Der Tropenlandwirt, Zeitschrift für die Landwirtschaft in den Tropen und Subtropen
80. Jahrgang, April 1979, S. 38—46

Analysis of short portions of curves relating yield and uptake of phosphorus in glasshouse experiments

Analyse der kurzen Abschnitte der Ertrags-Phosphoraufnahmelinie in Gewächshausversuchen

By M. P. C. de Vries *)

1. Introduction

Many workers believe that yield variation between replicate treatments must be small in order to obtain useful information from glasshouse experiments. For that reason, the author discarded many results from glasshouse experiments with a wheat (Thimopheevi derivative) on a red brown earth with an unstable structure. The plants grew in pots containing about 16 kg of the dry soil in which different rates of phosphate were mixed. The soil crusted between waterings which adversely affected seed emergence and the early growth of the wheat. This caused considerable variation in yields from replicate treatments. Consequently, plots of yields against rates of phosphate applied provided no clear information. This form of plotting has another disadvantage, *i.e.* it does not distinguish between the health of the plants. In an attempt to find a more satisfactory method than the one above, I plotted yields dry weight against the uptakes of N, P, K and a trace metal, Mn. Of these plots, yields against phosphate uptake often gave useful information as can be seen in figure 1.

This figure gives the results of two, simultaneously conducted pot experiments with the wheat. Both series received four rates of phosphate applications which are shown in cwt/acre and in kg/ha. Each phosphate treatment had two replicates and all pots received a basal treatment of ammonium sulphate equivalent to 500 kg/ha. The series denoted by the closed symbols received the nitrogen fertiliser and the rates of phosphate; the series with the

---

*) M. P. C. de Vries, CSIRO, Division of Soils.

