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**In 1982, the name of the International Superphosphate Manufacturers' Associations (ISMA) was changed to International Fertilizer Industry Association (IFA).*

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ASSOCIATION INTERNATIONALE
DES FABRICANTS DE SUPERPHOSPHATE (I.S.M.A.)

COMITÉ AGRONOMIQUE

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JOINT TECHNICAL AND AGRICULTURAL MEETING

LAUSANNE (Switzerland) - Monday 24th - Thursday 27th September, 1956.

AGRICULTURAL APPLICATIONS OF RADIO-ACTIVE PHOSPHORUS

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(A) Introduction

The application to agricultural research of techniques using radio-active and stable isotopes has given the answer to problems which conventional methods had failed to solve and has at the same time considerably reduced the length of the experiments (6, 18). In particular, we have been able to make a thorough study of the action of phosphatic fertilisers thanks to an isotope whose half life is a convenient length in relation to the various factors influencing its activity. This is not the place to give a complete list of all these factors with examples, but I just want to mention a few of them.

If we can increase the mobility of phosphate ions in the soil, we increase the availability of phosphorus to plants and thus get a higher yield. Obviously, in this case "soil type" is the most important factor. HERBST (13, 14) used tagged primary potassium phosphate to show how soil type and soil structure influence the fixation or rather the mobility of water-soluble phosphates. The P fertilisers are mixed with the soil and well watered; the distribution of the radio-activity is then determined by taking samples at different depths. Fig. 1 shows that loess fixes some 90% and clay only 75% in the top 5 cm. This method - a laboratory method worked out by RUSSELL (24) and others (26, 28) - gives only an indirect estimate of the availability of P fertilisers to plants and does not provide qualitative data except in very rare cases; a quantitative measurement of the affinity of the soil towards a certain fertiliser is provided by a direct determination of the amount of tagged P fertiliser absorbed by the plant in the experiment. Thus it has been shown (4) for two different soils that there is a great difference in the absorption of Rhenania phosphate and monocalcium phosphate. Obviously it is not enough to record merely that P ions are more or less mobile in a certain soil, we must find out why this is so in order to provide information on which the manufacture of soil improvers can be based. Thus, we have been able to explain the form in which P ions are fixed in the soil by calcium carbonate (5). Weak concentrations of P ions are rapidly absorbed by the surface of the $CaCO_3$, while stronger concentrations cause a slow precipitation of dicalcium phosphate, or rather a combination of similar processes which changes as it proceeds.

The action of soil improvers has also been examined by means of isotopes and fig. 2 (14) gives a clear picture as regards peat.

Using P^{32} (2o), it has been shown that organic manures encourage the absorption of the phosphoric acid in superphosphate, the cause of this phenomenon being the ability of humates to release the phosphate ions in the soil (1).

Although the factor "soil" has a great influence on the action of a fertiliser, it is the difference in the fertilisers which mainly influences the plant's absorption of phosphoric acid and consequently its yield.

A great deal of research has been carried out in this field with radio-active isotopes (2, 4, 7, 11, 22, 23, 25), the object being to establish the interaction of soil and fertiliser under constant experimental conditions of cultivation. Here, as may be seen in fig. 3 (14), in a known soil superphosphate gave the best results with both wheat and barley.

To understand why different fertilisers behave differently, we need to understand the phenomena of the assimilation of P in the soil. We have already been able to develop theoretical explanations based on isotope researches (9, 1o) for the processes of synthesis (organic combination of P) and degradation (mineralization) which occur in the soil.

Another factor represents the method of applying the fertiliser - band placement or broadcast. Here we do not rely solely on experiments, for we can also obtain useful evidence on the best methods of application by recording the distribution in the soil of the roots of various crops (3, 6, 12), and here too we can make good use of methods based on the use of isotopes. Fig. 4 (14) illustrates this. A special method which is gaining in importance both in the U.S. (29, 3o, 31) and the U.S.S.R. (2o) as a complementary fertiliser is foliar or "rootless" nutrition. Our laboratory has carried out significant work in this field which we shall discuss in the course of this general paper.

The physical form of the fertiliser is closely related to the factor just mentioned. For instance, granule size is a problem on its own and it has been possible to show by P^{32} that at the beginning of the growing period the plant absorbs more phosphoric acid from small granules (2 x 2 mm) and later more from large granules (4 x 4 mm) (2o). Other experiments comparing ordinary with granulated superphosphate showed no significant difference in assimilation (25).

This fact brings us to the realization that the time at which the fertiliser is applied is another essential factor. Fig. 4 shows the interaction of P absorption and time of application. Conversely, fig. 5 (14) shows that P absorption depends on the stage of development reached by the various plants (21), as already seen in fig. 3 and proved by many other experiments besides (e.g. 4, 25).

Finally, let us take as our last factor the plant itself, the subject of the experiment. Figures 3 and 5 show how different plants behave differently and this means that it is not safe to generalize from observations made on one plant.

