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Chemical fertilizer treatments of Norway pine transplants in the U. of Michigan nursery.

Argetsinger

UNIVERSITY OF MICHIGAN

School of Forestry and Conservation

Chemical Fertilizer Treatments of Norway Pine Transplants in University of Michigan Nursery

by

Lyle Marques Argetsinger

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of the requirements for the Degree of

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PREFACE

The realization that a definite problem exists in attempting to manage the soil in this nursery to produce coniferous planting stock makes field experiments imperitive. A Masters canidate will find that one growing season is far too limited a period to make much definite progress in discovering the most practical method. Nevertheless, through the combined efforts of several interested students over a period of years, the soil management practices will be improved immeasureably. This will throw the heavy burden of coordination upon our tried and true adviser, Professor Leigh J. Young.

To Professor Young, the investigator is indebted for many suggestions and constructive criticism in organizing and carrying through the investigation. Not until one meets silviculture 'in the dirt' does one begin to appreciate the ability and resourcefulness of our professor of silviculture.

To Professor Maurice W. Senstius, the investigator is endebted for suggestions concerning soil and plant reactions in regards to individual

mineral elements. Professor Senstius's soils class analyzed the nursery soil samples, the results of which are incorporated into this paper.

Mr. Frank Murray offered suggestions as to proceedure and made accessible past nursery records. He was also helpful in discussion of past experience in the nursery. Frank Haggerdy cared for the plots while the investigator was in camp, the summer of 1940.

Professor William Kynoch made available the facilities of the products laboratory which were used in the dry weight determinations. Mr. Louis A Patronsky was helpful with suggestions concerning use of drying ovens and balances.

Miss Ina Rankin, school librarian, is every forester's time-saver. Without her innumerable hours would be lost and much valuable material not discovered.

"I am a part of all whom I have met." Adopting this philosophy, each member of the faculty and many other persons can be credited with making this thesis what it is.

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Introduction

Twenty odd years ago the Regents of the University of Michigan purchased some abandoned farm land southeast of the Botanical Gardens. Expansion of the Botanical Gardens req-uired increased space. Likewise, the need for more land was demanded for the Forest Nursery, then located on South State street. Accordingly, the School of Forestry and Conservation was given part of the recently acquired land at the Botanical Gardens. The present Forest Nursery is located off Packard street near the intersection of Stadium Drive, approximately one mile and a quarter from campus.

Upon taking over the new location the management soon discovered they had inherited a potential head-ache in soil management. When moist, the soil is exceedingly heavy, dark and very sticky. Having a high clay content, it has a high cohesive capacity. Potentiometer test for pH revealed pH ranges of seven to nine--extreme alkalinity. Cedar (Thuja occidentalis), Bavarian Scotch pine(Pinus sylvestris), and Austrian pine(Pinus nigra austrica) nursery stock thrives on this type of soil, being well adapted to heavy soils and soils tending to be less acid. Nevertheless, there are many other species which the management wishes to produce. Norway pine (Pinus resinosa), White pine(Pinus strobus), Jack pine Pinus banksiana), and White spruce (Picea glauca) produced in this nursery are inferior to those produced in neighboring nurseries. Normally these species are adapted to excessively heavy and alkaline soil conditions. Generally, the soils in the other nurseries throughout the state are definitely lighter in physical composition and show a considerably lower pH reaction.

Organic manure would be the most desirable fertilizer, since that would supply nutrient elements, microorganisms and improve the physical condition of the soil. Locally though, the cost of manure is prohibitive and in quanity unavailable. Buckwheat and soy bean cover crops have been grown and plowed under on a definite rotation. Experience has proven that intensive cropping can not be maintained at a high standard of quality by the use of cover crops alone. The drain upon nutrient elements in the soil is soon noticeable in the appearance of the planting stock.

Especially in the seed beds, sand has been worked into the soil improving its physical condition. Chemical mineral fertilizers must be relied upon to replenish the plant nutrients which have been absorbed in reproducing the nursery stock. Whether green cover crops or mineral fertilizers alone or used together will give the best economic results depends upon local conditions and physical and chemical characteristics of the soil. For various chemicals essential to plant growth, there is available very little information on the quantitative requirements of different species and age classes of nursery stock. Until such information is available, fertilizer experiments must remain on an empirical basis and should be conducted for each nursery and each set of different conditions.

As Toumey states, "The sole purpose of fertilizer is to increase growth and quality, whether it is brought about by their ameliorating effect upon the soil by directly supplying the essential plant nutrients in available form (Toumey and Korstian, 1931,p.282)". It is the problem of each forest nursery to discover by local experiments just which fertilizer practices best ~~to~~ accomplish the above purpose.

This particular investigation was initiated to indicate the effects of different chemical fertilizer treatments upon Norway pine during the first year in the transplant beds. The investigation has been further delimited to include only the effects produced by three commonly used fertilizers, which are, ammonium sulphate, superphosphate and muriate of potash.

REVIEW OF LITERATURE

Normal plant growth requires the presence of several elements which are secured from the soil and the atmosphere in various compounds. Plant tissue is built up of carbohydrates, comprised of carbon and oxygen as absorbed through the foliage, and hydrogen and oxygen as absorbed through the roots. This process of photosynthesis combines the raw materials, carbon dioxide and water, in the cells which contain chlorophyll and through the use of the energy of light a transformation into sugars and starches takes place. Extensive chemical reactions in the plant develop fats and proteins, the latter containing in addition other elements. The soil itself supplies the other essential elements for plant development. Those recognized as necessary are nitrogen, phosphorus, potassium, sulphur, magnesium, calcium, iron and manganese (Laurie and Chadwick,1931 p.85)

Trees remove mineral fertility from the soil as other plants do. In the woodlot, much of this mineral fertility is returned to the soil by the leaves and smaller branches, and consequently the depletion of the forest soil is exceedingly slow. However, in a forest nursery where trees are grown only for a few years and then top and root removed, very little material is returned to the soil. Consequently, such nursery soil must be replenished by barnyard manure, green manure, or a commercial fertilizer. As very little is known about the specific requirements of forest trees, most forest nurseries keep their soil productive by the use of either barnyard or green manure. Both contain all the mineral elements essestial to plant growth, and also improve the physical condition of the soil (Herbert, 1926, p.1). Some authorities believe that bulky fertilizers of organic origin are best for use in permenent forest nurseries (Wahlenberg, 1930, p.1). The justification for the use of commercial mineral fertilizers by these authorities seems to be only the angle of cost or inavailability of fertilizers of organic origin in the locality of the nursery. They do not consider that fertilizer requirements may very for different soils and different species which may be desireable to produce at each particular nursery.

Agronomists have demonstrated conclusively that three prerequisites are necessary for efficiency in the use of fertilizers. They are:

(1) a knowledge of the nutrient requirements of the plant to be grown,

(2) an evaluation of the nutrient-supplying powers of the soil,

(3) data regarding when and in what form it is best to apply fertilizers.

To obtain a knowledge of the nutrient requirements of the species will require much investigation, through the use of artificial media, requiring long periods of time and finely regulated conditions. This research will be conducted by highly trained ed specialists in the laboratories. Also, to obtain an evaluation of the nutrient-supplying powers of the forest nursery soil, there is no satisfactory technique available. Methods of soil analysis, which have been developed for determing suitability of agricultural soils for various field crops can not be used as a dependable evaluation for chemical fertility of forest nursery soils. This is due to the differences in nutrient absorptive powers, physiological growth, and regions of the soil to which the roots extend for nutrient absorption. For satisfactory results, to obtain the time and form of application of fertilizers will require more extensive investigation as demonstrated by the following. Efficiency in the use of mineral elements is maximum, when the rate of nutrient concentration is adjusted so as to maintain the internal plant supply at or near the experimentally determined optimum during the entire growing period. Thus, the supply of available nutrients should be relatively low at the beginning of the growing season in order to avoid toxic internal concentration ~~accumulation~~, and should be increased thereafter in proportion to the increased plant weight. (Mitchell, 1939 p.14).

On highly fertile natural soils, there is potentially available (reserve) supply of mineral elements, absorbed in organic and inorganic base-exchange compounds, upon which the plants may draw. Thus, in nature, there may be increases in the rate of nutrient intake resulting from the action of normal microfauna, normal microflora, weathering, and chemical exchange. Often the importance of the fundamental relationships between the rate of nutrient supply, the internal nutrient concentration, and the seedling growth are overlooked or disregarded by the nurseryman at the time of replenishment of plant nutrients on depleted nursery soil (Mitchell, 1939,p.114). The common practice of mixing fertilizers into the soil early in the season prior to use dis - regards the above relationships. The fertilizer is applied at a time, when the resulting high mineral nutrient concentration of the soil solution is most likely to be harmful, and when the plants need the nutrients the least. This is especially true of readily soluble fertilizers, when applied to soils of low-nutrient absorptive capacity.

Attention has been brought to the fact that the use of fertilizer in the forest nursery serves one or both of two purposes: first, the maintenance of soil productivity and second, the improvement of the planting stock. Under the heading of soil maintenance are included the physical condition of the soil, optimum balance of plant nutrients in available form, concentration of the soil solution, reaction of the soil solution, and retention of a favorable microbial population. Likewise, it is often possible to fertilize the nursery soil as to give a direct improvement in the planting stock. It may increase size in the same amount of time or the same size in shorter time, by increased vigor of the stock, increased resistance to adverse weather conditions.

By proper regulation of the physical condition is meant the keeping of collodial soil matter in a flocculated or loose condition. This way heavy soils may be kept open and porous, allowing ready entrance of air and water, and removal of the excess water by under-drainage. In many cases, for better soil structure and increased productivity artificial drainage may be warranted. Heavier soils, because of the small size of individual particles, have the capacity to hold more water. Also, because of the greater particle surface exposed the action of water, larger quantities of nutrients are obtainable from soil of this nature (Laurie and Chadwick, 1931,p,63).

In considering the respective effects on plant growth exerted by the three commonly deficient fertilizer elements, it is noticed that they tend to check, balance, and support one another. This relationship is very important in fertilizer practice, since it influences the results that may be attained by the application of fertilizers and has much to do with the economy of their utilization. The various elements should be so balanced as to produce a large and normal crop growth. Under actual field conditions, this is difficult to to attain because the soil remains always a more or less unknown quantity as to the probable availability of it constituents. Variation will occur due to the reactions of the fertilizer when applied, and the extent to which it remains active remains active and available in the soil. Chemical reactions with other elements in the soil affect the efficacy of a fertlizer. A knowledge of the nature and influence of various fertilizers and of the culture and the response of the crop is most essential. The ideal balance of the nutrient elements should be striven for, even if it can seldom be closely approached (Lyon and Buckman,1937,p.308).

During long periods of experimentation and general use, there has arisen several principles for the use of fertilizer: They are:

(1) Two or more elements, may not be toxic, since one ion reacts against another.

(2)Single elements may be toxic.

(3)Addition of single elements in normal quantities is not likely to be toxic, because of complexity of the soil.

(4)In some cases addition of a single element does not increase production as the element is already present is sufficient quanity.

(5)Use of a complete fertilizer will increase the efficiency of production over the sum of the increments of increase by use of single elements.(Young, 1939, lecture notes)

In a general way the nutrient elements of the soil exist in two conditions: (1) complex and rather insoluble forms, and (2) simple compounds usually soluble in the soil water and rather readily available to higher plants. Due to the chemical and biochemical processes at work in the soil the general trend and final disposition of the elements is from the complex to the simpler forms. It is from these simpler forms that the nutritional wants of the higher plants are served. Since the simpler and more soluble constituents of soils readily disappear in drainage or are synthesized by microorganisms and higher plants, the greater proportion of each nutrient remaining in the soil is in a complex form. Thus, the complex group is a repository, the fertility of the soil depending not only on the total amounts of various nutrients present but also on the ease with which transfer is made to simple and available forms. Therefore, a chemical analysis of the soil is uncertain value in deciding what the fertilizer needs of a soil may be (Lyon and Buckman, 1937,p.23).

The reaction of the soil solution, either acid, neutral, or alkaline, has an important influence on the availability of phosphorus, manganese, iron, and perhaps other nutrients. Also, microorganisms and higher plants appear profoundly affected by the reaction of soil ions, Hydrogen or hydroxyl. In addition these ions function as sources of hydrogen and oxygen (Lyon and Buckman, 1937,p.31). Likewise, the reaction of the soil solution affects the solubility of the soil minerals, thereby may profoundly influence leaching losses. The most favorable physical condition of a soil is usually reached, when the reaction lies in the range of slight acidity through neutrality and slight alkalinity. (pH 6.0-8.0). (Laurie and Chadwick,1931,p.78). Soils must be limed, which are acid beyond the most favorable range of the crops to be grown. Excessive alkalinity can be corrected by addition of gypsum, sulhur, aluminium sulphate and other materials. Most bacterial processes take place best in the pH range of 6.0-8.0. Thus, it can be concluded that the efficacy of all the other soil factors is directly associated with the pH reaction of the soil.

The microorganisms with which we are concerned are the bacteria. Their activities are influenced by the same factors which affect the growth of crops; namely: moisture, temperature, aeration, supply of available nutrients and organic matter. The aerobic bacteria serve the valuable funtion of making available nutrient elements in simpler form for the higher plants. Limitation of abundant air supply sets in motion the activities of of other bacteria which produce detrimental reactions. Soil temperatures also exert much influence on bacterial growth. During cold weather, the activity of bacteria is curtailed, and which results in poor growth of plants, because nitrogen in the soil is not made available. As previously described, the soil is a complicated medium teeming with microorganisms of all sorts in which many physical and chemical changes take place profoundly influencing plants growing in the soil. Ideal conditions are attained only when the physical changes are properly regulated, when the chemical reactions are under control, and when bacterial activity of the right sort takes place.

Fertilizers are more effective when applied in the form of fertilized soil of compost. Thereby, the danger of excessive application is not likely to occur. Also, the plant nutrients are

are brought to the young trees in their most useful form. Nevertheless, the quantity of the necessary fertilizer depends not only upon the kind of soil, but also upon the species and the length of time that the plants remain in the beds. The condition of the stock invariably indicates whether adequate fertilizer has been used for acceptable results(Toumey and Korstain, 1931,p.288-9). Innumerable materials have been used for fertilizer. Whitney lists two hundred ninety six materials, one hundred thirty four inorganic and one hundred sixty organic, which have been tested on soils or in culture solutions and resulted in increased plant growth, vigor, or general health. On the other hand, the mineral elements most likely to be deficient will be nitrogen, phosphorus, and potassium(Whitney, 1924,p.297). Thus, fertilizers which supply these elements are called 'complete fertilizers' and those which supply one or two of these elements are called 'incomplete fertilizers'. The three general classes of fertilizers are fertilizers of organic orgin, fertilizers of mineral origin, and green cover crops turned under. It is understood that all materials which may improve the soil conditions or the planting stock are desireable.

This investigation has been limited primarily to addition of these three nutrient elements in mineral form, Accordingly, it would seem adviseable here to describe the reactions of nursery stock to a deficiency, normal amounts, and surplus of each of these nutrient elements. It is not to be construed that appearances of the plants as described in the following paragraphs necessarily indicates abnormality positively due to that one element. Several different defficiencies may give similar superficial appearances. The chemical material here described is the form used during this investigation. Consequently, the grounds for comparison of the transplants are thus detailed:

Nitrogen:

Although and analysis of the majority of soils shows sufficient amounts of the needed elements, the degree of availability varies and particularly with nitrogen. Of the three elements commonly deficient, the application of nitrogen seems to have the quickest and most pronounced effect. Nitrogen supplement tends to encourage vegatative growth and to impart to the leaves a deep blue-green color. Nitrogen is also a regulator, since it governs to a certain extent the utilization of potassium, phosphorus and other constituents. Plants receiving insufficient nitrogen are stunted in growth and possess a restricted and fibrous root system. Nitrogen deficient plants can be detected by yellowing foliage which remains hanging on the branch, by short sickly growth, and by premature loss of leaves. This is not conclusive as several other deficiencies may leave the same symtoms. In contrast, an over-supply of nitrogen is manifest by heavy, brittle foliage, long stems and susceptible to pest attack. Also, succulence may delay maturing of foliage and buds in the fall thereby subjecting the plants to winter-kill. At this nursery ammonium sulphate has been used to supplement the nitrogen supply naturally available. Ammonium sulphate is a grayish material, a by-product of coke manufacture, and contains twenty to twenty five per cent ammonia. It is readily soluble in warm soils.

Before it can be utilized by the higher plants it must be converted into nitrate form by bacterial action. Ammonium sulphate is acid forming and therefore greatly favored for use upon alkaline soils. In this connection, a simultaneous fertilization with lime or carbonate of lime should be avoided, as by decomposition of the salts the ammonia becomes liberated and escapes into the atmosphere. (Tillotson,1917,p.79) Laurie and Chadwick, 1931,p.86) Lyon and Buckman,1937,p305) Young, 1940, Lecture notes).