Anschrift: Private Bag No. 2, Glen Osmond, South Australia, 5064

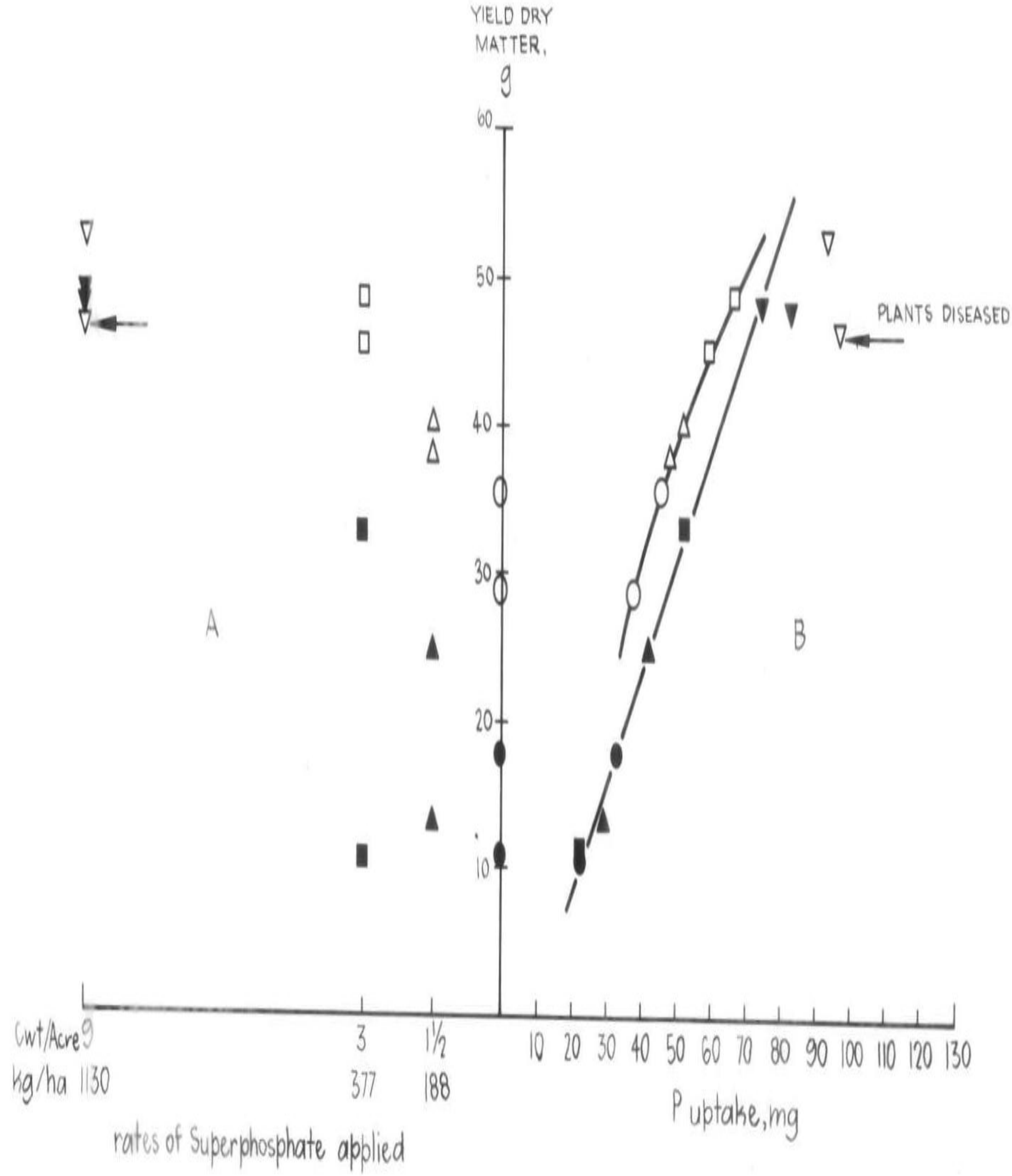

Fig. 1. Plots of yields dry matter of wheat tops against rates of superphosphate (A) and P uptake in the tops (B).
Closed symbols: only phosphate and nitrogen fertilisers applied.
Open symbols: an application of molybdate superimposed on the phosphate and nitrogen fertilisers.

open symbols also received a basal application of ammonium molybdate. Plants denoted by the closed symbols looked pale green and seemed to suffer from a nutrient disorder. Those denoted by the open symbols looked dark green and grew more vigorously than the wheat without the molybdate. In spite of the great variation between yields of the replicate treatments there is a linear relationship between yield and P uptake.

Plants in one of the pots with the 1130 kg/ha phosphate and the molybdate treatment (marked by arrow) suffered from a disease. This may have been one of the reasons why this point lies away from the line drawn through most of the other yield-P uptake points. The point of its replicate pot does not lie close to the line either, although these plants showed no symptoms of a disease.

It will be noted in figure 1B that yield-P uptake points of one of the 377 and one of the 188 kg/ha phosphate treatments are situated on the line in lower positions than one of the points of the controls. This implies that yield-P uptake points of different phosphate treatments can belong to overlapping portions of yield-P uptake lines.

Figure 1B shows that a) it is possible to distinguish between plants from different fertiliser treatments, and b) that there are two types of variation in yield-P uptake points from replicate phosphate treatments: one along the line, the other away from it.

The objective of this work was to find reasons for the two kinds of variation. It will be shown that yield-P uptake analysis has practical value. The experiments discussed in this paper were carried out either by the author or by associates during a span of several years. Experimental details will be kept to a minimum. They are available on request.

2. **Experiments**

2.1. *Experiment 1*

I investigated the yield-P uptakes of French bean (Phaseolus vulgaris L.) grown under conditions kept as constant as possible. Seeds were selected for size and weight and three of them were planted at the same depth and in the same position in pots containing a coarse sand drenched with a half-strength Arnon and Hoagland solution (Hewitt 1966, p. 190). There were eight pots, each held 3.5 kg dry sand. They were widely spaced in an open glasshouse to avoid shading. Water losses were restored to the surface of the sand.

The experiment was terminated after about six weeks when mites attacked plants in two pots. Tops of the beans were dried and weighed and P uptake in the tops determined. Plots of yields and P uptake are presented in figure 2.

The six points lying close or on the line belong to the healthy plants. In spite of all the care exercised to conduct an experiment in which plants were grown under identical conditions from what appeared to be uniform seeds, there is still some yield variation. However, the yield-P uptakes of these healthy plants are close to a line. In contrast, the yield-P uptake points of the plants attacked by the mites are well to the right of that line. This deviation had also been observed in figure 1B with the yield-P uptake point of the diseased wheat plants in one of the experiments.

