THE APPLICATION OF MITSCHERLICH'S GROWTH LAW AND POT METHOD OF SOIL TESTING TO NUTRITIONAL STUDIES WITH RASPBERRIES AND OATS

by

Bruce Anderson Dickson

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THE APPLICATION OF MITSCHERLICH'S GROWTH LAW AND POT METHOD OF SOIL TESTING TO NUTRITIONAL STUDIES WITH RASPBERRIES AND OATS

Introduction

The importance of determining the manurial requirements of soils and the interpretation of these determinations in terms of probable plant yields, has long been recognized by agriculturists. A method which purports to form a new approach to this problem and which has enjoyed considerable popularity in Europe for the past thirty years, has been proposed by E. A. Mitscherlich (8) of Konigsberg, Germany. Although Mitscherlich published his first papers on his plant method of soil testing in 1909, they recieved little attention in the English language publications until 1932 when Stewart, of the Imperial Bureau of Soil Science, published a literature review of the subject (13). Since then, however, Capo (4), Hartung (5), Macy (6), Magistad (7), and Willcox 9 (15), all of North America, have made contributions on the Mitscherlich method.

The Mitscherlich method for soil fertility investigations is essentially the study of the trend of the yields from a series of plants grown to maturity under a systematic scheme of fertilization. Mitscherlich is so convinced of the validity of his method that he claims, and offers proof(9), that he has derived a general yield law which is amenable to mathematical treatment. He also claims that when specially designed experiments are considered in the light of his yield law, a quantitative relationship between soil fertility and plant yield may be found.

Recognizing the impotance of these claims, it was decided to test the validity of the Mitscherlich method and to ascertain, thereby, whether an application of it would be of value in supplimenting the rapid chemical methods (10) (12) of estimating soil fertility now in popular use in British Columbia. It was decided also to investigate whether the use of the Mitscherlich method with different agricultural plant types would suggest an improved technique for plant nutrition experiments.

With this purpose in view, two experiments were undertaken. The first, during the summer of 1940, was an experiment in the nitrogen nutrition of Cuthbert raspberries, and the second, during the season of 1941-1942, was an experiment with oats, where the method was used in conjunction with the rapid chemical soil test methods.

Review of the Mitscherlich Growth Law

Many of the early workers in the field of plant nutrition such as Leibig, Hellreigal, and Wagner, began experimentation by studying the effect of varying the application of a single nutrient from an ample level down to a zero application, at the same time keeping all other known growth factors at an ample level. Although some of these men obtained excellent results (9), the full mathematical possibilities of their yield curves were not pointed out until Mitscherlich recognized the similarity in the shape of these growth curves and postulated that if the experiments were done under specified conditions, a general equation could be written which would apply to all of them. Mitscherlich studied these growth curves, as well as those obtained from his own experiments, and concluded that the yield was a logarithmic function of a growth factor, when that factor was increased in unit increments from zero, all other growth factors being supplied at an ample level(9).

Expressed in symbols, his relation is represented by,

$$\frac{dy}{dx} \propto (A-y)$$

Which states briefly that the increment of yield, dy, obtained per unit increment of growth factor, dx, is proportional to the decrement from the maximum (i.e. proportional to the difference between the yield obtained, y, and the maximum possible yield of the series, A).

In order to equate these quantities, the right hand side is multiplied by the needed numeral, which may be known as a proportionality constant, or effect factor, c.

$$\frac{dy}{dx} = c(A-y) \qquad \text{- - - - - - -} \quad \text{(I)}$$

When integrated and transformed this equation becomes

$$\log(A-y) = \log A - c.x \qquad \text{- - - - - - -} \quad \text{(II)}$$

or, solving for y:

$$y = A(1 - 10^{-cx}) \quad - - - - - \quad (III)$$

This is a general equation which has already been fitted to many natural phenomena. Stewart (13) points out that this logarithmic equation is identical with the equation applied to the velocity of reaction of a monomolecular chemical change at constant temperature, such as the decomposition of hydrogen peroxide in aqueous solution. It is also identical with that applied to the rate of radio-active disintegration of metals.

Under some circumstances, it has been found difficult to determine the maximum possible yield, A, of the series experimentally. It can, however, be calculated by simultaneously solving three equations. In order to do this, the increments of growth factor must be deliberately chosen so that $x_2 - x_3 = x_3 - x_2$. The resulting yields may then be applied to the three equations of the form(II), which may take the rearranged form of

$$A = \frac{(y_2)^2 - (y_1)(y_3)}{2(y_2) - (y_1) - (y_3)} \quad --- - - - \quad (IV)$$

where y_1, y_2, and y_3 are the yields obtained from fertilizer treatments x_1, x_2, and x_3 respectively.

Thus, having obtained the experimental yield data, the most probable value for the maximum yield may be calculated and used in subsequent calculations.

In the foregoing equations, the symbol x represents the amount of the growth factor added to the soil. One treatment in the series, however, recieves none of the growth factor in question, so that if a yield is obtained at all in that treatment, it is the result of the amount of the growth factor originally present in the soil. The amount of growth factor is designated by the symbol b. As a result of its presence in all of the pots the whole growth curve is displaced upwards by a given amount. Therefore, in order to complete the meaning of equation (II), the total amount of the growth factor present in the soil is represented by, x + b. The equation now becomes

$$\log(A-y) = \log A - c(x+b) \qquad ------ \qquad (V)$$

Since both b and c are, as yet, unknown quantities in this equation, two such equations must be solved simultaneously, the condensed form of which is

$$c = \frac{\log(A-y_1) - \log(A-y_2)}{x_2 - x_1} \qquad ------ \qquad (VI)$$

The solution of equation (VI) provides us with a number called a proportionality constant, c, which makes it possible to interpret Mitscherlich's yield law as a workable equation. Mitscherlich goes further than this, however, and shows that this number is characteristic of the slope of the yield curve and that this number is always the same for a given growth factor, regardless of the plant used, provided he uses the same size of pot, the same weight of soil, and the same units of measurement in all of the experiments. He, therefore, gives this proportionality constant special significance by calling it an "effect factor of the growth factor" (9).

When the proportionality constant, c, is found by solving equation (VI), then equation (V) may be solved for b, the amount of growth factor originally present in the soil. When rearranged equation (V) becomes

$$b = \frac{\log A - \log(A - y_o)}{c} \qquad \text{------ (VII)}$$

where y_o is the yield obtained when the soil received all of the growth factors except the one concerned in the series.

Having obtained all of the information required for equation (V), the calculation procedure may be reversed and the yields, y, which theoretically should have been obtained in the experiment, may be calculated. This is done purely as a check on the yield law, that is, to see how closely the yield curve obtained resembles a true logarithmic curve of the same slope (same proportionality constant).

Conducting nutrition experiments in this quantitative manner not only affords us a means of evaluating soil fertility in terms of actual weight of growth factors, but it also affords us a means of evaluating it in terms of plant yield. Thus, when the yield is plotted as percent of the maximum, the amount of growth factor required for a 50% yield can quickly be determined. Mitscherlich's law states that the increase in growth per unit of factor is proportional to the decrement from the maximum. From this, it follows that if the amount of fertilizer required for a 50% yield is doubled, it will give an increase of 50% of the decrement, that is, 50% of 50% = 25%, and the yield from the doubled amount will be 75% of the maximum. Baule(2) has proposed that the amount of each nutrient required for a 50% yield be designated as a "food unit" (now known as the Baule unit). Furthermore, it has been found that when half the maximum yield is obtained in one of such a series, the amount of growth factor present is one tenth as high as it is for the maximum. Thus, although four Baule units will theoretically produce a 93.75% yield, it will take more than twice as much (10 Baule units) to raise it to 100%, providing toxic conditions are not reached for the plant species being used.

Mitscherlich's yield law and Baule's proposal for "food unit" evaluation of nutrients are diagramatically represented in Figure 1.

In experiments which illustrate this growth law, it has been generally found (15) that, in sand or soils of low phosphate fixing power, the maximum yield is obtained when the

