ROOT SYSTEMS OF SEVEN VARIETIES OF PEAS GROWN UNDER SIMILAR CULTURAL CONDITIONS

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(CONTRIBUTION FROM THE INSTITUTE OF PLANTBREEDING)

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INTRODUCTION AND PURPOSE

It is considered a task of our Institute for Plantbreeding at Wageningen, to search for varietal differences with respect to prominent functions so that we may come to somewhat deeper insight regarding the causes of different yield.

Only few investigations into the development of the root system of our crop-plants have been made in direct relation to plantbreeding.

The number of investigations into the spreading of the root system of various plants for several reasons is small (no direct value as commercial product, difficulties with the investigation) and moreover more attention has been paid to the reaction of the root system to manuring, tillage of the soil, rotation of crops, watersupply, than to differences of variety.

A few more extensive investigations have been made by FREIDENFELT (10), SCHULZE (26), MODESTOV (23) and of late, especially by WEAVER and his co-operators. The latter points repeatedly to the significance of root investigations for plant-breeding but yet in his two important summaries (31; 32), only the root development of one variety of every species is usually described.

Some root investigations, that have for their main object the tracing of differences between varieties of the same kind are i. a. those by HOLBERT (14) (corn) and KLÄSENER (18) (potato) JEAN (15) (pea), CARLSON (5) (alfalfa).

The whole matter is to determine hereditary differences, without the necessity of thinking immediately of a genetic analysis however.

If these differences are significant for culture, they will, in the first place, appear when the plants grow under normal conditions. The determination of differences in root-devolopment under abnormal conditions (MERKENSCHLAGER, 21, 22) may bring to light distinct differences of variety it is true, but then the significance of those differences for practice must be determined afterwards, in so far as it is not only a question of distinguishing between the varieties for the use of seed-determination.

I have endeavoured to find differences of variety in rootforming under natural growth-conditions. The pea has been chosen as object because its roots are relatively heavy and strong and therefore give less difficulties at washing-out than those of many other plants.

Furthermore I thought it necessary to be able to form an idea of the reliability of the differences found either by tracing the root-development during its lifetime in fortnightly periods in which case the preceding and the following determination check each other to some degree (first year) or by determination of the root-development only a few times, but then of several plants (series of plants) of the same variety which enables a calculation of the mean-error (2nd and 3rd year).

This last method of investigation generally used quite rightly for above ground parts under cultural conditions, as yet, has never been applied to under ground parts as far as I know. The very understandable reason that the investigation takes up so much time, compelled me to take no more than an average of three groups of plants, each consisting of six individuals. I will add at once however that owing to the very great variability (which makes a calculation of the mean error still more necessary) this number is too small to be able to determine with certainty the greater part of the commonly slight differences.

The possibility exists that the differences stated are produced through influences of the weather. In order to be able to form an idea about this, the experiments with two varieties were repeated in three consecutive years. The corresponding results obtained thereby make it probable that the differences stated do not assert themselves only as a reaction to a specific state of the weather which considerably increases the chance of an important significance for practice.

When cultivating crop plants in larger fields more value should be attached to the depth of the root systems than to their spreading in so far as a better anchorage in the soil is not necessary to be considered. Only borderplants by a wider spreading of the root-system can add particles of soil that would otherwise remain unused to the field under culture. With the rest of the plants this is only possible by a deeper root-system.

This reasoning does not only apply to the nutrients present in the soil but also to the important factor, water. By a wider spreading of the root-system no more water is available except in the case of the border-plants but with roots going deeper there is. Therefore in this investigation less attention has been paid to the spreading of the root-system than to the depth of the roots. It is natural to attach greater value to a root system the more intensively it penetrates the soil as the surfacecontact between soil and root is greater per volume of the soil. It would therefore be very desirable to measure the surface of the root-system per plant as well as per soil unit and then at various depths.

The measuring of the surface of a full-grown root-system and that in such a heterogeneous medium as the normal culture-soil, until now is only possible with a very rough approximation.

In the preceding century attemps in this direction were made (See literature cited bij Böhme (2), p. 57). These investigators determined the lengths of the main root with all its laterals. It is clear however that in doing this we do not determine the size of the surface of the roots touching the soil and certainly not the surface of the absorbing part.

It is, in the first place the surface of the roothairs which we would like to ascertain, for the absorption takes place almost exclusively by the root hairs. Compare for criticism Priestley (27). A greater length of the roots proper has even in itself an aggravating effect because the transport resistance is increased thereby.

Weaver too occasinally gives a calculation of the surface of a root-system and uses also an estimation of the number of roothairs.

The lack of a suitable method for determining the surface of the rootsystem is always felt. Several attempts have been made to supply this needed want. Of older date is the method by Girard (12), who powdered the roots with flower of sulphur and used the increase of weight as a measure for the surface. Of more recent date is the method by Dustman (8), who immerges the roots in a methylenblue solution and determines the diminution of the colour of the solution. An objection to both methods is, that not only the absorbing cells act, but also older parts, even dead matter. Very new, but little promising, is the effort by Kampe (16) of using the electric current and Röntgen rays to get informations about the root-system still being in the soil.

A much applied method which also is no more succesful in giving the size of the absorbing surface however, is the determination of the weights. This is the method I have used. It has the advantage of being much simpler to execute and makes it moreover possible to form a judgment of the activity of the root-system, as we can determine how many gramms of above ground parts are formed per gram of root. In this respect I attach a greater value to a root-system as it is able to provide per gram of root a greater quantity of above ground parts with nutrients and water. Hence I calculate the shoot to root ratio (for short: the shoot/root), which number I take as a standard of the value of a root-system. I would point out emphatically that with this expression: shoot/root for the value of a root-system very important characteristics play a part that under normal conditions of growth are not or with greath difficulty, accessible to determination, such as permeability of cellwall and protoplasm, transportresistance and suction pressure. For the value is here not only a function of the surface but also of the above mentioned qualities and others that must yet be added.

In short the purpose of my investigation has been to determine:
1°. the depth (not the length) of the root-system.
2°. the distribution of the roots in the different layers of the soil.
3°. the relation in weight of above-ground parts to subterraneous parts (the shoot/root).

To this is added, for the first year, the periodicity of the root-development and the growth-rate, and for the last year the function of the roots that go deeper than 30 cm.

METHODS OF OTHER INVESTIGATORS

Out of the various methods that have been used to make investigations into rootsystems, those that make use of water-cultures and potcultures remain out of consideration (BÖHME (1), p. 174: „Es ergibt sich also, dasz ein Vergleich zwischen der Wurzelentwicklung im Felde und der in den Gefäszen nicht möglich ist"). Also with SCHULZE's method (26) the plants grow as a matter of fact as in pots, even though these are very big and though it is attempted to fill the holes in such a manner that the normal soil is imitated as much as possible. SCHULZE himself says on page nine: „Es gelingt allerdings trotz der gröszten Sorgfalt nicht, eine Dichtigkeit der Lagerung des Bodens zu erzielen, wie sie auf dem freien Felde in den tieferen Schichten vorhanden ist."

In excuse of this he points to the fact „dasz es eine „normale" Dichte des Bodens überhaupt nicht gibt". Of course this is true, but in his speculation on this subject he only indicates the possibility that in his experiments the roots „daher in der Tiefe vielleicht etwas weniger Widerstand finden als auf den freien Felde".

Together with the resistance, more things have changed however. In the first place the quantity and the exchange of O and CO_2, factors that are of great importance for the forming of the roots (See i.a. Cannon and Free (4)). Further it is difficult to estimate to what extent the watercapacity and water-supply have been influenced hereby and likewise the microflora and -fauna. To this circumstance is perhaps also due the great difference in the photos of the roots, which immediately strikes the eye when we compare his photo and mine of the root-system of the Victoria-pea, which happens to be taken as an object by us both. SCHULZE gives a much greater depth, but further the development makes a poor impression. Of course the different soil plays also an important part in this respect. For further criticism to which I quite agree I would refer to the article by MASCHAUPT: „De bewortelling onzer cultuurgewassen" (20).

MASCHAUPT uses Rotmistrof's method (25). This method differs from SCHULZE's on account of the containers being much smaller in one direction so that they may be taken out of the soil and lie flat when the soil is washed away, so that the roots have less chance of breaking.

Moreover the roots are being kept as much as possible in their place by iron needles that are driven through the soil before washing out. According to MASCHAUPT this method can be also used for root investigations of plants, that grow under perfectly normal conditions in the field. In this case he makes a ditch with a vertical side, places a wooden partition against it and then drives at some distance behind the plants a sharp-edged partition vertically into the soil. Afterwards these two partitions firmly tied together with the intervening earth are lifted on to the field and washed out, after needles have been driven through the wooden partition in order to keep the roots in their places.

The great advantage of this method is, that the plants grow under absolutely natural conditions. The root-system is however not obtained in its entirety, but is considerably demaged. This is not such a great objection if it may be assumed that the missing quantity of roots of the washed out plants is compensated by the parts of roots that have been cut from their neighbours and that get into the slice.

A first requirement is then, that the thickness of the slice of ground agrees exactly with or is a multiple of the distance between the plants. Besides, with this method of washing out, the root-system is practically speaking, compressed into one plane: when the earth is removed the roots sink to the bottom board. Further it seems hardly possible to force the second partition into the soil in the same direction as the first.

To prevent the roots not only from sinking to the bottom during the washing out, but also to prevent displacement in horizontal direction as much as possible and to acquire in this manner a root-preparation with three dimensions, the method by HAYS (13) is to be used. HAYS fills a prismatic frame of gaspipes with sifted earth and puts on this foundation every 2 or 3 inches a piece of poultry wire netting. Before the roots are washed out afterwards, this netting is firmly fastened to the frame and prevents a removal of the roots in any direction over distances greater than the diameter of the meshes of the netting. The advantage of this method, in my opinion, does not counterbalance the disadvantage that use is made of a soil that deviates considerably from the natural growing place.

As early as in 1893 KING (17) used a method however that prevents as much as possible a displacement of the roots in all three directions at washing out and which moreover can be used with plants growing under normal conditions.

For this purpose he cuts off the soil in such a way that a prism of the soil wirh the trial objects remains standing. This block of soil he encloses by means of an iron frame. Round about it, poultry-wire netting is attached, and the bases of the plants are fastened by means of a cake of plaster of Paris. In horizontal direction (from left to right as well as from front to back) long pins are driven through the column of soil and fastened to the netting.

This method, though one of the oldest, has undoubtedly great advantages. The reason why afterwards it has been hardly ever applied, is probably that the washed-out roots cannot be closely observed and measured. Moreover the washing out whilst the plants are still in the soil seems also very injurious. Almost every control on loss of roots is missing and with a block of earth of some size it gives great difficulties to clean the middle roots of earth.

Washing out the roots on the spot on the field is also done by DEHERAIN (7), who preferably chooses for this purpose the slope of a hill (MODESTOV (23), also on the level field). With this proceeding the roots are laid bare on one side and photographed. It is obvious however that in this way a photo of only one section of the root-system is obtained.

Finally I emphasise the method used by WEAVER (31), who works also with plants grown under normal circumstances and who lays bare the roots one by one with the help of pincette, small pickaxe etc., measures, counts laterals and draws up a design of the whole root-system on the spot. With this method no water is used.

Probably it is the most laborious of all methods. No doubt many important data about the various root-systems may be obtained in this manner — WEAVER's publications bear witness thereof — yet I am not convinced that in this way it is possible to follow all the roots of a plant in their course and to collect these roots so as to obtain reliable data about their weight. Also the designs in my opinion can not possibly give a true idea of the entire root-system. A comparison of the designs with the photos in WEAVER's book shows clearly the artificiality of the design. For that matter WEAVER does not intend to describe exactly the root-system of one plant, but rather to give a typical average picture, leaving out extremes. He says thereabout on page 259:

„When the depth of the roots of several plants has been determined and the general direction and greatest extent of the laterals are known, enough details will have been observed so that a mental picture of the root habit may be obtained", and on page 261:

„In every case it is sought to represent the typical condition rather than the extreme."

I perfectly agree to this, but the danger lies in the fact that the judgement becomes too subjective in this way. It is a pity that the data have seldom been collected into tables, so that afterwards it could always be traced, whereon the conclusion drawn, was founded.

WEAVER himself says (page 259):

„Such a description should include, among the other things, the number of main roots (or branches from a taproot); their diameters; how rapidly they taper; the average (as well as the minimum and maximum) number of branches per inch of main root at various places throughout their..."

The greater part of these data may be very easily collected into a statement so that the survey is facilitated and at the same time an idea is given of the variability and the reliability. Especially when it is a question of slight differences, as we may expect when comparing varieties of the same crop, a calculation of the mean error will be necessary so as to draw no wrong or rash conclusions. (See also: MARKLE (19)).

The work of WEAVER does not aim in the first place at establishing differences of variety, but yet I think it a great pity that the undoubtedly considerable expenses attached to the execution of the work, chiefly in the form of labour, have not been increased a little to lay down the observations as much as possible in tables.

The fact that the weights of the root-system are not given will probably be connected with the almost insuperable difficulty to lay bare the whole root-system and to collect the roots completely. Even though it is not intended to trace and to compare the relation shoot/root of several kinds or varieties of plants, yet the correlation between above ground and sub soil parts plays an important role (CRIST & STOUT (6). In general it may be said of plants of the same variety: the stronger the above ground development, the stronger also the subterraneous. (In every special case this thesis need not hold good of course. That with different manures plants that suffer from want of food develop a relatively big root system has been observed by many investigators. Especially N and H_2O play an important part here.)

To judge rightly of the root-system of a plant, the development of the above-ground part should be consequently taken into account. Now WEAVER in this respect often states merely the age of the plant, height or stage of development, surface of the leaf or a few of these together. Some idea of the above-ground development may be formed thereby, but yet the best criterion is the weight of the dry matter. After all the normal cultural conditions have not always been maintained. For instance turnips are grown in rows of 3,5 feet distance and 2 feet apart in the rows (32, p. 139). Also the distance of the peas seems very great (30 inches × 8 inches) (p. 174), when I compare it to the ordinary spacing in our country, which amounts to abt. 40 to 4 cm, so that here more than nine times the number of peas is grown on the same surface.

In WEAVER (31) the distance is mostly not stated at all whereas in

WEAVER (30) is pointed to the great influence of the spacing. From the preceding considerations it should not be deduced that I disapprove of WEAVER's work. On the contrary, I think it to be one of the best. It has been my intention however to put forth my objections to his method and to show that this method is less suitable for investigation in differences of variety.

Not a single one of the methods mentioned can be used unaltered for the purpose which I had in view.

All the methods (SCHULZE, KING, HAYS) that make use of pots or containers in which the earth is filled, are unsatisfactory because they do not meet the requirement „under normal cultural conditions''.

The methods (SCHULZE, KING, DEHERAIN, MODESTOV) according to which the roots of the plants are washed bare on the field in their more or less vertical position are too dangerous because a control of the loss of roots is missing. Moreover it gives rise to great difficulties with the drainage under the circumstances of our ordinary flat soil.

ROTMISTROF's method, as it has been altered by MASCHAUPT, is unsuitable because not all the roots are caught. When we assume that their quantity agrees with the roots collected from plants growing by their side, this is permissible on an average but in each special case it is not reliable if the plants considered one by one are not very equable. Moreover this method has the disadvantage that the direction of the partitions that are driven into the soil is difficult to regulate and that at the excavation lumps of earth with roots may easily be lost at the sides (see photo p. 88, MASCHAUPT (20)). To determine the weight of the root-system this method is therefore not reliable.

WEAVER's method is too laborious if it is the intention also to determine the weight of the entire root-system. Moreover I doubt whether this method is accurate enough for weight determination.

NEW METHOD

I made use of iron containers, that were driven into the soil before sowing time, so that in the soil very little was altered. The construction of these containers (photo 1) is as follows:

Four corner irons of 1,30 m length are joined with hoop iron on 5 cm distance from both ends in such a way that the whole forms a frame of 1,20 × 0,50 × 0,20 m.

Of this frame the 4 length-faces between the hoop-irons are covered with sheet iron. Thus the whole has the shape of a prismatic sheath of 1,20 m length and 1000 cm^2 diameter. Above and below, the corner-irons stick out 5 cm. This makes it possible to put a heavy block of wood on the container during the driving into the soil, which block receives the blows of the hammer and transmits them to the corner-irons, without exposing the much weaker sheet iron to these blows. The protruding parts at the bottom render service afterwards when the containers are hoisted up onto the ground.

