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Response of Five Grass Species to Phosphorus on Six Soils*

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INTRODUCTION

Phosphorus deficiency is one of the major nutritional problems in grassland agriculture. A question of considerable practical interest concerns the relative ability of turf species to obtain phosphorus from soils of low phosphorus supplying power. Ecological studies in pastures have shown species distribution to be influenced by phosphorus levels (4) and sand culture studies have likewise shown that some grasses vary in their responsiveness to phosphorus supply (2). In this study, five turfgrass species, in pure stands, were grown on six soils which had been characterized on the basis of HCO_3 extractable P (3). This test procedure is showing considerable promise in neutral and alkaline soil (1, 3).

PROCEDURE AND RESULTS

Five grasses were each grown on six soils which had been differentially fertilized with phosphorus to establish three levels. Each treatment was replicated 3 times making a total of 270 individual pots (5 grasses x 6 soils x 3 phosphorus levels x 3 replications = 270).

The grasses used in this study were common bermuda *(Cynodon dactylon),* Kentucky bluegrass *(Poa pratensis).* Highland bent grass (Agrostis tenuis), Emerald zoysia (Zoysia *japonica x Zoysia tenufolia).* and Alta fescue *(Festuca arundinacea).*

The six selected for this study had the following characteristics:

1. Oxalis silty clay; "field capacity" approximately 17%; pH 8.1; $CaCO_3$ 0.4%. This is a young, fine-textured, alluvial soil from sedimentary parent material having slight profile development.
2. Coachella very fine sand; "field capacity" approximately 21%; pH 7.9; $CaCO_3$ 2.8%. This series is a wind-modified soil of granitic alluvium showing no profile development.
3. Panoche fine sandy loam; "field capacity" 13%; pH 7.8; $CaC0_3$ 0.1%. The Panoche series is formed from sedimentary alluvium showing no profile development.
4. Vista sandy loam; "field capacity" about 12%; pH 6.0; $CaCO_3$ none. The Vista soil is an upland soil developing from hard igneous rock having a moderately well developed profile.
5. Glenview gravelly clay loam; "field capacity" about 16%; pH 6.5; $CaCO_3$ none. The Glenview series is a dark-red, upland soil apparently having developed from obsidian and having a moderately well developed profile. It is noted for having a remarkably high phosphorus fixing capacity.
6. Hanford sandy loam; "field capacity" about 16%; pH 7.0; $CaC0_3$ none. The Hanford series is a young soil from igneous alluvium showing no profile development.

*Adapted from a paper presented at the IX International Grassland Congress.

With the exception of the Glenview series, the soils used are typical of those found in arid regions. These soils, while coming from a variety of parent materials and showing some range in age and reaction, are composed of minerals which have not been intensively weathered. The Glenview, on the other hand, is similar to intensively weathered soils, high in iron oxides, which are characteristic of subtropical and tropical areas.

The soils were screened and weighed into containers having a volume of about 1400 cc. The quantity of soil required to fill the containers varied between 1500 and 2000 grams depending on the series. The following phosphorus levels were established on each soil series by adding the appropriate amount of single superphosphates:

P0 = no phosphorus added

P1 = 15 ppm P_2O_5

P2 = 150 ppm P_2O_5

All soils also received 5 ppm zn from ZnS04. A uniform stand of grass was established in each container. Zoysia, being slower to grow, was planted from rooted stolons one week before the other grasses were seeded. After the grasses became well established - requiring about one month - they were clipped to one inch height weekly for a period of 15 weeks. The clippings were weighed and analyzed. Pots were irrigated when soil moisture suction, as determined by weight changes, was about 0.4 bar. About 20% leaching was achieved at each irrigation. Tap water was used for irrigation and fortified with fertilizers to produce the following concentrations in m.e. per liter: Ca-7.5, Mg-1.5, Na-2, K-l, No_3-8, Cl-l, HCO_3-2, and SO_4-1.

Yields obtained during a 15 week period from August to mid November are summarized in Tables 1 and 2 and phosphorus analyses of clippings obtained during the 10th week are summarized in Table 3. As may be seen in the summation row, Table 1, fescue, bluegrass, and bermuda produced about the same amount of dry matter, bentgrass produced slightly less and zoysia about 60% as much as the other grasses. The data are organized in Table 2 to clearly show the effect of soils and phosphorus application on grass growth. Approximately 100 percent yield increases from phosphorus applications were obtained on the Oxalis and Glenview soils and about one-half this percentage response was obtained on the Vista soil. The other soils produced small responses of doubtful significance from phosphorus application. The statistical summary is also presented in Table 1. Very highly significant differences were obtained for the main effects and interaction of P-levels and soils, and soils and grasses as would be expected since some soils showed a response to phosphorus and others did not. A highly significant interaction occurred between P-levels and grasses. This was mostly attributable to the fact that the absolute growth increase from phosphorus applications was smaller for bentgrass and zoysia than for the other grasses.

Table 3 summarizes P analyses of clippings obtained during the 10th week of the study. Averages of grass yields from the three soils on which large responses to phosphorus were obtained are grouped as are those obtained from soils showing doubtful responses to phosphorus.

