CORRELATION OF THE SATURATED PASTE EXTRACT METHOD OF MEASURING SOLUBLE SALT CONTENT OF SOILS WITH THE ONE-TO-TWO EXTRACT METHOD IN MICHIGAN GREENHOUSE SOILS

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RUFUS B. RUTLAND

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies

of Michigan State University of Agriculture

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ABSTRACT

Much work has been reported in the literature correlating plant response to levels of salinity of soils as measured by the conductivity of the saturated paste extract. Routine measurements are made by growers and soil testing centers using the 1:2 extract for this measurement, and some work has been done correlating these measurements to response of specific crops in specific soils.

In this research, the ratio of conductivity of the saturated paste extract to that of the 1:2 extract has been correlated to saturation percentage for a number of soil mixtures and greenhouse soils actually in use in Michigan. An average curve representing different salts at various levels in all the soils studied was determined by laboratory experiment.

This curve was tested by growing *Chrysanthemum moriflorum*, variety Indianapolis White, at various levels of salinity as measured by the 1:2 extract method. Reduction of response occurred at a salts level equivalent to 360×10^{-5} mho/cm of the saturation extract. This corresponded to the point of reduction reported by other workers for another variety in terms of conductivity of the saturated paste extract.

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INTRODUCTION

Much research work is being conducted to study the problem of excess soluble salts in greenhouse soils. Crop response in most of this work is correlated to soluble salts levels as measured by the electrical conductivity of the saturated extract. Many growers and some soil testing laboratories, including the one at Michigan State University, use the simpler method of measuring conductivity of the 1:2 extract. Differences in the soils in use in greenhouses causes difficulty in relating the latter method to the former.

If a relationship could be clearly defined, the results of experiments reported in terms of the conductivity of the saturated paste extract could be directly converted into terms of conductivity of the 1:2 extract without having to go through the necessary experimental procedure of correlating plant growth to salts levels as measured by the 1:2 extract method. In this research, the relationship of these two methods has been studied by correlating the saturation percentage of the soil with the ratio of the conductivity measurements of one method to that of the other.

The research was undertaken in two parts. Laboratory experiments were conducted so that several soils and several salts could be studied and an initial relationship established. An experiment with plants was conducted to test this relationship with plant response.

LITERATURE REVIEW

SALTS ACCUMULATION

Soluble salt content of the soil has come to be recognized as a problem affecting greenhouse soil management. Merkle and Dunkle (14) found in analyzing some 300 soil samples from greenhouses that about 20 percent had high soluble salt content. McCall, Stinson, and Lindstrom report that of 73 greenhouse soils tested in one year by Michigan State University Soil Testing Service, 65 percent contained excessive amounts of soluble salts (27). Spurway (18) cites the accumulation of salts as one of the factors contributing to "exhausted soil" in the greenhouse. He recommended that fertilizer rates be determined by needs as indicated by soil tests and excesses avoided.

Conditions which lead to accumulation of soluble salts in the greenhouse are similar to those conditions in the field. Spurway points out that soluble salts build up where water falling on soil is not sufficient to dissolve and remove salts in the drainage water. Richards (16) describes the mechanics for field conditions. Soluble salts are introduced by water containing them. They accumulate through evaporation of water from the soil. The process is promoted by the absence of vigorous leaching action and by restricted drainage.

Baker (2) further considers notable the problem in clay pot culture. Salts accumulate in clay pots by the evaporation through the sides. He states that high salts levels can result from the fertilizers, water, or soils used.

Fertilizers used in high rates as in the greenhouse can easily lead to accumulation of soluble salts (18,19,2). Merkle and Dunkle (14) found high salts accumulation resulted from the use of inorganic nitrogen and potassium fertilizers. Phosphates and bone meal were found to be relatively safe. Ayers, Wadleigh, and Magistad (1) believe that fertilization operations should be given careful study to weigh the advantages of adding plant food through fertilizers against the disadvantages of the salt effect from such additions. Tisdale and Nelson (17) state that the use of high analysis fertilizers lessens the danger of accumulation of salts. White and Ross (24) studied the effects of various fertilizer materials on the osmotic pressure of soil solutions. They found this order of increasing effect on osmotic pressure: anhydrous ammonia, urea, ammonium nitrate, ammonium sulfate, potassium nitrate, and sodium nitrate. They found relatively low osmotic pressure effects from applications of potassium sulfate, potassium chloride, superphosphates, and diammonium phosphate, with the phosphates lower than the potassium materials. They also found less salt injury from the use of high analysis materials.

Irrigation waters can have profound effects on soil conditions and salts accumulation. Calcium, sodium, magnesium, bicarbonate, chloride, and sulfate ions are often introduced in irrigation water (18,16,10).

EFFECTS OF HIGH SALT LEVELS

Much interest has been shown in the study of the effects of high soluble salts on plant responses. Reduced growth and yield are usually the first observable effects. In fact, Richards (16) defines a saline soil as one having sufficient soluble salts to impair its productivity. Spurway (18) said that plant symptoms usually were poor growth, and in extreme cases wilting, dying of plant parts, and finally death of the entire plant. Practically all investigators agree with this view, but the question of how this effect is brought about still remains.

The restriction of water availability to the plant by increased osmotic pressure is held to be an important factor by most researchers. Many believe this to be the major factor (19), (13), (6), (5), (14). Fox (5), Reitmeyer and L. V. Wilcox (15), and Wadleigh and Ayers (20) elaborate on the concepts of the similarity of moisture stress from salinity-induced osmotic pressure and moisture tension from the attraction forces between soil particle and the surrounding water film. They consider these forces to be additive in determining the total moisture potential of soil moisture.

Many researchers have shown another problem associated with salinity to be that of a changing pH of the soil solution. High pH is particularly a problem when sodium carbonate and bicarbonates are involved (16,22,10), and pH can be lowered by accumulation of acid ions (18).

EFFECTS OF SPECIFIC IONS

Much work has been done to define symptoms and establish tolerance limits to specific ions found to be toxic to plants. Wadleigh and Gaugh (21) believed that some plants show more sensitivity to the toxic effect of specific ions present in soil solution than to osmotic pressure resulting from high concentrations of salts. They found guayule sensitive to magnesium. With Kolisch in another experiment (22) they found that the presence of chloride ion caused the death of orchard grass at isosmotic levels which were tolerable for other salts. Chloride was much more detrimental to the plants when associated with calcium than with potassium or sodium. Furthermore, the association of calcium with nitrate was detrimental.

Kohl, Kofranek, and Lunt in studies with Saintpaulia (9) and chrysanthemums (26) found ammonium ion in moderate excess to be particularly toxic to those plants. The same authors (8) show boron to be toxic to poinsettia at low concentration, causing chlorosis, necrosis, and abscission of leaves. They found similar symptoms in azalea and gardenia (11). In studies of irrigation water with azalea (10), they show the effect of bicarbonate and sodium ions on that plant.

SALTS EFFECT ON ROOTS

The restriction of root development is another problem with saline conditions. Wadleigh, Gaugh, and Strong (23) consider salinity effects on roots to be two-fold: restriction of water entry and restriction of cell activity by toxic ions. And they consider plant response to high salts to be measurable on the basis of the limitation of root penetration caused by varying concentrations of salts.

Ayers, Wadleigh, and Magistad (1) concluded from studies of salt affecting bean growth that inhibition of root ramification might be more important than direct osmotic pressure effect on water absorption. High salts not only limit root growth, but also cause early suberization according to their findings. This means limited volume of soil ramified by roots and limited area of root hairs.

Injury to roots is also a possibility. Henderson (7) found that wilted plants could be watered with salt solutions and their turgor restored. However, when the same salt solution was applied to turgid plants, they wilted and died. He concluded that plasmolysis caused death of root tissues. The higher osmotic pressure of root cells in wilted plants made possible the utilization of water from the salt solution.

CHEMICAL ANALYSIS FOR SALTS

The determination of concentrations of soluble salts is another aspect of the problem that has attracted much attention. The three most common methods of determining the concentrations of soluble salts according to Magistad (12) are chemical analysis, evaporation of aliquots of soil solution, and estimation by means of electrical conductivity measurements.

The most exact, and also the most time-consuming method is chemical analysis. Magistad (12) described methods of chemical analysis for specific ions. Campbell, Bower, and Richards (3) used chemical analysis to determine salt concentrations of soil solutions. They compared these determinations with electrical conductivity and osmotic pressure determinations and found good correlation.

Chemical analysis methods are usually used to determine composition of soil solution salts rather than total amounts, according to Richards (16). He points out that these determinations are markedly influenced by moisture content of the soil when extraction is made. As moisture content increases the amounts of some ions as determined chemically becomes greater, while for other ions the amounts determined decreases, and almost invariably the values for total salt content increases with increases in moisture content. The ideal moisture level for extraction is within field-moisture range. Such extractions require special equipment and are time-consuming, though, and he uses extraction at saturation percentage. The semi-micro methods that he describes require the use of centrifuge, flame photometer, and photoelectric colorimeter.

EVAPORATION

Evaporation to total dissolved solids is often used in work where concentrations of specific ions are not necessary information. Merkle and Dunkle (14) used this method and determined total soluble and colloidal materials in the soil solution. These authors and Wilcox (25) consider this method more accurate than electrical conductivity. Osmotic pressure of soil solution is affected by non-ionizing molecules which do not affect conductivity. They found electrical conductivity to be sufficiently closely correlated to osmotic pressure however to warrant its use for routine work, and prefer it to evaporation for such work.

ELECTRICAL CONDUCTIVITY

By far the most frequently used method for estimating soluble salt concentrations is the method involving electrical conductivity. Richards (16) states that electrical resistance has been used since 1897 as a means of estimating soluble salt content. Electrical conductance, expressed in mhos, as he points out, is a more suitable value to use. This is the reciprocal of resistance (ohms) and has the advantage of varying directly with salt concentration. To clarify further its value, specific conductance, or electrical conductivity (EC) as it is also called, is used. Electrical conductivity has the dimension of mho per centimeter and this does not vary with the size of the sample. Readings are corrected to a standard temperature, 25 degrees centigrade.

Davis (4) advocated the use of the resistance bridge for routine laboratory approximations. He worked out conversion tables to find percentage of salt where chloride and sulfate predominate, and he made different tables for the different textural classes of soils.

