THE EFFECTS OF DIFFERENT LEVELS OF SIX NUTRIENT ELEMENTS UPON THE GROWTH AND SEED PRODUCTION OF *ZOYSIA JAPONICA* STEUD.

by
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THE EFFECTS OF DIFFERENT LEVELS OF SIX NUTRIENT ELEMENTS UPON THE GROWTH AND SEED PRODUCTION OF *ZOYSIA JAPONICA* STEUD.

Introduction

Zoysia japonica Steud. is a grass introduced from the Orient which forms a very dense turf desirable for many uses. It seems to be particularly well adapted to use on parks, cemeteries, athletic fields, lawns, and golf course fairways. No serious disease or insect pests are known to attack it when it is grown under field conditions. Inasmuch as *Z.* japonica grows actively throughout the summer months and forms an exceptionally dense turf, it is able to compete successfully with crabgrass and most of the other common turf weeds. In that part of the eastern United States which has been called the "crabgrass belt" (a triangular area which has as its points St. Louis, Philadelphia, and Richmond, there is a great need for such a turf grass (17).

There is no domestic production of seed of *Z. japonica* on a commercial scale. It is believed that the availability of seed supplies would make possible the use of *Z. japonica* in many more large turf areas. There are two chief reasons why the Zoysia grasses have not been grown commercially in the United States. One is that germination normally is low in untreated seeds. This difficulty may be eliminated by the simple operation of removing the glume which covers the caryopsis (18). The other reason is that seed yields of common *Z. japonica* are rather low and unpredictable.

Preliminary treatments of small plots of *Z. japonica* in the field have indicated that the nutritional status of the grass may be one of the more important factors governing seed yield. The applications of mixed fertilizers sometimes have affected seed yields adversely. This is especially true in the case of heavy applications of nitrogen.

It was the purpose of this study to determine the effects of various levels of six nutrient elements upon the growth, seed production, and turf-forming ability, of the Z-52 strain of *Z. japonica*. The elements whose effects were studied included nitrogen, phosphorus, potassium, calcium, magnesium, and boron. The study is based upon the concept that each nutrient element, under a given set of environmental conditions, will produce a maximal effect at a certain critical level of concentration within the plant tissues. If the concentration of the element is beyond that critical level, it will produce no greater effect. Concentrations of any particular element which are higher than optimal actually may be harmful to the plant, because of the fact that an improper balance may occur. This experiment was designed to determine the optimal levels of concentration of these six elements within the leaf blades of the grass, when grown under the conditions governing the experiment.

REVIEW OF LITERATURE

An account of the climatic and soil conditions of the native habitat of *Zoysia japonica* appeared in the Bulletin of the United States Golf Association Green Section in 1930 (1). Seed and plants of this grass were sent to the United States Department of Agriculture by Morse and Dorsett (1) from Korea in 1931. Forbes and Ferguson (17) reported on this and earlier introductions, and on the distribution and behavior of the Zoysia grasses in the United States. They also (18) reported the results of germination tests as affected by seed treatment, planting methods, and genetic variability. Childers (10) has reported that *Zoysia matrella* Merr. is a short day plant. This fact has been found to be true also in the case of *Z. japonica* by the author and by Forbes (16). The value of *Z. japonica* for use in turf has been discussed by Grau and Ferguson (19).

The literature on the subject of mineral nutrition of higher plants has grown tremendously in recent years. Goodall and Gregory (20) recently reviewed the subject very thoroughly. The volume of the literature is indicated by the fact that the work by Goodall and Gregory (20) is appended by a bibliography consisting of 37 pages. Beeson (3) reporting on mineral composition of crop plants, cites 607 references. In addition to these rather extensive reviews, there are several excellent review papers which have appeared in the Annual Review of biochemistry (7,9,30,31, and 46). Nightingale (34) has reviewed the subject of nitrogen nutrition. Hoagland (23) in a series of lectures has provided an excellent insight into the problems involved in the mineral nutrition of plants.

The work of Hoffer (24, 25) and others has stimulated interest in the use of tissue analyses as a guide to the nutritional status of plants.

While many workers are agreed upon the principle of assessing mineral nutritional status by analyses of plant parts, there appears to be a diversity of opinion regarding the interpretation of results. Lundegardh (30) has stated his views, in part, as follows:

"It has been objected against leaf analysis that the nutrients can vary a great deal without a corresponding variation in yield. A thorough investigation shows that this is true only at supra-optimal percentages. A distinct limit can be distinguished, below which growth inevitably decreases. Values below this limit are the only ones which have an interest from the viewpoint of fertilization."

Chubb and Atkinson (11) and Atkinson, et al. (2) have reported that they found no satisfactory relationships between tissue tests and crop yields. Tissue tests were of some value in the case of nitrate response. On the other hand there are reports of direct relationship between tissue tests and growth response by Hill and Cannon (22), Tyner (43), and Kenworthy and Gilligan (26). There are many modifying factors, however, and the relationships are not simple. Factors such as time of sampling and environmental conditions have been shown by Cain and Boynton (8) and by Sayre (37) to be important in attempts to correlate growth and yield responses to tissue tests.

The concept of nutrient balance has been the subject of a great deal of investigation (39, 41). This facet of the mineral nutrition of plants appears to be particularly difficult to study because of the many interrelationships of elements necessarily involved. Chapman (9) has indicated that the absolute total of a given nutrient is of some value in assessing the nutritional status of plants, but that the amount of a given nutrient in relation to the levels of other nutrients is a better criterion. He summarizes his views thus: "... it is both the balance and the total which count."

There are reports of several cases in which the testing of plant parts has been used successfully in determining the fertilizer needs of plants. Boynton and Compton (6), Nightingale (32, 33) and Scarseth (38) are among those who have reported the successful use of such methods.

Concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in various grasses have been reported (5,12,13,14,28,35,45). Pierre and Robinson (35) report phosphorus concentrations ranging from 0.161 to 0.299 percent in the dry matter of Kentucky bluegrass grown under experimental conditions, 0.126 to 0.226 percent of phosphorus in the dry matter of broomsedge, and 0.105 to 0.263 percent of phosphorus in poverty grass. They reported ranges of calcium from 0.302 to 0.575 percent in Kentucky bluegrass, 0.263 to 0.379 percent in broomsedge, and 0.255 to 0.368 percent in poverty grass. They stated that the minimal percentage of phosphorus for Kentucky bluegrass is 0.16 and that the "critical" is 0.30 percent. Table 1 consists of data taken from a report by Cooper, Mitchell and Page (13) in which the mean concentrations of several mineral elements in grasses are listed.

Reid (36) has reported the growth responses of several turf grasses to variations in concentration of mineral elements in nutrient culture. Spencer, Jewett, and Fergus (40) have reported increased yields of Kentucky bluegrass seed resulting from the use of nitrogen in fertilizers and lesser yield increases resulting from the use of phosphorus and potassium.

Kraus and Kraybill (27) and Nightingale (32,33,34) have discussed the relationship of nitrates and carbohydrates reserves as it affects fruiting. Chapman (9) has reviewed the subject of nutrition in relation to fruitfulness and fruit quality. He has also (9) reviewed the interrelations of nutrients.

TABLE 1. Concentrations of elements in percentage in the dry matter of grasses.

Grasses	K	Ca	Mg	P	N
Kentucky bluegrass	1.96	0.13	0.11	0.25	1.51
Rhode Island bentgrass	1.21	0.24	0.11	0.17	1.32
Canada bluegrass	0.98	0.20	0.09	0.10	0.83
Sweet vernal grass	1.53	0.11	0.08	0.18	1.11
Poverty grass	1.20	0.19	0.08	0.10	0.88
Broomsedge	0.33	0.16	0.03	0.13	0.71
Bermuda grass	0.38	0.37	0.27	0.22	----
Dallis grass	0.45	0.32	0.36	0.15	----
Centipede grass	0.35	0.21	0.42	0.15	----
Carpet grass	0.71	0.32	0.21	0.17	----

Eaton (15) has reported boron deficiency, toxicity, and accumulation data for a large number of plants.

MATERIALS AND METHODS

Zoysia japonica was grown in a greenhouse at Beltsville, Maryland, during the period from December 28, 1948 to February 18, 1950. From December 28, 1948, until May 1, 1949, the greenhouse temperatures ranged from 65° F. to 85° F. During the period from May 1, 1949, to February 18, 1950, the temperature ranged from 75° F. to 110° F. The higher temperatures were experienced during the summer months, especially during July and August.

Stolon tips from a single clone of the M-52 strain of Zoysia japonica were rooted in washed quartz sand. Each stolon tip contained three nodes. Six stolons were rooted in each crock. The glazed crocks were painted on the inside with asphalt varnish. Plastic screening was placed over the drainage holes in the crocks to prevent leakage of the sand.

Nutrient stock solutions were dispensed from burettes and diluted to the desired concentrations with distilled water. Nutrient solutions were supplied twice a week. Distilled water was used to flush the crocks at approximately weekly intervals. During extremely hot weather, distilled water was applied twice a week.

For convenience the study was divided into six simple randomized block experiments. These were designated as the nitrogen, phosphorus, potassium, calcium, magnesium, and boron series. There were seven treatment levels for each nutrient element. Each treatment was replicated four times. Therefore, in each of the six experiments there were 28 crocks. All other nutrient elements, except the one which was being studied in each case, were maintained at a constant (i.e., the median)level. It was assumed that the small amounts of sodium and chloride ions which were used for maintaining an "ionic balance" in the nutrient solutions were without effect.

Table 2 contains a listing of the rates at which the elements were applied.

In each of the six experiments the median level of each of the nutrient elements was maintained constantly except in the case of the one element which was being studied. Iron was supplied as iron citrate. One milliliter of a 0.5 percent solution was added to each liter of nutrient solution. Zinc, manganese, copper and molybdenum were included in a micronutrient solution. One milliliter of this micronutrient stock solution added to one liter of the nutrient solution provides 0.5 p.p.m. of manganese, 0.05 p.p.m. of zinc, 0.02 p.p.m. of copper, and 0.05 p.p.m. of molybdenum.

Treatments with the nutrient solutions were begun on January 1, 1949. At that time the stolons had started to take root and were ready to begin growth. Clippings were made at approximately monthly intervals beginning April 1, 1949. The grass was clipped each time to a height of approximately one inch. Grass which is being grown for turf would be cut more often than once a month under normal conditions. In this case, however, it was necessary to allow the grass to grow for about a month in order that there would be a large enough volume of clippings to measure accurately small differences in weight. The larger volume of clippings was necessary also in order that there would be sufficient material from the slowest growing pots for mineral analyses. Turf quality is not dependent upon the production of forage. However, no better method has been devised for comparing the vigor and general well-being of turf plants than the use of clipping-yield data. Therefore, these data were used as growth criteria. The clippings were dried for at least 48 hours at a temperature of approximately 160° F. They were then weighed. Yields are expressed as oven-dry weights. The total

TABLE 2. Rates of application of nutrient elements in solution

Level	m.e./L					Boron p.p.m.
	NO_3	H_2PO_4	K	Ca	Mg	
1	0.1	0.05	0.1	0.1	0.05	0.1
2	0.5	0.2	0.5	0.5	0.2	0.3
3	2.0	1.0	2.0	2.0	1.0	0.4
4	5.0	2.0	5.0	5.0	2.0	0.5
5	10.0	5.0	10.0	10.0	5.0	1.0
6	15.0	7.0	15.0	15.0	7.0	2.0
7	20.0	10.0	20.0	20.0	10.0	5.0

yields from each pot during the entire course of the experiment has been used as the growth rate criterion.

Perhaps the best measure of turf quality is the density of the crown. The crown of the plant in this case is intended to mean that part of the leaf blade which remains after the clippings have been removed, together with the stolon and rhizome mat and the upper portion of the root system. At the end of the experiment, the turf was removed from the pots, washed free of sand, and oven-dried. Weights of this material were recorded and they are expressed as "weights of crowns."

Inasmuch as Z. japonica is a short-day plant, (10, 16) flowers began to appear in mid-November. No further clippings were made after that date. Flowers continued to appear until after lights were turned on in order to provide long days. Additional light was supplied beginning January 16,1950. During the period from December 1, 1949 to January 16, 1950, black cloth covers had been used to provide an 8-hour day and to prevent a disturbance in flowering due to incidental light. At the time seed heads were harvested, (February 18, 1950), they were not uniformly mature. Therefore, seed head number appears to be a more satisfactory way of expressing seed yield than an expression of seed weight. Although some seed heads were smaller than others, the small seed heads were produced only in the case of the pots which had received small amounts of nitrogen. Inasmuch as these pots produced yields (on a seed head number basis) which were significantly lower than pots which had received higher amounts of nitrogen, it is felt that this difference in seed head size is not important.

Clippings which were harvested on four different dates were analyzed chemically to determine the concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, and boron within the leaf tissues. The dates of these clippings were July 25, 1949; August 16, 1949; September 14, 1949; and October 25, 1949. The dried leaf material was ground finely enough to pass a 40-mesh screen.

The rapid analytical methods described by Lindner (29) were used to determine the amounts of nitrogen, phosphorus, calcium, and magnesium. The nitrogen, phosphorus and magnesium tests are colorimetric, while the calcium test is turbidimetric. These methods make use of a digestion technique which involves the use of sulfuric acid and 30 percent hydrogen peroxide. Fisher's electrophotometer was used to determine the various degrees of color and turbidity. Potassium was determined by means of the Beckman Flame Spectrophotometer.1/ The peroxide-digested material used in the other tests was used for the spectrophotometric determinations.

The quinalizarin technique described by Berger and Truog (4) was used for the determination of boron.

1/ This instrument was made available for these determinations through the courtesy of Dr. L. A. Scott of the Department of Horticulture.

RESULTS AND DISCUSSION

Chemical Analyses of Clippings

Clippings harvested at four different dates were analyzed chemically in order to determine the concentrations in the leaves of the nutrient elements studied. (See tables 3,4,5, and 6.). One of the aims of the experiment was that of determining whether there were appreciable changes in the concentrations of the elements as the experiment progressed. Some changes in concentration were found to occur, but with a few exceptions the values were found to be relatively constant. Therefore, for the sake of clarity and simplicity, only the values obtained from chemical analyses of the clippings harvested on October 25, 1949 are referred to in this discussion.

The data in table 6 show that there is a considerable range in the concentrations of the elements studied. The data also indicate that variations in the concentration of one element may affect the levels of other elements within the plant. This observation is in agreement with many reports in the literature. However, it is not the purpose of this study to attempt a correlation of the concentrations of various nutrient elements. The fact that a considerable range in the amounts of the nutrient elements exists within the leaves, provides a basis for studying the relationship between various levels of nutrient elements and yields of clippings, weights of crowns, and yields of seed.

General Appearance

Throughout the course of the experiment the plants were observed carefully in an effort to discover any deficiency or toxicity symptoms which might occur. Deficiency symptoms were recognizable only in the case of nitrogen. Grass plants which contained very low amounts of nitrogen

TABLE 3. The concentration of various elements in clippings harvested July 25, 1949. All elements were supplied at a constant (median) level in each case, with the exception of the element studied.