This brief review should suffice to show how complex agricultural research needs to be before it can produce evidence capable of practical application, since the various factors interact in a number of different ways.

(B) Author's own work

Working with tagged P fertilisers, we concentrated first on the problem of foliar application. Here our object was not so much to determine the increased yield which had already been found in many trials (e.g. : 2o, 29, 3o, 31) on combined foliar/root application, as to determine to what extent foliar absorption is affected by a wide variety of factors (16, 17). An autoradiograph kindly made available to us by S.H. WITTVER, of the Horticultural Department of the University of Michigan, shows in the top row foliar absorption or radio-active P and in the bottom row absorption by the roots of a strawberry crop at different times.

After a brief explanation of the method employed, we summarize the results as follows:

Method

We shall not go into details here (for full account see reference 16). The nutrient solution used was KH_2PO_4, which is easily tagged, and the crops were black nightshade, tall oat-grass and wheat. The first two plants, with their horizontally extended leaves, are particularly well-adapted to the drip watering method where leaves placed in the same row are watered in pre-determined places with one drop of the tagged nutrient solution. The wheat leaves, on the other hand, were placed in contact with the nutrient solution by a brief immersion at a constant depth.

After harvesting, most of the plants were divided into aerial parts and roots, immersed and drip-watered and not immersed and not drip-watered respectively. After drying and igniting each sample, we measured its radio-activity. Using suitable standard tests, it is a simple matter to calculate the proportion of KH_2PO_4 which has penetrated into the various parts of the plant.

Problems investigated

The following factors were investigated thoroughly:

1) Stage of development and rate of application

We determined the growth function (15) of the experimental crop (black nightshade), and applied the nutrient solution at various stages of development, thus obtaining the absorption curve shown in fig. 7 (16). A similar curve was obtained for wheat (see figures 8 (16) and 9 (17)) and we thus have some justification for reaching the following conclusion:

There are two stages in the growth of a plant - the first stage and the period of maximum growth (maximum vitality) - when foliar feeding is most effective (16). These results were thoroughly checked on wheat (17), each plant being given a nutrient solution whose concentration differed in various ways within the range 1o to 10^{-5} mg KH_2PO_4. It was found that the strongest relative effect was obtained within the range 10^{-3} to 10^{-4} mg KH_2PO_4 per plant, and that in addition to the two favourable periods for heavy rates of application, there must also be a third period, about four weeks after the germination of the crop. A thorough study shows that the best time to apply sprays is between the 4th and the 8th week.

These trials have shown the vital importance of variations in several factors.

2) Air humidity

Here we studied the case of an extremely heavy fall of dew; after the nutrient solution had been allowed to dry out, we watered the trial crops each morning for several days with a small amount of water. We found that this caused an appreciable increase in the absorption of nutrients. We thus recommend that (a) atmospheric humidity should be high when plants are being watered; (b) hygroscopic substances should be used as nutrients (16). Other authors have been able to offer partial confirmation of this phenomenon, although in some cases results have been negative (31).

3) Temperature

The nutrient solution was applied to the trial crops at 23º and 16º C, and the lower temperature was found to give about 100% more absorption. This is probably because at the lower temperature the nutrient solution dries out more slowly while the air humidity remains relatively higher (16).

4) Time of application

We found that evening watering is more effective than morning watering, which is also partly due to the temperature (16).

5) Fertiliser placement

Partly in agreement and partly in disagreement with other authors (31), we found with drip watering that the underside of the leaf has about double the absorptive capacity of the upper side. This is due to the cohesive forces whose activity is more intensive on the underside of the leaves and not on the opening of the stomata. From this we may draw the practical conclusion that in crops where the underside of the leaves is accessible (fruit trees), this is the best part to spray (16).

6) Fertiliser contribution of soil

From the point of view of P absorption, we compared the application of fertilisers to the soil with foliar application, and with a combination of both, in soils that were poor or rich in P. We found that foliar application (and incidentally any other way of applying P fertilisers) is effective only where the soil is P-deficient. Combined application is better than either equivalent soil or foliar application alone. This phenomenon leads us to several interesting conclusions about the absorption mechanism of fertilisers applied to the leaves or the soil, for which we will refer you to the original references (6).

The experimental results we have been discussing were obtained from pot trials and the next thing is to confirm them by large-scale field experiments where, according to Russian authors (20), some hundreds of hectares are needed for cereals, for instance.