The further construction of these containers is such that two of the corner-irons with a side-wall of 1,20 × 0,50 m. are detachable. For this purpose the two walls of 0,20 × 1,20 each are fastened with 10 screws to the above mentioned corner-irons.

As mentioned before, the containers are driven into the soil before sowing-time. Within the container nine peas are sown (or more) and later on thinned out to six, which corresponds with the number of peas per 1000 cm^2 surface of the soil outside the container. For further arrangement of the experiment-field see each year separately.

When the plants are collected the above ground parts are cut off first of all, exactly at the level of the soil.

Then a hole of abt. 1,30 m depth is dug just in front of the container to be excavated (see photo 2). The latter remains in its place, also when by means of a small spade the earth under and partly beside the container is removed carefully, without undermining the protruding corner-irons. The earth within the container is so firm that it does not show inclination to sag. During the hoisting of the container this would often happen however and therefore a piece of wood of abt. 48 × 18 cm is put under the container. A similar plank is laid on the top. Between the protruding corner-irons a cable rope is then drawn all around the narrow side-walls, with which container, with soil and planks is hoisted up by means of a tackle. If later on when the cable is removed, which causes the plank to get loose at the same time, part of the earth is in danger of dropping out of the container the planks are pressed against the soil by means of iron wire. Under the hoisted container two long beams are laid right across the hole. Onto these beams the container is lowered, hooked off the tackle and carefully moved in horizontal direction along the beams until abt. 2. Meter's distance from the hole. In the beginning it happened occasionally that when the cover was unscrewed and taken off, the two narrow side-walls bent somewhat outwards and a length-crevice appeared through the soil within the container. In order to prevent this a couple of big clamping-screws were used.

So as not to lose parts of roots that might have got loose in washing, a long wooden partition of 1,80 × 0,55 m is placed under the lower end of the container and pushed under it over some distance, so that all the washed off earth etc. drops onto it (see photo 3). This partition has upright edges of 3 cm and on $^1/_3$ and $^2/_3$ of its length a detachable cross-lath of 2 cm in thickness. Container with lengthening piece slope very slightly in the direction of the hole. During the washing-out earth, gravel etc. eventually together with loose roots collect on the partition in front of the cross-laths, whereas the water flows over them. Should parts of roots happen to be carried along by this water, they are not yet lost, for as a last precaution the lower end of the partition rests on a wire sieve, with a mesh width of 3 mm. In this way even the small particles of roots remain behind.

Here and there (two or three times per layer of 10 cm) the earth that has sunk in a thin layer on to the board and the earth on the sieve are cautiously rinsed away and when parts of roots are no longer found, the sieve is removed and the earth, gravel etc. washed into the hole.

With containers where the roots are washed out as a whole the matter on the partition does not usually amount to much; in the earlier stages till the flowering often to nothing.

When the distribution of the roots over the various layers of soil is controlled, the washing out takes place in nearly the same manner. Every time a layer of 10 cm is cut off with a sharp iron sheet of 48 × 22 cm and washed out. By the cutting off many loose and short particles of root appear. Especially in this case „slide'' and sieve render great service.

As may be readily understood, by this cutting off the washing out costs much more work. As a rule the washing is done by two men. The washing out of a container in its entirety then lasts from 3 to 6 hours whereas the washing out layer after layer costs from 6 to 10 hours.

It stands to reason that masses of water are necessary for this washing. This water could be obtained by means of a long garden hose from the waterworks of the laboratory of microbiology. My thanks to prof. Söhngen for the collaboration afforded.

The roots that have been washed out in their entirety are carefully taken out of the container and laid down on paper. The mass of roots of the 6 plants has — except in very early stages — intergrown to a whole. That makes it possible to roll them in the paper and to convey them in a narrow box of 1,20 m length to the laboratory without danger that they will get mixed up. In the laboratory the paper is unrolled, under water, in a zinc basin of 1,30 × 0,60 m and the roots are cleansed from straws etc. that have remained after the washing out.

When photographing roots with lengths up to 1,20 m several difficulties present themselves. Photographing in moist condition cannot be done because the drops of water between the roots cause blots on the photo. Drying the roots first is not permissible, because they have not yet been sufficiently cleaned for a determination of the weight and this cleaning cannot be done easily if the roots have been dry. The best thing is to photograph the roots under water. For this purpose an elevator is made use of. In the bottom of the elevator a hole has been bored, big enough to let through the lens of the apparatus. The basin with the roots is standing under the elevator whereas the light is procured by 2 × 6 lamps, fastened to the bottom of the elevator. Now the photographer takes the photo in the elevator through the hole in the bottom. The apparatus is focussed by causing the elevator to rise or descend to the right distance. The exposure must be long (20 or 30 minutes) in connection with the quantity of water above the roots.

After the photo has been taken the roots are freed as much as possible from all impurities by repeated transmission into clean water, unravelling with pincette, if necessary, rubbing off with pencil; and finally the dry weight is determined. The treatment, the roots undergo in this manner in the laboratory takes up even more time than their washing out on the field.

Intentionally I describe this treatment of the roots rather exhaustively to make in this respect also a judgement of the reliability of the results, possible. I feel prompted to do this, the more so, because I must acknowledge after all that in spite of all the precautions small mistakes occur. We must not think in the first place of loss of roots at the washing out. This mistake has been reduced to a minimum, I daresay.

We should rather look for mistakes in the cleaning of the roots in the laboratory. This difficulty is connected with the growing of the objects in the arable soil, which is naturally very much tainted with remains of plants of previous years. More than once, especially with the roots washed out in layers and therefore cut to pieces, I had to resort to the dissecting microscope in order to find out whether a supposed particle of root did belong indeed to the root-system of the pea. With the roots that are washed out in their entirety, this difficulty is eliminated almost entirely.

To measure the growth rate of the roots a so-called root cellar was made use of. In the ground a ditch has been dug of 10 m length, 1 m width and 1,90 m depth. The side walls each consist of 20 panes whilst a wooden roof excludes the light. At one end there is a ladder with trap door, whereas at the other end an airshaft supplies fresh air. Thus a subterranean passage is formed, through the glass walls of which one can observe with the help of a candle or pocketlantern the roots that grow along the outside of the glass.

In order to increase the chance that the roots will be and remain visible, the glass panes slope from above to below somewhat in outward direction. With the help of a pencil and paint the depth of the roots may be indicated on the glass at every observation and in this way determined how much the roots have grown in the period between two observations. It cannot always be clearly seen whether the visible part is indeed the top of the root. As the roots turn away more than once from the glass and so become invisible it is necessary to leave the last observation of a series of observations of the same root out of consideration. For it is probable that the turning away from the glass does not happen at the very moment of the observation but before it, even at an indefinite time, after the last observation but one. The number of measurings of the growth-rate is therefore in each series two less than the number of observations. If it is kept in view that many roots are only visible once or twice, to disappear then for good into the soil or to appear again only after some days, it is evident that a great many of the observations do not arrive at a result at all.

Moreover these observations of the growth have not been obtained under absolutely natural conditions. It will be readily understood that in order to get a good contact between glass and soil, the open space beside the glass had to be filled with earth after the root-cellar had been constructed. In 1927 the root-cellar was used for the fourth year.

Quite another difficulty presents itself at the working up of the data. It is really not to be seen whether a definite root is the mainroot or a lateral. The growth rate will probably be connected with this however, so that the calculated average growth rate is properly speaking, an average of not quite equivalent magnitudes.

INVESTIGATION IN 1927

For objects served ,,Mansholt's Nieuwe Kruising" for short M.N.K. and V 38. M.N.K. is a Pisum sativum bred by Dr. R. J. Mansholt, mediocre producer, already superseded by newer selections. Height about 75 cm.

V 38, a Pisum arvense, is a selection from a cross made bij VENEMA at the ,,Instituut voor Plantenveredeling", with luxurious growth, high straw yield, but low seed yield. Height about 75 cm.

See photo 4.

A. *Length growth measurings in the rootcellar.*

The root-cellar has the length-direction N–S. On either side five rows of peas were sown on the 13th of April. The frontrow at 5 cm's distance from the glass. On either side of the root cellar half M.N.K. and half V. 38. It lasted a long time before some roots became visible. Most of the observations took place in June and July. It has little value to state the separate observations.

Fig. 1 gives the average growth-rate since the 4th of June. The figures added indicate from how many roots the average has been calculated. As was remarked previously at the description of the method it cannot be ascertained whether the root observed is a main-root or a lateral of a lower order. As they probably differ in growth-rate this decreases the value of the average. The observations of finer roots, that were evidently laterals and had about a horizontal growth direction were indeed excluded at the calculation of the average. Although the growth rate is not improbably also a function of the depth and the

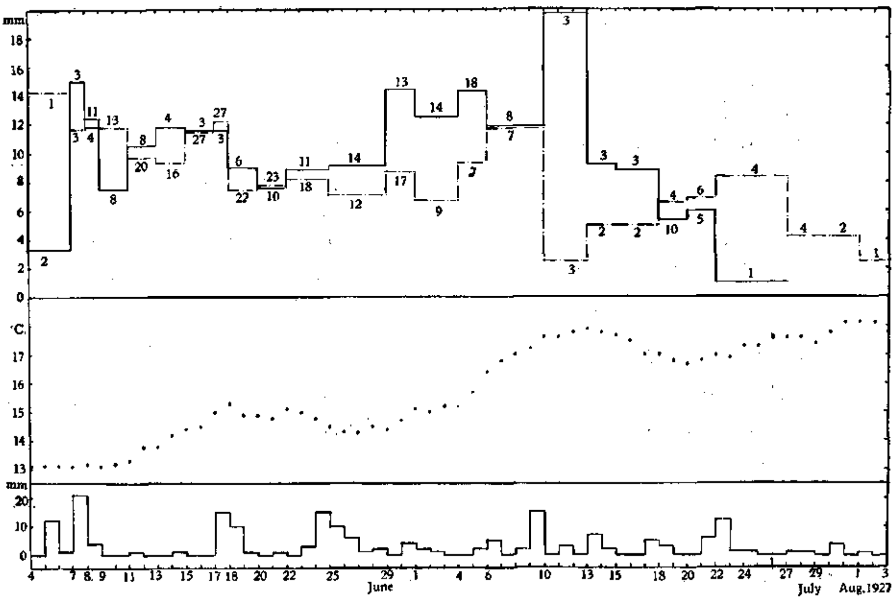

Fig. 1

Rate of root growth.
x-as: date of observation.
y-as: mean rate of growth, temperature of the soil at 50 cm depth and rain fall.
———— = M.N.K.
— · — · — = V. 38.
The figures signify on how many roots the calculation of the average is founded.

latter was continually noted therefore, it was not possible as a consequence of too few data, to trace this relation.

The dates of observation have been mentioned in the abscissa.

Besides the growth-rate, fig. 1, also gives the temperature of the soil taken on the spot at 50 cm depth and the rain-fall which data were procured by prof. dr. VAN GULIK, to whom I render thanks. From the fig. appears no clear relation between growth-rate and temperature of the soil or between growth-rate and rain-fall. At best we might say that the roots grow more in a dry period than in a wet one.

On comparing the two varieties it is evident that the M.N.K. grows more rapidly, but stops its root growth sooner than the V 38. The V 38 is later ripe than the M.N.K. The consequence of the greater

TABLE I RATE OF ROOTGROWTH

Date	d	g	v	d	g	v	d	g	v	d	g	v	d	g	v
M.N.K.															
8 Juny															
9 „							21,5	0							
11 „								1,5	8						
13 „								4,5	15						
15 „								?	25						
17 „								14,5		6	0				
18 „								16,5	20		0,5	5	19,5	0	
20 „								19	13		1	3		3	15
22 „								20	5		2	5		6,5	18
25 „				71	0			22	7		3,5	5		11	15
29 „	74,5	0			9	23		25,5	9		5	4		18,5	19
1 July		6	30		12	15		26,5	5		6	5		23	18
4 „		?	28		20	27	48,5	27			7	3		28	17
6 „		20			23	15					8	5		33,5	28
10 „		31,5	29		26,5	9								45	29
13 „		36,5	17	98	27,5									52	23
15 „		38	8							14,5	8,5	7	1,5	52,5	
18 „		40,5	8												
20 „		42,5	10												
22 „		44	8												
27 „		44,5	1												
29 „		?													
1 Aug.		?													
3 „	118,5	45													
V 38															
8 Juny	7,5	0													
9 „		1,5	15	2	0										
11 „		4,5	15		2	10									
13 „		7	13		4	10									
15 „		?	11		5,5	8	2,5	0							
17 „		11,5			7,5	10		4	20						
18 „		12,5	10		8,5	10		5,5	15						
20 „		14	8		9,5	5		8	13						
22 „		15	5		10	3		10	10						
25 „		16,5	5	12	10,5		13	12							
29 „		18	4							41	0				
1 July		18,5	3								3	15			
4 „		19	2								5,5	8			
6 „	27,5	20									?		25	0	
10 „											?	5		5,5	14
13 „											?			?	
15 „											11,5			?	9
18 „											13,5	7		13	
20 „											14	3		15	10
22 „											14,5	3		17	10
27 „											18	7		22,5	11
29 „											19	5		24	8
1 Aug.											20	3		?	
3 „										61,5	21		53	28	

d = distance from the level of the soil to the roottip.
g = growth in cm from the first observation.
v = mean rate of rootgrowth in mm per 24 hours.

TABLE 2

Date	ROOT					
	Average depth in cm.		Greatest depth in cm.		Dry matter in gr.	
	M.N.K.	V 38	M.N.K.	V 38	M.N.K.	V 38
May 3	26,6	23,0	30	28	0,144	0,218
May 17	46,5	40,8	56	51	0,664	1,339
May 31	65,0	56,7	72	71	2,100	3,066
June 13	86,8	76,3	90	95	5,348	4,900
June 27	71,2	78,8	77	85	5,173	6,853
July 11	100,3	83,4	115	94	5,334	6,699
July 25	108,0	105,6	113	114	7,602	9,352
Aug. 12	88,0	96,0	99	108	4,958	7,700

Date	SHOOT							
	Average length in cm.		Greatest length in cm.		Total dry matter in gr.		Dry matter of fruit only, in gr.	
	M.N.K.	V 38	M.N.K.	V 38	M.N.K.	V 38	M.N.K.	V 38
May 3	5,8	7,1	7	9	0,311	0,340		
May 17	9,7	11,2	11	13	0,807	1,247		
May 31	17,7	21,8	24	31	3,108	4,921		
June 13	45,3	42,3	49	48	10,717	11,445		
June 27	55,2	?	59	?	26,292	29,456		
July 11	82,0	82,5	95	96	44,870	43,470	9,870	1,120
July 25	75,5	73,8	79	80	76,090	81,200	32,340	24,220
Aug. 12	66,3	74,5	85	80	57,022	66,843	32,893	28,840

Date	SHOOT OF PLANTS FROM THE FIELD			
	Total dry matter in gr.		Dry matter of fruit only, in gr.	
	M.N.K.	V 38	M.N.K.	V 38
May 3	0,223(42) *)	0,269(18)		
May 17	0,823(46)	1,336(43)		
May 31	2,982(76)	4,452(57)		
June 13	7,476(40)	11,046(45)		
June 27	20,202(50)	32,256(50)		
July 11	36,456(12)	66,360(12)		
July 25	57,750(15)	113,904(12)	11,760	27,868
Aug. 12	80,052(12)	85,092(12)	44,100	28,056

*) Number between brackets gives the number of plants where upon the average is founded.

growth-rate of the M.N.K. is, that this variety reaches a greater depth notwithstanding its shorter vegetationperiod (see also 1928 and 1929).

The greatest depth observed is with the M.N.K. 114,5 cm and with the V 38 112,5 cm both as an average of 14 panes.

In table 1 the 10 longest series of observations have been united. Here also we see that the growth-rate of the roots of the M.N.K. is greater than of those of the V 38 and not seldom amounts to 3 cm per 24 hours. (Compare also per 24 hours: FRUWIRTH (11) potexperiments, peas, during six week average 2,23 cm, field experiments during six weeks average 1,5 cm. WEAVER (30) field experiments potato during two weeks 2,5 cm; corn during three à four weeks 5 à 6 cm. KING (17) potexperiments corn during 9 days 5 cm.)

