Soil Reaction and Reforestation

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SOIL REACTION AND REFORESTATION

A Study of the Relationship of Tree Species to Soil Reaction, the Use of Soil Reaction in Forest Nursery and Planting work; together with an Experiment in the Determination of Soil Reaction Preferences of Tree Species, and a Recommended Procedure for this Determination.

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PREFACE

The writer acknowledges his debt to Professor L. J. Young who assisted in the experiment both with his advice and in the procurement of equipment. Dr. M. W. Senstius of the Geology Department also gave a great deal of help, in advice and equipment. The writer is also indebted to Mr. R.S. Carman, Superintendent of the Provincial Seed Extracting Plant of the Ontario Department of Lands and Forests who provided the seed used in the experiment as well as much helpful information.

Throughout the essay the writer has intentionally deviated somewhat from the usual practice of thesis writing in that the use of cross references and footnotes has been completely omitted. This was not done with the purpose of distracting from the credit due to the original workers on the subject but rather to bring as much as possible of the more securely founded information together in one place in as easily readable a form as possible in which the sequence of thought was not interrupted by repeated references to notes outside the text.

SOIL REACTION AND REFORESTATION

Introduction

Over a period of many years, experiments and investigations have been carried out by foresters and others to determine optimum soil reaction values and ranges of soil reaction tolerance for many of our common tree species. The results of these experiments, although perhaps not directly comparable in many cases, have produced reasonably accurate values and the problem of the practical application of these values in forest nursery work and reforestation has attracted the author's attention.

This type of problem is a difficult one as it is a point of meeting and overlapping of several sciences, Plant Physiology, Plant Ecology, Edaphology and Silviculture being the main ones but Chemistry too must be considered. The problem was approached from the view point of Silviculture which may be considered as a science of correlation and intensification of these other sciences in respect to tree growth. Hence in the preparation of this essay the literature of all these sciences was reviewed on the assumption that we may feel free in adapting and using in our own problems the methods and conclusions of workers on similar problems outside of Forestry as well as within.

In addition to the experiments mentioned in the first paragraph, soil reaction has been the subject of many investigations directly or indirectly connected with Forestry along two main approaches; first, to find the effect of certain species or mixtures of species of trees in plantations on the reaction of the soil; and second, to attempt to relate the distribution of certain tree species to soil reaction. Investigators on the former subject have shown that the rate of decomposition of litter may be related to the reaction of the litter itself. They have shown that it will be difficult to correlate the rate of decomposition of litter to the reaction of different soils and even more difficult to find the relationship between the tree species and any effects or changes of soil reaction in different soils. One of the important results of the investigations on distribution has been to show that the continual slight variations in the soil reaction of forest soils probably precludes this from being a limiting factor of distribution of either species or types except in extreme cases. By this last phrase is meant extremes of soil reaction as well as extremes of sensitivity of species.

Some of the outstanding conclusions of each of these types of experiments have been incorporated in the text of the first part of this essay. Also in both parts of the essay the relations of the individual tree species to soil reaction have been stressed. In the Appendices will be found a list of the literature that was consulted and also a list of tree species for which reaction values have been determined and the values as given by different authorities.

The use of these later data has been somewhat speculatively discussed in the essay itself, in connection with nursery work and reforestation in particular.

In the second part of the essay, the method and results of an experiment carried on at the University of Michigan in 1946 are also given, not because they can be accepted as conclusive but because the method recommended and the difficulties encountered may be of assistance in planning of experiments along similar lines.

CHAPTER I

THE IMPORTANCE OF SOIL REACTION

To show just where soil reaction fits into the general picture of Forestry it may be pointed out that this can be used as both a site characteristic and a silvicultural characteristic of the species, similar to temperature and light tolerance, moisture requirements, seed and seeding characteristics etc. However in addition to this it is important from the following standpoints as well; these are presented in numerical order but not necessarily in order of importance, and then a note of explanation is given later for each to aid in ease and clarity of presentation:

1. The direct toxicity of hydrogen and hydroxyl ions.
2. The effect of reaction on the solubility and form of plant nutrients.
3. The effect of reaction on the rate and ease of nutrient absorption.
4. The effect of reaction on the living part of the soil.
5. The effect of reaction on the disease resistance of plants.
6. The effect of reaction on the processes within the plant.
7. The changes of reaction that are caused by certain plants on certain soils.

1. In respect to this first point, direct toxicity, as outlined above, this matter may be dealt with simply by stating that

both hydrogen and hydroxyl ions are toxic in very high concentrations but that in nature, any injurious effect of soil reaction are likely due to one of the following actions, rather than direct toxicity.

2. The second point, solubility and form of nutrients, is much more complex and has been the subject of considerable investigation. It is known that at certain concentrations there is a direct relationship between hydrogen ions and the form in which aluminium occurs; it may be present in a toxic form at high concentrations. In some of the literature concerning this it is accepted without a great deal of supporting evidence that the main harmful influence of soil reaction on certain plants, for example an acidity beyond its tolerance, was due to preventing in part the securing of bases by the plant which are needed to neutralize and precipitate organic acids within the plant. It has been shown also that the reaction affects the solubility of identical chemical compounds at different degrees of acidity or alkalinity and this in turn will have some effect on plant nutrition. As is the case with aluminium it has been shown that at different degrees of acidity or alkalinity some of the other nutrients have tendencies to appear in different forms of more, or less, solubility and hence probably affects the availability to plants. Again in connection with the form in which nutrients appear, some work has been done on colloids and their dispersion in the soil solution. The effect here is so pronounced that a definite point, the iso-electric point, can be determined at which a

sol of a certain colloid is least stable, therefore most likely to appear in the gel state. This is very important in nutrient supply in soils as those colloids in a sol state are easily leached out but those flocculated or in the gel state are more stable and will remain in the soil, exerting all their important influences on the nutrition of plants through cation exchange, water relations, etc.

3. The third point, rate and ease of absorption, although some writers have referred to it, can not yet be tied down with any great accuracy. Suffice it then to say that it is empirically known that for one element of nutrition, available in equal quantities and form as close as it is possible to tell, will not be absorbed equally at different degrees of acidity. As a correlation to this it may be said that in different concentrations of hydrogen ions in one solution, a plant will absorb different proportions of different nutrients.

4. That soil reaction has a very important part in the growth, activity and the presence of micro-organisms in the soil has been known for a long time. With this in mind it can be stated that bacteria, while not confined to, are more active in soils that are neutral or almost neutral whereas fungi are more active in the more acid soils. This relationship has in turn a direct influence upon the type of decomposition that takes place. This may be related also to the presence and activity of the nodule-forming bacteria of legumes and the mycorrhiga-forming fungi associated with many of our tree species. The correlation of bacteria occurrence to soil re-

action is so close that at one time Azotabacter was used as an indicator of the acidity.

5. That disease resistance of a plant may be related to the reaction of the soil is a relation used by many farmers in the cultivation of the common potato. Just whether this could be proved for other plant species is not definitely stated as yet but it is thought that such a relation does hold, with each species of course having different limits. Work on this point in connection with the potato has shown that it is possible to regulate the reaction of the soil so as to be beneficial to the plant but it must be remembered that in this case it is an annual crop whereas we are dealing with trees. Some work has also shown that healthy development of certain parts of plants, the roots in particular can for some species be related to soil reaction. The validity of separately recording the response of one part of a plant instead of the health of the whole plant to soil reaction is not beyond question but for the present purpose it is not necessary to go into this side of the problem at the present time.

6. The effect of the hydrogen ion concentration on the processes and structure within the plant need only be mentioned here as this is indeed a problem for the plant physiologist. It does have an effect though on the organic acids of the plant itself.

7. On this final point, the changes of reaction caused by plants, there has been considerable discussion in the liter-

ature and yet again it is somewhat difficult to express the conclusions briefly and sharply. It has been shown that under normal conditions carbonic acid only is produced by living cells of plant roots. That this does have an effect on soil reaction, either with or separately from, the effect of removal of nutrients, is shown by the fact that certain crops affect the soil reaction in different ways and it is probable that this holds for trees as well but because of the length of time required to investigate, the information is not available on this point. Some authorities have inferred or stated that the development of a woodland soil is on the whole towards a more acid condition but that deciduous forests favour the continuance of the reaction level more than conifers do.

It might be opportune at this point in the essay to point out a few of the general aspects of soil reaction that may help to stress its importance.

The first of these is that under natural conditions the reaction of the soil remains fairly constant throughout the year in spite of the different rates of decomposition and leaching, different water contents, etc. This is because the soil is in itself an excellent buffer, that is, it resists any attempt to make violent changes in the soil reaction. Also a soil with a high organic content exerts a very powerful buffering action which decreases with the amount of organic matter. This is because the organic matter is in itself an excellent buffer.

The results of certain farming practices or of fertilizing practices may tend to change the soil reaction considerably and have been known to make the soil more, or less, suited for the purpose desired.

Studies made in the field for soil reaction preferences and distribution studies of the species can not be taken as being too reliable because of the competition factor, and this holds true particularly for the frequency data. Some writers have pointed out that for certain plant species that grow within a certain soil reaction range there is no evidence that the frequency of occurrence is influenced by soil reaction within that range. Hemlock (Tsuga canadensis) however appears to be one tree species whose frequency of occurrence is influenced by soil reaction, but this statement must be qualified as shown above.

Also studies in both Europe and America have shown that closely related species of plants may have a large difference in their soil reaction preferences and that as a result of this, may have a corresponding difference in their geographic range. However there are no results which could be related to our trees concerning this point.

CHAPTER II

THE NATURE OF SOIL REACTION

To start a basic explanation of the phenomena of soil reaction it is necessary to first mention the dissociation theory. It is not necessary, however, to go into this theory any more than to say that it is an attempt to explain the action by which certain chemical compounds in solution are separated, to some extent, into separate ions.

It was found that even in pure water there was some dissociation into ions, positive hydrogen ions and negative hydroxyl ions. It was later found that a definite relationship existed between these ions in their respective amounts and also that only when they were in equal concentrations was the water neutral. Due to the former relationship it follows that the concentration of either ion alone will permit determination of the concentration of the other, in an aqueous solution. It is usually the practice to express the soil reaction in terms of the hydrogen ion concentration and if it is required the concentration of the hydroxyl ions can be calculated. The usual mode of expression is the p^H which will be explained more fully in the next chapter. However there are two main ways of expressing soil reaction, first by the concentration of the hydrogen ions in grams per litre and second by the logarithmic method, p^H. The first method is cumbersome and has largely been dropped from the literature since the second mode of expression became popular. The express p^H may be defined as the logarithm of the reciprocal of the hydrogen ion concentration.

One definition of soil reaction gives the following "the concentration of the hydrogen-ions in the soil and in the soil solution." This effectively refers to the two main types of soil reaction which may be described as follows:

1. Active Acidity. By this is meant the concentration of hydrogen ions which are free in the soil solution.
2. Exchange Acidity. This is a type which is hidden from simple measurement. It has been divided in different manners by authors on the subject but may be described in a group, as being the concentration of hydrogen ions in the soil which are not free in the soil solution. In another way of speaking, it is the potential concentration of hydrogen ions due to those ions held in cation exchange on the surface of the colloidal micelles.