Element varying	Treatment level	% N	m.e./100g. Dry matter				Boron p.p.m.
			PO_4	K	Ca	Mg	
Nitrogen	0.5m.e.NO_3/L	0.77	19.74	20.51	11.85	16.36	60
"	2.0 do	0.94	20.68	24.36	15.00	10.69	80
"	5.0 do	1.25	20.68	29.49	20.00	15.05	110
"	10.0 do	1.55	16.92	20.51	11.25	18.17	110
"	15.0 do	1.70	20.68	19.23	7.50	18.67	110
Phosphorus	0.05m.e.H_2PO_4/L	1.16	9.40	23.08	10.95	13.16	60
"	0.2 do	1.06	12.22	23.08	14.85	13.32	50
"	1.0 do	1.10	16.92	23.08	13.15	10.36	55
"	2.0 do	1.19	22.56	23.08	15.65	11.27	75
"	5.0 do	0.99	32.90	19.23	11.90	15.29	60
"	7.0 do	0.99	37.60	17.95	10.00	9.20	70
"	10.0 do	0.97	37.60	15.38	8.45	8.63	60
Potassium	0.1m.e.K/L	1.03	18.80	2.56	13.15	9.95	55
"	0.5 do	1.09	15.98	5.12	11.90	16.12	60
"	2.0 do	1.01	18.61	14.10	10.00	15.13	55
"	5.0 do	1.11	24.44	20.51	15.00	15.95	60
"	10.0 do	0.97	18.80	28.20	17.50	6.25	50
"	15.0 do	1.01	15.04	32.05	15.00	10.36	45
"	20.0 do	0.96	15.88	28.20	5.65	6.41	50
Calcium	0.1m.e.Ca/L	0.85	17.86	12.82	5.30	12.17	60
"	0.5 do	0.79	17.86	15.38	6.25	12.66	80
"	2.0 do	0.94	19.74	15.38	4.40	13.57	90
"	5.0 do	1.04	21.62	20.51	15.30	14.55	110
"	10.0 do	0.82	15.04	20.51	8.15	12.83	90
"	15.0 do	1.12	15.04	20.51	13.75	9.70	100
"	20.0 do	1.09	19.74	20.51	13.75	8.06	90
Magnesium	0.05m.e.Mg/L	0.94	21.62	20.51	21.25	0.99	80
"	0.2 do	1.00	19.74	20.51	18.15	4.44	80
"	1.0 do	1.06	21.62	20.51	15.15	9.46	80
"	2.0 do	1.08	19.74	19.23	15.00	9.13	85
"	5.0 do	0.97	18.80	23.08	33.15	18.58	65
"	7.0 do	1.06	18.80	23.08	24.40	17.35	75
"	10.0 do	0.98	15.98	21.79	10.65	14.88	85
Boron	0.1p.p.m.of B	1.14	21.62	19.23	15.00	12.17	85
"	0.3 do	1.17	21.62	19.23	24.40	15.46	95
"	0.4 do	1.28	22.56	23.08	15.65	15.13	90
"	0.5 do	1.13	23.50	24.36	15.30	13.40	80
"	1.0 do	1.18	24.44	23.08	15.65	13.16	110
"	2.0 do	1.10	24.44	23.08	13.75	15.95	160
"	5.0 do	1.00	22.56	23.08	24.40	12.17	240

TABLE 4. The concentration of various elements in clippings harvested August 16, 1949. All elements were supplied at a constant (median) in each case with the exception of the element studied.

Element varying	Treatment level		% N	m.e./100g. Dry matter				Boron p.p.m.
				PO_4	K	Ca	Mg	
Nitrogen	0.5m.e.NO_3/L		0.92	19.74	20.51	16.25	11.02	58
"	2.0	do	1.27	22.56	28.20	12.50	11.59	55
"	5.0	do	1.72	24.44	38.46	15.35	15.05	100
"	10.0	do	2.04	27.66	33.33	10.60	20.80	80
"	15.0	do	2.10	29.14	30.77	10.60	20.64	80
Phosphorus	0.05m.e.H_2PO_4/L		1.69	9.40	30.77	14.85	9.79	60
"	0.2	do	1.59	15.04	30.77	14.40	7.15	55
"	1.0	do	1.50	20.66	33.33	10.00	8.06	45
"	2.0	do	1.72	23.50	33.33	15.65	13.65	70
"	5.0	do	1.51	25.38	25.64	15.65	9.13	70
"	7.0	do	1.59	37.60	24.36	15.00	7.89	70
"	10.0	do	1.63	41.36	24.36	11.25	8.06	58
Potassium	0.1m.e.K/L		1.59	23.50	5.12	13.15	15.46	55
"	0.5	do	1.77	24.44	10.24	13.15	18.34	55
"	2.0	do	1.47	28.20	23.08	18.75	14.64	65
"	5.0	do	1.57	24.44	38.44	15.65	14.55	85
"	10.0	do	1.53	20.66	48.72	25.00	12.66	70
"	15.0	do	1.43	21.62	52.56	11.90	13.57	65
"	20.0	do	1.50	19.74	52.56	15.65	6.09	60
Calcium	0.1m.e.Ca/L		1.80	19.74	23.08	11.90	12.66	90
"	0.5	do	1.62	23.50	24.36	15.00	11.02	80
"	2.0	do	1.75	23.50	25.64	13.75	9.21	100
"	5.0	do	1.67	24.44	30.77	18.75	3.45	105
"	10.0	do	1.64	20.66	30.77	16.40	4.28	85
"	15.0	do	1.64	21.24	30.77	20.30	9.46	65
"	20.0	do	1.62	28.65	30.77	25.65	7.32	65
Magnesium	0.05m.e./Mg/L		1.46	25.38	33.33	11.90	4.28	90
"	0.2	do	1.31	28.20	33.33	14.40	0.66	90
"	1.0	do	1.51	23.50	30.77	11.90	5.84	90
"	2.0	do	1.59	27.66	33.33	11.90	9.70	95
"	5.0	do	1.40	18.80	32.05	9.40	14.55	65
"	7.0	do	1.40	18.80	30.77	9.40	11.67	75
"	10.0	do	1.42	20.60	30.77	6.90	11.59	70
Boron	0.1p.p.m.		1.42	25.38	28.20	11.25	10.36	65
"	0.3	do	1.52	25.38	28.20	13.75	8.06	65
"	0.4	do	1.48	24.44	30.76	14.40	8.22	60
"	0.5	do	1.45	26.13	30.76	11.25	9.05	70
"	1.0	do	1.51	26.13	28.20	14.40	8.63	90
"	2.0	do	1.41	26.13	28.20	10.00	6.41	110
"	5.0	do	1.60	27.66	28.20	11.90	10.60	160

TABLE 5. The concentration of various elements in clippings harvested September 14, 1949. All elements were supplied at a constant (median) level in each case with the exception of the element studied.

Element varying	Treatment level	% N	m.e./100g. Dry matter				Boron p.p.m.
			PO_4	K	Ca	Mg	
Nitrogen	0.5m.e.NO_3/L	1.31	27.66	17.95	17.95	0.90	55
"	2.0 do	1.47	27.66	24.36	11.90	1.40	58
"	5.0 do	1.87	25.38	28.20	13.75	3.21	90
"	10.0 do	1.94	30.08	25.64	13.15	11.49	70
"	15.0 do	2.02	33.84	25.64	15.00	16.45	70
Phosphorus	0.05m.e.H_2PO_4/L	1.80	9.40	29.49	25.00	10.69	50
"	0.2 do	1.81	19.74	29.49	30.65	1.15	60
"	1.0 do	1.80	23.50	29.49	31.90	3.29	70
"	2.0 do	1.82	29.14	29.49	29.40	4.11	70
"	5.0 do	1.73	32.90	24.36	26.55	4.52	80
"	7.0 do	1.75	52.64	21.79	17.95	0.90	70
"	10.0 do	1.85	48.50	19.23	24.40	5.18	70
Potassium	0.1m.e.K/L	1.74	23.50	5.12	24.40	8.88	60
"	0.5 do	1.84	23.50	10.24	23.75	12.17	70
"	2.0 do	1.69	25.38	21.79	27.80	9.54	80
"	5.0 do	1.93	25.38	28.20	21.05	11.92	70
"	10.0 do	1.72	23.31	38.46	20.30	9.96	58
"	15.0 do	1.69	22.56	41.02	14.40	6.09	55
"	20.0 do	1.55	21.62	41.02	16.45	9.62	48
Calcium	0.1m.e.Ca/L	1.56	28.20	25.64	15.00	10.36	55
"	0.5 do	1.78	28.20	25.64	21.25	11.27	70
"	2.0 do	1.78	26.13	27.97	28.75	13.32	100
"	5.0 do	1.82	24.44	32.05	25.00	17.27	90
"	10.0 do	1.59	21.62	32.05	27.80	8.06	58
"	15.0 do	1.79	24.44	32.05	26.55	11.18	58
"	20.00 do	1.62	15.04	32.05	26.55	4.28	70
Magnesium	0.05m.e.Mg/L	1.72	24.44	30.77	16.80	2.06	45
"	0.2 do	2.04	30.08	34.61	7.50	0.41	55
"	1.0 do	1.85	24.44	34.61	11.90	3.04	70
"	2.0 do	1.89	25.38	35.90	25.65	11.67	48
"	5.0 do	1.98	24.44	43.59	9.40	16.77	45
"	7.0 do	1.62	30.08	39.74	15.30	10.20	33
"	10.0 do	1.62	21.62	39.74	6.25	13.81	48
Boron	0.1p.p.m.	1.72	26.32	30.77	15.00	14.31	48
"	0.3 do	1.62	23.50	-----	10.00	6.25	45
"	0.4 do	1.69	24.44	32.05	15.00	15.13	50
"	0.5 do	1.59	26.32	28.20	23.75	15.05	60
"	1.0 do	1.45	29.14	28.20	17.20	15.95	90
"	2.0 do	1.55	21.62	28.20	10.65	12.09	120
"	5.0 do	1.72	28.20	28.20	11.90	10.69	140

TABLE 6. The concentration of various elements in clippings harvested October 25, 1949. All elements were supplied at a constant (median) level in each case, with the exception of the element studied.

Element varying	Treatment level	% N	m.e./100g. Dry matter				Boron p.p.m.
			PO_4	K	Ca	Mg	
Nitrogen	0.5m.e.NO_3/L	1.14	25.13	28.20	18.90	9.54	70
"	2.0m.e.NO_3/L	1.57	24.10	33.33	18.25	9.05	60
"	5.0 do	1.72	26.79	39.74	17.65	12.83	90
"	10.0 do	2.05	33.75	35.90	17.65	8.55	90
"	15.0 do	1.97	38.73	38.46	17.00	16.45	90
Phosphorus	0.05m.e.H_2PO_4/L	1.54	1.45	30.77	17.00	4.36	43
"	0.2 do	1.66	17.86	35.90	17.00	6.66	40
"	1.0 do	1.55	21.53	35.90	16.35	11.59	40
"	2.0 do	1.50	24.06	30.77	22.65	19.00	60
"	5.0 do	1.53	32.90	28.20	22.65	12.66	60
"	7.0 do	1.69	33.84	25.64	17.65	11.67	60
"	10.0 do	1.50	37.98	25.64	17.65	12.42	70
Potassium	0.1m.e.K/L	1.47	23.12	5.12	17.50	13.98	80
"	0.5 do	1.67	21.24	12.82	20.65	20.97	55
"	2.0 do	1.54	26.88	19.23	20.65	23.68	50
"	5.0 do	1.45	26.13	25.64	19.40	24.67	53
"	10.0 do	1.70	20.12	38.46	23.75	15.79	50
"	15.0 do	1.54	23.12	43.59	25.95	13.57	48
"	20.0 do	1.61	21.15	48.72	23.15	12.66	48
Calcium	0.1m.e.Ca/L	1.51	32.90	19.23	13.15	12.75	70
"	0.5 do	1.56	32.71	23.08	17.20	8.06	60
"	2.0 do	1.57	29.14	25.64	19.40	15.46	65
"	5.0 do	1.73	24.44	27.97	21.90	2.88	75
"	10.0 do	1.56	21.62	30.77	28.75	7.65	55
"	15.0 do	1.74	21.62	30.77	21.90	4.60	60
"	20.0 do	1.61	24.44	32.05	23.75	6.25	50
Magnesium	0.05m.e.Mg/L	1.53	32.34	30.77	18.15	1.07	55
"	0.2 do	1.61	29.61	28.20	18.75	1.07	55
"	1.0 do	1.56	26.32	25.64	25.00	4.11	58
"	2.0 do	1.56	26.32	28.20	21.90	10.36	70
"	5.0 do	1.59	30.08	33.33	21.05	15.95	48
"	7.0 do	1.60	23.50	28.20	20.30	12.42	40
"	10.0 do	1.44	26.32	28.20	23.75	15.54	45
Boron	0.1p.p.m.	1.53	25.38	33.33	22.50	13.65	45
"	0.3 do	1.56	30.08	28.20	16.40	5.59	53
"	0.4 do	1.45	31.02	30.77	20.30	12.83	60
"	0.5 do	1.39	32.90	28.20	25.00	7.89	80
"	1.0 do	1.50	31.96	30.77	22.80	10.35	90
"	2.0 do	1.62	25.38	25.64	23.75	11.76	130
"	5.0 do	1.56	25.19	30.77	23.75	10.35	160

produced shortened leaves, shortened internodes, made very little growth, and presented a yellow, nonvigorous appearance. The lower leaves of the plant became dry and straw-colored.

An over-abundance of nitrogen produced an appearance that was also quite easy to recognize. The leaves were exceptionally long and were a rich, dark green. Growth was extremely rapid.

Toxicity symptoms appeared on the pots of grass which had received high rates of boron. The tips of the leaves became dark brown for a distance of about 0.5 to one centimeter. The margins were usually brown for a slightly greater distance than was the center of the leaf.

Yields of Clippings

Although yields of clippings are poor indicators of turf quality, they do furnish a basis for estimating the vigor and the rate of growth of grass plants. The effects of each of the various nutrients on clipping yields will be discussed separately.

Effects of Nitrogen upon Yields of Clippings

Nitrogen is the element which is most important in the growth of turf grasses. Seven levels of nitrogen in the nutrient solution were studied. (Yields are reported for the pots in this experiment in table 7. The analysis of variance may be found in Appendix table 1). The lowest level (0.1 m.e.NO_3/L) produced such a small amount of growth than an insufficient quantity of clippings could be obtained at any of the four clipping dates for chemical analyses. However the total clipping yield for this level of treatment is reported in table 7. The highest level of treatment (20.0m.e. NO_3/L) produced a very lush, succulent growth. Due to the high level of leaf production, with a resulting increase in the rate of transpiration, the pots receiving

TABLE 7. Effects of various levels of nitrogen in the nutrient solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (NO_3)					
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.0m.e./L
1	1.6	4.4	15.7	43.1	49.9	57.6
2	1.4	3.9	25.5	39.4	57.7	54.5
3	2.0	3.4	22.1	39.6	37.1	50.9
4	.8	2.5	21.3	42.4	49.4	49.9
Mean	1.45	3.55	21.15	41.13	48.53	53.2

L.S.D. at 5% level = 6.408

L.S.D. at 1% level = 8.778

this level of nitrogen wilted at one time in July, 1949. The grass in these pots was injured permanently and therefore was discarded and eliminated from the experiment. Figure 1 shows the relationship between growth as indicated by clipping yields and the concentration of nitrogen in the grass leaves. The points on this graph represent values obtained from all the pots included in the study, regardless of which element was varied. Table 7 shows that clipping yields increased in direct proportion to increases of amounts of nitrogen in the nutrient solution.

Effects of Phosphorus Upon Yields of Clippings

Table 8 contains the yields of clippings from the phosphorus series. The analysis of variance for these data is shown in Appendix table 2. The values for yields resulting from applications of the first and third levels of phosphorus (0.05 and 1.0 m.e. of H_2PO_4/L, respectively) are shown to be significantly lower than those resulting from treatment at higher levels. The reason for the fact that the second level (0.2 m.e.H_2PO_4/L) produced a yield that is significantly higher than those produced by the first and third levels, is not apparent.

Figure 2 shows the relationship existing between levels of phosphorus found in the leaves and the yields of clippings. On the basis of the relationship shown here, it is doubtful if phorphorus can be considered to be an important limiting factor in the production of clippings of *Zoysia japonica*.