Phosphorus:

Phosphorus is an essential constituent of all plants, and its general deficiency may be noted, because of the steady withdrawal of the material from the soil over a period of years. Only infrequently do we find a lack of response to the application of soluble phosphorus. Phosphorus supplement may be attended by the following conditions: rapid development of the plants, hastening of maturity, increase of root system, precipitation of aluminium, by counteracting the ill effects of excess nitrogen supply. It is serviceable in the production of nursery stock which should have a strong, fibrous root system. Also phosphorus will increase disease resistance. A deficiency of phosphorus results in a restricted root system. Phosphorus defficiency is frequently recognized by the yellowing of leaf edges, shortening of growth, weakening of stems, and slow maturing. Phosphorus deficiency may limit the availability of of potassium. There appears no ill effects due to over supply of this element. Superphosphate (acid phosphate) was used during this investigation as the source of phosphorus. Superphosphate is rock phosphate treated with sulphuric acid to produce a more soluble form of a combination of monocalcium and dicalcium phosphates. It contains from sixteen to twenty per cent phosphorus. When used with a ammonium sulphate, its solubility is increased and thereby its availability to higher plants in increased. Phosphorus tends to alleviate the effects of over-liming. Accordingly, a proper balancing of nitrogen and phosphorus is necessary for normal plant growth(Laurie and Chadwick,1931,p.90) Lyon and Buckman,1937,p.306)(Young, Lecure notes)

Potassium:

In a general way potassium exerts a balancing effect on both nitrogen and phosphorus. Also, it is especially important in a mixed fertilizer, if the potash of the soil is lacking or unavailable. By increasing resistance to certain diseases and encouraging the root system, it tends to counteract the ill effects of too much nitrogen. In delaying maturity, it works against undue ripening, the influence of phosphoric acid. The presence of plenty of available potash in the soil has much to do with the general tone and vigor of the plant. Potash deficiency is readily recognized by thin stems and poor root systems. A lack of potassium greatly impairs the capacity of a plant to assimilate carbon dioxide. The leaves along the underside of rim turn brown and the whole leaf appears blotchy. They do not contain their normal amounts of sugar and starch. Potassium is likewise essential to nitrate changes which occur in the plant. The addition of available potash rectifies the condition by encouraging the process of photosynthesis, the utilization of nitrate nitrogen in protein synthesis, the intake of water and the development of fibrous root system. Potash is essential for starch development and translocation. Potassium chloride (muriate of potash) was used in this investigation as the source of potassium. This salt has approximately forty five per cent available potassium. (Lyon and Buckman, 1937, p. 319) (Laurie and Chadwick, 1931, P.90) (Young, 1940 lecture notes)

Previous experiments at other nurseries indicate that on moist soils mineral fertilizers increase the size and vigor of forest tree seedlings. This is a distinct advantage in forest planting, as larger stock can withstand drought and other adverse climatic conditions better than smaller stock of the same age. European experience indicates that the early advantage gained by forest seedlings from fertilizer is not maintained in later years. Commercial mineral fertilizers act promptly and may be satisfactory where immediate results are desired, but are likely to leach rapidly (Herbert, 1926, p. 188). Increased susceptibility to disease was noted on experimental plots at the Savenac Nursery where chemical mineral fertilizers were used. This was attributed to heavy nitrogeneous fertilization or disruption of the nutrient balance of the soil (Wahlenberg, 1930, p.2). Extensive studies in soil management must be carried out before concentrated mineral fertilizers can be used with satisfactory results. Nevertheless, forest nursery stock can be improved by the proper use of mineral fertilizers.

The Experiment

The purpose of the study is deemed here worthy of restatement. In the Forest Nursery, University of Michigan, the continued production of coniferous planting stock requires the use of heavy applications of fertilizer due to the condition of the soil prior to University ownership as well as present intensive cropping practices. Organic fertilizers are available only at an exorbinate rate. This study is attempting to discover the combination of ammonium sulphate, superphosphate, and potassium chloride which will improve the soil condition and produce satisfactory coniferous planting stock.

Materials

Location:

The ground alloted for use on this experiment is part of the Forest Nursery on the south-east corner of the Botanical Gardens, University of Michigan, off Packard Street about a mile and a quarter south-east of campus. In the nursery the plots lie in two rows, running north-south four feet west of the second sprinkler line east of the windbreak. Also, starting at the center road the plots run south thirty two feet. This ground the preceding two years was carrying transplant stock of Scotch pine, Norway pine and Norway spruce. The third and fourth years prior to the experiment the ground was sown to Buckwheat. The fifth year prior to the experiment, it supported a miscellaneous assortment of conifers one to four feet in height.

Planting Stock:

The planting stock was 2-0 Norway pine from seed beds in the north-east corner of the nursery adjacent to and north of the road. These seed beds had been treated with formaldehyde prior to seeding to prevent white grub (Phylophaga) infestation. Also, the beds were treated with ammonium sulphate of an indetermined amount. The healthy and vigorous seedlings were of good color. The spacing of plants appeared favorable in the seed bed and no white grub damage was evident. Sand is used on seedbeds in this nursery but not in the transplant beds which explains the improved physical soil condition found in the seedbeds. The stock was selected for uniformity by visual observation.

Quantities of fertilizer:

In each case, the amounts of each fertilizer to be used were first determined on a per acre basis. The limits of amounts being determined by using quantities found favorable by other research; also some additional quantities as purely a matter of chance based on the soil condition. The number of grams of each fertilizer applied on each plot is given on the following page (p.23). Also, the corresponding number of pounds per Acre is given. The number of grams per plot were computed as follows:

28.349 grams equals one ounce

453.584 grams equals one pound

0.0002 or one fifth mil-acre equals one plot area

2.95 feet square equals one plot

0.0907 grams equals one pound per plot

0.0907 x number of pounds per acre equals number of grams per plot

The plots were laid out, each being 2.95 feet square. There was a one foot isolation zone left around each plot. The plots were numbered consecutively north to south. The easterly row containing plots numbered one to twenty-one and the westerly row containing plots numbered twenty-two to forty-one.

On May 4, 1940 the fertilizers were weighed on balances and the total for each plot placed in a sprinkling can which was then half filled with water. This was stirred until the chemicals went into solution, then applied as evenly as possible to the whole plot. This was followed by more water but not fast enough to cause washing. When sufficiently dry the plot was worked with a rake.

On May 10-11, 1940, one week after applying the fertilizer, the two year old seedlings of Norway pine were dug and transplanted into the experimental plots. The ground, being very moist, was difficult to work. Twenty seedlings were placed per plot, four rows of five seedlings each. To avoid competition for nutrients, the plants were spaced about six inches each way.

Around the first of June, the plots were weeded and the surface soil worked to reduce caking which seemed present. When needed, the over-head sprinkling system supplied water from the city mains, throughout the summer. The plots were weeded and cared for by the forest properties crew during the summer in the same manner as the other transplant beds.

On October 5, 1940, the trees were measured for height before being dug. The mortality was recorded for each plot. Also, at this time notes were taken on the general appearance of the trees by plot and as compared to adjacent plots regardless of treatment--entirely visual observation.

The trees were carefully dug, so as to lose as few of the fine roots as possible. To remove the dirt completely, the trees were then washed. The trees were separated by plots, but were not individually identifiable.

Laboratory measurement followed. Each tree was calipered at first leaf scar, and the average determined for each plot. The trees were then placed in an oven heated by steam at the Wood Utilization Labratory. The heat was not allowed to exceed 150° F. From each plot, the trees were placed on tray (tops of shoe boxes)to catch any parts which might break and fall off. To insure complete drying, the trays of trees were left in the oven four days. The trays were then taken out and immediately weighed on balances. There was apparent, after weighting several trays, an unaccountable variation. However, after bringing a tray out of the oven, two or three minutes would make an appreciable difference in weight due to moisture absorption. Upon, consultation, it was found that the high temperatures would have no ill effects on either the balances or their accuracy of weighting. Next, in the oven on the shelf the balances were placed, while the weighing proceeded with an open oven door.

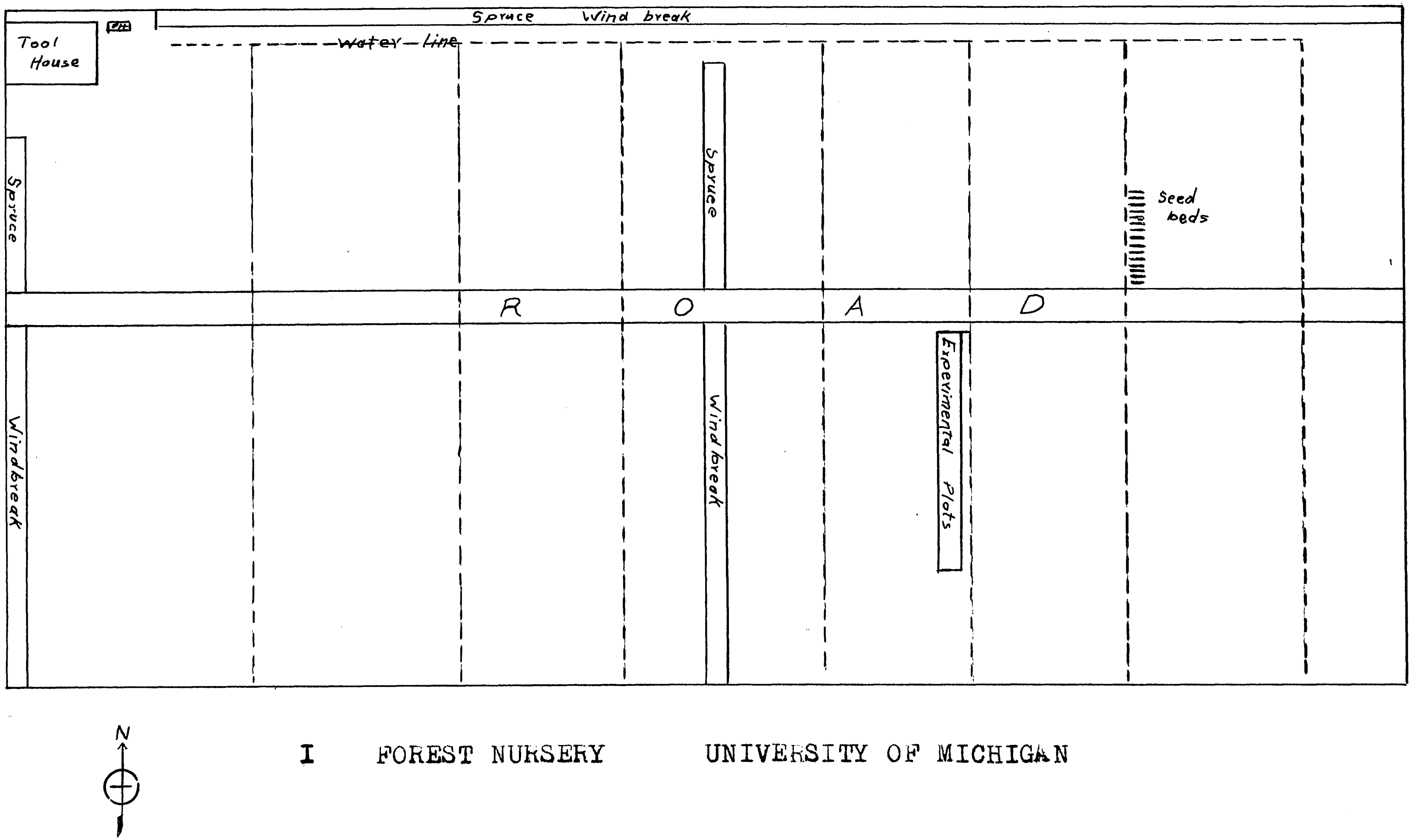
The trees were cut at the ground line and the tops weighed separately from the roots. The trays of trees were again placed in the oven, left twenty four hours and then reweighed to check discrepancies in procedure.

Thus, the data is complete with records of the mortality, average height, general condition of appearance, average diameter, at ground level, average dry weight of top, and average dry weight of roots.

Results of the Experiment

On the following page appears a diagram (I) of the Packard Street Forest Nursery, School of Forestry and Conservation, University of Michigan. On this diagram will be found the location of the experimental plots and the seed beds from which the seedlings were selected.

The second diagram (II) shows the position of the plots in relationship to the adjacent road and over-head water line.



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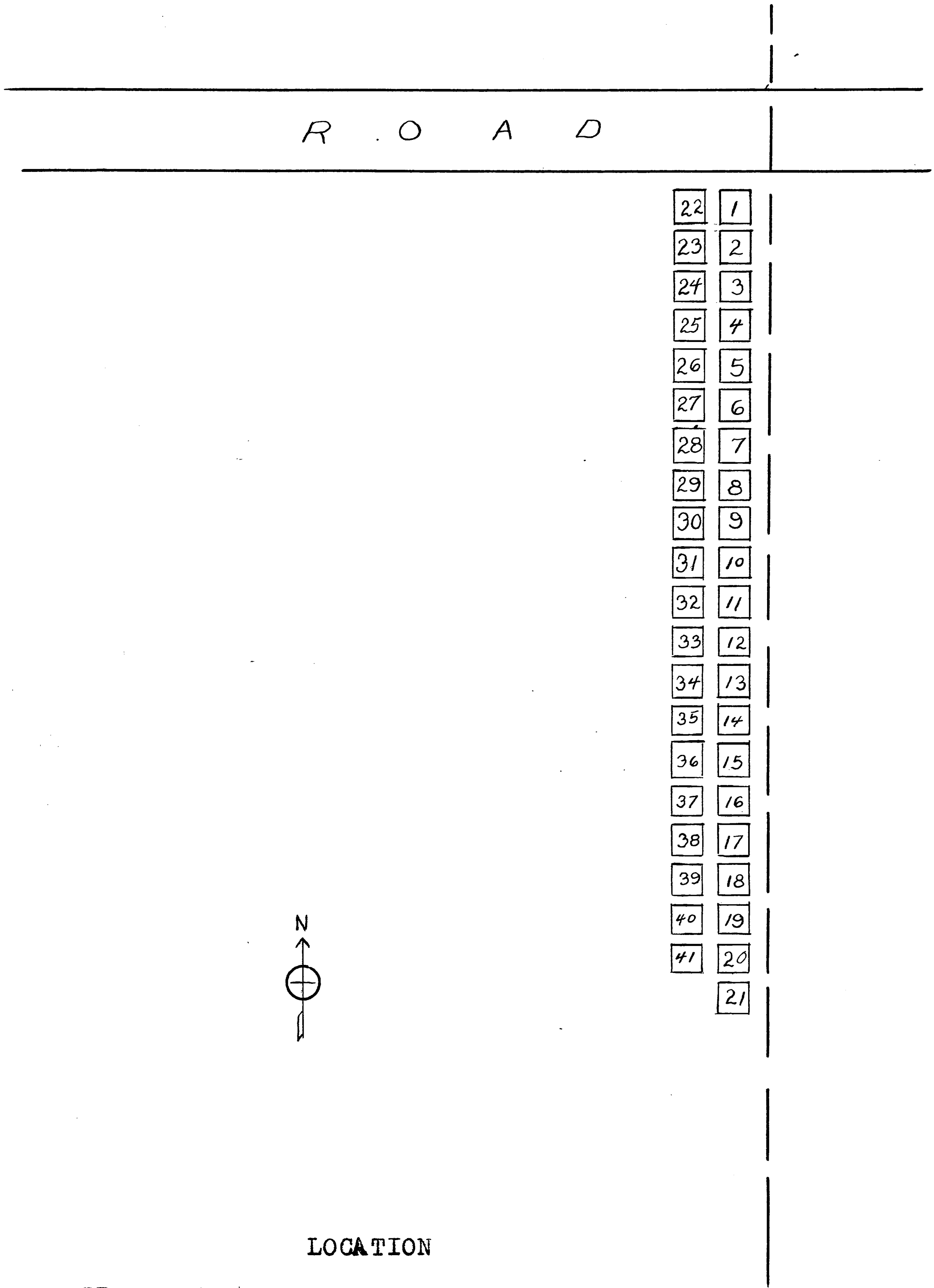


LOCATION

II DIAGRAM OF EXPERIMENTAL PLOTS

Tabular Statement

The following tabular statement (No. III) gives the treatment made on each plot. The numbers correspond to the numbers on the diagram of the nursery plan. The figures are given first, on the basis of pounds per acre and second, the actual amounts in grams applied to the plots.

The Dow listing represents a commercial by-product plant stimulant produced in 1938 by Dow Chemical Company. The chemical analysis is not available. The company gives an analysis of the 1939 plant stimulant which they maintain has been stepped up over the 1938 product.

Their analysis is as follows:

Moisture	48.30%
Humus	28.30%
Total nitrogen	3.93%
$P_2 O_5$	2.30%
MgO	0.68%
Sulphate	4.03%
Lime (CaO)	3.84%
Iron (Fe_2O_3)	0.50%

III

FERTILIZER TREATMENT

Plot No.	$(NH_4)_2SO_4$ lbs./A	$(NH_4)_2SO_4$ Gm/plot	$CaH_4(PO_4)_2$ lbs/A	$CaH_4(PO_4)_2$ Gm/plot	KCl lbs./A	KCl Gm/Plot
1.	480	43.537	240	21.769	30	2.721
2.	480	43.537	150	13.605	0	
3.	480	43.537	90	8.163	15	1.360
4.	480	43.537	0		20	1.814
5.	480	43.537	0		0	
6.	360	32.653	150	13.605	30	2.721
7.	0		0		0	
8.	360	32.653	150	13.605	0	
9.	360	32.653	90	8.163	15	1.360
10.	360	32.653	0		30	2.721
11.	0		0		0	
12.	240	21.769	240	21.769	0	
13.	240	21.769	150	13.605	30	2.721
14.	240	21.769	90	8.163	15	1.360
15.	240	21.769	0		0	
16.	240	21.769	90	8.163	0	
17.	240	21.769	150	13.605	15	1.360
18.	0		0		30	2.721
19.	150	13.605	150	13.605	30	
20.	150	13.605	150	13.605	15	1.360
21.	150	13.605	90	8.163	15	1.360
22.	150	13.605	0		15	1.360
23.	0		0		0	

Plot No.	$(NH_4)_2SO_4$ lbs./A	$(NH_4)_2SO_4$ Gm/plot	$CaH_4(PO_4)_2$ lbs./A	$CaH_4(PO_4)_2$ Gm/plot	KCl lbs./A	KCl Gm/plot
24.	0		240	21.769	30	2.721
25.	0		240	21.769	0	
26.	0		0		30	2.721
27.	0		150	13.605	15	1.360
28.	0		0		0	
29.	0		90	8.163	0	
30.	0		90	8.163	15	1.360
31.	600	54.420	240	21.769	30	2.721
32.	800	72.560	300	27.210	30	2.721
33.	800	72.560	150	13.605	30	2.721
34.	800	72.560	0		60	5.442
35.	600	54.420	150	13.605	30	2.721
36.	0		0		0	
37.	Dow Complete fertilizer				200	18.14
38.					350	31.75
39.					500	45.35
40.					650	58.95
41.	0		0		0	

IV Fall Measurements

On October 5, 1941, these measurements were taken before the transplants were dug. The mortality column gives the number of trees on the plot which did not survive. The average height column gives the average height in inches of the terminal bud above the ground level or the actual length of the main stem. The average diameter column gives the average diameter in millimeters at the first leaf scar by use of V-shaped calipers.