EVALUATION AND DISCUSSION

The extensive field work of Sonneveld et al (4) on the distribution of pasture species as related to the availability of phosphorus strongly implicates phosphorus supply as a major ecological factor in the botanical composition of pastures. Bradshaw et al (1) working in sand culture obtained similar results to those of Sonneveld et al, regarding relative responsiveness of several grass species to phosphor us. It was notable in Bradshaw's work that a few species required high phosphorus levels for maximum growth. The data obtained in our studies with five grass species growing in pure stands in soils emphasize the similarity among the species in their ability to obtain phosphorus from low-phosphorus soils. All grasses consistently made large responses to phosphorous additions on three of the soils and doubtful responses on the other soils. These data, therefore, ate not consistent with the hypothesis that some grasses may be able to effectively utilize phosphorus supplies in low-phosphorus soils while other grass species cannot. The limited number of grasses involved in these studies does not require the abandonment of such a hypothesis however, but does indicate more work is needed along this line. The differences existing among the grasses in their responsiveness to phosphorus and their relative ability to accumulate phosphorus from low-phosphorus soils (in the grasses studied here this variation, if present, was not detectable) probably do constitute a considerable ecological factor when they are growing together.

In these studies soils exhibiting less than 5 ppm (soil basis) of bicarbonate extractable phosphorus showed large responses to phosphorus additions; w he rea s the Panoche series which had 8.2 ppm HCO_3 extractable P showed a doubtful response.

Bingham (I) summarizing data on phosphorus test-plant response, some of which had been previously unpublished, placed grasses in a low phosphorus requirement category and indicated response is expected when soil levels contain 4 ppm HCO_3 extractable P or less and no response above 8 ppm. Thus, our data check well with Bingham's generalization.

Space does not permit an adequate discussion of problems related to soil phosphorus tests but from these data it appears that the bicarbonate procedure offers considerable promise as a means of characterizing soil phosphorus levels for grasses.

Tissue analysis of the grass also represents a means of assessing phosphorus levels in pastures. Unpublished data by authors indicate a yield of about 50% of maximum is obtained in Alta Fescue when tissue levels are 0.19% P and 0.35% P is required for maximum yields. The data presented in Table 3, although not sufficiently detailed to precisely establish critical levels, indicate that about 0.35% P is required for maximum growth of the grasses studied except zoysia where 0.30% may be adequate.

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TABLE 1. Yield of five grasses in grams dry weight per pot (85 CM_2 surface area) during 15 week period on six soils with 3 levels of phosphorus.

Soil	ppm HCO_3-P in Soils	PPM P_2O_5 Added To Soil: 0					15					150				
		Ber.	Blue	Bent	Zoysia	Fes.	Ber.	Blue	Bent	Zoysia	Fes.	Ber.	Blue	Bent	Zoysia	Fes.
Oxalis	2.8	2.19	2.46	2.02	1.39	2.65	3.38	3.52	2.70	1.87	3.25	4.59	4.51	3.74	2.57	4.76
Coachella	13.8	5.48	5.34	4.08	2.49	5.14	4.94	5.73	4.39	2.45	5.30	5.77	5.86	4.42	2.76	6.08
Panoche	8.2	4.52	5.15	3.98	2.68	5.21	5.02	5.35	4.10	2.86	5.20	4.99	5.78	4.31	2.80	6.18
Vista	4.3	4.10	4.85	4.71	3.49	4.35	5.25	5.62	5.35	4.22	5.26	6.23	6.70	6.35	4.73	6.28
Glenview	4.6	3.15	2.98	3.79	1.36	2.72	4.02	3.66	4.39	2.51	4.03	5.59	5.26	5.57	4.22	5.48
Hanford	17.5	5.48	5.73	5.53	3.03	5.47	6.17	6.06	5.68	3.30	5.92	6.59	6.22	6.02	3.74	6.33
Totals across soils		24.92	26.51	24.11	14.44	25.54	28.78	29.94	26.61	17.21	28.96	33.76	34.33	30.41	20.82	35.11

LSD (.05) treatment means 0.526
LSD (.01) treatment means 0.696

TABLE 2. Sums of average of five grass yields per pot on six soils at various phosphorus levels.

Soil	PPM HCO_3-p in soil	PPM P_2O_5 Added to Soil: 0	15	150
Oxalis	2.8	10.71	14.72	20.17
Coachella	13.8	22.53	22.81	24.09
Panoche	6.2	21.54	22.53	24.06
vista	4.5	21.50	25.70	30.29
Glenview	4.6	14.00	18.61	26.12
Hanford	17.5	25.24	27.13	20.90
Totals		115.52	131.50	154.43

TABLE 3. Percentage P in grass clippings taken during 10th week of study.

Soil	PPM P_2O_5 Added to Soil: 0					15					150				
	Ber.	Blue	Bent	Zoysia	Fes.	Ber.	Blue	Bent	Zoysia	Fes.	Ber.	Blue	Bent	Zoysia	Fes.
Ave. from Oxalis, Glenview, & Vista	.26	.28	.26	.20	.26	.29	.29	.33	.23	.30	.44	.40	.43	.29	.39
Ave. from Coachella, Panoche, & Hanford	.39	.36	.44	.30	.35	.42	.38	.44	.31	.36	.43	.53	.50	.33	.46

Dichondra Leafspot

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Leafspot caused by *Alternaria porri f. sp.* solani is a limiting factor in the culture of dichondra in the San Francisco Bay area. The disease occurs throughout California and is most severe in the rainy winter months. Leafspot is also favored by frequent watering especially late in the day which results in the presence of water on the leaves for many hours.

The fungus attacks the foliage killing the tissue which becomes brown. As long as wet conditions prevail the spots continue to enlarge until the entire leaf is consumed. Petioles also may be attacked. In dry weather the disease subsides unless the foliage is moistened frequently by irrigation.