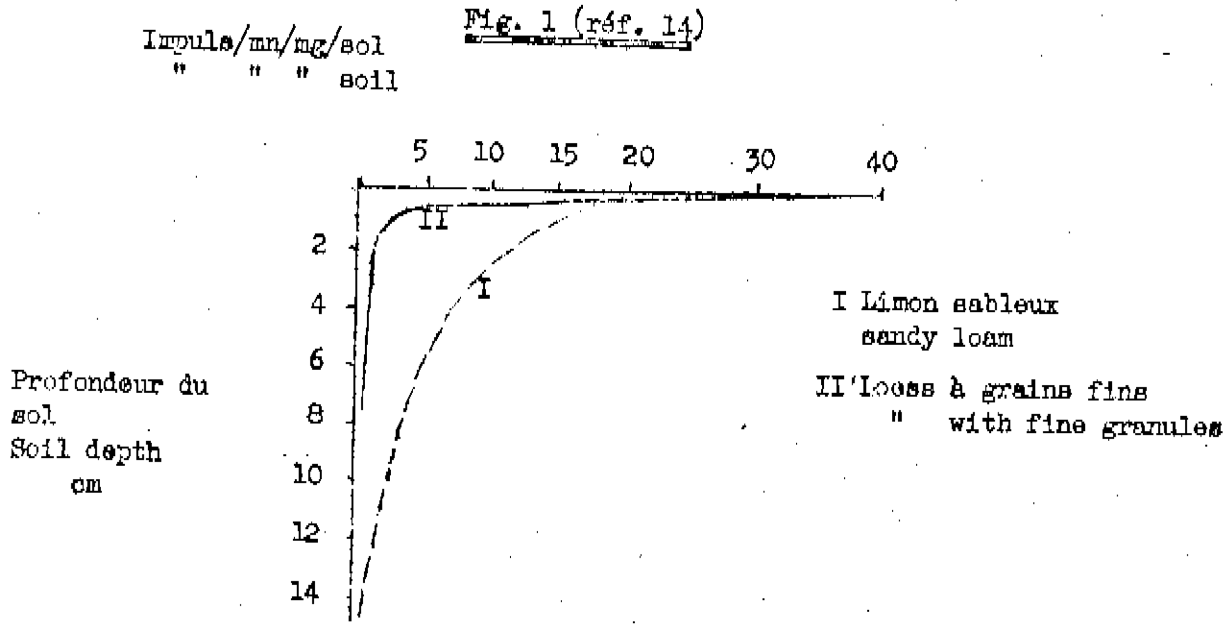
The results obained in this connection on cereals, sugar beet and cotton (2o) were very satisfactory. But, as always, results obtained in the U.S. or the U.S.S.R. are not directly applicable to Europe because of differences in climate, so that it would be as well if several European countries would collaborate in order to check the usefulness of foliar nutrition under a wide variety of climatic conditions.

Last year our laboratory began a series of trials on the advisability of applying fertilisers to fruit trees and bushes in the form of sprays. After meticulous preliminary trials in wooden boxes, we treated two wild cherries with soil and spray applications of equal amounts of a mixed fertiliser whose diammonium phosphate component was tagged with P^{32}. Nutrient absorption was measured over a period of several weeks in the leaves, buds or fruits, branches and bark, and it was found that spray application was about three times as effective as soil application. Subsequent trials on other fruit trees, to include comparisons with superphosphate, will give a more accurate picture of the fertiliser problem.

For your information, I would add that trials are in progress on the soil conditioning action of organic matter as it affects both the absorption of phosphates and the absorption of superphosphate under fixed climatic conditions.

Finally, I should like to say that generally speaking European research has made little use of P^{32} as a tracer, even in the study of superphosphate. This is partly due to a lack of staff trained in essentially physical methods and partly to the higher cost of measuring instruments.

Fig. 1 (réf. 14)



Détermination du P_2O_5 soluble-eau dans le cas d'arrosage superficiel et en profondeur.
Determination of water-soluble P_2O_5 for surface and deep watering.

Fig. 2 (réf. 14)

Détermination du P_2O_5 soluble-eau dans le cas d'arrosage en profndeur
Determination of water-soluble P_2O_5 for deep watering

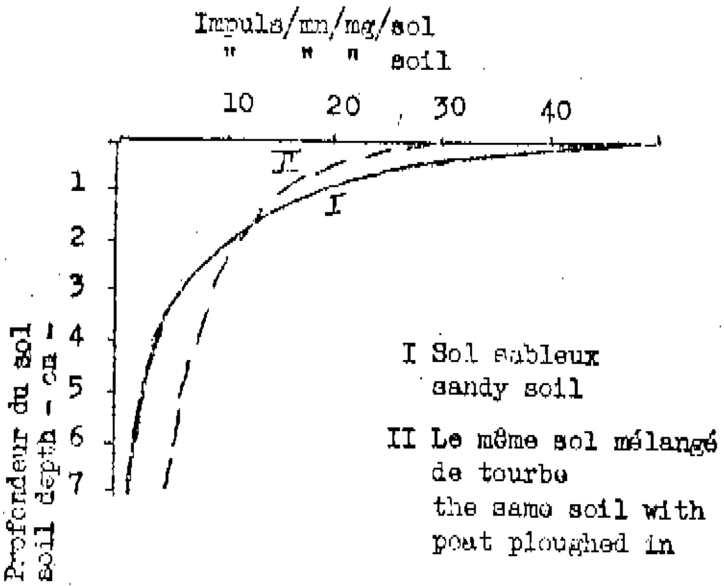


Fig. 3 (réf. 14)