In many discussions on the classification of soils for soil reaction, the following terms only are used, acid soils, neutral soils and alkali soils. However some authors go into much more detailed classifications using the words weakly, mildly, strongly, etc., each author having to describe his own interpretations of these terms. It would not seem to any great purpose to carry on any further this type of classifications when definite limitation values of p^H as determined in the field could be used instead. This will likely be necessary in time in order to circumvent the confusion caused by the use of numbers of qualifying adjectives and their definitions as found in past and present literature.

In addition to this confusion there have been several methods used to classify exchange acidity according to the reagents and methods of determination; the ease of replacement by neutral salts, strong bases etc. It is not believed worth while to go into this matter further in this essay as the type of reaction we are dealing with in the field, and that can be determined reasonably in the field, is active acidity, the concentration of hydrogen ions free in the soil solution which is expressed in p^H.

Neither is it believed necessary to go into the causes of soil reaction and its variations in soils. This would require going into several related subjects such as, soil genesis, the leaching processes of soils, formation of inorganic acid in the soil solution, decomposition of organic matter and the formation of organic acids in the soil solution; because for the purposes of this essay we can merely accept the fact that there are differences in reaction in different soils without attempting to explain the cause.

In regard to the nature of the soil reaction preferences for certain plant species as given by the writers on the subject, these values can not be taken as an absolute guide and applied directly for the species in any environment because the reaction tolerance range of the plant is determined by many factors, competition, light conditions, the nature of the soil solution as a nutrient supplier etc. In seeming neglect of this condition many writers have reported observations made with regard to plant frequencies in nature and made every attempt to select an optimum soil reaction value for the species based on the frequency of occurrence.

It would be well also as a conclusion to this chapter to mention that in many experiments on determination of soil reaction preferences in laboratory cultures that a double optimum was found for certain plant species. The significance of this is not clear and has not been explained at all successfully nor as yet has there been a parallel discovered in nature.

CHAPTER III

THE MEASUREMENT OF SOIL REACTION

As mentioned in a previous context, there are two primary methods of expressing reaction, first by a weight per volume method such as grams per litre; and second, by p^H, which is essentially a weight per weight method of expressing the hydrogen ion concentration. Due to the popularity of the latter method, the former has become almost obsolete and will not be referred to further.

The measurement of soil reaction by the p^H method was proposed by Sorensen, a Danish chemist, about 1909. It was found that even in the purest water there was some dissociation of the water into its components, the hydrogen ion and the hydroxyl ion. The amount of water dissociated in this way into free ions was found to be almost exactly one gram in ten million, or one gram in 10^7. Expressed as a ratio this becomes $\frac{1}{10,000,000}$ or one gram of hydrogen ions to ten million grams of water which is 10^{-7}. More accurate work done in later years has shown that this exact neutral point is at $10^{-7.07}$. Using the p^H system of expressing this hydrogen ion concentration this becomes a p^{H} 7.07, as the exponent only is required, the negative sign being omitted. In normal practice this neutral point is taken as $p^{H}7$, considered as accurate enough for most purposes.

At this neutral point the action of the hydrogen ions is exactly countered by that of the hydroxyl ions, and as water is composed of these chemically in a ratio of one to one, then at the neutral point there will also be an equal concentration of hydroxyl ions. This in turn could be expressed using the p^H method as p O H 7.07. The sum of these two exponents, which could likewise be expressed as $10^{-14.14}$ is called the dissociation constant of water. This remains a constant, no matter what the degree of acidity or alkalinity is and therefore the concentration of either hydrogen ions or hydroxyl ions can be easily calculated once the concentration of the other is known. For this reason it is only necessary to give measurements in terms of one and the practice is to use the hydrogen ion potential, or p^H.

One further point in this connection, the concentration varies in a geometric ratio as expressed in exponents using logarithms, for example the concentration of hydrogen ions at p^H6 is 10 times that at neutrality, or one per million, whereas at p^H5 it is 100 times that at neutrality or one per hundred thousand.

There are many different ways of determining p^H values but they may be divided into two main types, the physical and chemical. It must be remembered that in our work in the field we are only able to measure the active acidity of the soil solution and not the hidden or exchange acidity of the soil. The measurement of exchange acidity, involving methods of cation exchange and titration is complicated and necessarily a laboratory proceedure. As has been pointed out the results are of doubtful value and are not necessary for the purposes of this essay.

Under physical methods can be classed all the electrical methods, using instruments called Potentiometers which operate with different types of electrodes but give the p^H by means of comparison of the rate at which cations of the electrode pass into the solution being tested. Some are constructed also on the principle of electrical resistance of solutions containing different concentrations of hydrogen ions.

Under chemical methods can be classed several different proceedures, some of which are now obsolete. Among these are the Inversion methods and Saponification methods which depend on comparative rates of their respective chemical processes according to the concentration of hydrogen ions. Another chemical method is the indicator method which is dependent upon the changes in colour of certain reagents associated with different levels of hydrogen ion concentration.

With regard to both types of methods it is sufficient to state that the Potentiometer is the most common means for very accurate determinations whereas the Indicator is most used where less accuracy is required. For use in field measurements it is not believed that the accuracy of the Potentiometer is either needed or practical because of the variations found in p^H even within a few inches, in ordinary soil samples. Therefore the determination of p^H to the nearest one-half exponent is believed to be all the accuracy that is reasonable for field determinations and this can be done satisfactorily with most of the potential indicator preparations on the market. It is not intended here to attempt any comparison of these preparations for the accuracy of any can be tested by the use of a properly adjusted potentiometer,and the other main asset, ease of use, is soon learned by testing in the field.

CHAPTER IV

THE EFFECT OF SOIL REACTION ON NUTRITION AND GROWTH

For ease of discussion this chapter is broken into two parts, the first a brief outline of the effect of soil reaction on nutrition as related directly to the nutrient elements, and the second an outline of reaction on growth as a whole.

1. The Nutrient Elements and Soil Reaction

(a) Nitrogen. Experimental tests have disclosed that the p^H has a marked effect on the relative rates of absorption and utilization of Nitrogen; as in the nitrate form or as in the form of ammonium salts. It is also known that plants have a wider range of p^H for utilization of nitrates than for ammonium salts, but that there is no one optimum p^H value for either at which plants make their optimum growth as several other factors are involved. In general it may be said that in a distinctly acid medium the plants can best absorb nitrate nitrogen but in a mildly acid to alkaline medium they can best use ammonium nitrogen.

(b) Phosphorus. The effect of p^H is known to govern to some extent the phosphorus ion available to the plants. At a high p^H (alkaline) it is likely to be the phosphate (PO_4) form that is more available but at a low p^H (acid) it is more likely to be in an acid ion (HPO_4) or (H_2PO_4), all of which are available to plants. The phosphorus ion has in some manner an ability to offset the effect of high concentrations of hydrogen ions and this action has been called an "antagonizing action".

(c) Potassium. Not as much information is available with regard to this important element but the p^H of the nutrient medium does have an effect on the absorption of potassium. In general it may be said that potassium is absorbed in smaller quantities as the concentration of the hydrogen ion increases.

(d) Calcium. It is well known that highly acid soils have a deficiency of calcium both in the solution and in cation exchange. Calcium also is absorbed in smaller quantities as the concentration of the hydrogen ion increases. Calcium is also known to be able to offset the effect of high hydrogen ion concentration to some extent, an "antagonizing action". There has been some doubt as to whether the effect of Calcium concentration can be separated from hydrogen ion concentration but it is now certain that it can for some of its influences at least. However the effect on the physical properties of the soil of calcium ions compared to hydrogen ions is a very complex relationship that is difficult to express in terms of either, due to a balance which seems to exist between them.

(e) Iron. Investigations have disclosed that iron nutrition depends not only on the amount of iron available but also the form. Both the form and amount of iron available are dependant in some manner on the composition of the nutrient solution, the hydrogen ion concentration, the general environment and to some extent the plant being cultured. There is enough evidence to show, however, that iron actually becomes less available towards a high alkalinity, and towards the acid end of the p^H scale it is more active and more available.

(f) Aluminium. The effect of this element is quite definite, towards the alkaline side of neutrality this element is less available and may be precipitated from solution. But towards the acid end of the scale, a high acidity, it is in an available form and quite active, may even be so active as to cause toxicity in some fashion. Some authorities believe that this may be due to the fact that above a p^H 4.5 the aluminium is largely present in a colloidal form but at greater acidities there is more aluminium in the ionic form. At any rate, toxicity due to this element has been found on very acid soils.

(g) Manganese. This element has also been directly related in its nutritional effects to soil reaction, a high acidity increases the amount of manganese activity and more is absorbed by plants. It has been observed that diseases due to manganese deficiency are confined to plants on soils of a $p^H6.7$ or higher and this, together with experiments, has shown that manganese does become less available to plants towards neutrality and alkalinity. This may be due to a form of chemical precipitation of the manganese ions, similar to that which occurs for aluminium.

The above is far from a complete list of those elements concerned in plant nutrition and their relation to soil reaction but appear to be the only ones for which information of a definite nature is available.

2. Plant Growth and Soil Reaction.

Soil reaction has many influences on the physical chemical and biotic conditions within the soil. Some of the chemical influences which affect nutrition have been noted in the preceeding part of this chapter; the physical and biotic influences will now be reviewed briefly. The physical influences are concerned mainly with the structure of the soil, a high acidity being associated with poor physical structure of the soil for growth. This single influence of hydrogen ion concentration is considered by some authors as being more important than any other effect. However this view does not seem to fit the information now known and as yet there are few facts which would substantiate this view. With regard to the influence of hydrogen ion concentration on the biotic conditions within the soil, this has already been mentioned before but is worth repetition. The soil reaction has a profound influence on the number and species of micro-organisms in the soil, bacteria as well as fungi. The relation of each member of a symbiosis to soil reaction is also important, as the soil reaction tolerance for the two species must overlap and the symbiotic function will be at greatest amplitude only when the optimum for each species, for the existing conditions, is the same, and is that p^H existing in the environment.

A brief note on some of the ecological aspects of soil reaction, other than implied in the last paragraph, seems suitable at this point. There is enough evidence to show that the relative effects of the hydrogen ion concentration are dependant on the amount of nutrients in the soil and hence the p^H can not be used alone in comparison of soils for growth potentialities but may be considered as only one factor of the plant environment. However it does give some assistance when used in connection with the p^H tolerance range of plant species and the general rule that in soils of a high degree of acidity (low p^H) there is a shortage of nutrient matter available to plants, [4] That soil reaction, as a factor of environment has an influence on the akality of a plant species to compete successfully for life has been shown by the fact that optimums for growth can be determined. This then is the reason why many attempts have been made to correlate the distribution of certain plant species with soil reaction, but it must be remembered that soil reaction is only one factor of the environment, the combined effect of which will determine whether the species can exist. Also of ecological significance are the investigations made in an attempt to correlate the changes caused in the soil and its reaction by certain tree species and to correlate these changes to the tree species, its litter and the soil. The information on this aspect is very slight but it has been shown that Eastern Hemlock (Tsuga canadensis) in pure plantations keeps the p^H lower than the same soil assumes under a grass cover. It hardly seems possible that even in years of investigation such a difficult relationship could be clearly understood, enough to permit speculation even, of the changes that could be expected in the reaction of certain soils due to different types of plantations, save in a general way. Also, in ecological studies, it has been noted that while the needles of conifers are highly acid in reaction, they are low in buffer substances, whereas Larch and some hardwoods, also acid in reaction have a high buffer content. This is important because it has been shown that the reaction of the soil itself is correlated to this leaching through the forest litter, both the amount and the character of the percolating solution.