SATURATED PASTE

Electrical conductivity determinations are often made of the saturated soil paste, but this method is not generally considered very accurate. Davis (4) used the Bureau of Soils cup for such determinations, and worked out corrections to be applied for certain known variations: chloride and sulfate predominating, carbonate present in quantity, and varying texture. Richards (16) later found their correction factors for carbonates to be erroneous. Reitmeyer and Wilcox (15) do not consider this method accurate in the light of their determinations for 36 western soils. They showed that the variations are influenced by saturation percentage of the soil, degree of salinity, and conductivity of the soil minerals.

Richards (16) gives some of the advantages of the saturated paste method using the Bureau of Soils cup. The apparatus is simple and rugged; the measurements can be made rapidly; and results are reproducible. He stated that there are weaknesses in the method, however. Work done at the Salinity Laboratory showed that there is no easy method to simplify the relation of electrical conductivity of the saturated paste to electrical conductivity of saturated extract. He considers the method acceptable for soil classification work in most cases, but he recommends the use of saturation extract for soluble salts determinations.

WATER EXTRACTS

Most researchers apparently accept these views on the limitations of saturated soil paste and prefer to use water extracts. The dilution factor to be used has been questioned for some time. It is generally agreed that the lower the dilution the closer the results are to representing conditions in the soil solution. In fact, many feel that the extract from saturated soil is best from the standpoint of accuracy.

Richards presents the following views (16). The special advantage of taking saturation extracts is due to the close relationship between saturation percentages and field moisture range. Three correlated points of moisture content are: wilting point (considered to be fifteen-atmospheres tension), upper end of field moisture range, and saturation percentage. In a wide textural range of soils tested, water content at saturation percentage was found to be about four times fifteen atmospheres tension and about two times that at upper field moisture, and soluble salt concentrations vary proportionately. By using saturation percentage extracts we effect some compensation for variation in moisture holding capacity. Furthermore, he found these determinations to be very closely correlated with plant response. Richards, then, recommends using the electrical conductivity of the saturation extract directly for appraising the effect of soil salinity on plant growth. Reitmeyer and Wilcox (15) agree with this view, as does Fox (5).

Campbell, Bower, and Richards (3) found excellent correlation of the electrical conductivity of the saturation extract with both the osmotic pressure of soil solutions and salt concentrations as determined by chemical analysis. They give these equations for relationships established.

$$\text{milliequivalents/liter} = 10.37(EC \times 10^3)^{1.065}$$

$$\text{osmotic pressure} = 0.321(EC \times 10^3)^{1.065}$$

$$\text{osmotic pressure} = 0.029(\text{m.e./liter})$$

Wadleigh, Gaugh, and Kolisch (22) agreed that measurement of electrical conductivity of saturation extract could be taken as a good index of decrease in activity of soil water. They indicate as an inherent weakness of electrical conductivity the fact that low readings are obtained from carbonate and bicarbonate salts on basis of plant response.

A few workers have used moisture levels between saturation percentage and wilting point. Scofield (17) and Magistad and Reitmeyer (13) have used extracts obtained at some value of moisture content within field range. Scofield used a centrifuge for extraction, bringing moisture content from saturation point down to moisture equivalent. Richards (16) considers such extracts to be ideal for accuracy, but difficulty of obtaining them prevents their use for routine work. Richards and Reitmeyer (16) developed a pressure-membrane method for extractions and presents its description in Handbook 60.

DILUTE WATER EXTRACTS

Another very commonly used dilution factor other than saturation extract is the 1:2 by weight soil to water dilution. Merkle and Dunkle (14) used 1:2 extracts and found good correlation curves for converting readings to total soluble materials with the soil they used. They found this relationship: percent soluble salt $= 188.1(EC \times 10^5) - 0.032926$. This was from measurements made after organic matter had been removed by oxidation with hydrogen peroxide. They consider 200×10^{-5} to be the limit that most plants can tolerate. These authors in another experiment (4) found good correlation with plant response.

Magistad, Reitmeyer, and Wilcox (12) prefer 1:1 extract to 1:2. The 1:1 extract can be removed from soil by filtration on Buchner funnel, and sufficient extract is obtained from relatively small soil samples. At the same time 1:1 is close enough in moisture content to saturation percentage to assure reasonable accuracy.

To evaluate properly results of further dilution, such dilutions must be studied comparatively over a wide range of soil types. J. C. Wilcox (25) did such a study. He compared readings taken at 2:1, 1:1, 1:2, 1:4, 1:8, 1:16, and 1:32 for soils of different moisture holding capacity. He found rapid decrease in conductivity with increasing amount of water used, and the progression was not geometric. He concluded that dilutions above 1:1 should not be used if standards applicable to a wide range of soil texture is desired. He went further to compare readings at constant multiple of moisture-holding capacity for different soils. Comparing electrical conductivity at five times moisture-holding capacity to electrical conductivity at 1:1, he found range in ratios of 0.78 to 1.47. The high ratios came from soils of low moisture-holding capacity, and vice versa.

Reitmeyer's studies (12) found greater amount of soluble salt obtained at 500% moisture percentage than at two times wilting percentage. He felt that extrapolation of 1:5 extract would give distorted picture and recommended extraction within range of field moisture.

Richards (16) points out that increased dilution does not affect determination much where chlorides are the principle salts present. However, if sulfates and carbonates are present, their solubility is much increased at higher dilution, and errors would result from their use.

Considering these limitations to electrical conductivity and the different factors or conditions that cause variations, perhaps the advice of Reitmeyer and Wilcox (15) would be well taken. They suggested that the establishment of empirical calibration factors for the soils of a given area might increase the precision of the method of soil conductivity measurement for use in that area.

LABORATORY EXPERIMENTS

MATERIALS AND METHODS

Twelve soil mixtures of the type used for greenhouse florist crops were made. Three natural soils, a coarse sand, and two peats were used. The textural class of the natural soil, the volume proportions of this soil, the sand, and the peat, and the saturation percentage of the composted soil are given in the Table I. The first six soils were developed using German peat, and for the last six, Michigan peat was used.

The saturation percentage reported in the table is the percentage water content on oven-dry basis of the saturated paste from which extracts would be taken. This value is very close to maximum water-holding capacity as determined by other methods. In preparing the saturated paste, distilled water was added to the sieved sample of soil until these conditions were met: the surface glistens when the soil sample is consolidated; the soil has a tendency to flow; a portion picked up on the spatula slides from it easily; and no excess water rises to the surface when the sample is allowed to stand for one hour.

In the initial experiments these soils were used at various levels of salts content. Original salt content of the soils gave a conductivity of the saturated paste extract in the order of 145×10^{-5} mho/cm. This conductivity would be indicative of a salt content of approximately 15 milliequivalents per liter of solution according to the curves on page 12 of USDA Handbook #60. The amounts of potassium chloride required to give conductivities of 300×10^{-5}, 600×10^{-5}, and 1000×10^{-5} mho/cm were calculated. These amounts of that salt were added to samples of the soils. The samples

TABLE I

SOIL MIXTURES

	NATURAL SOIL	PROPORTIONS	SATURATION PERCENTAGE
1.	Brookston Clay Loam	1-1-1	47.6
2.	Brookston Clay Loam	2-1-1	44.8
3.	Hillsdale Loam	1-1-1	36.9
4.	Hillsdale Loam	2-1-1	28.8
5.	Kalamazoo Sandy Loam	1-1-1	35.8
6.	Kalamazoo Sandy Loam	2-1-1	30.9
7.	Brookston Clay Loam	1-1-1	42.4
8.	Brookston Clay Loam	2-1-1	40.9
9.	Hillsdale Loam	1-1-1	30.8
10.	Hillsdale Loam	2-1-1	29.3
11.	Kalamazoo Sandy Loam	1-1-1	29.4
12.	Kalamazoo Sandy Loam	2-1-1	25.6

were then moistened to field capacity and allowed to stand for three days. The soil samples were then thoroughly mixed to insure uniform distribution of the salt. A subsample was removed and allowed to air dry for the 1:2 extract procedure. The main sample was brought up to saturation percentage with distilled water. A subsample was taken at this point for the saturation percentage determination. The soil solution was extracted under partial vacuum on a Buchner funnel, diluted with equal volume of distilled water to give enough solution for the conductivity measurement. This measurement was made with an Industrial Instruments Solubridge, Model RD-15, using a dip cell of cell constant one.

When the first subsample had dried to air-driness, it was used in making a 1:2 extract. The sample of soil was weighed. Two times its weight of distilled water was added to it and the mixture thoroughly shaken. After the soil had settled, the solution was decanted and its conductivity measured with the same solubridge instrument and dip cell.

The ratio of conductivity of the saturated paste extract to the conductivity of the 1:2 extract was calculated for each sample. This ratio was plotted on the ordinate of a graph with the saturation percentage determined from the subsample taken for that purpose plotted on the abscissa.

After several samples had been studied in this manner and a correlation suggested, other salts were used at various concentrations to ascertain if the same relationship would hold for them. These salts were calcium nitrate, magnesium sulfate, potassium nitrate, potassium sulfate, sodium nitrate, and sodium carbonate.

Finally, a collection of greenhouse soils was made from greenhouses in various parts of the state. The same manipulations were performed on these soils to determine whether or not they fell within the range of saturation percentage studied earlier and whether or not the same relationship of conductivity ratio with saturation percentage held for them.

RESULTS

In the initial study using potassium chloride as a salt at various levels, samples of the soil mixtures were analyzed as described above. The data obtained is presented in graph form in Figure 1. In this graph, the ratio $EC_e:EC_2$ (Electrical Conductivity of the Saturated Paste : Electrical Conductivity of the 1:2 extract) is plotted on the ordinate and saturation percentage is plotted on the abscissa. The correlation coefficient calculated for this data is -0.939, which is significant at the 1% level. The regression coefficient of saturation percentage on ratio is -8.87. A straight line which best fits this data and whose slope is defined by this regression coefficient has been drawn.

The next question considered was whether this same relationship would hold for other salts, and particularly for salts with divalent ions. Potassium chloride and other salts with monovalent ions are ionized about 86% in 0.1 normal solution. Salts with one divalent and two monovalent ions are about 72% ionized in 0.1 normal solution. And salts with both cation and anion divalent are only about 45% ionized in 0.1 normal solution.[1] These differences affect the conductivity at different solution strengths and the ratio of conductivity at one equivalent solution concentration to that at a different equivalent solution concentration.

[1] Chemical Rubber Publishing Co. Handbook of Chemistry and Physics. 39th Edition. 1958. p. 1639.