A number of fungicides applied to the foliage will control the disease. In experimental trials tineb (zinc ethylenebis-dithiocarbamate) and Dyrene (2,) 4-dichloro6-(o-chloranilino-s-triazine) have been helpful in pro t e c t i n g the foliage from infection. In a recent test an experimental combination product composed of equal parts of Daconil 2787 (75% tetrachloroiso-phthalonitrile) and difolatan (80% tetrachloroethylmercaptocy-clohexene dicarboximide) gave outstanding control. Sprays applied to dichondra at 4 and 6 oz. of the combination per 1000 sq. ft. provided control for 3 months following the last application. Severely infected dichondra recovered and produced healthy foliage following 2 applications of 4 oz./1000 ft. of the combination.

At this time we do not know if one of the ingredients alone would provide as good control as obtained with the combination. The excellent control also suggests systemic action or redistribution of the fungicides since most of the leaves present several months following the last application were not sprayed.

Phosphorus And Its Relationship To Turfgrasses And Poa Annua L.

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Phosphorus is one of three important major elements used by plants. The total supply of phosphorus in soils is relatively small, and it is one of the first elements to become deficient after a soil is first cultivated. Phosphorus is essential to several major metabolic processes in plants, including transformation of carbohydrates (starches to sugar), assimilation of fats, and the formation of nuclear constituents. Phosphorus deficient plants have stunted root systems, ripen more rapidly, and have a purplish tinge either in the 1eaves or in other plant parts.

Analysis of grass clippings has shown that the uptake of macro-nutrients N-P-K approximate a ratio of 4-l-3. Continuous use of fertilizers containing a low ratio of nitrogen to phosphorus may contribute to an excess accumulation of phosphorui in soils of putting greens, lawns, and other turf areas. This observation has been substantiated in soil testing programs. In the midwest, none of the soil samples taken from over 350 putting greens tested very low or low in phosphorus. Excessive phosphorus accumulation was reported from 92% of the greens while 6% tested very high and 1% high. Applying large amounts of phosphorus adds to maintenance costs and in time may affect the growth of turfgrasses. Thus, there is a need for information on possible harmful effects attributable to excess soil phosphorus. Three studies are reported herein pertaining to the effect of P levels on the growth of turfgrasses and the influence of P on preemergence herbicides.

EFFECT OF P LEVELS ON THE GROWTH OF MERION AND COMMON KENTUCKYBLUEGRASS

In the first study, Merion and common Kentucky bluegrass, *Poa pratensis L.*, were grown in glazed gallon crocks at all combinations of eight levels of phosphorus and two levels each of nitrogen and potassium. Loamy sand soil used for this study was very low in all nutrients. Lime was added to the soil to obtain a pH of 7.0. Concentrated superphosphate (20% P) was thoroughly mixed into the soil to obtain the following amounts of elemental P per acre: 0, 218, 436, 655, 873, 1091, 1309, and 1527 Ibs. Nitrogen as urea and K as muriate of potash were incorporated into the soil to provide 2 levels: 0 and 131 lbs. of nitrogen and 0 and 252 lbs. of potassium per acre, respectively. The treatments were replicated three times. Ten seedling plants were planted in each crock in December, 1960. Following establishment, the plants were clipped weekly to a height of 2 inches. The experiment was maintained for 6 months and results evaluated in terms of dry weight of clippings, tops, and roots. The percent phosphorus uptake was measured colorimetrically.

RESULTS OF THE FIRST STUDY

In 1960-61 the largest increase in weight of tops, roots, and rhizomes of Merion and common Kentucky bluegrass resulted from the first increment of phosphorus (Table 1).

Differences between the other increments of P were small, but there was a definite trend toward more top growth at higher levels. The percent uptake of phosphorus from clippings and milligramsof phosphorus in tops (including crowns) are also presented in Table 1. The greatest increase of P uptake in clippings occurred with the first increment (218 lbs./A) of phosphorus. A slight but gradual increase in percent uptake of phosphorus was found with each additional 218 lb. increment through 873 lbs./A. A similar trend was obtained for both grasses but Merion was greater than common, 1.41 to 1.47%. respectively.

The response of Merion and common Kentucky bluegrass tops and. roots to levels of phosphorus appears in Figure 1.

Top weight for Merion bluegrass increased at a more rapid rate and to a higher level (170 gm.) than common. The average top growth of Merion was significantly greater and average root growth production significantly less than common bluegrass. The Merion variety produced significantly more top growth than common at higher levels of P. Merion root weights increased with phosphorus levels to 655 lbs. after which they dropped rapidly then leveled off to 1527 lbs. No appreciable change was observed in root weight of common bluegrass following the first increment of phosphorus.

COMPARISON OF COMMON KENTUCKY BLUEGRASSS RED FESCUE TO RATES OF PHOSPHORUS

Common Kentucky bluegrass and red fescue were grown in glazed crocks at all combinations of the following treatments: 6 levels of phosphorus, 2 levels of nitrogen, 2 levels of pH (4.5 and 6.5), and 2 soils (loamy sand and silt loam). Loamy sand was obtained from the same source as in the previous study. The silt loam soil was obtained from the turf area and tested high in P, medium for K, and had a pH of 4.5. Lime was added to both soils at the rate of 2200 lbs. of calcium carbonate per acre for the loamy sand and 3900 lbs./A for the silt loam. After the addition of lime, both soils tested approximately 6.5. Muriate of potash (60% K) and ureaform (38% N) were mixed in the soil at rates per acre of 149 lbs. of K and 44 and 131 lbs. of nitrogen, respectively. Phosphorus was incorporated into the soil at 6 rates: 0, 109, 218, 436, 873, and 1746 lbs. of P per acre. Ten seedling plants of either common Kentucky bluegrass or red fescue were planted per crock in December, 1961. Minor elements were added shortly after the seedlings were planted. The cultures were clipped weekly at 2 inches, harvested in June, and results tabulated in terns of dry weight of clipping crowns, roots, and rhizomes.