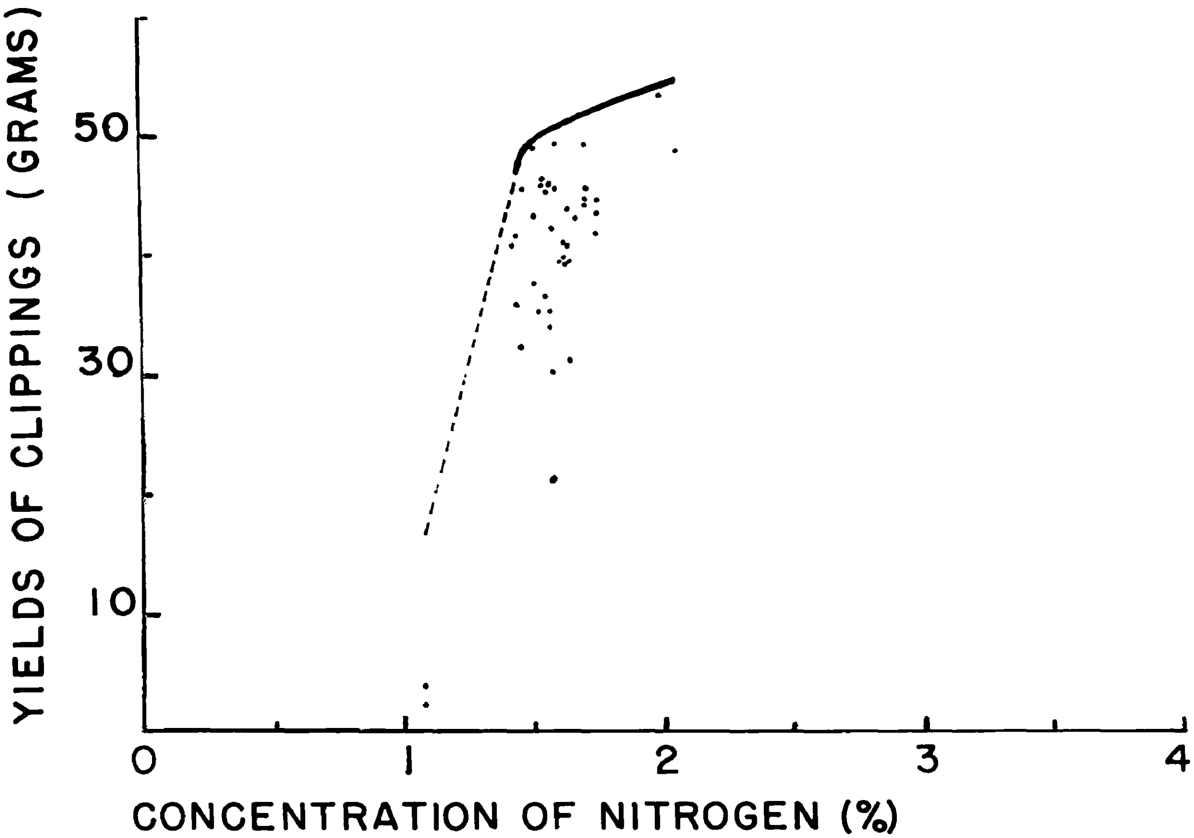

FIGURE 1. The relationship between the concentration of nitrogen (on a dry weight basis) and yields of clippings.

TABLE 8. Effects of various levels of phosphorus in the nutrient solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (H_2PO_4)						
	.05m.e./L	.2m.e./L	1.0m.e./L	2.om.e./L	5.om.e./L	7.om.e./L	10m.e./L
1	39.6	49.7	43.2	54.7	48.3	43.0	44.4
2	27.0	49.7	25.5	45.6	46.6	40.5	39.9
3	42.0	50.4	48.2	52.8	44.2	48.7	42.4
4	38.2	46.1	38.5	42.5	46.8	44.3	46.4
Mean	36.7	48.97	38.85	48.9	46.47	44.1	43.27

L.S.D. at 5% level = 6.48

L.S.D. at 1% level = 8.87

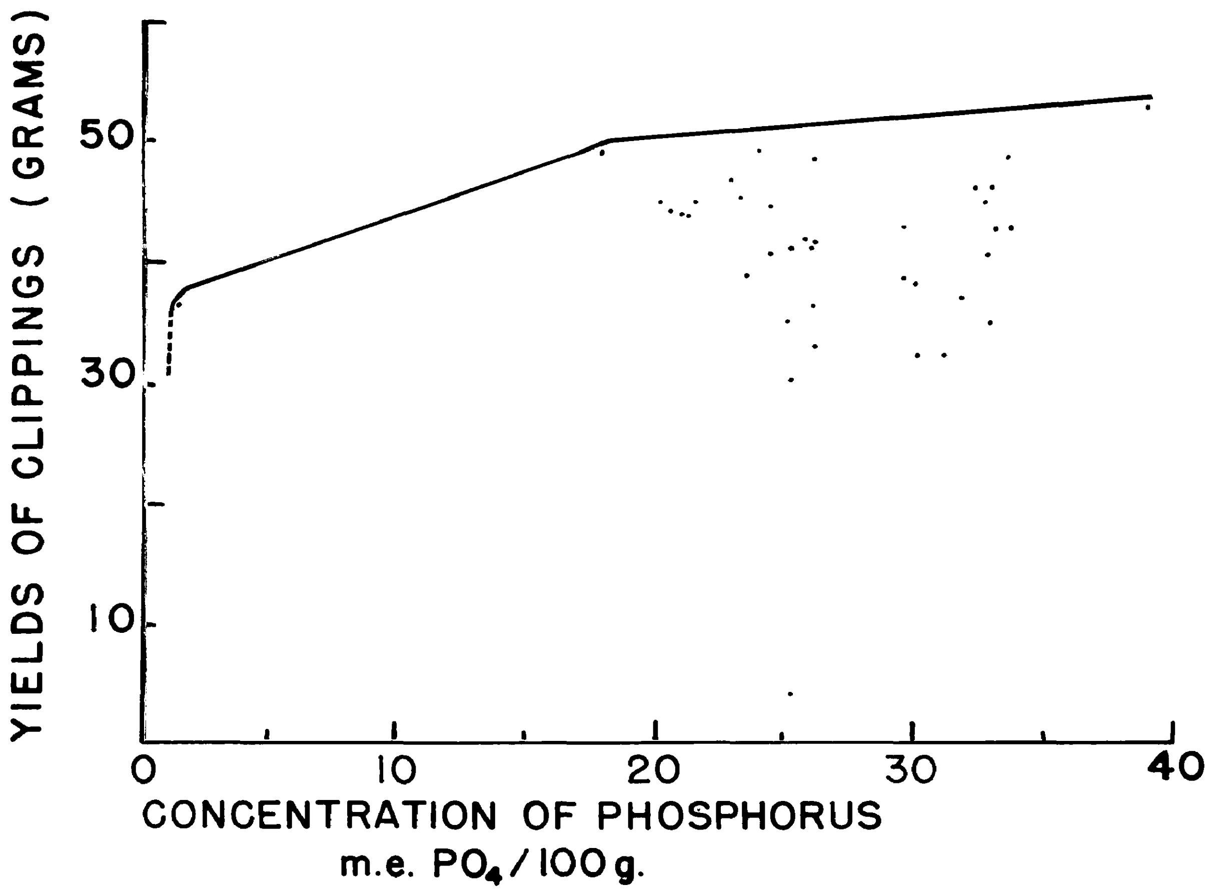

FIGURE 2. The relationship between the concentration of phosphorus (on a dry weight basis) and yields of clippings.

Effects of Potassium Upon Yields of Clippings

Yields of clippings from pots in the potassium series are given in table 9. The analysis of variance for these data is shown in Appendix table 3. The yield resulting from the application of the third level (2.0m.e.K/L) is significantly higher at the 5 percent level for significance than the yield resulting from the application of the fourth level of potassium (5.0 m.e.K/L). There are no other significant differences in clipping yields obtained from the potassium series.

Figure 3 shows the relationship between concentrations of potassium in the grass clippings and yields of clippings. Although a wide range of concentrations of potassium was found to exist in the clippings from this study, there is no apparent correlation between potassium concentration and yield of clippings. Under the conditions of this experiment, the lowest levels of potassium were not found to be limiting vegetative growth.

Effects of Calcium Upon Yields of Clippings.

Yields of clippings obtained from pots in the calcium series are given in table 10. The analysis of variance for these data is contained in Appendix table 4. The lowest rate of application of calcium (0.1 m.e.Ca/L) produced yields that were poorer at the 5 percent level for significance, than those produced by the second level of application (0.5 m.e.Ca/L). There were no other significant differences in the yields produced by variations of the calcium levels.

Figure 4 is a graph which shows the relationship between the

TABLE 9. Effects of various levels of potassium in the nutrient solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (K)						
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.0m.e./L	20.m.e./L
1	44.3	41.6	39.8	42.0	43.1	47.0	43.8
2	41.9	46.9	46.8	42.3	40.3	39.4	46.2
3	46.9	51.1	52.1	43.3	47.5	48.4	47.4
4	49.3	38.3	54.8	40.9	50.1	50.5	39.0
Mean	45.6	44.5	48.4	42.1	45.25	46.3	44.1

L.S.D. at 5% level = 6.18

L.S.D. at 1% level = 8.46

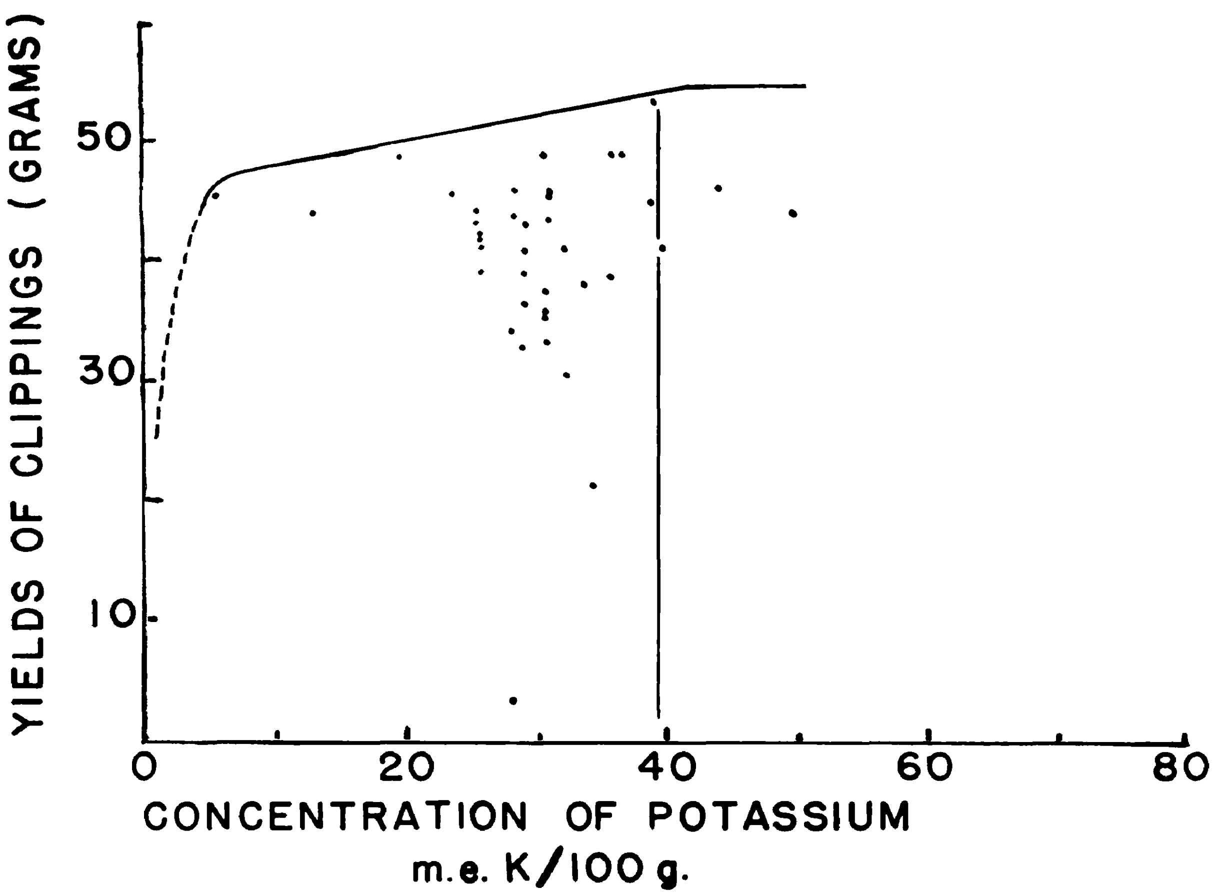

FIGURE 3. The relationship between the concentration of potassium (on a dry weight basis) and yields of clippings.

TABLE 10. Effects of various levels of calcium in the nutrient solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (Ca)						
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.om.e./L	15.om.e./L	20.om.e./L
1	44.1	38.5	35.4	35.7	46.0	43.9	37.9
2	22.6	48.5	33.9	46.4	48.6	37.4	36.1
3	26.4	45.5	37.2	49.7	43.3	49.0	41.3
4	48.1	48.5	49.3	46.6	45.8	43.8	49.0
Mean	35.3	45.25	38.95	44.6	45.63	43.53	41.08

L.S.D. at 5% level = 9.33

L.S.D. at 1% level = 12.78

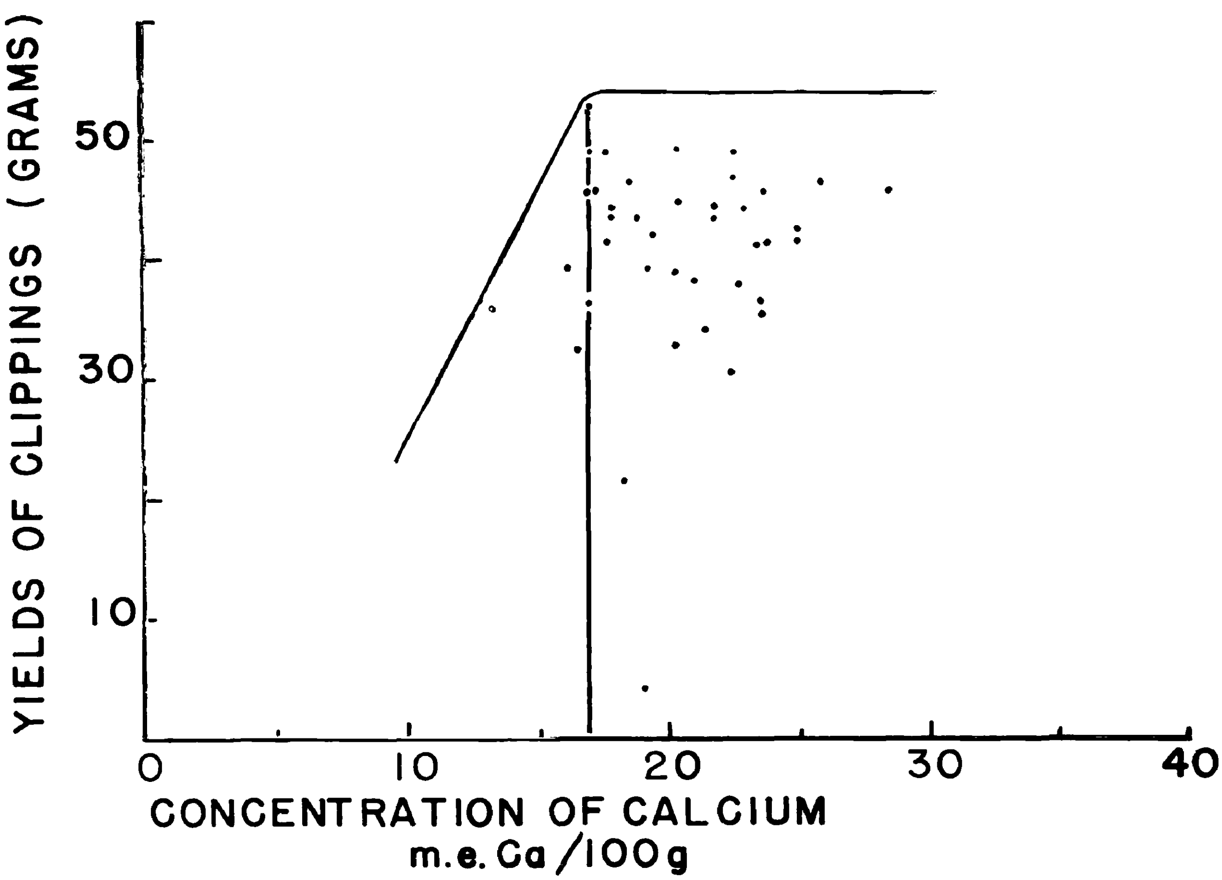

FIGURE 4. The relationship between the concentration of calcium (on a dry weight basis) and yields of clippings.

concentrations of calcium within the leaves and the yields of clippings. It may be seen from this graph that most of the concentrations of calcium obtained in this experiment were in the sufficiency range. The three values which were below the "sufficiency" level are regarded as insufficient evidence upon which to base an assumption that calcium will limit vegative growth of Zoysia at concentrations below 17.0 m.e.Ca per 100 grams of dry matter.