B. *Investigations on the field.*

On the 4th and 5th of April 26 iron containers were driven into the soil; two of 40 cm, two of 60, two of 80, two of 100 en twenty of 120 cm depth. On the 11th of April the trial field (abt. 8 × 12 m) was sown with peas. Per container 12 peas were sown, which number was thinned out to 6 after their coming up (abt. 20 April).

The two objects M.N.K. and V 38 were distributed equally over the field and care was taken that every container was surrounded by peas of the same variety as grew within.

On the 3th of May the two shortest containers were excavated and further every fortnight, two, so that during the whole vegetation period the development could be followed. Allthough every time only one container (6 plants) of each variety was harvested, the successive harvests control one another. The roots were washed out in their entirety, always beginning with the root tips, to determine the rooting-depth exactly and not the root-length after stretching. The washing out in layers of 10 cm only took place at the end of the vegetation period.

As the root tips showed some injury by touching the (zinc covered) iron sheets, the following years heavily painted containers were always used. This precaution was decisive.

a. *Length and depth.*

In table 2 has been stated the average depth to which the mainroots have penetrated and beside it the greatest depth found in that stage. With the stems the height is not given but the length, measured from basis of the stem (surface of the soil) to the remotest leaftop.

With climbing plants like the pea, stating the height has little value as the latter is dependent on the support found.

In general the figures given for the root-depth are only somewhat smaller than the root length, (which has not been stated), because the root grows down almost perpendicularly.

If we compare the figures on the 6 plants of one variety the numbers diverge considerably, and the length of the root fluctuates even more than that of the stem.

From the table may be seen that with both varieties the length of the root surpasses that of the stem. Especially in the beginning of the development the root grows much more rapidly than the stem. It is striking that this is to a still greater extent the case with the M.N.K. than with the V 38. This appears so on consideration of fig. 2.

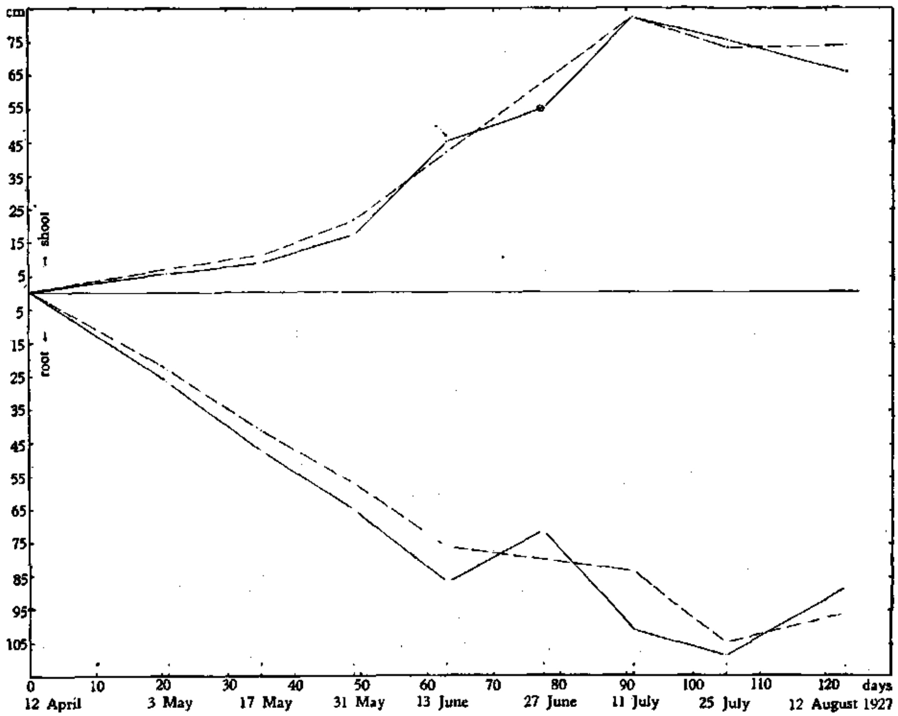

Fig. 2

——— = M.N.K. — — — — = V 38
Length of shoot and depth of root. Average of six plants.
Abscissa: age in days and dates of yield.
Ordinate: distance of remotest leaf top, resp. root tip to the level of the soil.

As regards depth of the root, the M.N.K. is foremost, whereas on the contrary the length of the stem remains behind that of the V 38.

As appears from the fig. the course of the curves is rather gradual with a considerable deviation for the roots of the M.N.K. at the harvest on June 27th.

An explanation hereof cannot be given. It is remarkable, that the poorer length-development of the roots is not reflected in the dry matter-yield of the above-ground parts as appears especially from fig. 3, where the growthcurve of the M.N.K. proceeds very regularly also in this place. If we want to attach any value to this phenomenon, we must conclude from it that there is no close correlation (during the development!) between the depth of the roots and the dry matter production of the above-ground parts and that there are consequently other qualities of the roots that have more influence in this respect.

Though it is not very probable, a possible loss of roots during the washing out must be kept in mind, the more so as the rootweight

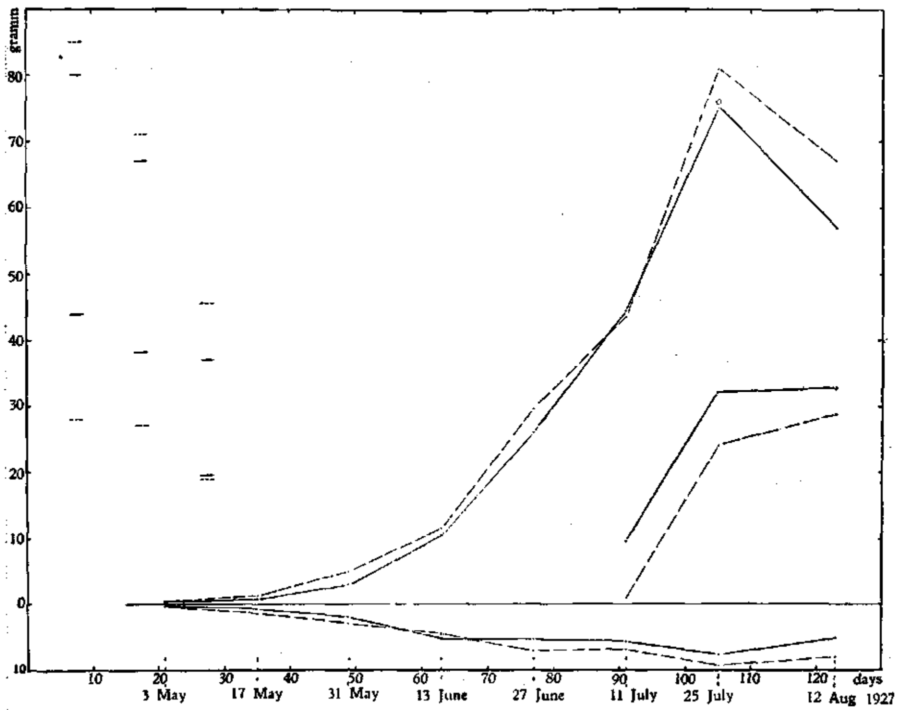

Fig. 3

——— = M.N.K. — — — — = V 38.
Dry matter of shoot and root (six plants).
Abscissa: age in days and date of yield.
Ordinate: weight in grams.
From July 11th to August 13th also the weight of fruit. To the left of the curve separate dots from left to right indicate the same for plants grown on the field beside the containers, aside the root cellar and in the green house.

from June 13th to June 27th according to the figures recedes indeed. On consideration of fig. 3 a deviation in positive direction for June 13th should be assumed rather than a deviation in negative direction for June 27th.

b. *Weight.*

Table 2 gives also the dry weights of the shoots and roots on the harvest dates, which data have been united into a graphic representation in fig. 3. It strikes the eye that here the lines for shoot and root of the M.N.K. both fall within those of the V. 38. In absolute weights both root and shoot of the V 38 are heavier than of the M.N.K., whereas with the M.N.K. the root depth surpasses that of the V 38. If follows that the distribution of the roots over the consecutive horizontal layers must be different (see p. 22).

The rather strong descent of the curves at the end of the vegetation period should be partly ascribed to over-ripeness, whether with loss of more or less matter, and partly to the accidentally bad health in a couple of these containers.

Besides the total weights of all above-ground parts table and fig. give also the weights of pod + seed (fruit). It is evident that the M.N.K. contrasts favourably with the V 38 as regards fruit yield.

TABLE 3

DISTRIBUTION OF THE ROOTS OVER THE VARIOUS LAYERS OF 10 CM

Layer	Dry weight of roots in gr.		The same in % of the total rootweight		From the total wootweight are found		
	M.N.K.	V 38	M.N.K.	V 38	till	M.N.K.	V 38
0– 10 cm	1,050	1,610	24,0	26,0	10 cm	24,0%	26,0%
10– 20 cm	1,638	2,058	37,5	33,2	20 cm	61,5%	59,2%
20– 30 cm	0,560	1,162	12,8	18,7	30 cm	74,3%	77,9%
30– 40 cm	0,294	0,434	6,7	7,0	40 cm	81,0%	84,9%
40– 50 cm	0,273	0,322	6,3	5,2	50 cm	87,3%	90,1%
50– 60 cm	0,147	0,266	3,4	4,3	60 cm	90,7%	94,4%
60– 70 cm	0,168	0,189	3,8	3,0	70 cm	94,5%	97,4%
70– 80 cm	0,098	0,119	2,2	1,9	80 cm	96,7%	99,3%
80– 90 cm	0,063	0,021	1,4	0,3	90 cm	98,1%	99,6%
90–100 cm	0,050	0,007	1,1	0,1	100 cm	99,2%	99,7%
100–110 cm	0,021	0,007	0,5	0,1	110 cm	99,7%	99,8%
110–120 cm	0,007	0,007	0,2	0,1	120 cm	99,9%	99,9%

With every yield besides the plants in the container also plants from the open field, were cut off to serve as checks. As these plants had not been put at definite distances from each other within the row and these distances were neither measured at the yield, a comparison per unit of surface or — which comes to the same here — per unit of the available soil, is not possible.

Only a comparison per plant can be made and then it should be taken into account that the plants of the field had a varying density.

For the sake of completeness, I have inserted the statement of comparison (see table 2), mentioning, from how many plants the average has been calculated each time. In general the dry matter yield per plant in the open is with the M.N.K. somewhat less, with the V 38 somewhat more than the yield per plant from the containers. Further I have indicated on fig. 3 for comparison the dry matter yield of the above-ground parts total and of the fruits: 1°. of plants grown on the same field outside the containers, 2°. of plants grown near the root-cellar and 3°. of plants grown in a hot house and in clay. In absolute weights these data diverge rather much (especially the hot house plants deviate); with respect to each other we continually find the same order of succession as with the plants in the containers.

c. *Distribution of the root mass over layers of the soil of 10 cm.*

At the end of the vegetation period, when the plants were ripe,

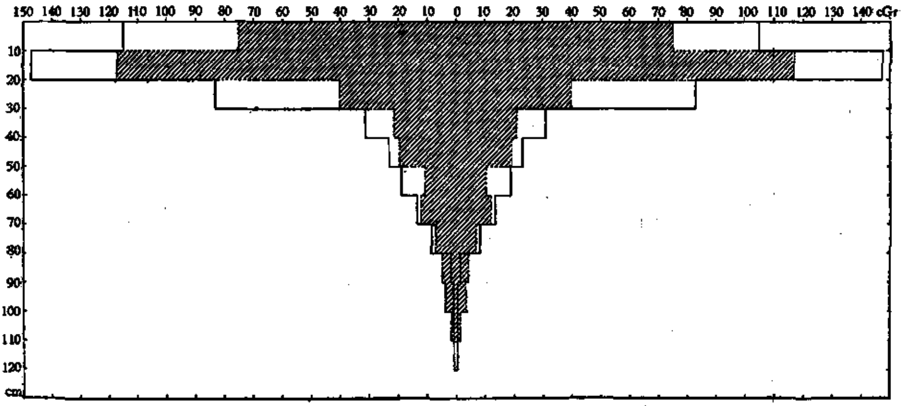

Fig. 4

Distribution of the roots over the various layers. of 10 cm.
Ordinate: depth in cm.
Abscissa: weigth in cgr.
////// = M.N.K. (hatched)
| = V 38.

on August 17th, 18th and 19th two containers were washed out in layers of 10 cm. Table 3 gives the quantity of dry matter per layer both in absolute figures and in percentage of the total.

By far the greatest part of the roots was found in the uppermost 30 cm of the soil and of these three layers it is the layer of 10–20 cm where the roots ramify most and that contributes therefore most to the root weight. The layer of 20–30 cm contains already fewer roots and beneath it the rootquantity diminishes very considerably (fig. 4).

The cause of this sudden strong decrease of the quantity of roots will probably have to be sought in the tillage of the soil. Exactly in the layer of 20–30 cm we find the ploughpan. The underlying soil has consequently never been loosened and offers therefore a great resistance to the penetrating roots. The greatest hardness of the soil we find just under the furrow, so still partly in the layer of 20–30 cm. (Compare the appendix where the permeability for water has been determined for the soil in natural condition and also TEN EYCK (9), who says on page 334: „In washing out this sample it was noticed that the soil between the depths of seven and twelve inches, that is the portion lying just beneath the region ordinarily loosened by the plow, was harder and more gummy than the soil either above or below it. The roots do not seem to penetrate this zone readily, but rather prefer to run laterally and almost horizontally in the looser soil above."

Next to the great resistance also the quantity of food plays a great part, of course, as well as the gasexchange. Which factor plays the most important part is difficult to decide. In the literature we repeated-

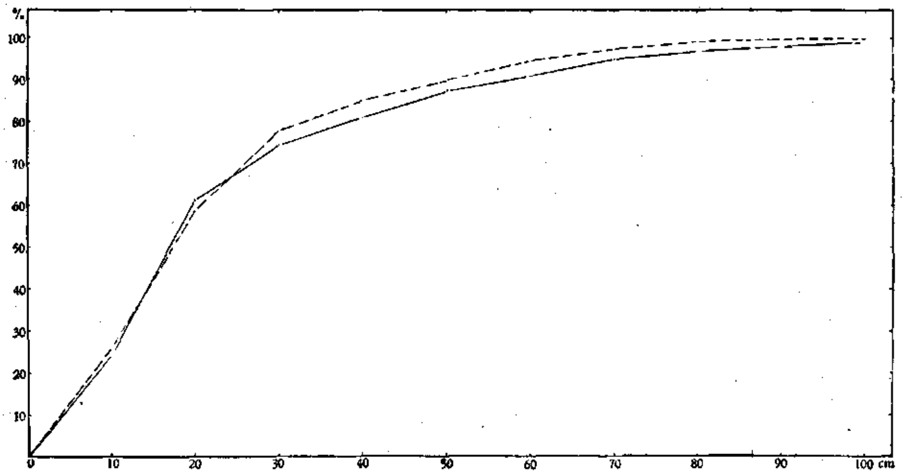

Fig. 5

——— = M.N.K. — — — — = V 38.
Rootweigth in percentage as a function of the depth.
Abscissa: depth in cm.
Ordinate: rootweight in %.

ly find mention made of a great influence of the resistance (CARLSON (5), KAMPE (16), MARKLE (19), POLLE (24), TEN EYCK (9)). Various investigators are even of opinion that the roots require the wormholes and other canals, (remainders of former roots) in order to be able to penetrate deeply into the soil (BÖHME (1, 2). BRENCHLEY and JACKSON (3), KLÄSENER (18) and MODESTOV (23). Others (FRUWIRTH (11), SEELHORST (28)), protest against this conception however.

In my opinion the wormholes are not necessary but they are followed with preference. Probably not only for the sake of the smaller resistance however, but also in connection with food (excrements). Very often several roots go down together through one wormhole. In the root cellar I have been able to determine that the growth rate in the wormholes is mostly greater than outside.

In the deeper layers the branches are usually few in number, which is likely to be connected with the poverty of food on the spot (see appendix), may be in particular with the nearly total absence of N.

If we compare the two objects in the graphic representation of the quantity of roots per layer, it is striking that the V 38 produces many more roots in the uppermost layers, whereas the M.N.K. has more roots in the deeper layers. Further the rootweight in the successive layers continually decreases with the V 38, whereas the M.N.K. has formed more roots in the layer of 60–70 cm than in the previous layer.