IV Fall Measurements

Plot No.	Total Mortality	Average Height Inches	Average Diameter Millimeter
1.	2	3.71	2.50
2.	2	3.33	2.73
3.	2	3.57	2.43
4.	6	3.81	2.52
5.	13	3.03	2.23
6.	6	3.60	2.64
7.	1	3.58	2.62
8.	5	3.06	3.17
9.	7	3.55	2.47
10.	3	3.49	2.50
11.	0	3.36	2.64
12.	3	3.98	2.83
13.	2	4.29	3.18
14.	2	3.94	2.93
15.	3	3.84	2.66
16.	11	4.52	2.82
17.	6	4.31	3.29
18.	1	4.10	2.72
19.	1	4.36	3.04
20.	0	3.92	3.10
21.	1	4.19	3.16
22.	1	3.94	2.50

Fall Measurements

Plot No.	Total Mortality	Average Height Inches	Average Diameter Millimeter
23.	0	3.48	2.36
24.	0	4.19	2.55
25.	0	3.72	2.43
26.	0	4.23	2.41
27.	0	3.53	2.57
28.	1	3.59	2.18
29.	6	3.99	2.19
30.	1	4.19	2.21
31.	3	3.68	2.20
32.	12	4.00	2.23
33.	14	2.96	2.22
34.	12	3.70	2.17
35.	14	4.12	2.56
36.	0	3.63	2.32
37.	1	3.53	2.31
38.	1	3.34	2.45
39.	1	3.11	2.12
40.	0	3.70	2.29
41.	1	3.28	1.99

Dry Weight Measurements

In an attempt to lose as little as possible of the root system, the transplants were carefully dug. The plants were washed to remove the dirt. Those plants which gave evidence of grub damage to the roots were rejected. The number in the second column gives the number of trees remaining; only these were measured. From here the trees lose their individual identity, the measurements given being the total weight in grams of all remaining divided by the number remaining. Before weighing, the trees were dried in an oven for forty eight hours at temperatures not exceeding 150° Fahreheit. The average weight in grams are recorded for the whole tree, for the portion above ground, and for the portion below ground. The ratio of average weight of top to average weight of root is found in the last column.

V Dry Weight Measurements

Plot No.	Based on #trees	Total grams	Top grams	Root grams	Top/root ratio
1.	17	1.62	1.10	.52	2.1
2.	17	1.66	1.14	.52	2.2
3.	18	1.43	.95	.48	1.9
4.	13	1.40	.94	.45	2.1
5.	6	.82	.50	.32	1.7
6.	11	1.70	1.16	.54	2.1
7.	14	1.00	.75	.38	2.0
8.	16	1.34	.85	.49	1.7
9.	12	1.22	.88	.33	2.7
10.	18	1.49	.88	.60	1.5
11.	20	2.33	1.46	.87	1.7
12.	16	1.96	1.18	.68	1.7
13.	18	2.50	1.66	.84	2.0
14.	18	2.10	1.31	.79	1.7
15.	16	2.00	1.20	.80	1.5
16.	11	1.57	1.00	.57	1.7
17.	13	2.58	1.69	.86	2.0
18.	18	2.28	1.51	.77	2.0
19.	19	2.83	1.84	1.01	1.8
20.	17	2.70	1.67	1.03	1.6
21.	20	2.87	1.74	1.13	1.5
22.	16	1.47	.91	.56	1.6
23.	20	1.35	0.97	.38	2.5
24.	20	1.94	1.37	.58	2.4

Dry Weight Measurements

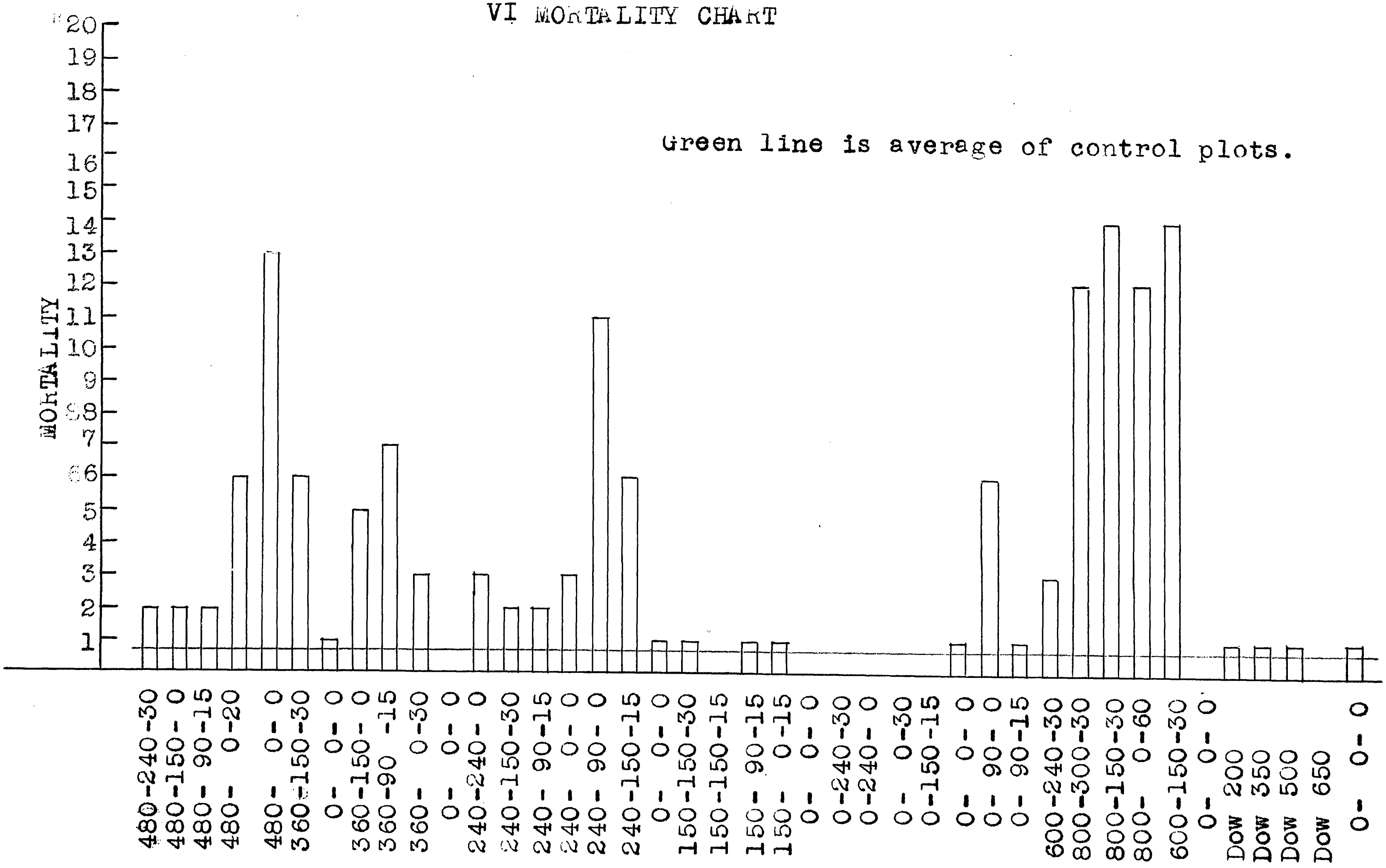
Plot No.	Based on # trees	Total grams	Top grams	Root grams	Top/Root ratio
25.	20	1.53	1.07	.46	2.3
26.	20	1.63	1.08	.55	2.0
27.	18	1.97	1.40	.57	2.5
28.	19	1.24	.85	.39	2.2
29.	17	1.16	.80	.36	2.2
30.	18	1.34	.92	.42	2.2
31.	17	1.12	.78	.33	2.4
32.	8	1.25	.84	.41	2.0
33.	5	.96	.74	.22	3.4
34.	7	.99	.69	.30	2.3
35.	6	1.75	1.32	.43	3.0
36.	20	.98	.53	.45	1.2
37.	17	1.52	1.05	.47	2.2
38.	19	1.71	1.21	.50	2.4
39.	18	1.16	.81	.35	2.3
40.	20	1.63	1.12	.51	2.2
41.	17	1.07	.73	.33	2.2

Mortality

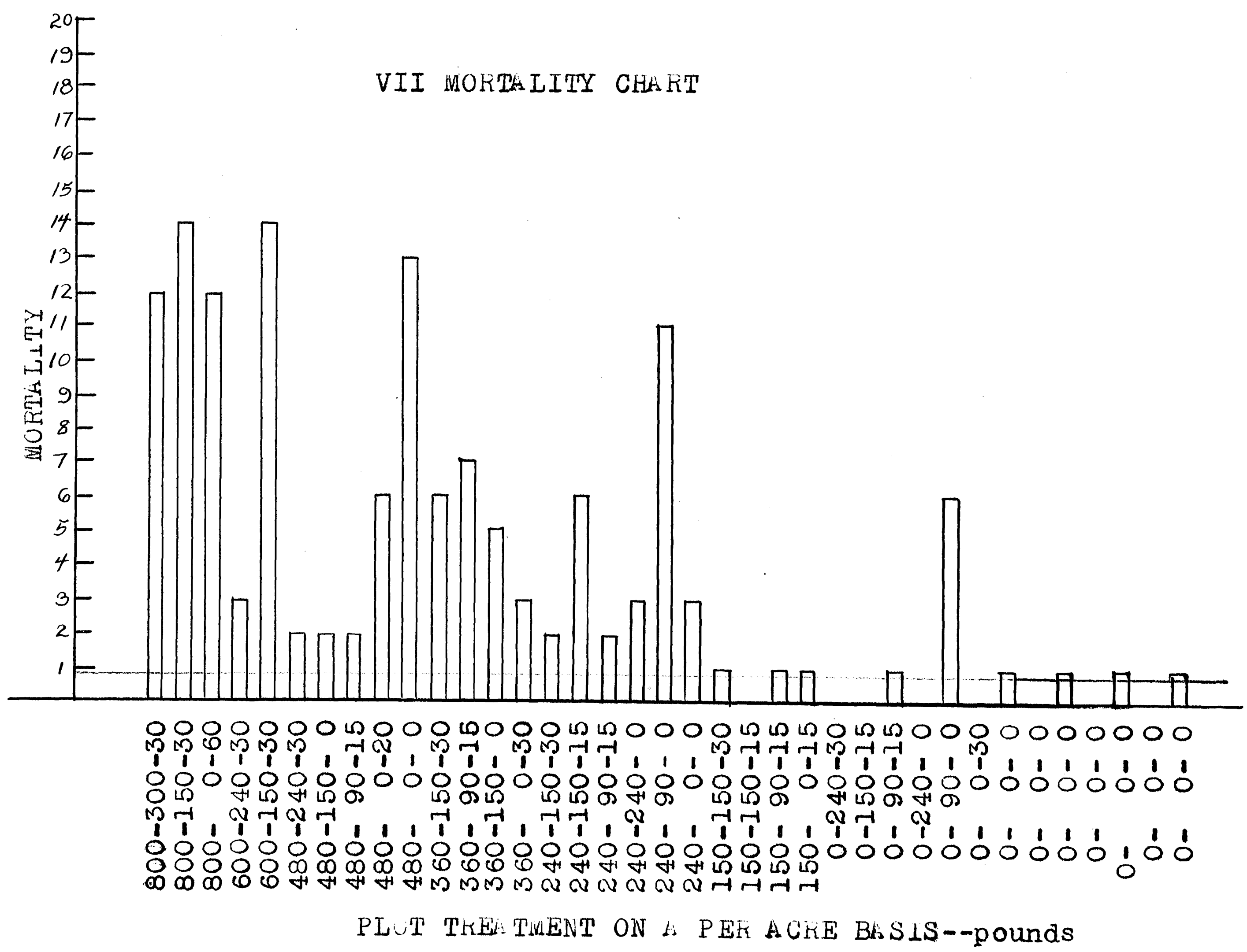
The mortality charts numbered VI, VII, & VIII are the first to be analyzed. The white grubs are the unknown factor believed to be very important as causing mortality. The average mortality among control plots was six tenths of one plant per control plots with no control plot losing over one plant. In contrast, the treated plots lost as many as fourteen plants out of twenty. From this it is belived that their must be some cause for mortality other than general grub infestation. Since four of the five plots receiving 600 or more pounds per acre of ammonium sulphate had a mortality of over sixty per cent, chemical burning might have been the causal agent. The incomplete fertilizers showed much higher losses than did the plots receiving a balanced fertilizer. The counter-balancing effects of the three nutrient elements is credited with this last observed effect.

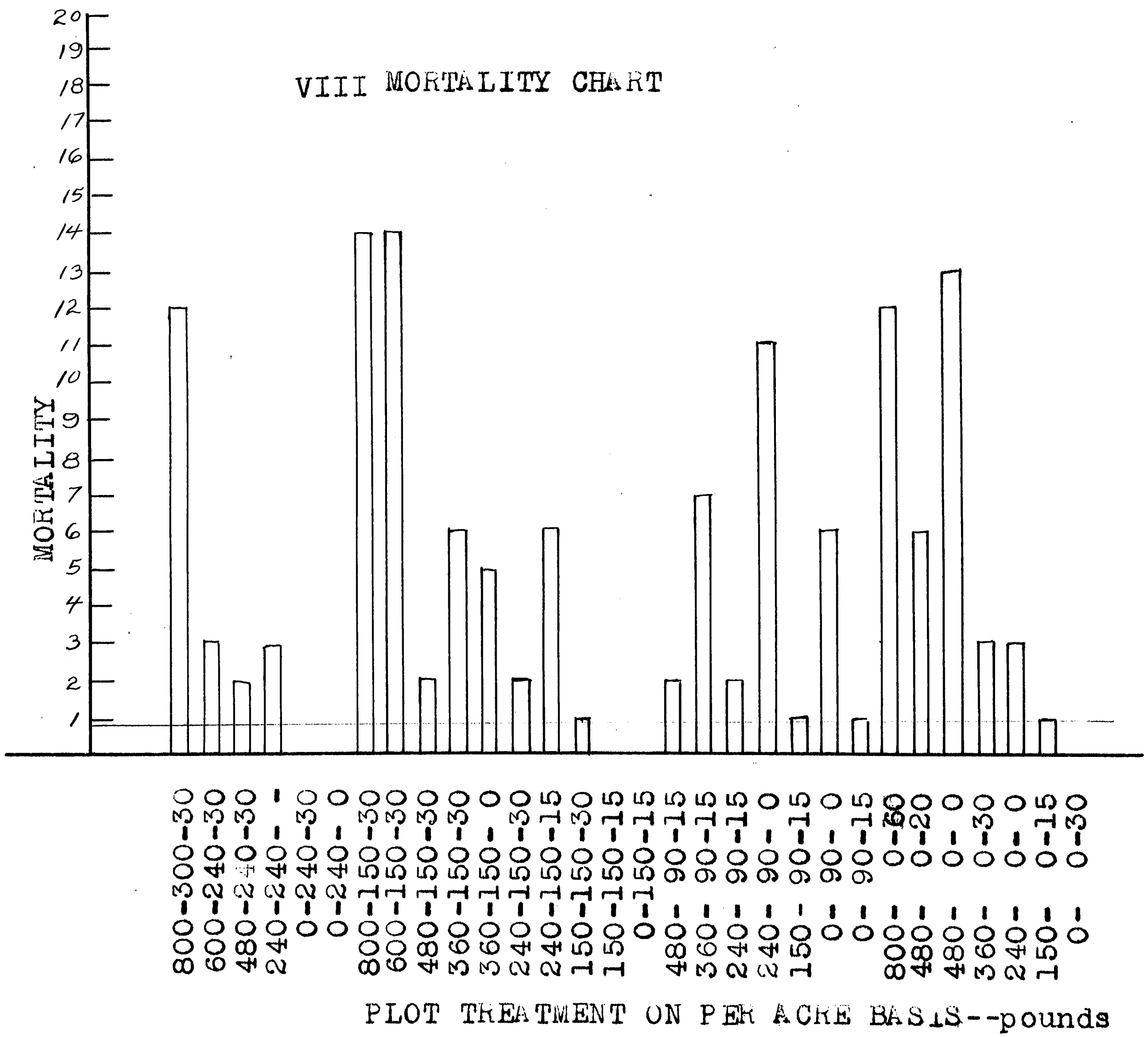
VI MORTALITY CHART

Green line is average of control plots.



PLOT TREATMENT ON PER ACRE BASIS**pounds

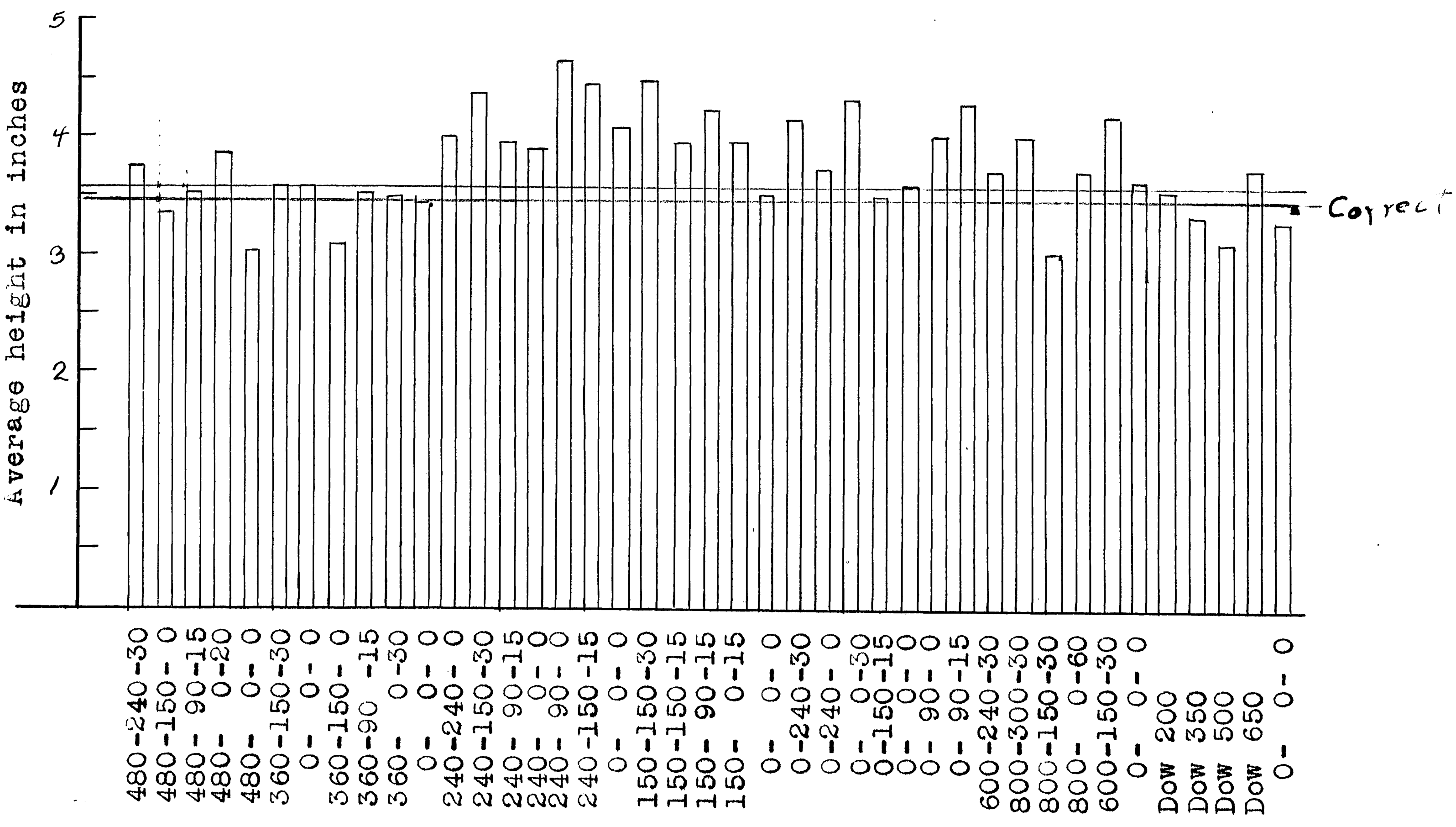

VII MORTALITY CHART
MORTALITY
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
800-300-30
800-150-30
800- 0-60
600-240-30
600-150-30
480-240-30
480-150- 0
480- 90-15
480- 0-20
480- 0- 0
360-150-30
360- 90-15
360-150- 0
360- 0-30
240-150-30
240-150-15
240- 90-15
240-240- 0
240- 90- 0
240- 0- 0
150-150-30
150-150-15
150- 90-15
150- 0-15
0-240-30
0-150-15
0- 90-15
0-240- 0
0- 90- 0
0- 0-30
0- 0- 0
0- 0- 0
0- 0- 0
0- 0- 0
0- 0- 0
0- 0- 0
0- 0- 0
PLOT TREATMENT ON A PER ACRE BASIS--pounds