FIGURE 1

Graph of Saturation Percentage versus the Ratio of the Conductivity of the Saturated Extract to the Conductivity of the 1:2 Extract for Soil Samples in which Potassium Chloride is the Principle Salt.

FIGURE 1

Potassium Chloride

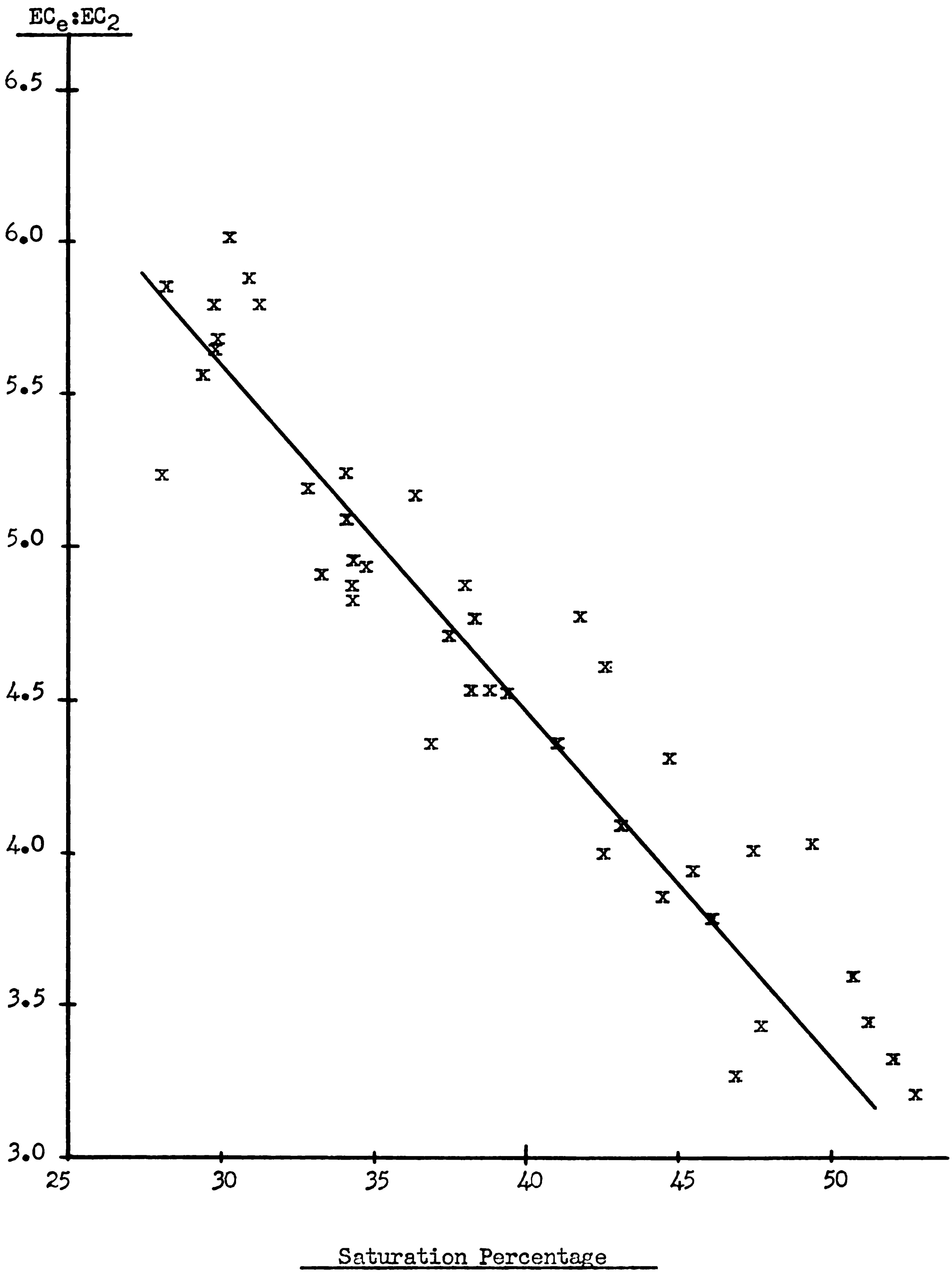


FIGURE 2

Electrical Conductivity versus Equivalent Concentration expressed as Milli-equivalents per Liter for Magnesium Carbonate, Calcium Carbonate, Calcium Sulfate, Magnesium Sulfate, Sodium Carbonate, Potassium Chloride, Sodium Chloride, Sodium Nitrate, Potassium, Sulfate, and Potassium Nitrate.

FIGURE 2

Conductivity of Equivalent Solutions

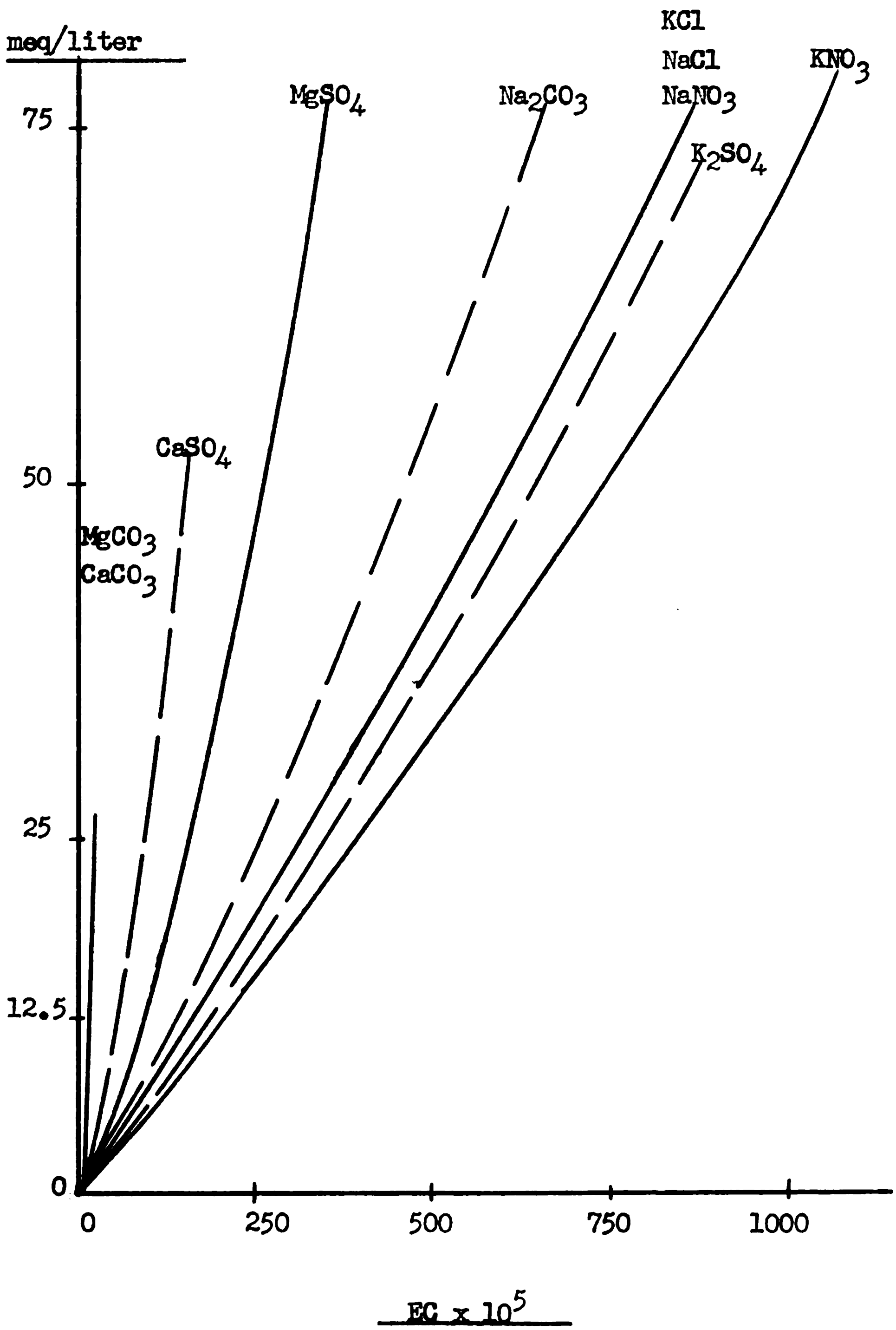


FIGURE 3

Graph of Saturation Percentage versus the Ratio of the Conductivity of the Saturated Extract to the Conductivity of the 1:2 Extract for Soil Samples in which the Principle Salt is Magnesium Sulfate. The same Line as that in Figure 1 is drawn for Comparison with this Data.