RESULTS OF SECOND STUDY

Data for the response of common Kentucky bluegrass to rates of phosphorus are given in Table 2. Yield of roots increased with rates of P through 873 lbs. per acre after which a nonsignificant decrease in weight occurred. Yield of rhizomes closely followed the same trend. Crown weight except for the first increment was variable with rates of phosphorus; however, the trend for yield of crowns was upward. A consistent increase in weight of clippings was obtained for each increment of phosphorus. The mean yield for red fescue (Table 3) at rates of phosphorus were more variable than for bluegrass; however, the trends were similar. As with bluegrass, the average weight of plant material increased with but one exception with each increment of phosphorus.

Soils X pH X P interactions for total plant growth of common Kentucky bluegrass and red fescue (Figures 2 and 3, respectively) were significant. Yields of bluegrass and red fescue were variable at pH 6.5 in silt loam and showed no appreciable response to rates of P. At pH 4.5 in silt loam, bluegrass showed a consistent yield increase with higher rates of phosphorus through 1746 lbs./A. With the same treatments, response

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of red fescue to phosphorus was minor; however, total yield exceeded that of bluegrass at all phosphorus levels. These data compliment other research which has shown that red fescue will persist better than bluegrass at lower pH levels.

The largest increase in yield for both grasses grown in loamy sand at either ph 4.5 or 6.5 was obtained with the first increment of phosphorus. Beyond the first increment of phosphorus at pH 6.5 a consistent increase in the yield for bluegrass was found, but the response for red fescue was variable with a very slight upward trend in yield with higher rates of phosphorus. The base exchange of the loamy sand is very low, thus the phosphorus requirement for red fescue was largely satisfied with the first increment of phosphorus. These data indicate that P has a greater influence on the yield of bluegrass than on the yield of red fescue. Less response to rates of phosphorus was found for both grasses in silt loam. This soil originally tested high in phosphorus and has a relatively high base exchange capacity, and the ability to fix phosphorus and other elements into the soil colloids.

PHOSPHORUS LEVELS AND THEIR EFFECT ON PREEMERGENCE CRABGRASS HERBICIDES

Five preemergence crabgrass herbicides were compared at seven levels of phosphorus and two planting dates. Five-inch clay pots containing potting soil were used for this study. The potting soil tested high in phosphorus and potassium and had a pH of 6.4. Phosphorus as 0-46-O was thoroughly incorporated into the soil at the rates of 0, 109, 218, 436, 873, 1746, and 3492 lbs./A. The following herbicides were applied to the soil surface at 30psi in water at 40 gpa, except for calcium arsenate which was applied in the dry form: DMPA 'Zytron' (3 lb. active/gal.), DCPA 'Dacthal' (50% wettable powder), trifluralin (2 lb. active/gal.), bensulide (4 lb. active/gal.), and tricalcium arsenate 85%, water soluble arsenic 4%. Rates per acre appear in Table 4 except for trifluralin which was applied at 2 lb./A.

One-hundred seeds of annual bluegrass, Poa annua L., were seeded in one-half of each 5-inch pot, divided with a label, and watered as needed to obtain optimum growth. Results were recorded in terms of plant counts obtained approximately 25 days after each planting date.

RESULTS OF THIRD STUDY

Data for the trifluralin treatment (2 lb./A) were omitted from the. analysis and tables because 100% control of annual bluegrass was obtained at both planting dates. A comparison of four herbicides and rates of phosphorus on the control of annual bluegrass expressed in terms of plant count is presented in Table 4. Plant counts for the bensulide treatment showed a slight trend toward less control of annual bluegrass with added phosphorus. Plant counts for DMPA and DCPA with rates of phosphorus were inconsistent. Plant counts for the calcium arsenate treatment showed a definite trend toward less control of annual bluegrass with increasing rates of phosphorus, Table 4 and Figure 4. All herbicide treatments were better than the control; and following complete control with trifluralin, best results were obtained with DMPA and bensulide with average plant counts of 14.1 and 33.2, respectively, compared with 72.9 in the control.

A comparison of plant counts for the two planting dates and for herbicides is given in Table 5. Based on plant counts both DMPA and bensulide had a higher degree of residual toxicity to germinating annual bluegrasses than either calcium arsenate or DCPA. This study indicates that some of the preemergence crabgrass herbicides may have merit for use on greens and other turf areas after additional work on toxicity to existing grasses is determined.

SUMMARY

Three experiments were conducted in the greenhouse: two studies to determine the influence of several phosphorus levels on the growth of red fescue, Merion, and common Kentucky bluegrass and one study to determine the effectiveness of herbicides on soils differing in phosphorus level.

In the first study, topweight increased more rapidly and to a higher level with rates of P than common bluegrass. The percent of P in leaves of Merion exceeded that of common for all rates of P except for the first increment. Root weight for Merion increased rapidly to the 655 lb.-per-acre-P tate then dropped sharply; root weight for common bluegrass leveled off after the first increment of P.

Results of the second study indicated that red fescue outyielded bluegrass in total weight, and that both grasses yielded more at 6.5 than at pH 4.5. More underground growth was harvested from bluegrass and red fescue grown in loamy sand than silt loam. The mean total yield for both red fescue and bluegrass increased with each increment of P with but one exception, and a consistent increase was found in yield of clippings for both grasses. With rates of P, the yields of roots, rhizomes, and crowns were more variable than for clippings.