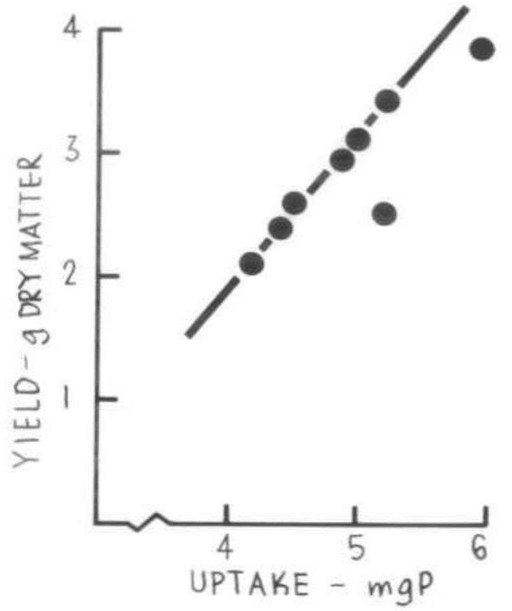

Fig. 2. Plots of yields dry matter of French bean tops against P uptake in these tops. The plants were subjected to identical treatment. Points on the line are from healthy plants; points to the right of the line are from plants affected by mites.

2.2. *Experiment 2*

This experiment investigated the effect of soil structures. It used the same soil and wheat as in the experiments described in figure 1. One series of pots contained the red brown earth with its structure improved and stabilised with a conditioner, the other series contained the unamended soil. Three rates of phosphate were applied and there were two replicate pots for each rate of phosphate.

Figure 3 shows that the plants on the soil treated with the conditioner produced a different yield-P uptake line than the plants on the soil with the original structure. There was considerable variation between the yields of replicate treatments, but yield-P uptake points lie close to or on the lines.

2.3. *Experiment 3*

Joseph (1958) carried out this pot experiment on a lateritic soil from Kangaroo Island, South Australia, to investigate the availability of phosphate mixed in different volumes of soil to subterranean clover (Trifolium subterraneum L.). He mixed four rates of superphosphate with, respectively, 50 g, 500 g, 2500 g of the soil placed in the top of the pots and included a treatment in which the phosphate was mixed through the whole soil (14 kg). Where the phosphate was mixed in the 50 and 500 g soil, he covered it with 1 kg untreated soil. Highest recovery by the clover was about 18 percent. This was obtained with all levels of phosphate supplied in the 50 and 500 g soil.

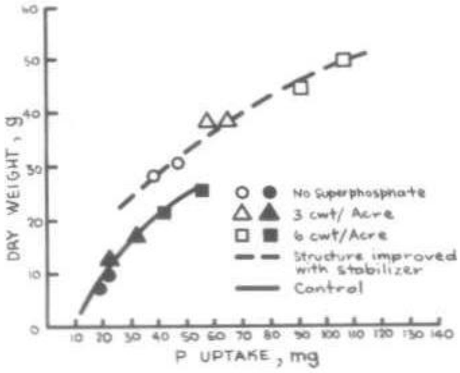

Fig. 3. Plots of yields dry matter of wheat tops against P uptake in the tops.
Closed symbols: unamended soil.
Open symbols: structure of the soil is improved and stabilised by a soil conditioner from de Vries 1969).

I replotted Joseph's data for yields and P uptakes for the phosphate treatments mixed in the 500 g, 2500 g and the whole soil. The results are presented in figure 4.

The experiments show that even the placement of phosphate in the soil can affect the position of the yield-P uptake points in the co-ordinate system.

3. **Discussion**

In a well-conducted experiment that investigates the effect of increasing application rates of phosphate on yields, one can expect the yield-P uptake points to be situated on, or close to, portions of sigmoid yield-P uptake curves. Curves relating yield and the uptake of a nutrient have been discussed by Steenbjerg (1951) and others. Short portions of yield-P uptake curves can be considered to be straight lines with equation $Y = bX + c$, where Y is the dry weight of the plant tops, X the P uptake in mg, b the slope and c the intercept of the line on the ordinate. As yield-P uptake points from different phosphate treatments can occupy overlapping portions of the lines we can elongate portions of the yield-P uptake lines by using replicates of not too different phosphate treatments.