Effects of Magnesium Upon Yields of Clippings

Yields of clippings of plants grown with varying levels of magnesium are given in table 11. The analysis of variance for these data is given in Appendix table 5. There is a trend toward lower clipping yields as the level of magnesium in the nutrient solution was increased. The fact that yields from the pots supplied with the lowest rate of magnesium (0.05 m.e. Mg/L) were higher at the 5 percent level for significance, than yields from pots supplied with the fourth rate of magnesium (2.0 m.e. Mg/L), indicates that magnesium could not be considered to be one of the factors limiting growth under the conditions of this experiment.

Figure 5 is a graphic presentation of the relationships between the levels of magnesium in the leaves and yields of clippings. The lowest value for concentration of magnesium in clippings is 1.07 m.e. of magnesium per 100 grams of dry matter. That this level of magnesium is sufficient to produce clipping yields which are among the highest in the experiment is evidence that for leaf growth Zoysia has a very low magnesium requirement. It may be assumed

TABLE 11. Effects of various levels of magnesium levels in the nutrients solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (Mg)						
	0.05m.e./L	0.2m.e./L	1.om.e./L	2.om.e./L	5.om.e./L	7.om.e./L	10.om.e./L
1	37.4	38.2	39.2	32.6	46.4	40.8	37.9
2	51.7	38.9	34.2	38.6	31.1	33.8	29.4
3	46.6	51.5	48.1	26.6	43.0	43.3	40.4
4	51.0	45.8	48.2	38.5	32.0	37.2	37.8
Mean	46.68	43.6	42.43	34.08	38.1	38.78	36.38

L.S.D. at 5% level = 8.95

L.S.D. at 1% level = 12.125

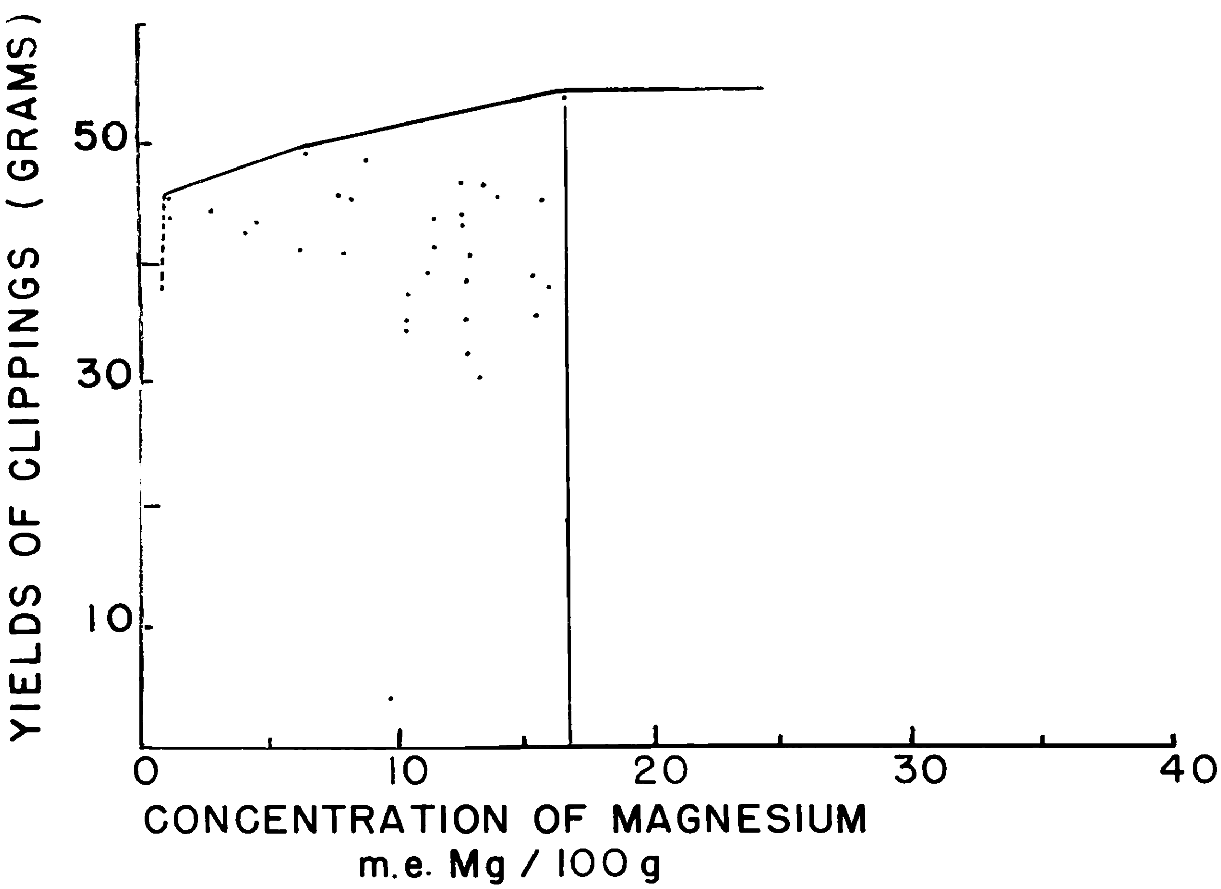

FIGURE 5. The relationship between the concentration of magnesium (on a dry weight basis) and yields of clippings.

that magnesium would seldom be a factor limiting vegetative growth under field conditions.

Effects of Boron Upon Yields of Clippings

Clipping yields from pots of Zoysia supplied with varying levels of boron are shown in table 12. The analysis of variance for these data may be found in Appendix table 6. There were no significant differences in yield of clippings harvested from pots receiving varying levels of boron.

The relationship between levels of boron within the leaves of Zoysia and yields of clippings is presented in figure 6. It appears that boron is relatively unimportant, within the range of concentrations found in this experiment, in its effect upon the vegetative growth of Zoysia.

Weights of Crowns

The crown of a turf grass plant as defined in the foregoing section describing materials and methods, represents the turf that remains after mowing or clipping. The weight of the crown is therefore a good numerical value to indicate the density of the turf. Density of turf is one of the most important factors determining turf quality. Weights of crowns in relation to variations in levels of the nutrient elements included in this study are reported and discussed in the following paragraphs.

Effects of Nitrogen Upon Weights of Crowns

The weights of crowns obtained from pots receiving different levels of nitrogen are reported in table 13. The analysis of variance for these data is shown in Appendix

TABLE 12. Effects of various levels of boron in the nutrient solution upon clipping yields. Yields are expressed in grams of dry matter.

Blocks	Levels of Treatment (Boron)						
	0.1p.p.m.	0.3p.p.m.	0.4p.p.m.	0.5p.p.m.	1.0p.p.m.	2.0p.p.m.	5.0p.p.m.
1	19.1	41.8	34.8	41.2	36.1	45.5	32.9
2	27.3	40.0	38.1	50.2	31.1	40.4	27.9
3	30.2	28.4	37.9	37.2	46.4	45.5	42.1
4	44.0	19.9	19.7	35.5	36.4	33.8	38.4
Mean	30.15	32.53	32.63	41.03	37.5	41.3	35.33

L.S.D. at 5% level = 11.99

L.S.D. at 1% level = 16.43

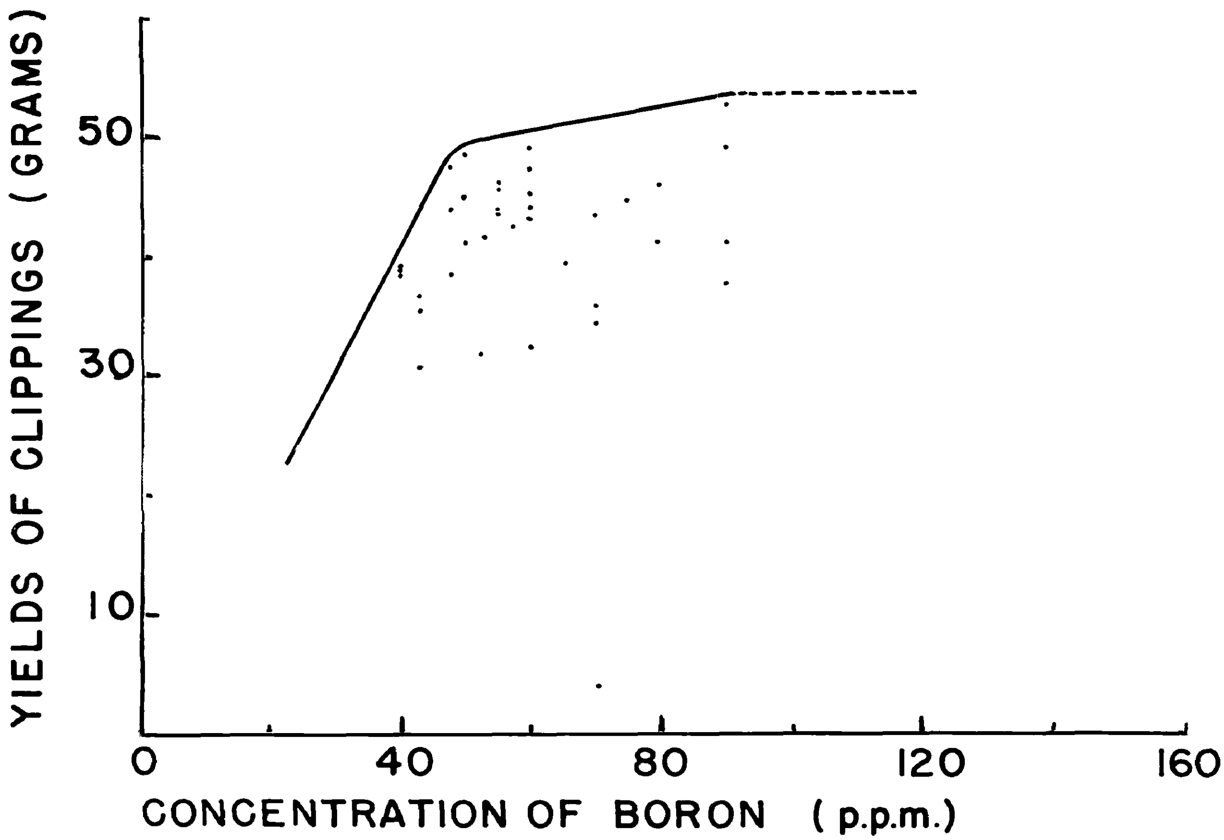

FIGURE 6. The relationship between the concentration of boron (on a dry weight basis) and yields of clippings.

TABLE 13. Effects of various levels of nitrogen in the nutrient solution upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (NO_3)					
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.0m.e./L
1	27	24	28	29	24	21
2	20	29	36	25	27	24
3	20	30	35	31	26	32
4	23	29	36	31	29	27
Mean	22.5	28	33.75	29	26.5	26

L.S.D. at 5% level = 5.42

L.S.D. at 1% level = 7.5

table 7. The third level of nitrogen (2.0 m.e.NO_3/L) produced a turf with a crown having a significantly greater weight than that produced by any other level of nitrogen in the study, with the exception of the fourth level (5.0 m.e.NO_3/L). The crowns produced by the fourth level of nitrogen were not significantly heavier than crowns produced by the other levels.

These data illustrate the fact that yields of clippings and density of turf are not necessarily correlated. While higher levels of nitrogen produced correspondingly higher yields of clippings, turf density did not follow the same pattern.

The relationship between weights of crowns and concentrations of nitrogen found within the clippings is shown in figure 7. The points on this graph represent the weights of crowns and concentrations of nitrogen found in all the pots in the experiment. Most of the points therefore represent variations in levels of nutrient elements other than nitrogen. This figure indicates that very low levels and very high levels of nitrogen both produce less desirable turf from the standpoint of density than is produced by the application of median levels of nitrogen.

Effects of Phosphorus Upon Weights of Crowns.

The weights of crowns from pots of turf grown under varying levels of phosphorus in the nutrient solution are shown in table 14. The analysis of variance for the data in this table may be found in Appendix table 8. The weights of

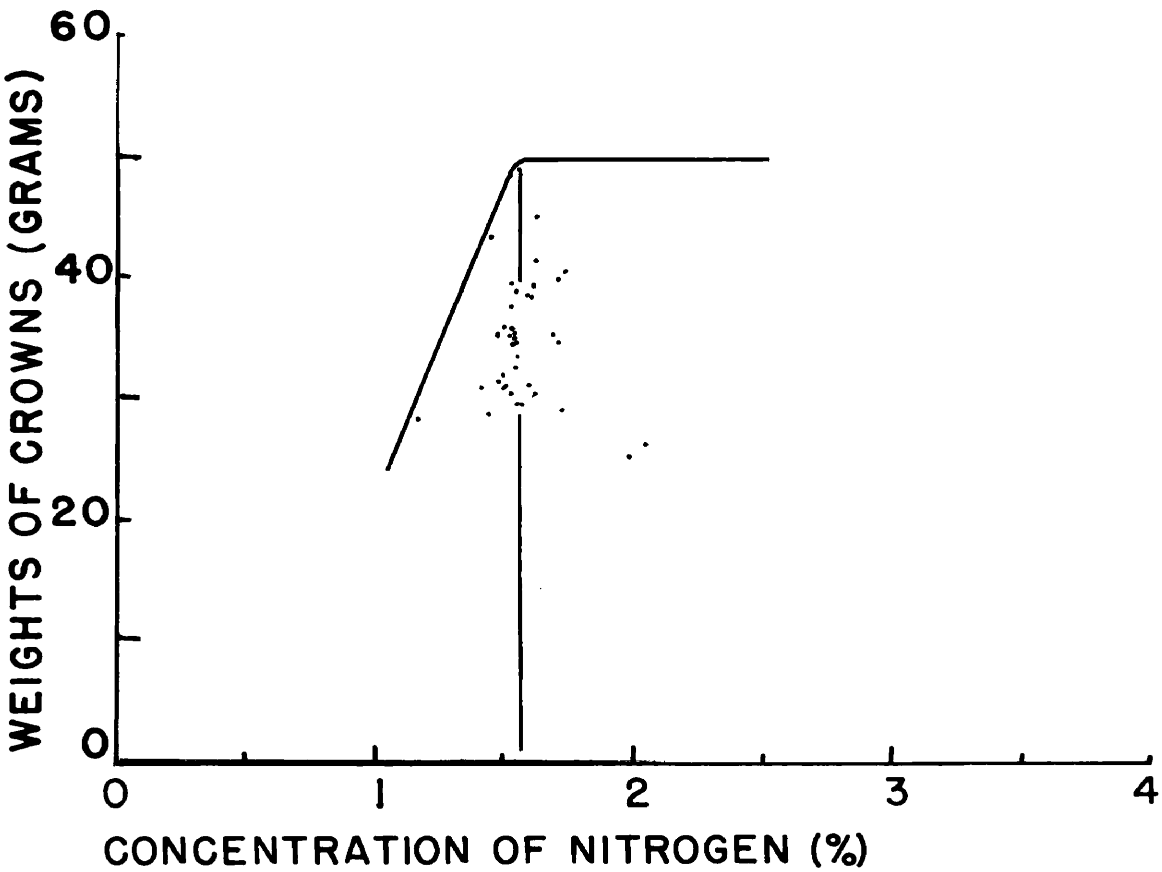

FIGURE 7. The relationship between the concentration of nitrogen (on a dry weight basis) and weights of crowns.

TABLE 14. Effects of various levels of phosphorus on the nutrient solution upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (H_2PO_4)						
	0.05m.e./L	0.2m.e./L	1.0m.e./L	2.0m.e./L	5.0m.e./L	7.0m.e./L	10.m.e/L
1	38	43	37	30	38	31	29
2	44	39	31	29	32	41	44
3	30	39	38	31	34	32	34
4	42	38	33	37	32	33	39
Mean	38.5	39.75	34.75	31.75	34	34.25	36.5

L.S.D. at 5% level = 6.767

L.S.D. at 1% level = 9.27

crowns from pots receiving the fourth level of phosphorus (2.0m.e.H_2PO_4/L), were significantly lower than those from pots receiving the first and second levels of phosphorus (0.05 and 0.2 m.e./L, respectively), were significantly lower than those from pots receiving the first and second levels of phosphorus (0.05 and 0.2 m.e./L, respectively). Weights of crowns from other pots fell between these values and were not significantly different. Inasmuch as the median level of phosphorus produced the poorest turf insofar as density is concerned, it must be assumed that the phosphorus content of Zoysia is not important in determining turf density as long as the phosphorus concentration is within the range found in this experiment. The range of concentration is from 1.45 to 38.73 m.e. per 100 grams of dry weight in clippings harvested on October 25, 1949.