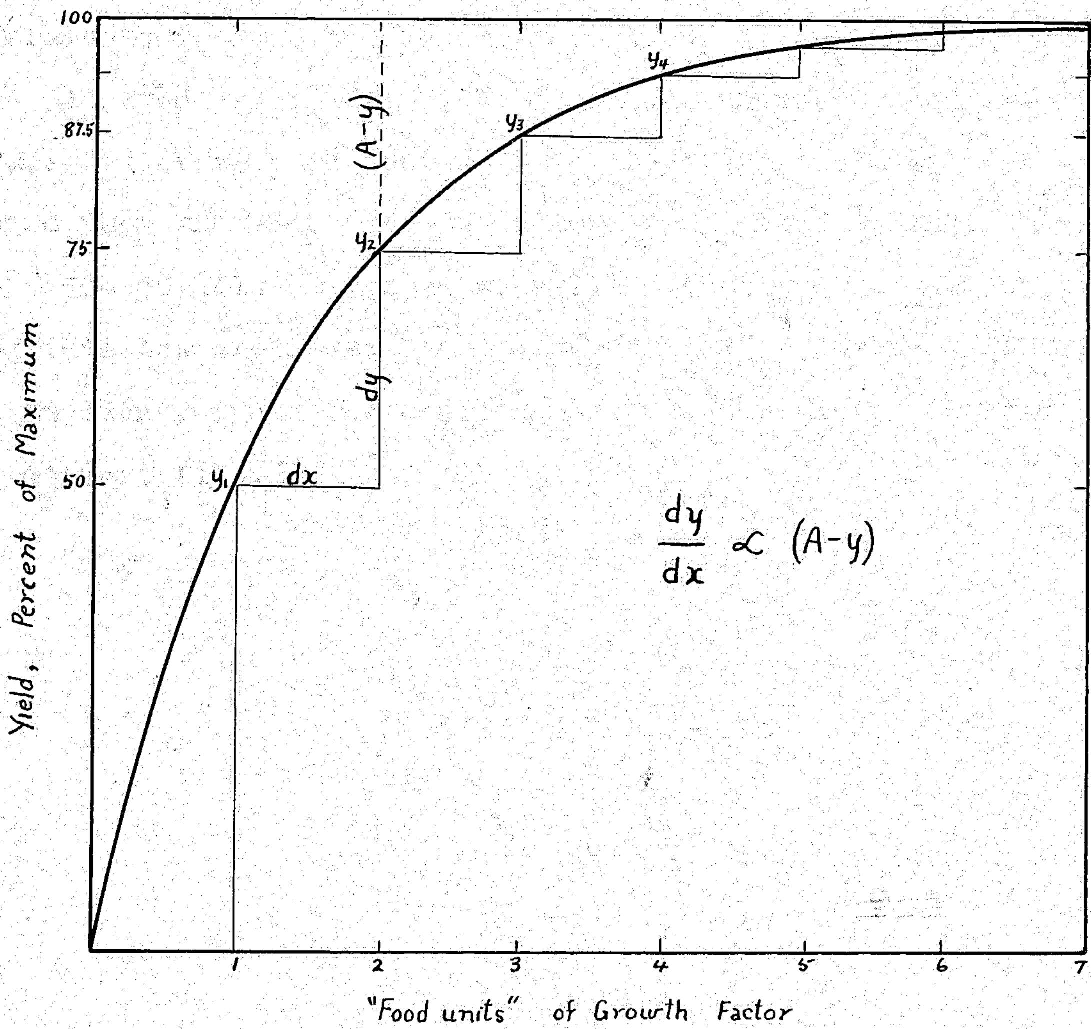


Figure 1. Diagramatic Representation of Mitscherlich's Yield Law and Baule's "food units" of Growth Factor.

three main factors are present in the ratio 5:1:2 ($N:P_2O_5:K_2O$) Thus when the phosphate and the potash are at their maximum values for growth and nitrogen is varied upwards in unit increments from zero, the greatest yield is obtained where the nitrogen is 5 times higher than the phosphate and $2\frac{1}{2}$ times higher than the potash. The same relation has been found when the other growth factors are varied in turn.

The details of the Mitscherlich technique for illustrating this law are given in his own book (8). The most detailed English language account of the procedure is that given by Stewart (13).

Part I

AN EXPERIMENT WITH CUTHBERT RASPBERRIES

Introduction

For several years now one of the major problems of the Fraser Valley of British Columbia has been that concerned with the difficulties met in raspberry growing. Many different phases of the problem have been studied by the personnel of the British Columbia Raspberry Committee (14).

The importance of nitrogen fertilizers is generally recognized by this body. According to Woods (14), results from both the Experimental Farm at Agassiz and the plots at Hatzic, show that only nitrogenous fertilizers are of value, although he could find no consistant correlation between the analysis of soils from "good" and "poor" plantations. Harris (14) has stressed water as being of prime importance and has shown good results with nitrogen and phosphates as nutritional factors in the raspberry problem. The nitrogen nutrition of the raspberry plant, therefore, has been and still is an important part of the raspberry decline problem, and the author felt that the quantitative methods originated by Mitscherlich should be tried as a new approach.

Chemical analysis of the plant material was carried out for the purpose of finding out whether or not the percentage composition and the total nutrient content were in any way correlated with the soil nutrient level and the obtained yield.

Experimental

Materials and Control of Conditions

Twenty-five ten inch clay pots were thoroughly washed and dried. The interiors of these pots were then heated by inverting over an electric hotplate and thoroughly coated (inside only) with melted paraffin (Parawax). The pots were filled with a mixture of washed sand and freshly powdered peat of low fertility value. This mixture was 50-50 by volume (approximately 6100 grams dry sand and 400 grams dried peat per pot). From the apparent specific gravity of this mixture, the acre weight to a depth of six inches was determined as 3,764,000 pounds.

Twenty-five Cuthbert raspberry suckers were selected on the basis of uniformity of size from 300 or more taken from the University field plots. Variations in vigor and growth power were present never-the-less and ultimately caused considerable error in the experiment.

The roots of the plants were washed free of soil and they were then transplanted to the pots on May 18, 1940. The nutrient solutions were administered and the experiment was continued during the summer months until October 11, 1940.

The experiment was set up in a lath-house south of the

University greenhouse, partial shade being given by four-inch planks spaced four inches apart, six feet above the surface of the pots. At times of heavy rainfall a canvas was spread over the top of the lath-house to prevent the flooding of the pots and the consequent overflowing of the drainage pans.

Disease and pest controls were made with lime sulphur and nicotine sprays. The raspberry saw-fly succeeded in causing small injuries to the leaves before they were satisfactorily controlled.

Plan of Experiment

The series of raspberries were supplied with ample amounts of all nutrients including water, except nitrogen, which was varied downward from an ample level to a definitely deficient level.

The ample level was derived from Baule's food unit evaluation of nutrients(15). For example, when 225 pounds of nitrogen are available to an acre of a crop, it will make a 50% yield. Thus, 4 units or 900 pounds nitrogen per acre will give a theoretical yield of 94% in a field trial. The efficiency of the fertilizer, however, is increased (on an area basis) when it is confined to a pot. Therefore, $2\frac{1}{2}$ Baule units of nitrogen (550 pounds per acre) were used as an ample level. The same level was used for the potash but the phosphate application was derived on a 6 Baule unit basis in order to take care of possible fixation in insoluble forms.

In this experiment the nitrogen was the only variable, being supplied at six different levels.

(1)	0.12	gm N per pot
(2)	0.33	"
(3)	0.54	"
(4)	0.67	"
(5)	1.34	"
(6)	2.01	"

These values were chosen such that (2)-(1) = (3)-(2) and (5)-(4) = (6)-(5) in order that the yield values obtained would be applicable to equation (IV) which is

$$A = \frac{(y_2)^2 - (y_1)(y_3)}{2(y_2) - (y_1) - (y_3)}$$

where A is the calculated maximum possible yield and y_1, y_2, and y_3 are the yields obtained either from treatments (1), (2), and (3) or (4), (5), and (6), respectively, expressed in grams dry weight.

The P_2O_5 was supplied in the same amount to all the pots, namely 1.03 gm per pot (1.71 gm monocalcium phosphate). The K_2O was supplied in a similar manner at 0.815 gm per pot (1.62 gm potassium sulphate). The minor elements were supplied to each pot as follows,

$MgSO_4$ ..... 400 mg

$MnSO_4$ ..... 100 mg

$CuSO_4$ ..... 20 mg

$FeSO_4$ ..... 50 mg

H_3BO_3 ..... 4 mg

The experiment was kept well moistened throughout the growth period. The drainage water was returned carefully to its respective pot at each watering so that no nutrients were lost from the system.

The experiment was done in quadruplicate. The single check pot received no fertilizer at all.

Harvest Methods

The lower leaves which showed signs of dropping off during the experiment were harvested from time to time and were kept in labeled bags. On October 11, the rest of the leaves were stripped off. The canes were cut up into small pieces. The roots were so thickly matted that it was found difficult to wash them completely free of sand. Most of it shook free however, when the roots were dry. The material was dried to a constant weight at 75-80°C. Both top weights and root weights were obtained.

Methods of Analysis

The dried plant material from each pot (roots, stems, and leaves) was ground to a coarse meal in a meat grinder. The nitrogen analysis was run in triplicate and two gram samples were used in order to minimize the sampling error. The Kjeldahl method was used (1). Ash solutions were made on five gram samples. The phosphate determinations were made on the ash solution using Tschopp's method as modified for use with the B.D.H. Nesslerizer color discs (3). The potash in the ash solution was determined by the Sherrill centrifuge method (11).

Results of the Raspberry Experiment

The Dry Weight Data

The yields obtained in the experiment are shown in Table 1. The figures are the dry weight of the whole plant (roots, stems, and leaves).

The general trend of increase in yield with increase in nitrogen level was evident in spite of the rather large deviation and lack of conformity with a true logarithmic curve (Figure 2). Since the phosphate and potash were supplied at 1.03 and 0.815 gm per pot respectively, it will also be seen from the table that the yield continued to increase until the nitrogen was twice as high as the phosphate or potash.

By far the most satisfactory growth was obtained in the high nitrogen treatment, where the canes were nearly six feet tall, 5/8 inches thick at the base and supported large healthy leaves. The low end of the series showed definite nitrogen starvation symptoms of small yellow leaves and very spindly canes. It will also be noted from Table 1 that, although the check plant was definitely smaller than that of the lowest nitrogen application, it made sufficient growth to indicate the presence of a small amount of nitrogen in the sand-peat mixture.