Pourcentage du P total du blé et de l'orge à deux époques différentes, provenant des engrais suivants : I Ph. tricalcique
II Ph. bicalcique
III Métaph. de calcium
IV Super

Percent of total P in wheat and barley taken up at two different times from the following fertilisers : I Tricalcium ph. II Dicalcium ph. III Ca metaphosphate IV Super

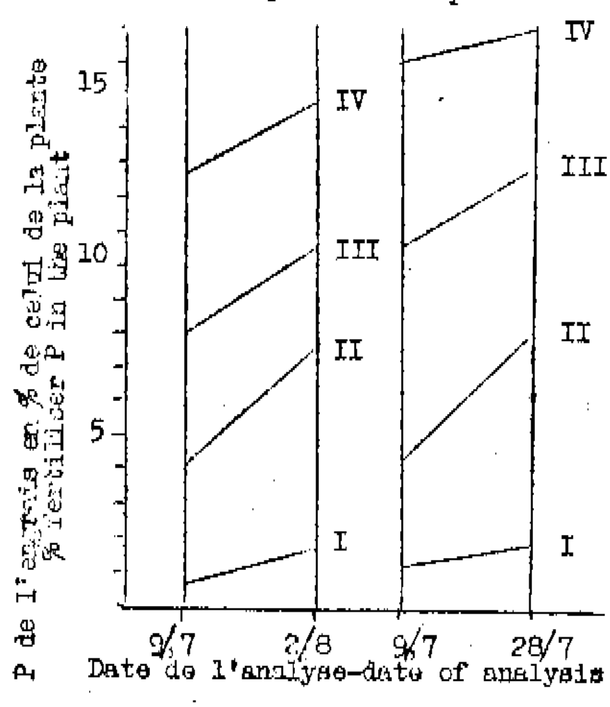
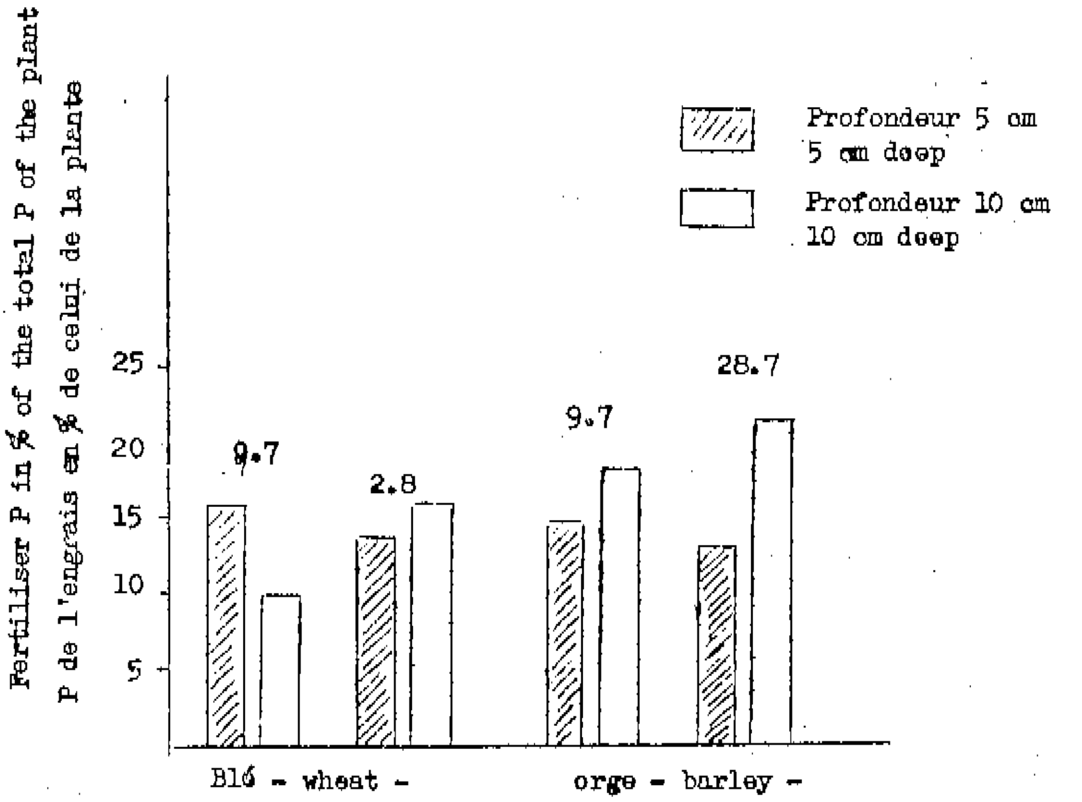


Fig. 4

Influence du mode d'application sur l'absorption de P_2O_5

Influence of the method of application on the P_2O_5 uptake

a) Application à diverses profondeurs, super épandu à la volée
Various depths of application, super broadcast



b) Superphosphate sur betterave à sucre, à la volée et localisé
Superphosphate on sugar-beets, broadcast and placed

