

THESIS

EFFECT OF FERTILIZER ON BIG BLUEGRASS

Submitted by

Marshall R. Haferkamp

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

June, 1969

Property of
U. S. Forest Service
Rocky Mountain Forest and Range
Experiment Station

B201
B5H3

COLORADO STATE UNIVERSITY

June 1969

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION
BY MARSHALL R. HAFERKAMP
ENTITLED EFFECT OF FERTILIZER ON BIG BLUEGRASS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE.

Committee on Graduate Work

<u>Clifford A. Myers</u>	<u>D. N. Hyder</u>
<u>Charles K. Swilling, Jr.</u>	
<u>Pat O. Currie</u>	<u>C. W. Cook, Jr.</u>
Adviser	Head of Department

Examination Satisfactory

Committee on Final Examination

<u>Clifford A. Myers</u>	<u>D. N. Hyder</u>
<u>Charles K. Swilling, Jr.</u>	
	<u>Pat O. Currie</u>
	Adviser

ABSTRACT OF THESIS

EFFECT OF FERTILIZER ON BIG BLUEGRASS

Sherman big bluegrass (Poa ampla Merr.) is a long-lived bunchgrass native to the Pacific Northwest. This species has been seeded in the Rocky Mountains and in some areas has produced greater livestock gains than native range during spring, summer, and late fall.

Unfortunately, big bluegrass has an undesirable characteristic that reduces its value and use; plants are frequently pulled up by grazing animals. This occurs because the root system breaks at the crown to 7 to 10 cm below the soil surface.

Low soil fertility was suspected as a possible cause of root breakage. To evaluate this factor, 96 vernalized and unvernallized big bluegrass plants were grown in two sets of 24 glass-faced planter boxes, one set containing new soil, and one set containing soil that was stored for a year. Plants received one of four treatments; a check, with no fertilizer, 56 kg/ha elemental N, 56 kg/ha elemental P, or both N and P at the 56 kg/ha rate. Foliage and roots were measured to establish what effect the fertilizers had on growth, and how breakage of root systems was altered.

Pullup tension appeared to be closely correlated with total root weight, and results indicate that fertilizers can be used to reduce root breakage.

N fertilizer produced significant increases in total number of vegetative and reproductive shoots, number of tillers, pullup tension, foliage weight, and total root system weight and length. P fertilizer produced a significant increase in the total number of vegetative and reproductive shoots, while the N-P interaction produced significant increases in total root system weight and length, and the weight of roots pulled with the plants.

Plants grown on stored soil out-produced plants grown on new soil. This was probably due to nitrification that occurred to the organic matter during storage. Vernalized plants consistently out-produced non-vernalized plants, indicating that annual cold stratification is needed for optimum production.

Marshall R. Haferkamp
Department of Range Management
Colorado State University
Fort Collins, Colorado, 80521

ACKNOWLEDGEMENTS

This study was financed by the Rocky Mountain Forest and Range Experiment Station, U.S.D.A. Forest Service, the National Science Foundation, and the Range Science Department, Colorado State University. I want to thank these agencies and individuals working with them who helped in completion of the project, especially Mr. Gary Godsey and Mrs. Don Reckseen of the Rocky Mountain Forest and Range Experiment Station.

I would like to thank the members of my committee: Dr. C. Terwilliger, Dr. D. N. Hyder, Dr. C. Myers, and Dr. P. O. Currie, who offered valuable suggestions and encouragement throughout the study. I would especially like to express my appreciation to Dr. P. O. Currie who worked with me and offered encouragement continually throughout the study.

I would like to thank all my friends and family for their time and encouragement during the study and, particularly, my wife, Gwen, and daughter, Jalene.

TABLE OF CONTENTS

<u>Chapter</u>		<u>Page</u>
I	INTRODUCTION.	1
II	REVIEW OF LITERATURE.	3
III	METHODS AND MATERIALS	12
IV	RESULTS AND DISCUSSION.	30
	Pullup tensions	30
	Response to fertilizers	37
	Number of shoots and tillers.	37
	Reproductive shoots	37
	Basal area.	38
	Leaf growth	38
	Foliage and root yields	41
	Root growth	44
	Response to vernalization	47
	Response to soils	51
V	SUMMARY AND CONCLUSIONS	54
	LITERATURE CITED.	56
	APPENDIX.	62

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Observations and measurements made on individual big bluegrass plants.	26
2 Test of significance for N and P to evaluate the estimated responses from the effects and interaction of the elements on growth and development characteris- tics of big bluegrass plants. N and P values are expressed as increases or decreases in relation to the control treatment and the interaction as an increase or decrease over the effect of N and P alone. Each value is based on 24 observations, except foliage weight values which are based on 16 observations	35
3 Effect of vernalization on growth and development of big bluegrass plants. Each value is the average of 48 observations, except foliage weight values are the average of 32 observations.	50
4 Effect of soils on growth and development of big bluegrass plants. Each value is the average of 48 observations, except foliage weight values are the average of 32 observations.	53

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Glass-faced planter box in which the plants were grown and observed.	14
2	Planter box on the left contains a vernalized plant on the left and a non-vernalized plant on the right; both received no fertilizer. Planter box on the right contains a vernalized plant on the right and a non-vernalized plant on the left; both were fertilized with N. Both boxes contain new soil.	18
3	Dynamometer is connected to a plant using a pants' hanger. Experimenter is beginning to apply slow, steady pressure. All boxes were placed in the same position for pulling the plant	21
4	Plant has been pulled from the soil with a tension of 49 lb (22 kg). It is now ready for roots to be washed, clipped and have the crown diameter measured. . .	21
5	Soil columns on large mesh screen during washing process. With the gravelly soil used, the larger mesh provided for easier cleaning and less loss of root material	24
6	Plant and roots remaining with plants being washed over fine mesh screen, in preparation for root clipping and crown measurements	24
7	A grid point showing root and root branch intersections with a line of the same length used during the study. The roots intercepted beneath the center black hairline gives the N for this grid point.	28
8	Tensions required to pull Sherman big bluegrass in relation to total root weight of the plants	32
9	Total root weight of Sherman big bluegrass plants in relation to the number of shoots per plant	34
10	Leaf height and rate of growth on leaves of Sherman big bluegrass as influenced by fertilizer treatment . . .	40

11	Foliage and root yields of Sherman big bluegrass plants as influenced by fertilizer treatment. Each foliage value is based on 4 observations and each root value is based on 6 observations.	43
12	Rate of root system extension for Sherman big bluegrass plants as influenced by fertilizer treatment	46
13	Planter containing a vernalized nitrogen fertilized plant on the left side and a non-vernalized plant on the right side, both planted in new soil. Note the larger size, more numerous leaves, and inflorescence produced by the plant receiving the cold treatment	49

CHAPTER I

INTRODUCTION

Seeding adapted forage species is a valuable range improvement practice for providing forage at specific seasons to supplement native range for early spring and fall grazing. These seeded species often have a particular growth habit which makes them particularly useful. For example, Sherman big bluegrass (Poa ampla Merr.), a long-lived bunchgrass native to the Pacific Northwest, is well adapted to the Rocky Mountain and Intermountain regions. This grass has a winter growth habit so that it provides green herbage when other plants are dormant, and an abundance of culmless vegetative shoots. Because of these growth characteristics, livestock gains from big bluegrass grazed in spring, summer, or late fall have generally been greater than those for animals grazing native range. Unfortunately, this species has an undesirable characteristic that reduces its value and use; the plants are frequently pulled up by grazing animals because the root system breaks at the crown to 7 to 10 cm below the soil surface.

The pulling phenomenon has been reported by several authors from various geographic locations in the United States. In some areas, pulling has not lasted as many growing seasons as it has in others.

The critical period for pulling during the growing season is not the same at all locations. This variation in number of years and the periods of severe pullup indicate the problem may be one of soil fertility and plant nutrition. Therefore, it was the purpose of the present study to investigate the big bluegrass pullup problem at the Manitou Experimental Forest, Colorado, a location where plant pullup has persisted for over five growing seasons after planting. The investigation was undertaken in two phases: (1) a field study, and (2) a greenhouse study. The present report is for the greenhouse phase where big bluegrass plants were grown in glass-faced planter boxes. These plants were treated with nitrogen and phosphorus alone and in combination to determine how the plants respond to the fertilizers and how fertilization affects the tension required to break the root systems.

CHAPTER II

REVIEW OF LITERATURE

Sherman big bluegrass, a selected strain of Poa ampla, Merr. commonly referred to as the general utility strain of big bluegrass, is a long-lived, cool-season bunchgrass, which frequently grows 35 - 38 inches tall, is fine stemmed with moderately abundant leaves and a large, compact seedhead (Hafenrichter, et al., 1949; Schwendiman, 1958). This native of the Pacific Northwest is a very desirable species for reseeding (Hanson, 1965). It produces a predominance of culmless vegetative shoots and large herbage yields (Hyder and Sneva, 1963) associated with high yields of seed and roots (Hanson, 1965). Other favorable points are very early spring growth and drought resistance (Hanson, 1965; McGinnies, et al., 1963; Schwendiman, 1958).

In Colorado, big bluegrass is generally best adapted for seeding at elevations above 7,000 ft. or where precipitation exceeds 14 inches (McGinnies, et al., 1963). Studies on established stands at the Manitou Experimental Forest indicate that it is also very productive for late fall grazing. Currie (1966) reported that calves grazing big bluegrass pastures in October and November gained approximately 1 lb. more per day than calves grazing native range. He believed these higher gains resulted from the fact that big bluegrass remained green and continued growth during the winter, a characteristic also reported by Cooper and Hyder (1958). In the same study, Malechek (1966) found that

dietary protein rose sharply in late autumn for cattle grazing big bluegrass pastures while the protein declined in the diets of animals grazing native range. Dietary phosphorus was also usually higher for the animals grazing big bluegrass. Despite these favorable reports, a serious problem exists with Sherman big bluegrass in that grazing cattle pull the plants out of the ground and it is frequently slow and difficult to establish (Cooper and Hyder, 1958; Lavin and Springfield, 1955; McGinnies, et al., 1963; Schwendiman, 1958).

