THE INFLUENCE OF SOIL MIXTURES ON TURF GROWTH AND SOIL STABILITY FOR HIGHWAY SHOULDERS AND AIRPORTS

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AN interest in the use of grasses and legumes has been evidenced in the highway field for shoulder construction and in the airport interests for airstrips and airparks. The value of turf for highway shoulders has been recognized for many years, but varying results have led to dissatisfaction with both performance and maintenance. The use of turf landing strips, during the emergency of World War II, was practiced from necessity, with success that has led to wider civilian use of turf for landing strips and air parks.

To date, the comparative resistance to wear and load-bearing capacities of sods have received only a limited amount of attention. The wider variation of climatic conditions and soil types prevailing along highway rights-of-way and on airfield sites obviously will require close attention for the selection of grass species for the revegetation of highway shoulders and berms, as well as airfields. The widespread interest in the use of grasses as valuable construction materials is evidenced by experimental as well as functional projects by various governmental organizations and various state highway organizations.

The most desirable grasses for these purposes should have the following characteristics: (1) adaptation to local soil and climatic conditions; (2) resistance to load penetration and traffic abuse; (3) rapid recovery following intensive use; (4) drought resistance; and (5) low maintenance cost. Relatively few known grasses commercially available possess all of these characteristics. Previous experimentation has indicated fescue grasses and Kentucky bluegrass to be the most desirable from the standpoint of wheeled traffic abuse.

With the above factors in mind a study was initiated in 1944 for construction of highway shoulders in Michigan. This was a cooperative project between the Soil Science Department of Michigan State College, and the Michigan State Highway Department, Research Division. A previous progress report by Mr. E. A. Finney and Professor J. Tyson was presented at the 27th Annual Meeting of the Highway Research Board to the Committee on Roadside Development. This report is a summary of all data to the conclusion of the field plot studies in 1951. All work on the study subsequent to 1947 was under the author's supervision.

The ultimate objective of the study was to determine the effects of mixing the various amounts and types of soils into the top 6 inches of the commonly employed sand and gravel subbases, or base courses, on growth of various grasses and also upon the stability of the surfaces produced with varying soil materials and grasses.

The results of the test sections indicated that Chewings fescue was an excellent grass to plant on shoulder surfaces stabilized with sandy or gravelly materials. Those plots on which quackgrass predominated showed very good results on load-bearing capacity. This can be attributed mainly to the widespread root-basket and heavy top growth which flourished on all soil types involved in the test. Topsoils consisting of Miami loam, Brookston loam and Bellefontaine sandy loam can be satisfactorily mixed with sands and gravels to produce a turf, while mixing clay and peat had varying results. Chewings fescue was best suited when planted with small amounts of nurse grass to aid in starting and protecting the slower growing fescue. An excess of the so-called nurse grass was detrimental to the establishment of a cover of Chewings fescue since the nurse grass flourished the first year following quick germination and died out, leaving a sparse cover of fescue the second and subsequent years. Fertilizing and reseeding were required to maintain a good stand. The results presented are not based on any reseedings or fertilizer additions since attempts were made to minimize any and all variables to obtain analyzable data.

No further rutting tests were conducted subsequent to the progress report submitted in 1947.

The study of load-bearing tests and penetrometer studies indicated a definite relation whereby dependable data can be obtained with a special penetrometer to predict load-bearing values of greater magnitude. Two correlative studies were made and both proved valuable and dependable for load-bearing predictions. In both study series load-bearing tests and penetrometer tests were taken to insure close correlative studies.

Test Plot Experiments

The description of the experimental test plots was presented in the previous report included in the 1947 proceedings. A plan of the plots is included as Figure 1 for reference. Tables I and II contain the physical characteristics and typical profiles of the soils series employed in the tests.

Turf Growth

Adequate standard methods have not been established for measuring the quality of turfs for highway shoulders or airports, but an attempt has been made during the period of the test to estimate the percentages of grass coverage, type of grass coverage, and in general the density of the turf. Attention is again called to the fact that no additional seeding has been applied since the start of the test, and fertilizer was applied only three times following the initial application. Under present accepted standards, from studies of the Highway Research Board Committee on Roadside Development (1)*, a turf for highway shoulders is considered to be satisfactory if it is distributed fairly evenly over the ground or shoulder surface equivalent to a 65 to 70 percent coverage. A more dense turf covering would present a more pleasing appearance, but has not necessarily proven better for shoulders or more suitable for traffic duration tests, as brought out in previous literature (2) and in this study. The effects of the various soil mixtures on the growth of the grasses are shown in Table III.

It will be noted from a study of Table III that the Kentucky bluegrass did not survive into the second year, in competition with the better adapted Chewings fescue and domestic ryegrass, on any of the test plots.

The domestic ryegrass germinated very quickly in the fall of 1944 and the early part of 1945. The growth of the domestic ryegrass seemed to correlate very closely with the proportion of fine materials in the mixtures, and an excellent cover was observed on the plots containing the greater relative amount of fines. This was observed on the plots containing Brookston loam material in combination

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*Numbers in parenthesis refer to "References" at end of paper.

with the 22-A graded gravel material and also on Bellefontaine sandy loam material over incoherent sand, pit-run gravel, or 22-A graded gravel. In each case the percentage of fines, material passing a 200-mesh sieve, was large in proportion to the other plots in the test section.

On plots containing Brookston loam and mixtures of clay and peat added to a graded sand base material, Chewings fescue was the only grass to survive into the 1945 growing season. It was also found to be the dominant grass on all plots over incoherent sand, pit-run gravel, and 22-A graded gravel subbase materials in the 1945 test data. The following exceptions to the above were noted: (1) domestic ryegrass predominated on all plots in which Bellefontaine sandy loam was incorporated into the top 6 inches of the subbase material; and (2) on the 22-A graded

PLAN OF SOIL PLOTS

Each Plot 10 ft. by 8 ft.