Finally in the relation of plants and soil reaction the problem of the soil reaction range or tolerance and optimum must be discussed. It has been found that for any given set of conditions, such as controlled, light, temperature and nutrient solution or water or such as the varying conditions of light temperature and moisture on a soil as found in nature, a definite range of p^H tolerance can be determined for any plant species. For some species this is a narrow range but for others it is a relatively wide range. Under certain conditions and with a definite plant species there may also be determined a p^H value at which growth or some process of life is at an optimum. For other species, some horticultural and agricultural, experiments have shown a double optimum for best growth and in many cases the inbetween zone or central poor growth region is at a $p^H 6$ or $p^H 7$ approximately. The exact significance of this is not too clear but it has been suggested that the iso-electric point of plant tissue is in some way related.

This leaves us then with an unanswered question of major importance, namely, whether plant species may be divided into two groups, those which have a single optimum and those which have a double optimum or whether the development of a single or double optimum depends not on the plant species but upon the conditions under which the plant is tested. That this latter view may be correct is supported by the fact that in many investigations the results have shown that the p^H tolerance range of the species does vary under the conditions of environment and nutrition but stays within rather narrow limits.

CHAPTER V

THE USE OF SOIL REACTION IN FOREST NURSERY WORK

It is well known that for the growing of conifer stock in nurseries an acid soil is essential, as on this type of soil, damping-off by fungi will be less prevalent. Not as much is known however about the damping-off of hardwood seedlings but it would seem that a less acid condition, than is required for conifers, would be more suitable for the majority of species handled in the nurseries.

Major changes in the soil p^H may be the result of anything aiding the leaching of calcium and magnesium and in a humid climate such as ours, leaving the soil bare will encourage this loss and increase the acidity. The action of certain fertilizers which tend to leave an acid residue may also increase acidity; examples are sulphate of ammonia and flowers of sulphur. On the other hand fertilizers may be chosen which have the opposite effect, such as lime and the nitrates. In considering changes in reaction however the action of certain buffering substances in the soil itself must be considered as these serve as a natural resistance to changes in p^H. The main buffers of the soil can be considered as the organic and inorganic colloids.

S. A. Wilde lists the following as reaction influences in nursery practice, the seedling growth of different species, the development of soil organisms, rate and kinds of fertilizer required, and the amount of watering. In this connection he recommends nursery soils between p^H 4.5 and p^H 6.5. He also lists as important the fact that there may be a difference in reaction between planting site and nursery which may interfere with absorption or action of root cells and his estimate is that this difference should not be more than 1.5 p^H as shown by experiments.

To round out this discussion regarding the p^H value and nursery practice, two divisions will be made and each discussed in order.

1. Fixed or Permanent Uses.

This would involve survey of the part of the nursery used for both seedling and transplant cultivation from year to year on a periodic basis. Depending upon the amount of variation in reaction discovered in the nursery soils, it might be wise to have a record of the reactions in the form of a chart which would be of assistance in assigning of the tree species, each to a particular area, in accordance with their p^H requirements. As a caution though it must be noted that this is only one indicator of suitability of site and must be treated as such.

The accumulation of the records of p^H for each nursery compartment would in time give an indication of the results of certain fertilizer practices and hence an indication of practices to retain or adjust the p^H values to those required. As mentioned before certain fertilizers tend to leave an acid residue and more guidance in the use of these could be obtained from the above practices.

In addition to the following of the results and changes in p^H value of fertilizers the same information could be obtained for the different mulches used on the seed beds, such as rye straw, marsh hay, deciduous leaves etc. The effect of these various mulches is important at the time of seed germination and first growth and therefore would merit investigation.

2. Temporary Uses.

At times, in nursery work, there arise certain apparent peculiarities in the behaviour of seedlings, most particularly during the first part of the first season of growth. Among these are the spots or patches of seedlings which did not emerge or seedlings that have become yellowish or unhealthy, the cause of which is difficult to determine. There are other times when conifer seedlings instead of forming straight normal needles become twisted into a miniature witches-broom for a small percentage of the stock in certain places whereas the seedlings from the same seed in another place may be quite normal. In the examination of such areas the nurseryman might find assistance in the use of p^H as changes and local variation in p^H might have an effect like this.

Finally, among the temporary uses in the nursery, the use of p^H as a factor and as a recorded result in the continuous experiments that are a necessity to keep a nursery running smoothly is recommended. This is in reference to those experiments with the amount of moisture and shade required for the different species; the mixtures of sand, peat and muck used for a covering on some seed; the use of chemicals for damping-off control and so on.

CHAPTER VI

THE USE OF SOIL REACTION IN REFORESTATION

Among the changes resulting from clear cutting or from retiring land from cultivation is a change in the soil and its micro-organisms due to the new environment. After clear cutting the changes are quite profound even in a short period of time, changes in the moisture, the organic content, light etc, all of which result in changes in the micro-organic population. Investigations have shown that there is also a change in the soil reaction although this is difficult to determine and trace, due to the variations with depth and season. The changes caused by lighter cuttings and by retiring land from cultivation and pasture are much less abrupt and more difficult to follow.

The changes in soil reaction as a result of reforestation or afforestation of such areas are much in the way of unknown quantities at present. Morever, they will be very difficult to establish as equations or correlations because of the differences that will be encountered on different soils and under the different conditions of slash, grass cover, herbaceous cover etc. So far it is known that conifer slash and opening of a forest soil tend to increase the acidity whereas the establishment of a grass cover tends to decrease the acidity.

These changes of acidity will have an effect on the micro-organisms of the soil and this is important in creating the right conditions of growth for seedlings. It has been shown that for some of our conifers, the genus Pinus for example, there exists a direct relationship between healthy mycorrhizas and thrifty growth. Thus the conditions of the soil should be such as to favour the propagation of the mycorrhiza-forming fungi to obtain the best growth from the planted stock and one of these conditions is proper acidity. This can be followed as a correlation of S.A. Wilde's premesis regarding similarity of reaction between the nursery and the planting site so as to allow the fungus already associated with the seedlings to continue its work right from the start. A variation in p^H larger than 1.5 might have an adverse effect on the fungus although perhaps affecting the tree to a much less extent.

The question that arises next then is, what use can be made by the forester, of p^H values in the appraisal of an area for planting or for the compilation of a planting plan? First it can be considered as an aid to the appraisal of site quality, a very low p^H (acid) indicating a rather infertile soil and can be used here in conjunction with the moisture content and drainage conditions, the organic content, texture and structure, presence of a hard pan etc.

Secondly, it can be used as an aid in the selection of suitable species for planting, for the p^H of the site must fit within the p^H range of the species and the closer it is to the optimum then the better the chances of success of the plantation. In glaciated country this will tend to decrease the size of the planting unit of the plan as there is considerable variation of p^H in these soils. The treatment of smaller units although involving more planning and administration can not be considered as poor forestry for it will tend to cut down the areas over which certain species might dominate. In many cases however the variation in p^H will not be sufficient to warrant division of the area on this basis alone. The purpose of the selection of the species suited to the reaction of the soil is made more apparent by consideration of the fact that natural seedlings are able, by a form of chemotropism, to select the more favourable local areas of the soil whereas planted seedlings must immediately contend with whatever p^H exists in the soil where they were placed and must obtain their first nutrition from this area.

Thirdly, and this must be considered more theoretical, the changes in the p^H due to the planting of certain species may be considered, as to whether such changes might be favourable or unfavarable for the species planted or for the future plans for the soil. There is no doubt that plantations of certain species on certain soils do change the soil reaction as such has been shown to be the case by different investigations. The changes have been assumed to be the result of the type of leaching through the litter although there are other things that should be considered too, the type of ground vegetation and the secretions of the roots. So far there is not enough information available which would make possible the prediction of the changes in reaction due to the planting of certain species or mixtures. It is reasonable though, to say that in a general way, conifers will tend to establish a condition of higher acidity than deciduous trees on the same soil.

In conclusion of this part then the determination of the p^H is recommended for reforestation and afforestation purposes for two purposes only, as an aid in judging of site quality and as an additional factor to aid in the selection of species. Both of these purposes will show greater importance at the extremes of soil reaction. The use of any convenient indicator which will show soil reaction to the nearest half unit for a range of p^H from about 3 to 8.5 would be considered accurate enough for these purposes. Thus the final purpose of p^H determination for reforestation and afforestation can be considered as but another means of helping to eliminate some of the guesswork involved in selection of species for the site under consideration.

PART II

AN EXPERIMENT IN THE USE OF NUTRIENT SOLUTIONS IN THE DETERMINATION OF SOIL REACTION PREFERENCES OF TREE SEEDLINGS

REPORT OF AN EXPERIMENT CONDUCTED AT THE
UNIVERSITY OF MICHIGAN
IN THE WINTER OF 1945 - 1946.

CHAPTER I

METHOD AND EQUIPMENT

The experiment was undertaken as a test of a method of soilless culture or hydroponics for the determination of the p^H preferences for germination and first growth of common tree species. The purpose was to establish a method of testing for p^H preferences easily and quickly under conditions comparable to those in the forest tree nursery, obtaining values for post emergence germination and for the first six week period after emergence to simulate the critical period in the nursery.

(a) Outline of the Method.

The seed of the species tested was sown in non-reactive quartz sand which was placed in wooden flats, the sand to act merely as a physical support for the seedlings. The sand flats were then placed in metal trays containing a nutrient solution of pure chemicals in water which was to moisten the sand by capillary action. One general nutrient solution was used and the p^H of this was regulated by means of potassium hydroxide and sulphuric acid. The p^H of the solution was kept controlled and adjusted as necessary for the range of p^H desired. Counts were kept of germination (post-emergence) and the living or green weight of material produced under each degree of p^H was determined 42 days after the peak of emergence.

(b) Equipment Used in the Experiment.

The tree seed used was from the stock of the Provincial Seed Extracting Plant of the Ontario Department of Lands and

Forests at Angus, Ontario; forwarded by the Superintendent, Mr. R. S. Carmen, to whom the author is indebted for this assistance.

The species used in the test and their germination percentages, post-emergence, as tested in sand at Angus is given in the following table.

Species	Locality	Serial No.	Germination Days	Germination Percent
Red Pine	Callender Ont.,	4-07	18 days	85%
Norway Spruce	Angus "	44-294	14 days	69%
Rock Elm	Angus "	44-16	12 days	93%

The Red Pine (Pinus resinosa Ait.) was from seed collected in 1940, the Norway Spruce (Picea abies L.) and the Rock Elm ((Ulmus racemosa Thomas) were from seed collected in 1944.

Ottawa sand, a coarse pure sand was used in the experiment. It was placed in wooden flats, approximately 8" x 9" and 2½" deep which were sufficiently open to allow easy capillary action, the cracks being covered with medicinal gauze and cotton batten. Metal trays, 12" x 20" and 2" deep were prepared, each designed to hold two of the wooden flats.

The nutrient solution used was prepared from pure chemicals and the formula was taken from "The Use of Nutrient Solutions and Plant Hormones" by Hubert L. Davis. It was prepared in five gallon quantities as required using the following proceedure and chemicals.