In the herbicide-phosphorus study, high levels of P reduced the effectiveness of both calcium arsenate and to a small degree DCPA 'Dacthal.' Trifluralin gave 100% conaol of Poa annua for both planting dates following DMPA 'Zytron', and bensulide. Further research is needed to determine whether these herbicides can be used safely on bentgrass turf.

These results indicate that grasses can tolerate very high levels of P. In these experiments the upper limits of tolerance were not attained for the species tested.

These results indicate that grasses can tolerate very high levels of P. In these experiments the upper limits of tolerance were not attained for the species tested.

Table 1. Average weight of tops, roots, and rhizomes of Kentucky bluegrasses (Merion and common) and uptake of P from clippings and tops *obtained from different increments of P.*

P lb. /A.	Tops* g.	Roots and rhizomes, g.	Clippings % P	Tops* mg. P
0	5.9	5.9	0.63	3.4
218	8.5	8.3	1.42	12.1
436	8.9	8.5	1.50	13.3
655	8.8	8.8	1.51	13.3
873	9.0	8.2	1.60	14.4
1091	9.2	8.3	1.59	14.6
1309	9.5	8.3	1.65	15.9
1527	9.6	8.2	1.61	15.8
LSD.05%	.34	.52	.067	.77

* Includes clippings and crowns.

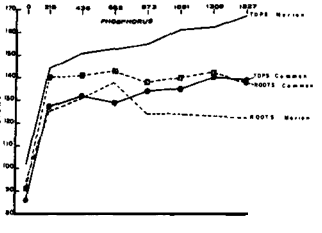

Figure 1. Influence of P rates (lbs. per acre) on the growth of tops and roots of Merion and common Kentucky bluegrass expressed in *grams total weight.*

Table 2. Mean yield of common Kentucky bluegrass roots, rhizomes, crowns, and clippings with rates of phosphorus.

P lb. /A	Yields, grams Roots	Rhizomes	Crowns	Clippings	Aver.
0	2.34	1.27	3.76	4.81	3.05
109	3.13	2.03	5.16	6.34	4.17
218	3.37	2.17	5.04	6.39	4.24
436	3.92	2.49	5.41	6.72	4.64
873	4.11	2.72	5.51	7.06	4.85
1746	3.98	2.70	5.45	7.43	4.90
LSD.05%	.40	.16	.27	.27	

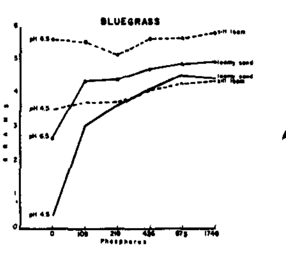

Figure 2. Effect of pH X soil X P on the average dry weight in grams for common Kentucky bluegrass (total plant).

Table 3. Mean yield of red fescue of roots, rhizomes, crowns, and clippings with rates of phosphorus

P lb. /A	Yield, grams				
	Roots	Rhizomes	Crowns	Clippings	Aver.
0	3.82	0.28	5.25	6.26	3.90
109	4.90	0.30	6.54	7.90	4.91
218	5.00	0.42	6.32	8.05	4.95
436	4.80	0.28	6.06	8.51	4.91
873	5.04	0.37	6.13	9.02	5.14
1746	5.70	0.46	6.09	8.79	5.26
LSD. 05%	.40	.16	.27	.27	

Figure 3. Effect of pH X soil X P on the average dry weight in grams for red fescue (total plant).

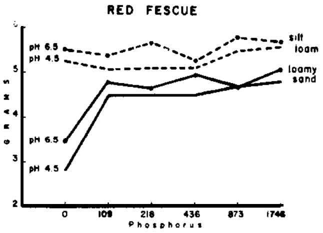

Table 4. Plant counts of Poa annua as influenced by preemergence herbicides and P levels. Average of 2 dates planted at 48-hour intervals. (Greenhouse 1964-65)

Herbicide	lb. /A	Phosphorus lb. /A							
		0	109	218	436	873	1746	3492	Average
Control		74.0	73.5	72.3	72.8	72.5	73.5	71.5	72.9
Bensulide	15	28.8	38.5	37.8	29.0	30.3	33.0	35.3	33.2
DMPA	15	14.0	17.5	9.8	13.8	14.0	17.3	12.3	14.1
DCPA	10	43.5	46.3	45.8	47.0	46.3	47.8	46.0	46.1
CaAs	440	35.8	43.3	52.5	60.5	58.5	67.0	68.0	55.1

LSD 5% for herbicides and P 8.13

LSD 5% for herbicide averages 3.08

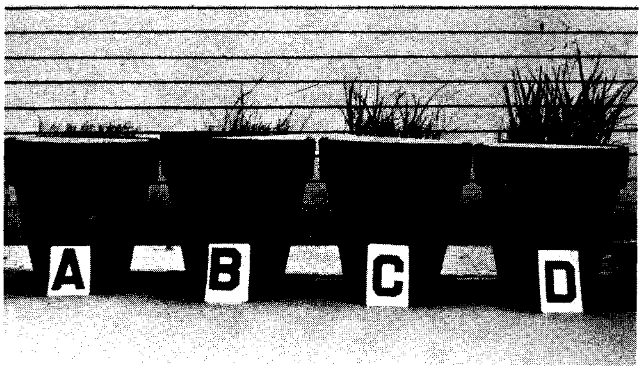

Figure 4. Poorer control of annual bluegrass with increasing rates of P. Soil was treated with 440 lb./A of CaAs. A-control, B-109, C-218, C-436 lb./A of P.