VIII MORTALITY CHART
MORTALITY
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
800-300-30
600-240-30
480-240-30
240-240- -
0-240-30
0-240- 0
800-150-30
600-150-30
480-150-30
360-150-30
360-150- 0
240-150-30
240-150-15
150-150-30
150-150-15
0-150-15
480- 90-15
360- 90-15
240- 90-15
240- 90- 0
150- 90-15
0- 90- 0
0- 90-15
800- 0-50
480- 0-20
480- 0- 0
360- 0-30
240- 0- 0
150- 0-15
0- 0-30
PLOT TREATMENT ON PER ACRE BASIS--pounds

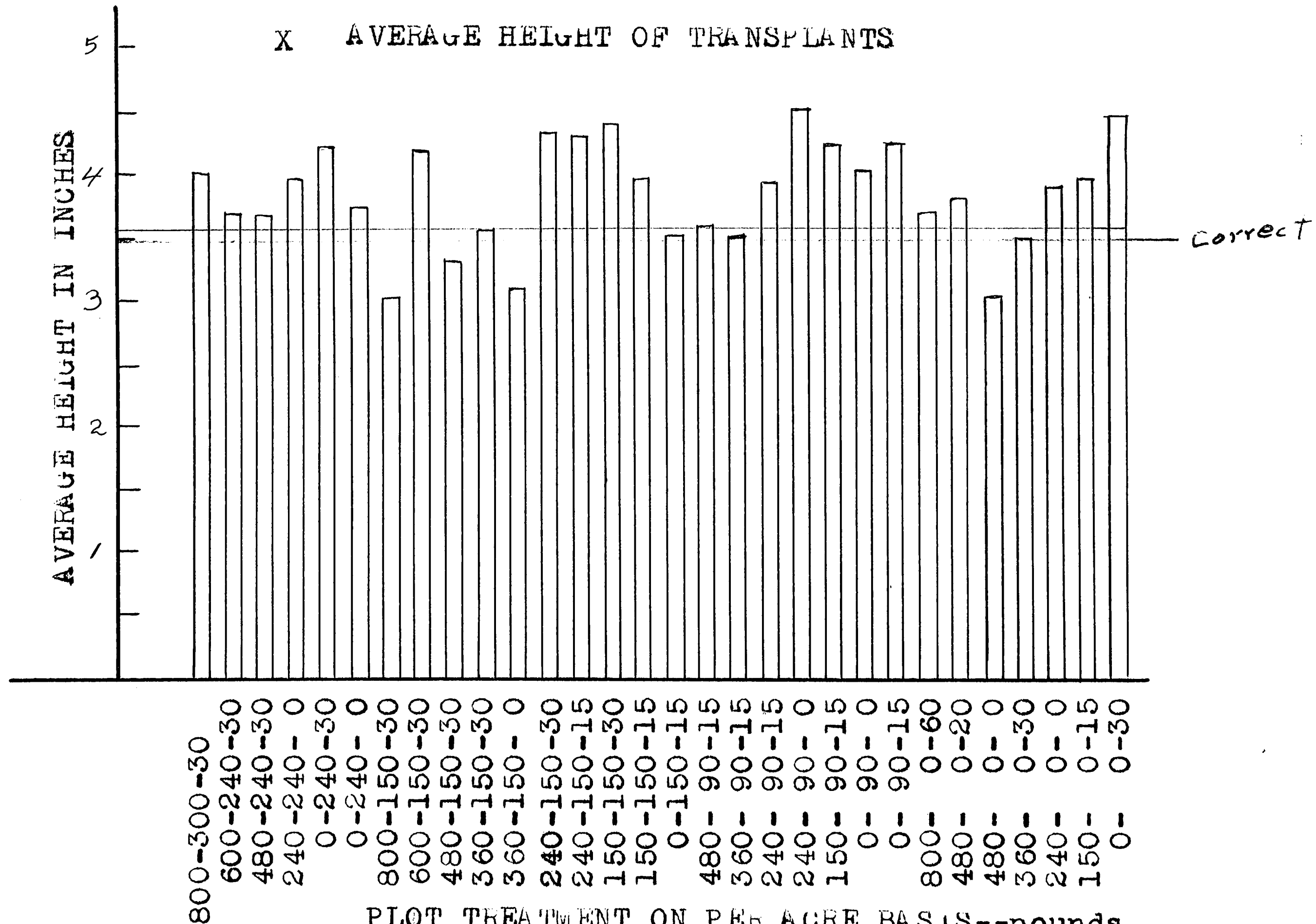
Height

Bar charts numbered IX, X, & XI were next analyzed for the effects of different treatments upon height growth. It was especially noted in the field that the trees in each plot were not uniform in height. The average height of the plants in the control plots was 3.49 inches. Eighty five per cent of the treated plots exceeded this average. From this it is eveident that height growth was increased by most of the treatments. Examination of graph no.IX, nursery order, indicates no general trend, thus the differences in heights are credited to the individual plots and not to any general nursery condition. Examination of graph no. XI, superphosphate order, likewise indicated, no significant trend. However, an over supply of phosphorus would produce no ill effects and a deficiency would be difficult to detect. Examination of graph no.X, ammonium sulphate order, does show some significant differences. The plots treated with 360 or more pounds per acre of ammonium sulphate are noticeably shorter than those treated with 150 or 240 pound. Two exceptions--800-300-30 & 600-150-30--were plots received well balanced heavy fertilizer applications. From this it would seem that if very heavy applications of nitrogen carriers are made, there must also be heavy applications of phosphorus and potassium carriers. On the other hand it appears that with a moderate application of nitrogen the counter-balancing effects of other minerals is not so necessary. From these graphs it appears that a well balanced moderate fertilizer produced the most satisfactory results as to height growth.