Figure 8 shows the relationship between phosphorus concentration in clippings and the density of crowns as indicated by their dry weight.

Effects of Potassium Upon Weights of Crowns.

Table 15 contains the weights of crowns of plants grown under varying levels of potassium. The analysis of variance for these data may be found in Appendix table 9. The seventh level of potassium (20.0 m.e. of K/L), produced crowns which were barely significantly heavier (at the 5 percent level) than crowns produced by the second and third levels (0.5 m.e. and 2.0 m.e. of K/L, respectively). There were no other

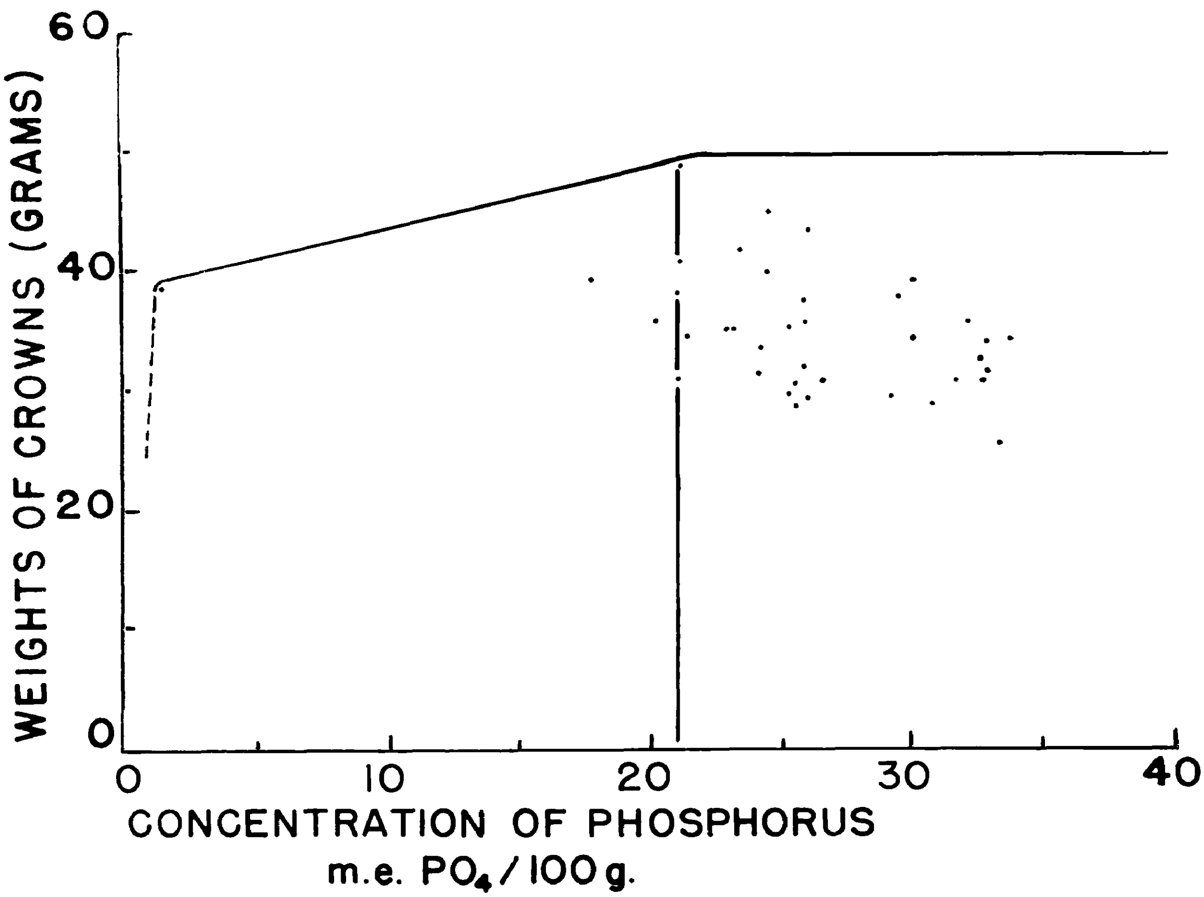

FIGURE 8. The relationship between the concentration of phosphorus (on a dry weight basis) and weights of crowns.

TABLE 15. Effects of various levels of potassium in the nutrient solution upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (K)						
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.0m.e./L	20.0me/L
1	31	32	33	35	32	37	47
2	32	31	33	34	40	34	35
3	36	30	30	28	35	25	34
4	43	28	25	31	38	45	36
Mean	35.5	30.25	30.25	32	36.25	35.25	38.0

L.S.D. at 5% level = 7.08

L.S.D. at 1% level = 9.69

significant differences in weights of crowns. Chemical analyses of the clippings discloses that the range of potassium is from 5.1 to 48.7 m.e.K per 100 grams of dry weight in clippings harvested on October 25, 1949. Inasmuch as these two values are associated with yields which are not significantly different, one must assume that potassium concentrations falling within the range found in this experiment are not important from the standpoint of turf density.

The relationship between crown weights and potassium concentration in clippings is presented graphically in figure 9.

Effects of Calcium Upon Weights of Crowns.

The weights of crowns from pots supplied with varying levels of calcium are presented in table 16. The accompanying analysis of variance for these data is shown in Appendix table 10. There is a general trend toward an increase in the weights of crowns as the calcium supply is increased. The fact that increasing amounts of calcium produce a corresponding increase in density, whereas there was no corresponding increase in clipping yields, is further evidence that yields of clippings are of little value as a measure of turf quality.

The relationship between crown weights and calcium concentration in the clippings is shown in figure 10. This relationship indicates that the higher levels of calcium are of value in producing dense turf of *Zoysia japonica*.

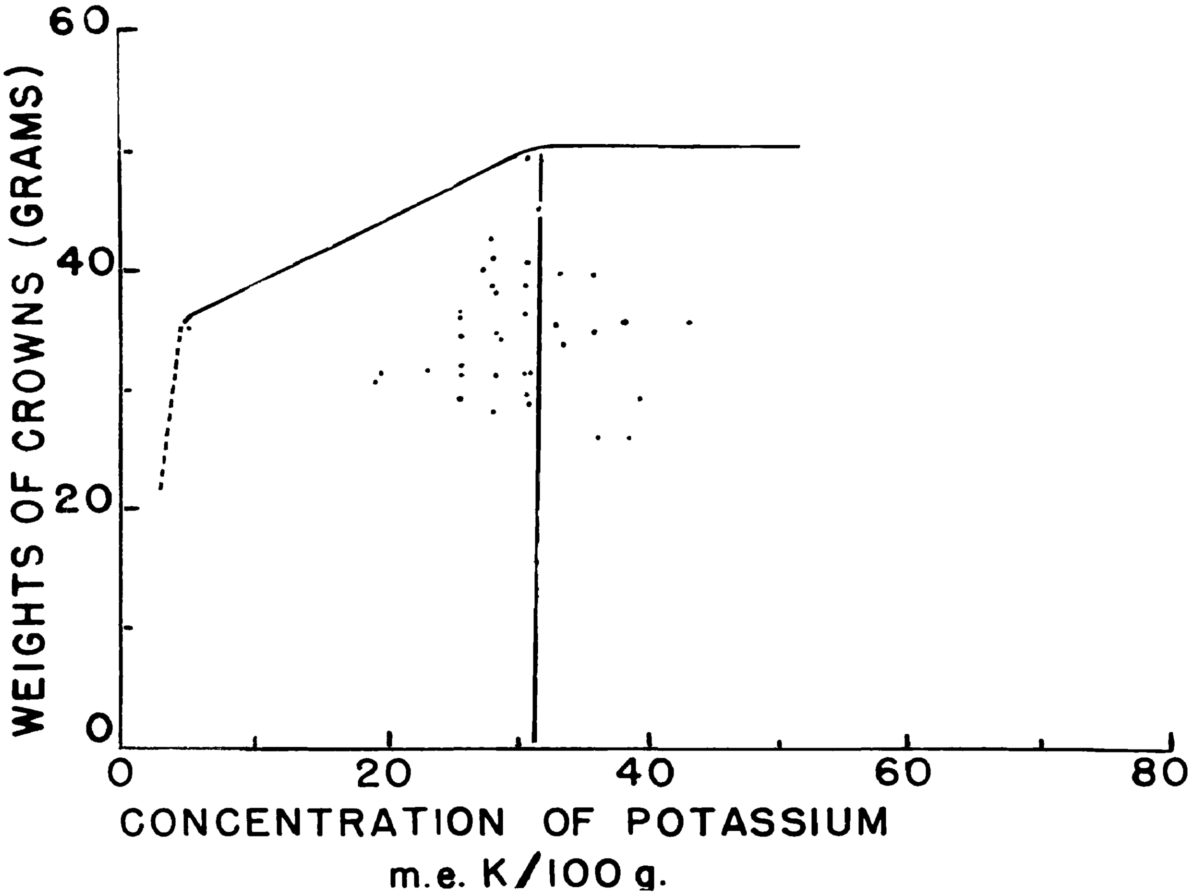

FIGURE 9. The relationship between the concentration of potassium (on a dry weight basis) and weights of crowns.

TABLE 16. Effects of various levels of calcium in the nutrient solution upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (Ca)						
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.om.e./L	20.0m.e/L
1	37	28	27	32	54	46	46
2	39	39	30	49	51	38	59
3	25	34	32	38	43	41	33
4	27	29	30	41	47	38	42
Mean	32	32.5	29.75	40	48.75	40.75	45

L.S.D. at 5% level = 8.257

L.S.D. at 1% level = 11.31

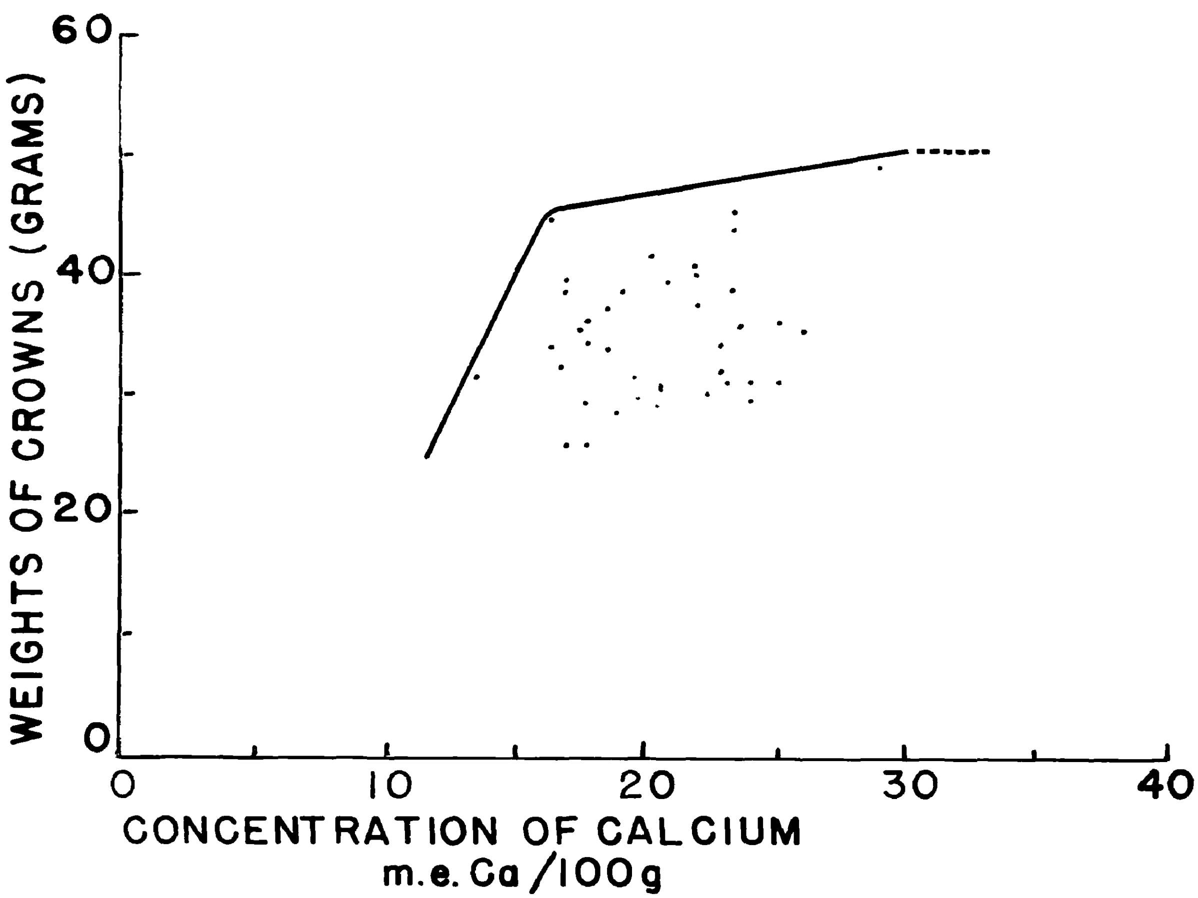

FIGURE 10. The relationship between the concentration of calcium (on a dry weight basis) and weights of crowns.

Effects of Magnesium Upon Weights of Crowns.

Table 17 shows the effects on weights of crowns of Zoysia plants produced by varying the levels of magnesium in the nutrient solution. The analysis of variance for these data is shown in Appendix table 11. As the magnesium level is increased there is a corresponding increase, with a few minor irregularities, in the weights of crowns produced. It has been previously stated that magnesium concentration is not important in the production of clippings. It must be considered important, however, in the production of density in turf.

Figure 11 is a graph which indicates the relationship existing between magnesium concentration in leaves of Zoysia and weights of crowns.

Effects of Boron Upon Weights of Crowns.

The weights of crowns of Zoysia plants grown by the use of nutrient solutions containing various levels of boron are shown in table 18. Appendix table 12 contains the analysis of variance of these data. The lowest rate of boron (0.1 p.p.m.) produced crowns which were significantly heavier (at the 5 percent level) than crowns produced by the third level of boron (0.4 p.p.m.). However, none of the other differences are significant. It is assumed that within the range of boron studied in this experiment, it is relatively unimportant insofar as turf density is concerned.

Figure 12 is a graphic presentation of the relationship of boron concentration in the clippings and the weights of crowns produced.