In Oregon, Hyder and Sneva (1963) found that although culms and roots were strong, the culm-crown junction in the region where reproductive culms originated, was very weak. Because of this weakness, big bluegrass suffered heavy pullup damage during July and August grazing in the second and third growing season. Damage occurred particularly in widely spaced rows where reproductive culms were numerous. After the third growing season pullup was immaterial. In Colorado, big bluegrass was subject to pullup by livestock until the plants were about 5 years old (McGinnies, et al., 1963).

A limited amount of study has been directed toward eliminating or reducing the problem of pullup by animals grazing this plant. One method suggested was to reduce the number of reproductive culms available for late summer and fall use, by close utilization of the plants in April. This treatment reduced the development of reproductive shoots (Hyder and Sneva, 1963). Another suggestion was to plant big bluegrass seed in furrows and then later to harrow across the rows, thereby burying the crowns of established plants to a greater depth. Thick planting

(rows 6 to 12 inches apart) was also recommended as a means of reducing reproductive differentiation and pullup. These same workers tried an earlier recommendation of planting big bluegrass with crested wheatgrass to reduce the pullup, but found that it was undesirable because big bluegrass was weakly competitive. Also, the desirable characteristic of very early growth and high palatability of cured herbage were not compatible with those for the less palatable crested wheatgrass.

Studies have been conducted to determine the effect of nitrogen (N) fertilizer on yields of big bluegrass and on reproductive shoot production. In Colorado, the Pacific Northwest, and Northern Great Plains, big bluegrass yields were increased by N fertilizer (Currie, 1967; Cooper and Hyder, 1958; Hafenrichter, et al., 1949; Hedrick, et al., 1964; Hyder and Sneva, 1963; Stitt, 1958). Currie (1967) found that big bluegrass plants in Colorado that received N, were larger and much more vigorous than plants not receiving N. In Oregon, big bluegrass planted in 12 inch rows produced more reproductive shoots when fertilized with N than when not fertilized (Hyder and Sneva, 1963). Except for these reports, fertilizer effects on big bluegrass must be derived by inference from other plant species.

Rate of foliage growth of most grasses seems to be affected by applications of N. Rogler and Lorenz (1957) reported that western wheatgrass and other cool-season grasses responded to N by exhibiting darker color and increased growth. Hylton, et al., (1965) found that the

foliage of Italian ryegrass grew at an accelerated rate as the N supply was increased. Similarly, other characteristics of foliage are affected by N application. Lorenz and Rogler (1964) found that applications of N increased the crown diameter of irrigated Russian wildrye, while Robertson (1964) reported that the number of tillers for crested wheatgrass and Russian wildrye was increased with N fertilization.

Fertilizer also affects the root development of plants and the influence may be beneficial or detrimental depending on the inherent fertility of the soil and the amount of fertilizer applied. Troughton (1957) stated: "In general, it appears that plants grown in conditions where available nitrogen was a factor limiting growth have a well developed root system, but a poorly developed shoot system. Plants grown with an excess of nitrogen exhibit the opposite relative development. The addition of available nitrogen to the nutrient media of plants, which previously had no excess nitrogen, results in an increased growth of both shoot and root and a decrease in the percentage of the plant's weight in the roots, i.e., shoot growth is accelerated to a greater extent than root growth. Further increases produce smaller and smaller increases in root growth until a point is reached where further increases cause a retardation of growth. Thus, the effect of a moderate increase in the nitrogen supply is to increase a plant's root weight compared with that of a plant receiving a lesser supply, but further increases result in the plant having a lower root weight than one having a less liberal supply of nitrogen."

The preceeding seems to follow closely the results observed in studies in more recent years. Black, C. A. (1968) indicated that an increase in the supply of N increased the growth of the above-ground portion of plants relatively more than the root growth. Haas (1958) found that N had a profound effect on the quantity of roots produced. Yields of root material for Russian wildrye, crested wheatgrass, and brome grass were increased with increasing rates of N applications. Oswalt, et al., (1959), while working with orchard and brome grass, noted that an increase in root diameter occurred as the rate of N was increased.

Boesmark (1954) reported that generally an inverse relationship exists between N and root development. An N deficiency produces long and slender roots, but with an increasing amount of N, roots grow shorter and sturdier. In comparison, Linscott, et al., (1962) found that corn fertilized with N produced deeper and more extensive root systems than those plants not fertilized, but the distribution and extent of growth was about equal at the end of the growing season. Wiersum (1958), working with peas, observed that a complete nutrient solution produced short, well-branched roots. Considering individual ions, he found that NO_3^- showed more activity than H_2PO_4^+ in causing root branching, a factor also reported by Fried and Broeshart (1967). Extracts from roots of corn seedlings, fertilized with N showed higher growth activity on a total root-per-treatment basis than those not receiving N (Wilkinson and Ohlrogge, 1962). Also, the roots from

fertilized plants had a higher level of a lateral root producing substance than those from unfertilized plants.

Phosphorous (P) seems to be second only to N as a limiting element. Troughton (1957) stated that early researchers had the opinion that P had some beneficial effect upon the roots of plants. Today, the hypothesis has been discredited, but he believed that the exact function of P is not known. From studies he had reviewed, it was found that P fertilizer has (1) increased, (2) decreased, and (3) not affected the weight of root and shoot.

Black, C. A. (1968) reported that P does not have any special "stimulating" effect on roots, and the increase in yield of the above-ground parts is usually greater than that of the absorbing roots. An ample amount of P supplied to a plant can promote rapid growth. This has been shown by the rapid maturation of plants supplied with P. This response to P is greatest early in the season and declines with maturity, although, generally, there is not a substantial increase in total foliage yield if absorption lasts over a long period of time.

Studies with soybeans showed that extracts from roots of plants fertilized with P showed less activity than root extracts from plants fertilized with N and were about equal to root extracts from plants receiving no fertilizer (Wilkinson and Ohlrogge, 1962). Root extracts from plants fertilized with P produced fewer laterals per root than the controls.

Several studies on grasses have shown little or no increase in foliage production from P fertilizer. For crested wheatgrass, Black, A.L.

(1968) found that yields increased with P fertilization, but not significantly; while Stitt, et al., (1955) reported no significant increase in crested wheatgrass yield from P fertilizer. Robertson (1964) working with one soil deficient in P and one with an ample supply, found that crested wheatgrass tiller numbers and leaf lengths were increased on the deficient soil, but not on the other. Two out of ten locations in Canada showed increases in native range yields due to P fertilizer (Kilcher, et al., 1965).

Results of compounding fertilizers have had a variable influence which often has characteristics peculiar to each fertilizer used alone. Troughton (1957) stated that the effect of any compound fertilizer would depend on the elements contained in them. Treatments of N-P fertilizer have increased yields, but in some cases, the yield was not much more than that achieved by adding N alone. Yields of crested wheatgrass were increased by N-P fertilizer. N alone increased yields almost as much although soil P levels were low (Black, A. L., 1968). Stitt (1955) found that at certain harvest dates and high rates of N, yields of crested wheatgrass were increased with N-P fertilizer. At lower rates such as 25 and 50 lb./acre, the yields were erratic. For native ranges in Canada fertilized with N-P, plant yields were above those where only N was used at eight out of ten sites (Kilcher, et al., 1965). At three of the sites the increase averaged about 100 lb./acre.

Varying results have been reported for the influence of N-P fertilizer on rate of foliage growth. Some of the variation depends on species and their season of growth. Honnas, et al., (1959) applied ammonium phosphate at varying rates to the warm season grasses side oats, hairy, and blue grama. They observed that shoot and leaf lengths of blue grama were increased inversely to the amount of fertilizer applied. Shoots of hairy grama increased in length at low and high levels, but leaves increased in length only at the high levels. Both shoot and leaf lengths of side oats grama were depressed by the fertilizer applications. In comparison, the number of shoots and shoot lengths of crested wheatgrass were increased by addition of N-P as well as by N alone (Segura, 1962). In addition, the vegetative to reproductive shoot ratio decreased with both N and N-P applications, with the largest decrease occurring in the N-P treatment. Robertson (1964) found no increase in number of tillers per plant when crested wheatgrass or Russian wildrye plants were treated with an N-P fertilizer.

Weight and growth of roots appear to be affected by N-P fertilizers. McKell, et al., (1962) working on annual range, found that applications of N-P fertilizer increased root yields over a no-fertilizer control, but not over an N treatment alone. They believed that decomposition of root material could have been slower on the N treatment and possibly a composition change could have affected the results. Haas (1958) found yields of crested wheatgrass roots at the 6 to 12 inch depth were greater with an N treatment than with an N-P combination. Duncan and

Ohlrogge (1958) found that root weights of corn showed N-P induced root development when both were present together, but that root weights alone did not represent a concise picture of total rooting behavior. Their observations indicated that roots receiving the fertilizer combination were finer, silkier, and more numerous, contributing to a greater surface area. An even greater difference between surface area existed than the difference indicated by root weights for the fertilizer treatments. Wilkinson and Ohlrogge (1962) showed similar results working with soybeans. They found that extracts from roots of plants fertilized with N-P showed more activity and promoted more lateral root growth than extracts from roots of plants receiving no fertilizer or N or P alone.

Experiments reviewed by Troughton (1957) indicated that tensile strength varied directly with diameter within a species; but, this factor did not hold between species. In contrast, a study by Stevenson and White (1941) showed that diameter did not have a measurable effect on strength of crested wheatgrass roots, and in a comparison between species, roots of some species were stronger than those of others.

CHAPTER III

METHODS AND MATERIALS

Soil and plant collections were made from the nursery pastures at the Manitou Experimental Forest, 28 miles northwest of Colorado Springs, Colorado. The area is characterized by alluvial soils derived from Pikes Peak granite. Surface soils are reddish brown, sandy loams or loams usually 12 to 18 inches deep, with the subsoils being mostly sandy loams or sandy clay loams grading into unconsolidated, gravelly parent material at varying depths of 10 to 62 inches (Schuster, 1964).

The study was conducted during a 98-day period beginning November 26, 1967, and terminating March 2, 1968, in a greenhouse at Colorado State University. For the study, transplanted clones of Sherman big bluegrass were grown in glass-faced planter boxes (Figure 1).