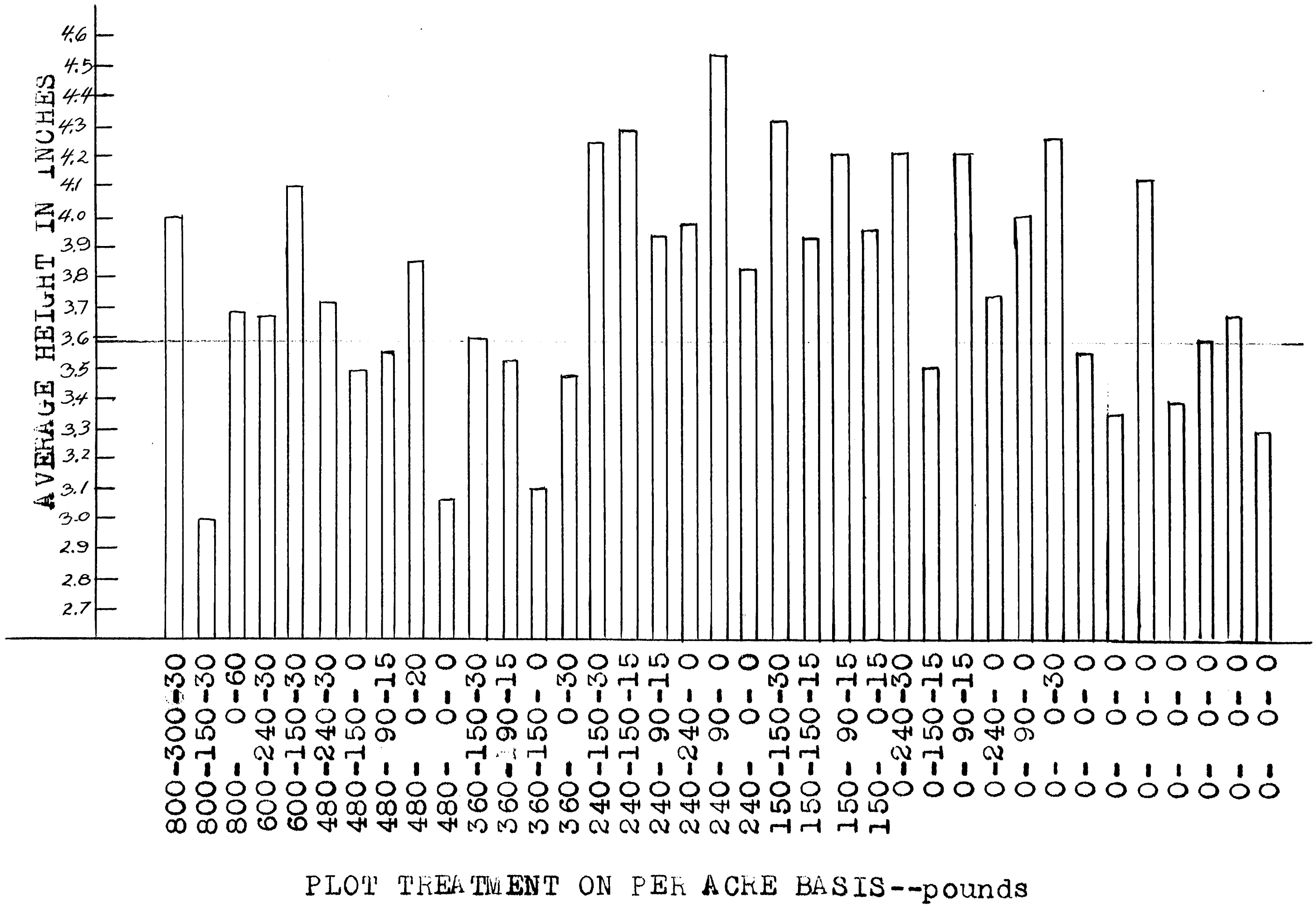
IX AVERAGE HEIGHT OF TRANSPLANTS



X AVERAGE HEIGHT OF TRANSPLANTS

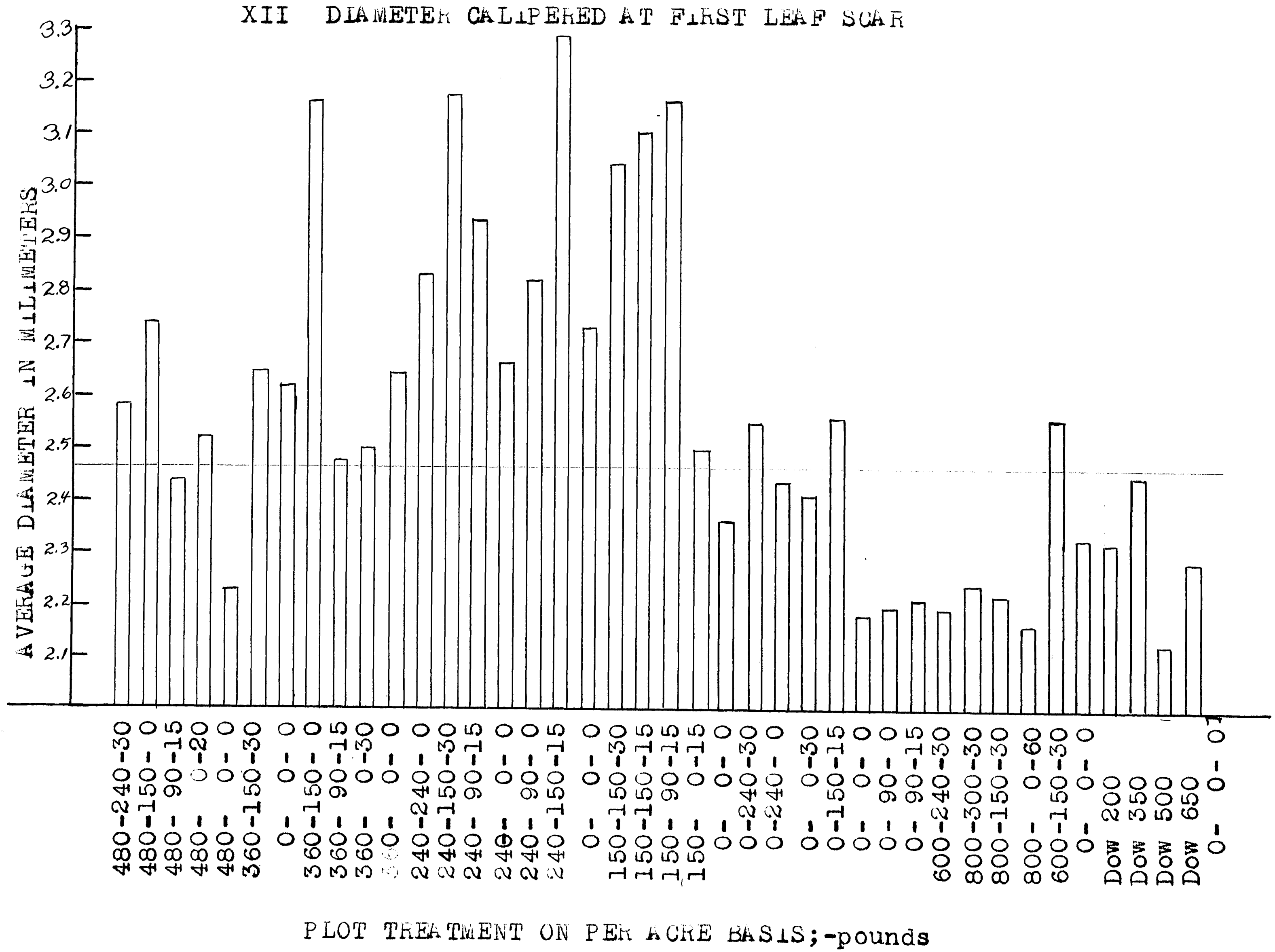


XI HEIGHT CHART

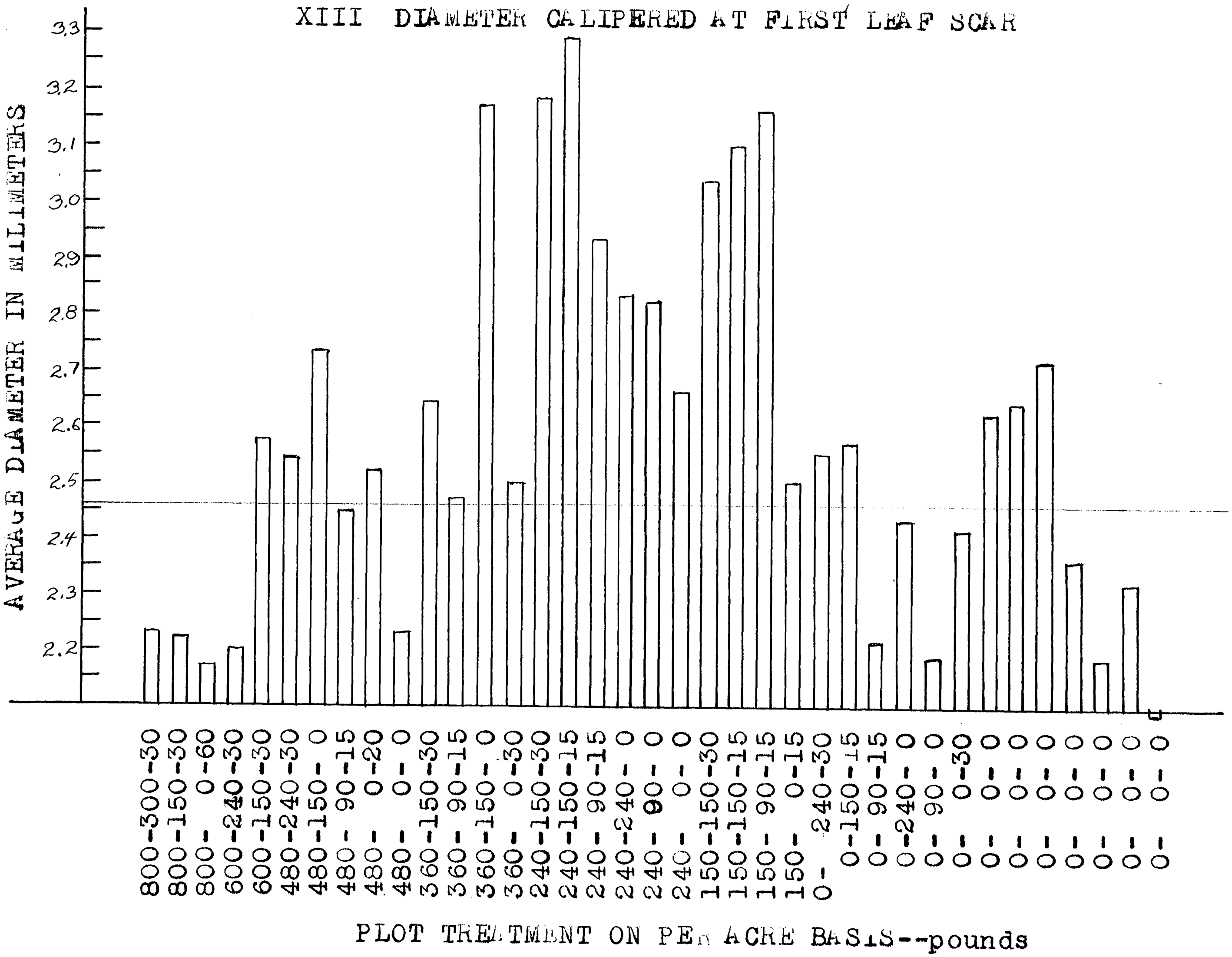


Diameter

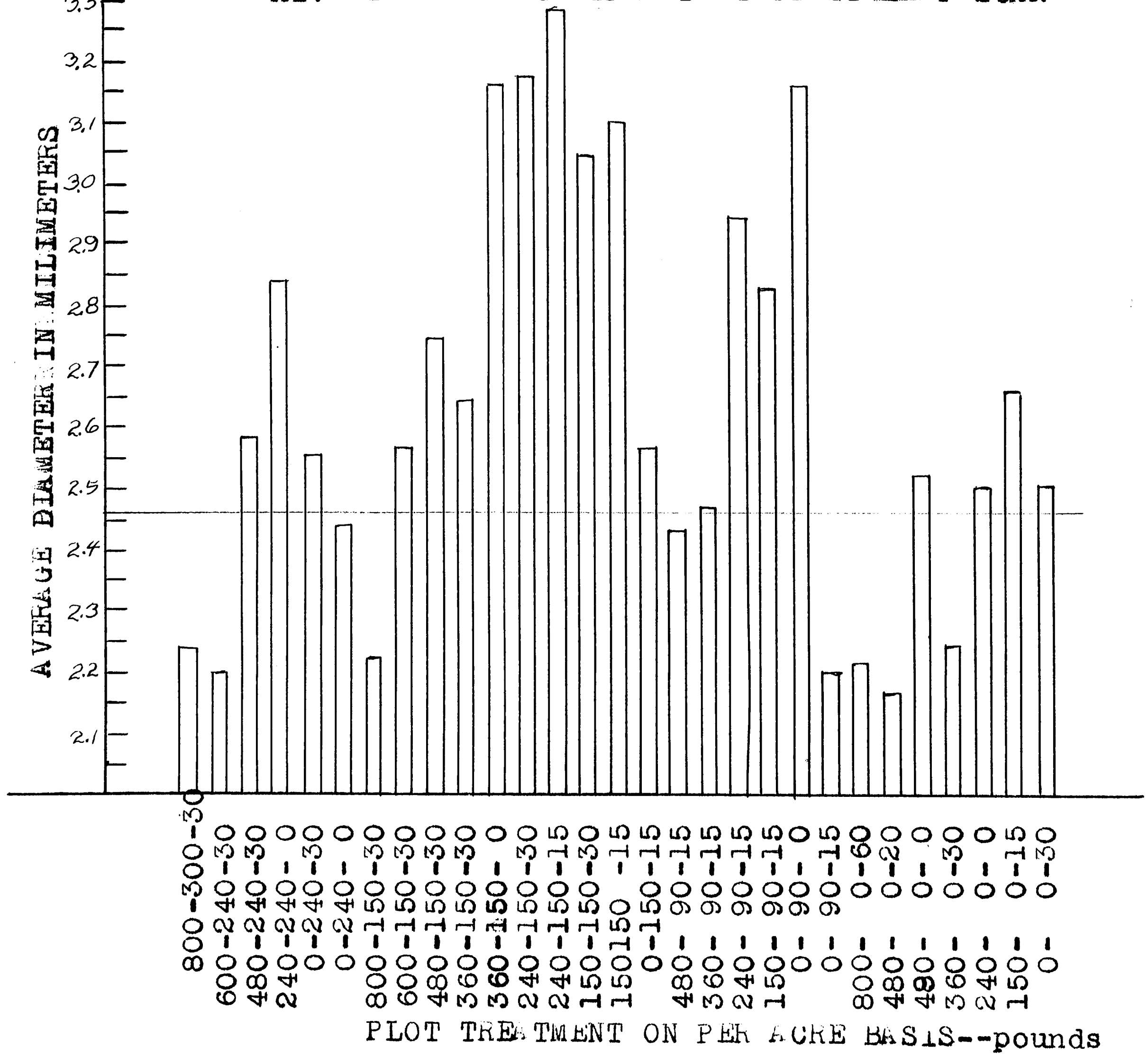
Determining just where 'diameter breast height' is on a 2-1 Norway pine was the first problem which had to be solved before the trees could be calipered. It was found that the diameter of trees at this age vary considerably within an inch along the stem. The diameter at the first leaf scar was arbitrairily chosen. This point was chosen as being most comparable. The diameters were measured in milimeters by use of V-shaped calipers. The bar charts no. XII, XIII, & XIV were analyzed for diameter differences among the plots. Examination of chart no XII, nursery order, shows a large difference in general between the plots in the easterly row and those in the westerly row. Examination of charts no. XIII & XIV illustrate two trends: First, with applications of 360 or more pounds per acre ammonium sulphate the plots failed to show increase in diameter over the control plots. Second without nitrogen supplement, the other treatments were ineffective in increasing diameter growth. The best results were consistently produced by plots receiving balanced complete fertilizers 240-150-30 to 150-90-15. Incomplete fertilizers were less satisfactory.


XII DIAMETER CALIPERED AT FIRST LEAF SCAR
AVERAGE DIAMETER IN MILLIMETERS
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
480-240-30
480-150- 0
480- 90-15
480- 0-20
480- 0- 0
360-150-30
0- 0- 0
360-150- 0
360- 90-15
360- 0-30
360- 0- 0
240-240- 0
240-150-30
240- 90-15
240- 0- 0
240- 90- 0
240-150-15
0- 0- 0
150-150-30
150-150-15
150- 90-15
150- 0-15
0- 0- 0
0-240-30
0-240- 0
0- 0-30
0-150-15
0- 0- 0
0- 90- 0
0- 90-15
600-240-30
800-300-30
800-150-30
800- 0-60
600-150-30
0- 0- 0
Dow 200
Dow 350
Dow 500
Dow 650
0- 0- 0
PLOT TREATMENT ON PER ACRE BASIS;-pounds

XIII DIAMETER CALIPERED AT FIRST LEAF SCAR

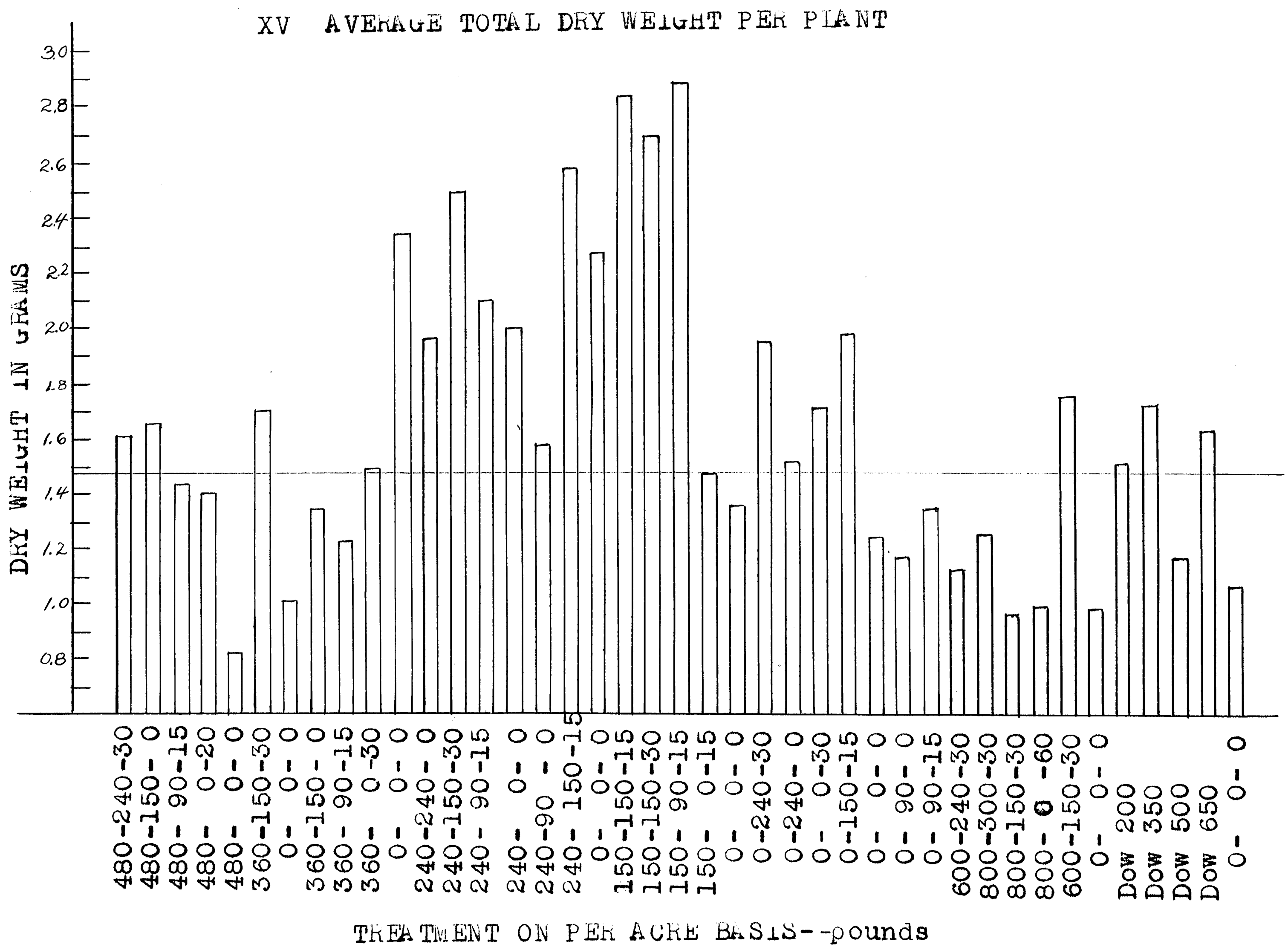


XIV DIAMETER CALIPERED AT FIRST LEAF SCAR



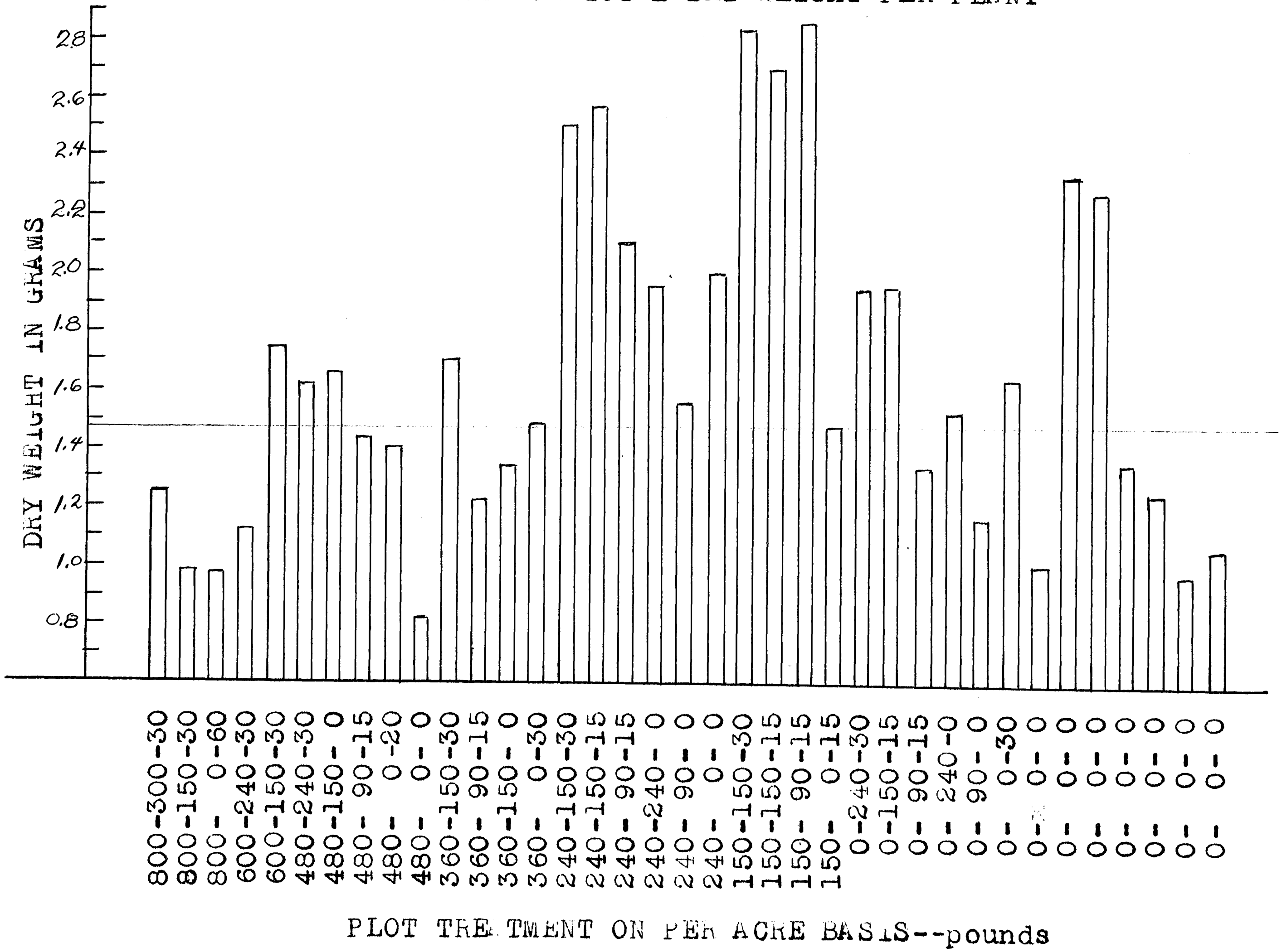
Total Dry Weight

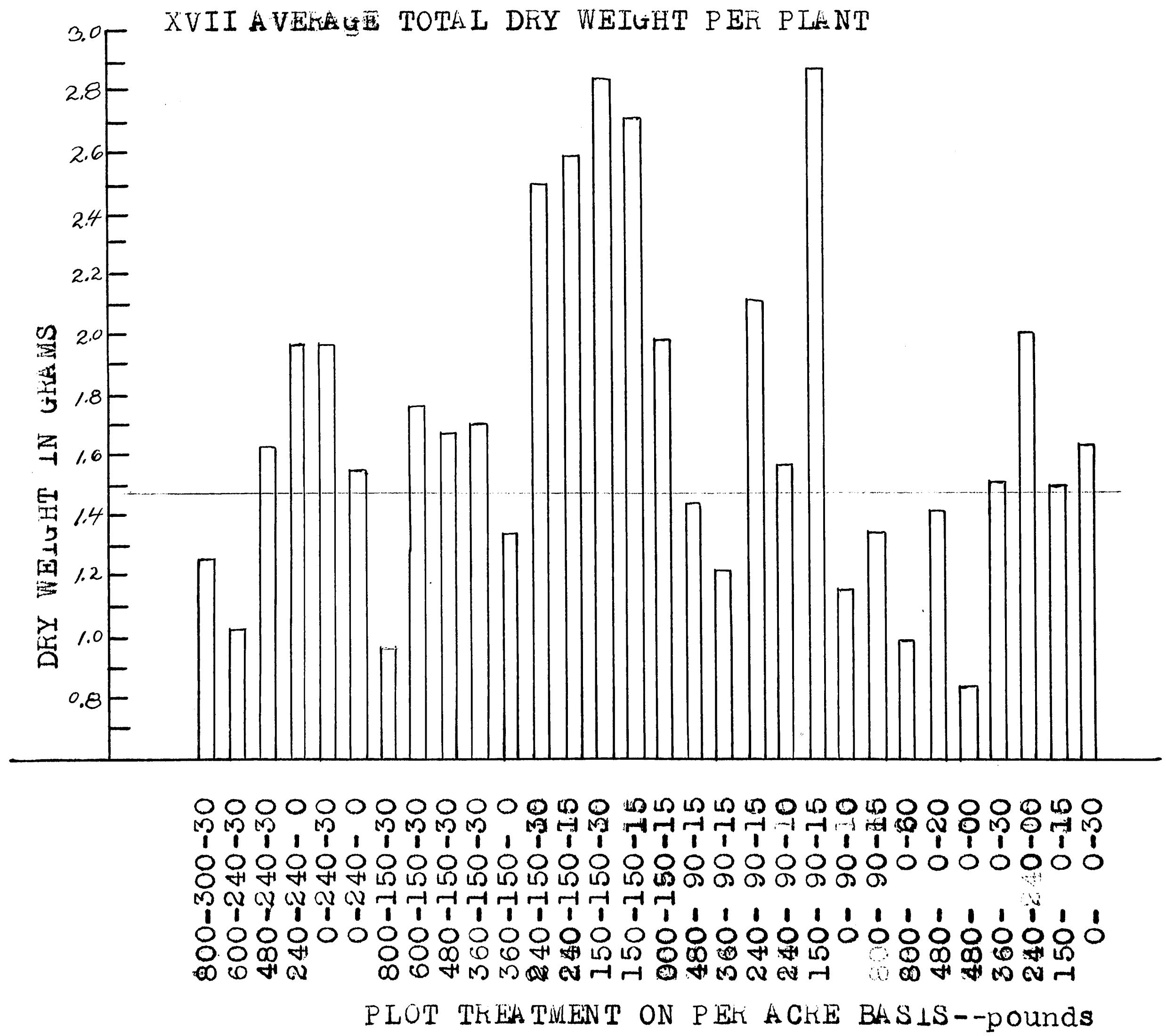
Bar charts numbered XV, XVI, and XVII illustrate graphically the differences in average total weight per plant among the plots. Examination of these charts brings out the following features: First, incomplete fertilizers usually produced negative results. Second, applications of ammonium sulphate to the extent of 360 or more pounds per acre produced little growth stimulis during the first growing season. Third, without a nitrogen carrier other mineral additions failed to appreciably increase the growth in total dry weight. This may well be attributed to the acid radical of ammonium sulphate as well as nitrogen supplement. The largest increases in total dry weight over the control plots were attained by those plots which were treated by balanced fertilizers 240-150-30 to 150-90-15. This may be attributed to the temporary increased concentrations of plant nutrients in the soil solution or the acid reaction of the materials added.