Table 1. Total Dry Weight of Raspberry Plants Resulting from Nitrogen Supplied at Different Levels

Nitrogen Applications per pot (gm)	Dry Weight of Plants				
	Replications				Average
Check	-----	-----	-----	-----	36.4
0.12	30.6	93.0	36.2	71.2	57.8
0.33	120.0	103.6	104.9	103.4	107.9
0.54	127.1	90.7	105.8	119.1	110.7
0.67	128.3	63.4	109.6	167.5	117.2
1.34	126.2	138.3	157.9	134.8	139.3
2.01	156.7	204.6	191.3	204.6	189.3

The Maximum Possible Yield

The marked variation in this experiment, as shown in Table 1, makes the use of calculations rather hazardous. However, since the general trend is present, certain of the values obtained may be used as the basis of approximate calculations. The yields which best suit the logarithic curve are 71.2 gm, 103.4 gm, and 127.1 gm. These yields were obtained from pots supplied with nitrogen at 0.12 gm, 0.33 gm, and 0.54 gm respectively. Applying this information to the equation:

$$A = \frac{(103.4)^2 - (71.2)(127.1)}{2(103.4) - (71.2) - (127.1)} = 193.2 \text{ gm}$$

This calculated value for the maximum yield is only four grams higher than the average of the highest yields obtained in the experiment. When one considers the inherent variation in the raspberry suckers, even if carefully selected, these values are in fair agreement.

The Proportionality Constant, c

It is desirable now to compare the obtained yield curve with a true logarithmic curve, in order to estimate the conformity of the experiment to the Mitscherlich yield law. Since the maximum yield, A, and the minimum yield, y_o, (yield from the check pot) are already determined for the true curve, it remains to find which one of the possible logarithmic curves that could fit between these points,best suits the shape of the obtained curve. That is to say, it remains to determine the slope of the curve between the maximum and the minimum. As already pointed out, this slope is determined by the proportionality constant of the

Mitscherlich yield relation and this is found by solving equation (VI). Owing to the great variation in the yields obtained, each set of values applied to the equation resulted in a different value for the proportionality constant. This rendered the use of equation (VI) unsatisfactory. In order to avoid this difficulty, a series of calculations were carried out on a group of numbers between 0.5 and 1.0 until it was found that a proportionality constant of 0.74 resulted in a curve that closely approximated the curve of the obtained yields (Figure 2).

The Fertility of the Sand-peat Mixture

Before proceeding with the calculations for the theoretical yields indicated by the true logarithmic curve, it is necessary to find the initial nitrogen content of the sand-peat mixture. This can be determined by solving for b in equation (VII).

Equation (VII) is $$b = \frac{\log A - \log(A - y_o)}{c}$$

The data are,

$A = 193.2$ gm (the maximum yield)

$y_o = 36.4$ gm (the yield where no nitrogen was added)

$c = 0.74$ (the proportionality constant)

Substituting, $$b = \frac{\log(193.2) - \log(193.2 - 36.4)}{0.74}$$

$$b = 0.12 \text{ gm nitrogen per pot}$$

This is the amount of nitrogen that was originally present in the sand-peat mixture as dtermined by the Mitscherlich method of soil testing.

Calculation of the Yields for a True Logarithmic Curve

Having obtained the above information, the theoretical yields indicated by the true logarithmic curve which has the same slope ($c = 0.74$) as the obtained curve, may now be calculated and plotted in order to see how closely the experiment conforms to the Mitscherlich yield law.

Equation (V) which includes the value for b is used.

$$\log(A-y) = \log A - c(x+b)$$

For example, when $A = 193.2$, $c = 0.74$, $b = 0.12$, $x = 0.12$ and y is the yield which should normally have resulted from it, then

$$\log(193.2 - y) = \log 193.2 - 0.74(0.12 + 0.12)$$
$$y = 67.0 \text{ gm}$$

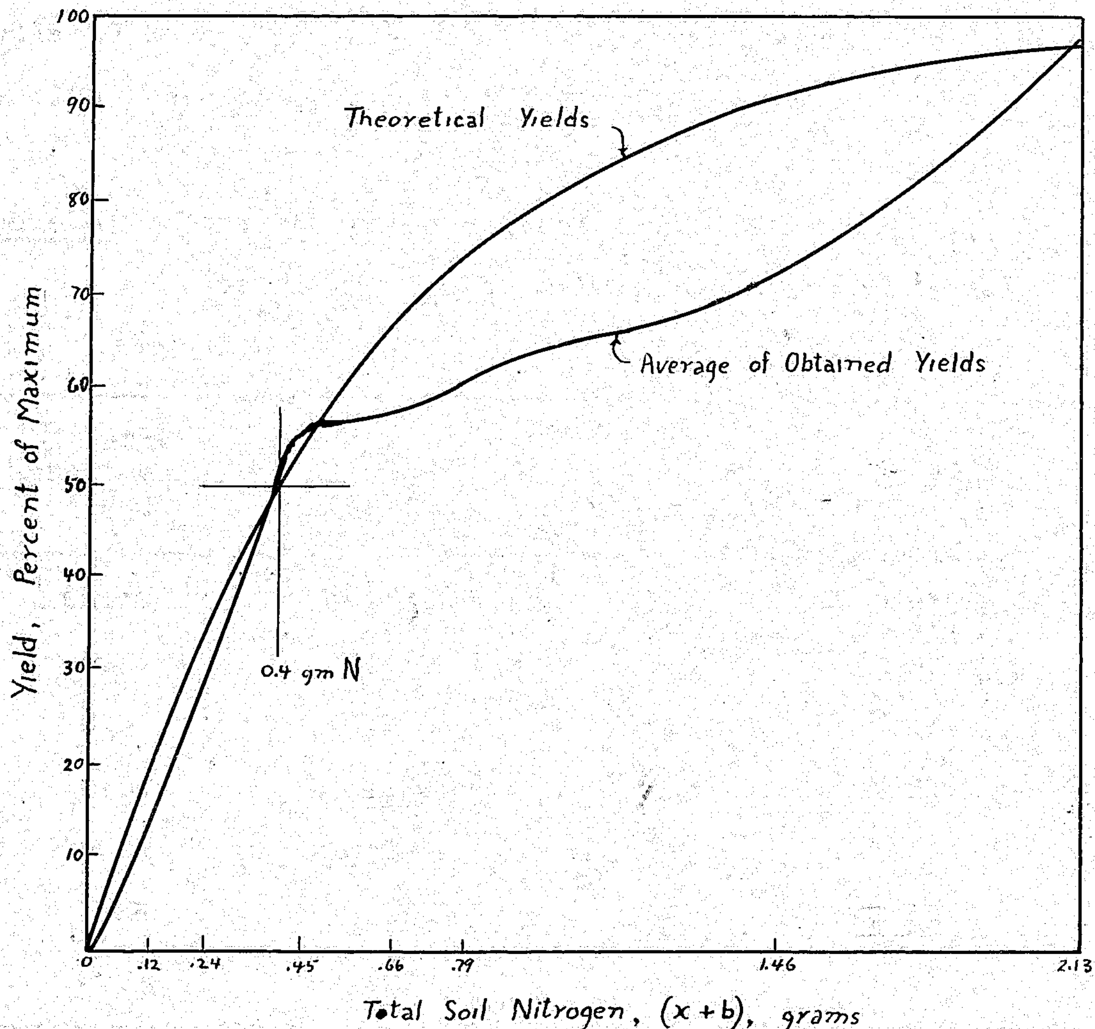
In this manner, all of the yields which theoretically should have been obtained from the seven treatments were calculated. The results are tabulated in Table 2, and are expressed both in grams dry matter and in percent of the maximum yield (193.2 gm).

Table 2. Comparison of Obtained Yields and Theoretical Yields of Raspberry Plants

Nitrogen Applied per pot (gm)	Grams Dry Weight		Percent Maximum	
	Calculated Yields	Obtained Yields	Calculated Yields	Obtained Yields
Check	35.3	36.6	18.3	18.8
0.12	67.0	57.8	34.7	29.9
0.33	103.4	107.9	53.5	55.8
0.54	130.4	110.7	67.5	57.3
0.67	142.9	117.2	74.0	60.7
1.34	177.1	139.3	91.7	72.1
2.01	188.1	189.3	97.4	98.0

From Table 2, and particularly from Figure 2 which contains this data, it is clear that the obtained yield curve follows the general increase expected in a Mitscherlich trial, but it obviously deviates from the logarithmic curve in three of the seven treatments. According to Figure 2, a 50% yield of raspberry plant was obtained when the nitrogen level was 0.4 gm per pot (0.06 gm per kilogram of soil).

In Figure 2, the yield data expressed as percent of the maximum yield is plotted against the total soil nitrogen, (x + b) of each treatment.



<u>Figure 2</u>. The Effect of Varying Nitrogen Levels on the Total Dry Weight of Raspberry Plants Compared with a True Logarithmic Curve

Results of Raspberry Analysis

The results of the analysis are expressed both as total content per raspberry plant and as percentage composition in Tables 3 and 4, respectively. The total content per plant is also represented graphically in Figure 3.