Table 5. Effect of four preemergence herbicides on Poa annua plant counts for two different planting dates. (Greenhouse 1964-65)

	Bensulide	DMPA	DCPA	CaAs	Control
Date 1	28.6	6.4	39.0	44.3	72.2
Date 2	32.0	23.1	56.0	66.7	73.0

LSD 5% level dates and herbicides 4.82

Shade Grasses And Maintenance*

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Good landscaping calls for utilization of trees and turfgrasses in association. Although no accurate data is available, it is estimated that 20 percent of the existing turf areas in the United States are maintained under some degree of shade. In view of the extensive acreage of shade turf that exists throughout the country, it is surprising how little turfgrass shade ecology research has been conducted. Before we can discuss shade grasses and maintenance, the microclimate typical of shaded conditions must be considered.

SHADE MICROENVIRONMENT

Shade adversely alters rhe turfgrass microenvironment. The most obvious change is the reduction in light intensity. A canopy of trees can screen out as much as 98 percent of the incoming solar radiation. Light quality is also affected in comparison to the normal distribution within the visible spectrum. The light quality under a canopy of ***trees*** has a spectrum low in blue and red wavelengths, and a predominance of green and far-red wavelengths. The blue and red wavelengths required for photosynthesis are also the wavelengths screened out to the greatest extent.

Poor turf quality under shade conditions is frequently attributed to a lack of light. However, a number of h e important environmental factors must be considered in shade ecology. Included are:

1. A moderation of diurnal and seasonal temperatures, both air and soil.
2. Increased relative humidity.
3. Restricted air movement.
4. Increased intensity and duration of dews.
5. A reduction in atmospheric carbon dioxide.
6. Tree root competition for water and nutrients.

Grass adaptation to shade does not involve any single factor, but is the result of a complex microclimatic regime. The increase in relative humidity and dew, plus the reduction in wind movement under shaded conditions, does enhance disease activity. The more favorable microclimate for disease and the lack of disease resistant varieties has been shown to be a key factor in the adaptation of cool season grasses to shade (1).

PLANT RESPONSE TO SHADE

The low light intensities which occur under shaded conditions limit the amount of carbohydrate a plant can synthesize. As a result, carbohydrate deficiencies cause a decrease in top, ***root,*** rhizome, and stolon growth. In general, growth reduction of roots under shade is greater than rhe tops, and the root to shoot ratio is lowered. This suggests that when carbohydrate supplies are not sufficient to support growth of both the shoots and the roots, the above ground portions of the plant have preference or first priority at the expense of the rootsystem.The root system of shaded grass plants is also reported to be shorter, thinner, wiry, and less branched.

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Plants respond morphologically to shade conditions. Typically observed under shade -are the following characteristics:

1. Thinner leaves.
2. Larger leaf area.
3. Thinner stems.
4. Longer internodes.
5. Reducing tillering.

TABLE 1. Effect of artificial shading (65% light reduction) on the growth characteristics of Merion Kentucky bluegrass. Gaskin. Palos Park, Illinois. 1964 (4)

Plant Character	Sun	Shade
Number of rhizomes	59.6	18.7
Number of shoots	4.8	1.1
Plant height (inches)	1.0	8.0
Leaf length (inches)	2.25	6.00

Turf density in terms of shoot numbers and rhizome numbers are reduced significantly under shade. On the other hand, shading increases plant heights and leaf lengths (Table 1). Shade stimulates the emergence or upright growths of rhizomes and stolons. A more upright growth habit causes a greater percentage of the plant to be removed during the mowing process and development of a more open turf. The establishment of sods by creeping type grasses is significantly inhibited by shade.

Physiologically shaded plants exhibit the following characteristics

1. Higher chlorophyll content.
2. Lower photosynthetic rate.
3. Lower respiration rate.
4. Lower compensation point.
5. Lower carbohydrate to nitrogen ratio.
6. Reduced respiration rate.
7. Higher tissue moisture content.
8. Lower osmotic pressure.

In general, these morphological and physiological changes will cause an over-all deterioration in plant vigor resulting in reduced resistance to heat, cold, drouth, disease, and wear.

TURFGRASS SPECIES ADAPTATION

Juska (5) evaluated the shade toleration of 11 bentgrass varieties under artificial conditions with fungicides used for disease prevention. It was found that those varieties which performed best in full sunlight performed similarly under shade. Reid (7) reported velvet bentgrass to be more shade tolerant than Metropolitan creeping bentgrass.

Studies were conducted at Michigan State University to study the mechanisms involved in the adaptation of turfgrasses to shade. The experimental area used in the study was developed in a woodland composed of two to three foot diameter sugar maples *(Acer saccharum Mersh)*. No tree root pruning was attempted other than the surface 2 inches to allow preparation of an adequate seedbed. The trees provided uniformly dense shade throughout the plot area. Measurements at one hour intervals from 7 a.m. to 7 p.m. showed light intensity to be only 5 percent of incident daylight. The plot size was 5 x 10 feet with 3 replications in a randomized block design. The sandy loam soil was limed to a pH of 6.0 and fertilized to provide adequate phosphorus and potassium. Seven grass varieties were seeded alone and in eight combinations on September 7, 1961. All plots were seeded at a rate of 3,500,000 seeds per 1,000 square feet. The grasses were not irrigated at any time during this experiment, and were mowed weekly at a 2 inch height. Two pounds of nitrogen per 1,000 square feet per year were applied, one-half in early spring and the other half September 1. Fallen tree leaves were removed twice weekly during the fall period.