	Incoherent Sand-Dune	Graded Sand	Pit-Run Gravel Parent Material Fox Bellefontaine C-Horizon	Processed Gravel M.S.H.D. Spec. 22-A
Miami	% (1) 10	% (13) 10	% (25) 10	% (37) 7
	(2) 20	(14) 20	(26) 20	(38) 15
	(3) 30	(15) 30	(27) 30	(39) 25
Brookston	(4) 10	(16) 10	(28) 10	(40) 7
	(5) 20	(17) 20	(29) 20	(41) 15
	(6) 30	(18) 30	(30) 30	(42) 25
Peat and Clay	(7) Clay 10, Peat 5	(19) Clay 10, Peat 5	(31) Clay 10, Peat 5	(43) Clay 10, Peat 5
	(8) 15, 10	(20) 15, 10	(32) 15, 10	(44) 15, 10
	(9) 25, 15	(21) 25, 15	(33) 25, 15	(45) 25, 15
Bellefontaine Top Soil	(10) 50	(22) 50	(34) 50	(46) 50
	(11) 75	(23) 75	(35) 75	(47) 75
	(12) 100	(24) 100	(36) 100	(48) 100

Figure 1.

TABLE 1

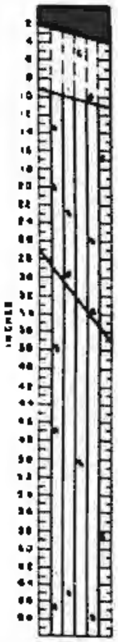
SUMMARY OF SOIL MATERIAL ANALYSIS

		Incoherent Dune Sand		Graded Sand		Bellefontaine Surface Soil A-B Horizon		Clay Miami, C Horizon		Miami Surface Soil A-B Horizon		Brookston Surface Soil A-B Horizon		Gravel 22-A M.S.H.D. Spec.	Pit Run Gravel Fox-Bellef. C Horizon
		Cum.	Ret.	Cum.	Ret.	Cum.	Ret.	Cum.	Ret.	Cum.	Ret.	Cum.	Ret.	Ret.	Ret.
SIEVE ANALYSIS, %															
Bureau of Soils	2 in.														100
Classification	1½ in.														96
	1 in.													100	87
Gravel	3/4 in.													99	82
	3/8 in.													84	74
	No. 4													70	68
	No. 10	100		100		100				100		100		54	60
Fine Gravel	No. 18	99	1	91	9	98	2	100		98	2	97	3		
Coarse Sand	(No. 20	98		88		97		99		97		96			
	(No. 35	92	7	66	25	94	4	99	1	90	8	94	3		
Medium Sand	(No. 40	90		60		93		99		90		93		26	25
	(No. 60	55	37	28	38	85	9	98	1	75	15	86	8		
Fine Sand	No. 140	7	48	8	20	62	23	95	3	51	24	72	14		
Very Fine Sand	(No. 200	4		5		55		94		46		67		6.5	2.2
	(No. 270	1	6	4	4	49	13	89	6	40	11	61	11		
Silt			1		4	14	35	38	51	10	30	21	40		
Clay							14		38		10		21		
Colloids															
Crush Materials														29.2	0.0
SOIL CONSTANTS															
Liquid Limit		18		18		24		34		24		40			
Plastic Index		Nonplastic		Nonplastic		7		13		4		10			
Specific Gravity		2.64		2.63		2.57		2.68		2.52		2.41			
Loss on Ignition		4.60		5.92		4.85		18.52		4.50		11.16			
Organic Content, %		0.76		1.54		4.23		6.26		3.37		9.18			
Field Moisture Equiv. %		18		18		21		28		22		32			
Shrinkage Limit, %						15.7		9.1		15.6		22.5			
Shrinkage Ratio						1.79		1.86		1.65		1.47			

SOIL SERIES USED *on* GRASS PLOT STUDIES

INVESTIGATION ON TURF GROWTH ON HIGHWAY SHOULDERS

MIAMI



Litter, leaf mold and humus soil.

Light grayish yellow loam.

Yellowish brown clay or sandy stony clay, relatively impervious.

Sandy or stony calcareous yellowish gray clay, usually extends to a depth of several feet

BROOKSTON

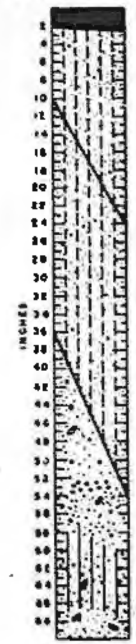
Litter, leaf mold and humus soil.

Dark brownish gray rather friable loam.

Dull gray compact sandy clay, mottled with yellow and brown.

Bluish gray massive clay to sandy clay, mottled with yellow and brown. May contain scattered boulders.

BELLEFONTAINE



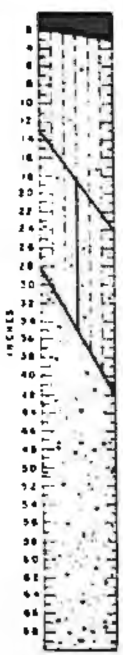
Litter, leaf mold and humus soil.

Yellowish brown friable sandy loam.

Reddish brown slightly compact sandy loam, made coherent by a small amount of sticky clay.

An unconsolidated mass of sand and gravel with occasional layers and pockets of sandy clay and silt which extends to a depth of several feet.

FOX



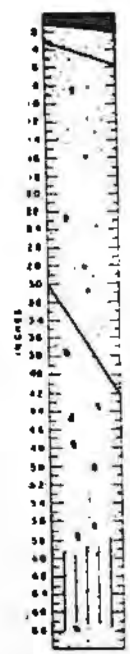
Litter, leaf mold and humus soil.

Yellowish brown friable sandy loam.

Reddish brown sandy loam. Made coherent by a small amount of sticky clay.

Stratified, calcareous, loose sand and gravel extending to a depth of 10' or more.

COLOMA



Litter, leaf mold and humus soil.

Grayish brown sand.

Dull yellow sand, dark and loamy in upper part.

Pale yellow sand containing pockets of clay and coarse drift extends to a depth of several feet.