This phenomenon is no characteristic difference!

Also the V 38 may occasionally form more roots in a deeper layer than in a layer above (see table 7). Moreover the arbitrary division into layers of 10 cm is apt to prevent the appearance of this phenomenon in some cases. A characteristic difference is indeed that the M.N.K. roots generally deeper than the V 38. For a good comparison thereof I have expressed the root distribution in the layers of the soil in percentage of the total rootweight and considered this rootweight in percentage as a function of the depth. See fig. 5 and table 3.

In the uppermost 30 cm as much as 77.9% of the roots of the V 38 and 73.4% of the M.N.K. are to be found.

d. *Shoot/root.*

As mentioned before in the introduction I have considered as criterion of the activity of the root-system the amount of the above-ground parts, that are provided by one gram of roots with water and nutrient salts. This proportion in dry weights of above-ground parts to roots I call the ,,shoot/root''.

TABLE 4

THE SHOOT/ROOT IN RELATION TO AGE

	May 3	May 17	May 31	June 13	June 27	July 11	July 25	Aug. 13
M.N.K.	1,90	1,37	1,48	2,00	5,08	8,41	10,00	11,50
V 38	1,56	0,93	1,61	2,34	4,30	6,49	8,68	8,68

In table 4 the shoot/root of both objects on the respective harvest-dates have heengathered, whereas fig. 10represents thesamegraphically.

In the first place it strikes the eye that with both varieties the curve shows an S shape. This indicates that the first ,,care'' of the pea is concerning the forming of an assimilation organ; that afterwards the root-system gets its turn. When the latter is well developed the growth of the above-ground parts again gets the upperhand and keeps it until maturity.

Further the shoot/root of the M.N.K. is in general considerably greater than that of the V 38. The fact that in the first half of June the shoot/root proportion is lower with the M.N.K. than with the V 38, we must put down to the strong root-development that takes place in that time with the M.N.K. on the strength of the figures obtained. As a consequence of the few observations (each time 1 container containing 6 plants) it is however really possible that the strong development of the roots of the M.N.K. found in this period is only accidental (compare also weight curve fig. 3).

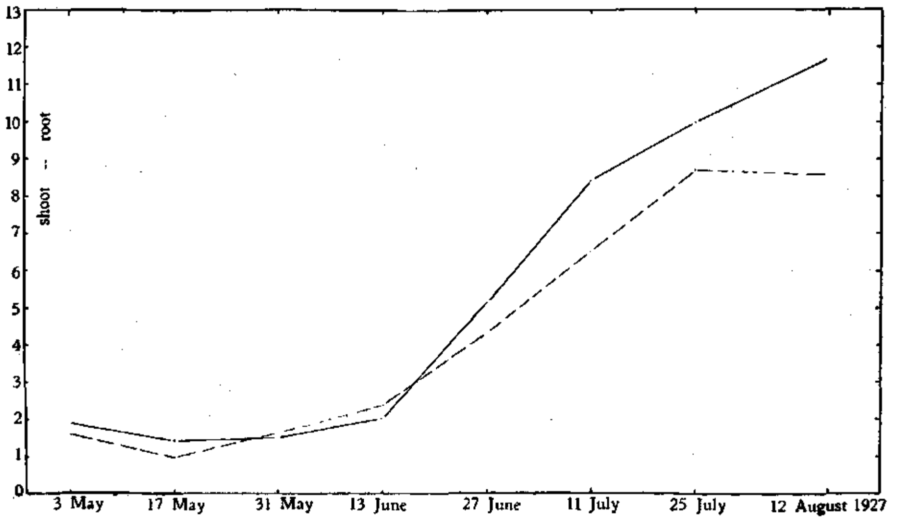

Fig. 6

The shoot/root as a function of the age.
Abscissa: dates of yield.
Ordinate: the ratio shoot: root.
——————— = M.N.K.
— — —·· = V 38.

Especially the quantity of roots of the M.N.K. on the 13th of June is probably too high.

Consequently the crossing of the curves for the shoot/root is perhaps not essential and in this case the root value of the M.N.K. during the whole of the vegetation period is greater than with the V 38. However in 1928 we meet with the same pehnomenon though not so pronounced.

INVESTIGATION 1928

In 1928 were used for objects:
Mansholt's Nieuwe Kruising '15 (M.N.K.);
Venema selection 38 (V 38);
Pois nain très hatif d' Annonay (Fr.);
Pflugs Baltersbacher Felderbse Peragis (Per.);
Capucyner G.Z.V. 8 (Cap.).

The first two objects are the same as in 1927.

Fr. = a P. sativum, bred by Vilmorin, Paris. Tender crop, very early ripe, very good seedyield. Height about 70 cm.

Per. = a P. sativum, bred by Rabbethge-Giesecke-Pflug, Berlin, with very long straw, heavy foliaged, but with small seeds and very low seedyield, fodderpea. Height about 210 cm.

G.Z.V. 8 = a P. arvense, bred by the Instituut voor Plantenveredeling. Good yielder. Height about 200 cm.

See photo 5.

The arrangement of the experiments deviated in the following respects from that in the year 1927.

1°. Per container only 6 peas were sown in order to be sure of a regular distribution of the plants within it. This had the disadvantage however, that a few plants that had not come up, had to be replaced by plants that had at first grown outside the container. For the Fr. this objection made itself strongly felt as appears from the following list of variety and container, where transplantation was necessary:

M.N.K. container 6, two transplanted; V 38: none transplanted; Fr.: container 1, one transplanted; container 3, one transplanted; container 4, four transplanted; container 5, four transplanted; container 6, one transplanted; Per.: container 1, one transplanted; Cap.: none transplanted.

2°. At the sowing was determined which individuals of the open field would be harvested later on as check. The latter as well as the adjoining rows, were sown at a mutual distance of twelve peas per 50 cm, which corresponds exactly to their distance within the container as regards volume of the soil, if we consider that the distance between two rows in the open field is 40 cm.

For each of the five containers with six peas each, there were in this way for the five varieties eight rows with twelve peas apiece as objects for comparison.

As mentioned in the introduction it was in 1928 i.a. the intention to be able to form a better judgment of the reliability of the results obtained by harvesting several containers of the same variety shortly after each other. For this reason the number of harvest-dates had to be restricted to two with a view to the expenses of the investigation. In all 2 × 3 containers of each variety were washed out, namely of

TABLE 6

Layer	Dry weight of roots in grams					The same in % of the total rootweight					From the total rootweight are found:					
	M.N.K.	V 38.	Fr	Per.	Cap.	M.N.K.	V 38.	Fr.	Per.	Cap.	till	M.N.K.	V 38.	Fr.	Per.	Cap.
0– 10 cm	1,155	1,965	0,915	1,485	1,785	25,2	34,5	23,7	25,9	31,2	10 cm	25,2	34,5	23,7	25,9	31,2
10– 20 cm	1,640	1,815	1,150	1,605	1,955	35,6	31,8	30,3	28,3	34,4	20 cm	60,8	66,3	54,0	54,2	65,6
20– 30 cm	1.065	1,390	0,915	1,040	0,835	23,1	24,4	21,9	18,6	14,8	30 cm	83,9	90,7	75,9	72,8	80,4
30– 40 cm	0,265	0,245	0,295	0,470	0,370	5,7	4,4	7,7	9,8	6,5	40 cm	89,6	95,1	83,6	82,6	86,9
40– 50 cm	0,225		0,395	0,575	0,410	4,8		8,7	9,6	7,3	50 cm	94,4	?	92,3	92,2	94,2
50– 60 cm	0,170		0,225	0,260	0,190	3,6		4,4	5,3	3,5	60 cm	98,0	?	96,7	97,5	97,7
60– 70 cm	0,065	0,290	0,190	0,195	0,090	1,3	5,1	3,8	2,3	1,7	70 cm	99,3	?	100,5	99,8	99,4
70– 80 cm	0,015		0,010	0,035	0,040	0,4		0,2	0,6	0,8	80 cm	99,7	?	100,7	100,4	100,2
80– 90 cm	0,012				0,005	0,3				0,1	90 cm	100,0	100,3			100,3
90–100 cm	0,010					0,2					100 cm	100,2				

TABLE 7

	Dry weight of roots in grams					The same in % of the total rootweight					From the total rootweight are found:					
	M.N.K.	V 38.	Fr.	Per.	Cap.	M.N.K.	V 38.	Fr.	Per.	Cap.	till	M.N.K.	V 38.	Fr.	Per.	Cap.
0– 10 cm	1,125	2,043	0,933	1,548	1,505	25,2	31,9	29,9	26,6	34,6	10 cm	25,2	31,9	29,9	26,6	34,6
10– 20 cm	1,115	1,763	0,723	1,465	1,218	24,7	27,0	23,1	25,2	29,2	20 cm	49,9	58,9	53,0	51,8	63,8
20– 30 cm	0,995	0,890	0,545	0,890	0,618	22,5	14,2	17,5	15,3	15,5	30 cm	72,4	73,1	70,5	67,1	79,3
30– 40 cm	0,315	0,450	0,243	0,413	0,230	7,2	6,9	7,7	7,1	5,4	40 cm	79,6	80,0	78,2	74,2	84,7
40– 50 cm	0,350	0,510	0,273	0,435	0.325	7,8	8,0	8,7	7,5	7,7	50 cm	87,4	88,0	86,9	81,7	92,4
50– 60 cm	0,313	0,455	0,235	0,463	0,233	6,8	7,2	7,5	7,9	5,5	60 cm	94,2	95,2	94,4	89,6	97,9
60– 70 cm	0,205	0,233	0,125	0,365	0,065	4,6	3,5	4,2	6,3	1,8	70 cm	98,8	98,7	98,6	95,9	99,7
70– 80 cm	0,035	0,080	0,040	0,185	0,015	0,8	1,2	1,4	3,2	0,4	80 cm	99,6	99,9	100,0	99,1	100,1
80– 90 cm	0,020	0,033	0,010	0,045		0,5	0,4	0,3	0,8		90 cm	100,1	100,3	100,3	99,9	
90–100 cm	0,010			0,013		0,3			0,2		100 cm	100,4			100,1	
100–110 cm	0,005			0,003					0,1		110 cm				100,2	

3 containers two in layers of 10 cm and one in its entirety.

The ground where the objects grew, joined that of 1927, so that the differences of the soil were restricted to a minimum.

a. *Root depth and weight distribution over layers of 10 cm.*

As was stated already in the report of 1927 the root depth fluctuates very considerably between individuals of the same variety so that in this respect no characteristic differences between the varieties can be determined, if not, as was done in 1927, the whole course of the growth is followed. The greatest depth of the roots in the containers reached was:

TABLE 5 THE GREATEST DEPTH OF THE ROOTS

		M.N.K.	V 38	Fr.	Per.	Cap.
Abt. 15th June	I	90–100	60–70	50–60	70–80	80–90
	II	66	87	72	88	74
	III	80–90	?	70–80	70–80	80–90
Abt. 15th July	IV	88	90	74	80	72
	V	90–100	70–80	70–80	100–110	70–80
	VI	90–100	80–90	80–90	80–90	70–80

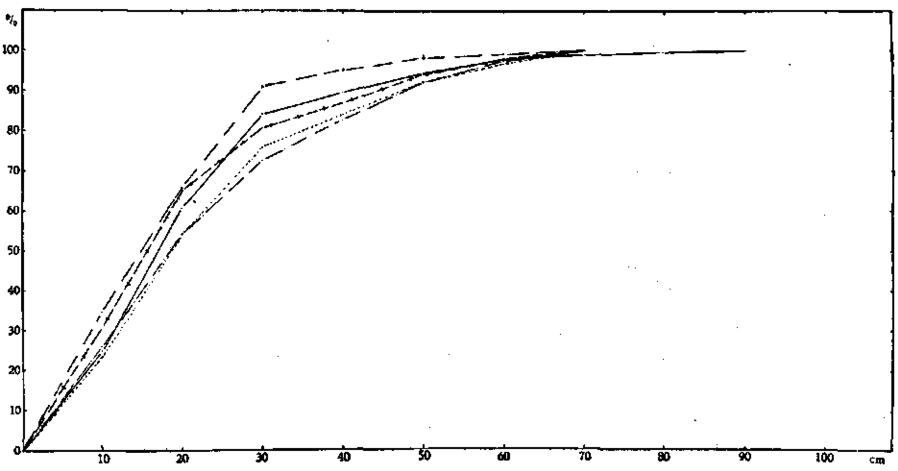

Fig. 7

— — — — = V 38. ——— = M.N.K. — + — + = Cap. ········ = Fr. — · — · — = Per.

Root weights in percentages as a function of the depth on abt. June 15th.
Ordinate: percentage of the total dry-weight of the rootsystem.
Abscissa: depth in cm.

If we compare the data of the M.N.K. and V 38 with those of 1927, it is obvious that in 1928 the roots in general penetrated not so deeply into the soil as in 1927.

At the distrubution of the root-weights over the layers of the soil of 10 cm we find again considerable differences. See tables 6 and 7. As in 1927 (see fig. 4) we find for 1928 and also for 1229 that, in general the rootweights of the better yielders in the dieper soil layers surpasses that of the poorer yielders. The curves for 1928 and 1929 corresponding to fig. 4 of 1927 have however been omitted as, with four of five objects, the curves would be overstocked with lines.

With all varieties we find again by far the greatest part of the roots in the three uppermost layers. Then the root-weight suddenly decreases very considerably to rise again somewhat in general in the layer of 40–50 cm. As was stated in the report of the results of 1927 I do not think that this increase of the rootweight in a deeper layer is an important question for the characterization of the different varieties.

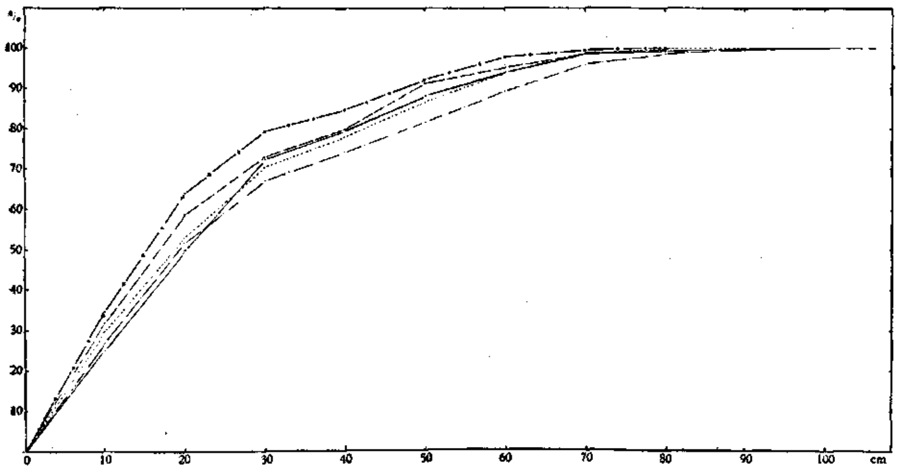

Fig. 8

—+—+ = Cap. ———— = V 38. —— = M.N.K. ········ = Fr. —·—·— = Per.

Root weights in percentages as a function of the depth on abt. July 15th.
Ordinate: percentage of the total dry-weight of the rootsystem.
Abscissa: depth in cm.

For the detection of differences of variety we should not pay attention to absolute rootweights but to the proportional distribution, as otherwise we get confusion by an accidentally poor or firm development of the limited number of individuals. The figures given on the 15th of July show for instance, that the rootweights of the Cap, are lower than on the 15th of June, which is evidently due to lesser development of this variety in the containers harvested on Juli 15th, which also shows itself in the weights of the above-ground parts. The weight increase hereof since abt. June 15th is relatively speaking, much smaller than with the other varieties and with the plants of the field (see table 11).

Tables 6 and 7 give also the root weight of each layer expressed in percents of the total rootweights.

As far as a depth of 30 cm. (furrow) we find:

	M.N.K.	V 38	Fr.	Per.	Cap.
On abt. June 15th	83,9%	90,7%	75,9%	72,8%	80,4%
On abt. July 15th	72,4%	73,1%	70,5%	67,1%	79,3%

If we take into con. ideration that the figure for the Cap. on July 15th is probably too high in connection with the poorer development, the succession (according to decreased rooting-depth) on both dates is: Per.–Fr.–Cap.–M.N.K.–V. 38.