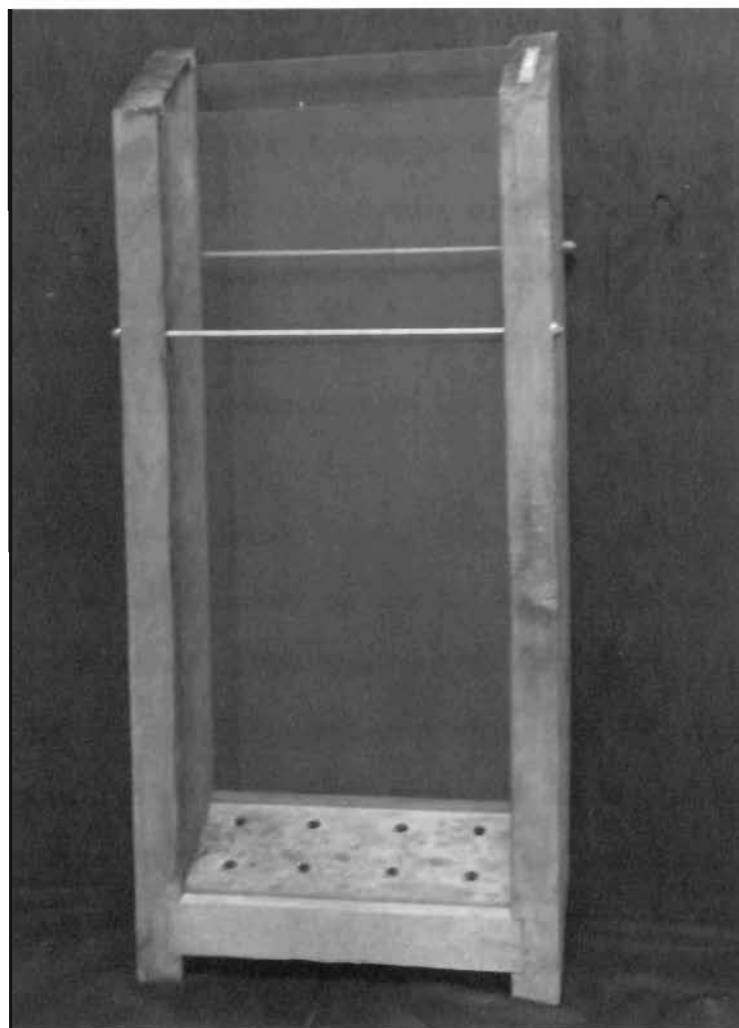
These glass-faced planter boxes utilized the same principle as those described by Crider (1955). Boxes were constructed of redwood with masonite backs and glass fronts and had inside dimensions of 10.2 cm wide, 32.8 cm long, and 73.7 cm deep. As the plants were growing, the boxes were tilted toward the front at an angle of 30°. Glass fronts were kept covered with pieces of fitted carpet and the masonite backs were covered with fiber glass insulation to protect against heat. Each box was divided in half vertically by a piece of plastic covered fiberboard, so that a vernalized and non-vernalized plant could be grown in the same box.



which the passage of
 the river is
 the only one

.

Figure 1. Glass-faced planter box in which the plants were grown
and observed.



A total of 48 boxes were filled with soil collected during the summers of 1966 and 1967. This soil was obtained from approximately the top 30 cm of soil between rows of bluegrass. After collection, the soil was cleaned of all old roots, material, and other particles too large to pass through .84 cm mesh hardware cloth. Following screening, the soil was allowed to air-dry before it was packed in the boxes.

The soil collected during the summer of 1966 was stored in the greenhouse for a year. To protect against changes occurring during storage, a mixture of this stored and the new soil collected in 1967 was used in 24 boxes. The remaining 24 boxes were filled with the new soil.

Box sections were uniformly packed with equal amounts of soil. A small amount of gravel was added to the bottom of each box to help drainage. Soil was added to the box sections in 4.5 kg increments and tamped uniformly using a tamper beveled to the 30° angle of the boxes. The tamper was dropped twice from a given height for each soil level in each box section. As settling occurred, soil was added to maintain the level within approximately 2.54 cm of the top.

Two plant collections were made from a 2-year old stand of Sherman big bluegrass. One collection was made on August 1, 1967, and the plants were brought to the greenhouse in Ft. Collins, Colorado. Another was made on September 12, 1967, and the plants were left at the Experimental Forest until November 17, 1967, at which time they were brought to Ft. Collins. These plants were left to obtain a cold treatment for vernalization needed to induce flowering.

Prior to planting, plants were washed, cloned, and clipped. Collected plant material was removed from cans and soil was washed from the root systems. Large plant clumps were broken down into clones with 3 cm diameters at the crown. Measuring from the crown, roots and foliage were clipped back to lengths of 10 and 5 cm, respectively. Clones were then planted in moist soil in each section. Care was taken not to cover the crowns with soil, but to maintain a planting depth observed in the field. A total of 96 plants were placed in the 48 boxes. Each box contained a vernalized and non-vernalized clone (Figure 2).

During the course of the study, the diurnal temperature regime of the greenhouse included 16 hours at 21° C and 8 hours at 4.5° C. Relative humidity was increased to approximately 80% at night by spraying water on the greenhouse floor. Natural daylight was used until January 15, 1968. Then, with artificial lighting, 16 hours of daylight were maintained until the close of the study.

Two elements were applied as fertilizer treatments. Nitrogen was applied as ammonium nitrate (33.5 - 0 - 0) and phosphorus as treble superphosphate (0 - 46 - 0). Since the areas were quite small, the rates were approximate and were applied as the following treatments:

Treatments	Rate (kilograms/hectare)
Control (0)	0 kg N; 0 kg P
Nitrogen (N)	56 kg N
Phosphorus (P)	56 kg P
Nitrogen plus Phosphorus (N-P)	56 kg N; 56 kg P



Left a letter to you

and some of the things in the

house, I think, of the

the, and in the house, and the

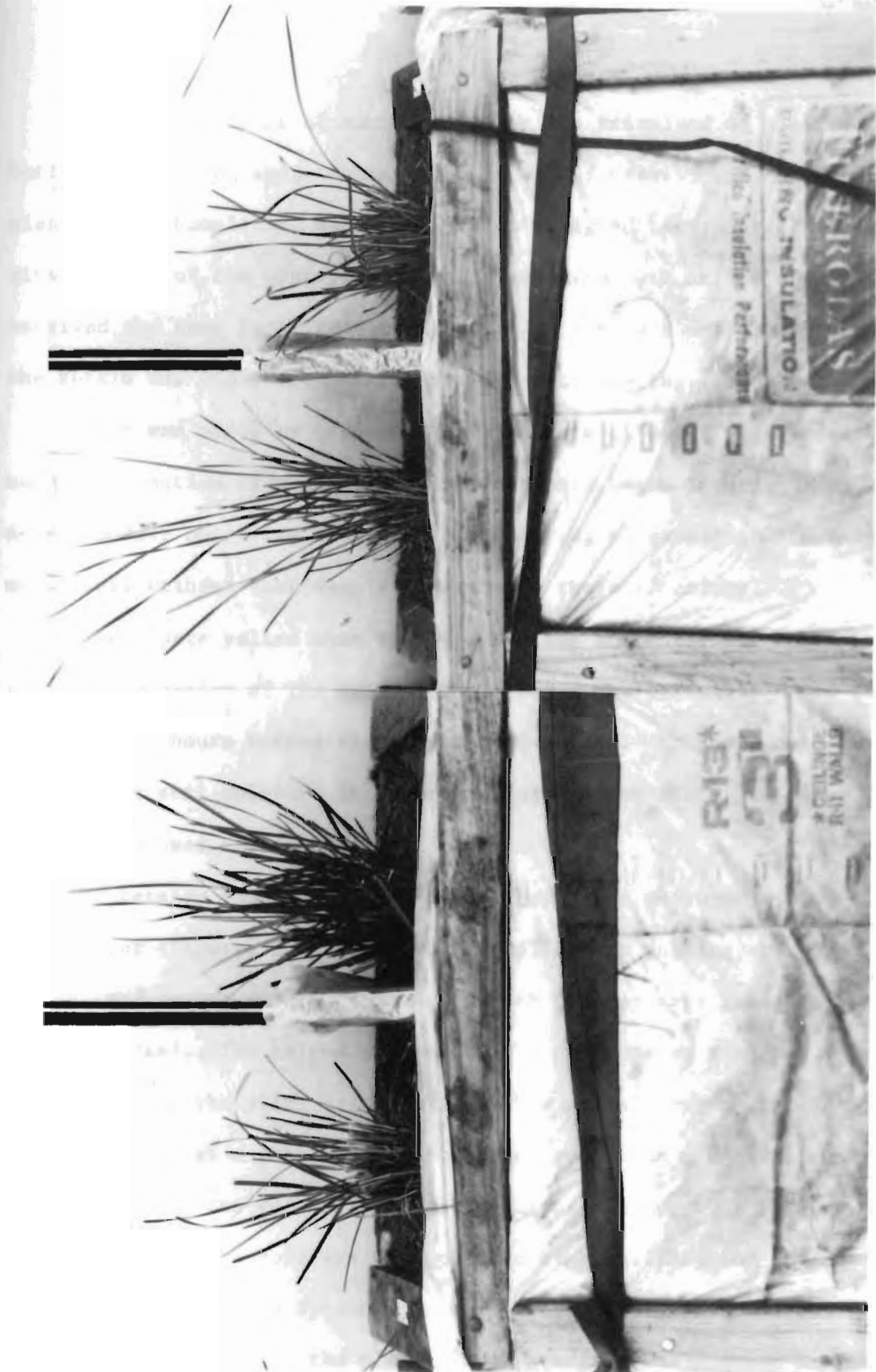
the, from the house, and the

the, from the house, and the

the, from the house, and the

the, from the house, and the

Figure 2. Planter box on the left contains a vernalized plant on the left and a non-vernalized plant on the right; both received no fertilizer. Planter box on the right contains a vernalized plant on the right and a non-vernalized plant on the left; both were fertilized with N. Both boxes contain new soil.