TABLE 17. Effects of various levels of magnesium upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (Mg)						
	0.05m.e./L	0.2m.e./L	1.0m.e./L	2.0m.e./L	5.0m.e./L	7.0m.e./L	10.0m.e./L
1	44	33	39	40	39	45	47
2	36	40	37	44	44	45	41
3	34	40	37	29	34	37	42
4	33	39	31	37	41	41	44
Mean	36.75	38	36	37.5	39.5	42	43.5

L.S.D. at 5% level = 3.97

L.S.D. at 1% level = 5.44

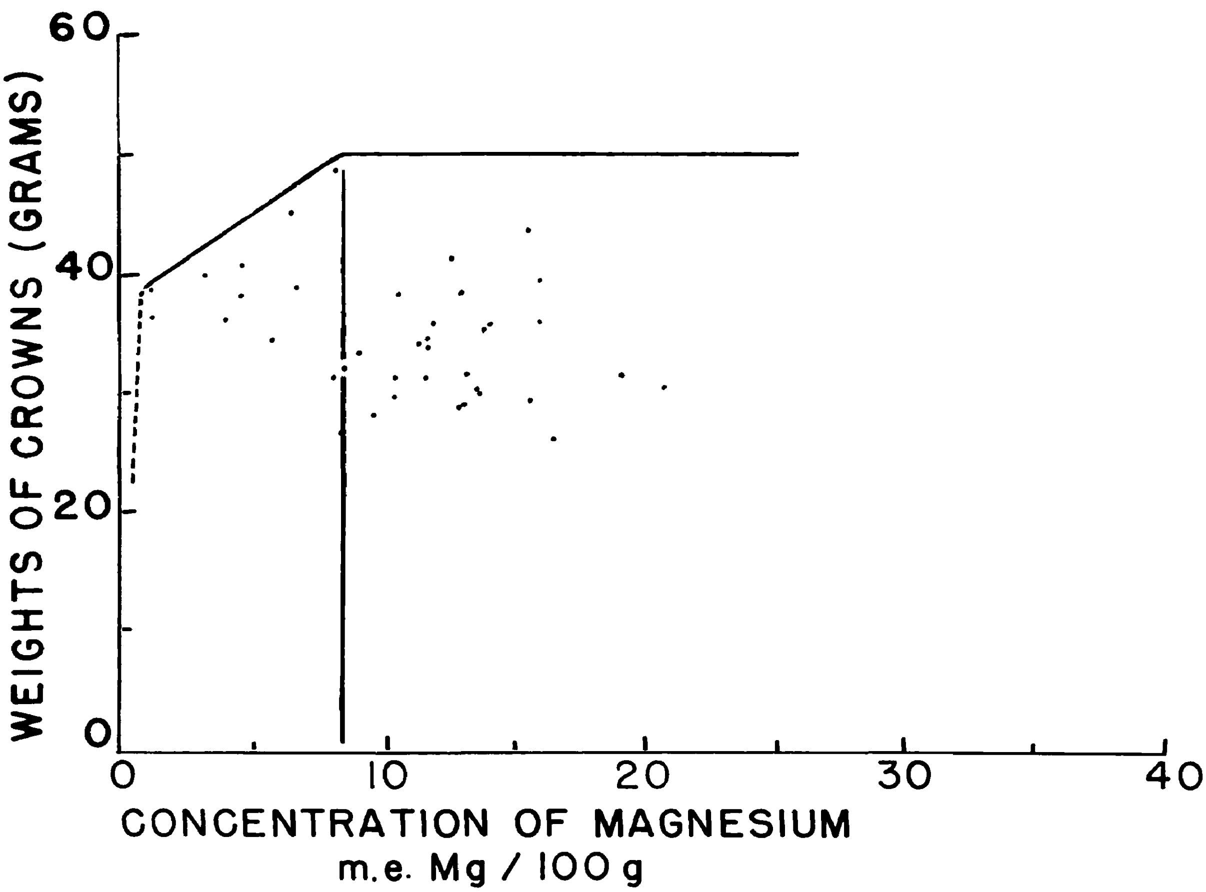

FIGURE 11. The relationship between the concentration of magnesium (on a dry weight basis) and weights of crowns.

TABLE 18. Effects of various levels of boron in the nutrient solution upon weights of crowns. Weights are expressed in grams of dry matter.

Blocks	Levels of Treatment (Boron)						
	0.1p.p.m.	0.3p.p.m.	0.4p.p.m.	0.5.p.p.m.	1.0p.p.m.	2.0p.p.m.	5.0p.p.m.
1	34	43	33	36	30	32	33
2	32	35	26	31	32	36	25
3	34	34	30	32	32	26	33
4	40	26	24	26	31	31	28
Mean	35	34.5	28.25	31.25	31.25	31.25	29.75

L.S.D. at 5% level = 5.94

L.S.D. at 1% level = 8.14

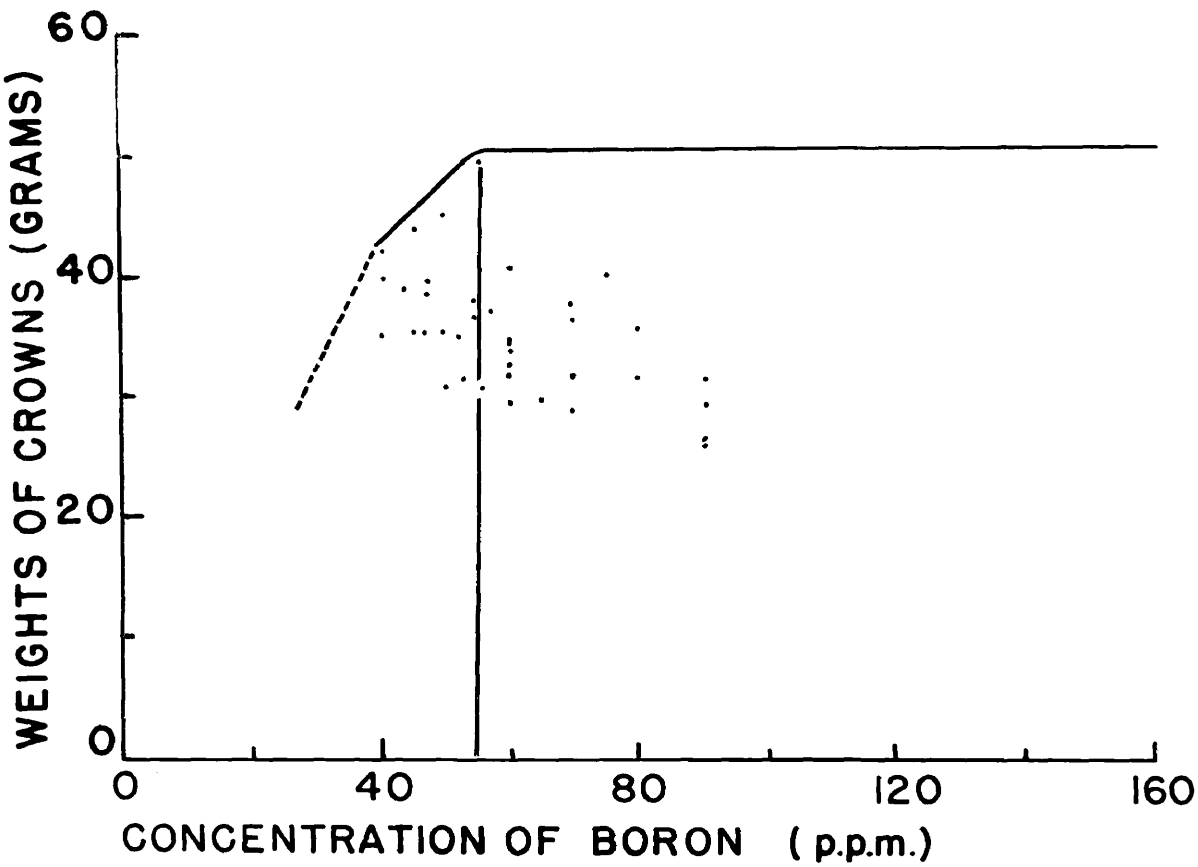

FIGURE 12. The relationship between the concentration of boron (on a dry weight basis) and weights of crowns.

Yield of Seed Heads

Inasmuch as this study was initiated primarily for the purpose of obtaining information with regard to the nutritional requirements of Zoysia for optimal seed production, the following results are considered to be relatively more important than those already presented. Seed head production as effected by the various nutrient elements will be discussed separately for each element.

Effects of Nitrogen Upon Seed Head Production

The effects of various levels of nitrogen in the nutrient solution upon the production of seed heads is shown in table 19. The corresponding analysis of variance of these data may be found in Appendix table 13. The third and fourth levels of nitrogen (2.0 m.e. and 5.0 m.e. of NO_3 per liter, respectively) produced significantly greater numbers of seed heads than did other levels of nitrogen used in this experiment. There was not a significant difference between the numbers of seed heads produced by the third and fourth nitrogen levels. These data corroborate earlier findings (27) with reference to the role of nitrogen in relation to fruitfulness in plants.

Figure 13 is a graphic presentation of the relationship between the concentration of total nitrogen in clippings and numbers of seed heads produced. Figure 14 shows a representative block of the nitrogen series at the time of flowering.

It may be concluded from these data that a total nitrogen content of approximately 1.56 percent of the dry weight is optimal for seed production under the conditions governing this experiment.

TABLE 19. Effects of various levels of nitrogen in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (NO_3)					
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.om.e./L	10.om.e./L	15.om.e./L
1	11	7	17	19	1	2
2	6	13	31	36	13	2
3	9	17	30	31	1	4
4	9	12	44	60	20	14
Mean	8.75	12.25	30.5	36.5	8.75	5.5

L.S.D. at 5% level = 10.88

L.S.D. at 1% level = 15.05

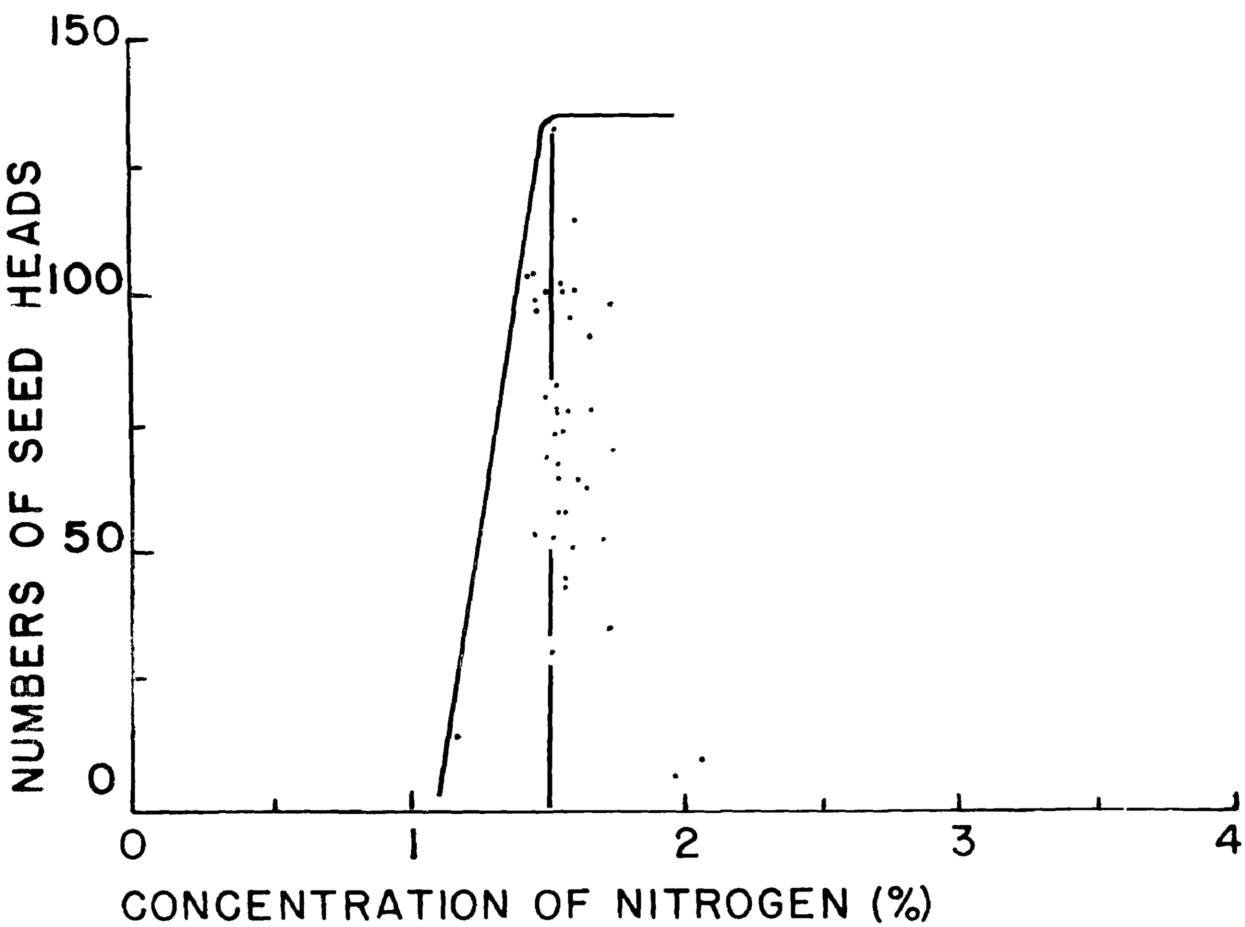

FIGURE 13. The relationship between concentration of nitrogen (on a dry weight basis) and numbers of seed heads produced.

FIGURE 14. Effects of various levels of nitrogen upon seed head production in *Zoysia japonica*.

Effects of Phosphorus Upon Seed Head Production

The effects of various levels of phosphorus in the nutrient solution upon production of seed heads of Zoysia are shown in table 20. The analysis of variance for these data is given in Appendix table 14. The fifth level of phosphorus (5.0 m.e. H_2PO_4 per liter) produced the greatest number of seed heads. This value was significantly greater (at the 1 percent level) than that for the first and third levels of phosphorus (0.05 m.e. and 1.0 m.e. H_2PO_4 per liter, respectively). However, there were no other significant differences.

Figure 15 is a graph showing the relationship between the concentration of phosphorus in the clippings and the number of seed heads produced. Figure 16 is a picture of a representative block in the phosphorus series at the time of flowering.

The data presented would indicate that the concentration which characterizes "sufficiency" of phosphorus in clippings for maximum seed production, is approximately 25.0 m.e. PO_4 per 100 grams of dry matter. It is recognized that this concentration denoting "sufficiency" may vary under conditions other than those prevailing during this experiment.

Effects of Potassium on Seed Head Production

The effects of various levels of potassium in the nutrient solution upon the numbers of seed heads produced is shown in table 21. The analysis of variance for these data is presented in Appendix table 15. Pots of Zoysia supplied with the lowest level of potassium (0.1 m.e. K/L) produced the greatest numbers of seed heads. The fact that this value is significantly greater

TABLE 20. Effects of various levels of phosphorus in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (H_2PO_4)						
	0.05m.e./L	0.2m.e./L	1.0m.e./L	2.om.e./L	5.om.e./L	7.om.e./L	10.om.e./L
1	36	54	32	40	87	67	45
2	33	49	32	83	89	70	48
3	45	53	55	89	61	90	72
4	47	92	61	82	91	86	107
Mean	40.25	62	45	73.5	82	78.25	68

L.S.D. at the 5% level = 21.11

L.S.D. at the 1% level = 28.92

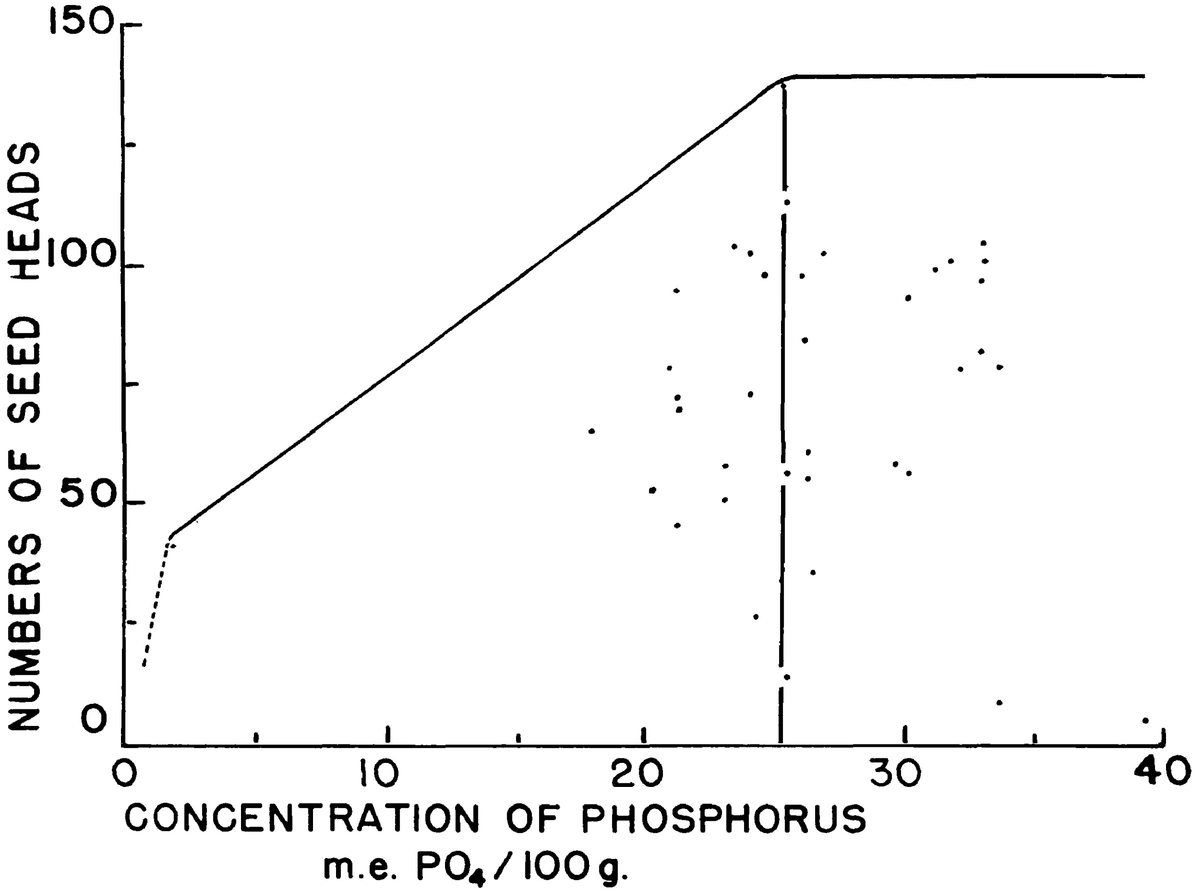

Fig. 15. The relationship between the concentration of phosphorus on a dry weight basis) and numbers of seed heads produced.