TABLE 3

Percentage of Grasses in Turf. (F = Red fescue Q = Quackgrass R = Ryegrass B = Kentucky Bluegrass O = Other plants)

	1					13					25					37				
Year	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51
F	50	60	25	40	10	50	50	25	40	5	80	70	40	70	35	80	80	70	60	50
Q	50	40	75	60	50	50	50	75	60	95	20	30	60	30	65	20	20	30	40	50
F	50	65	45	50	15	60	65	35	50	10	60	65	45	60	10	60	75	45	70	15
Q	50	35	55	50	85	40	35	65	50	90	40	35	55	40	90	20	25	55	30	85
R																				
F	65	75	50	60	45	70	65	35	50	45	60	60	35	60	15	60	50	35	60	25
Q	35	25	50	40	55	30	35	65	50	55	25	35	65	40	85	20	45	65	40	75
R											15	5				20	5			
F	95	98	100	95	85	95	98	100	100	80	70	98	90	60	50	50	95	95	100	70
Q					15					20			10	40	45					25
R	5					5					30					50				
O		2		5			2					2			5		5	5		5
F	80	98	100	90	80	95	98	100	90	80	70	90	97	100	50	20	95	95	95	90
Q				5	15					5			3		40					8
R	20					5					30	10				80				
O		2		5	5		2	10	15						10		5	5	5	2
F	70	98	100	85	80	60	98	100	60	70	40	100	90	50	90	20	95	95	100	90
Q				15	20				40	20			5							
R	30					40					60					80				
O		2					2			10			5	50	10		5	5		10
F	80	98	100	100	90	95	100	100	95	98	65	100	100	100	98	60	100	100	100	98
Q																				
R	20					5					35					40				
O		2			10				5	2					2					2
F	70	100	95	90	75	95	100	100	95	85	60	100	100	100	100	50	100	98	100	100
Q				10	10					10										
R	30					5					40					50				
O			5		15				5	5								2		
F	70	100	98	90	50	100	100	100	90	70	55	100	98	100	80	50	98	100	95	98
Q				10	40				10	20					10					
R	30										45					50				
O			2		10					10			2		10				5	2
F	50	98	85	80	55	60	50	95	80	55	50	75	90	70	80	70	75	95	90	95
Q			15	20	45				10	40				10	5					
R	50					40					50					30				
O		2					50	5	10	5		25	10	20	15		25		10	5
F	50	75	85	65	40	50	30	50	50	35	50	40	50	40	10	50	80	95	80	35
Q	10	25	15	30	50	10	50	45	40	55	10	40	40	40	80	10	10	5	15	30
R	40					40	20				40					40				
O				5	10			5	10	10		20	10	20	10		10		5	35
F	20	75	60	50	60	20	45	50	50	50	20	35	50	40	45	20	50	50	55	45
Q	20	15	35	40	20	20	45	45	40	45	20	50	45	50	45	20	35	50	40	45
R	60					60					60					60				
O					20		10	5	10	5		15	5	10	10		15		5	10
	12					24					36					4B				

gravel subbase material into which 20 and 30 percent Brookston loam surface soil was incorporated and also on the pit-run gravel material to which 30 percent of the Brookston loam surface soil was added. This could be explained by the fines in the 22-A graded gravel and the pit-run gravel in combination with the clay from the Brookston loam soil providing good water-holding and supplying properties.

On the plots in which 75 to 100 percent Bellefontaine sandy loam was incorporated, the turf contained from 10 to 50 percent quackgrass. This can be explained only in the fact that the topsoil of this series contained the quackgrass seed and rhizomes when it was used as an additive. This same observation was made on the plots containing large proportions of Miami topsoil and the same conclusions arrived at. For the above reasons some weed, plantain, sorrel, dock, dandelion, and thistle seeds were also transplanted with resulting occurrence on the plots. These weeds flourished and spread to other turf plots, especially on plots in which Bellefontaine sandy loam was incorporated as an additive material. As mentioned before, quackgrass proved to be a very good turf for stability and durability but, being classed as a noxious weed, its use for shoulder work or airport turf is prohibited.

During the 1945 growing season and subsequent winter all of the domestic ryegrass disappeared from the turf after flourishing so rank in the fall of 1944 and spring of 1945. The resulting turf cover on these plots was very low in 1946 since the Chewings fescue had been crowded by the rank growth of the domestic ryegrass. This observation was noted especially on plots with 22-A graded gravel, pit-run gravel, and graded sand materials containing 20 to 30 percent Brookston loam surface soil as an additive material.

The turf on all plots except those of incoherent sand deteriorated during the 1946 growing season, since there was extremely light rainfall during the period. The total rainfall from June 20, 1946 to August 1, 1946 was approximately 0.05 inch, and only 0.78 inch for the month of August.

Chewings fescue and quackgrass are drought-resistant, becoming dormant during drought periods and recovering quickly when moisture is again available. They recovered very well during the fall months of 1946 when the rainfall was nearer normal for this area, and also during the growing season of 1947. During the 1947 growing season the moisture conditions were near ideal for the growing of grasses.

During the 1947 growing season, and especially during the spring months, the quackgrass flourished with the high precipitation rates and good growing weather. During this period, on the plots containing additives of Miami soil, the quackgrass made up as much as 50 percent of the entire turf cover with only one exception, and that was on the plot consisting of a very low amount, 10 percent, of Miami soil additive to a 22-A graded gravel subbase. On the plots containing Bellefontaine additive materials the percent of the quackgrass turf was influenced by the soil mixtures, the greater the amount of additive material the more quckgrass turf. On the plots with only 50 percent additive material no quackgrass was evidenced on three plots and only 10 percent on the fourth plot. On these plots Chewings fescue was able to overcome the quackgrass which had a more scattered seeding and the fescue afforded a turf coverage of from 85 to 95 percent in all cases.

The results of this study tend to indicate a desirable source of the additive materials and the amounts of them to be used as additives to reduce the possibility of quackgrass running out the sown grass species.