The proper amount of each fertilizer was dissolved in plastic bottles containing approximately 3.6 liters of water. The day after planting was completed, each plant in an assigned treatment box was given 75 ml of the appropriate fertilizer, and both halves of the box received the same fertilizer treatment. To assure a uniform solution, the bottle was vigorously shaken between each pouring.

Water was added as needed. Equal amounts of water were added to each half section of a box as the surface soil began to dry. This was determined by observing root growth and trying to assure growth into moist soil without continual saturation of the soil column.

Plants were pulled when the root systems in nearly all boxes had reached the bottom of the soil column. Water was uniformly added to all boxes 24 hours before the plants were pulled. This was done to assure that soil moisture in the region of root breakage was about uniform and near field capacity.

The tension required to sever the roots was measured by use of a dynamometer (Figures 3 and 4). To accomplish the pulling, a tripod, pulley, and common wood pants' hanger with C-clamp were the accessory equipment used. The tripod was set so the dynamometer ring was directly above the plant being pulled. The pants' hanger was clamped to the foliage at a point 5 cm above the crown, and a C-clamp was used to tighten the wooden slats so no slippage occurred. Pulling the plants from the soil was accomplished by a pulley system attached to the tripod, and the dynamometer was attached between the lower pulley and the clamp on the plant. Even pressure was exerted on the

.

Figure 3. Dynamometer is connected to a plant using a pants' hanger. Experimenters are beginning to apply slow, steady pressure. All boxes were placed in the same position for pulling the plant.

Figure 4. Plant has been pulled from the soil with a tension of 49 lb (22 kg). It is now ready for roots to be washed, clipped and have the crown diameter measured.



rope, and when the plants were pulled the tension required to break the root system was registered on the dynamometer. The dynamometer was equipped with a needle that remained at the point of maximum tension required.

Following pulling of the plants, the soil columns were removed from the boxes and placed on large mesh screens (Figure 5). The plant and adhering roots were placed on fine mesh screens (Figure 6). The larger screen had diamond-shaped openings of 1.69 cm^2 in area. Preliminary washing with a fine cold spray of water left a certain amount of gravel and debris in the roots, but this was removed by flotation in a pan of water. Following the preliminary washing, plant roots were clipped from the stem bases and placed in small plastic bags filled with water, sealed, and frozen for future measurement.

Plant foliage was also placed in paper sacks for further measurement. Two replications of the foliage samples were placed under refrigeration in plastic bags for leaf area determination. The foliage weight measurements for those replications are not included in this report.

With the previously described factors as the basic components of the study, the experimental design was for a $2 \times 4 \times 2$ factorial experiment in a split plot design with 6 replications (Appendix Table 1).

The completely randomized three-way split plot design included soil, fertilizers and vernalization. The six replications were randomly located within the greenhouse area and boxes of soil were

THE BOSTON

TRADING COMPANY

100 NASSAU ST. N.Y.C. 100

ESTD 1826

1881

•

Figure 5. Soil columns on large mesh screen during washing process.

With the gravelly soil used, the larger mesh provided for easier cleaning and less loss of root material.

Figure 6. Plant and roots remaining with plants being washed over fine mesh screen, in preparation for root clipping and crown measurements.



randomly located within the replications. A vernalized or non-vernalized plant was randomly assigned to one half of a box and a fertilizer treatment to each box within a replication.

Statistical analysis of the data followed analysis of variance procedures set forth by Snedecor (1956) using a standard program for automatic data processing. The measurements shown in Table 1 were made on each plant during the study and analyzed by this procedure. All reference to time was with respect to days from the beginning of the study: day one being the day fertilizer was added, and day 98 being the day plants were pulled for tension measurements.

Root lengths were estimated on three replications by the method followed by Newman (1966) using regularly spaced fields and the mathematical formula $R = \frac{\pi NA}{2H}$ where:

R = total length of root

N = number of intersections between roots and straight lines

A = area of rectangle 25 cm by 39 cm or 975 cm²

H = total length of straight lines 20 x .833 cm

His procedure used microscopic observations where the observer counted the number of intersections made between the hairline in the microscope's eyepiece and roots at each of the randomly selected grid points (Figure 7). Root samples were split in half so four individual portions were sampled for each plant.

Table 1.--Observations and measurements made on individual big bluegrass plants.

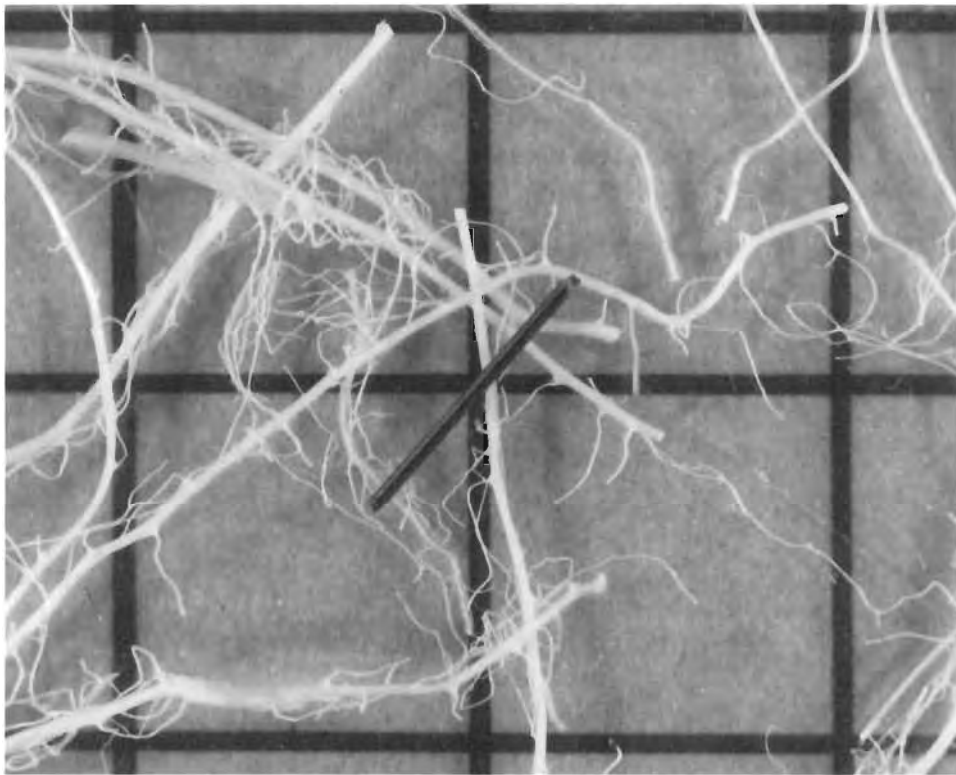
Measurement	Occurrence	Sampling Period Days	Units	
Rate of leaf growth	twice weekly	3 - 98	cm	maximum extension
Phenology	twice weekly	3 - 98	counts	plants checked for emerged inflorescences
Reproductive shoots	one time	98	counts	reproductive shoots had to have an extended node
Vegetative and reproductive shoots	one time	98	counts	shoots over 5 cm high
Tiller	three times	4 - 37 - 98	counts	new tillers were counted, those showing no evidence of clipping or reproductive characteristics
Basal area	one time	98	cm ²	measured diameters on two adjacent sides of the crown
Foliage weight	one time	98	.1 g	oven dried at 100° to 105° C for 24 hours
Root weight	one time	98	.1 g	oven dried at 100° to 105° C for 24 hours
Rate of root growth	twice weekly	11 - 84	cm	root growth observed and marked on glass fronts
Rate of root system extension	twice weekly	11 - 98	cm	maximum extension
Pulling tension	one time	98	kg	severance from soil column

0A

EXPLAINED

.

Figure 7. A grid point showing root and root branch intersections with a line of the same length used during the study. The roots intercepted beneath the center black hairline gives the N for this grid point.



The straight line was through the center of a micrometer. The micrometer was used at each check point to measure the diameter of the root nearest the zero end.

Regression analyses were made between root lengths and total root weights on the 3 measured replications. The regression equation derived was used to estimate root lengths for the remaining 48 plants. Then root length measurements were tested by analysis of variance.

CHAPTER IV

RESULTS AND DISCUSSION

Pullup tensions

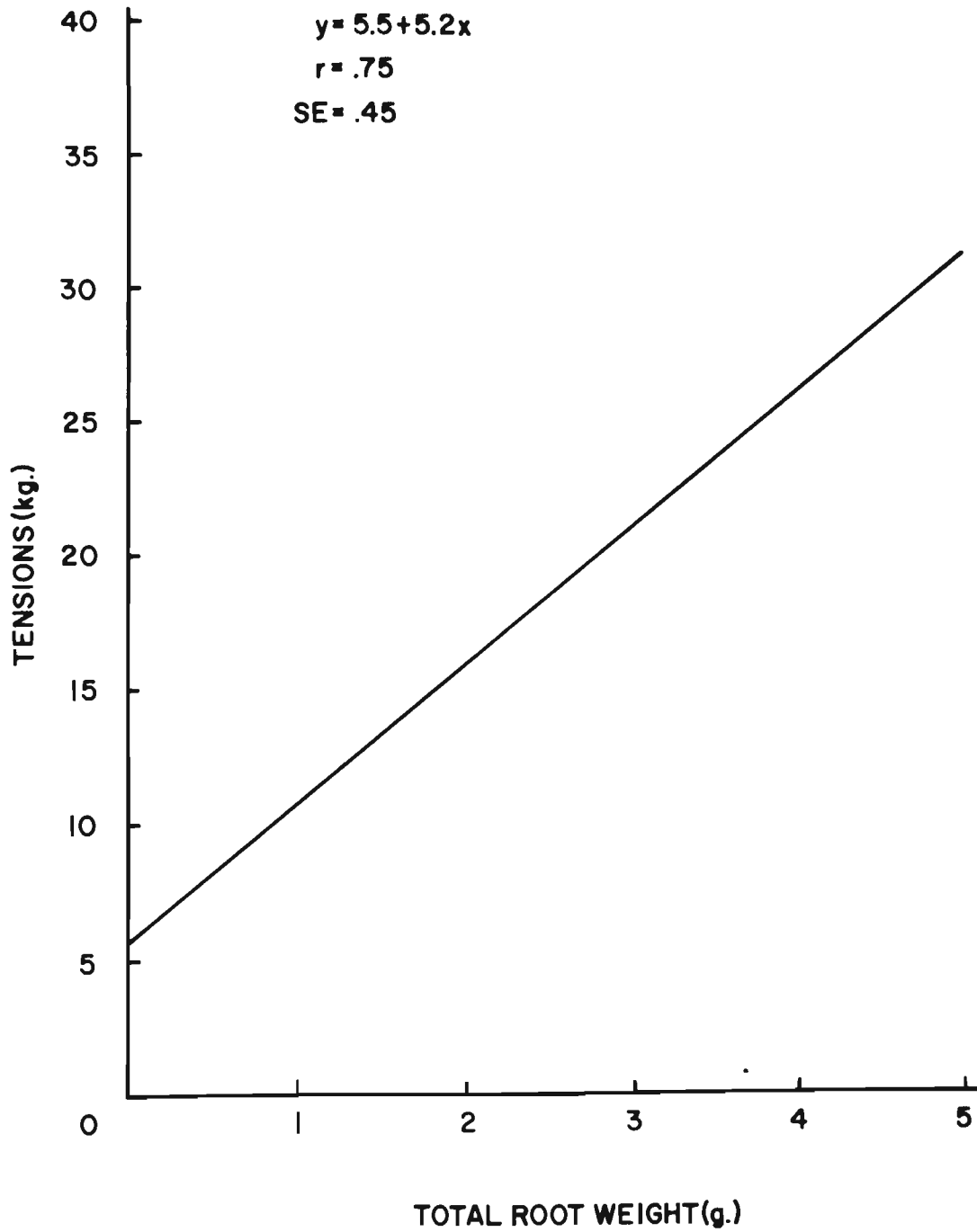
A positive correlation existed between tensions required to sever root systems and the total weight of the root systems (Figure 8). Likewise, regression analysis indicated a positive correlation between total root weight and the number of shoots (Figure 9). The close correlation between total root weights and number of shoots was understandable because the number of nodal roots produced per shoot is controlled by environment and all plants were maintained in a uniform environment. The positive correlation between tensions and root weights indicated that with an increase in root weight a plant became harder to pull.