FIGURE 16. Effects of various levels of phosphorus upon seed head production in *Zoysia japonica*.

TABLE 21. Effects of various levels of potassium in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (K)						
	0.1m.e./L	0.5m.e./L	2.om.e./L	5.om.e./L	10.om.e./L	15.om.e./L	20.om.e./L
1	127	83	114	95	62	87	86
2	95	99	97	115	45	52	100
3	101	76	78	87	56	57	73
4	95	111	115	92	46	39	58
Mean	104.25	92.25	101	97.25	52.25	58.75	79.25

L.S.D. at the 5% level = 22.2

L.S.D. at the 1% level = 30.4

than values obtained for some of the pots which were supplied with potassium at higher levels is not considered to be of great importance. The most important consideration is that the lowest level of potassium is still within the range of "sufficiency" for potassium in relation to seed production.

Figure 17 is a graph showing the relationship of potassium concentration in clippings to the numbers of seed heads produced. Figure 18 is a photograph of a representative block from the potassium series. The photograph was taken when flowering was at its peak.

The data gained from this experiment indicate that a concentration of potassium in clippings as low as 5.12 m.e. of K per 100 grams of dry matter (0.2 percent K) was sufficient to produce 104 seed heads per pot. This production was exceeded by only four other treatments in the entire experiment.

Effects of Calcium on Seed Head Production

The effects of various levels of calcium in the nutrient solution upon the numbers of seed heads produced is shown in table 22. The analysis of variance for these data is shown in Appendix table 16. Table 22 indicates that the yields of seed heads resulting from various levels of calcium in the nutrient solutions are characterized by irregularity. Levels 1, 2, 4, and 7, produced yields that are significantly higher than those produced by levels 3, 5, and 6. The reason for such irregularity is not apparent and it is perhaps not highly important. It is important to note that, as was the case with potassium, the

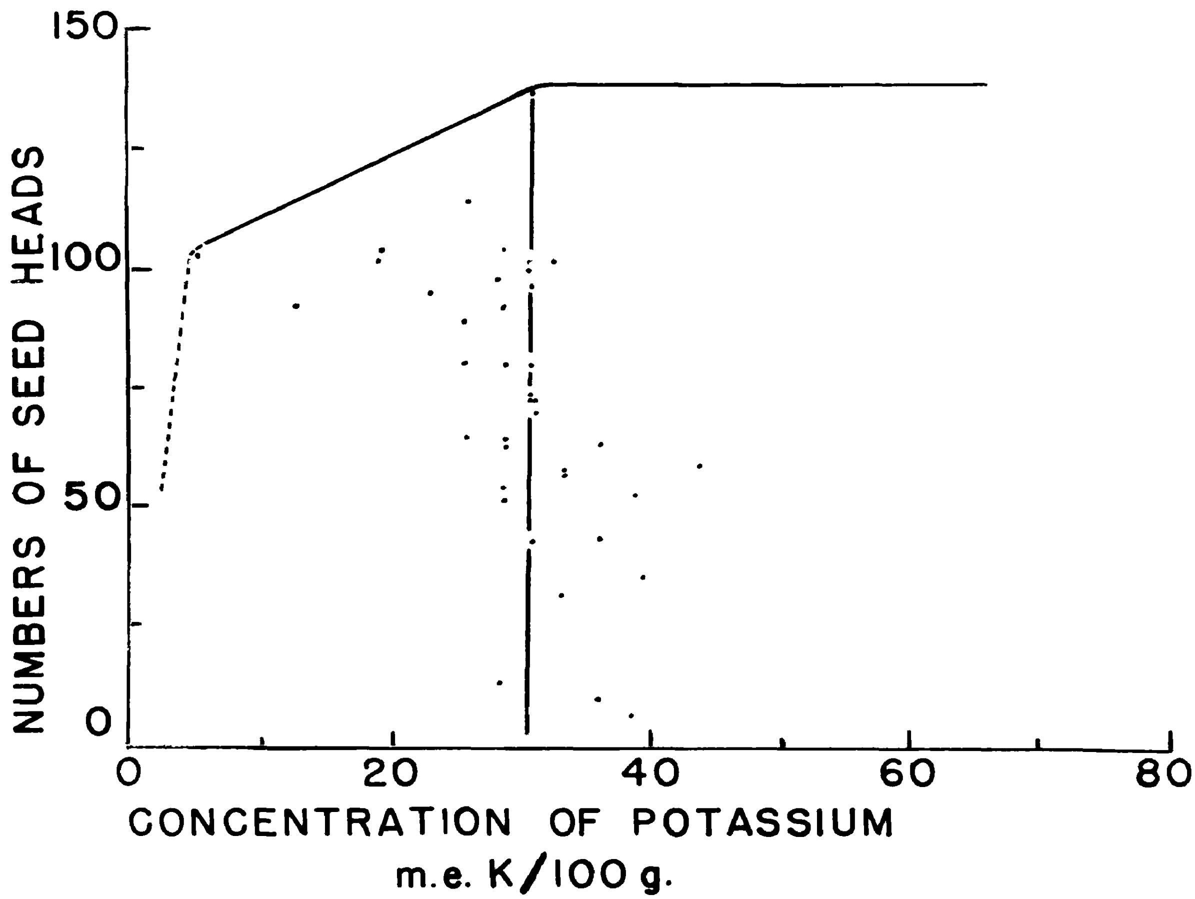

FIGURE 17. The relationship between the concentration of potassium (on a dry weight basis) and numbers of seed heads produced.

FIGURE 18. Effects of various levels of potassium upon seed head production in *Zoysia japonica*.

TABLE 22. Effects of various levels of calcium in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (Ca)						
	0.1m.e./L	0.5m.e./L	2.0m.e./L	5.0m.e./L	10.0m.e./L	15.0m.e./L	20.0m.e./L
1	110	94	98	121	83	95	110
2	96	80	46	103	100	73	105
3	87	82	68	86	71	55	99
4	108	125	86	82	36	60	97
Mean	100.25	95.25	74.5	98	72.5	70.75	102.75

L.S.D. at the 5% level = 20.42

L.S.D. at the 1% level = 27.97

lowest level of calcium supplied in the nutrient solution was sufficient to produce the maximal yield of seed. Figure 19 presents graphically the relationship between concentration of calcium in the clippings and the numbers of seed heads produced. Figure 20 is a photograph of one block of the calcium series at flowering time.

The lowest concentration of calcium found in the clippings harvested on October 25, 1949 was 13.15 m.e. of Ca per 100 grams of dry weight. This concentration of calcium produced a yield of seed heads which was near the maximum for the experiment.

Effects of Magnesium Upon Seed Head Production

The effects of various levels of magnesium in the nutrient solution upon the numbers of seed heads produced is shown in table 23. The corresponding analysis of variance for these data may be found in Appendix table 17. The greatest number of seed heads was produced by pots of Zoysia receiving the third level of magnesium (1.0 m.e. Mg/L). This value was significantly greater (at the 1 percent level) than values obtained for levels 5, 6, and 7 (5.0, 7.0, and 10.0 m.e. Mg/L respectively).

Figure 21 is a graphic presentation of the relationship between concentration of magnesium in the clippings and the number of seed heads produced. It may be noted on this graph that the point characterizing "sufficiency" of magnesium for seed head production under the conditions of this experiment is approximately 10.5 m.e. of magnesium per 100 grams of dry matter.

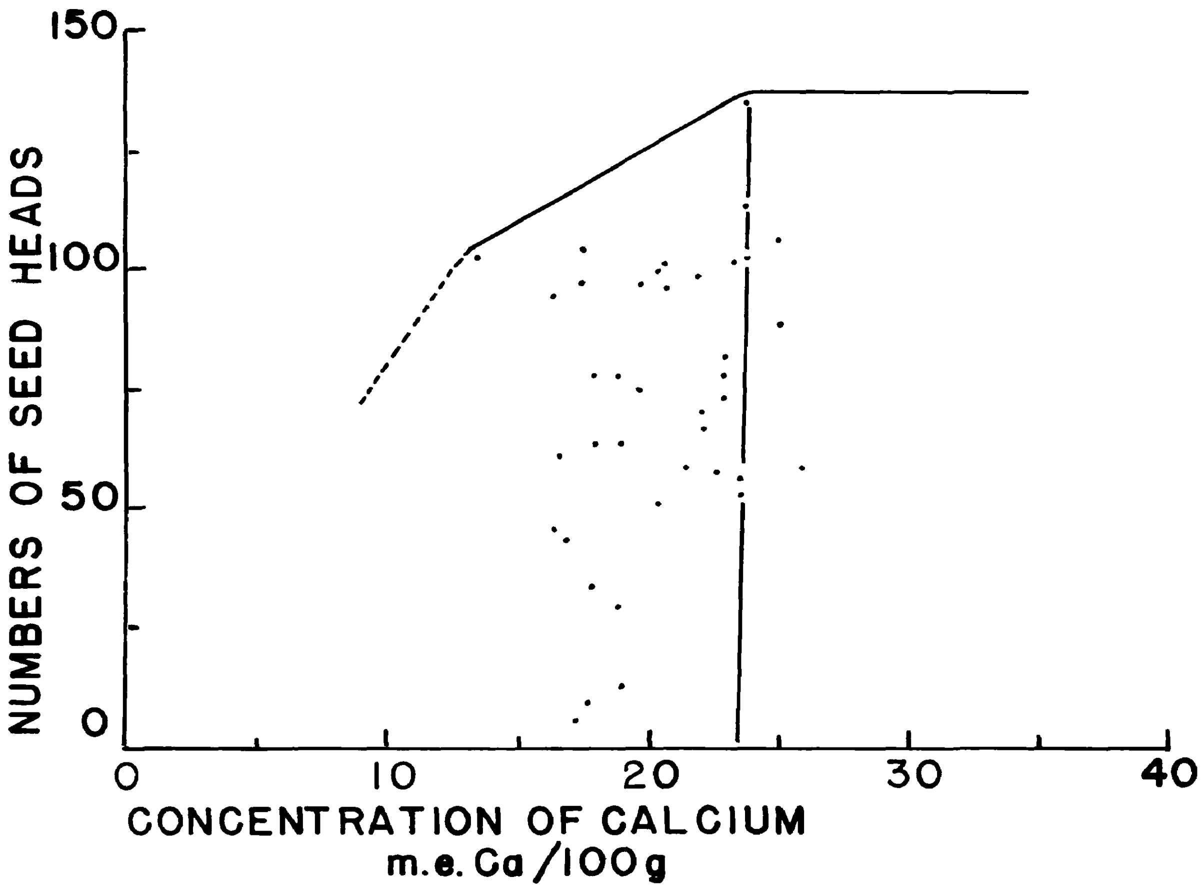

FIGURE 19. The relationship between the concentration of calcium (on a dry weight basis) and numbers of seed heads produced.

FIGURE 20. Effects of various levels of calcium upon seed head production in *Zoysia japonica*.

TABLE 23. Effects of various levels of magnesium in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (Mg)						
	0.o5m.e./L	0.2m.e./L	1.om.e./L	2.om.e./L	5.om.e./L	7.om.e./L	10.om.e./L
1	105	95	109	92	101	63	60
2	78	72	96	74	45	43	73
3	67	47	53	54	48	60	51
4	59	40	86	44	40	35	40
Mean	77.25	63.5	86	66	58.5	50.25	56

L.S.D. at the 5% level = 19.06

L.S.D. at the 1% level = 26.1

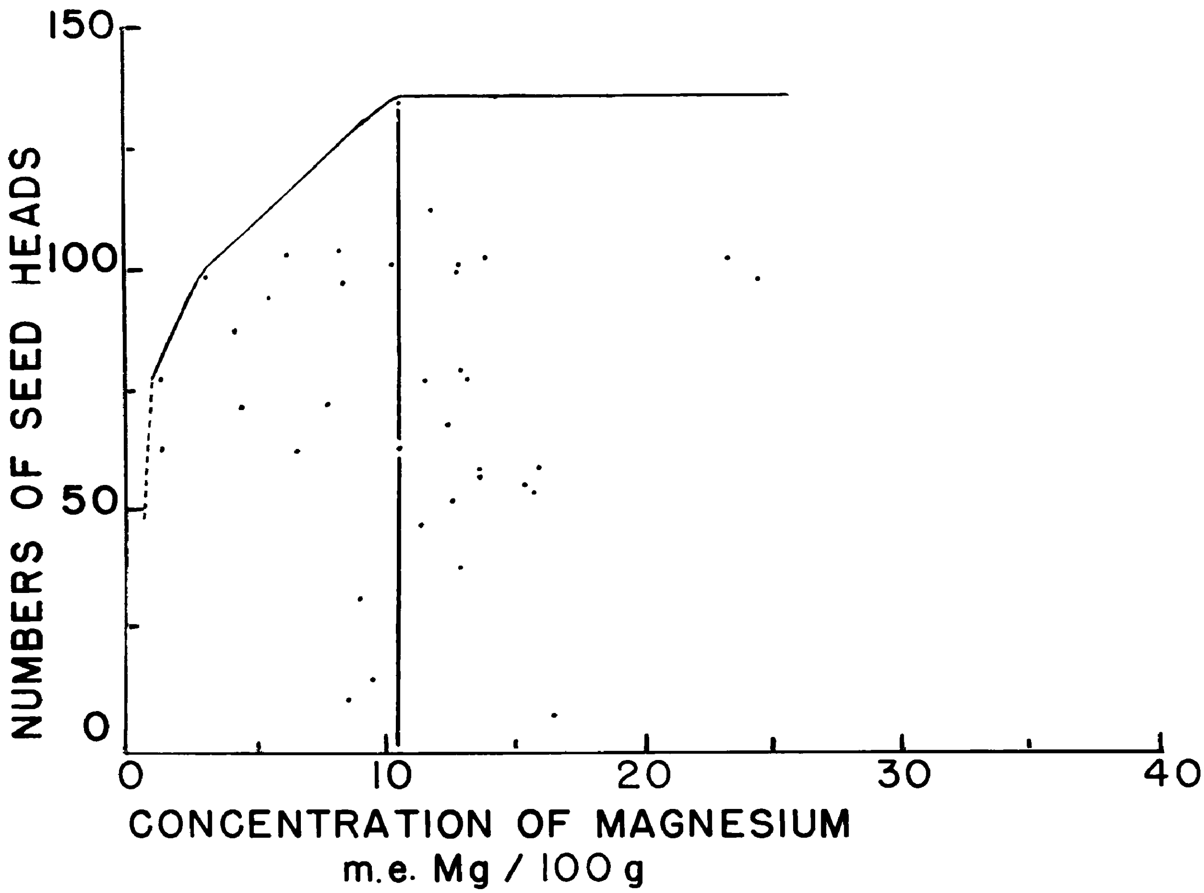

FIGURE 11. The relationship between the concentration of magnesium (on a dry weight basis) and numbers of seed heads produced.

FIGURE 22. Effects of various levels of magnesium upon seed head production in *Zoysia japonica*.

Figure 22 is a photograph showing a typical block from the magnesium series at the time of flowering.