Turf Coverage

To evaluate a given highway shoulder or airstrip, the density of turf coverage is the critical point in question and not the amount or rankness of the turf growth. The densities of the turf coverage from 1945 through 1951 on the plots are shown in Table IV. From these data the effects can be observed of varying soils, of seasonal and climate variations, and of the grass varieties for those planted and those occurring in the mixtures as vegetative additives with the surface soils on the turf.

On the basis of the standard 70 percent cover of turf stated previously (1) for shoulder turf coverage on highways, it will be noted from Table IV that all plots containing 22-A graded gravel subbase materials, incorporating all additives, and on all plots, in which 30 percent Miami loam, 30 percent Brookston loam, or 75 to 100 percent Bellefontaine sandy loam were incorporated as additives, proved to produce satisfactory shoulders in 1945, less than one year following construction and planting of the plots. This standard is only on coverage of turf density and is not taking into account load bearing which will be covered later in this report.

During the 1946 season the turf on the 22-A gravel base material was satisfactory for highway shoulder purposes, with grass coverage ranging from 60 to 90 percent of the plot surfaces. The same was found to be true on plots having 20 or 30 percent Miami loam surface soil as an additive to the subbase material, those having from 60 to 90 percent coverage. The plots having Bellefontaine sandy loam admixtures also resulted in satisfactory turf densities for shoulder purposes.

The turf on the plots of graded gravel, sand, or pit-run gravel was found to be inferior to standards, or in general not as satisfactory as that produced on the 22-A graded gravel subbases or on the incoherent sand based plots. The turf densities on the plots having clay and peat additives were found to be not as satisfactory as those on plots having loam mixture added to the subbases. As previously noted, the plots having a rank growth of domestic ryegrass were found to be below the standards during the 1946 season since the ryegrass died out, leaving Chewings fescue as the only cover. This condition prevailed on plots with subbases of pit-run gravel and graded sand with Brookston loam as the additive material.

The growth of the grasses was generally improved in 1947 on all plots with the relatively high precipitation during the spring and early summer months. The turf was found to be unsatisfactory on only six plots, as noted in Table IV. It was noted, however, that in all cases the turf density was greater than for the same period in 1946. The plots affected by the dying out of the ryegrass had regained density over the 1946 growing season until all plots were only slightly below the accepted standards of coverage. It will be noted from the data that all plots are approaching a maximum density in 1947 where no unforeseen events, such as dying out, have impeded the progress. By referring to Table III, it will also be noted that on the Miami soil additives quackgrass became the dominant grass over the Chewings fescue. It can be observed quackgrass was not increasing over the 1946 levels in any other plots regardless of subbase or additive materials.

After the 1947 growing season the plots were maintained in the same manner as in previous years but no further fertilizer applications were made in April as before. It will be noted that the coverage and turf-density data in Table IV bear this out and it is clearly reflected on all plots with the exception of the Miami and Bellefontaine additive plots where the turf density was not too much affected. The plots of clay and peat were the ones that clearly indicated the need of additional or supplemental seedings and fertilization continuation. The plots on the Brookston soil decreased in turf density but not as radically as the clay and peat. With increasing amounts of

TABLE 4.

Percentage of Coverage 1946-1951

						13					25					37				
	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51	'45	'46	'47	'48	'51
1	30	60	95	60	75	20	50	95	50	65	40	65	95	60	75	60	60	95	70	85
2	45	70	100	65	87	50	65	100	80	87	55	70	100	75	87	65	70	100	70	90
3	65	70	100	75	87	65	65	100	85	85	65	70	95	85	85	70	70	100	90	95
4	40	65	85	60	75	30	35	55	30	70	60	30	60	40	55	70	70	95	70	70
5	55	75	95	70	75	40	60	65	40	60	75	40	65	40	75	85	75	95	70	83
6	65	75	95	50	80	60	40	75	50	55	80	25	50	40	55	95	75	95	80	87
7	40	70	85	50	60	30	20	25	30	40	55	40	60	50	50	60	60	90	70	75
8	45	75	95	65	88	30	20	35	40	45	50	40	70	50	55	60	70	90	70	75
9	55	75	95	80	88	25	30	55	50	60	55	45	70	50	65	60	60	95	85	87
10	50	70	100	80	88	50	40	70	40	83	55	40	75	65	80	70	60	95	70	85
11	75	85	100	90	97	75	40	90	80	93	75	50	90	80	95	75	60	95	85	95
12	90	90	100	95	95	90	80	100	95	98	90	75	100	95	98	90	75	100	90	95
						24					36					48				

Brookston soil there was a marked variation in density of turf on both incoherent sand and processed 22-A graded gravel with only slight variations on the graded sand and pit-run gravel. In general the incoherent sand and processed 22-A graded gravel were better with all additives through this portion of the test, and this was also reflected in the plate bearing studies.

The percent of different grasses in the various plots showed slight variations during the period from 1948 to 1951. It will be noted in Table 3 that the percent of quackgrass on the Miami additive plots increased in all cases. This can be explained by the gradual dying out of Chewings fescue and replacement with quackgrass.

On the Brookston plots the turf density was fairly constant with very little variation in percentages of various grasses. The quackgrass did not seem to spread too rapidly in these plots on any of the subbase materials. The same was true for the clay and peat additive soils on all subbase materials.

The Bellefontaine plots had very little variation in the percentages of Chewings fescue and quackgrass, but bluegrass, originating from surrounding cover on experimental plots in the vicinity, was found in amounts ranging from traces on up to significant percentages.

In general, a satisfactory turf coverage to meet current requirements for highway shoulders was present throughout the test period on all plots having Miami and Bellefontaine additives, on incoherent sand and processed 22-A graded gravel with Brookston and clay, and peat additive soil materials. The plots with Brookston and clay and peat additive materials on pit-run gravel and graded sand were, in general, below the accepted standards of from 65 to 70 percent coverage.