Table 3. Total Nutrient Content per Raspberry Plant. (each figure is an average of four replicates)

Nitrogen Treatment (gm)	Nitrogen (N) (gm)	Phosphate (P_2O_5) (gm)	Potash (K_2O) (gm)
Check	0.232	0.117	0.238
0.12	0.438	0.214	0.565
0.33	0.860	0.417	0.934
0.54	0.895	0.415	0.947
0.67	0.944	0.461	1.022
1.34	1.116	0.541	1.224
2.01	1.752	0.774	1.565

The total absorption curves follow the shape of the yield curve very closely (Figure 3). This was not only true for nitrogen but was also true for phosphate and potash as well. That is, as the nitrogen applications were varied downward to a deficient level not only the yields and their

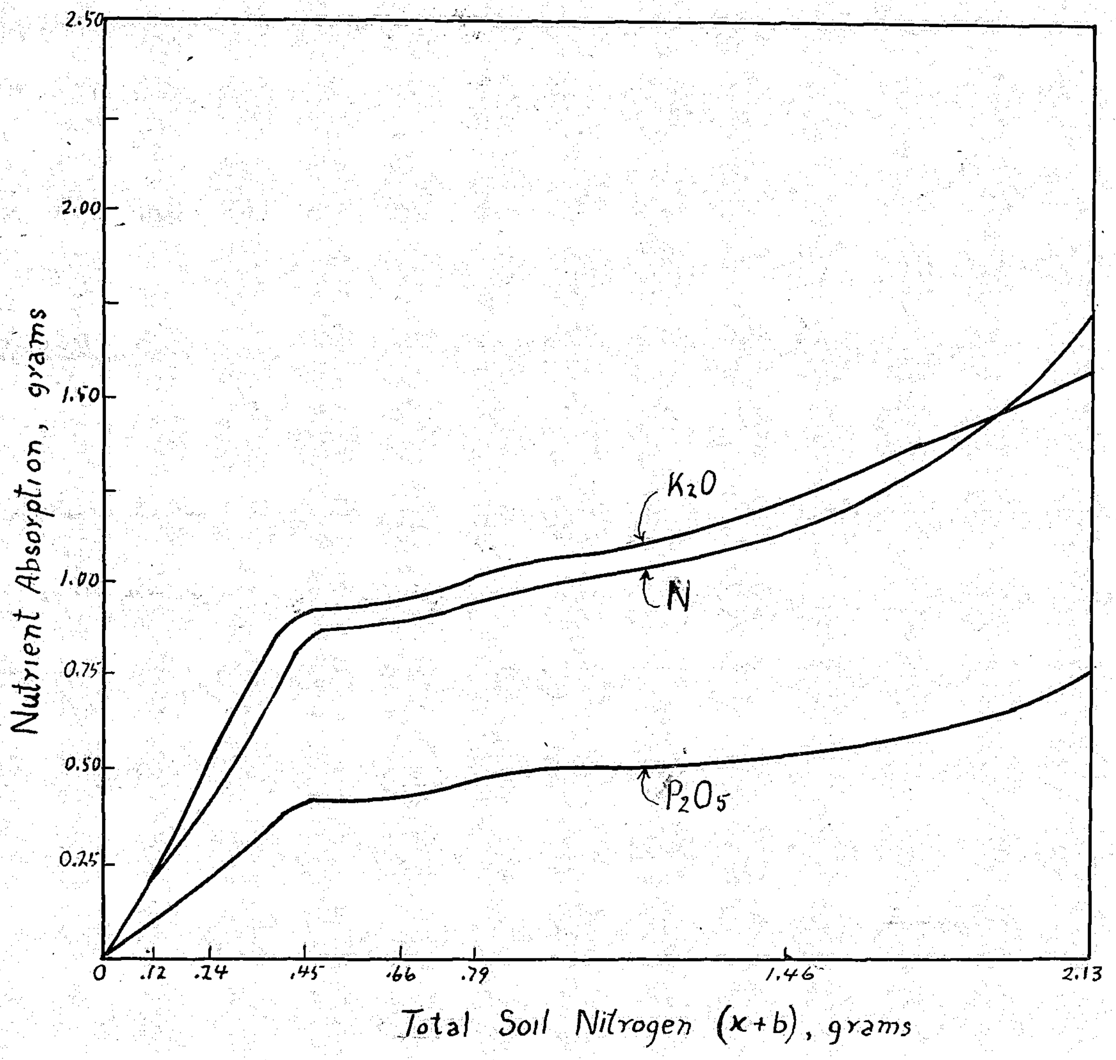


Figure 3. The Effect of Increasing Nitrogen Level on the Total Nutrient Absorption in Raspberry Plants

nitrogen contents, but also their phosphate and potash contents deminished, even though these last were supplied at an ample level in all treatments. The ratio of the absorbed nutrients, therefore remains approximately the same throughout the series at 2:1:2¼. This ratio held in spite of the fact that the nitrogen in the fertilizer applications was varied downward to 1/20 of the highest application.

Table 4. Percentage Composition of Raspberry Plants.
(each figure is an average of four replicates)

Nitrogen Treatment (gm)	Nitrogen (N) (%)	Phosphate (P_2O_5) (%)	Potash (K_2O) (%)
Check	0.60	0.30	0.70
0.12	0.83	0.41	1.05
0.33	0.80	0.39	0.87
0.54	0.80	0.38	0.86
0.67	0.81	0.39	0.93
1.34	0.79	0.39	0.88
2.01	0.92	0.41	0.82

The most noticeable result shown by the analysis data was the lack of any trend in the percentage composition of the plants reflecting the fertilizer treatment which the plants received. That is, regardless of the size of plant or the state of nutrient unbalance (except in the check pot) the percentage composition remained approximately constant.

The percentage composition of the check plant, where phosphate and potash as well as nitrogen were present in limiting amounts, was, however, definitely lower than that of the treated plants (Table 5).

Table 5. Comparison of Percentage Composition of Treated and Untreated Plants

	Composition of 24 Treated Plants, %	Composition of Untreated Plant, %
N	0.8 ± 0.03	0.6
P_2O_5	0.4 ± 0.02	0.3
K_2O	0.9 ± 0.08	0.7

Although it is unfortunate that the check plant was not run in quadruplicate, the difference between its composition and that of the treated plants appears significant.

Conclusions on the Raspberry Experiment

This experiment supplies additional information to the work of Woods and Harris (14) by showing the quantitative effect of increasing the nitrogen fertilization. The nitrogen supply was increased until it was twenty times the amount of nitrogen originally present in the soil. By far the most satisfactory growth was obtained in the high nitrogen treatment, whereas the growth obtained in the low nitrogen pot was quite comparable to poor field plantations, a 50% yield being classed here as definitely poor growth.

The experiment also indicates that there is a definite amount of nitrogen which will give a certain amount of cane growth when the other growth factors, including water, are present in sufficient amounts. For instance, 50% growth is obtained from a sand-peat mixture when nitrogen is present at 0.4 gm per pot. In this experiment, therefore, one "food unit" is 0.4 gm nitrogen per pot. Interpreting this in terms of nitrogen per acre (6" deep), it amounts to 230 pounds(calculated on a soil weight basis), which is in marked agreement with the recognized Baule unit of nitrogen, 225 pounds per acre (15).

From the standpoint of making fertilizer recommendations, the most important information shown is the fact that the best growth was obtained when the nitrogen was two times higher than the phosphate or potash. In preliminary raspberry trials (unpublished) canes were grown successfully in the greenhouse, with good growth and fruiting, when the nitrogen was five times higher than the phosphate and 2½ times higher than the potash.

Although the total amount of absorbed nutrients is proportional to the increase in the yield and therefore to the increase in the soil nutrients, the ratio of the absorbed nutrients bears no relation to the ratio of the same nutrients in the soil. This seems to indicate that the total amounts of the nutrients in the raspberry plant are absorbed in a definite ratio regardless of the state of the nutrient unbalance and size of plant.

The apparent constancy of the percentage composition shown in this work is not in accord with the results of the following experiment with oats, nor with the published data of Mitscherlich, Pfeiffer, Macy, et al, (6).

On the whole the results obtained are sufficiently indicative to warrant the further use of the Mitscherlich method in raspberry nutrition work, especially with an improved technique. One material drawback is the fact that second year growth cannot be measured satisfactorily, that is, it cannot be measured independent of the first year's growth. Strictly speaking, therefore, this method is confined to the first year's growth, except for qualitative observations, such as the deficiency symptoms, incidence of virus disease, dying of buds, and quality of product. Since the raspberries in this experiment were only studied for the first year of growth, observations of this type could not be made.

Part II

AN EXPERIMENT WITH OATS

Introduction

In view of the very moderate success with the raspberry experiment, particularly in regard to the Mitscherlich growth law, a more extensive experiment with oats was designed.

In this experiment, a pear orchard soil from the Experiment Station at Saanichton B.C. was used as the growth medium. The size of pot used was 1/6 the size of that used by Mitscherlich and much smaller and of a different type than that used in the raspberry experiment. Oats were chosen as the plant indicator because the genetic variation in the seed is practically negligable, thus eliminating the greatest source of error that was present in the raspberry experiment. This experiment was run in three series (nitrogen, phosphate, and potash) in order to check the yield law with all three nutrient.

Since rapid chemical soil testing is a very popular method of evaluating soil fertility, special attention was paid in this experiment to a comparison of the rapid chemical tests with the Mitscherlich plant method of soil testing.

The analysis of the plant material, as in the raspberry experiment, was carried out as a check on the yield phenomena and as a study on the relation between soil fertility and nutrient absorption.

Experimental

Apparatus .