XV AVERAGE TOTAL DRY WEIGHT PER PLANT
DRY WEIGHT IN GRAMS
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
480-240-30
480-150- 0
480- 90-15
480- 0-20
480- 0- 0
360-150-30
0- 0- 0
360-150- 0
360- 90-15
360- 0-30
0- 0- 0
240-240- 0
240-150-30
240- 90-15
240- 0- 0
240-90 - 0
240- 150-15
0- 0- 0
150-150-15
150-150-30
150- 90-15
150- 0-15
0- 0- 0
0-240-30
0-240- 0
0- 0-30
0-150-15
0- 0- 0
0- 90- 0
0- 90-15
600-240-30
800-300-30
800-150-30
800- 0 -60
600-150-30
0- 0- 0
Dow 200
Dow 350
Dow 500
Dow 650
0- 0- 0
TREATMENT ON PER ACRE BASIS--pounds

XVI AVERAGE TOTAL DRY WEIGHT PER PLANT

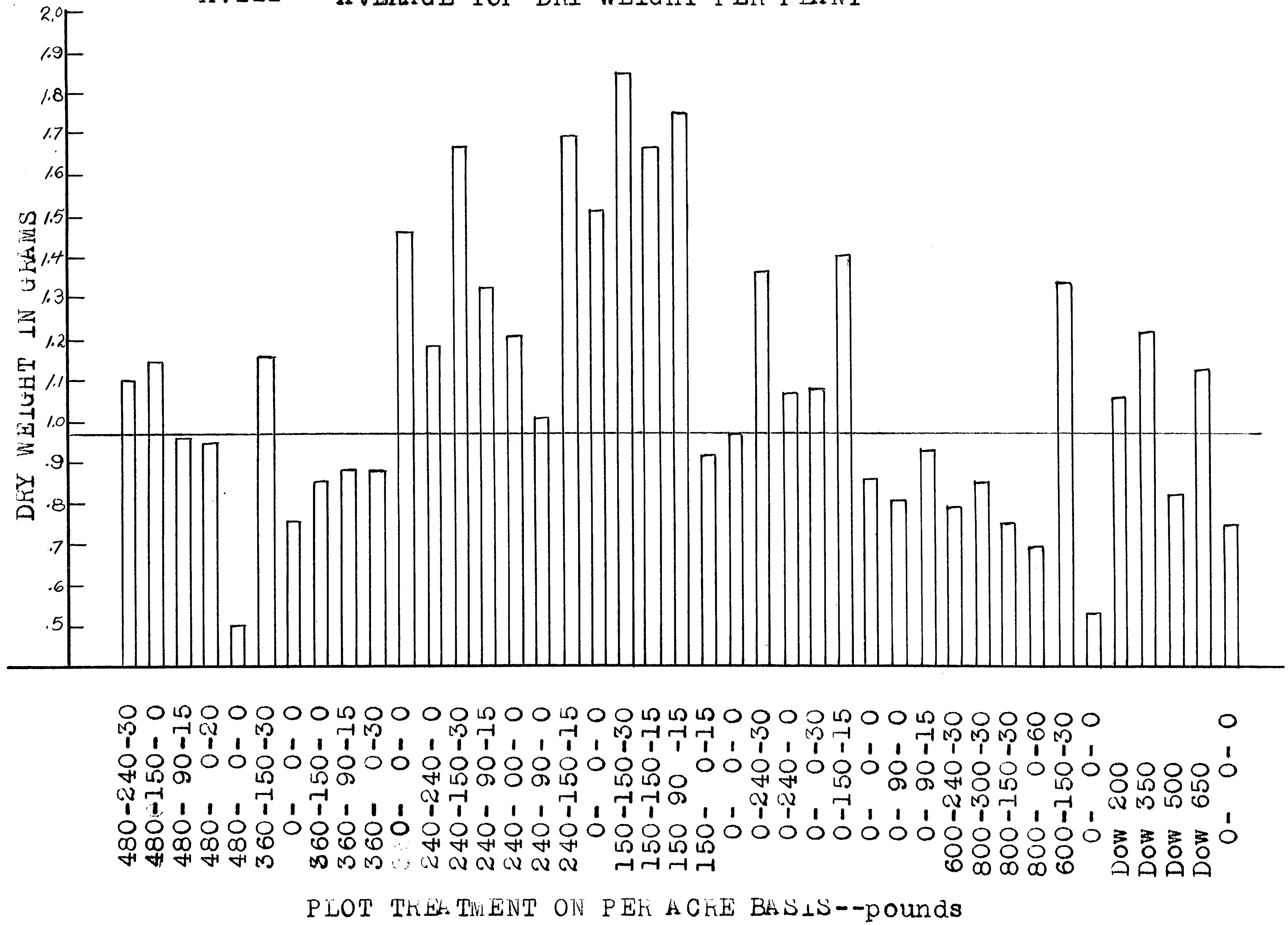


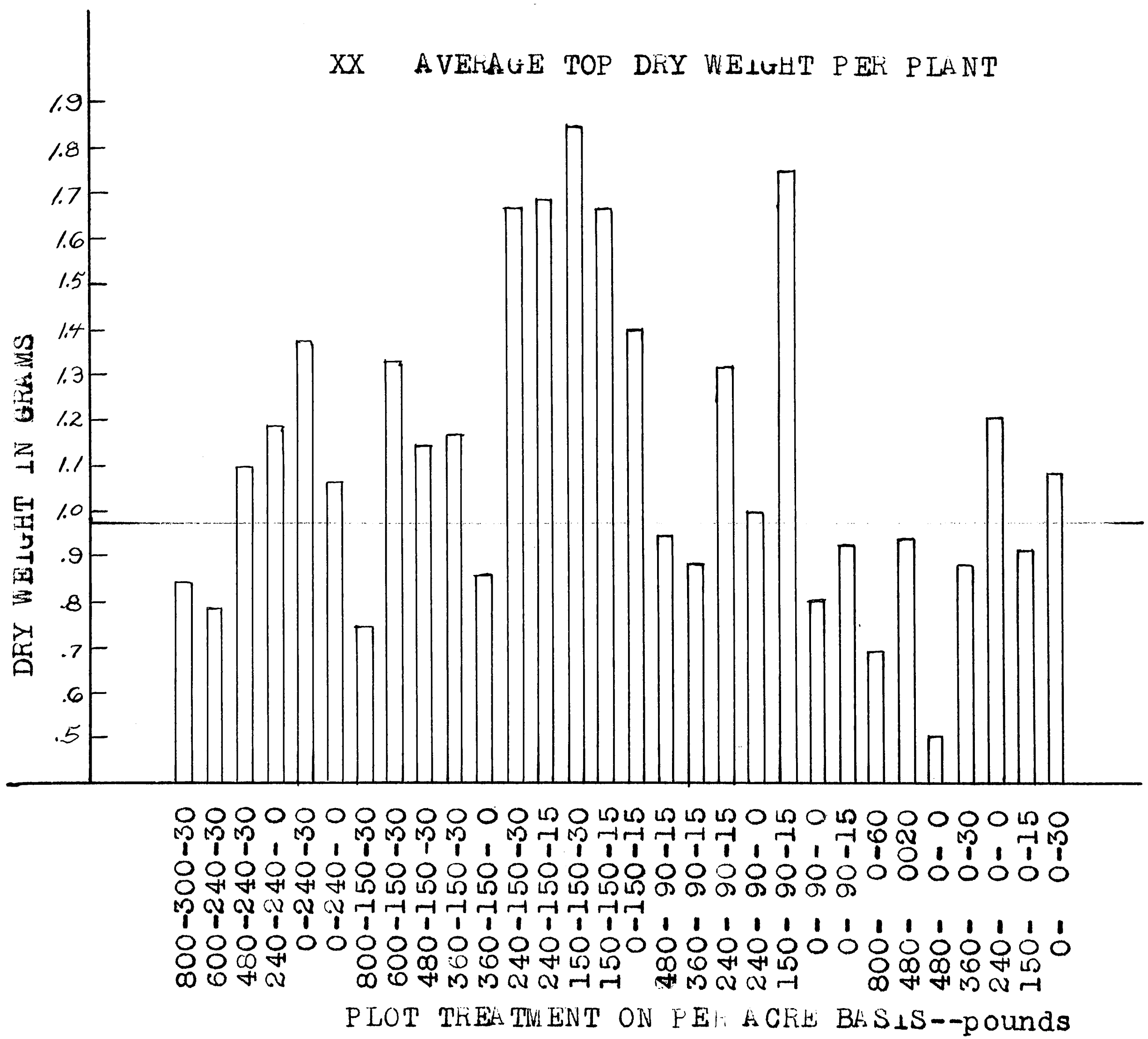

XVII AVERAGE TOTAL DRY WEIGHT PER PLANT
DRY WEIGHT IN GRAMS
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
800-300-30
600-240-30
480-240-30
240-240- 0
0-240-30
0-240- 0
800-150-30
600-150-30
480-150-30
360-150-30
360-150- 0
240-150-30
240-150-15
150-150-30
150-150-15
000-150-15
480- 90-15
360- 90-15
240- 90-15
240- 90-10
150- 90-15
0- 90-10
600- 90-15
800- 0-60
480- 0-20
480- 0-00
360- 0-30
240-240-00
150- 0-15
0- 0-30
PLOT TREATMENT ON PER ACRE BASIS--pounds

Top Dry Weight

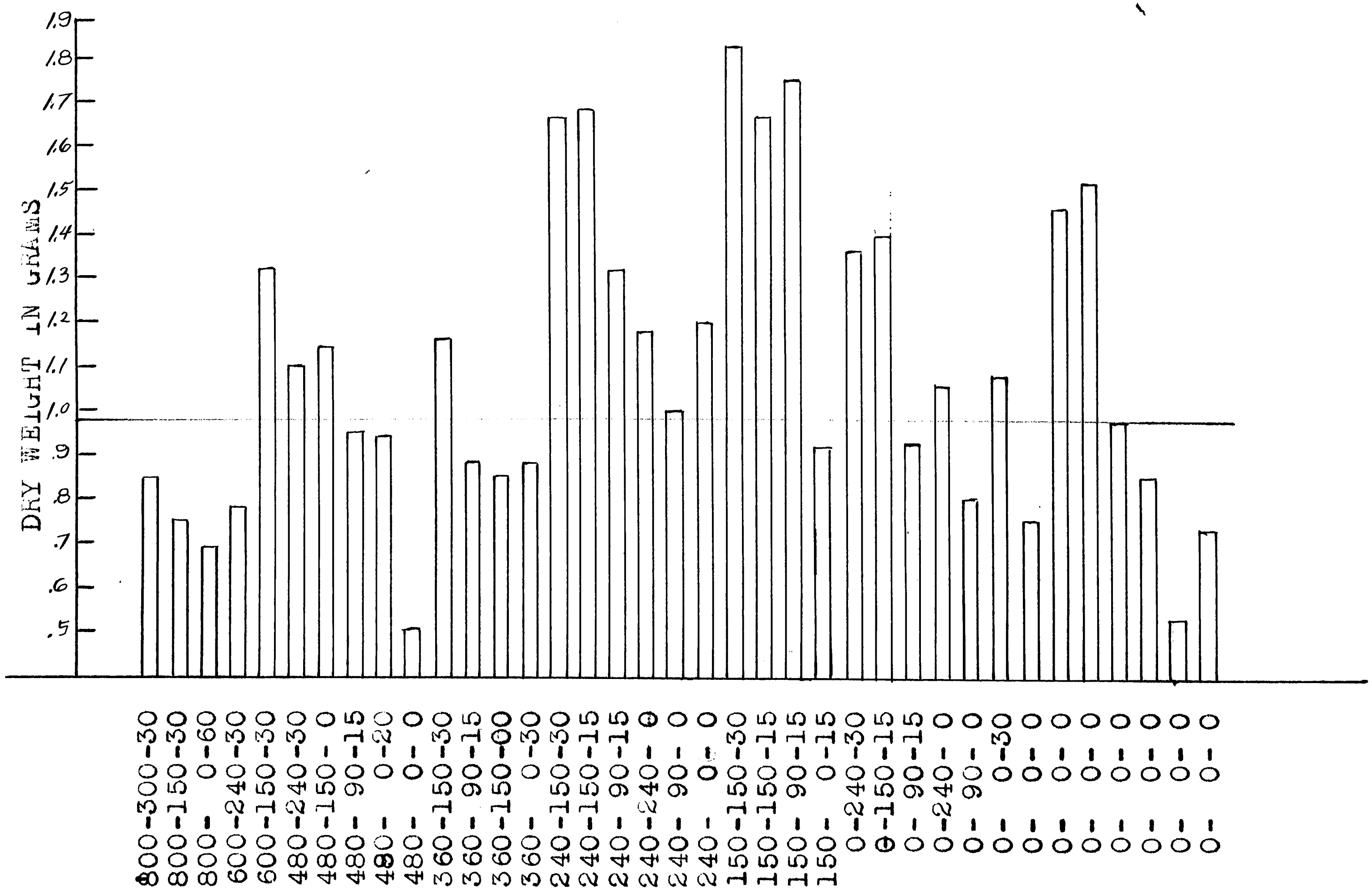
Bar charts numbered XVIII, XIX, and XX illustrate graphically the variation in average top dry weight among the plots. Examination of the graphs indicates that the weight of plant tops varies about the same as the weight of the total plant. When 360 or more pounds per acre of ammonium sulphate was used, negative results followed. The plots which showed the largest top growth were those receiving moderate amounts of complete fertilizers. As previously noted, the variability among control plots makes all conclusions of a dubious character.

XVIII AVERAGE TOP DRY WEIGHT PER PLANT




XX AVERAGE TOP DRY WEIGHT PER PLANT
DRY WEIGHT IN GRAMS
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
800-300-30
600-240-30
480-240-30
240-240- 0
0-240-30
0-240- 0
800-150-30
600-150-30
480-150-30
360-150-30
360-150- 0
240-150-30
240-150-15
150-150-30
150-150-15
0-150-15
480- 90-15
360- 90-15
240- 90-15
240- 90- 0
150- 90-15
0- 90- 0
0- 90-15
800- 0-60
480- 0020
480- 0- 0
360- 0-30
240- 0- 0
150- 0-15
0- 0-30
PLOT TREATMENT ON PER ACRE BASIS--pounds