Tap water was used, allowed to stand open overnight to remove as much of the chlorine as possible. The solution itself was then prepared in three parts.

i Essential Element Solution

The weights are given for a 5 gallon solution

Calcium Nitrate	17 grams.
Magnesium Sulphate	6.75 grams.
Potassium Acid Sulphate	6.5 grams.
Potassium Nitrate	11.4 grams

Each of these compounds was dissolved separately in a small amount of water and then added to a container of almost 5 gallons of water.

ii Trace Element Solution

The weights are given for a 200 CC solution.

Boric Acid	.4 grams.
Manganese Sulphate	.4 grams.
Zinc Sulphate	.4 grams.

Each of these was dissolvéd in a small amount of water and enough water was added to bring the solution up to 200 CCS. To each 5 gallons of the main solution as prepared above, 20 CCS of the true element solution was added.

iii Supplementary Iron Solution.

The weight given is for a 5 gallon solution.

Iron Sulphate	.02 grams.

This was dissolved in water and added to each 5 gallons of the main solution as prepared above. The quantity of iron required will vary for different species so it was necessary to make a guess and a little more was used than was specified (.0125 grams). The amount of iron required varies with the light intensity and other factors.

Enough water was then added to bring the nutrient solution up to five gallons.

(c) Preparation of the Experiment.

As a precaution against fungus infection as much as possible, the wooden flats were washed thoroughly in a formaldehyde solution of about 1 part formaldehyde to 20 parts of water, allowed to stand overnight and then washed in running water.

Also as a precaution, the metal trays were coated with parrafin, melted and applied to the inside with a paint brush, to protect against the possibility of the occurrence of zinc in a toxic concentration.

The seed of the two conifers was sown in one flat, and the seed of the Rock Elm in another, 12 flats of each being prepared so as to cover a range of p^H from 4 to 8.5 by half units and to have controls, one in nutrient solution and one in water. The sand in the flats was levelled off to a uniform depth by means of a cardboard scraper, the seed sown in lines on top and then covered with the sand to a uniform depth using the same method.

The flats were then placed in the metal trays and the nutrient solution put in the trays to a uniform depth. The p^H was first regulated in these trays by means of a potentiometer but this was soon found to be beyond the limit of accuracy warranted by the experiment. The control trays, one containing water and one containing nutrient solution were filled to the same depth but not regulated for p^H.

It was found necessary to test the p^H and adjust it every other day, and for this purpose the indicator "Soiltex" produced by the Michigan State College was used. Counts were taken and recorded as soon as the seedlings broke surface. Also the green weight of the material produced was taken, 42 days after the peak of germination of each species for each p^H and for the controls.

CHAPTER II

THE RESULTS OF THE EXPERIMENT

For the sake of brevity, all but the important data has been omitted. The data collected is presented separately for each species, in the following order, Rock Elm, Norway Spruce and Red Pine.

Each species has the same class of data, presented in the same manner to make comparison easier. The first page is a table summarizing the data, showing the total germination; the survival at the time of removal, 42 days after the peak of germination; the total green weight of the seedlings removed at that time, and the weight per seedling; and lastly, the weight of one half of the number of seedlings removed, the largest by ocular selection, and the weight per seedling of this group.

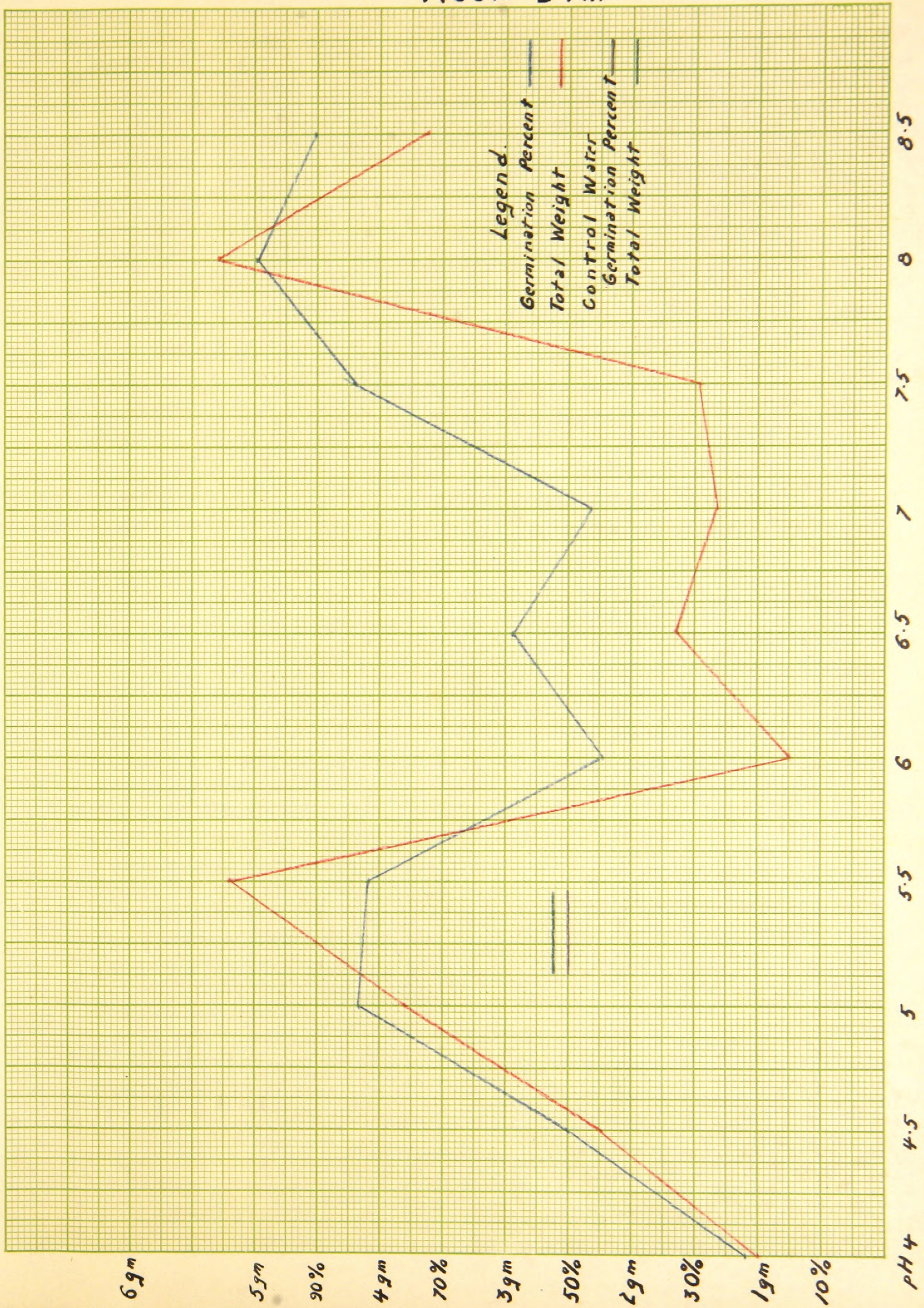
The following page is a graphical presentation of the data for the germination percent and the total green weight produced.

The third sheet for each species is a graphical presentation of the data for weight per seedling for all seedlings removed and the weight per seedling for the top half or the half made up of the largest seedlings.

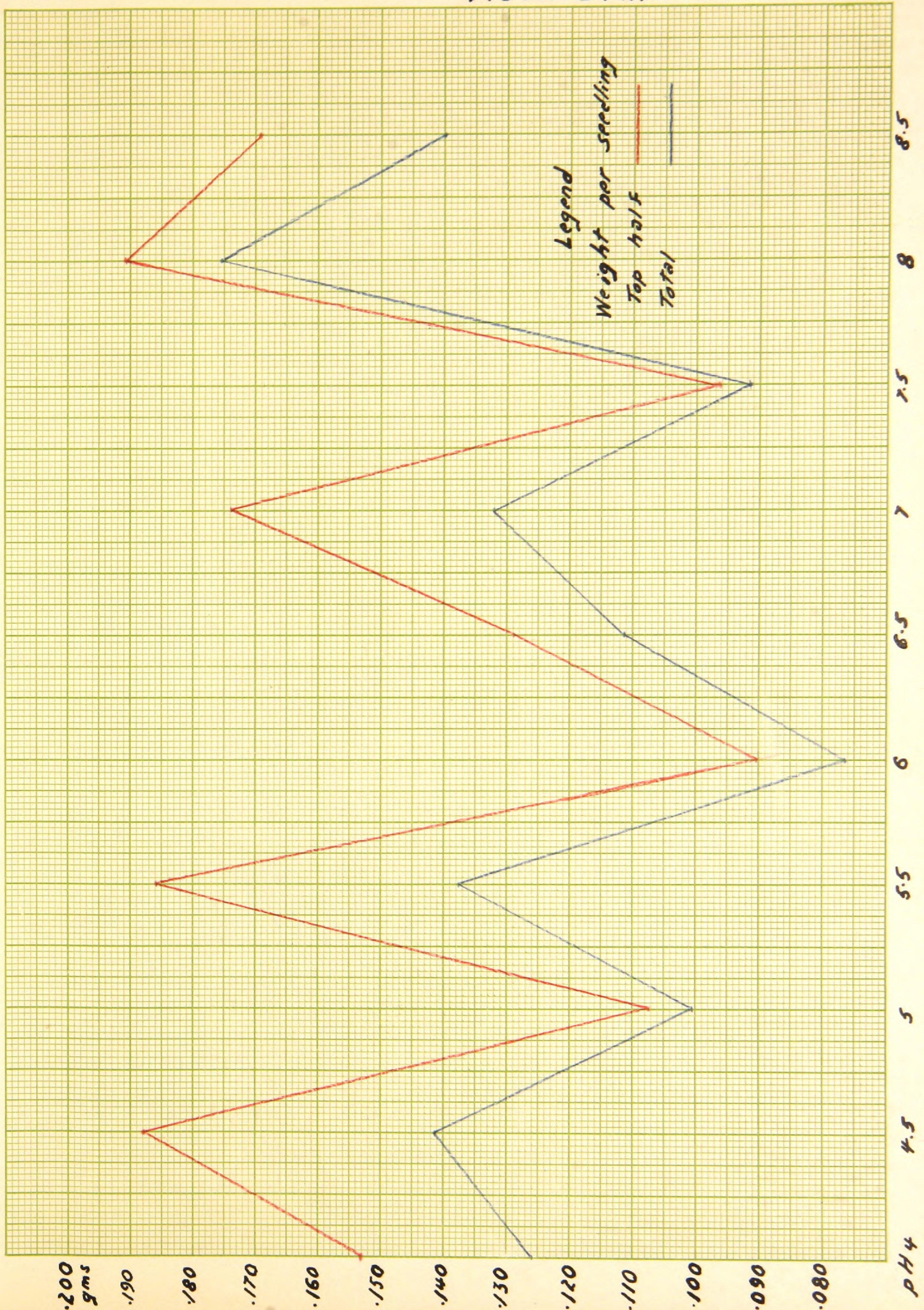
SUMMARY OF DATA - ROCK ELM

Test	Termin-ation	Germination Percent	Survival	Survival Percent	Total Green Weight	Weight per Seedling	Weight of top half	Weight per seedling top half
$p^H 4$	11	22	8	72.7	1.00 gms	.126 gms	.601 gms	.153 gms
$p^H 4.5$	25	50	16	64.0	2.28 gms	.142 gms	1.50 gms	.188 gms
$p^H 5$	42	84	38	90.5	3.81 gms	.100 gms	2.04 gms	.107 gms
$p^H 5.5$	41	82	38	92.6	5.24 gms	.138 gms	3.54 gms	.186 gms
$p^H 6.$	22	44	10	45.4	.753 gms	.075 gms	.451 gms	.090 gms
$p^H 6.5$	30	60	15	50.0	1.66 gm	.111 gms	1.03 gm	.129 gms
$p^H 7$	23	46	10	43.5	1.32 gm	.132 gm	.870 gm	.174 gms
$p^H 7.5$	42	84	19	45.2	1.72 gm	.091 gm	.960 gm	.096 gms
$p^H 8$	50	100	30	60.0	5.30 gm	.176 gm	2.86 gm	.191 gms
$p^H 8.5$	45	90	26	57.8	3.64 gm	.140 gm	2.20 gm	.169 gms
Control Nutrient	46	92	39	84.8	4.91 gm	.126 gm	2.92 gm	.146 gms
Control Water	25	50	23	92.1	2.64 gm	.115 gm	1.69 gm	.158 gms