Instead of the large enameled metal pot used by Mitscherlich, Capó, Magistad, et al, laquered tin cans of 4" diameter and 4" soil depth were used. Their capacity was one kilogram of screened soil and they had an area of 12.56 square inches or 0.000002 acre. These pots, 44 of them comprising eleven treatments in quadruplicate, were placed in a rack arranged so that small laquered tin cans could be placed under them to act as drainage pans. The pots were provided with a central drainage hole. Wire supports were provided for the plants.

Soil Samples

Soil samples were taken from half an acre of a gravely loam pear orchard soil at the Dominion Experiment Station at Saanichton, B.C. Sixteen samples, amounting to approximately 150 pounds of soil, were taken to a depth of 8 inches with a spade. This was screened in a ¼ inch riddle and, from the weight of screenings, the soil was found to be approximately 20% stones. A sample of soil was kept for analysis. From the apparent specific gravity, the acre weight of this soil was determined as 2 million pounds.

Mixing Procedure

The screened soil was thoroughly mixed in a galvanized iron tub. Eight kilograms of this were weighed out in an enamel basin. The approximate amounts of stock solutions for one of the treatments were then pipetted into the soil, care being taken not to spray it on the sides of the basin. The soil was then thoroughly mixed by hand, making sure all moist lumps were broken up. It was then divided into four equal parts by weight and transferred to the pots which were then labeled as the four replicates of a single treatment. Each of the eleven treatments was mixed in this manner. The bottom 3 to 4 centimeters were tamped down and the top soil left relatively loose. The replicates were staggered on the rack so that none were adjacent.

Plant Material and Stand

Victory oats (S/2, 1940) were treated with Cu_2CO_3 dust. Seeds were selected to a uniform size and were planted to a depth of 1.5 centimeters, 12 in each pot. The soil was moistened with distilled water and covered with a sheet of heavy wax paper until germination was completed. At the second leaf stage (August 9, 1941), they were thinned out to 6 plants per pot, care being taken to remove seeds in the operation (forceps were used).

Watering

When it appeared necessary, the pots were brought as nearly to saturation as possible without overflowing to the drainage pan. If the pots were accidentally flooded, the water was returned from the drainage pans to their respective pots before the next watering. Care was taken to avoid over watering in order to guard against poor airation. Distilled water was used. Watering was discontinued a week before the harvest.

Control of Conditions

The experiment was carried on in a relatively cool greenhouse at the Experiment Station. For the final two weeks it was removed to a warmer house in order to hasten maturity. The plants were dusted several times with sulphur and were sprayed once with nicotine sulphate for the control of aphids. They were also dusted once with a lead arsenate-nicotine dust to control chewing insects.

Feeding Plan and Stock Solutions

The experiment had three series (nitrogen, phosphate, and potash). In each series all growth factors were supplied at an ample level except the variable, which was varied downward in equal increments to a zero application. The ample levels in this experiment were chosen as one Baule unit of each, that is, 225 pounds nitrogen, 45 pounds P_2O_5, and 82 pounds K_2O per acre. The amounts per pot were calculated from this on an area basis. The general plan was as follows:

Table 6 Feeding Plan of Oat Experiment

Series	Pot Number	Nitrogen (gm)	P_2O_5 (gm)	K_2O (gm)
All high	1	0.204	0.039	0.075
	2	0.136	0.039	0.075
N	3	0.068	0.039	0.075
	4	0.000	0.039	0.075
	5	0.204	0.026	0.075
P_2O_5	6	0.204	0.013	0.075
	7	0.204	0.000	0.075
	8	0.204	0.039	0.050
K_2O	9	0.204	0.039	0.025
	10	0.204	0.039	0.000
Check	11	0.000	0.000	0.000

In Table 6 the "all high" pot receives the greatest amount of each of the growth factors and was, therefore, the top pot for each of the series.

The nitrogen was supplied as $(NH_4)_2SO_4$ and $NaNO_3$ in such proportion that half the nitrogen was supplied by each salt. The amounts of the salts used are represented by the following values for the "all high" pot.

Table 7. Salt Weights of the Highest Applications.

Unit	$(NH_4)_2SO_4$	$NaNO_3$	Superphosphate 18%	K_2SO_4
gm per pot	0.48	0.62	0.21	0.14
lbs per acre	530	682	250	150

The nitrogen stock solution was made up by dissolving 17.28 gm $(NH_4)_2SO_4$ and 22.32 gm $NaNO_3$ in water and making it up to 270 ml. Then 30 ml contained 4 units; the amount required for the maximum application for 4 pots (replicates). Thus 20 ml contained enough for the 2/3 unit level for 4 replications, and 10 ml contained enough for the 1/3 unit level for 4 replications.

Using Mitscherlich's procedure for dissolving superphosphate (13), 8.28 gm of it were dissolved and administered as above. In the same manner, 5.04 gm K_2SO_4 were distributed.

Harvest Methods

The height of the tops were measured. The heads were stripped off, the straw cut off at the ground, and the roots were washed clean. Green weights of the straw and grain were obtained. The number of stalks were also counted. The material was dried in an oven at 90°C for 24 hours. Dry weights of roots straw and grain were recorded separately.

The growing period was 127 days from August 3, 1941 to December 7, 1941.

The material was ground to a powder and stored in envelopes for analysis.

Methods of Analysis

The soil samples were analysed by means of the rapid chemical tests of Spurway (12) and Morgan (10). The total phosphate content of the soil was determined by the A.O.A.C. method (1) modified for use with Tschopp's colorimetric method and the B.D.H. standard color discs (3).

The plant material was analysed for total nitrogen, phosphate, and potash. The nitrogen analysis was carried out with the Kjeldahl method (1) using one gram samples. For phosphates, the 0.3 gram samples were digested in perchloric acid, neutralized, and the determination carried out by Tschopp's method as modified for use with the B.D.H. Nesslerizer color discs (3). The potash was determined by the Sherrill method (11) on the ash solutions obtained from one gram samples.

Results of the Oat Experiment

Dry Weight Data

The following tables and graphs are composed of the measurements made on the growth of the plants and indicate the trend of the results which will be discussed in greater detail later. The dry weights given in Table 8 include the weights of the roots, straw, and grain.

Table 8. Total Dry Weight of Oats Resulting from Differential Fertilizing with Nitrogen, Phosphate, and Potash.

Treatment (gm)		Replications				Average
N	--0.204					
P_2O_5	--0.039	11.5	10.6	9.6	10.2	10.5 ± 0.8
K_2O	--0.075					
	0.136	11.6	10.5	11.1	10.1	10.8 ± 0.7
N	0.068	10.6	9.4	10.0	10.0	10.0 ± 0.5
	0.000	4.9	4.6	4.9	4.6	4.75 ± 0.2
	0.026	11.6	11.9	11.6	10.5	11.4 ± 0.3
P_2O_5	0.013	12.4	9.7	10.7	11.5	11.1 ± 1.1
	0.000	11.5	10.9	11.1	11.2	11.2 ± 0.2
	0.050	11.1	10.9	9.8	10.5	10.6 ± 0.6
K_2O	0.025	10.9	10.7	10.6	10.6	10.7 ± 0.1
	0.000	10.7	10.7	10.4	10.2	10.5 ± 0.2
Check	(0-0-0)	4.6	4.5	4.4	4.5	4.5 ± 0.1

Standard deviation $= \sqrt{\frac{\Sigma f d^2}{n-1}}$

The data given in Table 8 are graphically represented in Figures 4, 5, and 6.

All of the measurements made on the oats reflect the same trends as do the total dry weights. For the sake of simplicity, therefore, only total dry weights of the oat plants are reported.

It is noteworthy that the replicates in all treatments agree very closely, having an average standard deviation of 0.4 grams for the eleven treatments. No single treatment shows a standard deviation greater than 1.1 grams (Table 8).

The nitrogen series shows a general increase in yield, indicating a good response to nitrogen fertilization (Table 8 and Figure 4). Both the phosphate and the potash series show no general increase in yield, indicating that there is no positive response to fertilization with these elements (Figures 5 and 6).

The "all high" treatment, which received the greatest amount of each of the growth factors and which was the highest treatment for each of the three series, unfortunately gave a lower yield than was expected, especially in respect to the nitrogen and phosphate series. This appeared to be due to excess nitrogen, judging by the dark green color of the leaves, much branched habit, shorter straw, and low grain formation. It is unlikely, however, that it was due to excess nitrogen alone, because all of the pots in both phosphate and potash series received the same high amount of

The Yield Curves of Oats Resulting from Differential Fertilizing with Nitrogen, Phosphate, and Potash.

Figure 4. Nitrogen Series

Figure 5. Phosphate Series

Figure 6. Potash Series

nitrogen(0.204 gm nitrogen per pot). In spite of this, the phosphate series showed the highest yields in the experiment and neither the phosphate or the potash series showed any excess nitrogen symptoms.

All pots of both the nitrogen and potash series, as well as the high phosphate treatment of the phosphate series, received P_2O_5 at 0.039 grams per pot. However, the remainder of the phosphate series, which all received less than 0.039 grams P_2O_5 per pot including the treatment which received no phosphate, consistantly gave yields that were one gram higher than any other treatment in the experiment.

An important point revealed by the data of Table 8 is the lack of a significant difference between the "no nitrogen" treatment which received phosphate and potash fertilizer, and the check treatment which received no fertilizer at all.

Since the phosphate and potash series showed no measureable response, it was not possible to make calculations on these series. Calculations for the nitrogen series were, however, carried out.