XIX AVERAGE TOP DRY WEIGHT PER PLANT

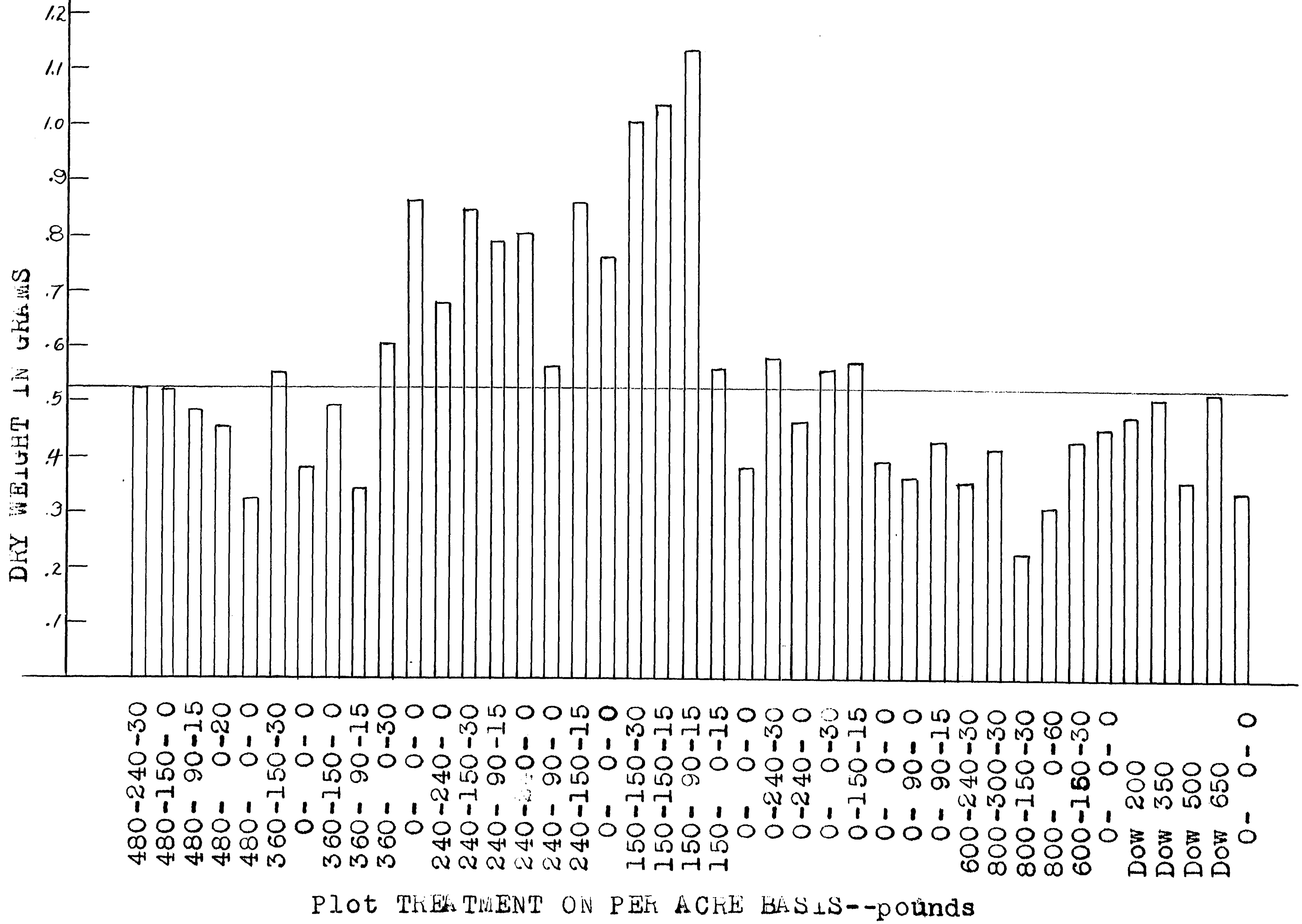


PLOT TREATMENT ON PER ACRE BASIS--pounds

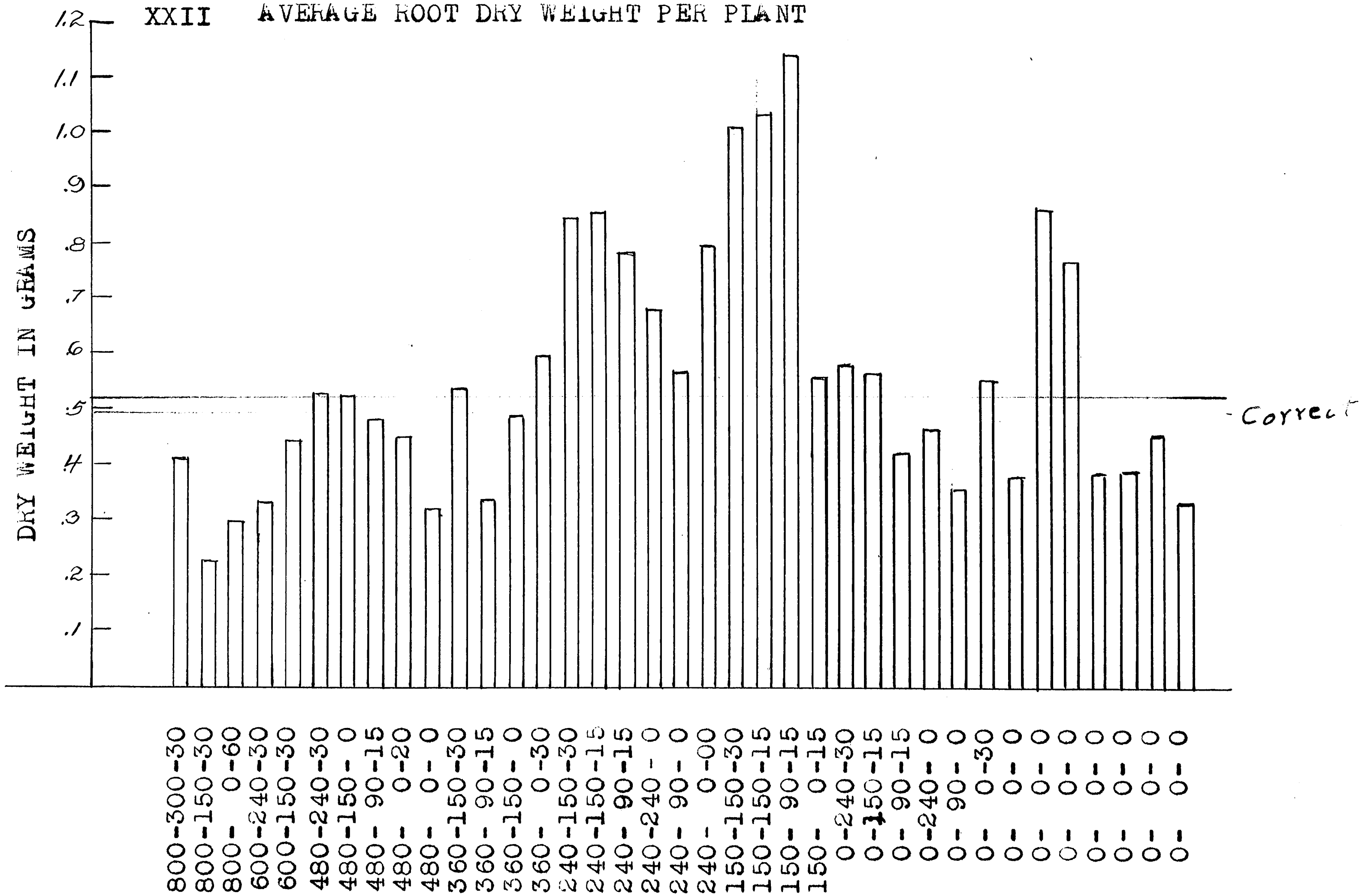
Root Dry Weight

Bar charts numbered XXI, XXII, and XXIII illustrate graphically the variation in average dry weight of roots per plant among the plots. Examination of the graphs shows results similar to previous weight charts. Plots receiving 360 or more pounds per acre of ammonium sulphate give negative results. The plots receiving no nitrogen carrier produced negative results. The plots receiving incomplete fertilizers in most instances failed to show larger root systems than the adjacent control plots. The three plots which showed the largest increase over nearest control plots were treated with moderate complete fertilizers --150-150-30, 150-150-15 and 150-90-15. Control plots in this sector had exceptionally large root systems, therefore while several of the other plots had large root systems they do not show a higher weight than adjacent control plots.

XXI AVERAGE ROOT DRY WEIGHT PER PLANT

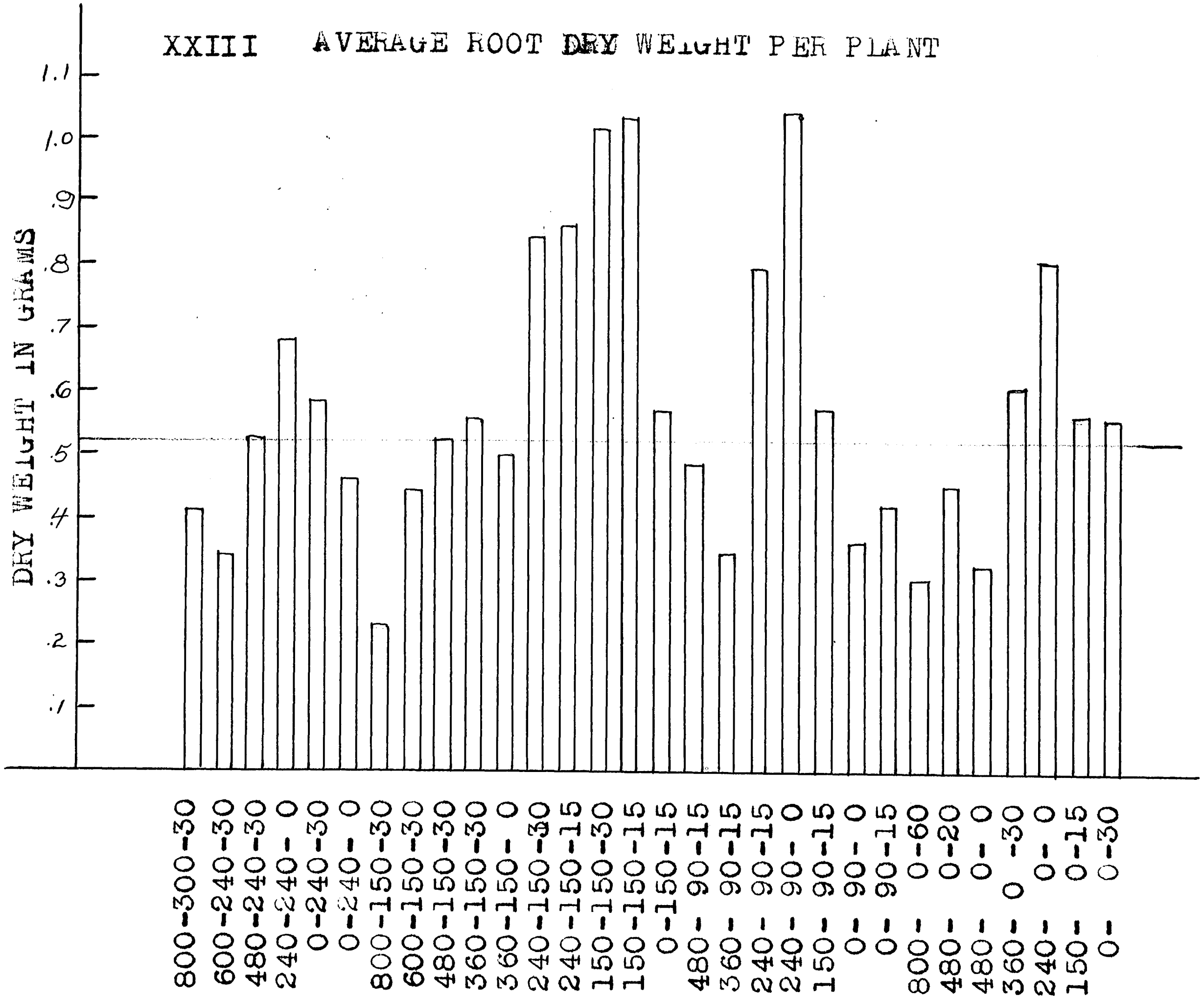


XXII AVERAGE ROOT DRY WEIGHT PER PLANT



PLOT TREATMENT ON PER ACRE BASIS--pounds

XXIII AVERAGE ROOT DRY WEIGHT PER PLANT

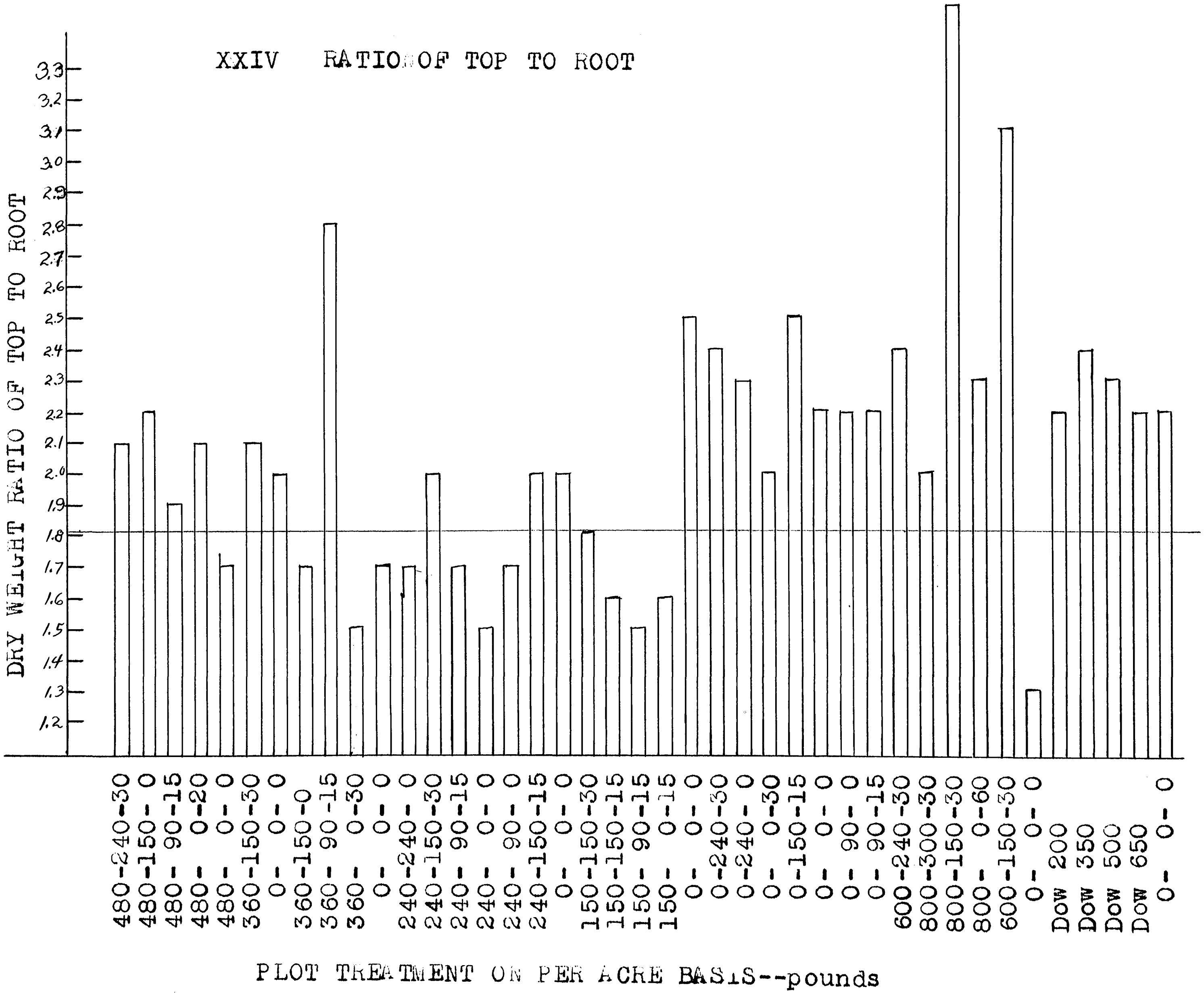


TREATMENT ON PER ACRE BASIS--pounds

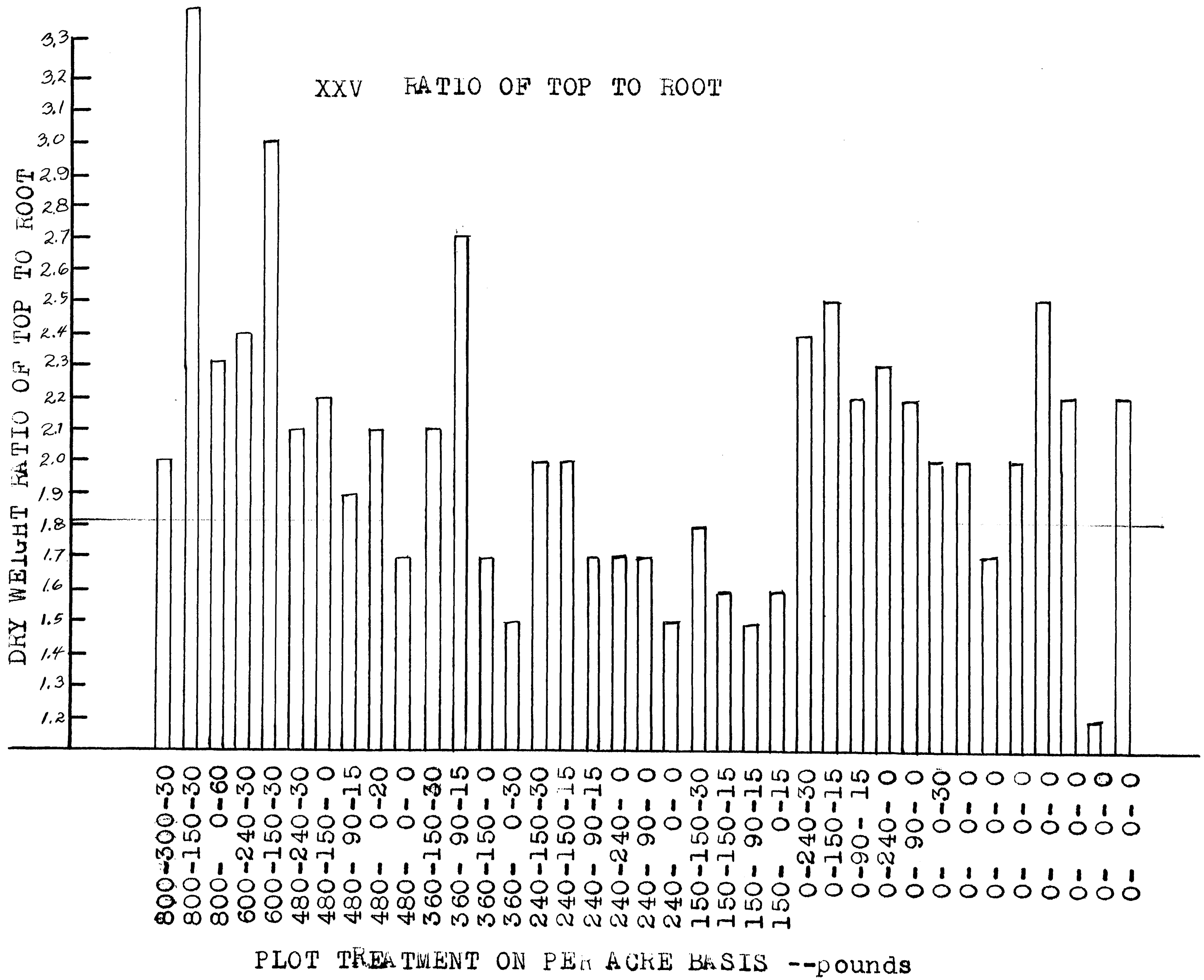
Ratio of Top to Root

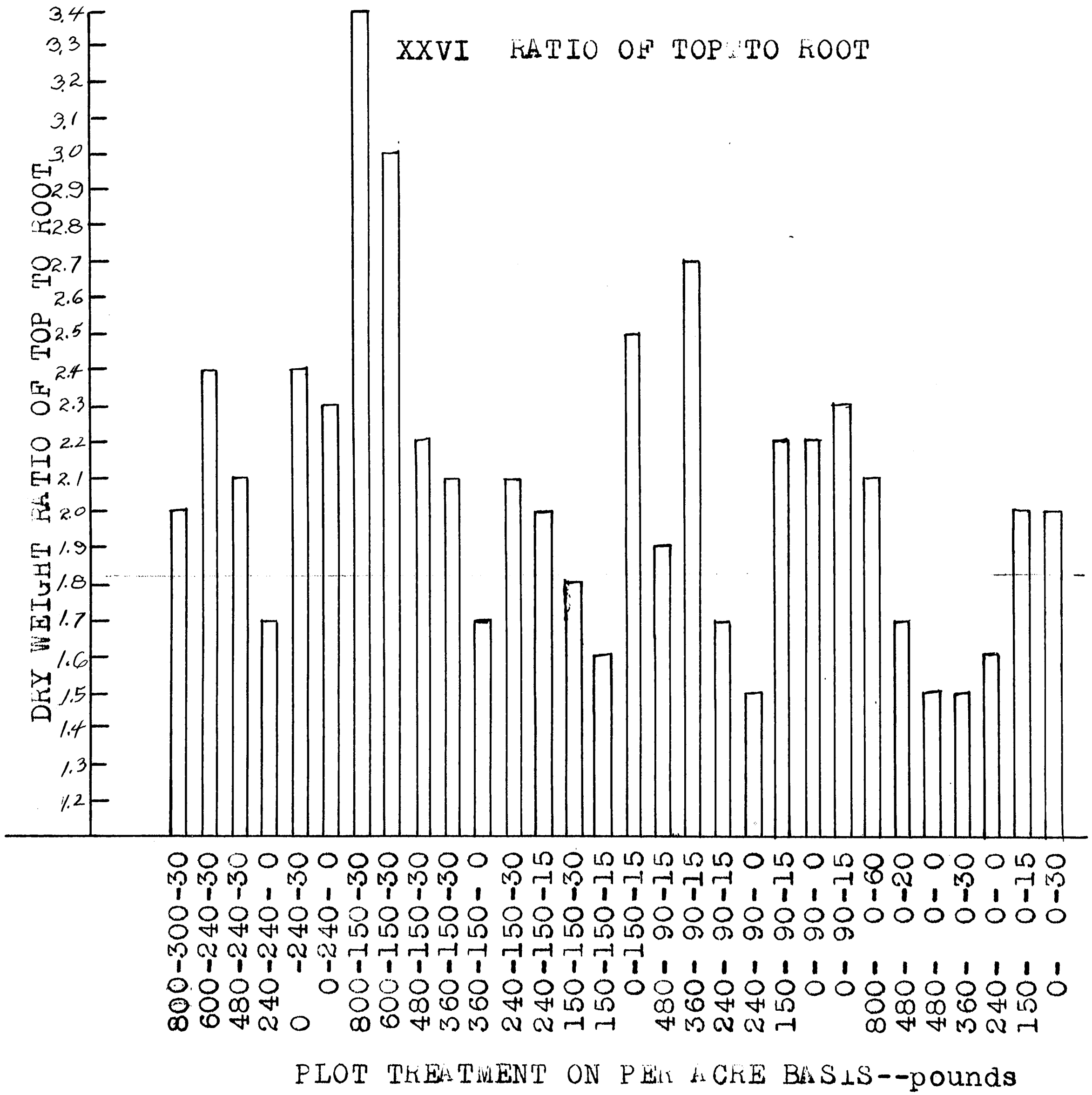
Bar graphs numbered XXIV, XXV, and XXVI illustrate the variation among the plots of the dry weight ratio of top to root. The extreme variability of these graphs has been caused by a variation in either top or root or damage and loss of parts of either top or root. From these graphs it appears that heavy nitrogen fertilization pushed the top-root ratio out of balance. Probably, in this case, grub damage to roots reduced the fibrous root system tremendously. It is evident that the balanced fertilizer applications maintained a better top-root balance than did other treatments.