Effects of Boron on Seed Head Production

The effects of various levels of boron in the nutrient solution upon the production of seed heads of Zoysia are shown in table 24. The analysis of variance for these data is shown in Appendix table 18. There is an increased production of seed heads which corresponds to the increases in boron concentration in the nutrient solution. The seventh level at which boron was supplied (5.0 p.p.m.)produced a significantly greater number of seed heads (at the 5 percent level) than did the fifth level (1.0 p.p.m.). It is apparent that boron is quite important in seed head production in Zoysia. Because of the fact that the highest level of boron produced a sizable, though not statistically significant, increase over the next lower level of boron it must be assumed that the point of "sufficiency" for seed head production has not been reached. The highest concentration of boron found in the clippings harvested October 25, 1949 was 160 p.p.m.

Figure 23 is a graph showing the relationship between boron concentration in clippings and the number of seed heads produced. Figure 24 is a photograph showing a typical block from the boron series at flowering time. The seed heads in this photograph appear to be taller at the higher boron levels. However, they were not found to attain a significantly greater average height than those seed heads produced at lower boron levels.

TABLE 24. Effects of various levels of boron in the nutrient solution upon the number of seed heads produced.

Blocks	Levels of Treatment (Boron)						
	0.1p.p.m.	0.3p.p.m.	0.4p.p.m.	0.5p.p.m.	1.0p.p.m.	2.0p.p.m.	5.op.p.m.
1	56	81	109	114	58	122	123
2	55	91	82	89	87	108	96
3	47	79	85	108	118	108	141
4	73	115	123	109	140	117	176
Mean	57.75	91.5	99.75	105	100.75	113.75	134

L.S.D. at the 5% level = 26.66

L.S.D. at the 1% level = 36.52

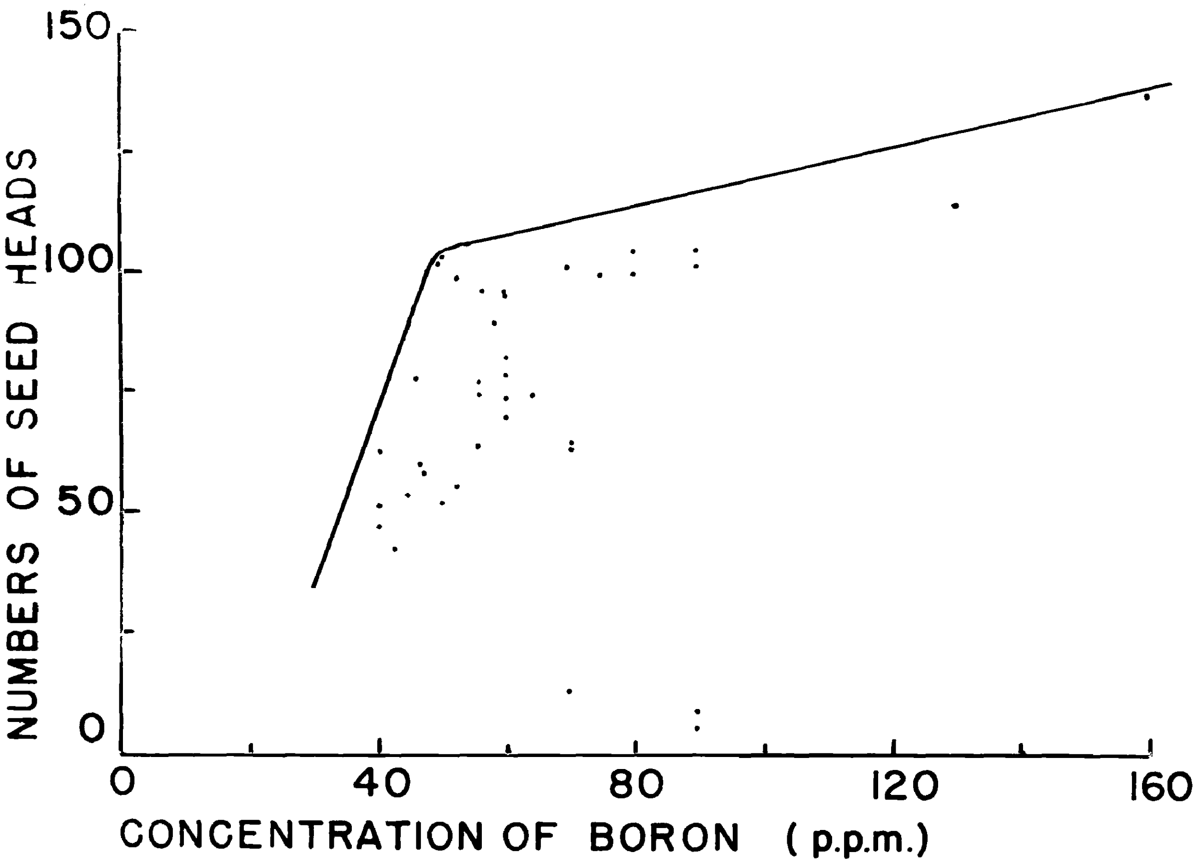

FIGURE 23. The relationship between concentration of boron (on a (dry weight basis) and numbers of seed heads produced.

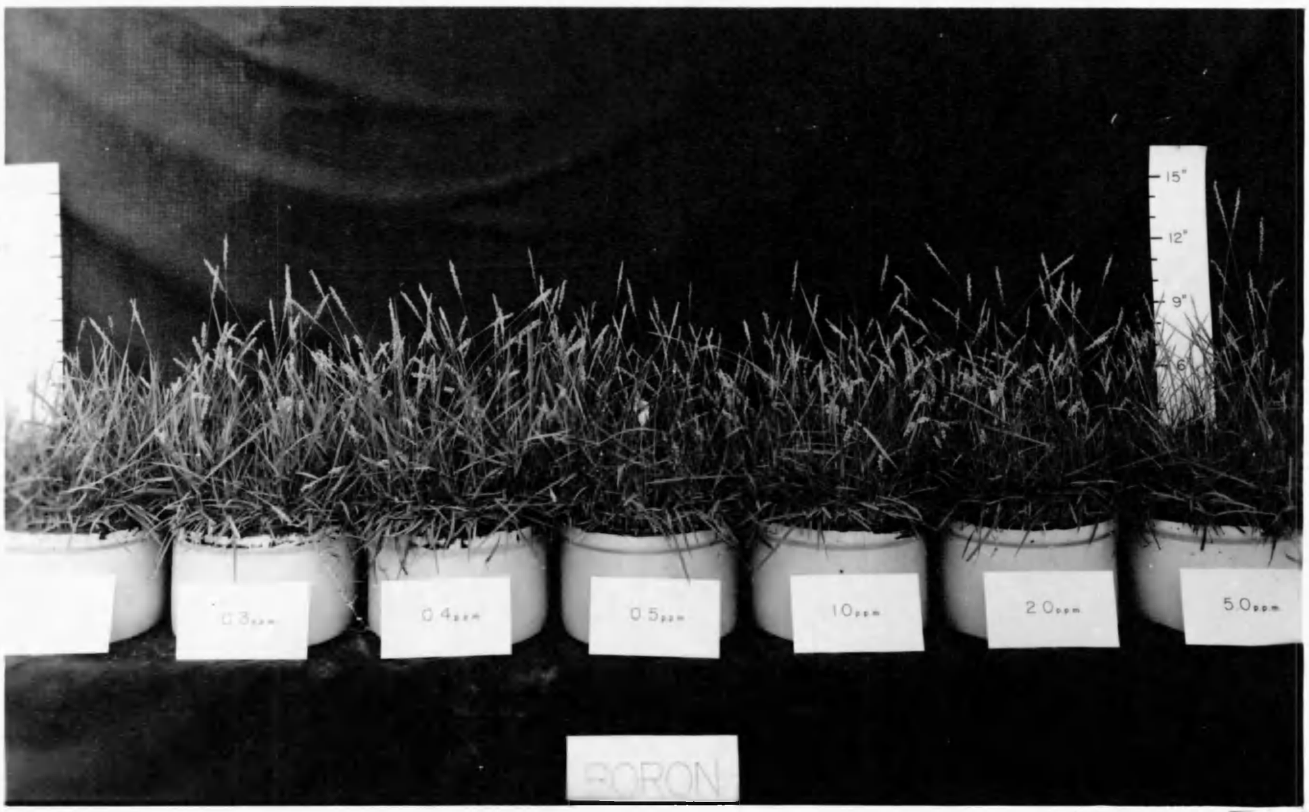

FIGURE 24. Effects of various levels of boron upon seed head production in *Zoysia japonica*.

SUMMARY AND CONCLUSIONS

The Z-52 strain of Zoysia japonica was grown in the greenhouse at Beltsville, Maryland, and was watered with nutrient solutions containing seven levels of six nutrient elements. The elements which were varied were nitrogen, phosphorus, potassium, calcium, magnesium, and boron. The study was arranged in six simple randomized block experiments; each experiment contained four replications of the seven treatments. The effects of various levels of each element were studied independently.

The results are reported for total clipping yields, for weights of crowns, and for numbers of seed heads produced at six levels of nitrogen and at seven levels of phosphorus, potassium, calcium, magnesium, and boron.

The data indicate that the following conclusions may be drawn from this experiment:

1. Variations in nitrogen levels are much more important than variations in the levels of any other element, within the ranges studied in this experiment, with respect to the production of clipping yields. Yields increased as nitrogen supply increased.

2. The minimal amounts of potassium, magnesium, and boron which were used in this experiment (o.1 and o.o5 m.e./L and o.1 p.p.m., respectively) were adequate to produce the maximal quantity of clippings.

3. Calcium and phosphorus appeared to limit the production of clippings only at relatively low concentrations (o.1 m.e.Ca/L. and o.o5 m.e. H_2PO_4/L.).

4. The level of nitrogen is important in determing the density of Zoysia turf as indicated by weights of crowns. The heaviest crowns produced in the nitrogen series corresponded to the clippings which contained

1.57 percent of total nitrogen (on a dry-weight basis).

5. Weights of crowns increased as the calcium concentration in the clippings increased.

6. There was a gradual increase in weights of crowns as the concentration of magnesium in the clippings increased.

7. The minimal amounts of phosphorus, potassium, and boron which were used (o.o5 and o.1 m.e./L., and o.1 p.p.m. respectively) under the conditions of this experiment appear to be adequate for the production of turf of maximal density.

8. Nitrogen is highly important in its effect upon the production of seed heads. The level of nitrogen "sufficiency" for seed head production appears to be approximatdly 1.56 percent of nitrogen (on a dry weight basis). Concentrations beyond approximately 1.75 percent of nitrogen in the clippings appear to be detrimental to seed head production.

9. The concentration of phosphorus in the clippings appears to have a marked influence upon the production of seed heads. The level of "sufficiency" in this experiment was approximately 24 milliequivalents of PO_4 in 100 grams of dry matter, (.25 percent P).

10. The addition of larger increments of potassium than the minimal level (o.1 m.e. of K/L.) in the nutrient solution failed to effect an increase in the yield of seed heads. On the contrary, lower seed yields were associated with concentrations of potassium above approximately 32.0 milliequivalents of K per 100 grams of dry matter, (1.25 percent K).

11. The lowest levels of calcium and magnesium in this experiment were apparently sufficient to produce maximal yields of seed heads.

12. Boron appears to be very important in the production of seed heads. The highest concentration of boron found in this experiment (160 p.p.m. of boron in dry matter) was associated with the highest production of seed heads.

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A P P E N D I X

APPENDIX TABLE 1. Analysis of variance on effects of various levels of nitrogen in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	65.16	21.72	1.17
Treatments	5	10,292.18	2,058.43	111.28**
Error	15	277.53	18.50	
Total	23	10,634.87		

APPENDIX TABLE 2. Analysis of variance on effects of various levels of phosphorus in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	253.97	84.65	4.44*
Treatments	6	540.68	90.11	4.73**
Error	18	342.79	19.04	
Total	27	1,137.44		

APPENDIX TABLE 3. Analysis of variance on effects of various levels of potassium in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	118.86	39.62	2.290
Treatments	6	90.79	15.13	1.14
Error	18	311.42	17.30	
Total	27	521.07		

APPENDIX TABLE 4. Analysis of variance on effects of various levels of calcium in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	279.13	93.04	2.36
Treatments	6	360.18	60.03	1.77
Error	18	709.62	39.42	
Total	27	1,348.93		

APPENDIX TABLE 5. Analysis of variance on the effects of various levels of magnesium in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	149.14	49.71	1.39
Treatments	6	466.58	77.76	2.18
Error	18	641.24	35.62	
Total	27	1,256.96		

APPENDIX TABLE 6. Analysis of variance on the effects of various levels of boron in the nutrient solution upon clipping yields.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	119.53	39.84	1.68
Treatments	6	453.57	75.59	1.12
Error	18	1,211.84	67.32	
Total	27	1,784.93		

APPENDIX TABLE 7. Analysis of variance on effects of various levels of nitrogen in the nutrient solution upon weights of crowns.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	6.4	2.13	6.14
Treatments	5	278.9	55.78	4.26*
Error	15	196.3	13.08	
Total	23	481.6		

APPENDIX TABLE 8. Analysis of variance on effects of various levels of phosphorus in the nutrient solution upon weights of crowns.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	39.3	13.1	1.58
Treatment	6	185.5	30.91	1.48
Error	18	373.7	20.76	
Total	27	598.5		

APPENDIX TABLE 9. Analysis of variance on effects of various levels of potassium in the nutrient solution upon weights of crowns.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	86.86	28.95	1.22
Treatments	6	237.86	39.64	1.68
Error	18	425.14	23.61	
Total	27	749.86		

APPENDIX TABLE 10. Analysis of variance on effects of various levels of calcium in the nutrient solution upon wiehgts of crowns.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	292.98	97.66	3.16*
Treatments	6	1,237.45	206.24	6.67**
Error	18	556.27	30.9	
Total	27	2,086.70		

APPENDIX TABLE 11. Analysis of variance on effects of various levels of magnesium in the nutrients solution upon weights of crowns

Variance due to	Degrees of freedom	Sums of squares	Mean Square	F value
Blocks	3	120.14	40.04	2.73
Treatments	6	187.25	31.21	2.13
Error	18	263.61	14.64	
Total	27	571.00		

APPENDIX TABLE 12. Analysis of variance on effects of various levels of boron in the nutrient solution upon weights of crowns.

Variance due to	Degrees of Freedom	Sums of squares	Mean square	F value
Blocks	3	91.53	30.51	1.9
Treatments	6	139.93	23.32	1.45
Error	18	289.22	16.06	
Total	27	520.68		

APPENDIX TABLE 13. Analysis of variance on effects of various levels of nitrogen in the nutrient solution upon the number of seed heads produced.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	895.83	298.61	5.70**
Treatments	5	3,413.75	682.75	13.03**
Error	15	785.42	52.36	
Total	23	5,095		

APPENDIX TABLE 14. Analysis of variance on effects of various levels of phosphorus in the nutrient solution upon the number of seed heads produced.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	3,388	1,129.3	5.58**
Treatments	6	6,249	1,041.5	5.15**
Error	18	3,639	202.1	
Total	27	13,276		

APPENDIX TABLE 15. Analysis of variance on effects of various levels of potassium in the nutrient solution upon the number of seed heads produced.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	1,311	437	1.95
Treatment	6	10,455	1,742.5	7.78**
Error	18	4,028	223.7	
Total	27	15,794		

APPENDIX TABLE 16. Analysis of variance on effects of various levels of calcium in the nutrient solution upon the number of seed heads produced.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	1,998	666	3.52*
Treatments	6	4,959	826.5	4.37*
Error	18	3,401	189.0	
Total	27	10,358		

APPENDIX TABLE 17. Analysis of variance on effects of various levels of magnesium in the nutrient solution upon the number of seed heads produced.

Variance due to	Degrees of freedom	Sums of squares	Mean square	F value
Blocks	3	6,785	2,261.67	13.71**
Treatments	6	3,738	623.00	3.78*
Error	18	2,968	164.89	
Total	27	13,491		

APPENDIX TABLE 18. Analysis of variance on the effects of various levels of boron in the nutrient solution upon the number of seed head produced.

Variance due to	Degrees of freedom	Sums of squares	Mean squares	F value
Blocks	3	4,773	1,591	4.94*
Treatments	6	12,409	2,068	6.42**
Error	18	5,803	322	
Total	27	22,985		