The Maximum Possible Yield

Since the nitrogen curve exhibits a decline at the high end of the series, the calculated value for the maximum yield (10.9 gm) is slightly lower than the highest average yield (11.4 gm). It seemed wise, therefore, to use 11.4 grams as the maximum yield, although it makes little difference to the calculations.

Proportionality Constant

When no nitrogen was added to a pot, a yield of 4.75 gm was obtained. This was the result of an amount of nitrogen, b, which was in the normal soil. The whole yield curve was therefore, displaced upwards by an amount of 4.75 gm. The fertility of the soil is then represented by, x + b, which includes both the original fertility, b, and the known fertilizer, x. This term, it will be remembered, is included in equation (V) which is

$$\log(A - y) = \log A - c(x + b)$$

Since both b and c were, as yet, unknown quantities in this equation, two such equations were solved simultaneously using the condensed form (VI) which is

$$c = \frac{\log(A - y_1) - \log(A - y_2)}{x_2 - x_1}$$

Since A was 11.4, y_1 was 4.75, y_2 was 10.0, x_1 was 0.000, and x_2 was 0.068, then

$$c = \frac{\log(11.4 - 4.75) - \log(11.4 - 10.0)}{0.068 - 0.000}$$

$$c = 10$$

This means that the value of the proportionality constant which is characteristic of the slope of the curve obtained in the nitrogen series of this experiment was 10. Use is made of this number in the following calculations for the soil nitrogen and the yields for a true logarithmic curve.

Soil Nitrogen

The amount of nitrogen already present in the pot was then calculated from equation (VII) where y_0 is the yield obtained when no nitrogen was added to the soil.

$$b = \frac{\log A - \log(A - y_0)}{c}$$

$$b = \frac{\log 11.4 - \log(11.4 - 4.75)}{10}$$

$$b = 0.023 \text{ gm nitrogen per pot}$$

According to the Mitscherlich method, therefore, this soil contained 23 mg nitrogen per kilogram of screened air dry soil.

Calculations of the Yields for a True Logarithmic Curve

It was desirable then to check the validity of the Mitscherlich soil test. This was accomplished by computing a true logarithmic curve between the maximum (11.4 gm) and the minimum (4.75 gm) of the same slope as the obtained yield curve (c = 10). The purpose of this operation was to estimate the accuracy of the experiment by finding how closely the observed curve resembles a true logarithmic curve.

Having determined the value for the maximum yield, A; the soil fertility, b, or x + b as the case may be; and the proportionality constant, c; the theoretical yields for each treatments were then calculated by means of the general equation (V). The results of these calculations are given in Table 9, both in terms of grams dry weight and as percent of the maximum (11.4).

Table 9. Comparison of Observed Yields and Calculated Yields of Oats.

Nitrogen Supplied (gm)	Grams Dry Weight		Percent of Maximum	
	Observed	Calculated	Observed	Calculated
0.204	10.5	11.4	92.1	100.0
0.136	10.8	11.1	94.7	97.3
0.068	10.0	10.0	87.8	87.8
0.000	4.75	4.7	41.7	41.2

The data of Table 9 is represented graphically in Figure 7.

From Table 9 and Figure 7 it may be seen that the observed yields of the nitrogen series follow the shape of a true

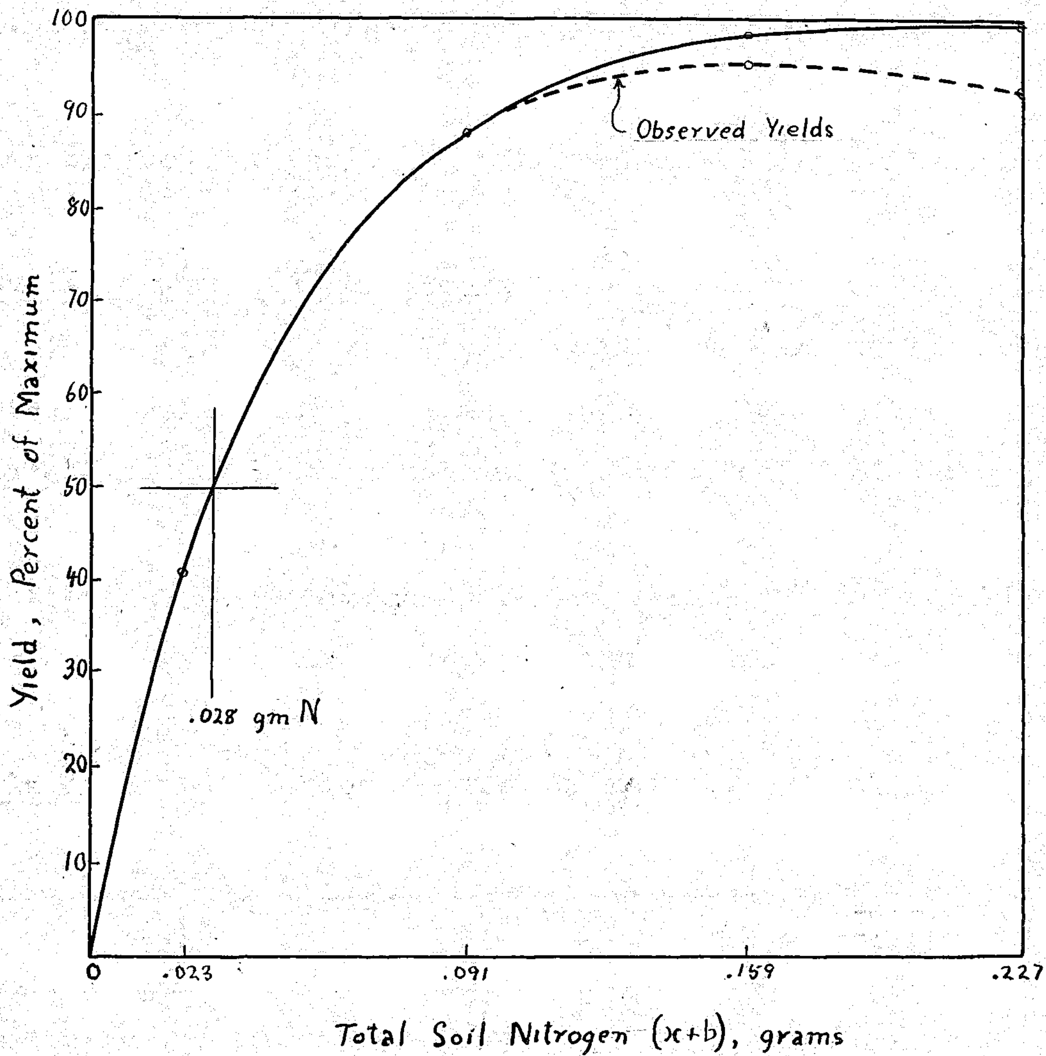


Figure 7. Comparison of the Observed Yield Curve of Oats with a Theoretical Curve

logarithmic curve very closely, excepting for the slight decline at the high end of the series.

From Figure 7, a 50% yield of oats was obtained in this series when the available nitrogen was present in the soil at 28 mg per kilogram, and an 87.8% yield was obtained with 91 mg nitrogen per kilogram of screened air dry soil.

Results of Chemical Soil Tests

The soil sample was first tested with the Spurway method of soil testing (12). In these tests (Table 10), 2.5 gm soil were diluted to 13.5 ml with weak acetic acid extracting solution. The p.p.m. refer to the concentrations in this solution. The amounts per pot were calculated for one kilogram of soil, the amount of soil used in each pot.

Table 10. Spurway Extract Analysis.

Nutrient	p.p.m.	gm per pot
Nitrogen (N)	3	0.016
Phosphate (P_2O_5)	1	0.005
Potash (K_2O)	8	0.042

In view of the results obtained from the Mitscherlich test, it was felt certain that the values for phosphate and potash were far too low. Further analysis was therefore carried out, this time using the strong action of Morgan's sodium acetate-acetic acid mixture (10) as the extracting agent. In these tests (Table 11), 5.5 gm soil were diluted to 13.5 ml (twice as concentrated as the Spurway extract).

Table 11. Morgan Extract Analysis

Nutrition	p.p.m.	gm per pot
Nitrogen (N)	6	0.016
Phosphate (P_2O_5)	2	0.005
Potash (K_2O)	24	0.060

Tables 10 and 11 show a close agreement on a "low" nitrogen content (16 mg per kilogram) and on a low phosphate test (5 mg per kilogram) but they do not agree on the potash test. This was to be expected because the Morgan extracting solution frees potassium from the base exchange complex.

The soil was rather high in available iron (40-50 mg per kilogram) and consequently it had a rather high phosphate fixing power.

The total phosphate content of the soil, estimated by fusion with sodium peroxide, was 2.54 gms P_2O_5 per kilogram.

Results of the Plant Analysis

The results of the analysis of the oat plants is presented in Table 12 in terms of total absorption of nutrients per pot (six oat plants) and is expressed as averages of the four replicates.

Table 12. Analysis of Oats as Total Nutrient Absorption per Pot

(Each figure is the average of four replicates)

Treatment (gm)		Total N (gm)	Total P_2O_5 (gm)	Total K_2O (gm)
All high		0.170	0.047	0.234
	0.136	0.127	0.049	0.223
N	0.068	0.081	0.045	0.228
	0.000	0.027	0.021	0.123
	0.026	0.166	0.051	0.217
P_2O_5	0.013	0.164	0.050	0.240
	0.000	0.163	0.050	0.219
	0.050	0.163	0.048	0.214
K_2O	0.025	0.160	0.048	0.187
	0.000	0.160	0.047	0.197
Check		0.025	0.020	0.126

Total Nutrients Absorbed by Oats when Differentially Fertilized with Nitrogen, Phosphate, and Potash.