Tensions required to sever the root systems were significantly increased ($P < .10$) by N fertilizer (Table 2). Bosemark, (1954), reported that the roots of plants become shorter and sturdier from N fertilization, and articles reviewed by Troughton (1957) showed that root strength varied directly with root diameters for a given species. Therefore, if the effect of N in the present study was to induce production of shorter and sturdier roots, then a greater tension would be required to break them.

More study is needed to determine the depth in the soil at which the greatest amount of weight increase occurred. The small number of root diameter measurements recorded did not indicate any increase in diameters with N fertilizer. The N-treated plants, however, in the presence of P removed the largest amount of root system with them

.

Figure 8. Tensions required to pull Sherman big bluegrass in relation to total root weight of the plants.



.

Figure 9. Total root weight of Sherman big bluegrass plants in relation to the number of shoots per plant.

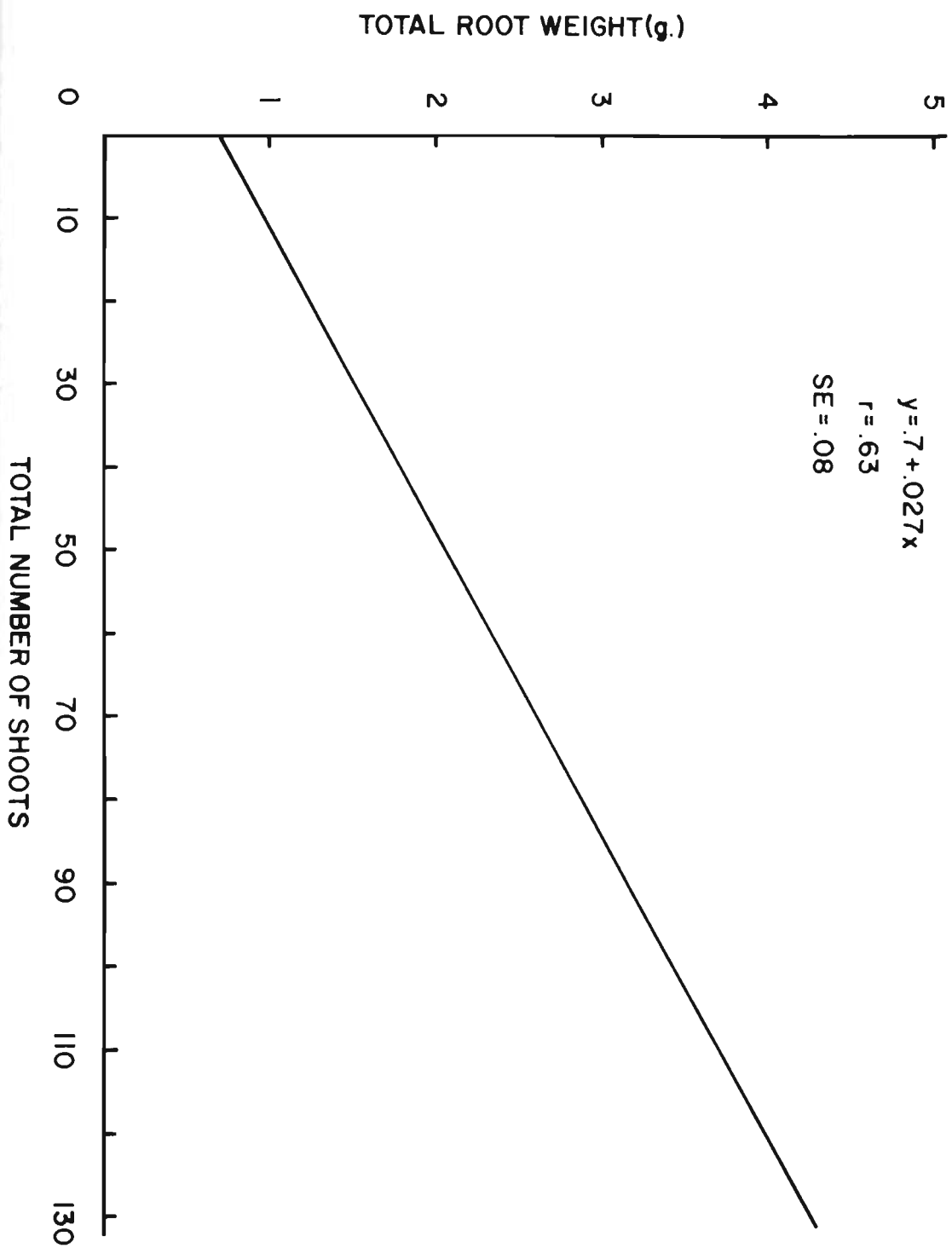


Table 2. Test of significance for N and P to evaluate the estimate responses from the effects and interaction of the elements on growth and development characteristics of big bluegrass plants. N and P values are expressed as increases or decreases in relation to the control treatment and the interaction as an increase or decrease over the effect of N and P alone. Each value is based on 24 observations, except foliage weight values which are based on 16 observations.

Characteristics	Treatments				Significance level
	0	N ¹	P ²	NP ³	
Total number of vegetative and reproductive shoots	74	19*	5*	5	.01 and .10, respectively
Number of tillers	58	15*	3	4	.05
Number of reproductive shoots	3	1	0	0	NS
Proportion of reproductive shoots in relation to total number of shoots (%)	4.1	0.5	-0.5	-0.45	NS
Basal area (cm ²)	14.1	0.5	0.9	1.1	NS
Foliage weight (g)	11.8	1.4*	0.6	1.4	.10
Total root weight (g)	2.7	0.6*	0.3	0.3*	.10
Foliage weight:root weight ratio	4.6	-0.2	-0.4	0	NS
Pulled root weight (g)	0.7	0.1	0	0.1*	.05
Total root system length (cm)	60,473.3	7,482.7*	3,410.3	3,930.2*	.10
Pullup tensions - greenhouse (kg)	18.8	3.6*	1.6	0.9	.10
Pullup tensions - field (kg)	14.8	1.6	1.4	5.0	

*significant increases

$$^1 \frac{(N_1P_0 + N_1P_1) - (N_0P_1 + N_0P_0)}{2}$$

$$^2 \frac{(N_0P_1 + N_1P_1) - (N_1P_0 + N_0P_0)}{2}$$

$$^3 \frac{(N_0P_0 + N_1P_1) - (N_1P_0 + N_0P_1)}{2}$$

($P < .05$) (Table 2). Such roots were definitely stronger near the base of the plant, even though they were not necessarily larger.

Proportion of reproductive shoots was not found to be closely correlated with the tensions required to pull the plants. This was contrary to results obtained by Hyder and Sneva (1963). They found that plants with a high proportion of reproductive shoots could be pulled easier. Perhaps my results would have been different if the proportions of reproductive shoots were larger. Larger proportions are usually produced in undisturbed field situations.

Tensions recorded in the greenhouse did not agree entirely with the tensions required to pull plants in the field. All tensions recorded in the greenhouse were higher than those measured in the field. In the greenhouse study, N produced a significant increase in tension while the N-P interaction produced a smaller increase that was not significant. In the field study, however, N-P produced plants which were harder to pull. The tension measured 5 kg larger than that for plants which received N or P alone. That all greenhouse tensions were higher than field tensions indicated plants grown in the greenhouse benefited from fertilizers where field plants did not. This could have resulted from a lack of plant competition for the available nutrient supply in the greenhouse and perhaps a difference in moisture regime, since the greenhouse study was more comparable to an irrigated study.

Response to fertilizers

chance

Fertilizers produced significant increases in 7 out of the 11 characteristics studied (Table 2). N fertilization produced a significant response in 6 of the 11 characteristics, while N-P and P produced significant increases in 3 and 1 of the characteristics, respectively. The significant increases from N-P were due to root characteristics i.e., pulled root weight, total root weight, and total root system length (Table 2). Although the significant increase in tension was due to N, the root characteristics which were correlated with tensions were increased most by the N-P fertilizer.