FIGURE 3

Magnesium Sulfate

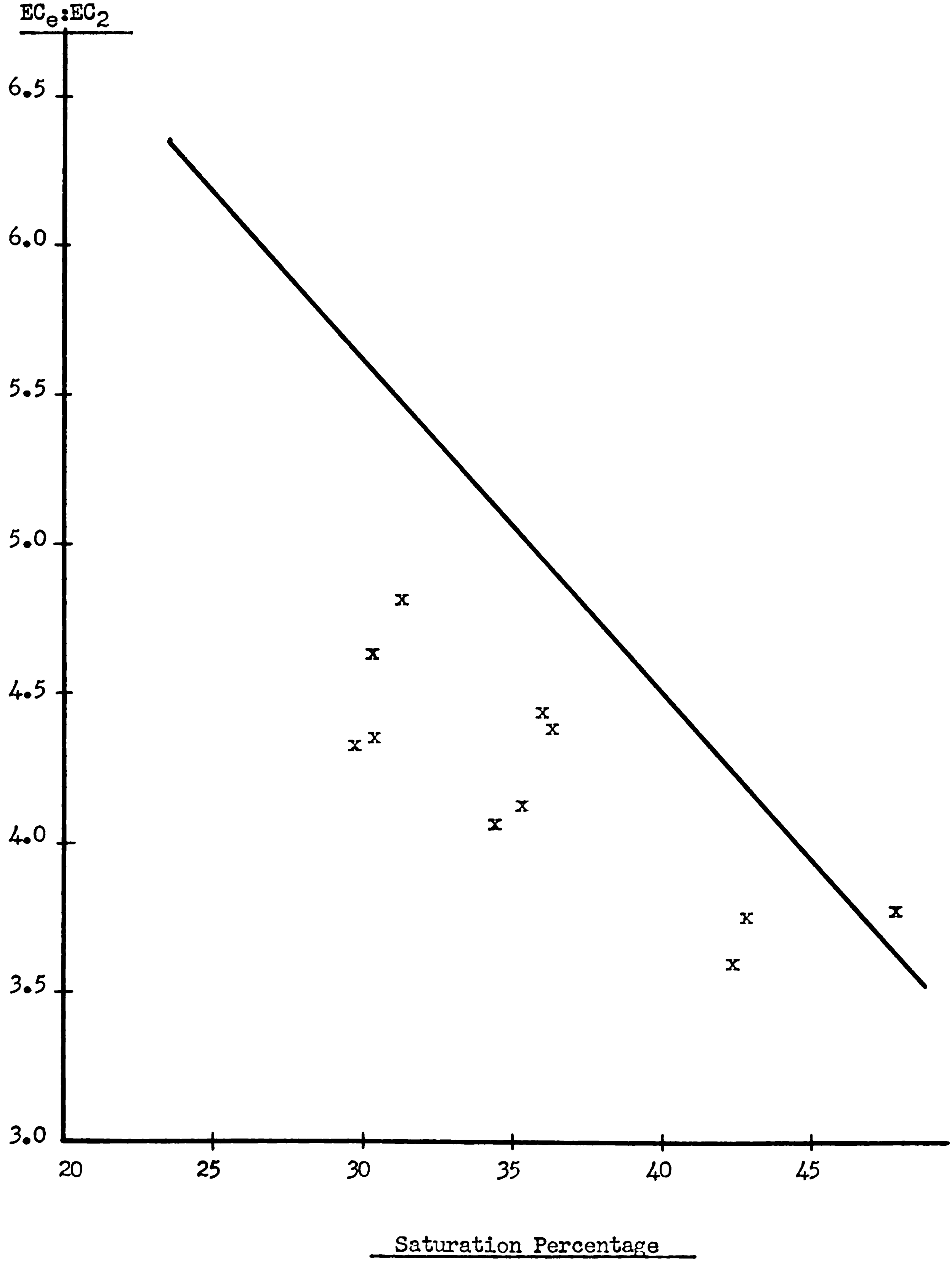
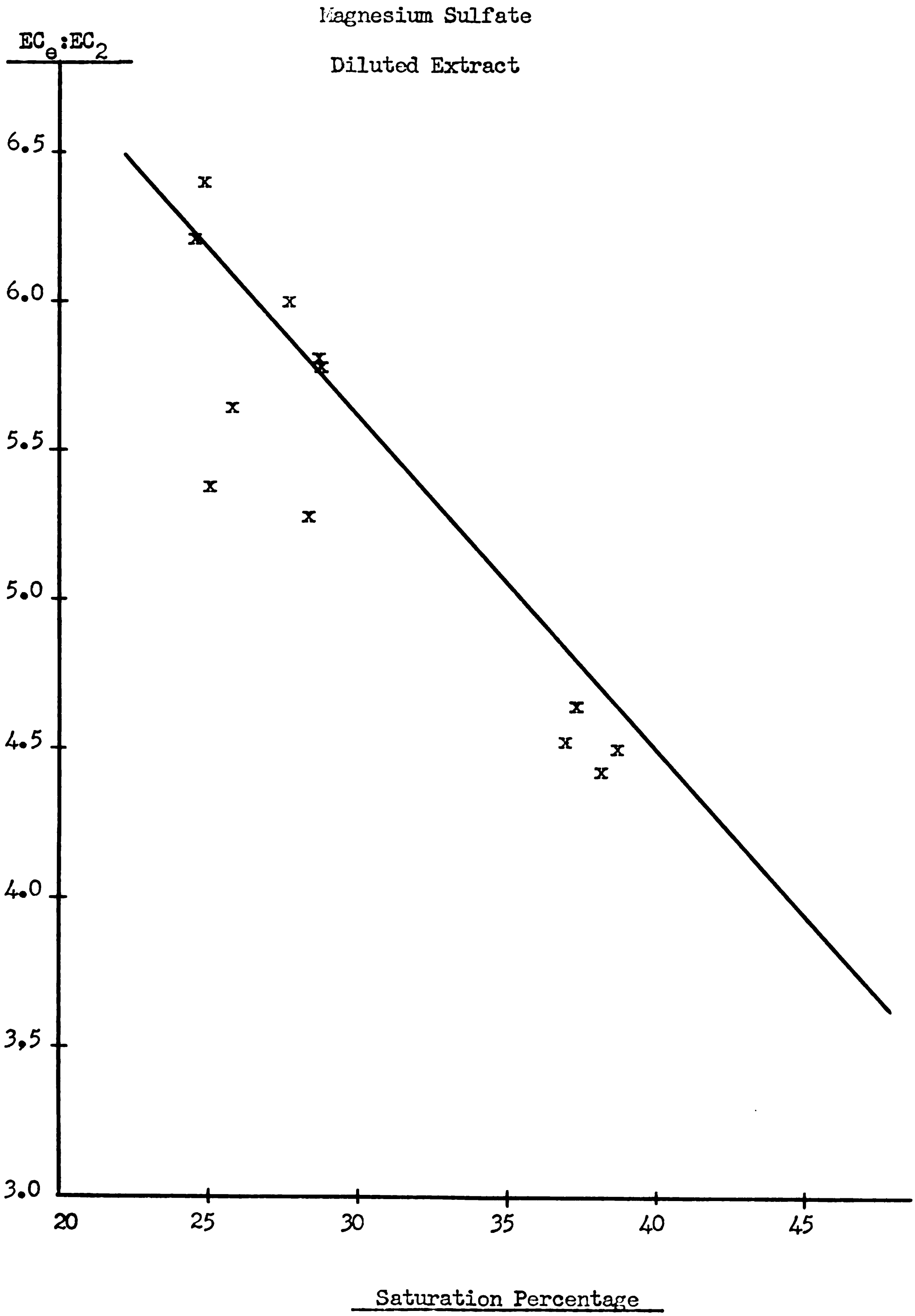


FIGURE 4

Graph of the Saturation Percentage versus the Ratio of the Conductivity of the Saturated Paste Extract to the Conductivity of the 1:2 Extract for Soil Samples in which the Principle Salt is Magnesium Sulfate. The Saturated Paste Extract in this Case was diluted to One-fourth Concentration before its Conductivity was measured. The same Line as that in Figure 1 is drawn for Comparison with this Data.

FIGURE 4


Magnesium Sulfate
Diluted Extract
EC_e:EC_2
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
20
25
30
35
40
45
Saturation Percentage

Series of solutions were prepared using these c. p. grade salts: KNO_3, $NaCl$, $NaNO_3$, K_2SO_4, Na_2CO_3, KCl, $MgSO_4$, $CaSO_4$, $MgCO_3$, $CaCO_3$. Electrical conductivity measurements of equivalent solution concentrations of 0.075 N, 0.050 N, 0.025 N, and 0.0125 N were made using the same Solubridge as used in all the soil tests. The results of this study are shown in the graph in Figure 2. Solution normality is plotted on the ordinate, and EC x 10^5 on the abscissa.

In studying this graph, we note differences in the conductivities of the different salts at equivalent strength as well as differences in the slopes of the curves. Differences characterized by displacements of the curves are reflected in the accuracy of estimating solution concentration from conductivity. Differences in the slopes of the curves are reflected as differences in ratios of conductivities at different concentrations for the different salts.

By using magnesium sulfate to raise the salinity of the soils under study, the effect of the latter difference on the ratio EC_e:EC_2 could be determined. Twelve samples were treated in the same manner as in previous analyses. The results of these determinations are shown in Figure 3. This graph is plotted in the same way as that of Figure 2, and the same line established in the first graph is drawn here, so the difference from using magnesium sulfate is clearly seen.

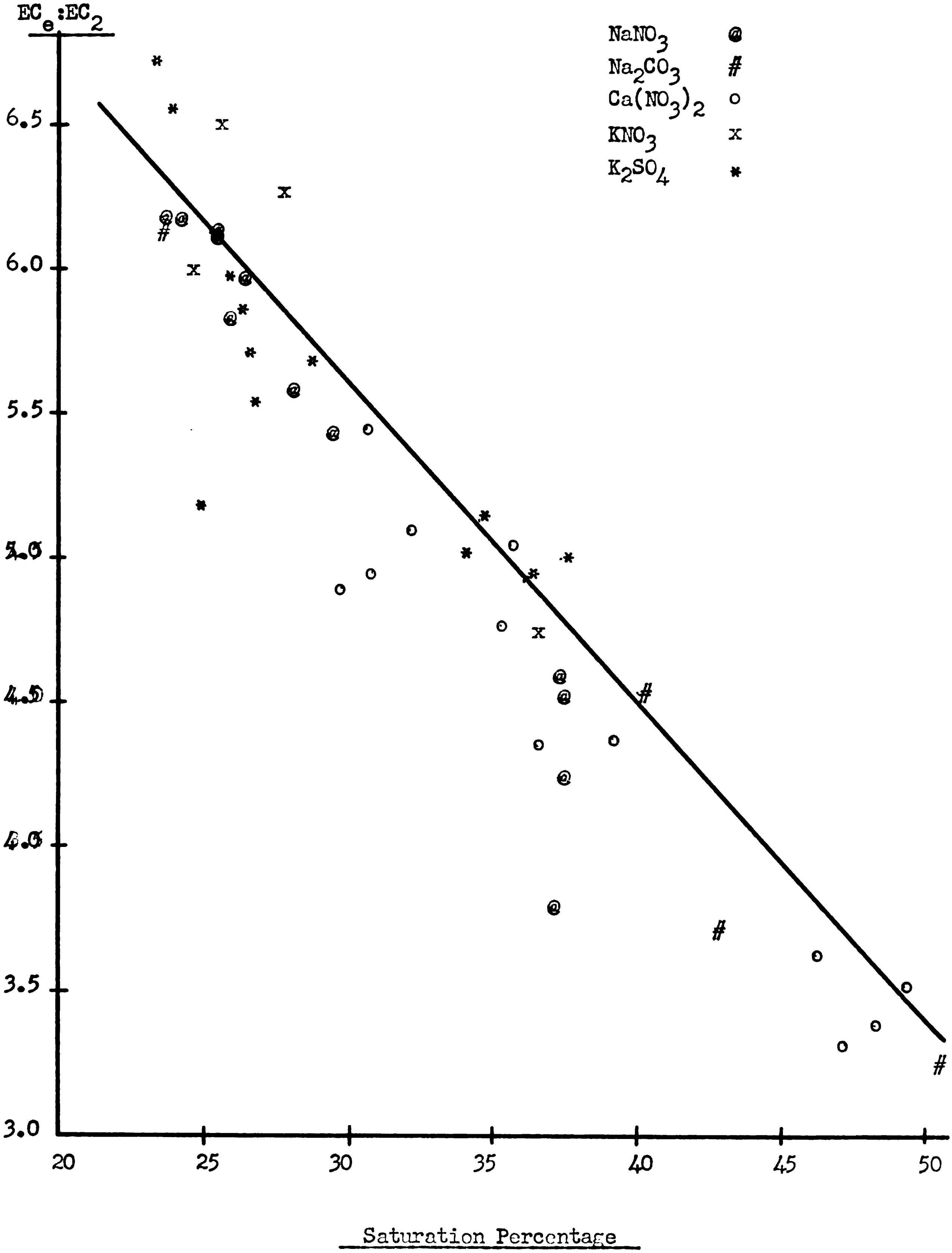
The question next considered was whether this difference in relationship would tend to disappear if the extract obtained from the saturated paste were diluted to be about approximate to the concentration of the 1:2 extract before measuring the conductivity, which measurement would then be multiplied by the appropriate factor. Again twelve samples were treated and extracts obtained. The extract from the saturated paste was diluted to one-fourth concentration.