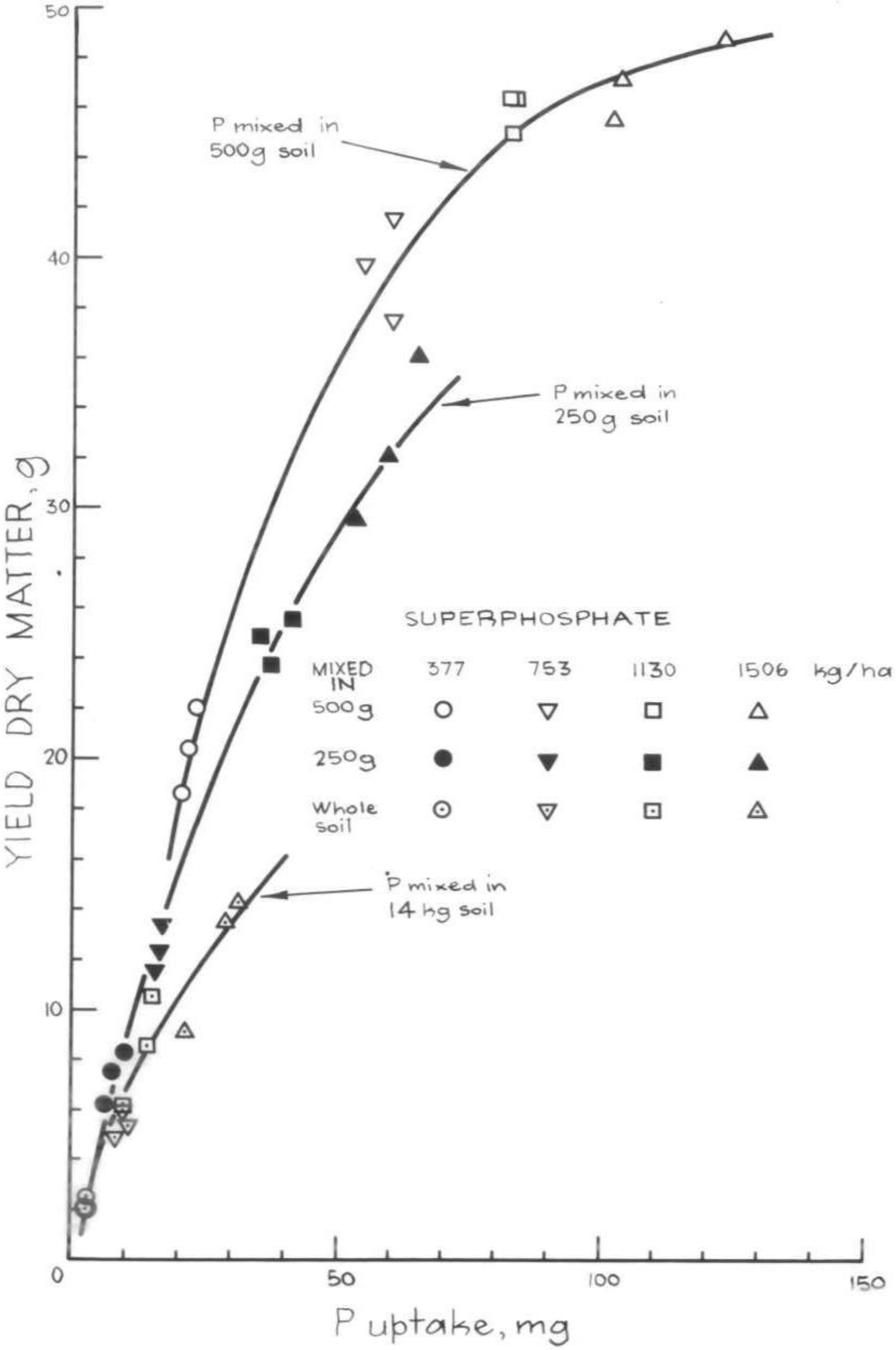

Fig. 4. Plots of yields dry matter of tops of subterranean clover against P uptake in these tops. Effect of placement of the phosphate fertiliser in the soil.

The position of a yield-P uptake curve in the coordinate system depends on many factors. Some of them have been shown (application of molybdate in addition to phosphate and nitrogen fertilisers, improvement of the soil structure, placement of a phosphate fertiliser, insect attack). Changes in the position of the curve imply that the efficiency in P use (the amount of P needed to produce plant dry weight) change. This efficiency of P use improves the closer the yield-P uptake curve moves towards the ordinate and/or away from the abscissa (see figure 4). We can therefore measure the effect of soil trements by the changes in the position of yield-P uptake regression lines in the coordinate system.

There will always be some variation in the growth conditions of pots in an experiment due to factors such as slight differences in mixing of the fertilisers in the soil, differences in the structure of the soil of replicate treatments, and shading of the pots. It is practically impossible to have all the yield-P uptake points lying on the line; they will rather be in a band. The narrower this band is, the better controlled were the growth conditions. The residual variance about regression lines provides a measure of scatter of experimental values and gives an objective test of the reproducibility of growth conditions. It is thus possible to compare residual variances of yield-P uptake points of plants from different soil treatments.