Rock Elm


Legend.
Germination Percent
Total Weight
Control Water
Germination Percent
Total Weight
pH 4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
6gm
5gm
90%
4gm
70%
3gm
50%
2gm
30%
1gm
10%

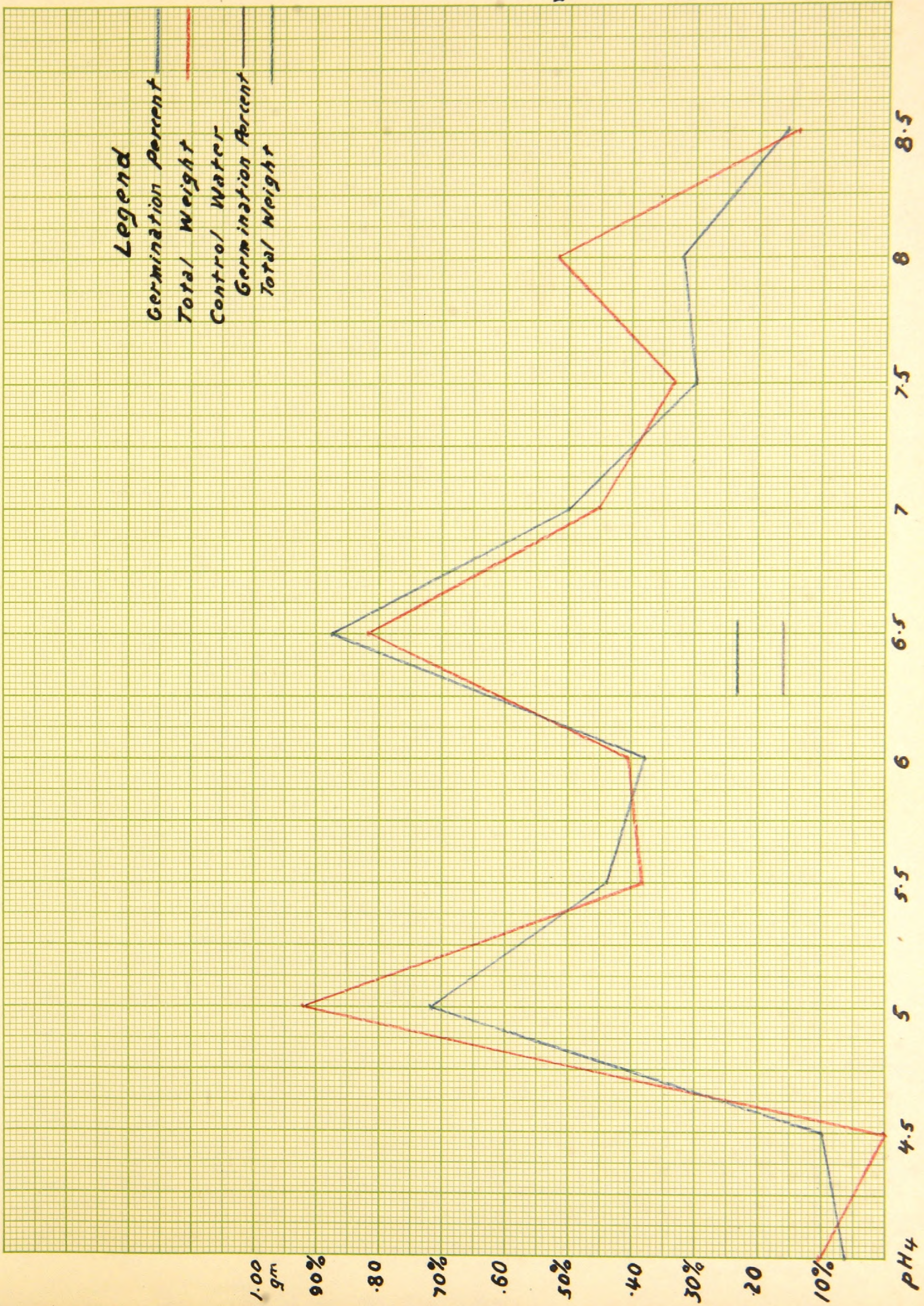
Rock Elm


Legend
Weight per seedling
Top half
Total
.200 gms
.190
.180
.170
.160
.150
.140
.130
.120
.110
.100
.090
.080
pH 4
4.5
5
5.5
6
6.5
7
7.5
8
8.5

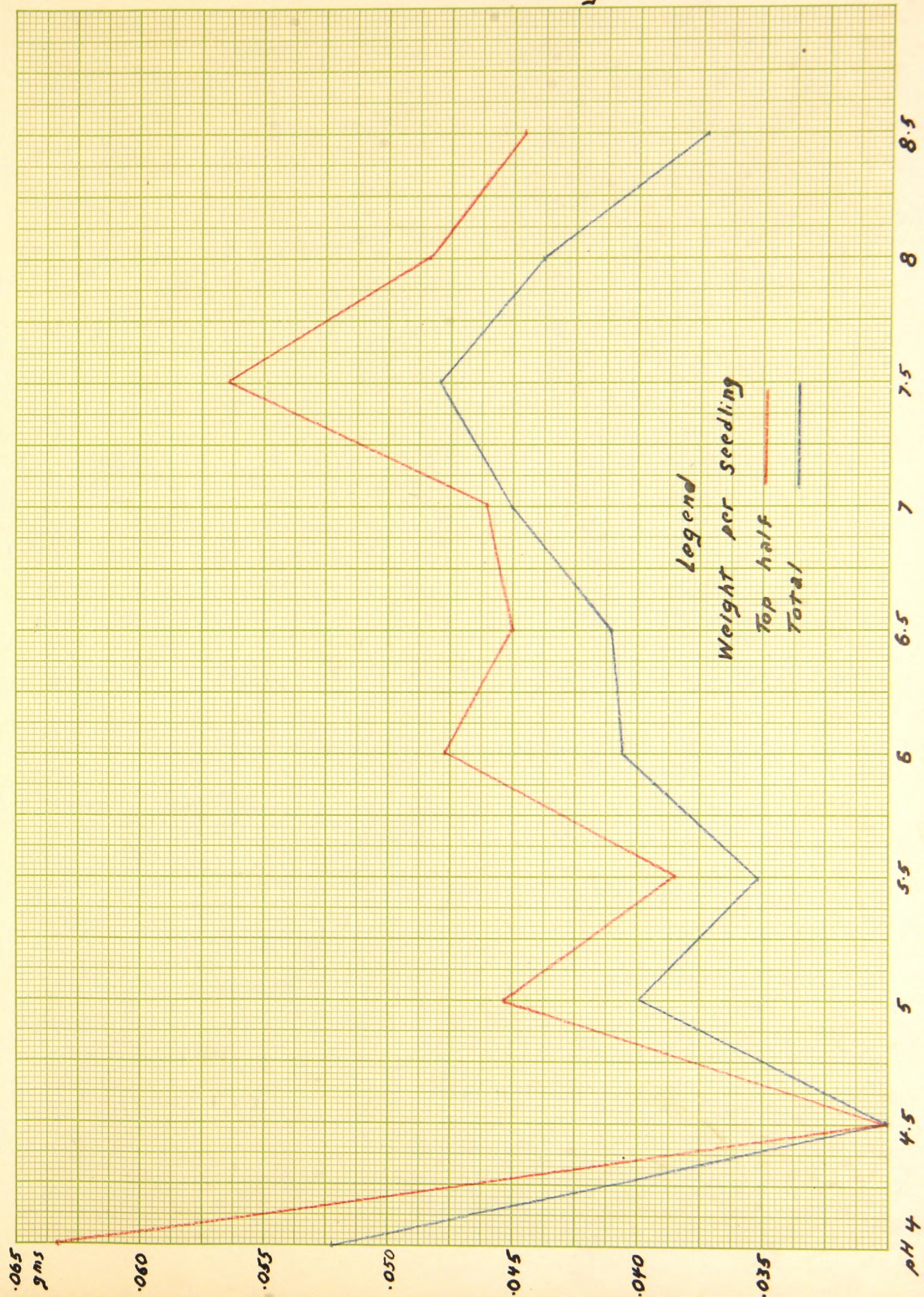
SUMMARY OF DATA - NORWAY SPRUCE

Test	Germin-ation	Germination Percent	Survival	Survival Percent	Total(green) Weight	Weight per Seedling	Weight of top half	Weight per seedling top half.
p^H4	3	6	2	66.6	.104 gms	.0523 gms	.0634 gms	.0634 gms
$p^H4.5$	5	10	0	0	0	0	0	0
p^H5	36	72	23	63.9	.920 gms	.0400 gms	. 545 gms	.0454 gms
$p^H5.5$	22	44	11	50.0	.386 gms	.0351 gms	. 231 gms	.0385 gms
p^H6	19	38	10	52.6	.407 gms	.0407 gms	. 239 gms	.0479 gms
$p^H6.5$	44	88	20	45.5	.822 gms	.0411 gms	. 450 gms	.0450 gms
p^H7	25	50	10	40.0	.451 gms	.0451 gms	. 220 gms	.0461 gms
$p^H7.5$	15	30	7	46.7	.336 gms	.0480 gms	. 226 gms	.0566 gms
p^H8	16	32	12	75.0	.525 gms	.0438 gms	. 290 gms	.0483 gms
$p^H8.5$	8	16	4	50.0	. 149 gms	.0374 gms	. 089 gms	.0447 gms
Control Nutrient	20	40	17	85.1	.554 gms	.0326 gms	.320 gms	.0356 gms
Control Water	8	16	7	87.5	.235 gms	.0336 gms	.150 gms	.0375 gms.