XXIV RATIO OF TOP TO ROOT



XXV RATIO OF TOP TO ROOT




XXVI RATIO OF TOP TO ROOT
DRY WEIGHT RATIO OF TOP TO ROOT
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
800-300-30
600-240-30
480-240-30
240-240- 0
0 -240-30
0-240- 0
800-150-30
600-150-30
480-150-30
360-150-30
360-150- 0
240-150-30
240-150-15
150-150-30
150-150-15
0-150-15
480- 90-15
360- 90-15
240- 90-15
240- 90- 0
150- 90-15
0- 90- 0
0- 90-15
800- 0-60
480- 0-20
480- 0- 0
360- 0-30
240- 0- 0
150- 0-15
0- 0-30
PLOT TREATMENT ON PER ACRE BASIS--pounds

Soil Test

Soil samples were analysed by a soils class at the University under the supervision of Professor Maurice W. Senstius of the geology department. The following soil test record is an average of the reports of three student analysis.

Abbreviations:

pH -Negative logarithm of hydrogen ion concentration

Ppm -Parts per million

Lbs.A/6in.- Pounds per acre in top six inches of the soil

Remarks - Based on fertility requirements for ordinary agricultural crops

Soil Test

Date: January, 1940

Location: Nursery of School of Forestry and Conservation at Botanical Gardens, Ann Arbor, Michigan

Type of class: Fine sandy loam

Reaction: pH 8.0

Carbonates: High content

Condition: Moist and poor

Data:	P;m.	Lbs. A/6 in.	Remarks
Nitrates	16	128	Medium
Phosphorus		6	Low
Potassium	5	40	Medium
Calcium	125	1000	Good supply
Magnesium	Trace	---	Deficient
Ammonia	None	None	
Nitrites	None	None	
Iron	None	None	Deficient
Aluminum	None	None	
Manganese	None	None	
Sulphates	None	None	Deficient
Chlorides	50	400	Normal supply
Sodium	None	None	

Soil Test

Date: January, 1940

Location: Nursery School of Forestry and Conservation, at Botanical Gardens, Ann Arbor, Michigan

Type or Class: Fine sandy loam

Carbonates: High content

Condition: Air dry sample

Data:	Ppm	Lbs.A/6 in.	Remarks
Nitrates	10	80	Normal supply
Phosphorus	.5	4	Deficient
Potassium	5	40	Medium
Calcium	150	1200	Good supply
Magnesium	Trace	---	
Ammonia	None	None	
Nitrites	None	None	
Iron	None	None	
Aluminum	None	None	
Manganese	None	None	
Sulphates	None	None	
Chlorides	Trace	---	
Sodium	None	None	

Soil Analysis

This soil analysis was made the winter prior to the start of this experiment, therefore should be indicative of the general soil condition.

The marl sub-soil produces an extremely alkaline soil condition. Without appreciable success, the management for many years has been treating the soil to lower the pH. Most of the acid fertilizing agents are neutralized by the basic substances.

Iron is undoubtedly present in sufficient quanity for proper plant development. Past nursery experience indicates no iron deficiency. Generally in this region, there is presence of iron in the soil to abundantly supply plant requirements. Due to the extremely alkaline soil the testing methods do not show the presence of iron.(Senstius, 1941, discussion)

Sulphate in form of ammonium sulphate has been added in large quanities over a period of years. The tests detected no sulphates for reason similar to negative test for iron.

Climate

The climate of Washtenaw County, Michigan is characterized by fairly cold winters and mild summers. The mean annual precipitation is 31.31 inches, including melted snow and the average snowfall is about thirty seven inches. Wind movement and evaporation are low, humidity is moderately high, and the county receives about fifty per cent of the possible sunshine. The mean annual temperature is 47.4° Fahreheit. Frost free season is one hundred sixty four days from May 2 to October 13 inclusive. Prevailing winds are westerly.

Discussion of Results

Within each plot the individual trees varied to a degree which could not be solely attributed to biological variation of response. In the first instance, only twenty seedlings were transplanted to each plot. To be experimentally sound a greater sampling would be necessary. In the second instance, the plants only remained in the experimental transplant plots one growing season. It is believed that much of the first year's growth in the transplant bed is expended in establishment following transplanting from the seed beds. In this case, the different treatments might show no significant differences after the first growing season, yet, in the second season the growth response would be such as to make the differences between plots valid and significant. Thirdly, Norway pine responds to treatment to a lesser degree than white pine. If white pine had been used, the differences might be more obvious.

White grubs(Phyllophaga sp.) were found irregularly through the experimental plots. It was believed that the grubs ere mainly responsible for the high mortality. Also, it was impossible to accurately define the effect of the grubs on the growth of the surviving trees.

The preliminary examination of most data is facilitated by use of diagrams. The tables of results (No. IV & V) of the experiment are given here in bar graph form. For purposes of comparison these graphs have arranged in three orders. The first arrangement gives the plots in the order as they were located in the nursery. The second arrangement gives the plots in the order of ammonium sulphate application. The third gives the plots arranged in the order of superphosphate application. On the graphs the plots are identified by the pounds per acre treatment the plots received--the order being ammonium sulphate, superphosphate and potassium chloride. There are seven bar graphs for each of the three arrangements. They will be analyzed in the following order: mortality, height, diameter, total dry weight, top dry weight, root dry weight, and ratio of top to root by dry weight.

Individual Plot Analysis

Here the results of the several factors are studied to determine the total effect of the particular treatment upon the transplants.

Of the plots receiving 600-800 pounds per acre of ammonium sulphate, all produced negative results except one. The plot 600-150-30 gave results considerably better in most phases than the adjacent control plots. In one important respect this plot failed, because it suffered heavy root damage. This may have been caused by grubs or chemical burning. Its effects were the following: mortality, fourteen trees; small root system, and high top-root ratio. Thus, these plants would not make satisfactory planting stock.

The plots 480-240-30, 480-90-15,360-150-30, and 360-90-15 were examples of plots receiving complete fertilizers with heavy nitrogen concentration. All were inferior to the control plots in all respects. This is believed due to the grub infestation primarily. The results were negative.

The plots 240-150-30,240-150-15, and 240-90-15, were examples of a well-balanced moderate complete fertilizer. These plots out grew the control plots in all phases of measurement. The positive results are believed due to the change in soil reaction by use of two acid fertilizing agents, and also the plant nutrients are immediantly available in water soluble form. The results were positive.

The plots 150-150-30, 150150-15, and 150-90-15, were examples of complete balanced fertilizer. These plots consistently produced the largest growth increases over the control plots. In these plots the nutrient solutions of the soil must have remained in balance and near optimum concentrations. Also, none of these plots lost over one plant. The top-root ratio was low indicating a good balance between top and root. The treatments of these plots were most satisfactory.

The plots 480-150-0, 360-150-0, and 240-90-0, were examples of heavy applications of incomplete fertilizers with potassium missing. The plots were inferior to the control plots. The top-root ratio indicated well balanced plants. The mortality was high indicating the presence of white grubs and their inevitable effect upon growth. The deficiency of potassium may indicate the failure of the plants to advantageously use the other two nutrient elements. The results were negative.

The plots 480-0-20, 360-0-30-, 150-0-15, were examples of heavy applications of incomplete fertilizers with phosphorus missing. The top-root ratio is low in the latter two cases as might be expected when phosphorus is deficient. A deficiency of phosphorus may cause a restriction of root growth. The growth results were negative.

The plots 0-240-30 and 0-150-15, were examples of an incomplete fertilizer with nitrogen missing. Mortality was zero. Growth results show quite an increase over the adjacent control plots. The top-root ratio is high which represents a poorly balanced plant. Because of this last condition the trees would not be the most desireable planting stock. This condition was probably caused by grubs and would not be a factor under conditions of no pest population. The results were positive but not satisfactory.

The plot 0-90-15 was an example of a very weak incomplete fertilizer. The results indicate very little deviation from the control plots. The results were negative.

The plot 480-0-0 was an example of a heavy application of a nitrogenous fertilizer. This is comparable with the fertilizer application being used generally in the nursery at the present time. The grubs caused a mortality of thirteen plants, thus this plot can hardly represent anything. The measurements and weights place this plot as the poorest growth showing of the entire experiment. The results were negative.

The plot 240-0-0 was an example of a moderate application of a nitrogenous fertilizer. Mortality of three makes this plot unsatisfactory from a comparison standpoint. Growth results are slightly lower in most respects than the adjacent control plots. Explanation of these results would perhaps be more satisfactory after two seasons growth. The results were negative.

The plots 0-240-0 and 0-90-0 were examples of phosphate fertilizers. The plots were very similar to the control plots in all measurements. There was no evident response. The results were negative.

The plot 0-0-30 was an example of a potash fertilizer. The plot showed slight deviation from the control plots. The mortality was zero. The response to growth stimulation was non-existent.

The Dow plant stimulant plots were put in as a test to see what the results might be. Previously, this fertilizer had been used in the nursery with little apparent effect upon the growing stock. The fertilizer was weak in nutrient supplement. The analysis of its successor which is claimed to be stepped up is nitrogen 3.9%, P O 2.3%, and K O 1.7%. The four plots treated with this stimulant failed to respond. The treatments were 200, 350, 500, and 650, pounds per acre. The results were negative as there was very little difference between the treated plots and the control plots.

Soil Test Comparison

For two reasons a satisfactory comparison can not be made between the results of the soil test and the growth in the experimental plots.

1. The soil test does not show accurately the presence and availability of the represented minerals. If, due to high pH, the tests failed to indicate the presence of iron and sulphates, how did this factor affect the tests of other minerals? How does the extremely alkaline condition affect the availablility of these minerals to the plants?

2. The effect of white grubs on the individual plots is indeterminate. It is, therefore, impossible to assess accurately the grub damage and isolate its effects.

Although the nitrogen supply seemed adequate from the soil test, the plants did respond to treatment of nitrogen. This might well be in response to the acid radical as affecting the release of phosphorus previously tied up in insoluble compounds.

Response to the addition of phosphorus or potassium alone was not indicated by the results. When ammonium sulphate was used in conjunction with the above minerals, there was a definite and positive response. From this it is possible to draw two conclusions: First, the soil is deficient in nitrogen or second, the acid fertilizer created a more favorable soil condition.

Where phosphorus and potassium were added together the results were positive. This would seemingly indicate that there was a deficiency of these two elements, which is compatible with the soil analysis.

Suggestions for Further Experimentation

1. Sampling--It would be desireable to place at least a hundred seedlings on each plot. Use of the regular transplant boards and planting four rows to each plot would facilitate the operation. This method would be convenient similar to usual nursery procedure, and give adequate sampling.

2. Growing season--By use of sufficient sampling it would be desireable to make a complete analysis of half the trees in each plot at the end of the first growing season, and analysis of the other half at the end of the second growing season.

3. Species--White pine would probably respond to treatment more readily than Norway pine, threby producing more tangible results (Young, 1941, discussion).

4. Fertilizer--Under the existing condition of very alkaline soil, it would be wise to use acid forming fertilizers. For nitrogen, ammonium sulphate would be the best. For phosphorus, superphosphate is good but double or triple surperphosphate would be better. For potassium, potassium sulphate would be most desireable (Senstius, 1941, discussion).

5. Physical properties of the soil--The soil is in need of physical improvement which might well be of more importance than the nutrient requirements.

6. Application--It is believed that application of moderate quantities of fertilizers twice each season over a period of years would produce better results than a single heavy application.

This procedure would result in decreased leaching.

This would provide a more constant supply of nutrients in a water soluble form.

Conclusions

1. The white grubs(Phyllophaga) operated to such extent as to cast suspicion upon any conclusions drawn from the results of the experiment. The frequent occurrence of high top-root ratio is considered to be evidence of grub damage to the roots more than to any growth stimulant. This is further evidence of the general presence of this pest.

2. A treatment which lowers the pH will in most instances show a positive growth response. This is caused by the release of mineral nutrients previouly tied up in insoluble compounds. This response may not be indicated by stimulated growth the first year due to the necessary time requirement for the nutrients to become available to the plants.

3. The moderate complete fertilizer indicated best growth response because it furnished an immediately available nutrient supply, and being acid it temporarily created a more favorable soil reaction.

4. The treatments carrying heavy ammonium sulphate applications would probably produce much better growth the second summer, as then the total effects of pH change and mineral nutrient release would be in effect for the full growing season.

5. The Dow plant stimulant contains such a weak plant nutrient supplement that this material is economically unsatisfactory as a fertilizer. Chemical analysis and nursery experiment indicate that very little response can be expected unless very large amounts are used.

Summary

1. This investigation was constructed to indicate the effects of different chemical fertilizers upon Norway pine during the first year in the seed bed. This investigation was further delimited to include only the effects produced by ammonium sulphate, superphosphate, and muriate of potash.

2. About twenty years ago expansion of the forest nursery led to the acquisition and location of the new nursery upon a very unsatisfactory site. The soil was poorly drained, excessively alkaline, not very rich in minerals, and had a marl base. It was difficult to cultivate and the physical composition was unsatisfactory.

3. Extensive search of pertinent literature leads to the acquisition of a large body of generalities concerning the use of fertilizers in the forest nursery. The different types of fertilizers produce such divergent results on different types of soil and on different species, that it is believed that actual field experimentation is the most thorough approach to developing a satisfactory soil management practice.

4. The research investigator must be observant to changes and differences in plant growth. From his general fund of knowledge he must determine the causes and effects of the conditions he has observed. After such an analysis the observer will be in a better position to determine future procedure in nursery practice.

5. Students in the geology department analyzed a soil sample from the nursery. Due to the high pH the soil analysis did not indicate

the presence of certain minerals in a satisfactory manner. The tests indicated a deficiency in most minerals, but a very high calcium content.

6. Intensive cropping practices constitutes a heavy drain upon the mineral nutrient supply of the soil. Therefore, it is necessary to regularly follow a mangement plan of soil building to maintain volume and quality production.

7. Forty-one- one-fifth mil-acre plots were laid out in the nursery. The different treatments were carefully determined; consisting of complete fertilizers, incomplete fertilizers, addition of single elements and control plots. Also, four plots were treated with varing quantities of Dow Plant Stimulant (1938). The fertilizer amounts were carefully weighed, dissolved and evenly applied to their respective plots. The ground was worked and allowed to rest one week.

8. 2-0 Norway pine seedlings grown in the nursery, were transplanted, twenty to each plot. These transplants received cultivation during the summer similar to the other transplant beds.

9. White grubs infested the beds irregularly, doing much damage to the root systems and causing the death of many trees.

10. In October the trees were individually measured for height and diameter at ground level, and the mortality recorded. The trees were dug, cleaned, oven-dried, and weighed in the laboratory. Dry weight of top, roots and the whole plant were found.

11. The results are given in tabular form. For purposes of analysis, bar graphs have been used to show the results visually and thereby more easily compared. Graphs are given for mortality,

height, diameter, average total dry weight, average top dry weight, average root dry weight and top-root ratio.

12. Moderate applications of complete fertilizers produced the largest increment of growth as compared with the control plots during the first summer after application. This was believed due to immediate availability of the plant nutrients and the favorable effect upon the pH condition of the soil.

13. Heavy applications of complete fertilizers while producing some stimulis were not among the best. The second growing season might give these plots the decided advantage.

14. The plots receiving incomplete fertilizers produced erratic results.

15. The Dow Plant Stimulant by analysis and field trial is apparently too weak to be expected to produce satisfactory results unless excessively large amounts are used.

16. Comparison of the soil analysis and the results of the experiment fails to adequately prove anything. This is due to inherent weaknesses of the soil analysis under extremely alkaline conditions. Also, the grub infestation effected the growth of the trees to such an extent as to make deduction of sound conclusions practically impossible.

17. During the course of the experiment there has arisen several difficulties which could be overcome by changes in the plan of the experiment. These necessary changes concern sampling, length of experiment(time), species, fertilizer, physical

properties of the soil, and methods of application.

18. This investigation was constructed to set up leads to successful soil management practice. It is only a beginning and must be amplified and verified by much further field experimentation.

VITA

Lyle Marques Argetsinger was born on a small farm near Fairmont, West Virginia on September 9, 1917. At Fairmont he attended elementary, junior high and senior high schools. Interest in song birds and wild flowers was aroused early by his mother. Two teachers are acredited with suggesting and developing interest in forestry while the author was in high school. In 1935 he entered Fairmont State Teachers College where four years of study led to a Degree of Bachelor of Arts in Education. His subjects of concentration were mathematics, biology and physical science. Instilled with an ambition to be a forester his studies were so planned that, if financially possible, he would enter a forestry school. In the Fall of 1939 he entered the School of Forestry and Conservation, University of Michigan. Silviculture in the Production Division was his major study. His nursery problem was supervised by Professor Leigh J. Young, silviculture. After graduation his ambition was to become associated with a paper and pulp concern. To the faculty he is indebted for the development of a keen appreciation of sound economics in each phase of forest operations. The development of sound basic knowledge in each of the various fields of forestry and the unity of those fragments will be more and more appreciated as the graduate works afield down through the years.

Mr. Argetsinger's father is Roy J. Argetsinger formerly from Mansfield, Pennsylvania, a graduate of Mansfield State Normal, and now is associated with J. M. Hartley Department Store in Fairmont. The author's mother is native to Worthington, West Virginia and prior to marriage was Pearl M. Sandy. Thus, the author's heritage is Pennsylvania Dutch and English.

L. M. Argetsinger

May 15, 1941

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