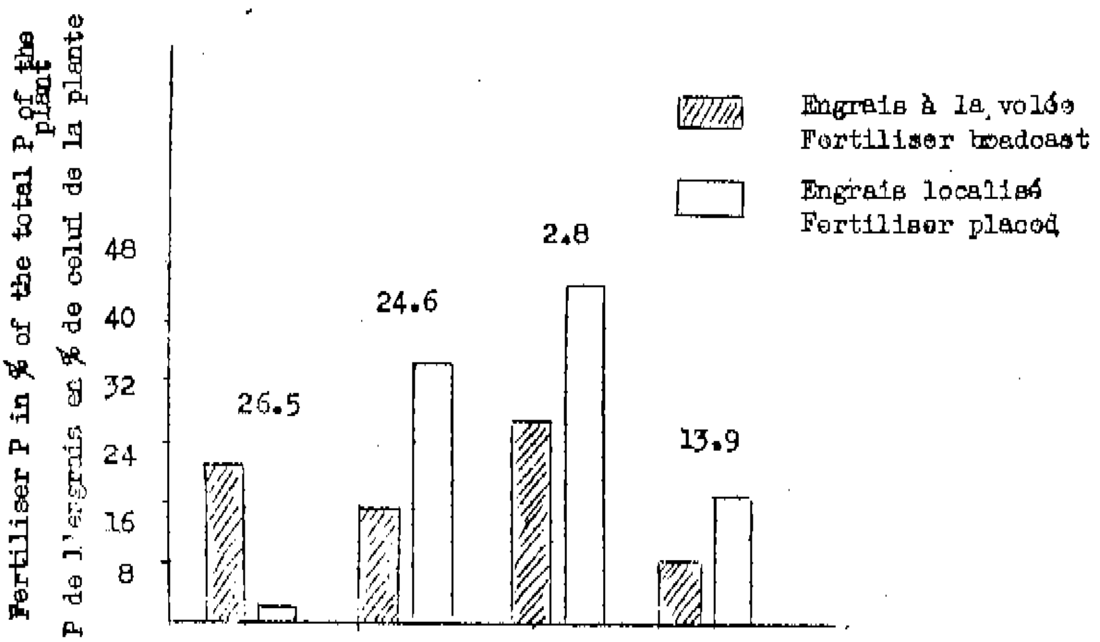


Fig. 5

P de l'engrais en % du P total absorbé

par I) le soja, II) le maïs, III) la pomme de terre à divers stades de développement

Fertiliser P in % of total P

taken up I) by soja bean, II) by maize, III) by potatoes at various growth stages

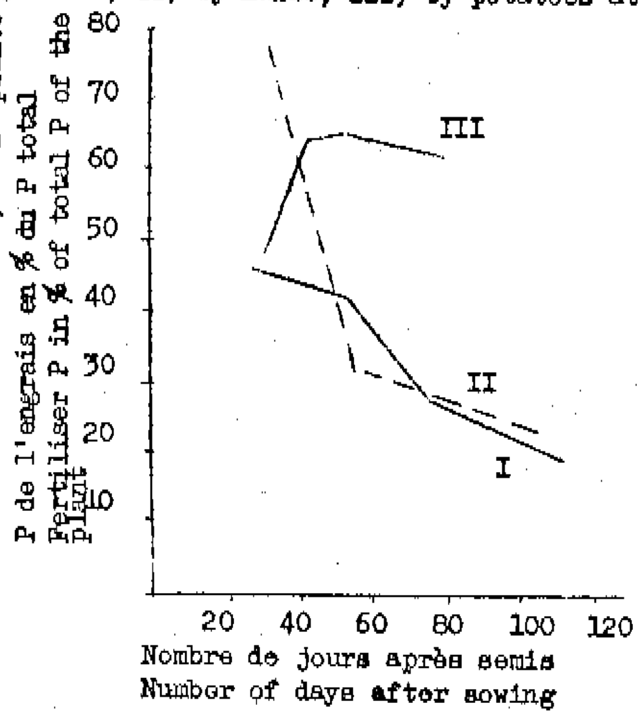


Fig. 7 (ref. 16)

La fonction de croissance d'une plante de morelle noire (axe de gauche)

The growth function of black nightshade (left axis)

a) Absorption totale selon la dose appliquée sur une surface d'humectation de 1 cm² pour la plante globale G P (trait plein)(à gauche de l'axe central des ordonnées) et quantité d'éléments fertilisants transportée dans les racines W (pointillés)(à droite de l'axe central des ordonnées) en fonction du stade de développement de la plante (abscisse)

b) Absorption spécifique selon la dose appliquée sur une surface d'humectation de 1 cm² pour la plante globale G P (trait plein) (axe de droite) et quantité d'éléments fertilisants spécifique transportée dans les racines W (pointillés) (axe de droite) en fonction du stade de développement de la plante