Still more clearly this is shown in the curves 7 and 8, where the rootweight in percentages has been set out as a function of the depth.

If we compare the distribution of the rootweights on June 15th and July 15th, it appears that after the 15th of June the rootweights of the M.N.K. and V 38 relatively speaking, increase until 30 cm and thereupon decrease; with Fr. the rootweight decreases until 40 cm., then increases. With Per. it decreases until 50 cm and then increases.

For the total rootweights in grams see table 11.

b. The shoot/root relation.

TABLE 8

Container		M.N.K.	V 38	Fr.	Per.	Cap.
Abt. June 15th	I	4,48	4,05	5,04	3,36	5,56
	II	3,84	3,93	4,61	4,90	5,65
	III	6,18	6,01	6,88	5,17	8,72
Abt. July 15th	IV	10,07	8,76	10,37	8,82	10,32
	V	9,17	7,33	12,55	11,29	12,43
	VI	9,99	9,15	19,05	10,13	16,03
		9,74 ±0,29	8,41 ±0,55	13,99 ±1,61	10,08 ±0,71	12,93 ±1,67

The shoot/root is naturally considerably larger in July than in June. In the second part of the vegetation period the growth is entirely shifted to the above-ground parts, in particular to pod with seed. As appears from table 8 the fluctuations of the shoot/root are very great. After all the precautions that were taken in order to make the error *)

*) N.B. Everywhere a group of 6 plants is taken as an unit and the mean error calculated as: $m = \sqrt{\frac{\Sigma a^2}{n (n-1)}}$.

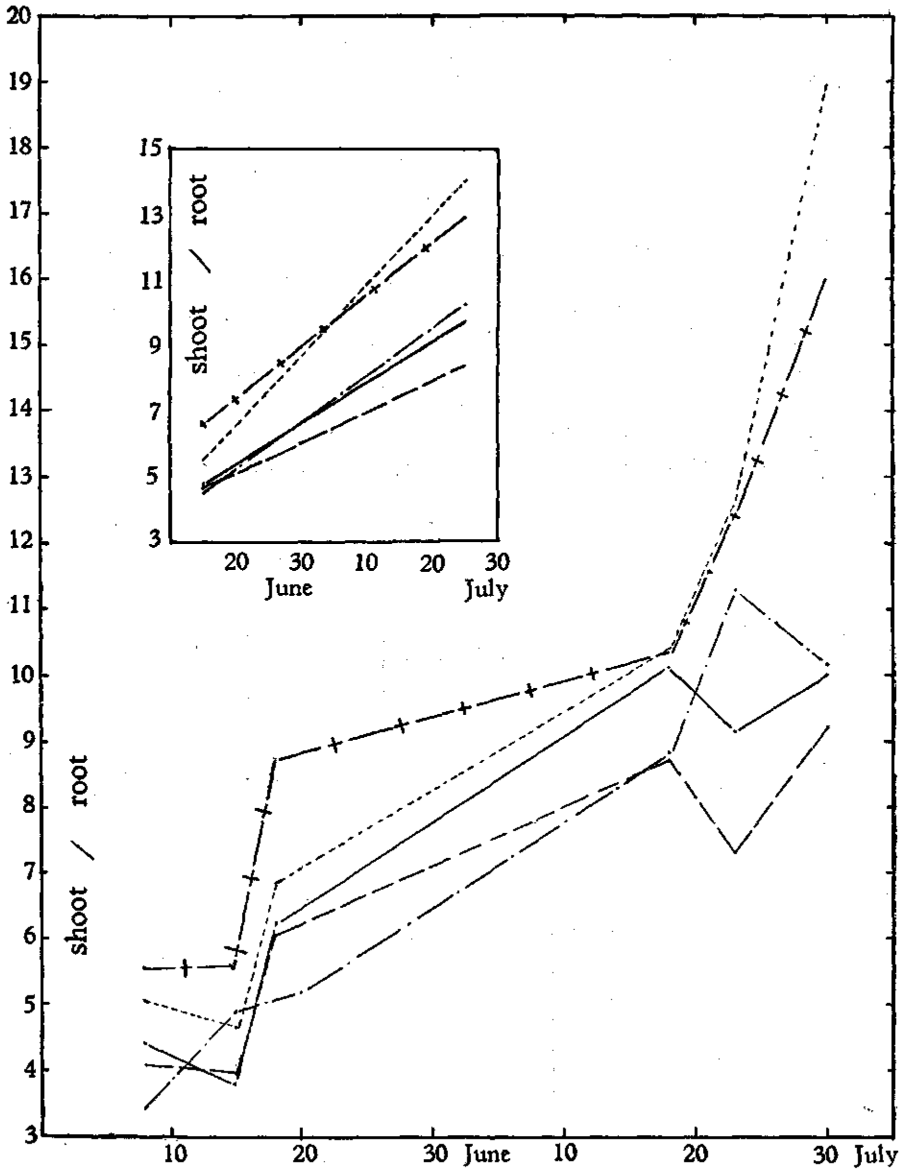

Fig. 9

The shoot/root in connection with age. Beneath for each container separately, above the average of the three containers yielded at flowering time and idem of the three containers yielded at ripeness.
Abscissa: date of yield.
Ordinate: shoot/root.
—+—+ = Cap. ---- = Fr. —— = M.N.K. —·—·— = Per. ———— = V 38

as small as possible by accurate working, this is not very encouraging. The necessity of parallel experiments is shown so much the more.

When judging the above figures we should not lose sight of the fact that it was impossible to harvest the containers all on the same day. Moreover not all three containers of the same variety were harvested one after an other, but of each variety first container I, then container II etc. Especially in the flowering time, when the growth is still very vigorous the harvests of the containers of the same variety differ so much in time (abt a fortnight) that the shoot/root modifies itself and thus makes the mean-error seem greater than it is. In this case we had better compare the shoot/root of the respective varieties as connected with the time (see fig. 9). To my regret the date of the washing-out has not been noted for each separate container in the flowering-time, but only when the first series was started with, when the second and when the third. If we arrange the varieties according to decreasing shoot/root we get for succession in the flowering time:

	Cap.	Fr.	M.N.K.	V 38	Per.
1st. container	1	2	3	4	5
2nd. container	1	2	5	4	3
3rd container	1	2	3	4	5

But for one exception we consequently find continually the same succession in shoot/root.

In the same manner we get for succession at maturity:

Fr.	Cap.	Per.	M.N.K.	V 38
1	2	4	3	5
1	2	3	4	5
1	2	3	4	5

Here also the succession of the 3 containers was the same with one exception.

With respect to the flowering time Fr. and Cap. have changed places and the Per. has been removed to the 3rd place. It is evident that for the shoot/root as an index of the root value the figures of the harvest at maturity have the greatest value.

If we calculate the mean error of the figures for the shoot/root in the final stage and assume therefore that in this harvest period the rootvalue is no longer modified, we obtain.

Fr.	13,99 ± 2,61.
Cap.	12,93 ± 1,67.
Per.	10,08 ± 0,71.
M.N.K.	9,74 ± 0,29.
V 38	8,41 ± 0,55.

The very considerable mean error with Fr. should be ascribed for an important part to the transplantation on account of not comming up (see page 26). For another part, perhaps, to over-ripeness so that the rootweight has already gone back in container 6.

That the cause of the great mean error does not depend or need not depend on the difficulties with the quantitative collection of the roots, appears for that matter from the fact that the mean error expressed in % of the average is of the same order with the above ground parts:

	M.N.K.	V 38	Fr.	Per.	Cap.
Abt. July 15th.					
Stems	5,2%	12,0%	23,7%	4,0%	2,4%
roots	8,3%	6,2%	16,8%	4,3%	14,6%
shoot/root..	3,0%	6,5%	18,7%	7,0%	12,9%

As a consequnece of the great mean error the differences in shoot/root which in themselves diverge 66% of the lowest value cannot be determined with ,,certainty" if we put as a requirement for the ,,certainty" that the difference has to amount to at least 3 × the mean error of the difference. See tabel 9.

TABLE 9

DIFFERENCES OF THE SHOOT/ROOT

	V 38	M.N.K.	Per.	Cap.
Fr.	5,58 ± 2,67	4,25 ± 2,63	2,91 ± 2,70	1,06 ± 3,10
Cap.	4,52 ± 1,76	3,19 ± 1,69	2,85 ± 1,80	
Per...........	1,67 ± 0,90	9,34 ± 0,77		
M.N.K........	1,33 ± 0,62			

Differences of the shoot/root with the mean error of each difference.

The above table represents the differences in shoot/root between

TABLE 11 DRYMATTER IN GRAMS

	M.N.K.			V 38			Fr			Per			Cap.		
	container		field	container		field	container		field	container		field	container		field
	root i. gr. 6 plants	shoot 6 pl.	shoot 12 pl.	root 6 pl.	shoot 6 pl.	shoot 12 pl.	root 6 pl.	shoot 6 pl.	shoot 12 pl.	root 6 pl.	shoot 6 pl.	shoot 12 pl.	root 6 pl.	shoot 6 pl.	shoot 12 pl.
± June 15	4,30	19,26	60,73	5,59	22,65	46,34	3,10	15,62	36,96	6,16	20,68	37,11	6,05	33,64	85,33
	5,23	20,06	64,11	7,24	28,42	36,08	5,47	25,22	43,31	5,84	28,61	42,30	7,53	42,57	72,27
	4,94	30,53	64,14	5,82	34,98	41,51	5,09	35,04	37,98	5,10	26,39	51,89	5,31	46,30	73,56
			30,76			50,33			33,88			35,07			76,47
Average	**4,82**	**23,28**	**54,94**	**6,22**	**28,68**	**43,56**	**4,55**	**25,29**	**38,03**	**5,70**	**25,23**	**41,59**	**6,30**	**40,84**	**76,91**
	±0,27	±3,63	±8,10	±0,52	±3,56	±3,08	±0,73	±5,61	±1,96	±0,29	±2,36	±3,76	±0,65	±3,76	±2,94
± July 15	4,11	41,40	100,40	6,01	52,63	88,08	2,16	22,40	74,00	6,60	58,22	120,14	5,92	61,11	153,02
	5,07	46,51	106,24	5,81	42,58	90,61	3,87	48,56	104,14	5,85	66,03	133,45	4,92	61,18	142,41
	3,90	38,97	107,81	7,08	64,75	77,54	2,88	54,85	108,60	5,80	58,73	117,59	3,50	56,80	159,56
			102,93			96,62			104,84			119,12			155,88
Average	**4,36**	**42,29**	**104,26**	**6,30**	**53,32**	**88,21**	**2,97**	**41,94**	**97,90**	**6,08**	**60,99**	**122,58**	**4,78**	**59,69**	**152,72**
	±0,36	±2,22	±1,73	±0,39	±6,40	±3,95	±0,50	±9,90	±8,02	±0,26	±2,52	±3,66	±0,70	±1,45	±3,69

the diverse varieties on the basis of the figures obtained at harvesting at maturity. The difference in shoot/root is nowhere 3 × the mean error. The possibility that the difference in shoot/root will deviate again in the same direction between the various varieties on repetition of the experiment gives table 10.

TABLE 10

	V 38	M.N.K.	Per.	Cap.
Fr.	0,9831	0,9400	0,8588	0,6328
Cap.	0,9945	0,9670	0,9401	
Per...........	0,9670	0,6694		
M.N.K........	0,9831			
or the odds are:				
Fr.	58 : 1	16 : 1	6 : 1	2 : 1
Cap.	180 : 1	29 : 1	16 : 1	
Per...........	29 : 1	2 : 1		
M.N.K........	58 : 1			

c. *Comparison yield of plants from containers with the controls on the field.*

Herewith of course, only a comparison of the above ground parts can be made.

See table 11.

If we express the average yield of the container in % of the average yield of the controls we obtain:

	M.N.K.	V 38	Fr.	Per.	Cap.
Abt. June 15th	85%	132%	133%	121%	106%
,, July 15th.....	81%	121%	86% 112%*)	100%	78%

*) If we discard containers IV en V, where in each 4 plants had to be transplanted see p. 26.

The yield of the peas that grew in the containers deviates considerably from that of the peas that grew on the field but the deviations do not lie continually in the same direction and of an unfavourable influence of the growing within the containers there is no question.

For the first harvest (June) we might even speak of advantageous influence.

Investigation in 1929

As experimental objects served:
Mansholt's Nieuwe kruising (M.N.K.)
Venema Selection 38 (V 38)
Unica (U.)
Victoria (yellow) (Vict.).

The first two objects are the same as in 1927 and 1928.

U=a P. sativum, bred by P. J. Hylkema, early ripe, high yield. Short, firm straw.

Vict.=a P. sativum, bred by Strube? (Schlansted), good producer, early ripe. Height 150 cm. See photo 6.

In relation to the experience of the preceding year that the fluctuations in dry matter production are very great, extra care was paid in the obtaining of an equable soil. In the autumn of 1928 the trial field (situated next to that recently used) was dug up once more and the rye-stubbles and other impurities removed. After the container had been driven in (spring 1929) the top layer of soil of 25 cm was scooped out everywhere of all the containers-, mixed, sifted and then brought into the containers again. In this way in every container the uppermost layer of the soil was as much equal as possible.

On the whole 36 containers were used, 9 for each variety. They were harvested in groups of 3. In order to lessen the influence of the modification of the shoot/root during the washing out, the 3 parallel containers of the same objects were harvested close to one another this year. In this way the yields of the respective varieties of course were not exactly collected at the same time but this method gave me the opportunity to follow the natural state of maturity of the various varieties better than the previous year.

Table 12

Container		M.N.K.	V 38	Unica	Victoria
Flowering	1	69	70–80	?	70–80
,,	2	40–50	82	80–90	90–100
,,	3	80–90	70–80	60–70	?
Fruiting	4	110–120	60–70	70–80	100–110
,,	5	94	90	?	125
,,	6	90–100	70–80	90–100	100–110
Ripe	7	95	90	60–90	60–90
,,	8	60–90	60–90	?	94
,,	9	60–90	90–120	90–120	60–90

Root depth in cm.