Norway Spruce



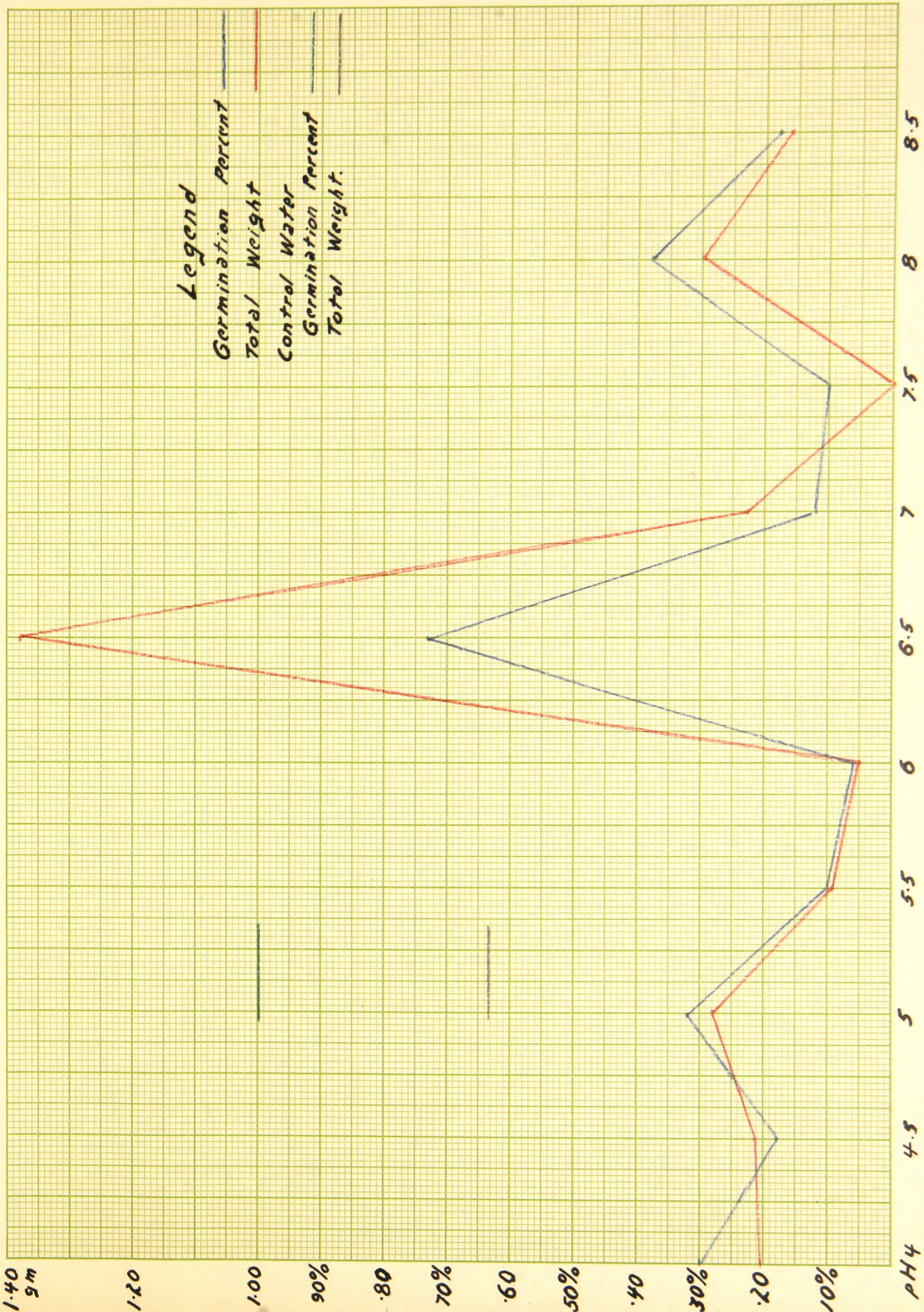
Norway Spruce



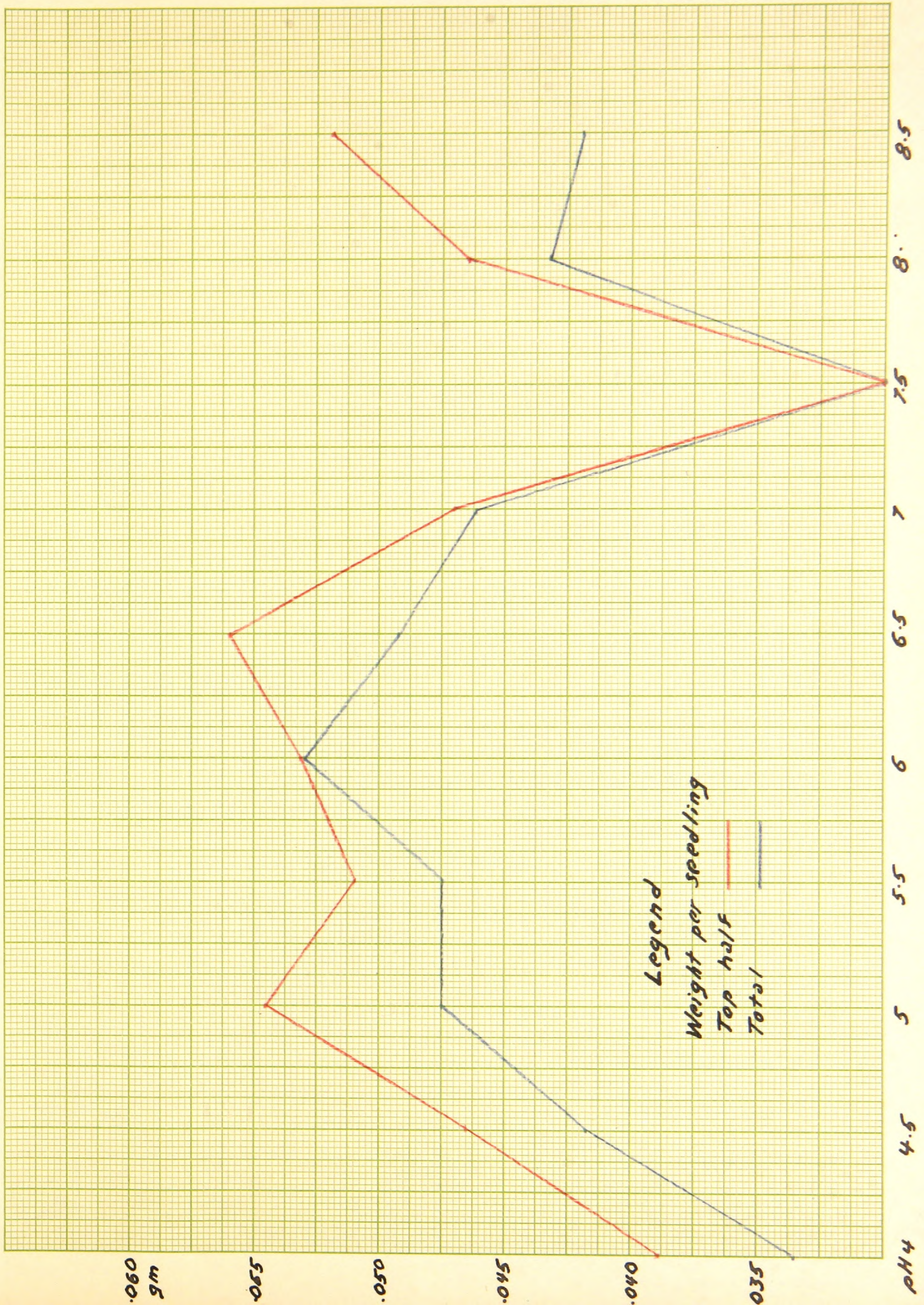
SUMMARY OF DATA - RED PINE

Test	Germin-ation	Germination Percent	Survival	Survival Percent	Total(green) weight	Weight per seedling	Weight of top half	Weight per seed-ling top half
p^H4	15	30	6	40.0	.2008 gms	.0335 gms	.1162 gms	.0387 gms
$p^H4.5$	9	18	6	66.6	.2112 gms	.0419 gms	.1398 gms	.0466 gms
p^H5	16	32	6	37.5	.2854 gms	.0476 gms	.1635 gms	.0545 gms
$p^H5.5$	5	10	2	40.0	.0950 gms	.0475 gms	.0510 gms	.0510 gms
p^H6	3	6	1	33.3	.0532 gms	.0532 gms	.0532 gms	.0532 gms
$p^H6.5$	37	74	28	75.7	1.380 gms	.0493 gms	.7860 gms	.0561 gms
p^H7	6	12	5	83.3	.2312 gms	.0462 gms	.1411 gms	.0470 gms
$p^H7.5$	5	10	0	0	0	0	0	0
p^H8	19	38	7	36.8	.3032 gms	.0433 gms	.1857 gms	.0464 gms
$p^H8.5$	9	18	4	44.4	.1676 gms	.0419 gms	.0990 gms	.0495 gms
Control Nutrient	14	28	7	50.0	..3150 gms	.0450 gms	.1900 gms	.0475 gms
Control Water	15	30	15	100.0	.6340 gms	.0423 gms	.3850 gms	.0481 gms

Red Pine


Legend
Germination Percent
Total Weight
Control Water
Germination Percent
Total Weight.
1.40 gm
1.20
1.00
90%
.80
70%
.60
50%
.40
30%
.20
10%
pH 4
4.5
5
5.5
6
6.5
7
7.5
8
8.5

Red Pine


Legend
Weight per seedling
Top half
Total
pH 4
4.5
5
5.5
6
6.5
7
7.5
8.
8.5
.035
.040
.045
.050
.055
.060
gm

CHAPTER III

CONCLUSIONS OF THE EXPERIMENT

Before attempting to relate the data collected to the soil reaction preferences of the species, a broad outlook at the experiment seems warranted. An experiment of this type should have been carried out in a greenhouse where the conditions of the environment were better regulated. Since it was carried out in a laboratory however, where the factors of environment were subject to variation and also because of errors in the method itself, the results can not be considered as more than indications of the p^H preferences of the species.

These variable factors of environment and the main errors in experimental methods are listed as follows:

1. Although all seeds were planted at the same time, all seedlings were not removed at the same time.
2. The reaction of the solution, although checked and adjusted every other day, showed considerable variation.
3. Due to limitations of time and equipment, no identical experiment was conducted as a check.
4. The plants grown under different conditions of p^H were subject to variations and inequalities of light.
5. There was also a variation in the temperature conditions within the laboratory. These last two conditions would of course be minimized in importance if all plants tested were exposed for an equal length of time, at the same time.
6. The moisture conditions of the quartz sand were unsatis-

factory and difficult to control, using this capillary method, due both to the speed of rise of the solution and the rate of surface evaporation. The irregularity in the germination percent is believed partly due to this cause.

7. There was also a possibility of unequal concentrations of the nutrients in the different p^H's as a result of the unequal evaporation.

The results of the experiment will therefore only be briefly discussed as regards the p^H preferences of each species, followed by a discussion of the method and equipment of the experiment.

A. Rock Elm

The results of the germination percent (counted on emergence) and the total green weight of plant material produced under each condition of p^H, as plotted on P.41, show a rather close correlation. Each of these properties shows indications of a double optimum, although the upper limit of the tolerance can not be stated too definitely as Rock Elm is apparently quite tolerant of the highest p^H of 8.5 as tested in the experiment.

Therefore it is only justifiable to assume that the indications of the p^H preferences of Rock Elm for germination and first growth are for a range of tolerance from p^H4.5 to p^H8.5 or 9, and an optimum of soil reaction from about p^H5 to p^H8.