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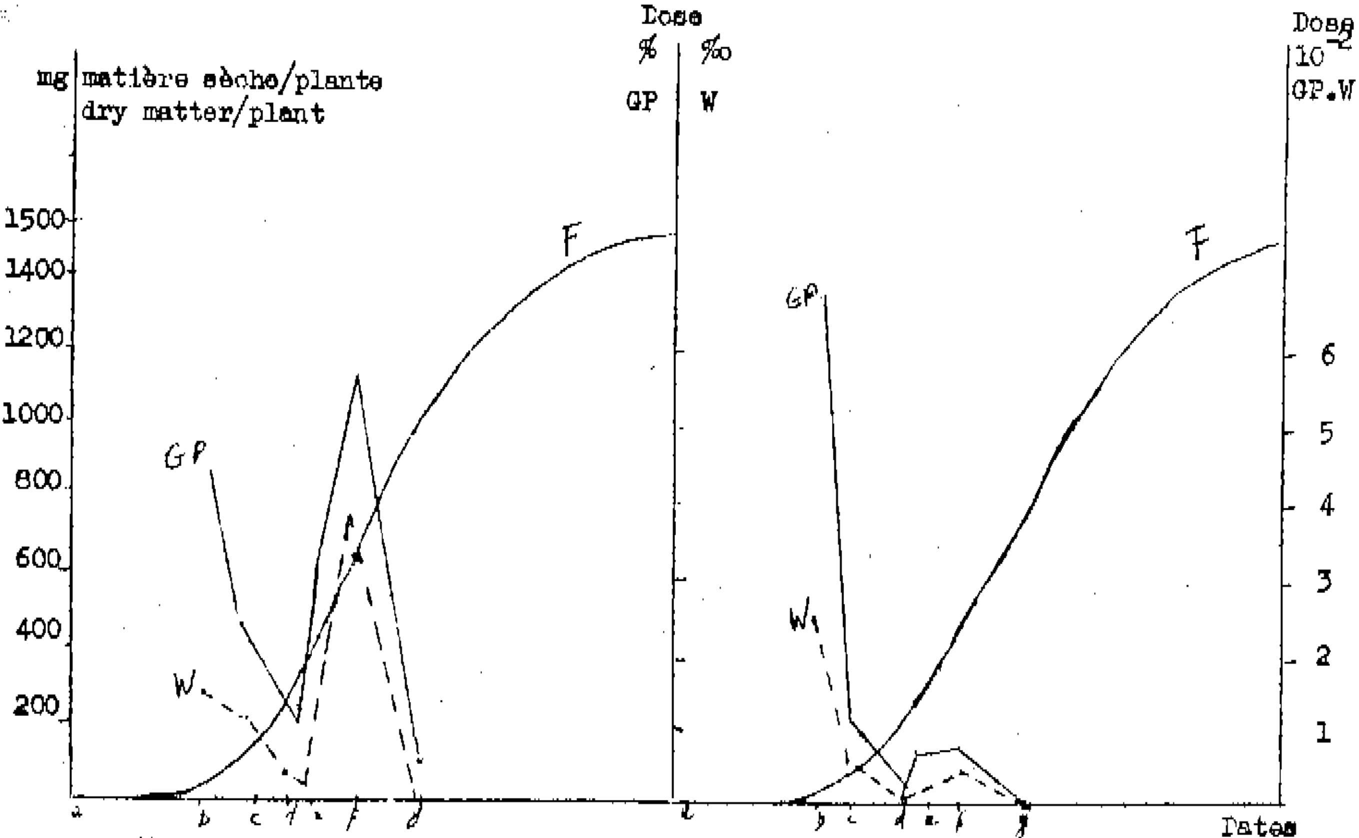
a) Total uptake according to the rate of application to a 1 cm² moistened surface for the overall plant G P (full stroke)(on the left of the central ordinate axis) and amounts of plant nutrients carried into the roots W (dotted line) (on the right of the central ordinate axis) in terms of the growth stage of the plant (abscissus)

b) Specific uptake according to the rate of application to a 1 cm² moistened surface for the overall plant G P (full stroke) (right axis) and specific amounts of plant nutrients carried out into the roots W (dotted line)(right axis) in terms of the growth stage of the plant



a = 27.9, b = 15.10, c = 20.10, d = 27.10, e = 29.10, f = 3.11, g = 12.11

Fig. 8 (ref. 16)

Fonction de croissance d'un blé (axe des ordonnées de gauche) (15)