FIGURE 5

Graph of the Saturation Percentage versus the Ratio of the Conductivity of the Saturated Paste Extract to the Conductivity of the 1:2 Extract for Soil Samples in which the Principle Salt was one of the Following, as indicated by Symbols: Sodium Nitrate, Sodium Carbonate, Calcium Nitrate, Potassium Nitrate, or Potassium Sulfate. The same Line as that in Figure 1 is drawn for Comparison with this Data.

FIGURE 5

Five Salts



The conductivity of the diluted saturated extract was then very nearly the same as that of the 1:2 extract. By multiplying this value by four, the saturated extract conductivity was determined. The ratio EC_e:EC_2 obtained from this method is plotted against the saturation percentage in Figure 4. Again, the original straight line is drawn.

Other salts were also used to raise the salinity of the soil samples. They were $Ca(NO_3)_2$, KNO_3, Na_2CO_3, $NaNO_3$, and K_2SO_4. The relationship of EC_e:EC_2 to saturation percentage for these salts is shown in Figure 5. The original straight line is again drawn for comparison.

Greenhouse soils were collected from greenhouses in various locations in the state. Conductivities and saturation percentages for these soils are shown in Table II. The location of the greenhouse from which the sample was taken is also indicated. No salt additions were made to these samples before the measurements were made. Some of the soil samples came from benches in which crops were growing; while some came from soil stock piles. The graph in Figure 6 indicates the relationship found to exist for these soils. The original straight line is again shown.

Figure 7 is a compilation of all the data shown separately before, except those obtained by diluting the extracts from samples treated with magnesium sulfate. The correlation coefficient for this data is -0.918, which is significant at the 1% level, and the regression coefficient of saturation percentage on ratio is -8.14.

TABLE II

MICHIGAN GREENHOUSE SOILS COLLECTED

SAMPLE NUMBER	GREENHOUSE	LOCATION	SATURATION PERCENTAGE	$EC_e:EC_2$
A	Allen	Blissfield	52.7	3.48
B	Tecumseh	Tecumseh	51.8	3.32
C	Harkness	Adrian	42.7	4.44
D	Furnival	Jackson	43.3	4.02
E	Furnival	Jackson	25.3	6.14
F	Beckwich	Jackson	55.4	3.33
G	Becks	Jackson	102.3	1.93
H	Smith	Lansing	79.8	2.73
I	Smith	Lansing	52.7	2.78
J	Plant Science	East Lansing	30.4	4.91
K	Plant Science	East Lansing	48.2	2.81
L	Plant Science	East Lansing	64.8	3.20

FIGURE 6

Graph of the Saturation Percentage versus the Ratio of the Conductivity of the Saturated Paste Extract to the Conductivity of the 1:2 Extract for Some Michigan Greenhouse Soils to which no Salts were added. The Letter designates the Soil Sample as listed in Table II. The same Line as that in Figure 1 is drawn for Comparison with this Data.

FIGURE 6

Michigan Soils

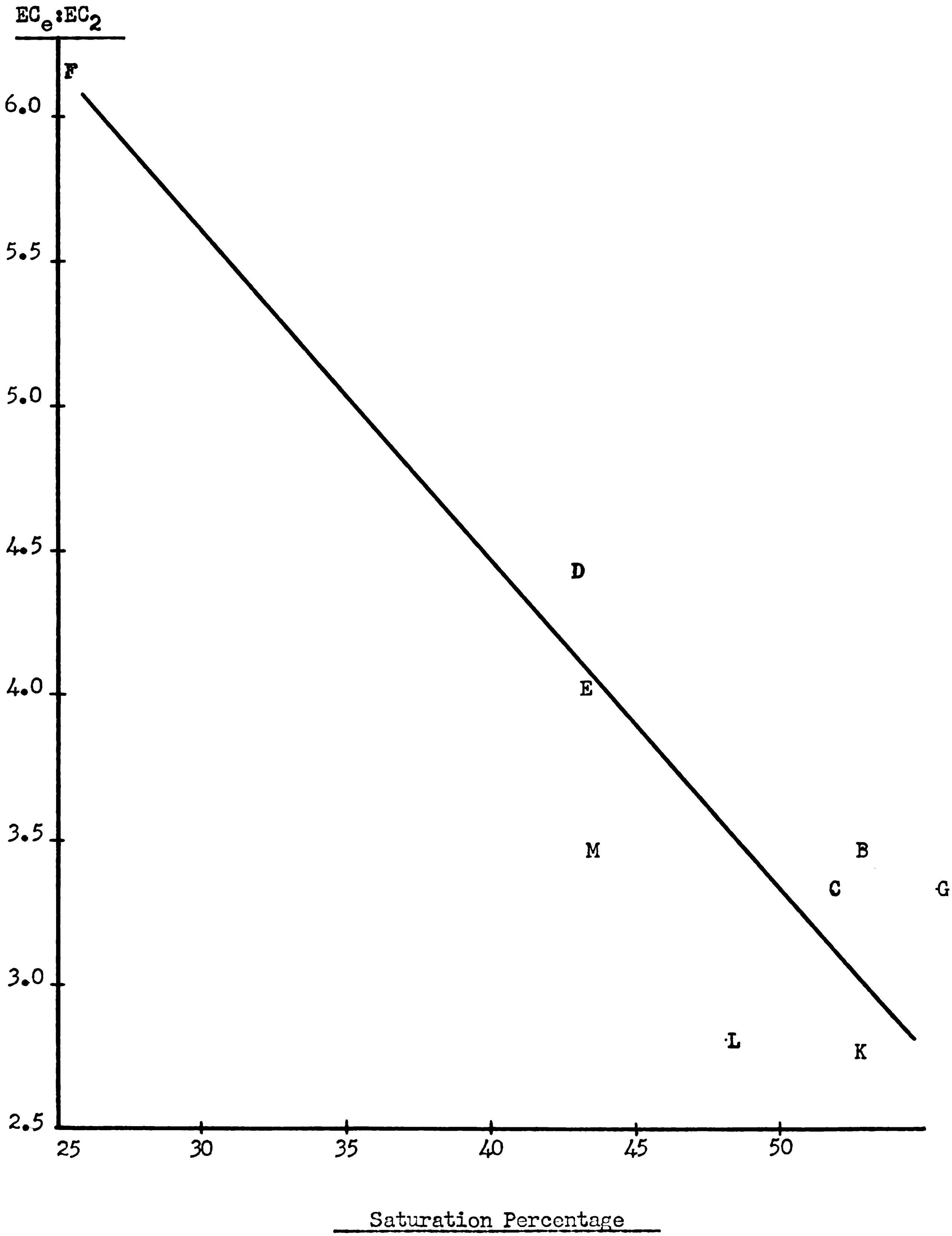
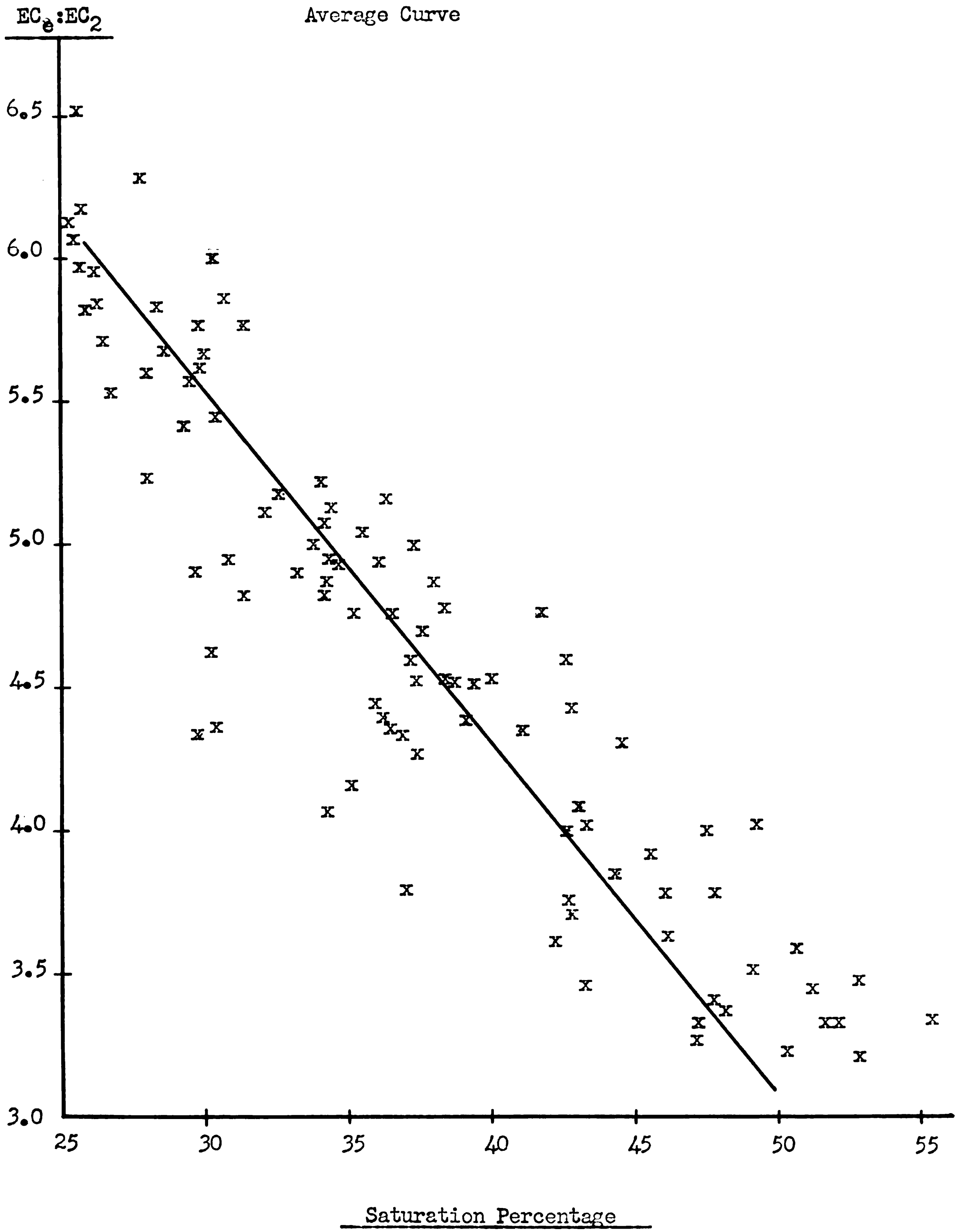