Results through the first four growing seasons will be summarized, (Table 2). During the initial winter of 1961-62, tall fescue was severely injured by gray snow mold *(Typhula* spp.) while common and Norlea perennial ryegrass exhibited over 65 percent kill from low temperature injury. Through April, 1962, roughstalk bluegrass, red fescue, common Kentucky bluegrass, and Merion Kentucky bluegrass ranked high in turf quality. In late May, 1962, Pennlawn red fescue was severely attacked by leafspot *(Helminthosporium sativum* PKB) resulting in over 90 percent thinning of the turf. In early May, 1962, a gradual build-up in powdery mildew *(Erysiphe graminis* P.C.) occurred in both Merion and common Kentucky bluegrass. As a result, these two species were 95 percent thinned by August, 1962. Roughstalk bluegrass performed exceptionally well throughout the 1962 season, particularly in view of the drouthy conditions that existed. Tall fescue and the two perennial ryegrasses showed no significant recovery from the snow mold and low temperature injury in the winter of 1961-62.

A surprising degree of recovery was noted in the red fescue turf during the spring of 1963, specially considering the severe thinningwhich had taken place in 1962. In contrast, Merion and common Kentucky bluegrasses showed little or no recovery.

TABLE 2. Turf quality ratings and density of 7 grasses grown under 5% of incident sunlight.

Grass variety	Density count*		Turf quality rating		
	1962	1964	1962	1963	1964
Pennlawn red fescue	25	34	**6.5**	5.4	4.3
Roughstalk bluegrass	54	44	3.2	4.9	5.8
common peren. ryegrass	23	10	5.9	5.3	7.0
Kent. 31 tall fescue	18	10	6.6	1.0	7.3
Common Kent. bluegrass	15	4	1.9	6.7	8.1
Norlea peren.	10	1	6.0	6.7	8.1
Merion Kent. bluegrass	10	0	1.4	9.0	9.0
LSD, 5%	11.5	14.5	0.8	1.0	1.8
DR, 5%	13.1	16.4	0.9	1.1	2.0

* Shoots per 12.5 square Inches. counts made the second week in October.
+ (l-best; 9-poorest) Average of the seasonal ratings.
Duncan's range test for equality with p of 7.

During the summer of 1963, *Helminthosporium* 1eafspot occurred again on red fescue. However, the attack was not as severe as in 1962. In late July, 1963, the roughstalk bluegrass was severely thinned within a 48 hour period by *Helminthosporium* species. The lower ratings of the roughstalk bluegrass plots in 1963 are a result of this severe disease injury.

In the spring of 1964, good recovery of the red fescue was again noted, but the Kentucky bluegrasses, tall fescue and ryegrasses continued to perform poorly throughout the season. Roughstalk bluegrass recovered considerably from the severe thinning of July, 1963. A slight, but minor, incidence of leafspot was noted in the red fescue and roughstalk bluegrass during the 1964 season.

TABLE 3. Species composition, density count, and turf quality ratings of 8 grass mixtures grown under 5% of incident sunlight.

Grass mixture*	Composition, %		Density counts‡		Turf quality ratings (l-best; 9-poorest)§		
	Original seed†	Plants on 10/10/64	1962	1964	1962	1963	1964
F-K	50-50	66-14	16	39	6.8	6.4	3.9
F-K	75-25	91-s	22	41	1.0	5.5	4.4
F-K	25-75	92-8	27	33	6.2	6.0	4.6
F-R	50-50	66-32	46	35	3.3	5.6	5.5
K-R	50-50	17-63	56	22	3.3	5.0	5.5
F-K-P	33-33-33	63-11-26	23	30	6.5	5.6	5.6
F-K-R	33-33-33	45-12-43	46	59	3.9	5.2	5.1
K-T	50-50	32-68	16	19	6.9	5.2	5.8
		LSD, 5%	11.5	14.5	0.6	1.0	1.6
		DR, 5%	13.2	lfi.6	0.9	1.1	2.0

* F-Pennlawn red fescue; K-Common Kentucky bluegrass; R-Roughstalk bluegrass; P-Common perennial ryegrass; T-Kent. 31 tall fescue. † Based on seed numbers. ‡ Shoots per 12.5 sq. tn., counts made the second week in October. § Average of the seasonal ratings. ¶ Duncan's range test for equality with p of 8.

Throughout the three years of observation, the grass mixtures performed similarly to the dominant grass components. During the initial year, those mixtures containing roughstalk bluegrass ranked highest, whereas in the subsequent years those mixtures containing predominantly red fescue showed marked improvement. Those mixtures containing predominantely Kentucky bluegrass, tall fescue, or ryegrass performed poorly. Species composition data presented in Table 3 show that where common Kentucky bluegrass is included with either red fescue or roughstalk bluegrass, the latter two species predominate. In the 50-50 red fescue-roughstalk bluegrass mixture, creeping red fescue was dominant in a 2 to 1 ratio. In mixtures with red fescue, roughstalk bluegrass persisted as a much higher portion of a stand than did Kentucky bluegrass. In the mixture containing equal numbers of red fescue, roughstalk bluegrass, and common Kentucky bluegrass seed, the red fescue and roughstalk bluegrass persisted in about equal percentages, whereas common Kentucky bluegrass was reduced by twa-thirds.

It should be noted in comparing Table 3 with Table 2 that after three years the 33-33-33 mixture of red fescue, roughstalk bluegrass, and Kentucky bluegrass was higher in density than any one of the grass components planted alone.