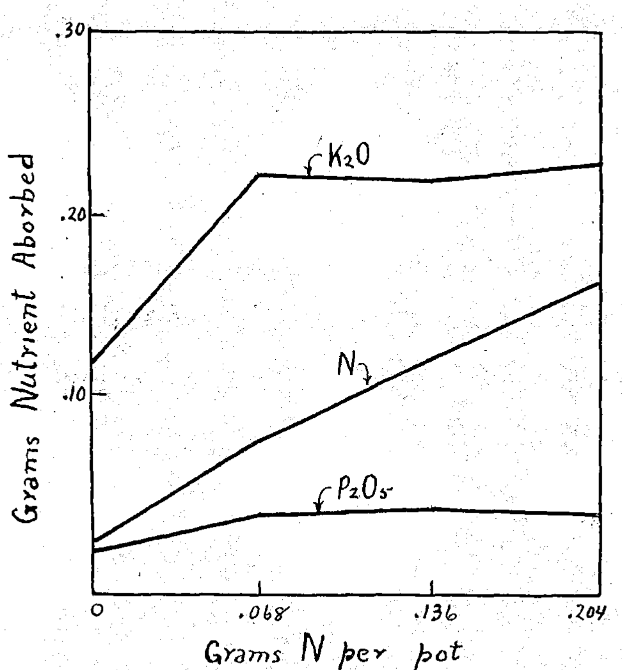


Figure 8. Nitrogen Series

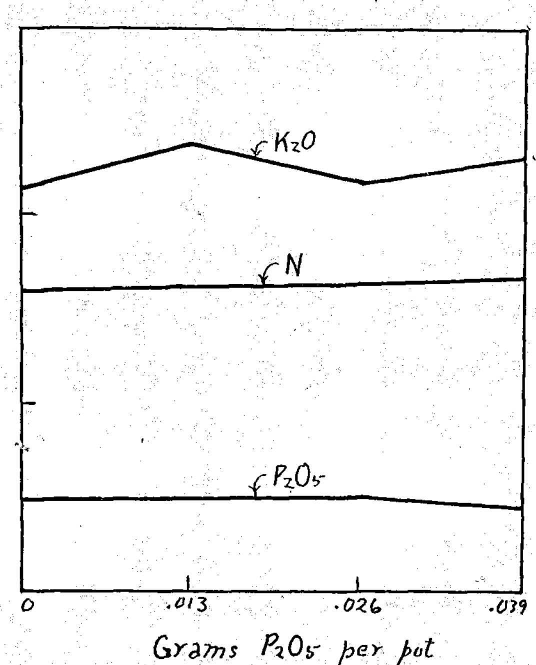


Figure 9. Phosphate Series

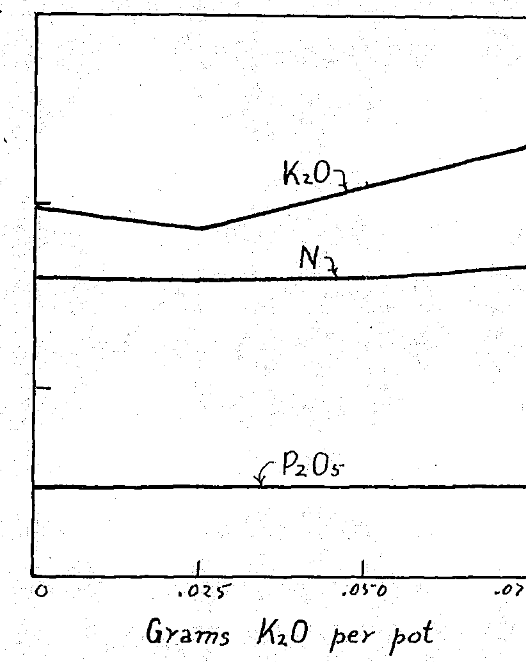


Figure 10. Potash Series

The data of Table 12 is represented graphically in Figures 8, 9, and 10. When Figures 4, 5, and 6 are compared with Figures 8, 9, and 10, it will be seen that the total nutrient absorption in each series followed rather closely the shape of the corresponding yield curves. The nitrogen, phosphate, and potash absorbed in the nitrogen series show curves similar in shape (Figure 8) regardless of the fact that the nitrogen was the only nutrient varied in supply.

It should be noted however, that the nitrogen absorption curve of the nitrogen series continued to rise after the phosphate and potash curves had leveled out in accordance with the yield curve. When the nitrogen, which was in the minimum, was raised to an excess, extra absorption of nitrogen occurred.

A similar phenomenon occurred in the potash series. The absorption curves of the potash series resemble the yield curve with the exception of the potash line (Figure 10). Although no excess potash symptoms were observed in the plants, they never-the-less underwent extra absorption of potash as the potash supply was increased.

The absorption curves of the phosphate series all resemble the phosphate yield curve. No extra absorption of phosphate occurred.

When the nutrient absorption was studied in conjunction with the manurial content of the pots, some evidence was obtained for the mass action theory of plant growth. In order to get the correct nutrient absorption figures it was found necessary to subtract the amount of nutrient supplied by the seed. The average analysis of six seeds, weighing 0.25 gm, was 4 mg nitrogen.

Table 13. Percent Soil Nitrogen Absorbed Compared with the Yield

Total Soil N (x+b)(gm)	Total Plant N (gm)	Plant N minus Seed N (gm)	% Soil N Absorbed	% Yield
0.023	0.027	0.023	100	41.7
0.091	0.081	0.077	85	87.8
0.159	0.127	0.123	77	94.7
0.227	0.170	0.166	73	92.1

From Table 13 it is apparent that as the fertilizer was increased by unit increments, it became less and less efficient at producing an increase in yield. In the "no nitrogen" treatment, all of the nitrogen in the soil was taken up by the plants, but, as the nitrogen was stepped up by unit increments, the nitrogen going into the plants and the yields went up by diminishing increments. At the higher end of the series it required a greater and greater nitrogen reserve in the soil to produce a smaller and smaller increase in yield.

Percentage Composition of Oats when Differentially Fertilized with Nitrogen, Phosphate, and Potash.

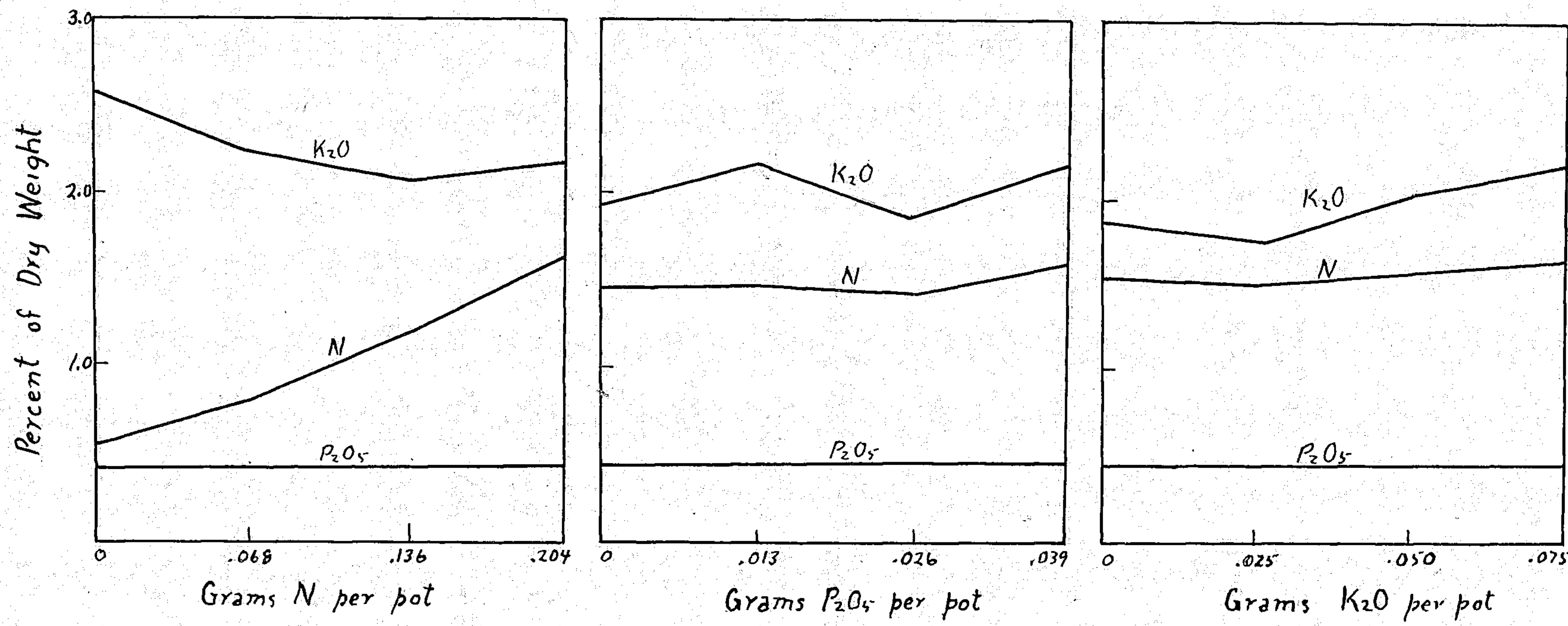


Figure 11. Nitrogen Series

Figure 12. Phosphate Series

Figure 13. Potash Series

The soil analysis figures for the phosphate and potash were less reliable and could not be considered in this connection.