FIGURE 7

Graph of the Saturation Percentage versus the Ratio of the Conductivity of the Saturated Paste Extract to the Conductivity of the 1:2 Extract for All Soil Samples shown in Previous Graphs except those in Figure 4. The Line drawn is the Best-Fit Line for the Compiled Data.

FIGURE 7



$EC_e:EC_2$
Average Curve
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
25
30
35
40
45
50
55
Saturation Percentage

DISCUSSION

A close relationship was found to exist between the ratio $EC_e:EC_2$ and the saturation percentage over a range of saturation percentages from 25 to 50 percent, when the salts involved were KCl, KNO_3, NaCl, $Ca(NO_3)_2$, or Na_2CO_3. The difference in degree of ionization and ion mobility of these salts did not appear to be great enough at the concentrations studied to have an adverse effect on this relationship.

The range of concentration studied here lies between 12.5 and 75 milli-equivalents per liter. This range of concentration corresponds to conductivities between 150 x 10^{-5} and 1000 x 10^{-5} mho/cm, which includes the critical range for almost any greenhouse crop grown in Michigan. Conductivities of less than 145 x 10^{-5} mho/cm indicate that no salinity problem exists. On the other hand, readings above 1000 x 10^{-5} mho/cm would almost certainly indicate that a salinity problem does exist.

Magnesium sulfate was studied as an example of a salt with a divalent cation and a divalent anion. It was found that the same relationship did not hold for it as did for the other salts mentioned. The reason appeared to be due to the difference in degree of ionization of this salt as contrasted to that of the other salts (43% contrasted to 86% and 72% at 0.1 normal). When the extracts from soils containing high amounts of this salt were diluted to one-fourth concentration before measuring the conductivity, the difference in the relationships essentially disappeared. The recommended procedure for measuring conductivity of the saturated extract does not, however, include the diluting of the extract before measuring its conductivity (16). This fact limits our ability to change our procedure to improve the usefulness of the average curve in Figure 7.

This limitation imposed on the use of the 1:2 extract method is of minor importance in view of the limitation imposed on the conductivity method as a whole when used to estimate soluble salts content of soils. We do not expect one salt to predominate in a greenhouse soil except in cases where a grower might have recently applied large amounts of one fertilizer salt to correct a particular nutritional problem. The average curve that is given on page 12 of USDA Agriculture Handbook #60 (16) is based on soils containing several different salts. This curve is recommended for use in estimating concentration of soluble salts from the conductivity of the saturated extract. That curve closely corresponds to the sodium carbonate curve in Figure 2 on page 18 of this paper. We see from Figure 2 that if the salts of divalent ions predominate in the solution, the estimate of salt concentration from the conductivity of the solution will be lower than the actual concentration if we use the average curve for this estimate. Conversely, if the salts with monovalent ions predominate, the estimate based on the average curve would be higher than the actual concentration. On the other hand, if the soil solution contains equivalent quantities of both classes of salts, the estimate based on the average curve would be the actual concentration. The authors of Handbook #60 point out that soils containing high amounts of calcium sulfate or magnesium sulfate had higher concentration than the conductivity would indicate from the average line in their graph.

An interesting aspect of the observations that can be made here is that the dilution involved in making the 1:2 extract and then multiplying the conductivity of the extract by a factor constant for all salts affects the divalent-ion salts more strongly than it does the monovalent-ion salts. The ratio of conductivity at 0.05 normal to the conductivity at 0.025 normal is almost 2 (1.9) for the monovalent-ion salts, but it is only 1.7 for the divalent-ion salts. This difference when multiplied by a conductivity of 200 to 600 will be quite noticeable. From this point of view, we might conclude that the 1:2 extract method has an advantage over the saturated extract method in accuracy in evaluating saline conditions.

The results of studying the greenhouse soils collected indicates that where a mixture of salts exist, the relationship of $EC_e:EC_2$ to saturation percentage holds over a rather wide range of saturation percentage. The range in saturation percentage was a little wider for these soils than for the soil mixtures prepared for these studies. It was found that some growers use unmanipulated natural soils ranging in texture from sandy loams to clay loams with high organic content. Some growers add manure to the natural soils before using them in the greenhouse. Some add sand and/or peat to them. The surprising aspect of the difference between these soils and the ones prepared was that many of the soils in use had higher water-holding capacity, while none had lower than that of the artificial soils studied. This was true because of the tendency to add peat or manure to loams or clay loams without adding sand.

GREENHOUSE EXPERIMENT

MATERIALS AND METHODS

To test the relationship of EC_e to EC_2 in terms of plant response, an experiment using Chrysanthemum moriflorum, variety Indianapolis White, was performed. Twelve-inch clay pots were steam sterilized and lines with 1.5 mil polyethylene. Drainage was provided through sphagnum moss and the drainage hole in the bottom of the pots. A soil mixture of two parts Brookston Clay Loam, one part coarse sand, and one part German peat moss was prepared and steam sterilized. Fertilizer salts of the proportions and quantities needed for each treatment, as specified below, were mixed with the soil before filling the pots.

The treatments employed were patterned after those used by Kofranek, Lunt, and Hart (26). A base solution was prepared which contained the following proportions of ions expressed as milli-equivalent per liter: 4 K, 8 NO_3, 2 Mg, 2 SO_4, 6 Ca, 2 H_2PO_4(see Appendix — Table A). The conductivity of the base solution was 180 x 10^{-5} mho/cm. This concentration was found to be optimum for response of C. moriflorum, var. Bronze Kramer in the experiments by Kofranek, et al.

Five treatments were established with seven replications of each. A random block design was devised using a table of random numbers to assign each pot a position in one of three rows in the bench in the greenhouse. Four of the treatments were provided with a wick watering system to insure uniform, adequate water level. One treatment was watered by hand method. The wick watering system was devised using a fiberglass wick in a polyethylene sheath. Five inches of wick was exposed from the sheath at each end. One end was plunged in moist peat moss buried just below the surface of the soil. The wick was passed over the side of the pot, and the lower end was placed in a trough of water running along the center of the bench.

The treatments were based on the concentration of the base solution. Treatment "A" received the base solution with conductivity 180 x 10^{-5} mho/cm. Treatment "B" received a solution of two times the concentration of the base solution (360 x 10^{-5} mho/cm). Treatment "C" received the same solution as "B", but differed by being hand-watered. Treatment "D" received a solution which contained the concentration of the base solution plus potassium chloride to raise the conductivity to 400 x 10^{-5} mho/cm. Treatment "E" received a solution which contained the concentration of the base solution plus potassium sulfate to raise the conductivity to 440 x 10^{-5} mho/cm.

The conductivities indicated would be that of the soil solution at saturation. The equivalent conductivity of the 1:2 extract was found by determining the saturation percentage of the soil mixture and referring to the curve established by laboratory examinations. The saturation percentage was found to be forty-five percent. This corresponds to a factor of four in the curve. The conductivity of the 1:2 extract for each treatment, then, would be: "A" — 45; "B" and "C" — 90; "D" — 100; and "E" — 110.

The 1:2 extract method was used to check the salt levels initially. At frequent intervals thereafter, samples were drawn and similar determinations made. Whenever the salt level was found to deviate from that desired, it was adjusted by drenching the soil with solutions of the appropriate concentrations.

The experiment was initiated on August 6, 1959, when three uniform, rooted cuttings of the chrysanthemum were planted in each pot. Uniformity was judged on the basis of length, stem diameter, internode length, and leaf size and color. At the time of planting, the tip of each cutting was removed to leave five nodes. As the plants grew, they were staked to keep the stems in a vertical position. They were allowed to develop and flower under the normal photoperiod of the season. All branches arising from lateral buds of the primary stem were allowed to develop. When the buds were set, disbudding was performed so that only the terminal bud was left to develop into the flower.

The first flowers were fully open on October 30. The flower was removed when it was fully open and white to the center. In removing the flower, the entire stem was removed by breaking it from the main stem. Fresh weight, stem length to the top of the bloom, and flower diameter were measured immediately. The flowers were then placed in water in a storage room of 40% relative humidity and a temperature of 50° F, which conditions were maintained continuously throughout the storage period. A suitable room at 70° F, which is the usual temperature for such tests, was not available. Bloom life was considered terminated at the time of first wilting of the outer petals. At that time a sample of stem with leaves was removed from the last true leaf downward for a length of five inches. This sample of stem was dried and dry weight per unit length determined.

RESULTS

On August 26, the first soil samples were taken and the conductivity of the 1:2 extract determined. Samples were taken from the upper two inches and the lower two inches of one replicate of each treatment. Results of these determinations are shown in Table III. The difference in concentrations of salts at different levels was great enough to require redistribution. A liter of solution appropriate to the treatment was poured onto the surface of the soil in each pot. Excess water began to drain from the bottom after the first liter was allowed to penetrate. Immediately a second liter of solution was applied, and a little more than one liter of displaced soil solution drained out. The applied solution was poured on all at once so percolation would maintain a practically horizontal saturation front through the uniformly moist soil. This application, then, was considered to be effective in exchanging solution of desired salinity for that existing in the soil.