Stability of Turf Plots

One year following the construction of the turf plots and the fall seeding, two types of stability tests were conducted on the plots to determine and evaluate their ability to support stationary and moving loads under conditions of saturation as well as when dry. The first of the series of tests consisted of applying a static load through a 100-square-inch bearing plate and measuring the amount of penetration at various load increments. A round bearing plate was employed which is considered general practice (3).

The second series of tests was made to check the resistance of the grass turf to rutting. This was accomplished by driving a heavy truck over the plots and measuring the various depths of resulting ruts caused by the moving wheels. The wheel loads on the rutting test were single-tire type. The plate bearing tests were all conducted on the soil in its normal environments as to percent moisture while the rutting tests were conducted on saturated plots to simulate early spring breakup conditions, and other rutting tests were carried out on dry or low moisture contents which would compare to summer conditions.

The series of rutting tests was carried out only once during the 1945 season, but the plate bearing studies were continued during the years 1947, 1949, 1950, and 1951 at approximately the same season to obtain comparable conditions on plots.

Testing

Plate bearing and rutting test methods were covered very comprehensively in the aforementioned report and will be omitted from this report. For comparative results of the turf plots there were accomplished determinations of the subgrade modulus "k" for a 2,500-pound load and the results are tabulated in Table 5. The moisture content of the respective plots, and density determinations are included in Table 6.

From the bearing plate tests, graphs were constructed for each test to indicate ratio of settlement to load. Table 1, Appendix, (at end of paper) contains representative examples of these graphs showing curves for successive years' tests to illustrate comparisons as the turf growth progressed and resulting bearing values increased.

Plate bearing tests carried out during 1950 and 1951 were correlated to penetrometer studies with a resulting study which is included later in this report as correlations with comparable results.

Penetrometer Tests

Following three years of stability tests the penetrometer studies were attempted on the turf plots to show some close correlation of such studies with previously conducted plate bearing tests.

The penetrometer has been used for a number of years more or less successfully for field checks of density, stability, and tilth studies in the field of agriculture. The main objections to its use were the small bearing area, non-uniform penetration rate, the possibilities of obtaining erroneous results caused by striking stones, or the formation of pseudo-heads on the bearing area. It is

TABLE 5.

Subgrade Modulus "k" for 2500-Pound Load

Plot No.	1947 Penetration*	1947 "k"	1949 Penetration*	1949 "k"	1950 Penetration*	1950 "k"	1951** Penetration*	1951** "k"
1	0.54	46	0.22	110	0.19	139	1.23	109
2	0.49	51	0.22	106	0.17	147	0.20	125
3	0.80	31	0.17	187	0.14	170	0.14	178
4	0.64	39	0.32	76	0.27	91	0.29	87
5	0.33	75	0.24	108	0.25	101	0.23	107
6	0.43	57	0.33	70	0.25	99	0.28	90
7	0.52	48	0.30	83	0.29	90	0.27	93
8	0.44	57	0.41	63	0.44	60	0.39	64
9	0.23	109	0.36	66	0.35	70	0.33	76
10	0.48	52	0.20	121	0.29	91	0.18	139
11	0.61	41	0.18	133	0.32	79	0.19	131
12	0.90	28	0.16	139	0.33	77	0.20	125
13	0.24	104	0.21	110	0.29	93	0.18	139
14	0.25	100	0.22	108	0.28	97	0.19	131
15	0.24	106	0.21	122	0.25	101	0.18	139
16	0.44	57	0.22	111	0.28	96	0.22	113
17	0.33	77	0.31	78	0.35	70	0.32	78
18	0.35	71	0.35	70	0.35	71	0.34	74
19	0.38	66	0.34	75	0.36	69	0.18	139
20	0.57	44	0.21	116	0.33	77	0.27	93
21	0.48	52	0.30	85	0.35	67	0.18	139
22	0.35	71	0.20	128	0.29	91	0.18	139
23	0.43	58	0.23	100	0.28	97	0.20	125
24			0.09	263	0.12	201	0.11	221
25	0.20	125	0.07	367	0.18	151	0.17	149
26	0.15	164	0.18	130	0.13	172	0.15	167
27	0.10	236	0.14	176	0.12	191	0.13	192
28	0.16	158	0.17	144	0.30	83	0.21	119
29	0.19	135	0.23	112	0.25	99	0.14	176
30	0.17	150	0.13	171	0.22	107	0.12	206
31	0.20	122	0.11	235	0.16	147	0.12	206
32	0.50	50	0.20	125	0.28	98	0.18	139
33	0.58	43	0.18	137	0.28	97	0.19	131
34	0.58	43	0.09	256	0.29	92	0.13	192
35	0.39	64	0.13	208	0.29	91	0.13	192
36	0.67	37	0.18	145	0.35	72	0.15	167
37	0.09	287	0.09	275	0.09	290	0.09	279
38	0.11	227	0.08	294	0.09	282	0.10	250

* Penetration in inches
** 1951 Data from Penetrometer curves

TABLE 5 (Cont'd)

Plot No.	1947 Penetration*	1947 "k"	1949 Penetration*	1949 "k"	1950 Penetration*	1950 "k"	1951** Penetration*	1951** "k"
39	0.14	179	0.09	295	0.10	271	0.09	279
40	0.19	130	0.09	325	0.10	270	0.10	250
41	0.16	154	0.06	390	0.09	281	0.09	279
42	0.25	100	0.13	188	0.14	175	0.13	192
43	0.16	156	0.11	223	0.12	194	0.13	192
44	0.59	42	0.06	465	0.11	206	0.11	221
45	0.52	48	0.27	93	0.13	177	0.21	119
46	0.36	69	0.05	510	0.28	95	0.26	96
47	0.22	114	0.06	415	0.26	109	0.20	125
48	0.55	46	0.18	305	0.28	97	0.27	93

TABLE 6.