Number of shoots and tillers.--Plants fertilized with N fertilizer produced a significant increase in shoots and tillers ($P < .01$, $P < .05$, respectively). N-treated plants produced an increase of 19 shoots over the control plants. The total number of 73 tillers produced by N-treated plants was 15 larger than the number produced by plants not treated with N. These results agreed with those found by Paulson and Smith (1968), who reported that the number of tillers was increased for smooth brome grass by N fertilization. They reported that N apparently stimulated the activity of basal axillary buds from which the new tillers were formed. A similar stimulation affected big bluegrass. Since an increase in tillers adds to the total number of shoots, one would expect total shoot numbers to increase.

Reproductive shoots.--A mean increase of 1 and 0.5% for number and proportion of reproductive shoots was due to N fertilizer.

the slight increases were not significant and probably due to chance alone. Whereas Hyder and Sneva (1963) observed that N fertilization increased reproductive shoots as much as 9% in big bluegrass plants grown in 12 inch rows. Their values were larger than those found in my study. However, this could have been due to vernalization or the root pruning received by the plants in the present study. The plants had received a cold treatment of 109 days with an average high of +23.5°C and an average low of -5.5°C, which is a few months less, as well as several degrees warmer, than the cold treatment normally received in the field. With either a longer or colder treatment, a larger proportion of reproductive shoots may have been obtained.

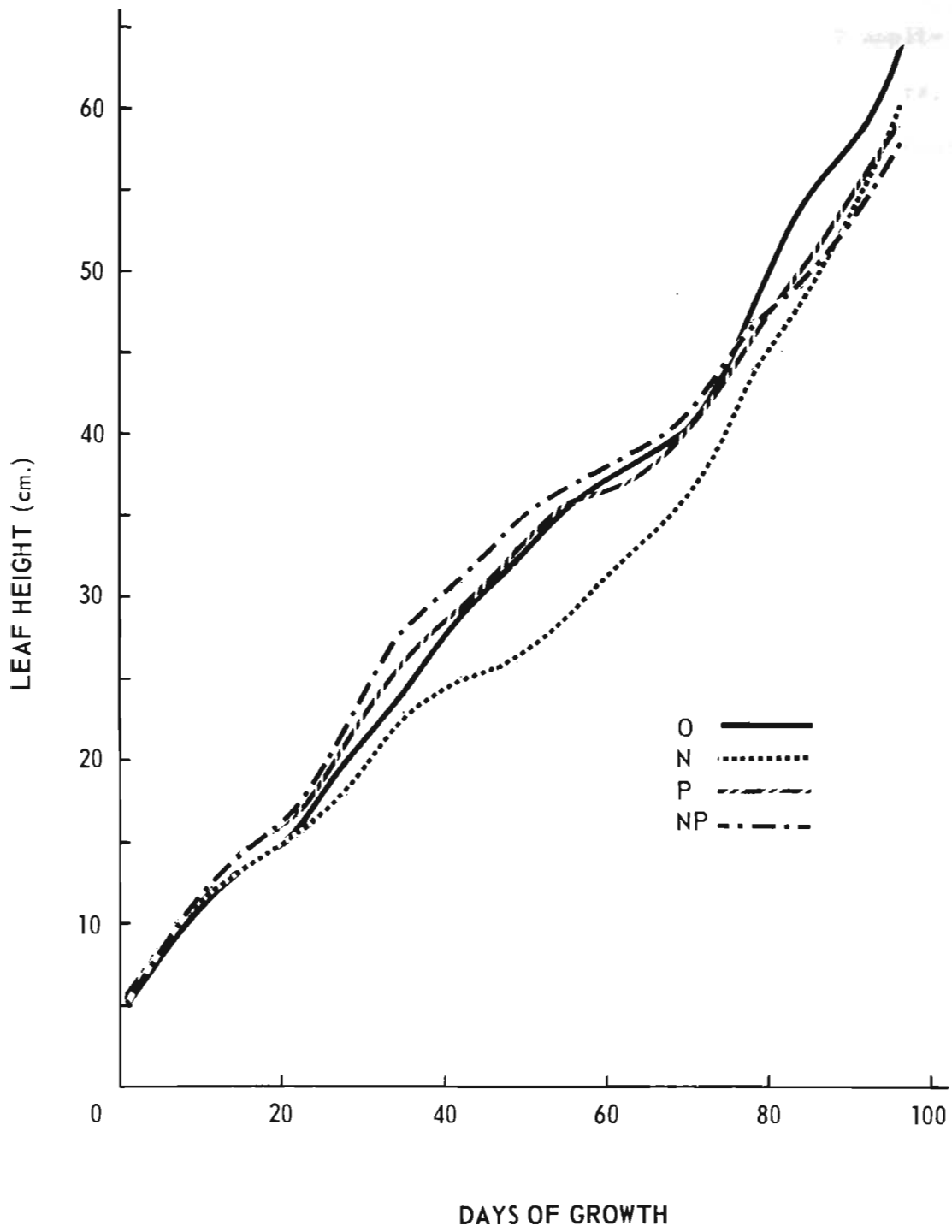
Basal area.--The data indicated that the mean increase due to N-P interaction was 1.1 cm², but these results may have been due to chance alone since the increase was not significant.

Leaf growth.--Since the new soil is more comparable to that found in the field, and because plants would normally receive cold stratification, rate-of-growth measurements are reported only for the vernalized plants grown on new soil. These comparisons are based on plant responses to the four treatments; control, N, P, and N-P fertilizers.

Generally, plants treated with the compound N-P fertilizer were largest and showed the most rapid growth. Plants treated with P alone or in combination with N produced the longest leaf lengths for the first 55 and 75 days, respectively (Figure 10). These results agreed with the statement of Black, C. A. (1968) that P applications increase the early growth and maturation of plants.

.

Figure 10. Leaf height and rate of growth on leaves of Sherman big
bluegrass as influenced by fertilizer treatment.



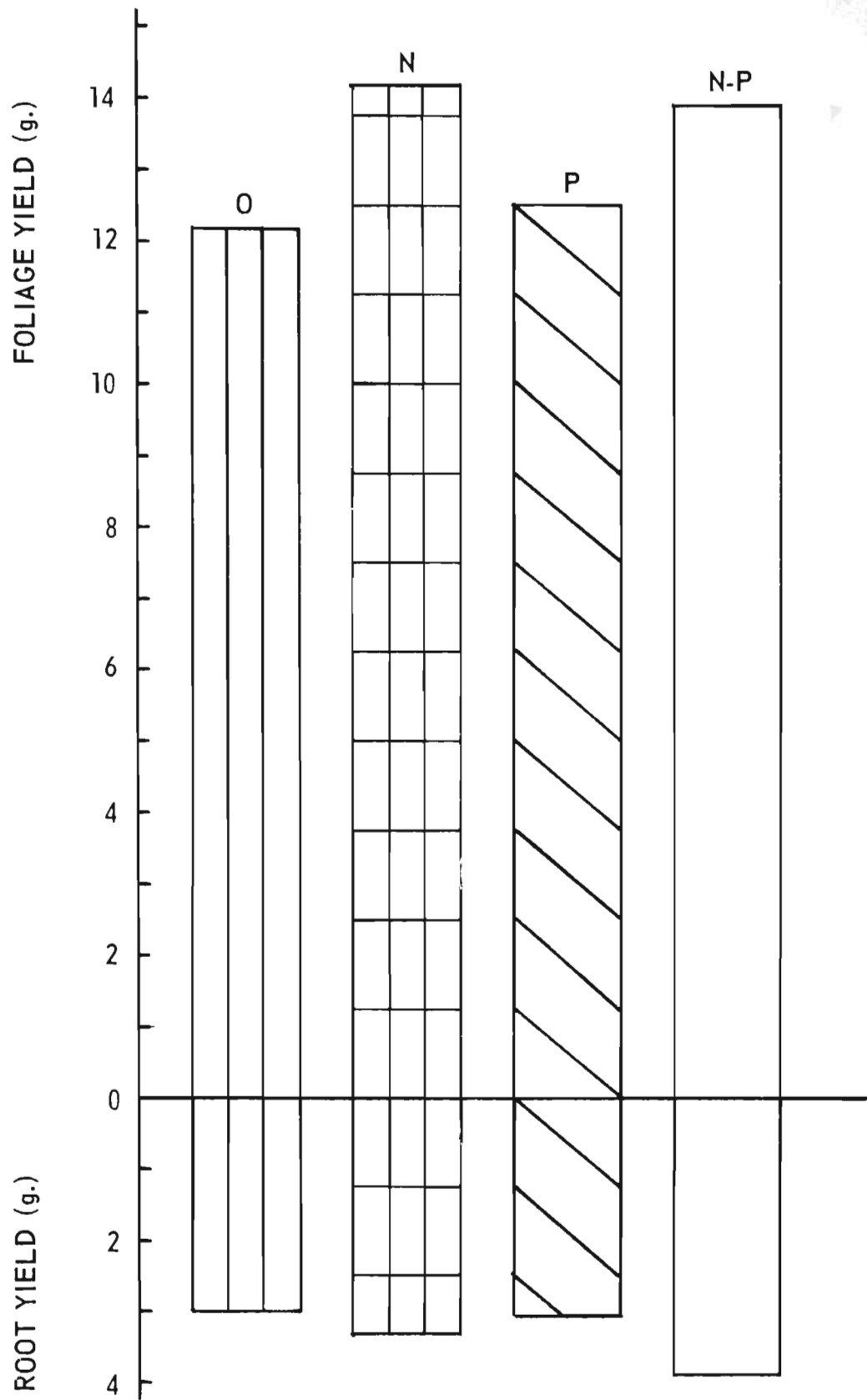
By the 98th day, leaf lengths were longest for control plants and then N, P, and N-P treated plants. Others have found that N-P applications increased the length of stems for crested wheatgrass (Segura, 1954).

The dominant height of plants without fertilizer treatment compared with N-P treated plants could be related to the phenological stage. The N-P treated plants were at a later phenological stage than those in the other treatments. Five out of six N-P treated plants had emerged inflorescences while 3, 2, and 1 of the P, N, and control plants had inflorescences, respectively.