The most significant observation in this study is the prominence of disease in influencing the adaptation of turfgrasses to shade. Actually, it is the more favorable microenvironment of shaded conditions plus the lack of disease resistance in many of the turfgrass varieties utilized that results in the severe disease problem. Powdery mildew caused complete kill of the Kentucky bluegrasses when planted in pure stand with no recovery in future years. It should be noted, however, that Kentucky bluegrass was able to persist better when included in a mixture with other species than when seeded alone. Pennlawn red fescue was severely injured by Helminthosporium leafspot in 1962, but exhibited significant recovery in subsequent years. Since the seriousness of leafspot attack was reduced in each succeeding year, it indicates that the leafspot susceptible strains in the red fescue plant community are being killed and the more tolerant strains persisting and increasing. The reduction in leafspot in each succeeding year is particularly significant, since leafspot infection on red fescue grown in full sunlight was actually more serious in 1963 and 1964 than in 1962. The roughstalk bluegrass performed satisfactorily during the 1962 growing se a son and through July of 1963. This was of interest since no irrigation was provided, and a serious drouth occurred during this period. This suggests that roughstalk bluegrass can persist and produce an adequate turf under drouthy conditions when shaded. Possibly not only drouth, but heat is a key factor in the deterioration of red fescue on unshaded drouthy sites. The importance of disease in influencing shade adaptation was clearly demonstrated in these studies. The microenvironment of shade, including (a) higher relative humidity, (b) extended dew periods plus (c) reduced light intensities that produced a more succulent growth, encouraged disease activity.

Reduced light intensities resulted in a decrease in turf density and quality. However, had disease attacks not occurred, the turf would have been adequate for the adverse shade condition. Moisture deficiencies were common throughout the study due to severe tree root competition, lack of rainfall, and low water-holding capacity of the soil. However, moisture was not the key factor affecting the extremely poor performance of some grasses, since turf deterioration was directly correlated with the time of disease incidence. If normal rainfall had occurred, improved fall recovery from disease injury would have been expected.

The value of mixing grass species is of particular interest. In 1964 several mixtures had higher densities than any one component of that mixture seeded alone. This suggests that mixtures function in reducing the severity of disease on any one specific grass species contained in the mixture.

Studies- by Burton and Deal (2) on southern turf species show *Zoysia matrella* and St. Augustine grass to have superior shade adaptation when compared with common bermudagrass. Bermudagrass varieties which performed best under full sunlight were also superior under shaded conditions. It was suggested that warm season grasses selected for superiority under full sunlight would also possess the characteristics for superior performance under shaded conditions. McBee and Holt (6) of Texas reported that the No-mow variety of bermudagrass was superior in shade tolerance, and performed better under reduced light intensity than when exposed to full sunlight. Also showing good shade adaptation were St. Augustine and T-135 bermudagrass. Grasses which were unsatisfactory under shading were Pensacola bahiagrass and Meyer zoysia.

Based on the limited data available on species tolerance to shade, the red fescue are the preferred grasses to be utilized. No comparisons between bentgrass and red fescue have been reported. However, assuming that disease control practices are utilized, the bent grasses should provide adequate turf under shaded conditions, although lower in quality compared to full sunlight. In order for cool-season turfgrass varieties to perform well under shaded conditions, they must possess improved disease tolerance. Characteristics such as growth habit and ability to capture and convert light energy into chemical energy at various wave lengths are involved in shade adaptation. However, disease resistance is currently the key limiting factor which must be resolved.

Among the southern grasses, St. Augustine is generally reported to be superior under shaded conditions, as are certain selected varieties of bermudagrass.

Plant Nutrients and Fertilizer Materials

CHEMICAL FERTILIZERS:

KIND	% NITROGEN (N) .	% PHOSPHORUS (P)	% POTASH (K)	APPROXIMATE POUNDS REQUIRED TO SUPPLY 1 LB. OF ACTUAL ELEMENT
Nitrogen Materials -				
Ammonium sulfate	20.5	-		5
Ammonium nitrate	32.5	-		3.5
Calcium nitrate	15.5	-		6.5
Amophos 16 - 20	16	8.5 - 9.0		6.25
Urea	45	-		2.2
Urea-formaldehyde	38	-		2.65
Phosphate Materials -				
Superphosphate - single	-	7.8 - 8.7	—	12
Superphosphate - double	-	18 - 20		5
Superphosphate - triple	-	18 - 20		5
Potassium Materials -				
Potassium chloride	-	-	51.5	2
Potassium sulfate	-	-	44.0	2.3

BULKY ORGANIC FER'TILIZERS:

KIND	AVG. % NITROGEN	AVG. % P_2O_5	AVG. % K_2O	% DRY ORGANIC MATTER	ONE TON PI		VIDE:	APPROX.	AVG. NO. CU. FT. PER TON	CU. FT. TO MAKE 1 LB. NITROGEN
					LBS. N	LBS. P	LBS. K	LBS. DRY ORGANIC MATTER		
Dairy manure - wet	0.5	0.3	0.7	25	10	6	14	500	45	4.5
Dairy manure - dry	1.0	0.5	1.8	40	20	10	36	800	65	3.25
Feedlot steer manure	2.2	1.0	2.2	69	44	20	44	1,380	70	1.59
Poultry droppings	4.1	3.1	1.6	73	82	62	32	1,160	55	0.67
Poultry No. 1	2.0	1.9	1.16	52	40	37	23	1,100	60	1.5
Hog manure	2.2	2.1	1.0	62	44	42	20	600	59	2.8
Rabbit manure	2.0	1.3	1.2	60	40	26	24	1,000	70	1.75
Alfalfa hay	2.5	0.6	2.0	83	50	10	40	1,660	-	
Bean straw (lima)	1.3	0.25	1.3	83	26	6	26	1,660		-
Cereal straw	0.6	0.3	1.6	85	12	6	32	1,700	175	14.6