DENSITY AND MOISTURE DATA

Plot No.	1947 Percent Moisture**	1947 Density*	1949 Percent Moisture	1949 Density	1950 Percent Moisture	1950 Density	1951 Percent Moisture	1951 Density
1	10.01		10.4	90	13.2	91	12.4	90
2	10.01		9.7	96	11.2	100	12.6	101
3	10.01		13.0	93	13.3	90	13.2	99
4	10.01		9.2	101	10.1	97	12.1	99
5	10.01		5.3	91	9.1	91	10.2	90
6	10.01		5.3	94	10.2	96	9.9	96
7	10.01		5.4	97	10.2	96	10.3	99
8	10.01		5.3	90	10.3	92	10.0	87
9	10.01		5.3	90	10.1	90	9.7	88
10	10.22	none taken	5.3	96	12.1	95	11.4	97
11	10.22		5.6	85	12.4	87	12.4	89
12	10.22		5.4	97	12.1	100	12.0	101
13	7.39		4.0	101	12.0	100	11.7	102
14	7.39		4.0	101	10.9	100	10.8	101
15	7.39		3.8	101	5.1	100	5.3	102
16	7.39		4.0	101	4.6	101	5.5	102
17	7.39		4.1	99	4.3	97	4.7	99
18	7.39		4.0	97	5.9	99	5.9	101
19	7.39		3.8	97	6.1	100	6.1	100
20	7.39		3.3	100	5.9	100	6.0	101

*Density units are p.f.c. ** Moisture units percent dry weight.

TABLE 6 (Cont'd)

Plot No.	1947 Percent Mois-** ture	1947 Den-sity*	1949 Percent Mois-ture	1949 Den-sity	1950 Percent Mois-ture	1950 Den-sity	1951 Percent Mois-ture	1951 Den-sity
21	7.39		4.0	95	7.1	96	7.1	95
22	11.16		5.3	99	8.1	100	8.3	100
23	11.16		5.3	91	8.0	90	8.1	91
24	11.16		5.4	97	8.7	97	8.3	97
25	2.67		3.0	122	7.9	120	8.0	121
26	2.67		3.0	120	6.5	122	7.4	124
27	2.67		3.2	119	7.4	120	7.4	120
28	2.67		3.0	120	9.7	121	9.1	122
29	2.67		3.1	116	13.6	120	10.6	119
30	2.67		2.6	117	10.1	117	10.1	117
31	2.67		3.0	116	9.7	117	10.1	117
32	4.68		3.5	112	8.9	113	9.1	110
33	4.68		3.4	115	8.7	117	9.0	117
34	4.68		2.0	116	7.2	115	7.9	116
35	4.68	none taken	3.7	101	7.0	100	7.6	101
36	4.68		4.0	91	7.1	90	7.4	91
37	4.11		3.0	116	7.7	115	7.6	118
38	4.11		2.8	110	8.1	110	7.4	111
39	4.11		3.0	109	7.5	109	7.5	110
40	4.11		2.8	112	7.1	114	7.1	113
41	4.11		3.0	114	6.7	114	6.6	114
42	4.11		3.0	106	6.1	105	6.6	105
43	4.11		2.5	115	6.4	117	6.7	116
44	6.26		3.1	114	7.3	114	7.1	114
45	6.26		2.2	108	7.2	107	7.2	107
46	6.26		3.2	108	7.7	107	7.1	107
47	6.26		3.3	87	8.0	97	8.1	97
48	6.26		4.5	85	8.2	102	8.1	100

not possible to change the bearing area since only the operator's weight is employed for effecting penetration. Eliminating pseudo-heads or the chance of striking objects is also impossible to correct or eliminate. The uniform penetration problem can, however, be accomplished by employment of the "Hanbertson" (4) penetrometer. This instrument, shown in Figure 2, employs a system whereby each penetration is recorded on a graph as shown in Figure 3. The graph is a trace of the resultant pressure required to force the probe into the soil, and the depth of penetration of the probe. The abscissa is drawn by the pressure of the soil transmitted to a calibrated coil spring and the ordinate is produced by the differential between the probe head and the float rod foot which rests on the soil surface. There are two pulley systems which produce the desired 4-inch graph and which compensate for the compression of the resistance spring.

Figure 2. A view of the Hanbertson penetrometer in operation.

The accomplishment of a load-bearing test requires considerable laborious and tedious work, with cumbersome equipment and considerable expense. It may be possible that the use of the penetrometer can provide an economical, convenient, and accurate method of obtaining load-bearing data to supplement tests on constructed structures of known soil materials.

The soil penetrometer as used in tilth studies had two heads, one a tapered point probe and the other a flat head with a circular cross-sectional area of 0.15 square inch. Additional heads were adpated to the equipment in various circular areas up to one square inch.

A location was chosen large enough to accommodate the bearing area and the float rod foot. This area was cleared of all loose surface material, such as stones and leaves, in order to provide a firm smooth plane for making the observation. Special care was taken to not disturb the turf or soil. Manual pressure was applied to the penetrometer in such manner to produce, within reason and without benefit of gauges, a slow, uniformly increasing pressure and resulting penetration. With this precaution the possibility of impact load was practically eliminated. The trace, resultant of this pressure produced in the coil spring and the depth of penetration produced by the differential between the float rod foot and the probe head, was recorded automatically on the blank chart for the instrument. In taking the data attempts were made to obtain at least three curves, from which composite data curves were produced for each plot.

A preliminary investigation was carried out to determine which load would be best adapted for the specific base materials. Theoretically the larger the head, the closer will be the trial curves to one another, and the erratic nature of the curves will be eliminated. The size of head is controlled, however, by the operator's weight, and that size which allowed penetrations of 3 or 4 inches.

Moisture-content and density determinations were carried out during the tests and are included in Table 6 for correlation to the penetrometer studies.