The control plants, in tap water, show an average germination and total weight produced neither as high as was produced in the nutrient solution at either optimum of p^H nor as low as that inbetween. This is taken as an indication that the nutrient solution was none too favourable for the growth of Rock Elm and that a better one could be found, as the growth at the low point between the two optimums should at least be better than the growth in an environment providing only limited nutrition.

The weights per seedling for all seedlings produced and for the largest seedlings, selecting half of those produced, do not seem to bear any direct relationship to the p^H preference of the species and it is obvious that the growth responses are in answer to some one or many factors of the environment as well as p^H. The fact that two of the four optima shown by this data coincide with the optima for total weight produced gives support to the latter as being the optima for the p^H preferences for this species under these conditions.

Thus the only justifiable conclusions respecting Rock Elm are that it exhibits a p^H tolerance of about p^H4.5 to p^H8.5 or 9, with an optimum range from about p^H5 to p^H8.

B. Norway Spruce.

The results of the germination percent and the total green weight of plant material produced, as plotted on page 44, show a rather close correlation. Two quite definite optima are indicated at p^H5 and p^H6.5 under the conditions of the experiment. Hence the indicated optimum for p^H of Norway Spruce is relatively more limited than that of Rock Elm.

In the case of Norway Spruce though, there is an irregularity in the germination percent and total weight produced which likely has no significance as regarding the p^H tolerance of the species and is more likely a reflection on the accuracy of the results to be expected under this experiment. The last statement is in reference to the peak presented for both values at p^H8. In view of these results then it is only justifiable to establish an indicated p^H tolerance for this species of between p^H5 and p^H7 approximately.

The data for the control seedlings in water, as it is relatively low compared to the majority of the results for the regulated p^H tests would indicate that the nutrient solution was thus more suited to the testing of Norway Spruce than Rock Elm.

The figures for the growth of the individual seedlings of Norway Spruce show too much variation to be taken as indicating any p^H preference or to be related to the preferences shown by the germination percent and total weight produced. This is probably due to the uncontrolled factors of the experiment and to the small number of seedlings from which this data was determined.

Thus the only justifiable conclusions as regarding the reaction preferences of Norway Spruce are that an optimum of about p^H5 to $p^H6.5$ and a range of tolerance from about p^H5 to p^H7 are indicated.

C. Red Pine.

The generally low percentage of germination which the Red Pine showed, together with the irregularity of germination and total weight produced, give a small and variable source on which to base conclusions regarding its p^H preferences. This seed, which germinated 89% in 18 days in sand at Angus, was the last to show germination and the germination was slow and spasmodic, from which it may be concluded that the conditions of the experiment were not favourable to Red Pine germination. The seed was subjected to a cutting test at the conclusion of the experiment and a large percent of the seed (over 60%) which did not germinate had rotted inside, becoming milky and soft. This would tend to show that the seed was too moist for proper germination.

The optimum which occurred at a p^H of 6.5 for both germination and total weight produced can not be interpreted as having any real bearing on the p^H preference of this species. Thus the experiment as far as determining the pH preference of this species may be considered as unsuccessful, by means of germination and total weight produced.

As regarding the indications of the preference by means of the weights per seedling, a trend is shown towards a range of tolerance from about p^H5 to p^H7 but this is based on a small number of seedlings in each p^H. The reason for the failure after germination at $p^H7.5$ is not known and hence the result was disregarded in assuming a downward trend from p^H7 to p^H8 as a prerequisite of the foregoing statement.

So for Red Pine a questionable preference only can be derived from the experiment, a tolerance from a p^H5 to p^H7 is indicated.

D. Conclusions regarding the Method of the Experiment.

Aside from the environmental factors of the laboratory certain inferences may be drawn as regarding the conditions established by the experiment itself.

1. The capillary method of feeding the plants appears to have definite drawbacks which are reflected in the results. The first of these is the irregularity in the germination, particularly as shown by the Red Pine, an upland species, which is believed to be largely due to differences in the moisture content of the sand.
2. The capillary method introduces the danger of concentration of salts in the upper layers of the sand due to evaporation and the possibility of these becoming present in such concentrations as to be detrimental to the health of the seedlings.
3. There is also the possibility that the changes in p^H necessary to control the solution may have a direct effect on the results of the experiment, for example

a change to a lower p^H having a greater effect than continual growth at that low p^H level.

4. The amount of moisture in the sand was not constant but varied due to evaporation and the addition of more solution to keep all up to the same predetermined line.
5. The difficulty of selecting the peak of germination for each p^H and determining an exact date, on which is based the 42 day growth period.
6. The relation of germination itself to p^H can not be determined but only the germination on emergence.
7. The roots of the plants penetrate into the sand to a depth at which the soil is saturated and hence aeration is poor.

Thus these conclusions tend to show the inadequacy of this experimental organization and they are used as a basis for the recommendations for similar experiments of soil reaction preference determinations as given in the following chapter.

CHAPTER IV

A RECOMMENDED PROCEEDURE FOR p^H PREFERENCE DETERMINATION

The method herein described has been developed for the purpose of avoiding the many errors and inaccuracies discovered in the previous experiment. It is similar in organization to the experiments conducted by many plant physiologists and the equipment used is very much the same. The majority of the sources of error in the previous experiment seemed to come from the use of a capillary or sub-irrigational method of supplying the nutrient solution. As a result the recommended proceedure involves the use of a gravity feed system of nutrient solution supply and it is believed that this method would give more satisfactory results for the determination of the p^H preferences of tree species for germination and for the first six to eight week period after germination. For ease of presentation and understanding, the method is presented in chronological sequence.

The first step of the process is the preparation of a buffer solution. This may be any one of the standard buffer solutions which are used in plant physiological work or for purposes of comparison, more than one buffer may be used. Only a small quantity of buffer solution is needed for this first step in the experiment. Smaller quantities of this solution are then adjusted for the range of p^H desired in the experiment and these amounts are used to moisten thoroughly either one or two filter papers placed in a petri dish.

The practice in many experiments in the past has been to determine soil reaction preferences of the species as accurately as one tenth of a p^H exponent but it is not believed now that such extreme accuracy is either required or justified as the preferences so determined are related to that environment only. Thus the determination of the preferences of the species to half exponents of the p^H ($p^H 4.5$) is thought to be sufficient for practical purposes.

The depth and size of the petri dish used will depend on the species of tree used and the values desired. Where the value for germination and first growth is to be judged on the results of the seed responses in the petri dish, followed by transplanting to determine the p^H preferences of later growth, the petri dishes should be quite deep, 1½ to 2". Each dish used in the experiment must have a tight cover and be sterilized and duplicate dishes must be prepared for each p^H of each species being tested.

The seed of the species used in the experiment is prepared as follows. The entire sample is first soaked in water. The length of soaking required will vary with the species but in the light of other experiments as little as one hour may be sufficient for upland tree species and as long as one day may be desired for lowland species. The seed is then sterilized as far as possible. For simplicity the use of a formaldehyde solution is recommended, soaking the seed for about 10 minutes in a solution of about three parts of the standard 40% commercial formaldehyde to 100 parts of water. The aqueous solution is more accurately termed formalin as formaldehyde is a gas at room temperatures. After soaking in this solution the seed is thoroughly washed in running water to remove any traces of the formaldehyde.

The seed is then divided on some basis of equal sampling, and equal numbers are placed in the petri dishes as prepared before. The seed should be evenly and openly spaced for ease of counting and to reduce the spread of fungus infection if such occurs. The petri dishes are then covered. For fast germinating species nothing further will be required but for slow germinating species it may be necessary to add a few drops of the regulated buffer solution every few days to keep the filter papers well moistened.

As soon as the seed coat is ruptured and the radicle emerges counts are taken and records kept, on which may be based the p^H preference of the species for germination. There is no agreement as to what should be termed germination but a tentative separation might be devised as follows for purposes of the experiment, germination being defined as extension of the radicle up to 1/4", first growth being that period of growth from germination to when the selling is no longer dependant upon the stored food of the seed and later growth covering the period from there on. For many species the p^H preferences of the first two stages may be determined by the use of deep petri dishes alone, for germination based on numerical data alone and for first growth on both numerical and weight data.

For special purposes only would it be necessary to determine the information regarding the p^H preferences of these first two stages. Normally the information desired for practical use in reforestation work, both nursery and planting, would be that regarding later growth. It is probable that the p^H tolerance and optima for the same species would be sufficiently alike in all three stages as to make determination of the first two preferences unnecessary for our purposes but no information could be found on this important point, as to whether there is any actual change in the p^H preferences of a species with the stage or size of the plant.

So far the method outlined has referred to determination of the p^H preferences of the first two stages and it is proposed now to continue the method to cover the third stage, later growth, limited, of course, to the six or eight week period as before.

The first major problem to be solved in this connection is that of finding a proper nutrient solution. In the previous experiment the nutrient solution used was obviously unfavourable to Rock Elm. In the ideal experiment, where space and equipment permitted it, a number of nutrient solutions would be used as it is not the exact range of p^H tolerance or the exact optima of the species for a single environment that is desired but rather the average of the p^H preferences and the ability of adjustment of the species to different environments that is expressed in its range of tolerance.

The seedlings as produced in the petri dishes in the first part of the experiment are removed from the dishes at the time desired and planted in moist quartz sand as in the previous experiment. However it is recommended that porcelain or glazed clay flower pots are used, to decrease the danger of infection and to increase the depth of the sand. One of the major difficulties of the previous experiment is removed as here all the seedlings are planted at the same time and can be selected of the same size. This eliminated the difficulty of determining the peak of germination which was a source of error in the previous experiment.

At the same time this provides for more accurate measurement of the six or eight week growth period and all the seedlings in the test are thus exposed to the same environmental conditions at the same time. To obtain the preferences of the species a small number of seedlings could be used, say 20 or 25 for each condition of p^H.

For the supply of nutrient solution the method of a gravity feed is recommended, to overcome the many difficulties and inaccuracies of the capillary method. The simplest form this would take would be that of a battery of containers of nutrient solution at a higher elevation than the pots containing the seedlings. The solution should be buffered to maintain its proper p^H and then regulated. From each container would run a feed line to the pot or pots it was supplying, such as a small bore glass tube or any tube working on the siphon principle which will deliver the solution in a slow but constant manner to the top surface of the quartz sand. The solution can be collected again after it has passed thru the sand, tested for p^H and adjusted if necessary, and used repeatedly for one or two weeks,

At the end of the desired period of growth the response of growth to p^H could thus be more accurately determined by weighing the material produced. The accuracy of the experiment under these conditions should be such as to warrant taking oven-dry weight of all the seedlings produced.

It can easily be seen that the experiment as ran under these conditions would come a great deal closer to the ideal experiment than the one previously described, the ideal being attained when all the factors of environment are identical for all the plants being grown except the one factor under examination, in this case p^H.