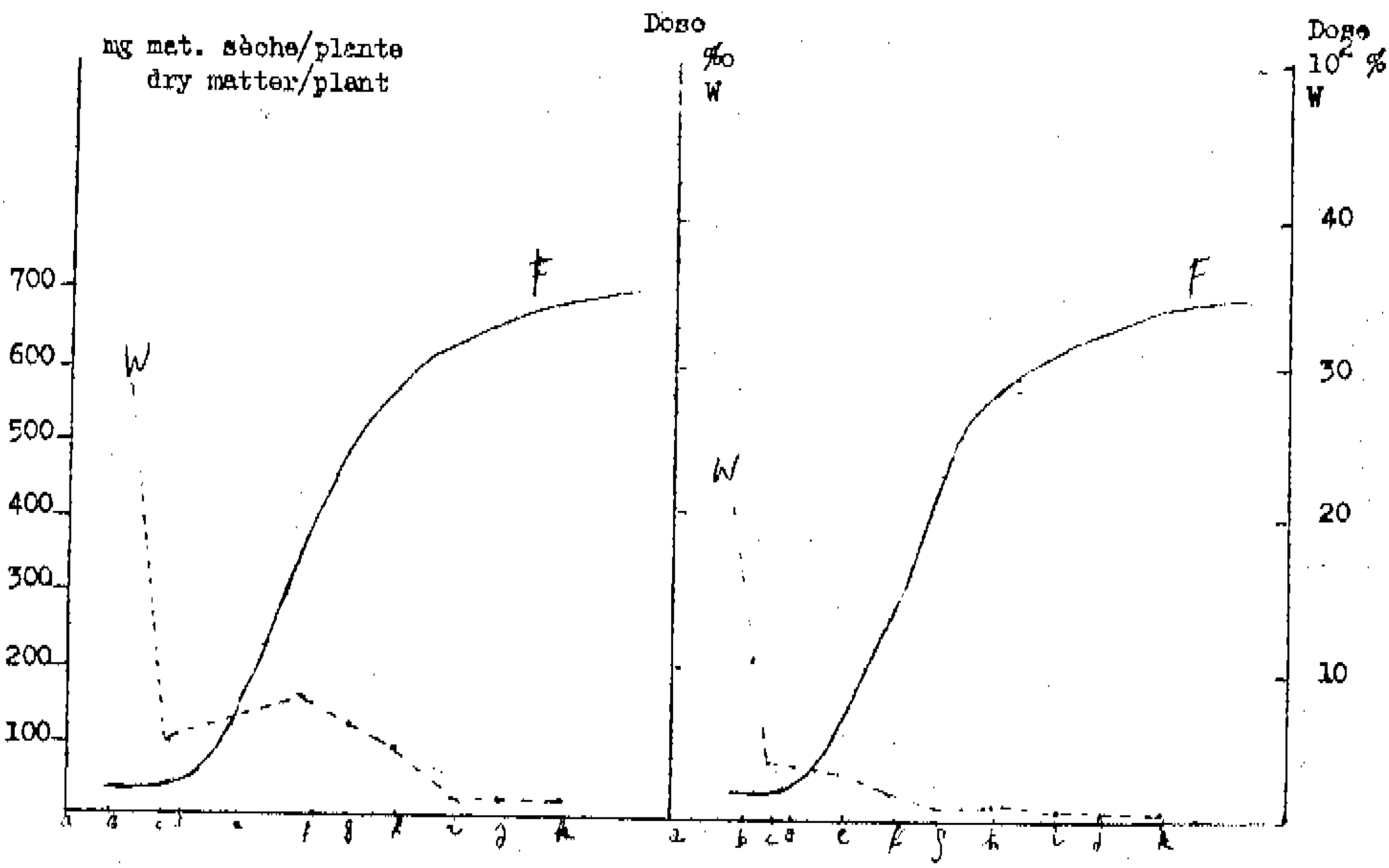
a) Quantité totale d'éléments fertilisants transportée dans les racines W (axe central) en fonction du stade de développement de la plante (abscisse)

b) Quantité spécifique d'éléments fertilisants transportée dans les racines W (axe central) en fonction du stade de développement de la plante (abscisse)

The growth function of wheat (left axis)

a) Total amount of plant nutrients carried into the roots W (central axis) in terms of the growth stage of the plant (abscissus)

b) Specific amount of plant nutrients carried into the roots W (central axis) in terms of the growth stage of the plant (abscissus)



a = 3.6, b = 11.6, c = 16.6, d = 18.6, e = 26.6, f = 27, g = 9.7, h = 16.7, i = 24.7
j = 30.7, k = 7.8