TABLE 13

STAGE OF FLOWERING

Layer	Dry weight of roots in gr.				The same in % of the total rootweight				From the total rootweight are found:				
	M.N.K.	V 38	U	Vict.	M.N.K.	V 38	U	Vict.	till	M.N.K.	V 38	U	Vict.
0– 10 cm	0,835	1,580	0,947	1,249	29,4	33,8	30,7	31,5	10 cm	29,4	33,8	30,7	31,5
10– 20 cm	0,995	1,735	0,770	1,105	35,5	37,2	25,4	27,8	20 cm	64,9	71,0	56,1	59,3
20– 30 cm	0,806	1,011	0,676	0,911	28,5	21,7	21,4	22,9	30 cm	93,4	92,7	77,5	82,2
30– 40 cm	0,708	0,242	0,157	0,182	2,6	5,1	5,1	4,2	40 cm	96,0	97,8	82,6	86,4
40– 50 cm	0,062	0,050	0,233	0,164	2,0	1,1	7,8	3,4	50 cm	98,0	98,9	90,4	89,8
50– 60 cm	0,042	0,032	0,227	0,165	1,3	0,7	7,4	3,4	60 cm	99,3	99,6	97,8	93,2
60– 70 cm	0,016	0,016	0,056	0,162	0,5	0,3	2,0	3,3	70 cm	99,8	99,9	99,8	96,5
70– 80 cm	0,003	0,004	0,004	0,133	0,1	0,1	0,1	2,7	80 cm	99,9	100,0	99,9	99,2
80– 90 cm	0,002		0,002	0,039	0,1		0,1	0,7	90 cm	100,0		100,0	99,9
90– 100 cm				0,004				0,1	100 cm				100,0

TABLE 14

STAGE OF FRUITFORMING

Layer	Dry weight of roots in gr.				The same in % of the total rootweight				From the total rootweight are found:				
	M.N.K.	V 38	U	Vict.	M.N.K.	V 38	U	Vict.	till	M.N.K.	V 38	U	Vict.
0– 10 cm	1,285	2,390	1,250	1,239	27,7	39,4	30,7	25,1	10 cm	27,7	39,4	30,7	25,1
10– 20 cm	1,676	2,010	1,094	1,285	36,1	32,3	27,1	27,1	20 cm	63,8	71,7	57,8	52,2
20– 30 cm	0,966	1,391	0,951	0,934	20,9	22,4	23,8	19,7	30 cm	84,7	94,1	81,6	71,9
30– 40 cm	0,160	0,145	0,193	0,264	3,4	2,4	4,8	5,8	40 cm	88,1	96,5	86,4	77,7
40– 50 cm	0,219	0,107	0,197	0,213	4,7	1,7	4,8	4,2	50 cm	92,8	98,2	91,2	81,9
50– 60 cm	0,165	0,088	0,212	0,226	3,5	1,3	5,2	4,6	60 cm	96,3	99,5	96,4	86,5
60– 70 cm	0,104	0,029	0,127	0,295	2,3	0,4	3,1	5,9	70 cm	98,6	99,9	99,5	92,4
70– 80 cm	0,038	0,002	0,016	0,220	0,8	0,1	0,4	4,3	80 cm	99,4	100,0	99,9	96,7
80– 90 cm	0,024		0,001	0,133	0,4		0,1	2,9	90 cm	99,8		100,0	99,6
90– 100 cm	0,005		0,001	0,013	0,1			0,3	100 cm	99,9			99,9
100– 110 cm	0,004			0,002	0,1			0,1	110 cm	100,0			100,0
110– 120 cm	0,001								120 cm				

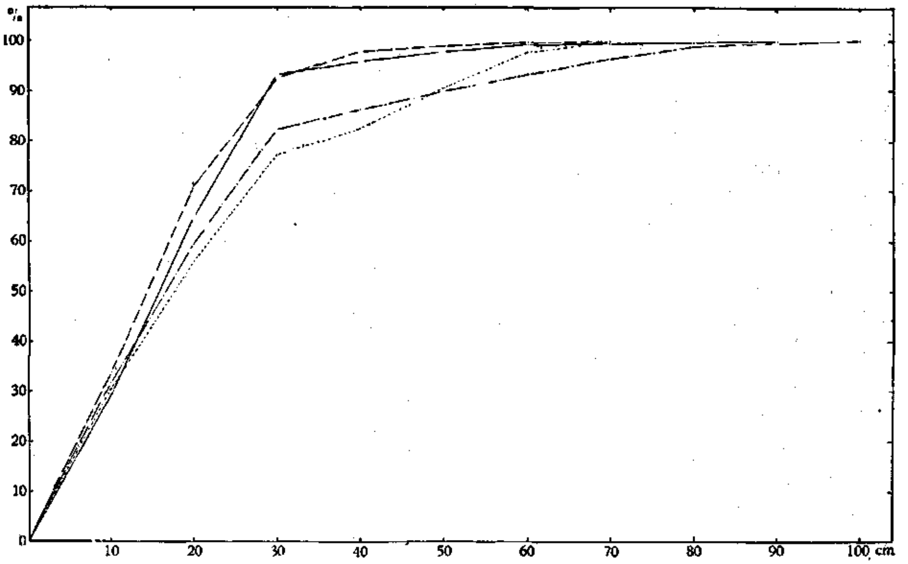

Fig. 10

— — — — = V 38. —— = M.N.K. .... = U. —·—·— = Vict.

Root-development as a function of the depth about 15 June (flowering stage).
x-as depth in cm.
y-as dry-matter in % of total dry-matter of the root.

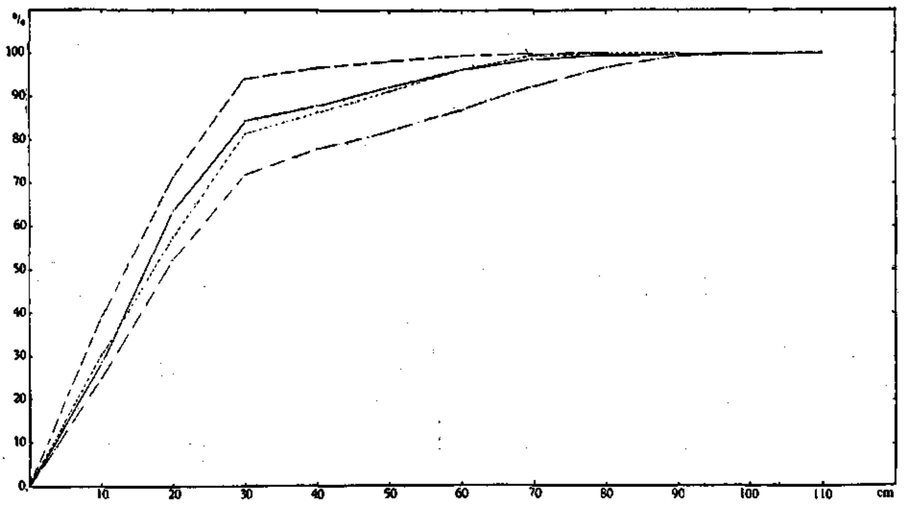

Fig. 11

— — — — = V 38. —— = M.N.K. .... = U. —·—·— = Vict.

Root-development as a function of the depth in the stage of fruitforming about 15 July.
Abscissa: depth in cm.
Ordinate: dry matter in % of the total root weight

The first yield was obtained at the beginning of the flowering, the second at the beginning of the fructification and the third at maturity. The succession in which the varieties were harvested, was determined anew at every harvest. In connection with this and with the practicability of the washing out, the chessboard distribution of the varieties over the field had to be given up. The four varieties now grew in four length-strips beside one another. This measure was more easily adopted because through the previous mixture the soil of the various containers only differed with regard to the sub soil.

Per container nine seeds were sown and the number of plants was restricted to six everywhere after the coming up of the seeds. Of three containers every time two were washed out in layers of 10 cm and one in its entirety.

a. *Root depth and weight distribution of the roots in layers of 10 cm.*

Also this year the exceedingly strong fluctuation in depth of the roots made itself apparent (Table 12). On the 6th of July for instance, roots of the M.N.K. were found in the layer 110–120 cm, whereas afterwards not a single container was found with roots deeper than 100 cm.

In the first three containers of the M.N.K. harvested from 10th to 12th of June the greatest depth fluctuated from 40–50 (container II) to 80–90 (container III). I draw attention to the fact that we have had one case with the Victoria that a root had grown through a wormhole deeper than the container and reached a depth of 125 cm (16th July).

TABLE 16 THE SHOOT/ROOT IN THE COURSE OF THE DEVELOPMENT OF THE PLANTS

	M.N.K.	V 38	Unica	Vict.
Flowering	2,65	4,28	3,87	5,54
,,	3,56	4,24	3,93	7,10
,,	4,35	5,24	3,75	5,91
Average	3,52 ± 0,49	4,59 ± 0,32	3,85 ± 0,05	6,18 ± 0,47
Fruiting	8,64	6,43	7,67	17,27
	7,52	4,76	6,75	12,32
,,	8,88	5,36	7,90	12,16
	8,35 ± 0,42	5,52 ± 0,49	7,44 ± 0,35	13,92 ± 1,68
Ripe	11,68	7,97	12,47	16,55
,,	11,38	8,12	12,19	14,55
,,	13,61	8,72	15,53	19,18
	12,22 ± 0,69	8,27 ± 0,23	13,40 ± 1,07	16,76 ± 1,34

Table 13 and 14 give the average weights of the roots in the consecutive layers of the soil at two harvests. At the third harvest the roots were not washed out in layers of 10 cm. We had to do this in order to save time, as otherwise the peas would become overripe.

If we calculate the quantity of roots per layer in % of the total weight of the roots (see table 13 and 14) and again set out this weight % as a function of the depth, we get fig. 10 and 11.

In the stage of fruitforming the succession according to the deeper rooting is: V 38, M.N.K., Unica and Vict. At the beginning of the flowering period the differences are not yet so marked, but nevertheless point in the same direction.

In the uppermost 30 cm we find:

TABLE 15

	M.N.K.	V 38	Unica	Vict.
flowering	93,4%	92,7%	77,5%	82,2%
fruit	84,7%	94,6%	81,6%	71,9%

b. *Shoot/root.*

Table 16 gives the shoot/root of the objects for all three harvests. If we pay attention to the succession according to shoot/root we find the latter to be at the beginning of the flowering in all containers (with one exchange in the 3rd container):

Vict.	V. 38	U.	M.N.K.
1	2	3	4

At the biginning of the fruitforming:

Vict.	M.N.K.	U.	V. 38
1	2	3	4

and at maturity:

Vict.	U.	M.N.K.	V. 38
1	2	3	4

This succession may be artificial, as the containers of the respective varieties have not been harvested simultaneously and the shoot/root is a function of age. We get a more reliable picture when we set out the shoot/root as a function of time (see fig. 12).

From this fig. it appears that the difference in shoot/root between

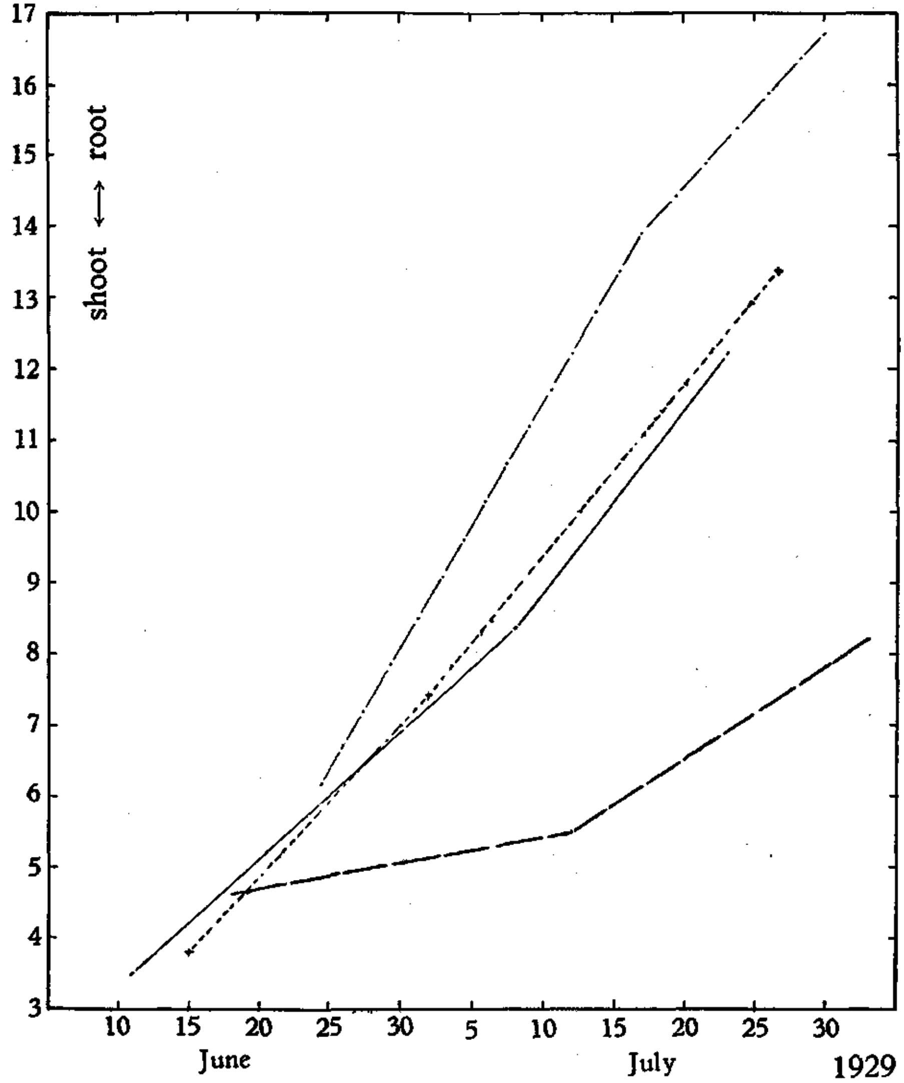

Fig. 12

—·—·— = Vict. ---- = U. —— = M.N.K. — — — = V 38.

The shoot/root as a function of time.
Abscissa: date of yield.
Ordinate: shoot/root.

the Unica and M.N.K. is small, that the Victoria deviates strongly in a favourable sense and the V. 38 again in an unfavourable. Further it is striking that just as in 1927 and 1928 the difference is not so great in the beginning of the vegetation-period and even partly reverses the order. It gives the impression here also that the bet+er varieties (i. e. as regards shoot/root and this need not go with greater seed-yeild) in the beginning of the vegetation-period concentrate their growth more upon the roots than the varieties, which are not so good.

If we pay attention to the mean error it appears that the latter is still very considerable, that the modified tillage of the soil and the harvesting of the parallel containers close upon each other have not been sufficiently effectual, though the results are more consistent indeed than in 1928.

TABLE 17 DIFFERENCES IN SHOOT/ROOT

	V 38	M.N.K.	Unica
Vict.	8,49 ± 1,36	4,54 ± 1,51	3,36 ± 1,71
Unica	5,13 ± 1,09	1,18 ± 1,27	
M.N.K. ...	3,95 ± 0,72		

In table 17 the differences in shoot/root between the respective varieties have been given with their mean errors. If we make it a requirement for the „certainty" of a difference that it must be three times its mean error, we find now that the difference in shoot/root between Vict. and M.N.K., between Vict. and V. 38, and between V. 38 and the remainder is „certain".

If we determine the possibility that on repetition of the experiment the differences fall out in the same sense we get table 18.

TABLE 18

	V 38	M.N.C.	Unica
Vict.	0,9999	0,9985	0,9761
Unica	0.9999	0,8019	
M.N.K. ...	0,9999		
or the odds are:			
Vict.	9999 : 1	666 : 1	41 : 1
Unica	9999 : 1	4 : 1	
M.N.K. ...	9999 : 1		

c. *Comparison of the yield of plants in containers with that of plants on the field.*

As may be seen from table 19, the yield of the plants in the containers

TABLE 19

DRY WEIGHTS IN GRAMS

	M.N.K.			V 38			Unica			Victoria		
	shoot		root	shoot		root	shoot		root	shoot		root
	field	container		field	container		field	container		field	container	
Beginning flowering	10,66	9,55	3,61	20,56	19,84	4,64	10,90	10,81	2,79	21,76	17,30	3,12
	9,30	9,28	2,61	19,12	21,44	5,06	11,63	10,10	2,57	32,14	36,22	5,10
	13,01	13,36	3,07	23,53	24,64	4,70	15,39	13,38	3,57	28,20	36,32	6,15
	8,34			15,83			17,81			28,19		
	10,33	10,73	3,10	19,77	21,97	4,80	13,93	11,43	2,98	27,57	29,95	4,79
	±1,01	±1,32	±0,29	±1,60	±1,38	±0,13	±1,63	±1,00	±0,30	±2,15	±6,32	±0,89
Beginning fruitforming	30,73	41,74	4,83	38,51	43,80	6,81	25,53	32,76	4,27	93,27	68,75	3,98
	28,06	39,85	5,30	26,50	29,77	6,26	39,42	33,40	4,95	58,04	84,49	6,86
	36,80	39,50	4,45	27,77	29,53	5,51	39,96	30,07	3,81	56,25	68,82	5,66
	30,03			38,00			35,56			71,77		
	31,41	40,36	4,86	32,69	34,37	6,19	35,12	32,08	4,34	69,83	74,02	5,50
	±1,88	±0,70	±0,25	±3,22	±4,72	±0,38	±3,34	±1,02	±0,33	±8,55	±5,24	±0,83
Ripe	61,83	42,75	3,66	69,70	54,77	6,87	57,22	32,79	2,63	68,28	24,00	1,45
	40,69	33,69	2,96	43,02	38,58	4,75	60,43	33,52	2,75	71,63	68,08	4,68
	47,20	34,56	2,54	60,94	40,03	4,59	50,01	46,11	2,97	67,93	51,41	2,68
	32,43			35,88			51,88			90,99		
	45,53	37,00	3,05	52,38	44,46	5,40	54,88	37,47	2,78	74,70	47,83	2,94
	±6,22	±2,89	±0,33	±7,82	±5,17	±0,73	±1,87	±4,32	±0,10	±5,49	±12,85	±0,94

is now higher and then again lower than that of an equally great number in the field. In general however, the yield within the container on the beginning of the vegetation-period is greater, towards the end it is smaller.