The percentage composition of the plants (Figures 11, 12, and 13) showed the same trends as the total absorption curves, with the exception of the percent potash in the plants of the nitrogen series. Although the total potash increased with the yield, the concentration of potash in the plant stayed at a high level and even decreased slightly from 2.6% to 2.05% at the maximum yield and then increased slightly in the depressed yield of the high nitrogen pot, (Figure 11). The phosphate determinations were not sensitive enough to detect small differences in phosphate concentration in the plants.

Conclusions on the Oat Experiment

Although the results of the phosphate and potash series showed no yield response and consequently were not applicable to the Mitscherlich equations, the nitrogen series demonstrated the application of Mitscherlich's growth laws to the yields of systematically grown oat plants. The fact that the average standard deviation of eleven treatments was only 0.4 grams, with a maximum standard deviation of 1.1, illustrates the accuracy that may be obtained. The comparison of the obtained yield curve of the nitrogen series with a true logarithmic curve of the same slope ($c = 10$), shows that the calculations for soil nitrogen are dependable.

Difficulty was encountered in trying to find a satisfactory explanation of the decline in yield at the high end of the nitrogen and phosphate series. Although this "all high" treatment showed excess nitrogen leaf symptoms and underwent extra absorption of nitrogen (Figure 8), none of the lower phosphate and potash series treatments which received the same high amount of nitrogen (0.204 gm) showed excess nitrogen leaf symptoms even though they showed the same high nitrogen content (Figure 9 and 10). On the other hand, all of the low phosphate treatments showed higher yields than all the other treatments which received the highest phosphate application (0.039 gm).

The lack of response in the phosphate and potash series indicates a plentiful supply of both these nutrients in the soil. This conclusion is supported by the lack of significant difference between the "no nitrogen" treatment and the check treatment.

From the nitrogen yield curve, it can be definitely stated that a certain quantity of nitrogen is equivalent to a definite yield of oats. That is, when available nitrogen is present in this soil at 28 mg per kilogram, a 50% yield may be expected in a pot culture. When the nitrogen level is 91 mg per kilogram, an 88% yield will be obtained. In this experiment, therefore, one "food unit" is 28 mg nitrogen per pot. Interpreting this in terms of nitrogen per acre

(6" deep), it amounts to 56 pounds (calculated on a soil weight basis). This is only $\frac{1}{4}$ of the recognized Baule unit of nitrogen, 225 pounds per acre (15).

Tables 10 and 11, and the results of the Mitscherlich method show that the chemical tests for nitrogen agree closely with each other at 16 mg nitrogen per kilogram of screened air dry soil, and that they check within 7 mg with Mitscherlich method (23 mg per kilogram). The higher value obtained by the plant method may be accounted for by the fact that this method takes into account the nitrogen that was fixed and released by microbiological activity during the growth period.

Since calculations were impossible with the phosphate and potash series, no direct comparison with the rapid chemical tests can be made. However, certain conclusions can be drawn on the basis of the plant analysis. The absorption of 197 mg of potash into the plants which received no potash fertilizer indicates that at least 197 mg of potash were vailable to the oat plants during the period of growth. Although no yield response was obtained with potash fertilizers, extra absorption of potash occurred (up to 37 mg extra) when potash fertilizer was added. It is most probable, therefore, that more than sufficient potash was available than was required for a maximum yield. The chemical tests for potash appear to be far too low (42-60 mg per kilogram). This may be partially explained by the fact that the plants take into account the potash which becomes available from mineral decomposition during the growing period. It is also possible that the plants made use of base replaceable potassium.

The chemical tests for phosphate (5 mg per kilogram) are too low with respect to the plant analysis results. The analysis of the plants of both the "no phosphate" and the check treatments shows that at least 20 mg of phosphate must have been available to the plants. Although the chemical test shows the amount of phosphate that is available at any one time, it offers no idea as to the rate at which it becomes available during the life of the plant, nor does it estimate the total amount that is likely to become available during that time. The total phosphate content of the soil offers no clue to the problem. From a plant yield viewpoint, therefore, the rapid chemical tests for phosphate are wholly unsatisfactory. However, it is possible that as long as the phosphate becomes available at the same rate that it is used, and is at all times available at 5 mg per kilogram, the plants will make satisfactory growth. This experiment does not preclude that better growth could not have been obtained if the phosphate had become available at a higher rate.

The analysis of the plant material is useful largely as a check on the conclusions drawn from the yield curves. In this experiment with oats, for example, important information has been gained on the extra absorption of nitrogen and potash, and, as already pointed out, the figures on total nutrient absorption in the check treatments served as an important check on the soil analysis data.

The relation between soil fertility, nutrient absorption, and plant yield has been demonstrated. As the nitrogen fertilizer is stepped up by unit increments, both the absorption of nitrogen and the yields go up by deminishing increments. Furthermore, when the fertility is low, the yield is also low, but the plants take practically all of the nitrogen from the soil. As the nitrogen fertility level is raised, the yields increase by deminishing increments and it takes a greater and greater nutrient "reserve" in the soil to produce a smaller and smaller increase in yield. This fact has an important bearing on the costliness of over-fertilization. Thus, 91 mg nitrogen gave an 88% yield, but in order to gain 7% in yield over this, the nitrogen in the soil had to be doubled to 180 mg per pot. Running the risks of excess fertilization, it is doubtful if this small increase in yield would pay for the extra fertilizer.

The plant analysis, expressed as percentage compostion, proved relatively uninformative as compared to the total composition of the plants.

General Conclusions on the Application of the Mitscherlich Method to Raspberries and Oats

The general conformity to the Mitscherlich growth law exhibited by both the raspberries and the oats, as well as the information gained on soil fertility and the nutrition of these plants, certainly warrants more extensive use of the Mitscherlich method.

Although these two experiments differed in plant type, soil texture, size and type of pot, locality, and year, they are directly comparable. This seems scarcely possible when it is remembered that the values obtained in the two experiments differed greatly in magnitude:

	Raspberries	Oats
Proportionality constants	0.74	10
"Food units" of nitrogen	0.4 gm	0.028 gm
Maximum yields	193.2 gm	11.4 gm

Never-the-less, these results are proportional to one another in the following manner:

$$\frac{0.74}{10} \propto \frac{0.028}{0.4} \propto \frac{11.4}{193.2}$$

$$0.07 \propto 0.07 \propto 0.06$$

As a result of these computations, we may say that,

$$\frac{c_1}{c_2} = \frac{x_2}{x_1} = \frac{A_2}{A_1}$$

where the subscript 1 indicates the values from the raspberry experiment and subscript 2 indicates the values from the oat experiment. The fact that this relation holds, demonstrates that the Mitscherlich law is fundamental and remains valid regardless of plant species, soil class, or atmospheric conditions. From this general validity, therefore, it is concluded here that, although most of the attention paid to the Mitscherlich method in the past has been concerned with its value as a soil testing agent, it also presents a standardized basis for carrying out comparable plant nutrition experiments.

The evaluation of nutrients in terms of plant yields by means of pot trials, however, still presents some important problems. One "food unit" in the raspberry experiment was found to be 60 mg nitrogen per kilogram of air dry soil, whereas one "food unit" in the oat experiment was 28 mg nitrogen per kilogram of soil. These experiments provide little grounds for an explanation of this difference. It must be pointed out, however, that in the oat experiment 11.4 gm of plant material grew on one kilogram of soil, whereas in the raspberry experiment 193.2 gm of plant material grew on only

6.5 kilograms of soil. This difference in "food unit" results may be due to a difference in crowding effect. In future experiments of this sort, the relation of pot size to plant size should be taken into account more carefully in order to make the experiments more comparable.

Since the acre weights of the two soils differed by 1,764,000 pounds, the breach between the Baule unit determinations is widened still further when calculations are made on an acre basis. Thus, one Baule unit as determined by the oat experiment was 56 pounds of nitrogen per acre, whereas one Baule unit as determined by the raspberry experiment was 230 pounds of nitrogen per acre. The latter figure checks satisfactorily with the proposed Baule unit of 225 pounds of nitrogen per acre. It is suggested that experiments with different sizes of pots in conjunction with a field trial on the same soil be used as an approach to this problem.

In regard to the making of fertilizer recommendations, an important feature of these investigations is the fact that the best growth is obtained when the available soil nitrogen is much higher than the available phosphate and potash. The evidence obtained tends to support the Mitscherlich ratio 5:1:2 as the optimum balance for soil nutrients.

The amount of space, time and equipment required for the plant method, however, eliminates it as a practical routine method for testing large numbers of soils, although it would be of considerable value to British Columbia agriculture if it was known how the different soil types and classes from the different agriculture districts responded to the Mitscherlich treatment. It is concluded here also that more extensive use of the plant method in conjunction with chemical tests, may lead to the adoption of more reliable chemical tests and may also serve to give the results of chemical testing a quantitative meaning in terms of plant yield.

It is also concluded that the analysis of the plant material gives important supporting information to the results of the Mitscherlich method.

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