Fig. 6

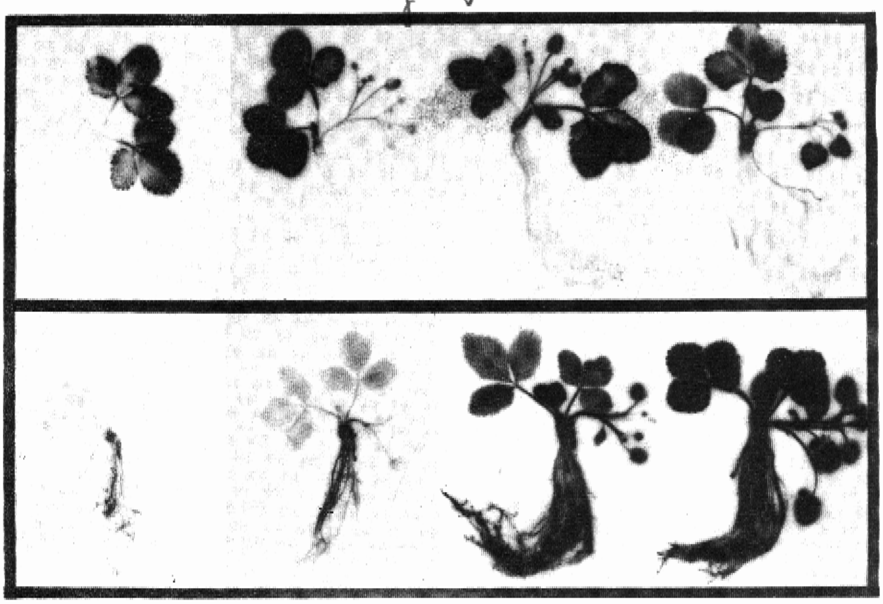


Fig. 9

Fonction de croissance d'un plant de blé (axe de gauche) (17)

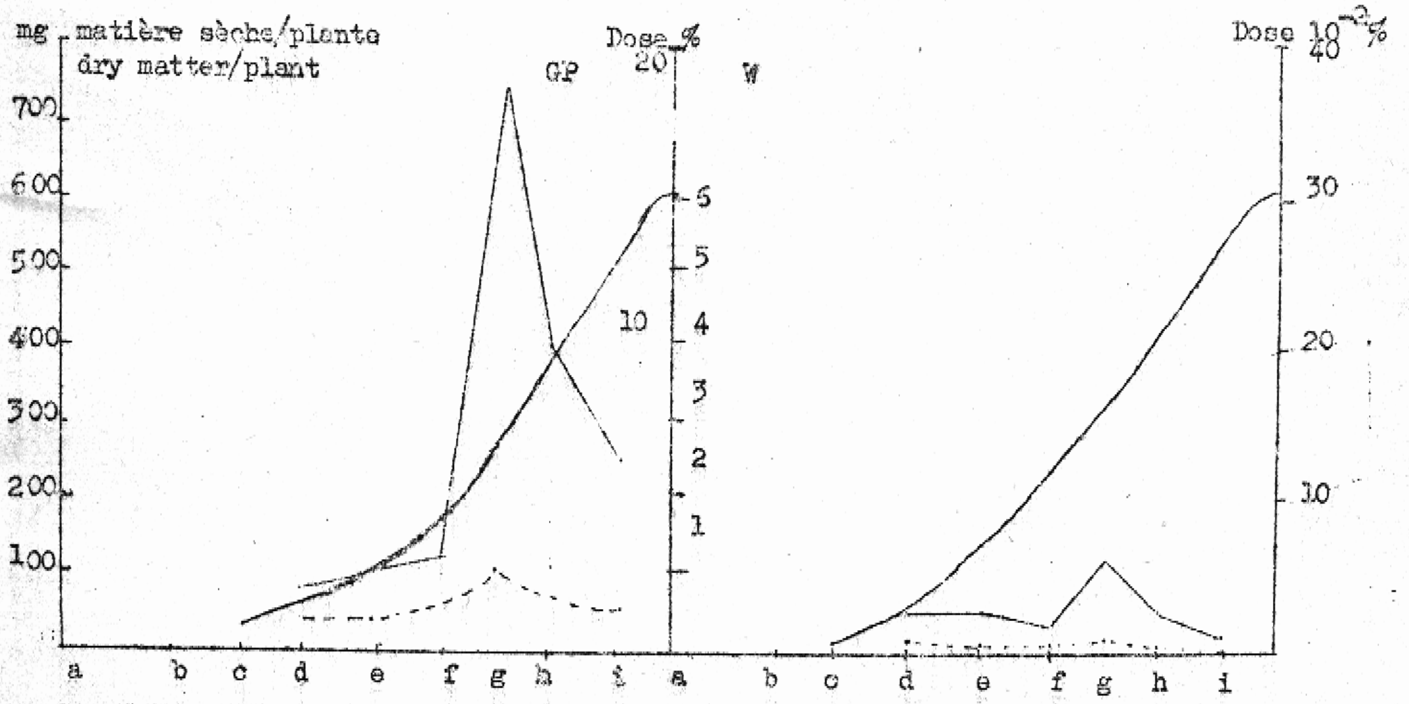
a) Absorption totale par la plante globale G P selon la dose appliquée (trait plein à gauche de l'axe central) et quantité d'éléments fertilisants transportée dans la racine W (pointillés à droite de l'axe central) en fonction du stade de développement de la plante (abscisse)

b) La même chose pour l'absorption spécifique (calculée pour 1 mg de matière sèche)

Growth function of wheat (left ordinate axis) (17)

a) Total uptake by the overall plant GP according to the rate applied (full stroke on the left of the central axis) and amount of nutrients carried into the roots W (dotted line, on the right of the central axis) in terms of the stage of growth of the plant (abscissus)

b) The same for the specific uptake of nutrients (calculated on the basis of 1 mg dry matter)



a = 17.3, b = 31.3, c = 8.4, d = 16.4, e = 26.4, f = 5.5, g = 12.5, h = 19.5, i = 28.5