section and this is not enough to measure so subtle an effect. Could it be measured, results similar to those found in the cut section would be anticipated. Anomalies would be expected. In this connection the frequency of realigning front wheels on the equipment used in maintenance of this project has noticeably increased in the fourth year.

The question of how long the beneficial effect of the combined nitrogen-phosphorus treatments will last cannot be answered now. The benefit of these treatments is being lost in the cut section in the fourth year. At the same time, the fill and level sections are just beginning to show the zero-N or/and zero-P response in completely bare area.

This study gives the four-year results of zero, two and three post-construction applications of two fertilizers under one sequence of time-related conditions. In some plots in all sections the turf has passed its prime and the amount of cover is decreasing. How long this trend will continue, how far it will go, and at what rates cannot be answered. Neither can questions be answered regarding the effect of a different number of applications, particularly one, and of different application sequences. The economic significance of these questions is great. Further study is recommended.

ACKNOWLEDGMENT

This investigation was supported by the Ohio Department of Highways, represented by W. J. Garmhausen and J. R. Riddle, in cooperation with the U. S. Bureau of Public Roads. The interpretation of the results of this study is the work of the authors and does not necessarily represent that of the sponsors.

While it is not possible to recognize each of the individuals who made important contributions, the assistance of the following is gratefully acknowledged: William F. Edwards, Research Associate; Dale T. Friday, Associate Professor Agronomy; and George R. Gist, Professor of Agronomy, The Ohio State University; and Richard Lee, Maintenance Engineer, Division VI, Ohio Department of Highways.

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