This procedure was used to compare the effect of two systems of watering of pots in a glasshouse experiment (de Vries 1969). One system was by sub-irrigation at a slow and constant rate (de Vries 1968): the other by periodically restoring water losses at the surface of the soil. Sub-irrigation gave significantly ($P < 0.01$) smaller variances than surface watering and therefore produced more reproducible growth conditions. The beneficial effect of sub-irrigation was most noticeable in the pots with the red brown earth which was also used in the experiments of which the results were shown in figures 1 and 3.

Above procedure of comparing residual variances could also be used to investigate resistance of a cultivar against a soil-borne disease. Small residual variances about the regression line would indicate a high resistance of the plants. The advantage of this procedure would be that the effect of the disease is measured well before the plants show any symptoms.

Analyses of short portions of yield-P uptake curves can be done only with genetical stable plants, which can be grown from seeds if they are homogamous. Examples of homogamous plants are wheat, oats, barley, rice, peas, beans and subterranean clover. Heterogamous plants may be grown from cuttings. It is important to avoid losses of plant material during the experiment. This implies that only young stages of the plants can be investigated.

4. Summary

It was shown that pot experiments with considerable variation between yields of replicate phosphate treatments can still give valuable information when the dry weights of the plant tops are plotted against their P uptake. This applies only to young plants that are genetically stable. The position of the lines relating yield and P uptake is subject to many factors which include the super-imposing of a fertiliser on the applied phosphates, structure of the soil, placement of the phosphate in the soil and attack of an insect.

The graphs show that there are two kinds of yield variation between replicate phosphate treatments. The first provides points along, the second points away from the yield-P uptake line. Yield variation between replicate treatments can be tolerated if yield-P uptake points are near to the line. Short portions of yield-P uptake lines can be considered to be regression lines. The position of yield-P uptake regression lines in the coordinate system and the residual variances about these regression lines can be used to explain the effect of soil treatments.

Zusammenfassung

Es wurde gezeigt, daß Gefäßversuche mit erheblichen Unterschieden der Erträge bei wiederholter Phosphatdüngung trotzdem wertvolle Auskünfte liefern können, wenn man das Trockengewicht der Pflanzenoberteile graphisch gegenüber ihrer Phosphoraufnahme darstellt. Dieses bezieht sich jedoch bloß auf junge Pflanzen, die genetisch stabil sind. Die Lage der Linien, die Ertrag gegenüber Phosphoraufnahme darstellen, ist vielen Faktoren unterworfen, zum Beispiel: Zugabe von Düngemitteln zu den bereits verabreichten Phosphatgaben, Bodenstruktur, die Stelle, wo das Phosphat im Boden verabreicht wurde, Insektenschädigung u. a. Die Diagramme zeigen zwei Arten von Unterschieden zwischen Erträgen von wiederholten Behandlungen. Die Erstere liefert Punkte, die entweder auf oder an der Ertrags-Phosphoraufnahmelinie liegen, während die Zweite Punkte liefert, die von dieser Linie abweichen.

Ertragsunterschiede zwischen wiederholten Behandlungen können nur dann gemessen werden, wenn die Ertrags-Phosphoraufnahmepunkte nahe an der Linie liegen. Kurze Linien dieser Ertrags-Phosphoraufnahme gerade können als Regressionen betrachtet werden. Die Lage dieser Regressionen innerhalb des Koordinatensystemes und ihre „residual variance“ um diese Regressionen können verwandt werden, um die Auswirkung von Bodenbehandlungen zu erklären.

References

1. DE VRIES, M. P. C., 1968: A constant level water system for long-term pot experiments. — Australian Journal of Experimental Agriculture and Animal Husbandry, 8, 749—755.

2. DE VRIES, M. P. C., 1969: An assessment of the reproducibilities of the growth conditions in pot experiments. — Journal of the Australian Institute of Agricultural Science, December, 263—265.

3. HEWITH, E. J., 1966: "Sand and Water Culture Methods used in the Study of Plant Nutrition." — Commonwealth Agricultural Bureaux, Farnham Royal U. K.

4. JOSEPH, K. T., 1958: Studies in the Reversion and Availability of Phosphorus in some South Australian Soils. — MSc.-Thesis, University of Adelaide/South Australia.

5. STEENBJERG, F., 1951: Yield curves and chemical plant analyses. — Plant and Soil, III (2), 97—109.