Though with the plants in the field the average is based on a greater number and we should consequently expect a smaller mean-error; this is not the case, obviously as a result of the more even conditions within the containers.

d. *Function of the roots deeper than 30 cm.*

In connection with the strong diminution of the rootmass on a depth of ± 30 cm, an effort has been made to determine of how much value is that part of the rootsystem that goes deeper than 30 cm. For this purpose the yield of normally developed plants has been compared with that of plants, the roots of which were cut through once a week. In order to be sure that no roots deeper than 30 cm escaped from the knife, the objects were grown in containers of special construction. They had a length of 50 cm, a width of 20 cm and a height of 30 cm. The side-pieces had a height of 40 cm and projected 5 cm below and above the sheath. Under the sheath proper is fastened hereupon a hoop-iron to the front and the back side in such a manner, that over the whole length of 50 cm a chink of ± 3 mm remains open between the wooden front (resp. backside) and this hoop-iron. The cutting takes place with a saw through these 2 chinks. During the cutting the saw projects somewhat beyond front- en backside. In this manner the root-depth is confined to 30 cm, whereas by the sawing till just into the side-walls not a single root can escape.

Of these containers 15 were used. They were driven into the soil in one row and each week a gully was dug in front- and at the back of containers, which was refilled immediately after the cutting to prevent the soil from drying up. Of every three containers only the first and the last were cut, whilst the middle one underwent no further treatment.

Further the plants in the first container received water when necessary in order to see in how far the damage done could be compensated for in this way. Should the deeper going roots only serve the water-supply, then it was to be expected, that the yield of the first container (group I) should remain only a little behind that of the second container (group II). Herewith it should be taken into consideration however, that by cutting-off not only the functioning of the roots that go deeper than 30 cm, was prevented, but also that the plant was damaged and most probably tried again and again to produce new roots at this spot. For this reason a full compensation would not be possible, even if the deeper-going roots should be exclusi vely useful for the waterprovision. Also in other respects objections may be made, e. g. influences upon gas exchange.

TABLE 20

DRY-WEIGHTS OF SHOOT IN GRAMS

	Group I cut off + water	Group II normal	Group III cut off without water
	33,89	55,79	34,96
	37,22	47,49	24,41
	39,88	56,78	31,57
	29,02	54,26	26,00
	22,91	50,92	26,76
Average ..	32,584	53,048	28,740
	± 3,02	± 1,71	± 1,96

Table 20 gives the results. That the giving of water compensated for the damage done only so very little, does not plead in favour of the supposition, that the deep going roots are exclusively useful for supplying in the want of water.

Striking is the high yield of Group II, when we compare it with the yield of the containers or of that of the field as given on page 43.

An explanation for this may be found most probably in the exposure to the sunlight. With a view to the cutting the objects had to be placed almost a Meter's distance from the rest of the experiment-field. In how far moreover the loosening of the soil on both sides of the containers has been of influence is difficult to estimate. As there is a chance that the containers of group I were not given sufficient water, especially in connection with the dry summer, this part of the investigation was repeated in 1930 and then the plants were given more water and when necessary oftener than once a day.

TABLE 21

DRY WEIGHTS OF SHOOT IN GRAMS

	Group I cut off + water	Group II normal	Group III cut off without water
	71,1	63,9	19,5
	51,2	82,8	37,1
	40,1	67,1	12,5
	52,2	79,5	12,8
	60,3	89,4	16,2
Average	55,0 ± 5,2	76,5 ± 4,8	19,6 ± 4,5

Indeed it proves from more careful irrigation in 1930 that the damage done by cutting-off the deeper going roots may be compensated for in a much greater part. See table 21.

DISCUSSION AND RÉSUMÉ OF THE PRINCIPAL RESULTS

The purpose of this investigation was to find differences in the root-systems of varieties of peas and to consider those differences in connection with the yield, in order to be able to form a judgment on the more or less favourable influence which any characteristic has on the yield.

A new method of investigation was used, that made it possible:

1°. to use the natural soil and environment as growing-place.

2°. to collect the roots quantitatively.

3°. to harvest the roots and the above-ground parts that belong together.

An objection to the method may be that the laterals cannot grow wholly free sideways but in that direction are restricted in their growth. However the normal volume of available soil is not altered and an unfavourable influence upon the yield could not be stated.

From the root-system in itself one cannot judge whether it is a good or a bad root-system. It is usually assumed à priori that a root-system is better in proportion as it is bigger, spreads wider, branches off more, etc. This is more or less assumptive and probably incorrect sometimes. The root-system is not the purpose merely a mean. A judgment of effectivness of the root-system is only possible on the basis of the above-ground development.

Reasoning so it seems logical to consider long roots as profitable to the plant, but to this consideration we can make the objection that together with the increase in length, the distance which the materials (both vice versa anorganic to – and organic from the above ground parts) have to be carried, increases, also. The development of the root-system lasts longer which may be a disadvantage for annual plants and especially if early-ripeness is desired. With plants that, like our crop plants are grown in masses close together it is not at all apparent, that long laterals are profitable. They snatch each others food and are consequently searching afar off for what they can also get close at hand. (Compare WEAVER 30, p. 62: „It should be kept clearly in mind that the ideal root-system is not necessarily one with the most extensive branching, but one that fully occupies the soil to an adequate depth and throughout a radius sufficient to secure enough water and nutrients at all times.")

Against the last remark may be said perhaps the roots do not only serve for the food-absorption but also for anchorage in the soil. This objection does not seem very important and in any case it does not hold good for peas, that — climbing plants as they are — need a support anyhow to stand firmly.

Moreover there are many factors that have to be taken into consideration when determining the value of a root-system, that cannot be traced in a simple way, such as suction pressure, permeability, inward resistance etc.

As the most effective criterion I have taken the weight-relation shoot:root and have called this proportionate number, for short: the shoot/root. Firstly, the root-system is considered by this in direct relation with the above-ground parts, that are harvested and secondly it denotes which root-system is most efficient, as it denotes with which root-system a gram of roots can supply the necessary minerals and water for the greatest number of grams of above-ground parts.

It is left undecided whether this is obtained by a more efficient construction, favourable suction pressure, permeability etc. A further analysis allows the possibility of getting some insight regarding the value of these simple characteristics mutually. Consequently whether the activity of a root-system is more connected with the branching-off than with the vitality of the functions.

The shoot/root is however not a measure for the absolute value, that has to be put down to a root-system. A low shoot/root for that matter need not be the result of a bad root-system, but may be the consequence as well of a bad shoot.

This reasoning is only right in so far as root-system and above-ground parts go on independent of each other in their growth. It is probable that in the given case the speed of the root-development will soon be checked by want of assimilates. To this points also the correlation that exists between the growth of the above-ground and underground parts. See CHRIST and STOUT (6). The possibility of a shoot/root being far too low is considerably lessened hereby. It is evident that the opposite deviation: the finding of a too great value of the root-system as a consequence of shoot-qualities does not exist.

Instead of simply speaking of shoot/root we ought to speak of a relative shoot/root viz. the value of the root-system with a given constellation of above-ground parts.

A judgment of the root-system „as such" or of its absolute value, consequently does not seem possible for the present.

With the help of pot-experiments it will perhaps sometimes be possible to determine whether a small relative shoot/root is the result of a small absolute value of the root-system or of the fact that the above-ground parts remain behind in growth through other causes than any root imperfection. In this case also a further analysis of the phenomenon of the diverging shoot/root ratios is possible. From experiments it appears, for instance, that the low shoot/root of the V. 38 as compared with that of the Fr. is not caused by a weak absorption of the various nutrients. The quantity of minerals which is absorbed per water-unit, is greater with the V. 38 than with the Fr. This phenomenon becomes more evident as the soil is kept drier. Also the ash-percent of the shootparts is with the V. 38 greater than with the Fr. and this difference also becomes more evident as less water is available per pot.

Further on is this in accordance with the results of the field-experiments of 1929. Here it appears that the ash-percentage of the abovegrounds parts of the V. 38 is greater than that of the other varieties with a greater shoot/root.

It is not my intention to enter further into the results of the pot-experiments, as these will be published in a further paper.

Of course in the experiment, attention was paid not only to the value of the root-system in its entirety, but at the same time to some simpler qualities.

TABLE 22 SHORT SUMMARY (WEIGHT IN GRAMS)

Object	Shoot/root	Total dry matter aereal parts	Dry matter roots	Dry matter seeds	% dry matter roots deeper than 30 cm
1927					
M.N.K.	11,50 (1)	57,02 (2)	4,96 (2)	*32,89 = 58% (1)	25,7% (1)
V 38	8,68 (2)	66,84 (1)	7,70 (1)	*28,84 = 43% (2)	22,1% (2)
1928					
Fr.	13,99 (1)	41,94 (5)	2,97 (5)	23,25 = 55% (1)	29,5% (2)
Cap.	12,93 (2)	59,70 (2)	4,78 (3)	22,11 = 37% (2)	(3?)
Per.	10,08 (3)	60,99 (1)	6,08 (2)	10,98 = 18% (5)	32,9% (1)
M.N.K.	9,74 (4)	42,29 (4)	4,36 (4)	17,01 = 40% (3)	27,6% (4)
V 38	8,41 (5)	53,32 (3)	6,30 (1)	14,44 = 27% (4)	26,9% (5)
1929					
Vict.	16,76 (1)	47,83 (1)	2,94 (3)	19.02 = 40% (1)	28,1% (1)
Unica	13,40 (2)	37,47 (3)	2,78 (4)	18,79 = 50% (2)	18,4% (2)
M.N.K.	12,22 (3)	37,00 (4)	3,05 (2)	13,37 = 36% (3)	15,3% (3)
V 38	8,27 (4)	44,46 (2)	5,40 (1)	9,71 = 22% (4)	5,9% (4)

* pod + seeds.

This is the case with the determination of the greatest depth of the roots, of the distribution of roots in the various layers of soil and of the root-mass (weight). This is to be considered as a further analysis, if we start from the shoot/root at least. In the subjoined table 22 — these data in the course of 3 years have been collected in an abreviated form, every time referring to the last harvest. For a total image of the connection of the various data for each year the succession of the objects has been indicated between brackets.

A relation between shoot/root and total absolute yield (1st and 2nd column) does not exist or it is not clear here at any rate. This does not surprise us when we consider that the total production of the above-ground parts, in grams is determined by the shoot/root × the weight of roots. The absolute weight of the root-system presents itself here as a simple factor which as may be understood — greatly influences the total yield in gr.

The relation between shoot/root and rootweights is neither very close, though here there is clearly the tendency that with a decreasing rootweight the shoot/root increases or in other words with increasing rootweight, also the topweight rises, but less rapidly!

More evident is the relation between shoot/root and seed-yield (in 1927 fruit-yield). With the exception of one case viz. the Peragis (a fodder pea) the shoot/root runs wholly parallel with the seed-yield. In column 5 has been added everywhere the share of the seed, (resp. pod in 1927), in % of the total weight of the above-ground parts. In general we may also say, the higher the shoot/root, the greater this percentage. This points to the fact, that for the forming of 1 gr of seed less roots are necessary than for the forming of 1 gr stem and leaves.

Remarkable is the relation between shoot/root and depth of the roots. The deeper-rooting varieties have a greater shoot/root. This is most evident on comparison of the shoot/root with the curves 5, 7, 8, 10, 11. In the last column of table 22 has been indicated how many % of the total quantity of roots are to be found deeper in the soil than 30 cm (more than the depth of the furrow). For the Cap. in 1928 the number 3 has been filled in, founded on the data of June. As communicated already in the discussion of the results of 1928, the July-harvest of the containers of Cap. is abnormally low as compared with that of the plants in the field (table 11, page 34. See also page 29). Apart from that, only the Peragis is an exception to this rule and this may be easily explained by the low shoot/root, in connection with the small quantity of seed, which Peragis produces. Consequently we see that shoot/root, seed yield and root depth vary in the same direction.

APPENDIX

Although the investigation was directed to the comparison of the different varieties of peas, it may be desirable for comparison with other root-investigations to communicate something about the soil, where the objects grew. Prof. Ir. J. Hudig has greatly obliged me by procuring the following:

„*Characteristics of the soil*" (by Prof. Ir. J. Hudig).

Sand-soil with about 5% of gravel.
± 20% coarse sand (1–0,2 mm).
± 68% fine sand (0,2–0.04 mm).
traces of fine silt (0,04–0,01 mm).
± 3% of fine silt (0,01 mm).
3% of humus.

The fluvial formation is of a pré-glacial type, now about 35 m above the water-level. Lea, in the deeper layers of the sub-soil occurs accidently but not on the experimentalfield itself.

The permeability is very sufficient whilst the content of humus and fine silt retain the percolating water to a good moisture content.

Unless the soil has been cultivated as far as we know since the 8th century, the humus content is not higher than 3% — which demonstrates a very good aeration of it.

Table 23

Depth	Humus percent	Lime-condition	Phosphoric acid	Permeability water	
0 – 10 cm	3,–	–17	11	120	
10 – 20 cm	2,7	–17	9	15	20
20 – 30 cm	2,4	–19	9	20	19
30 – 40 cm	2,–	–10	7	18	8
40 – 50 cm	1,6	– 9	7	8	
50 – 60 cm	1,5	– 7	6	5	
60 – 70 cm	1,2	– 7	6	4	
70 – 80 cm	1,–	– 6	5	6	
80 – 90 cm	0,7	– 7	4	7	
90 –100 cm	0,6	– 1	2	12	
100 –110 cm	0,7	– 4	2	12	
110 –120 cm	0,7	– 2	2	16	
				30	

We are able to produce some dates which are important for the knowledge of the chemical condition of the soil. Table 23 shows:

1. The humus content of the layers of 10 cm each from the surface down to 120 cm of depth.

   As is shown by the figures the humus has been divided to about a depth of 50 cm. This is not due to infiltration; but to the storing up with a kind of stable-manure applied by the former cultivators, which manure was prepared *with the sod of the near heath as an imbibition material.*

So we have rather to understand the surface soil as an artifical formation.

2. The lime-status means a degree of saturation of the humus complex; expressed as a lack or a surplus from a certain point considered as a zero-point. So f.i. –17 means that upon 1000 kg of humus, 17 kg of pure CaC03 is needed to bring the soil up to the zero-point. The zero-point itself is determined by the pH-value of 6,5.

   The figures show clearly that the lime-status increases to the deeper layers.
3. The phosphoric-acid-status has been determined by the method of shaking the soil during 16 hours bij 50° C. with destilled water and estimating afterwards the phosphoricacid by the Mo-blue-method of Doisy and Bell, later varied by v. Wrangel (Landw. Jahrb. 1926, 627–775).

   As has been shown by experience, figures of 6 mgr. pro 1000 gr soil and higher are only obtained by soils in a good phosphoric-acid status.
4. The potassum-status has only been determined for the upper layers of 30 cm and a date of 26 was found. The method by which this figure was obtained will be described soon by Prof. Hudig. It can only be said that soils with potassum-dates of 22 and higher are in good condition."

In the above table the last column contains data about the permeability of the soil with respect to water. These data were obtained as follows:

Zinc cases of 13 cm height and 1 square dm diameter were pressed into the soil as far as 3 cm without crumbling it. Then 1 ltr of water was measured and carefully poured into the sheath. The lapse of time from the infusion of the water until the moment that all the water has sunk away was noted. By doing this on different depths (0 cm, 10 cm, etc.) a measure was obtained for the permeability to water in the respective layers.

The numbers in the column are the average of 2 observations at a time. It is striking that the uppermost layer has a very small permeability. This will probably be the consequence of the closing of the surface by the rain and the swelling of the humus particles after wetting. Just below this upper thin layer the soil was much more loose and on 10 cm depth we find for the lapse of time of the transmission of 1 ltr water per square dm 15 min. At 20 cm the permeability is again less. Here we apparently come close upon the ploughpan, which probably plays a part in the growth of the roots through its firmness. On 30 cm the permeability becomes greater again, whereas on 40 cm it is suddenly much greater. In order to fix these transitions near the ploughpan somewhat more precisely, similar measurements were also done on 15 cm depth (20 min), 25 cm (19 min.) and 35 cm (8 min.).

This method for the determination of the permeability of the soil under natural circumstances is not new. I have applied it (perhaps somewhat modified) in consequence of a conversation with dr. Bünzli (Zürich), who first applied this „Einsicherungsverfahren". The great advantage of this method is that the soil is left undisturbed.