From the data taken it was found that the tapered probe was greatly influenced by local conditions and was, therefore, not used in these studies. With the smaller 0.15-square-inch head the penetration was excessive and the probe acted similarly to the tapered point; it was therefore impossible to obtain comparable results in this work. Other sizes were tried and resulting experience and data favored the 0.50-square-inch and 0.75-square-inch bearing area. In the final studies the 0.75-square-

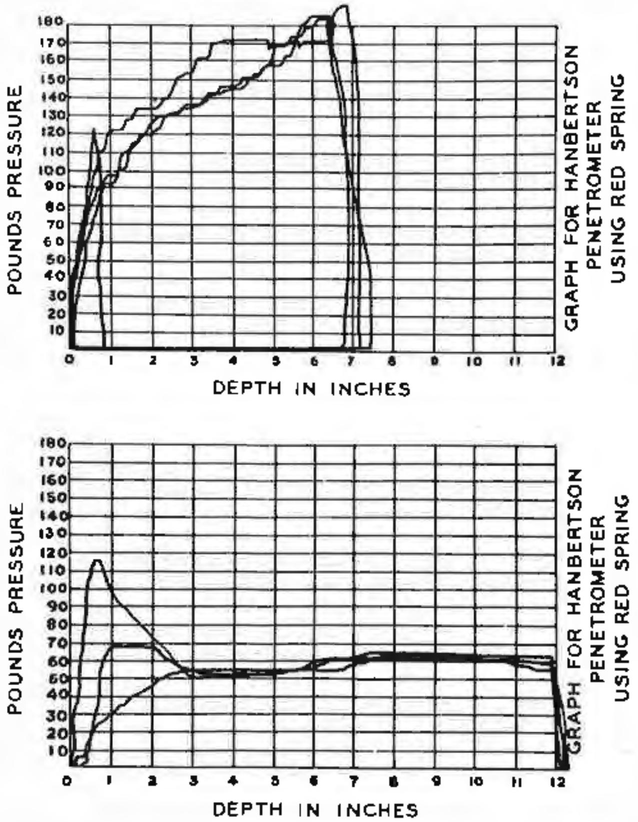


Figure 3. Empirical graphs from the Hanbertson penetrometer.

inch head was employed on sand subbase materials and a bearing area of 0.50 square inch on gravelly subbase materials. The penetrometer method was not looked upon with too much favor for use on gravel base materials due to the wide ranges of heterogeneity encountered with resulting eccentricities in curve data. Resulting pseudo-heads of unknown magnitude would result from the bearing surface striking stones or other foreign material.

The formula for the modulus of subgrade stiffness "k", as employed in the plate bearing tests, is:

$$k = \frac{P}{A \quad Z}$$

Where: k = Modulus of subgrade stiffness in lb. per cu. in.
P = Load in pounds
A = Bearing area in square in.
Z = Penetration in inches of bearing area.

Since the penetrometer is being considered a supplement, rather than a supplanter, of conventional load-bearing capacity studies, it was assumed that only one variable, P, be solved for and in turn to solve for "k" with that variable, using the load bearing plate area and some predetermined value of penetration. In this way the determined values of "k" would conform to existing bearing plate values of "k". The bearing plate area was constant at 100 square inches, and a value of penetration of 0.20 inch was decided on for the plate bearing studies. The only variable "P" could then be obtained from the penetrometer curves.

The ability of various base materials and admixtures to support plant life and the turf material density in depth are reflected in the first portion of the penetrometer graphs. The limits of the root zone as the probe penetrates it are shown by the shape of the curve.

It becomes evident then why the observations must be taken during the same periods of the year for any correlation, i.e. when the roots are growing and not in a dormant state.

The following is the method of comparison developed for plate bearing values and the penetrometer studies.

The equation:

$$M = \frac{P}{P_o}$$

P = Load in pounds from load-bearing studies with a penetration of 0.20 inch.

P_o = Load in pounds from penetrometer studies for a penetration of 2.0 inches.

M = Constant, which when multiplied by P_o will give a comparable load P for the solution of the subgrade modulus equation.

The arithmetic mean was used for the determination from the composite data.

To illustrate the method, the following example is given, employing the data of plot 1.

P = Load at 0.20 inch - 2,250 pounds

P_o = Mean load at 2.0 inches - 131 pounds

$$M - \frac{P}{P_o} = \frac{2,250}{131} = 17.2$$

If this value were now employed on any penetrometer value at 2.00 inches penetration for plot 1, theoretically we would obtain a comparable value for "P" from the load-bearing data. This is not, however, true since we have machine and equipment errors in both plate bearing and penetrometer studies. When the values of P_o are multiplied by "M" we only magnify the errors. In the illustrated case a 20-pound error in penetrometer studies, which could conceivably occur, would result in approximately a 350-pound error in load-bearing determinations.

A method conceived for reducing the induced error was that of employing common logarithmic values. In this way any small original errors can be practically eliminated, when converted to logarithmic values.

As before, P_o is computed from the composite data at 2.0 inches penetration and set up in the logarithmic form. The factor "M" is then found and "P" determined as follows: Data from Plot 11 - two trials.

P_o = 157 pounds

P_o = 146 pounds - a difference of 11 lbs.

P = 2,700 pounds

$$M = \frac{P}{P_o}$$

M = 17.2

1st. penetrometer trial.

P - 17.2 (157) = 2,700 pounds

2nd. penetrometer trial.

P - 17.2 (146) = 2,520 pounds

It can be seen the 11-pound error was magnified to 180-pound difference on the same plot.

By using common logarithmic values with the same conditions:

$$M = \frac{P}{\text{Log } P_o} = 1{,}230$$

Log 157 = 2.195

$P = (\text{Log } P_o)M$

P = 1230 (2.195) = 2,700 pounds

Error = 11 pounds

P_o = 157 pounds

P_o' = 146 pounds

Log 146 = 2.164

P - 1230 (2.164) - 2,670 pounds

The 11-pound error has thus been maintained to the second place to the left of the decimal and the final figures are not magnified as before with a resulting difference of only 30 pounds. Tentatively, a logarithmic system was employed with the determined factors of "M" as shown in Table 7. Only plots of sandy subbase materials are included since those with gravelly bases require further investigation and correlation which are covered later in the report.