Conductivity determinations made on August 31, three days after drenching with solution, indicated that the soil solution had been effectively displaced by the desired solution and that the salt concentration was again uniformly distributed throughout the soil mass of each pot. These determinations are presented in Table III.

At the end of another twenty-day period, September 21, the soil was again tested for conductivity. The plants by this time had begun to grow at a fast rate and the amount of salts removed by them was considerably greater than what had been anticipated, as indicated in Table IV.

From this time following, checks were made of conductivity at more frequent intervals. Dates of sampling were: October 1, October 6, October 14,

TABLE III

$EC_2 \times 10^5$ FOR TREATMENTS

AUGUST 26, 1959

TREATMENT	EC_2	TOP:BOTTOM RATIO	MID-RANGE
A - Top	57	0.95	59
A - Bottom	60		
B - Top	60	0.63	78
B - Bottom	95		
C - Top	78	0.56	104
C - Bottom	140		
D - Top	88	0.65	111
D - Bottom	135		
E - Top	50	1.72	40
E - Bottom	29		

AUGUST 31, 1959

TREATMENT	EC_2	TOP:BOTTOM RATIO	MID-RANGE
A - Top	40	1.03	40
A - Bottom	39		
B - Top	68	0.91	71
B - Bottom	75		
C - Top	85	0.88	86
C - Bottom	87		
D - Top	125	1.25	112
D - Bottom	100		
E - Top	107	0.89	114
E - Bottom	120		

TABLE IV

EC_2 x 10 FOR TREATMENTS

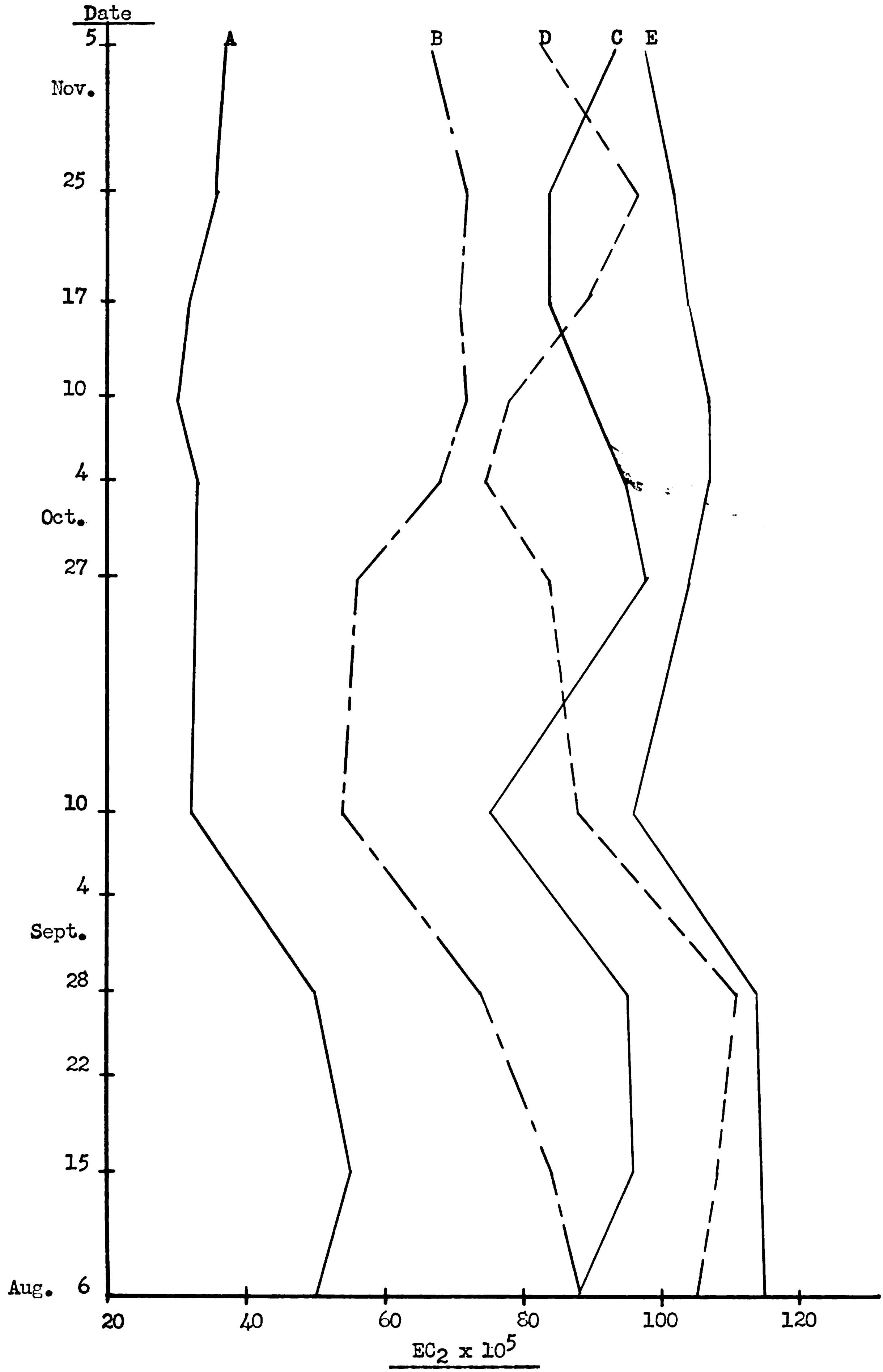
SEPTEMBER 21, 1959

TREATMENT	EC_2	TOP:BOTTOM RATIO	MID-RANGE
A - Top	27	1.35	24
A - Bottom	20		
B - Top	35	0.92	37
B - Bottom	38		
C - Top	44	0.54	63
C - Bottom	82		
D - Top	80	1.74	77
D - Bottom	46		
E - Top	88	1.35	77
E - Bottom	65		

FIGURE 8

Graph of the Conductivity of the 1:2 Extract versus the Date for the Soluble Salts Treatments used in the Greenhouse Experiment.

FIGURE 8 — Treatment Levels



October 19, October 23, October 27, October 30, November 2, and November 9. At each determination deviation from the desired level was sufficient to warrant application of fresh solution. The graph in Figure 8 shows the variations in salinity that occurred during the course of the experiment. Points plotted in this graph are median conductivity between that of the applied solution on the day of application and that of the soil extract at the end of the period before the next application. These median conductivity values are plotted on the abscissa of the graph. The dates of the mid-point of each period are plotted on the ordinate.

The graph indicates that an effective salinity level somewhat lower than that desired for each treatment was maintained over most of the growing period. Treatment "A" was at EC_2 of 35; "B" was approximately 70; "C" was very close to 90; "D" varied widely around 90; and "E" was maintained at about 105.

The contrast between "B" and "C", which were receiving identical solutions but with "C" hand-watered, indicates that the plants were able to take up large amounts of salts when water was always at an adequate level.

The fact that "E" was more easily maintained at the high level desired for it might be due to the possibility that sulfates were not taken up at the high rate that would have been necessary to deplete the content in the soil. This effect, however, might have been due to another factor. It is possible that potassium sulfate was introduced as a colloidal suspension in the drench solutions. It was observed that those solutions containing that salt were always turbid. If this turbidity were due to suspensions of undissolved and non-dissociated particles of potassium sulfate, that fact would not have been detected when the solution was checked with the solubridge before applying it. That excess could have dissolved and dissociated in the soil solution in time and thereby have maintained a high level in solution as increments were taken up by the plant.

As stated before, blooms were harvested during the period October 30 to November 9. Fresh weight, stem length, and flower diameter were measured immediately. The bloom life was determined as the blooms were stored at 50° F and 40% relative humidity. Finally, sections of stems with leaves were taken and dry weights determined. These measurements were taken only on those blooms judged to be of marketable quality on the basis of flower size and development (over four inches diameter and fully double to the center) and stem strength (sufficiently strong to support the bloom on a straight stem). Thus a count of the number of marketable blooms produced by each pot was also obtained. The total number of flowering stems produced by each plant was practically constant at four, so twelve was the maximum number of blooms possible for each pot.

The results of these measurements are presented in Table V. The significant contrasts for means found by using the "q" test are presented in Table VI.

When the plants were removed from the pots at the termination of the experiment, root growth was seen to be excellent, the roots being well distributed throughout the soil masses.

TABLE V

RESPONSE OF PLANTS UNDER FIVE CONDITIONS OF SALINITY

TREATMENT		CRITERIA MEANS			
NO.	EC_2	Fresh Weight (gm)	Dry Wt/ Length (gm/5")	Fresh Wt/ Length* (gm/5")	Dry Wt Percent** (%)
A	35	49.0	0.98	14.2	6.9
B	70	59.5	1.18	16.2	7.3
C	90	39.3	1.02	12.9	7.9
D	90	53.1	0.99	15.8	6.3
E	105	44.5	0.94	14.2	6.6

NO.	EC_2	Stem Length (in)	Flower Diameter (in)	Cut Life (day)	Number of Flowers (no)
A	35	17.3	4.69	11.8	7.7
B	70	18.4	4.90	9.4	8.9
C	90	15.2	4.46	4.8	6.1
D	90	16.3	4.77	7.2	8.4
E	105	15.7	4.69	7.4	7.4

* approximated from mean total fresh weight including flower

** approximated from mean wt/5" and mean dry wt/5"

TABLE VI

SIMULTANEOUS SIGNIFICANT CONTRASTS AT THE 5% LEVEL*

CRITERIA TESTED**

Fresh Weight	Dry Wt Length	Stem Length	Flower Diameter	Cut Life	Number of Flowers
B — A					
B — C		B — C	B — C	B — C	B — C
B — E	B — E	B — E			
D — C				A — C	
				A — D	
				A — E	

* using "q" contrasts for simultaneous tests

** The larger mean precedes the smaller mean.

DISCUSSION

Treatment "B" resulted in optimum response by all criteria of testing except bloom life, though it was not significantly greater than treatment "A" at the 5% level in any criterion except fresh weight.

Plant response under the relatively high salinity of EC_2 70, which is equivalent to 280 x 10^{-5} mho/cm by the saturation extract method, is seen to be quite good in conditions where water supply is continuously favorable. The effect of constant watering is very well illustrated by comparing response of treatment "C" and "D" (both at EC_2 90) with "B". Although the differences between "C" and "D" are not significant at the 5% level, the difference is great enough that in all criteria tested "B" responded significantly better than "C", but in no case did "B" respond significantly better than "D". It is believed that hand watering was frequent enough to maintain adequate water level without adversely affecting aeration. When approximate measurements of moisture were made with a Moisture Comparator probe, distributed by George J. Ball, Inc., West Chicago, Illinois, no differences were detected. Furthermore, at no point was water stress observed to be great enough to cause wilting.