Foliage and root yields.--Foliage and root yields were increased by N ($P < .10$) and N-P ($P < .10$). A significant increase in foliage yield of 1.4 g was produced by N-treated plants (Table 2). Although a large increase was indicated by the interaction, it was not significant. The effect of adding N and P together produced .3 g more roots than that produced by plants treated with N and P separately (Table 2). The results were understandable since the total root length produced by N-P treated plants was significantly greater than that produced by the N or P treated plants. Total root system weight and length were increased over 22 and 12%, respectively, by addition of N fertilizer. These increases were significant, but the increase due to the interaction indicates that N and P applied together produced larger responses.

Total yields of above-ground and below-ground parts for vernalized plants grown on new soil are shown in Figure 11. The N fertilized plants produced a 16% increase in foliage yield and 10%

Figure 11. Foliage and root yields of Sherman big bluegrass plants as influenced by fertilizer treatment. Each foliage value is based on 4 observations and each root value is based on 6 observations.



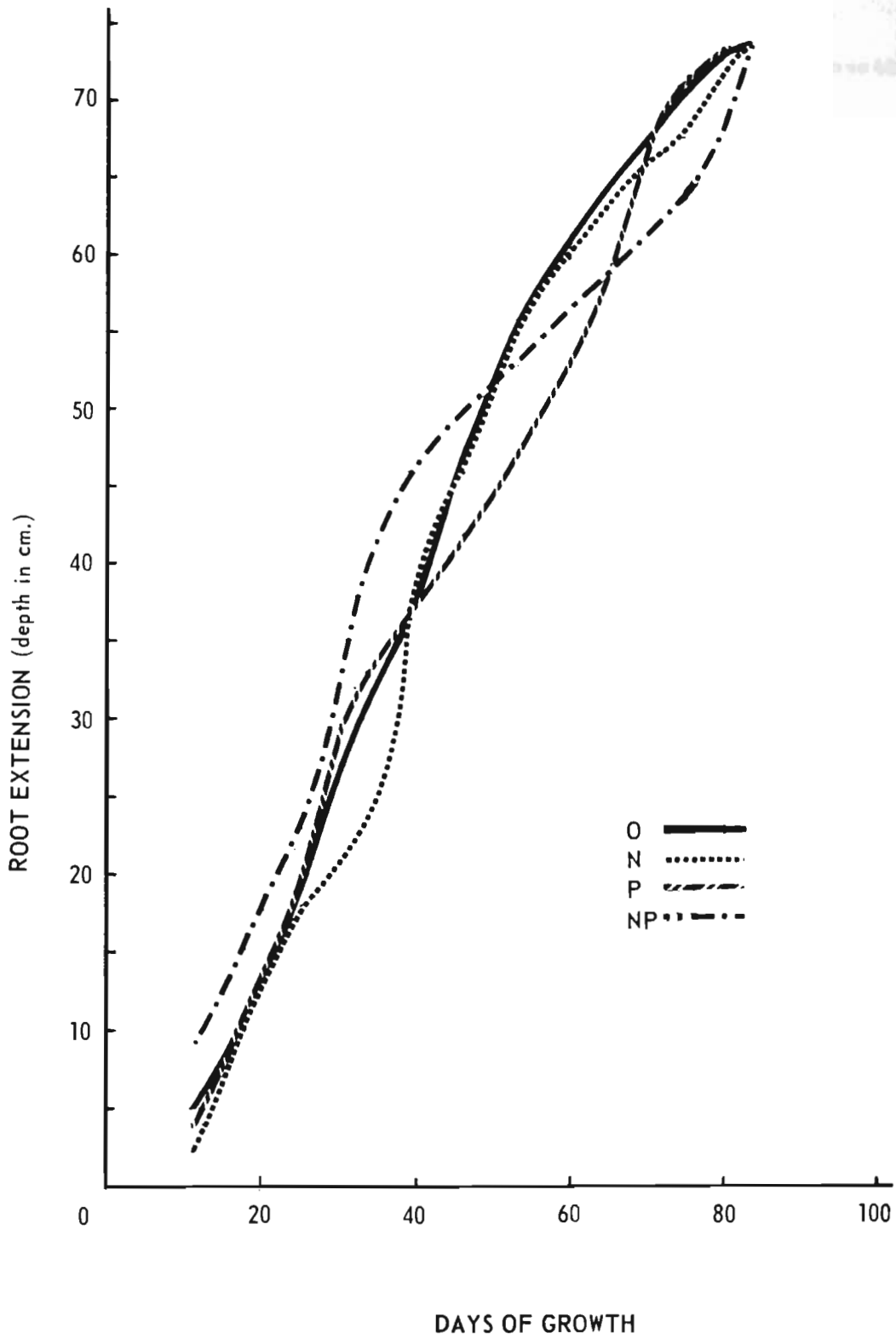
increase in total root yield over those of the control, while N-P produced increases of 14% and 30% for foliage and root yields, respectively.

Troughton (1957) reported that the addition of N fertilizer to plants not having an excess of N resulted in an increase in growth of both shoots and roots, but that the percent of the plant's weight in the roots was decreased. My results did not show any significant differences between treatments.

Root growth.--Vernalized plants grown in new soil and fertilized with N-P had the fastest root system extension for the first 50 days of growth. Plants treated with P showed increased rate of root system extension over the control and N-treated plants for the first 38 days of growth (Figure 12). Also, their root systems reached maximum length 3 days earlier than plants of the other treatments. Root system extension of N-treated plants was slightly below that of control plants, but the extension was not depressed by N applications as much as maximum leaf lengths.

Roots of control plants and N-P fertilized plants were more easily visible at the glass soil interface than the roots of plants treated with N or P fertilizers. The roots were able to push through the lower portion of the soil column better and showed more active penetration. Thus, indications were that N-P fertilizers increased the rate at which root systems grew or extended on the vernalized plants as well as having increased the total root length and weight for plants of the different soils and vernalization treatments.

Figure 12. Rate of root system extension for Sherman big bluegrass plants as influenced by fertilizer treatment.



During the phenological stages investigated, the rate of root system extension exceeded the rate of leaf extension.

Response to vernalization

Vernalized plants consistently out-produced non-vernalized plants (Figure 13). Foliage characteristics; i.e., proportion of reproductive shoots in relation to total number of shoots, number of reproductive shoots, number of shoots and tillers, foliage weight, and basal area were all significantly increased by the vernalization treatment (Table 3). The foliage weight:root weight ratio was the only characteristic where the difference was not significant.

All root characteristics except pulled root weight were significantly increased by the vernalization treatment. The heavier weight of roots, plus the additional root lengths of almost 7,110 cm on the vernalized plants, suggests root development as a possible reason why the tensions required to pull the plants were significantly larger.

A significant N-V interaction was produced for number and proportion of reproductive shoots, total number of shoots and tillers, foliage weight, pulled root weight, and total root system length. For all the foliage characteristics, the response to N was largest with the vernalized plants, but N produced the largest response for the root characteristics of non-vernalized plants.

The results on effects of vernalization agree with those found by Troughton (1960). In experiments on Lolium, he reported plants grown from vernalized seed produced a greater weight and number of shoots and roots than plants grown from non-vernalized seed. It



.

Figure 13. Planter containing a vernalized nitrogen fertilized plant on the left side and a non-vernalized plant on the right side, both planted in new soil. Note the larger size, more numerous leaves, and inflorescence produced by the plant receiving the cold treatment.



Table 3. Effect of vernalization on growth and development of big bluegrass plants. Each value is the average of 48 observations, except foliage weight values are the average of 32 observations

Characteristics	Treatments		Significance level
	Non-vernalized	Vernalized	
Total number of vegetative and reproductive shoots	72	88	.01
Number of tillers	60	70	.05
Number of reproductive shoots	2	5	.01
Proportion of reproductive shoots in relation to total number of shoots (%)	2.1	5.5	.05
Basal area (cm ²)	13.8	14.7	.10
Foliage weight (g)	9.9	14.2	.05
Total root weight (g)	2.7	3.3	.05
Foliage weight:root weight ratio	4.2	4.4	NS
Pulled root weight (g)	0.7	0.8	NS
Total root length (cm)	60399.8	67509.6	.05
Pullup tensions (kg)	19.4	22.6	.10

was not known if vernalization had affected the plants directly or if more vigorous seed had been selected for study, since some of the seed did not germinate during vernalization. My study on big bluegrass indicated that vernalization did affect the plants, and a consistent increase in production resulted from the vernalized plants.

In addition, the results confirmed the suggestion of Hyder and Sneva (1963) that big bluegrass plants need cold stratification for vernalization and production of reproductive shoots. Results from my study also indicate that this cold stratification is probably needed annually to promote high yields of big bluegrass.

Response to soils

Storing soils in the greenhouse had a definite effect on growth and development of Sherman big bluegrass plants (Table 4). Plants grown in stored soil out-produced plants grown in new soil. Foliage weights, total number of shoots, and tillers on the plants were significantly increased from storing the soils. The increased foliage weight probably resulted from the larger number of shoots and tillers per plant which resulted from altered nitrogen levels.

The soil was stored in environmental conditions that were warmer than those found in the field. It is possible nitrification of the organic matter occurred during storage and released available nutrients from the organic matter. Alexander (1965) reported that an increase in temperature favors oxidation by stimulating microbial activities up to a certain point. An increase of yield for control and P fertilized plants grown in stored soil indicated that the soil was

already rich in a usable form of N and the addition of P restored the N-P balance to a more optimum level. Also, a significant N-S interaction was found for number and proportion of reproductive shoots, number of tillers, and basal area. In each case, N application produced the largest response on the new soil.

Table 4. Effect of soils on growth and development of big bluegrass plants. Each value is the average of 48 observations, except foliage weight values are the average of 32 observations.

Characteristics	Treatments		Significance Level
	New Soil	Stored Soil	
Total number of vegetative and reproductive shoots	75	91	.05
Number of tillers	58	72	.01
Number of reproductive shoots	3	4	NS
Proportion of reproductive shoots in relation to total number of shoots (%)	3.7	3.9	NS
Basal area (cm ²)	13.9	14.6	NS
Foliage weight (g)	11.3	12.8	.05
Total root weight (g)	3.0	3.0	NS
Foliage weight:root weight ratio	4.1	4.5	NS
Pulled root weight (g)	0.7	0.7	NS
Total root length (cm)	64381.1	63527.4	NS
Pullup tensions (kg)	20.1	21.9	NS

CHAPTER V

SUMMARY AND CONCLUSIONS

Ninety-six Sherman big bluegrass plants were grown in 48 glass-faced planter boxes arranged as a 2 by 4 by 2 factorial split plot with 6 replications. The completely randomized design tested variations in soil, fertilizers, and vernalization. Of the 48 boxes, 24 were filled with stored soil and 24 with new soil, and each contained a vernalized and non-vernalized plant. Plants received one of four treatments: a check with no fertilizer, 56 kg/ha elemental N, 56 kg/ha elemental P, or both N and P at a rate of 56 kg/ha of each element.