Graphical Correlations

Using the same penetrometer data as in the previous discussion, an attempt was made to correlate the data in graphical form and thus simplify the computations for values of "P" on load-bearing test data which are used ultimately for determination of the subgrade modulus "k".

The data of unit load versus the ratio of settlement to diameter of circular bearing area, plotted on logarithmic scale, results in a straight line function which is independent of the plate size (5). In this method of plotting the data are generalized and supposedly make it possible to predict settlements of any size area. From these curves it is possible to take off values of unit load for various bearing surfaces at a given penetration and thus obtain a total load value to determine the subgrade modulus.

TABLE 7.

Logarithmic factors "M" for determining load "P"

Plot No.	Tentative "M"	Plot No.	Tentative "M"
1	1070	13	1070
2	1055	14	1010
3	1500	15	1175
4	760	16	1110
5	1180	17	875
6	675	18	720
7	965	19	930
8	670	20	1180
9	690	21	830
10	1145	22	1210
11	1230	23	865
12	1050	24	2235

The above analysis is very similar in nature to the previously presented study for the determination of the factor "M". The product of "M" and the logarithmic value of the penetrometer load in pounds per square inch determines the value of total load "P", for the subgrade modulus determinations.

The data drawn upon for the comparison cover a two-year period and would not be all conclusive, but they do, however, prove the possibilities and value for a simplified and quick means of verification or determination of load-bearing data with a recording-type penetrometer.

Conclusions

The Chewings fescue turf which is tolerant to low-organic-matter soil conditions proved to be an excellent grass to plant on sandy and gravelly shoulder materials where and when suitable stabilizing soils are available and added. It did not propagate vegetatively too rapidly, which is brought out in the turf cover data, thus not providing increasing cover yearly. The desired grass should, however, be planted alone to eliminate competition from nurse grasses, and larger applications of fertilizer made more frequently to make up for the lack of organisms and plant food in the raw subsoil materials.

Miami loam, Brookston loam, mixtures of clay and peat, and Bellefontaine sandy loam were all found to be satisfactory as additives with sandy or gravelly base materials for the production of turf. The Miami loam and Bellefontaine sandy loam also produced a very dense and stable turf as a result of the quackgrass introduced with them. The load-bearing tests proved these plots to have the highest inherent stability, and this may be attributed to the network of roots from the quackgrass.

Subsoil clay and peat added to subbase materials will furnish the needed binder and organic matter to produce a good turf on all subbase materials except washed sand.

Brookston loam soil was found to be satisfactory material for mixing with the various granular materials for the growth of turf.

The domestic ryegrass produced excellent cover for one or two years and then died out leaving the fescue sparse and unable to provide sufficient cover. No apparent advantage was gained by including ryegrass in the seeding mixture designed to produce a dense sod. The competitive nature of this grass was such that its presence in the seed mixture resulted in a bunchy-type turf of the Chewings fescue. This would lead to the assumption that the entire cover could and should have been Chewings fescue. A solution would be to eliminate the nurse grass entirely or provide a supplemental seeding of the Chewings fescue until the desired turf density was attained.

Where small percentages of fines were prevalent in the soils, the effect of the nurse grass dying out was not as marked as in those having a larger percentage of fines. On the low percentage plots the ryegrass blended with the Chewings fescue to produce a good cover the first year with no detrimental effects the following years as the ryegrass died out. The materials on which this was noted were the 22-A graded gravel materials.

Kentucky bluegrass did not survive under the conditions of the experiment on any of the turf plots.

Investigations of root penetration depths were found to be about 5 inches. This would indicate that, on the average, the roots were contained in the zone of the profile containing the additive soil materials and not down into the base course layers.

The 22-A graded gravel material, in addition to producing a satisfactory turf was found to exhibit greater stability than the other granular materials.

Bellefontaine sandy loam, 50 and 70 percent mixtures, produced high stability with incoherent sand, graded sand, and pit-run gravel. The turf was found to be satisfactory on all of these plots.

The incoherent sand with 20 and 30 percent Brookston loam; the graded sand with 20 and 30 percent Miami loam; the pit-run gravel with 30 percent Brookston loam and with mixtures of 25 percent clay and 15 percent peat; the 22-A graded gravel with 15 and 25 percent Miami loam, 15 percent Brookston loam, and mixtures of 10 percent clay and 5 percent peat all produced turf of good stability and coverage.

Density studies on the plots indicated no correlation of the turf growth or turf density to soil density. Higher load-carrying capacity would be expected with the combination of good turf cover and high soil density. A better shoulder condition for resistance to rutting or deformation under load would follow. This expected result was borne out in the tests and resulting data on the plots.

Moisture relationships were found to influence the inherent stability as demonstrated in the rutting studies. The plate bearing studies did not show any direct correlation to moisture variations on any soil subbases or additives.

It is evident that, with proper cultural methods, turf can be developed on practically any base designed to carry loads for highway shoulders or airstrips.

The penetrometer studies proved that a direct correlation could be drawn so that values of load could be derived to compare to plate bearing studies and thus arrive at values of subgrade modulus factors "k". The two methods, logarithmic computations and logarithmic plotted curve data, show very close correlation with the choice of method, dependent on amount of data available. The plotted data would require less data with the assumed and theoretical slope and shape of the curve.

It was observed that the higher the modulus "k" was from the plate bearing data the smoother the curve and the lower the slope of the resulting curve from the data. The curves show a definite trend and correlation of curves for each subbase and soil additive material. The 22-A graded gravel and pit-run gravel were found to produce curves with a greater break, at the lower ratios of settlement to bearing-area diameter, which would lead to difficulties in graphing. This can be explained by the same assumption that the penetrometer could not be depended on to produce reliable data in soils containing stones or foreign materials.

Suggestions for Future Study

Further tests should be conducted on rates of seeding, fertilization, and variations in seeding mixtures for shoulder stabilization and airfield projects. Future testing should also include studies of turf growth on compacted subbase materials which would prove very valuable for airport work and shoulder improvements on compacted subbase materials.

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APPENDIX TABLES