From these considerations one would conclude that the moisture level is critical in evaluating salinity effects. This conclusion has two-fold implication. First, in research, attempts should be made to maintain uniform moisture at known levels, and these levels should be reported. The rate and degree of drying of the soil mass between waterings should be taken into consideration whenever fluctuations occur. Second, in evaluating salinity conditions for greenhouse growers, soil testing centers should take into account the expected rate of drying of the soil in use under the conditions the grower provides, as well as the water-holding capacity of the soil.

Plant responses measured were essentially equal between plants grown under treatment "C" and "E". Since "B" and "E" were both wick-watered, the contrasts between these treatments are the most meaningful. We see from Table V that fresh weight, dry weight per unit length, stem length, and bloom life were significantly higher in "B" than in "E".

The most interesting aspect of response to salinity was brought out in the measurements of cut flower keeping quality. In this criterion, the most contrasts at a significant level were observed, and this was the only criterion wherein response was directly and inversely proportional to salinity.

Flowers produced under the treatment with the lowest soluble salt content, "A", had the longest cut life. This was significantly longer than that for flowers from "C", "D", and "E". The flowers from "B" were not of significantly shorter life than those from "A", and were of significantly longer life than those from "C". The very low keeping quality of flowers from "C" (hand-watered) suggests the possibility of interaction between water level and soluble salts level.

The mechanism by which salinity affects keeping quality is not understood, and the observations made here were not of a nature to shed new light on the subject. It is usually thought that plants growing under high nutrition, high water, and warm temperature produce succulent growth which is weak and of poor keeping quality. The flowers in this case which had the poorest keeping quality were not, however, from plants of weak, succulent growth. On the contrary, the plants growing under treatment "C" were quite woody, and those under "E" appeared to be more woody than those from the lowest two levels of salinity. Dry weight percentage could be used as an index of succulence. Since no direct data was taken which gives dry weight percentage, an indirect method was used to arrive at a close approximation of this value for each treatment. The mean fresh weight for each treatment was multiplied by five inches and this product divided by the mean stem length. This gave a value which is approximately the fresh weight of a mean five inch sample of stem. A certain amount of error is introduced by including the fresh weight of the bloom, but this error is less than if the weight of the bloom were removed from the fresh weight of the total stem by subtracting a constant mean weight of bloom, and the variation in bloom weight is unknown. To determine the estimate of dry weight percentage, the mean dry weight of a five inch sample was divided by the mean fresh weight of a five inch sample. The values thus obtained are shown in Table V. (It cannot be said that any differences in dry weight percentages are significant, since variances are not known.)

It is interesting to consider these data in their relation to keeping quality to see what trends might be suggested. With the first three treatments dry weight percentage increases, while bloom life decreases. However, the last two treatments, which had flowers of reduced keeping quality, had dry weight percentages which were lower than that for the treatment of optimum keeping quality. Therefore, it certainly cannot be said from these observations that the factor of keeping quality has a simple relationship to dry weight percentage.

SUMMARY

The ratio of the conductivity of the saturated paste extract to the conductivity of the one:two extract was studied in twelve artificial soils typical of those used in Michigan greenhouses. Various salts were used to raise salinity of the soil samples to levels of conductivity of the saturated paste lying between 145×10^{-5} and 1440×10^{-5} mho/cm. The ratios obtained were correlated to the saturation percentage of the soil samples. A close correlation was found for several monovalent-ion salts (potassium chloride, potassium nitrate, and sodium nitrate). This correlation also held for the salts with one ion monovalent and the other divalent that were studied (potassium sulfate, calcium nitrate, and sodium carbonate). Magnesium sulfate, a salt with both ions divalent, did not give the same correlation unless the saturated paste extract was diluted to one-fourth concentration before measuring its conductivity.

Some greenhouse soils taken from greenhouses in various locations in the state were also studied. No salts were added to these soils. The ratio $EC_e:EC_2$ was correlated to the saturation percentage in these soils.

An average curve was obtained from the compiled data of all these studies.

A greenhouse experiment to verify this correlation curve was conducted using Chrysanthemum moriflorum, variety Indianapolis White, grown at five conditions of salinity. Plant response measured in fresh weight, dry weight per unit length, stem length, and cut life of the flowers was found to be higher in plants grown at EC_2 70 as contrasted to those grown at EC_2 105 using a wick watering system. These conductivities corresponded to EC_e 280×10^{-5} and 420×10^{-5} mho/cm, respectively. A treatment at EC_2 90 (360×10^{-5} of EC_e) and hand watered was reduced in fresh weight, stem length,

cut life, number of marketable blooms, and bloom diameter contrasted to the optimum treatment. This treatment corresponded to that used by Kofranek, Lunt, and Hart (26), which was of the lowest salts level causing a reduction in plant response.

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APPENDIX - TABLE A

Salts Content of Greenhouse Treatments

Treatment	Gross Constituents	EC x 10^5
A	Base Solution Salts	180
B	Base Solution Salts x 2	360
C	Base Solution Salts x 2	360
D	Base Solution Salts plus KCl	400
E	Base Solution Salts plus K_2SO_4	440

Treatment	Salts Concentration (gm/l)					
	KNO_3	$MgSO_4$	$Ca(NO_3)_2$	KH_2PO_4	KCl	K_2SO_4
A	0.34	0.20	0.83	0.46	—	—
B	0.68	0.40	1.66	0.92	—	—
C	0.68	0.40	1.66	0.92	—	—
D	0.34	0.20	0.83	0.46	9.75	—
E	0.34	0.20	0.83	0.46	—	13.50

APPENDIX - TABLE B

Replicate Means of Fresh Weights

Replicate	Treatment				
	A	B	C	D	E
1.	53.9	68.0	48.2	56.7	34.0
2.	59.5	59.5	45.4	62.4	59.5
3.	51.0	62.4	34.0	51.0	42.5
4.	45.4	56.7	36.9	51.0	36.8
5.	36.9	48.2	34.0	45.4	45.4
6.	48.2	51.0	42.5	48.2	45.4
7.	48.2	70.9	34.0	56.7	48.2
TOTALS	343.1	416.7	275.0	371.4	311.8
MEANS	49.0	59.5	39.3	53.1	44.5

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	1690.56	4	422.64	$F = 10.19$
Within	1243.95	30	41.46	$F_{95}(4,30) = 2.69$
Total	2934.51	34		

APPENDIX - TABLE C

Replicate Means of Dry Weight/Length

Replicate	Treatment A	B	C	D	E
1.	1.07	1.25	1.02	0.91	0.88
2.	1.16	1.07	1.13	0.93	1.04
3.	0.96	1.11	0.91	0.92	0.77
4.	1.02	1.16	1.18	0.90	0.83
5.	0.81	1.03	0.78	0.91	0.98
6.	0.91	1.20	1.09	1.02	1.19
7.	0.95	1.43	1.00	1.32	0.87
Totals	6.88	8.25	7.11	6.96	6.56
Means	0.98	1.18	1.02	0.99	0.94

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	0.23	4	0.058	$F = 3.05$
Within	0.56	30	0.019	$F_{95}(4,30) = 2.69$
Total	0.79	34		

APPENDIX - TABLE D

Replicate Means of Stem Length

Replicate	Treatment A	B	C	D	E
1.	18.2	21.0	17.7	16.6	14.3
2.	17.5	18.9	17.6	16.9	18.3
3.	18.6	16.1	14.0	16.1	16.5
4.	14.4	17.9	14.3	16.0	14.3
5.	16.4	17.9	14.4	15.5	15.4
6.	17.7	17.6	13.4	16.1	15.0
7.	18.3	19.6	15.4	16.9	16.4
Totals	121.0	129.0	106.8	114.1	110.2
Means	17.3	18.4	15.2	16.3	15.7

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	45.09	4	11.27	$F = 5.63$
Within	60.14	30	2.00	$F_{95}(4,30) = 2.69$
Total	105.23	34		

APPENDIX - TABLE E

Replicate Means of Flower Diameter

Replicate	Treatment				
	A	B	C	D	E
1.	4.7	4.9	4.6	4.7	4.7
2.	4.9	4.9	4.5	4.9	5.0
3.	4.6	4.8	4.5	4.4	4.3
4.	4.7	5.0	4.3	4.9	4.8
5.	4.5	4.9	4.3	5.1	4.4
6.	4.7	5.0	4.3	4.7	4.9
7.	4.7	5.0	4.3	4.7	4.7
Totals	32.8	34.3	31.2	33.4	32.8
Means	4.69	4.90	4.46	4.77	4.69

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	0.73	4	0.182	$F = 5.64$
Within	0.97	30	0.0323	$F_{95}(4,30) = 2.69$
Total	1.70	34		

APPENDIX - TABLE F

Replicate Means of Cut Life

Replicate	Treatment A	B	C	D	E
1.	13.4	7.3	2.8	5.3	7.5
2.	8.5	9.2	2.8	5.8	5.2
3.	13.4	11.3	3.5	8.9	7.7
4.	9.2	12.0	5.0	8.2	9.5
5.	11.0	9.0	6.0	10.6	6.6
6.	14.4	11.1	8.4	6.5	6.8
7.	12.9	6.1	5.0	5.4	8.9
Totals	82.8	66.0	33.5	50.7	52.2
Means	11.8	9.4	4.8	7.2	7.4

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	194.52	4	48.63	$F = 12.37$
Within	121.61	30	4.04	$F_{95}(4,30) = 2.69$
Total	316.13	34		

APPENDIX - TABLE G

Replicate Means of Number of Marketable Blooms

Replicate	Treatment				
	A	B	C	D	E
1.	8	10	6	7	8
2.	5	10	6	6	5
3.	8	9	5	8	9
4.	8	8	7	9	7
5.	8	9	5	10	9
6.	8	10	8	9	6
7.	9	6	6	10	8
Totals	54	62	43	59	52
Means	7.71	8.87	6.14	8.43	7.43

Analysis of Variance

	Sum of Squares	df	Mean Squares	F Ratios
Means	30.57	4	7.64	$F = 4.06$
Within	56.57	30	1.88	$F_{95}(4,30) = 2.69$
Total	87.14	34		