Plant characteristics studied included the combined total number of vegetative and reproductive shoots, number of tillers and reproductive shoots, proportion of reproductive shoots to total number of shoots, basal area, foliage and root weight, total root system length, and pullup tension.

Pullup tensions in the greenhouse were highest for N-fertilized plants but in the field were highest for the N-P fertilized plants.

Total root system weight and total number of shoots were apparently related to the tensions required to pull the plants and sever the root system. N-P increased total and pulled root system weight and length. These in turn altered tensions required to sever the root systems. But, although changes in the characteristics altered the tensions, they were not the complete answer.

Fertilizers significantly increased production or altered growth for 7 of the measurements or observations recorded. Fertilizers increased foliage yields of the big bluegrass by increasing the number of shoots and tillers. Likewise, root weights and root lengths were increased. N was effective in increasing the total number of shoots and tillers, foliage weight, tension required to break the root systems, and total root system weight and length. P increased the total number of shoots and N-P increased total root system weight and length as well as the weight of root system pulled with the plants. The data indicated that N was the most important element for growth, but the interaction was important in increasing root characteristics that affect pullup.

Measurements of leaf growth and root system extension showed that N-P fertilizer increased the rate of growth early in the growth period. But, for the phenological stages studied, the rate of root system extension was faster than the rate of leaf growth.

Soils, vernalization, and fertilization all influenced the growth and yields of Sherman big bluegrass plants. Plants grown on stored soils out-produced those grown on new soils, perhaps due to nitrification of organic matter during storage. Vernalized plants consistently out-produced the non-vernalized plants and indicated that big bluegrass plants need cold stratification annually for vernalization and increased productivity.

Additional research needs to be done in the field to evaluate competition for nutrients and moisture availability between plants. These two factors can affect results in fertilizer trials and were not examined in the present study but may have caused the small differences in results of pulling tensions between the greenhouse and field.

LITERATURE CITED

Seeded paper

0.447

0.121

LITERATURE CITED

- Alexander, M. 1965. Nitrification, p. 309-343. In W. V. Bartholomew and F. E. Clark, Eds., Soil nitrogen. American Society of Agronomy, Inc., Wisconsin. 615 p.
- Black, A. L. 1968. Nitrogen and phosphorus fertilization for production of crested wheatgrass and native grass in northeastern Montana. Agron. J. 60: 213-216.
- Black, C. A. 1968. Soil-plant relationships. John Wiley and Sons, Inc., New York. 792 p.
- Bosemark, N. D. 1954. The influence of nitrogen on root development. Physiol. Plant. 7:497-502.
- Cooper, C. S. and D. N. Hyder. 1958. Adaptability and yield of eleven grasses grown on the Oregon high desert. J. Range Manage. 11: 235-237.
- Crider, F. J. 1955. Root growth stoppage resulting from defoliation of grass. U. S. Dept. Agr. Tech. Bull. 1102. 23 p.
- Currie, P. O. 1966. Seeded range improves calf weaning weights and profits. Colo. Rancher and Farmer. 20: 5.
- Currie, P. O. 1967. Seeding Sherman big bluegrass. J. Range Manage. 20: 133-136.
- Duncan, W. G. and A. J. Ohlrogge. 1958. Principles of nutrient uptake from fertilizer bands. II. Root development in the band. Agron. J. 50: 605-608.

- Fried, M. and H. Broeshart. 1967. Principles of fertilizer, p. 220-278. In M. Fried and H. Broeshart, The soil and plant system in relation to inorganic nutrition. Academic Press, New York. 358 p.
- Haas, H. J. 1958. Effect of fertilizer, age of stand, and decomposition on weight of grass roots and of grass and alfalfa on soil nitrogen and carbon. Agron. J. 50: 5-9.
- Haffenrichter, A. L., A. Mullen, and R. L. Brown. 1949. Grasses and legumes for soil conservation in the Pacific Northwest. U. S. Dept. of Agr. Misc. Pub. No. 678. 56 p.
- Hanson, A. A. 1965. Grass varieties in the United States. U. S. Dept. of Agr. Agriculture Handbook No. 170. 102 p.
- Hedrick, D. W., D. N. Hyder, and F. A. Sneva. 1964. Overstory-understory grass seedlings on sagebrush-bunchgrass range. Ore. Agr. Exp. Sta. Tech. Bull. 80. 31 p.
- Honnas, R. C., B. L. Branscomb, and R. R. Humphrey. 1959. Effect of range fertilization on growth of three southern Arizona grasses. J. Range Manage. 12: 88-91.
- Hyder, D. N. and F. A. Sneva. 1963. Studies of six grasses seeded on sagebrush-bunchgrass range. Ore. Agr. Exp. Sta. Tech. Bull. 71. 20 p.
- Hylton, L. D., Jr., A. Ulrich, and D. R. Cornelius. 1965. Comparison of nitrogen constituents as indicators of the nitrogen status of Italian ryegrass, and relation of top to root growth. Crop Sci. 5: 21-22.

- Kilcher, M. R., S. Smoliak, W. A. Hubbard, A. Johnston, A.T.H. Gross, and E. V. McCurdy. 1965. Effects of inorganic nitrogen and phosphorus fertilizers on selected sites of native grassland in western Canada. *Can. J. Plant Sci.* 45: 229-237.
- Lavin, F. and H. W. Springfield. 1955. Seeding in the southwestern pine zone for forage improvement and soil protection. U. S. Dept. of Agr. Agriculture Handbook No. 89. 52 p.
- Linscott, D. L., R. L. Fox, and R. C. Lipps. 1962. Corn root distribution and moisture extraction in relation to nitrogen fertilization and soil properties. *Agron. J.* 54: 185-189.
- Lorenz, R. J., and G. A. Rogler. 1964. Effect of row spacing and nitrogen fertilizer and production of irrigated Russian wildrye (Elymus junceus Fisch.) II. Relative crown and root development. *Agron. J.* 56: 7-10.
- McGinnies, W. J., D. F. Hervey, J. A. Downs, and A. C. Everson. 1963. A summary of range grass seeding trials in Colorado. Colo. Agr. Exp. Sta. Tech. Bull. 73. 81 p.
- McKell, C. M., M. B. Jones, and E. R. Perrier. 1962. Root production and accumulation of root material on fertilized annual range. *Agron. J.* 54: 459-462.
- Malechek, C. 1966. Cattle diets on native and seed ranges in the ponderosa pine zone of Colorado. U. S. Dept. Agr. Forest Service Res. Note, RM-77. 12 p.
- Newman, E. I. 1966. A method of estimating the total length of root in a sample. *J. Applied Ecology* 3: 139-145.

- Oswalt, D. L., A. R. Bertrand, and M. R. Teel. 1959. Influence of nitrogen fertilization and clipping on grass roots. Soil Sci. Soc. Am. Proc. 23: 228-230.
- Paulson, G. M. and D. Smith. 1968. Influences of several management practices on growth characteristics and available carbohydrate content of smooth brome grass. Agron. J. 60: 375-379.
- Robertson, P. A. 1964. Comparisons of growth responses of several cool season grasses to various nitrogen and phosphorus levels in the soil. M. S. Thesis. Colorado State University, Ft. Collins, Colorado. 82 p.
- Rogler, G. A. and R. J. Lorenz. 1957. Nitrogen fertilization of northern Great Plains rangelands. J. Range Manage. 10: 156-160.
- Schuster, J. L. 1964. Root development of native plants under three grazing intensities. Ecology. 45: 63-70.
- Schwendiman, J. L. 1958. Testing new range forage plants. J. Range Manage. 11: 71-76.
- Segura, M. 1962. Effect of nitrogen and phosphorus fertilization on the growth characteristics of crested wheatgrass. M. S. Thesis. Colorado State University, Ft. Collins, Colorado. 79 p.
- Snedecor, G. W. 1956. Statistical methods. Iowa State Univ. Press. Ames, Iowa. 534 p.
- Stevenson, T. M. and W. J. White. 1941. Root fibre production of some perennial grasses. Sci. Agr. 22: 108-118.

- Stitt, R. E., J. C. Hide, and E. Frulm. 1955. The response of crested wheatgrass and volunteer sweetclover to nitrogen and phosphorus under dryland conditions. *Agron. J.* 47: 568-572.
- Stitt, R. E. 1958. Factors affecting yield and quality of dryland grasses. *Agron. J.* 50: 136-138.
- Troughton, A. 1957. The underground organs of herbage grasses. Commonwealth Bureau of Pastures and Field Crops. Hurly, Berkshire. Bull. No. 44. 163 p.
- Troughton, A. 1960. Further studies on the relationship between shoot and root systems of grasses. *J. British Grassld. Soc.* 15: 41-47.
- Wiersum, L. K. 1958. Density of root branching as affected by substrate and separate ions. *Acta. Botan. Neerl.* 7: 174-190.
- Wilkinson, S. R. and A. J. Ohlrogge. 1962. Principles of nutrient uptake from fertilizer bands: V. Mechanisms responsible for intensive root development in fertilized zones. *Agron. J.* 54: 288-291.

trial split

APPENDIX

Table 1. Analysis of variance table for a 2 by 4 by 2 factorial split plot design separated on soils, fertilization, and vernalization with six replications.

Source	df
Total	95
Replications	5
Soils	1
R x S	5 - error (a)
Fertilizer	3
F x S	3
F x R	15)
F x S x R	) - 30 error (b) 15)
Vernalization	1
V x S	1
V x F	3
V x S x F	3
V x R	5)
V x S x R	) 5)
F x V x R	) - 40 error (c) 15)
F x S x V x R	) 15)