APPENDIX A

A LIST OF p^H VALUES FOR TREE SPECIES OF THE NORTHEASTERN UNITED STATES

Botanical Name	Common Name	p^H Range	Optimum	Source
A. Coniferous Species				
Abies balsamea	Balsam Fir	4.5 -	5.0 -6.0	Spurway
Abies spp.	Fir	4.8 -6.9	5.5 -6.1	Weir
Chamaecyparis thyoides	White Cedar	-6.0	4.5 -5.0	Spurway
"	"	4.8 -7.0	4.8 -6.1	Weir
Juniperus virginiana	Red Cedar	5.0 -	5.5 -7.0	Spurway
"	"	7.0 -8.5	7.1 -8.5	Weir
Larix decidua	European Larch	4.5 -	5.0 -6.5	Spurway
Larix laricina	Tamarack	4.5 -	5.0 -6.5	Spurway
"	"	6.2 -8.5	7.1 -8.5	Weir
Picea abies	Norway Spruce	-7.0	5.0 -6.0	Spurway
Picea glauca	White Spruce	-7.0	5.0 -6.0	Spurway
Picea mariana	Black Spruce	-6.0	4.0 -5.0	Spurway
Picea rubra	Red Spruce	-6.0	4.5 -5.0	Spurway
Pinus banksiana	Jack Pine		4.5 -5.0	Spurway
Pinus resinosa	Red Pine	4.5 -	5.0 -6.0	Spurway
Pinus strobus	White Pine	-7.5	4.5 -6.0	Spurway
Pinus sylvestris	Scots Pine		5.0 -6.5	Spurway
Pseudotsuga taxifolia	Douglas Fir		6.0 -7.0	Spurway

Botanical Name	Common Name	p^H Range	Optimum	Source
Thuja occidentalis	Western Cedar	5.5 -	6.0-7.5	Spurway
"	"	7.1 -	7.1-8.5	Weir
Tsuga canadensis	Hemlock	-7.0	5.0-6.0	Spurway
B <u>Deciduous Species</u>				
Acer saccharum	Sugar Maple		6.0-7.5	Spurway
"	"	4.8-7.0	6.2-7.0	Weir
Betula lenta	Cherry Birch		4.5-7.0	Spurway
Betula lutea	Yellow Birch		4.5-5.5	Wilde
Betula papyrifera	White Birch		5.0-6.5	Spurway
Betula verrucosa	European Birch		4.5-6.0	Spurway
Carya ovata	Shagbark Hickory		6.0-7.0	Spurway
Castanea dentata	Chestnut		5.0-6.5	Spurway
"	"	4.8-6.9	5.5-6.1	Weir
Catalpa speciosa	Western Catalpa		6.0-8.0	Spurway
Celtis pumila	Hackberry		6.0-8.0	Spurway
Cornus florida	Flowering Dogwood		5.0-7.0	Spurway
Crataegus coccinea	Hawthorn		6.5-7.5	Spurway
"	"	5.5-8.5	7.0-7.8	Weir
Fagus grandifolia	Beech	-7.5	5.0-6.7	Spurway
Fagus spp.	Beech	4.8-6.9	4.8-6.1	Weir
Fraxinus americana	White Ash		6.0-7.5	Spurway
Fraxinus nigra	Black Ash		6.0-7.5	Spurway
"	"	4.8-8.5		Weir
Ginkgo biloba	Maidenhair Tree		6.0-7.0	Spurway

Botanical Name	Common Name	p^H Range	Optimum	Source
Gleditsia triacanthos	Honey Locust		6.0-8.0	Spurway
Gymnocladus dioicus	Kentucky Coffee-tree		6.0-8.0	Spurway
Juglans nigra	Black Walnut		6.0-8.0	Spurway
Malus prunifolia	Crab Apple		6.0-7.5	Spurway
Malus pumila	Apple		5.0-6.5	Spurway
Platanus occidentalis	Sycamore		6.0-7.5	Spurway
Populus candicans	Balm of Gilead		6.0-8.0	Spurway
Populus Fremonti	Cottonwood		6.0-8.0	Spurway
Populus tremuloides	Trembling Aspen		3.8-5.5	Spurway
Prunus pennsylvania	Pin Cherry		5.0-6.0	Spurway
Prunus virginiana	Choke Cherry		6.0-8.0	Spurway
Quercus borealis	Eastern Red Oak		4.5-6.0	Spurway
Quercus macrocarpa	Bur Oak		5.0-6.0	Spurway
Quercus palustris	Pin Oak		5.0-6.5	Spurway
Quercus rubra	Southern Red Oak	4.8-7.0	4.8-6.1	Weir
Quercus velutina	Black Oak		6.0-7.0	Spurway
Robinia pseudo-acacia	Black Locust		6.0-7.5	Spurway
Salix spp	Willow		5.0-8.0	Spurway
Sorbus americana	Mountain Ash		4.5-5.5	Spurway
Sorbus Aucuparia	European Mountain Ash		6.0-7.5	Spurway
Tilia glabra	Basswood		6.0-7.5	Spurway

Botanical Name	Common Name	p^H Range	Optimum	Source
Ulmus americana	White Elm		6.0-7.5	Spurway
Ulmus spp	Elms	4.8-8.5		Weir

Note: The following are the sources mentioned for the above values.

Spurway -- Spurway C.H., 1944. "Soil Reaction (p^H) Preferences of Plants" Bulletin 306, Mich. State College-Agr. Exp. Sta.

Wilde -- Wilde, S.A., 1942 "Forest Soils" Kramer, Madison, Wisconsin.

Weir-- Weir, W.W., 1936 "Soil Science" Lippincott.

Most of these values have been taken from the bulletin by Spurway and in only a few cases are comparisons available. Differences are apparent though and these may be explained on the following basis. The response to p^H differences, when plotted for a species, form a smooth curve and thus the points selected on this curve for the optimum and the range of tolerance of the species are largely a matter of personal selection. For this reason, in addition to those mentioned previously, the identification of an optimum and a range of tolerance for a species to tenths of a p^H unit seems even less justifiable. Another point which deserves mention here is that much of this data has been collected from various experiments conducted under widely different conditions, the results of which are not comparable.

Thus for the reference of the forester, in nursery and planting work, the values of the most help and guidance and which can be relied on to the greatest extent are those given under the optimum of p^H preference of each species.

APPENDIX B

A BIBLIOGRAPHY OF REFERENCES ON SOIL REACTION IN REFERENCE TO TREES

1. Balfour E.B. 1942 "The Living Soil" Faber & Faber, London.
2. Barton-Wright E.C. 1930 "Recent Advances in Plant Physiology".
3. Baxter D.V. 1943 "Pathology in Forest Practice" Wiley & Sons.
4. Boyce L.S. 1938 "Forest Pathology" McGraw-Hill.
5. Chandler R.F. 1937 "A Study of Certain Calcium Relationships and Base Exchange Properties of Forest Soils" Jour. of Foresty V 35, p.27-32.
6. Clark G.R. 1936 "The Study of the Soil in the Field" Clarendon Press.
7. Clark W.M. 1922 "The Determination of Hydrogen Ions" Williams & Wilkins Co.
8. Coile T.S. 1933 "Soil Reaction and Forest Types in the Duke Forest" Ecology, Oct. V14-4 p.323-333.
9. Davis H.J. 1945 "The Use of Nutrient Solutions and Plant Hormones" Edwards Bros.
10. Dunlap A.A. 1939 "The Sand Culture of Seedlings and Mature Plants" Circular 129 Conn. Agric. Exp. Sta.
11. Dunlap A.A. & McDonnell A.D. 1939 "Testing Germination in Sand". Jour. of Forestry V 37 p.330-333.
12. Ellis C. & Swaney M.W. 1938 "Soilless Growth of Plants" Reinhold Publ. Co.
13. Gustafson A.F. 1941 "Soils and Soil Management" McGraw-Hill,
14. Gustafson F.G. 1928 "Notes on the Determination of the Hydrogen Ion Concentration of Soils" Ecology V 9-3 p. 360-363.
15. Hilgard E.W. 1911 "Soils" MacMillan
16. Kiplinger D.C. & Laurie A. 1942 "Growing Ornamental Greenhouse Crops in Gravel Culture" Bull 634 Ohio Agr. Exp. Sta.

17. Kostychev S.P. 1931 "Chemical Plant Physiology" Blakiston's.

18. Lundegardh H.G. 1931 "Environment and Plant Development" Arnold, London.

19. Lyon T.L. and Buchman H.O. 1943 "The Nature and Properties of Soils" MacMillan.

20. Maksimov N.A. 1938 "Plant Physiology" McGraw-Hill.

21. Miller E.C. 1938 "Plant Physiology" McGraw-Hill.

22. Mirov N.T. 1937 "Application of Plant Physiology to the Problems of Forest Geneties" Jour. of Forestry V 35 p.840-844.

23. Moore B. 1920 "Influence of Certain Soil Factors on the Growth of Tree Seedlings and Wheat" Ecology V 3-1, p. 65-83.

24. McComb A.L. & Kapel F.J. 1940 "Growth of Seedling Black Locust and Green Ash in Relation to Subsoil Acidity and Fertility". Jour. of Forestry V.38 p.228.

25. Perry G.L. 1928 "Calcium - The Key to Forest Productivity" Jour. of Forestry V.26 p.767-773.

26. Raber O.L. 1928 "Principles of Plant Physiology" MacMillan.

27. Rayner M.C. & Neilson-Jones W. 1944 "Problems in Tree Nutrition" Faher & Faher, London.

28. Robbins W.L. 1923 "An isoélectric point for plant tissue and its significance" Ammerican Jour. of Bot. 10 p. 412-440.

29. Robbins W.R. & Shire J.W. 1942 "Methods of Growing Plants in Solution and Sand Cultures Bull 636 N.J. Agr. Exp. Sta.

30. Russell, Sir E.L. 1937 "Soil Conditions and Plant Growth" Longmans Green.

31. Salisbury E.L. 1928 "Some Aspects of Forest Ecology" (With Special Reference to Soil Conditions) Empire Forestry Journal V-7 p.155.

32. Shear G.M. & Stewart W.D. 1934 "Moisture and p^H Studies of the Soil Under Forest Trees" Ecology V 15-2 p 145-153.

33. Sigmond A.A.L. 1938 "The Principles of Soil Science" Marby, London.

34. Spurway C.H. 1944 "Soil Reaction (p^H) Preferences of Plants" Bull 306 Mich State College -Agr. Exp.Sta.

35. Stone M.H. 1944 "Soil Reaction in Relation to the Distribution of Native Plant Species" Ecology V 25 p 379-386.

36. Thatcher R.W. 1921 "The Chemistry of Plant Life" McGraw-Hill.

37. Toumey L.W. & Stevens C.L. 1928 "Testing of Coniferous Tree Seeds" Yale School of Forestry, Bull #21.

38. Toumey L.W. & Korstian C.F. 1942 "Seeding and Planting in the Practice of Forestry" Wiley & Sons.

39. U.S.D.A. Yearbook 1938 "Soils and Men".

40. Wallace T. 1944 "The Diagnosis of Mineral Deficiencies in Plants by Visual Symtoms". H.M. Stationery Office. London.

41. Weir W.W. 1936 "Soil Science" Lippincott.

42. Wherry E.T. 1927 "Divergent Soil Reaction Preferences of Related Plants" Ecology V-8 p.197-205.

43. Wherry E.T. 1920 "Soil Acidity and a Field Method for its Measurement" Ecology V-1 p.160-173.

44. Wherry E.T. 1922 "Soil Acidity Preferences of Some Eastern Conifers" Jour. of Forestry V 20 p.488-496.

45. Wilde S.A. 1942 "Forest Soils" Kramer, Wisconsin.

46. Wilde S.A. 1934 "Soil Reaction in Relation to Forestry and its Determination by Simple Tests" Journal of Forestry V 32 p.411-448.

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