SUMMARY

1. A new method suitable for field conditions for comparative root investigations is described.

2. Generally varieties of peas with more roots (weight), produce a larger shoot, but the increase of the latter is less than proportional to the increase of the former.

3. The shoot/root ratio follows in the course of the growth a S-shape. It is suggested that the better producers in the early periods of growth have a more prominent root development than the others.

4. In my experiments deeper rooting varieties had a larger shoot/root and a higher seed yield. Of the seven tried varieties the only exception to this rule is a fodder pea, that gives a very heavy straw-yield, but a very poor seedyield.

5. The deeper going roots serve chiefly the water-supply.

6. Root development is strongly handicaped by the plough pan.

7. In photographing root preparations in water an elevator can be used profitably.

From the staff of our institute I wish to acknowledge especially the help of Mr. J. HOKSBERGEN and Mr. J. POST for doing chiefly the root washings on the field and of Mr. H. JANSEN for making the photographs.

HET WORTELSYSTEEM VAN ZEVEN ERWTENSOORTEN EN VARIETEITEN ONDER NATUURLIJKE OMSTANDIGHEDEN

Bij deze wortelonderzoekingen, die geduurd hebben van 1927 tot 1930 wordt gebruik gemaakt van ijzeren kokers (120 × 50 × 20 cm), die in de grond geslagen worden, zoodat de structuur van de grond ongewijzigd blijft (foto 1). Binnen de koker groeien 6 erwten. Het beschikbare bodemvolume per plant komt overeen met dat van de planten buiten de kokers (foto 2). Bij de oogst (in 1927 om de 14 dagen, in 1928 bij bloei en bij rijpheid, in 1929 bij begin bloei, 1×tijdens de vruchtzetting en bij rijpheid) worden de kokers met grond en al opgetakeld, plat neergelegd en de eene zijwand verwijderd. Met zeer veel water en nog meer geduld wordt het wortelsysteem in zijn geheel of in lagen van 10 cm schoongespoeld (foto 3). In het laborotorium vindt verdere reiniging plaats. De foto's worden genomen van uit een lift, terwijl het wortelstelsel zich daaronder bevindt in een bak met water. In de vloer van de lift is een gat geboord om de lens van het toestel door te laten.

De belangrijkste resultaten zijn samengevat in tabel 22. Met twee van de objecten zijn de proeven elk jaar herhaald om de invloed van het weer te kunnen beoordeelen. De cijfers in kolom 1 geven de wortelwaarde aan, d.w.z. hoeveel grammen bovengrondsche deelen door 1 gram wortels van de noodige voedingszouten en water kunnen worden voorzien. In de tabel zijn de objecten voor elk jaar geplaatst in de volgorde van afnemende wortelwaarde. Uit kolom 1 blijkt, dat ook bij nauw verwante objecten nog groote verschillen in wortelwaarde voorkomen.

In kolom 2 is het drooggewicht opgegeven van de bovengrondsche deelen en in kolom 3 evenzoo van de ondergrondsche. We zien, dat in 't algemeen de objecten met grooter wortelgewicht ook een grooter gewicht aan bovengrondsche deelen hebben, maar dat de toename van het gewicht aan stengel + bladeren + vrucht minder dan evenredig is aan de toename van het wortelgewicht.

In kolom 4 is het zaadgewicht (in 1927 vruchtgewicht) opgegeven. Letten we op de volgorde, (cijfers tusschen haakjes) dan blijkt, dat op één uitzondering na, deze volgorde dezelfde is als die van de wortelwaarde (kolom 1), of m.a.w. er bestaat een correlatie tusschen wortelwaarde en zaadopbrengst. Een dergelijke correlatie vinden we ook met de diepgang van het wortelstelsel (kolom 4). Hier is opgegeven hoeveel % van het totale wortelstelsel zich bevindt op een diepte, grooter dan 30 cm. Uit kolom 4 en kolom 1 blijkt nu, dat naarmate een grooter gedeelte van het wortelstelsel zich in de diepere bodemlagen bevindt, de wortelwaarde grooter is. Hierop is ook weer dezelfde uitzondering, nl. de Peragis, die in tegenstelling met de andere objecten een voedererwt is en zeer weinig zaad voortbrengt, maar zeer veel bladeren en stengels. In de laatste kolom is voor de Cap. het rangcijfer 3 ingevuld op grond van de gegevens van de oogst tijdens de bloei. De bij rijpheid geoogste planten waren niet normaal. Samenvattend krijgen we dus een correlatie tusschen worteldiepgang, wortelwaarde en zaadopbrengst.

Van de andere resultaten, die bij het onderzoek verkregen zijn, wordt nog gewezen op de groote invloed van de ploegzool op de wortelontwikkeling (foto 4, 5 en 6) en op de bijzondere beteekenis van de diepgaande wortels (proeven in 1930, waarbij elke week de wortels dieper dan 30 cm afgesneden werden, zie tabel 21) voor de watervoorziening.

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EXPLANATION OF THE PHOTOS

Photo 1. The driving of the iron containers into the soil.
„ 2. The iron containers shortly before the excavation. A hole is dugged in front of the containers. Remark that the soil is left undisturbed by driving the containers into the soil.
„ 3. The washing away of the soil from the roots. This photo has not been taken at the trial field and is only a mise-en-scène to show the tools. Compare text p. 7.
„ 4, 5, 6. Some photos of roots and shoots. The measurements of the black planes are 50 × 120 cm as agrees with the size of the containers.
„ 4. 1927. From left to right: M.N.K. and V 38 June 13 and idem July 25.
„ 5. 1928 about June 15. From left to right: M.N.K., V 38, Fr., Per., Cap.
„ 6. 1929. From left to right: Unica July 2, M.N.K. July 5, V 38 July 10 and Vict. July 15.

Everywhere:
M.N.K. = Mansholt's Nieuwe Kruising 1915.
V 38 = a selection of the Institute of Plantbreeding.
Cap. = a selection of the Institute of Plantbreeding.
Fr. = Pois nain très hatif d'Annonay.
Per. = Pflugs Baltersbacher Felderbse Peragis.
U. = Unica.
Vict. = Victoria (yellow).

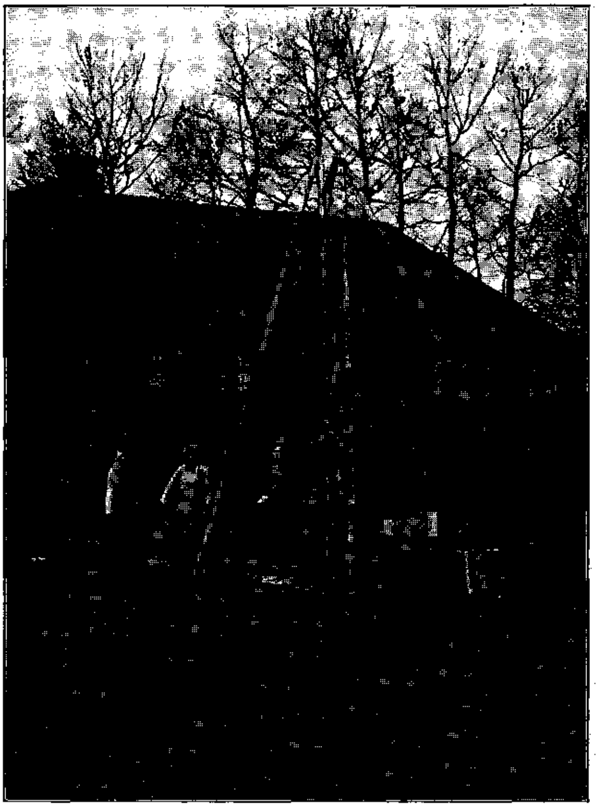


photo 1

2

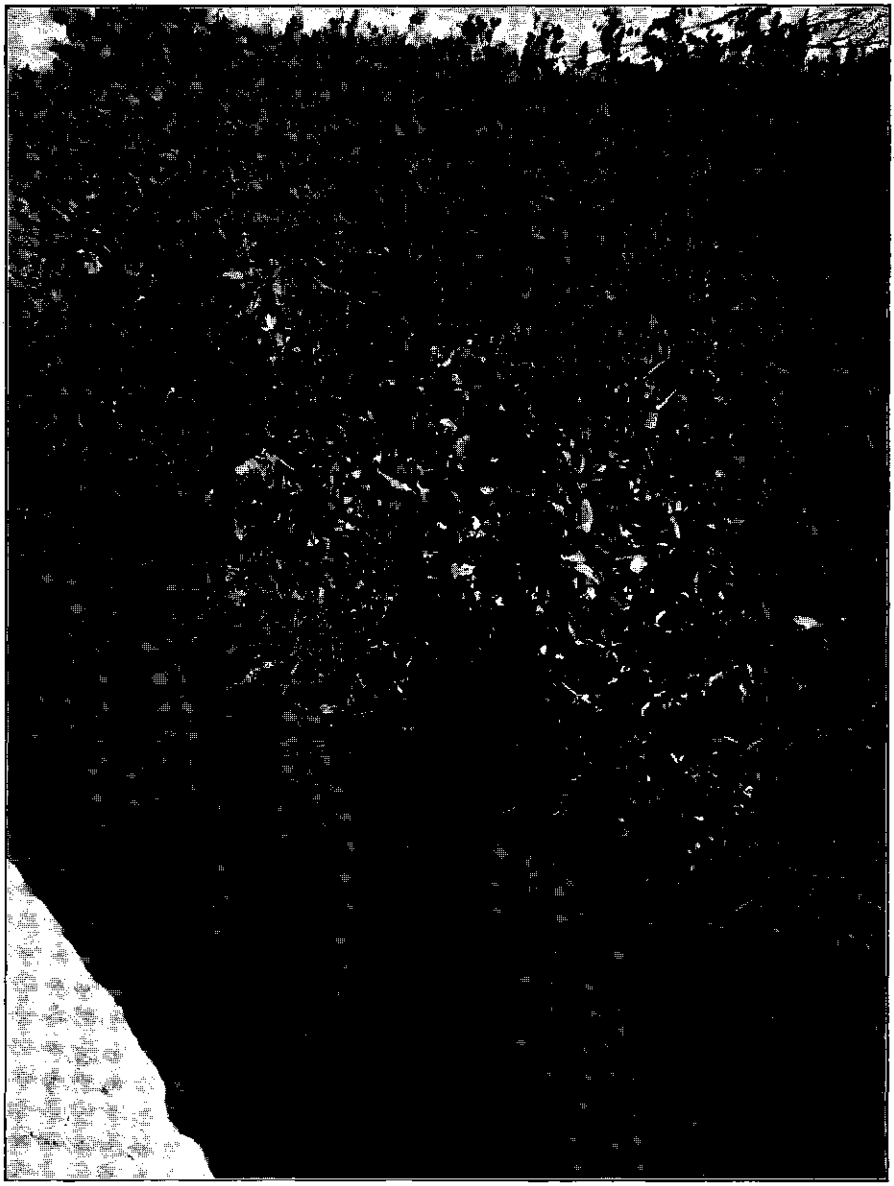
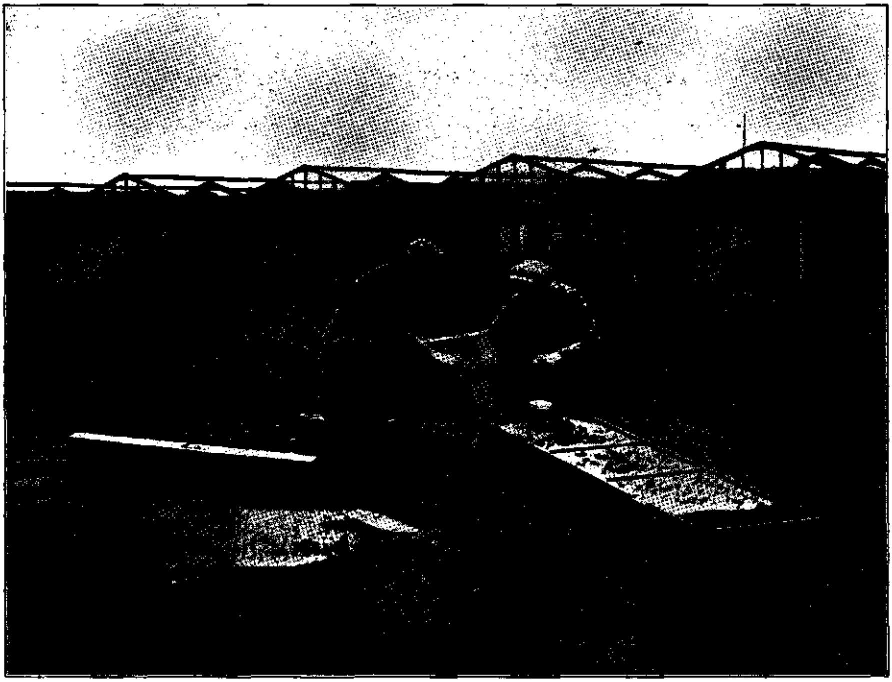


photo 2



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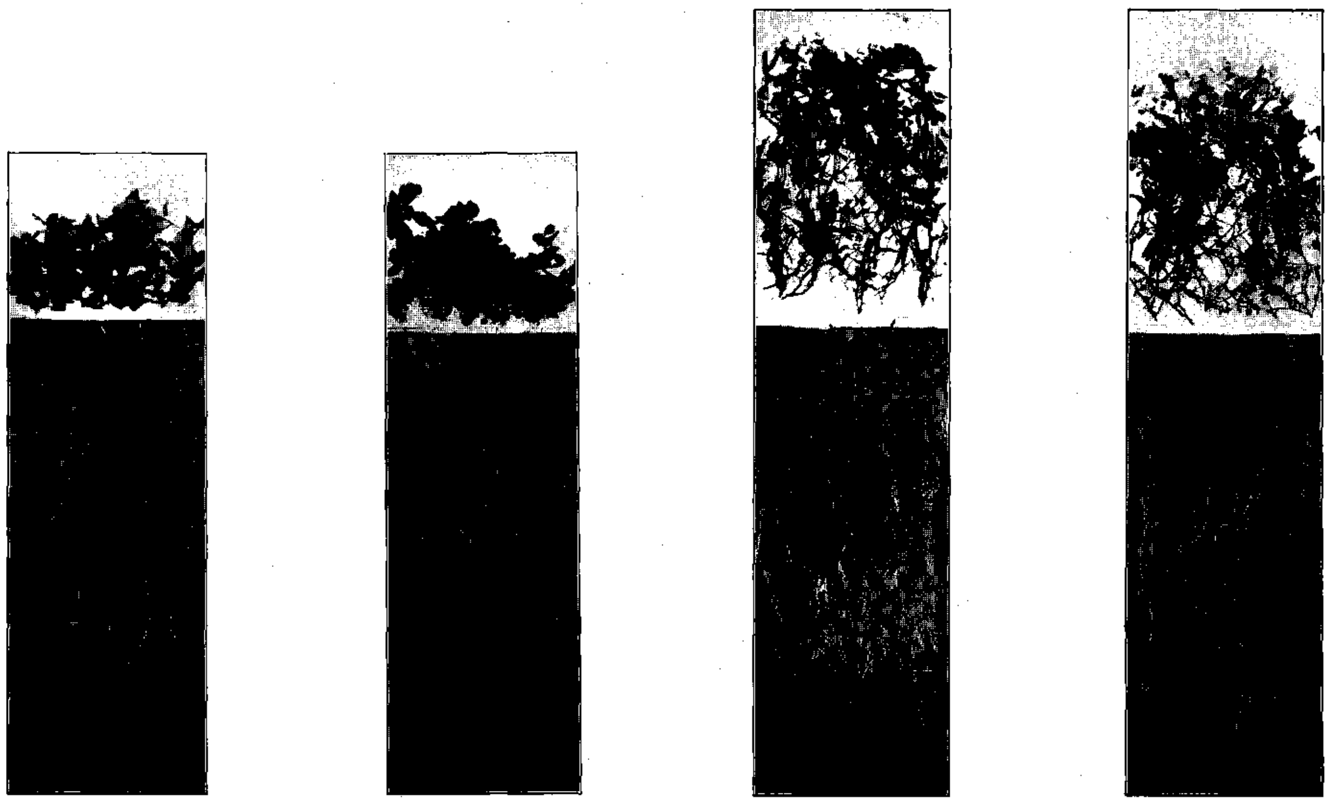

photo 4

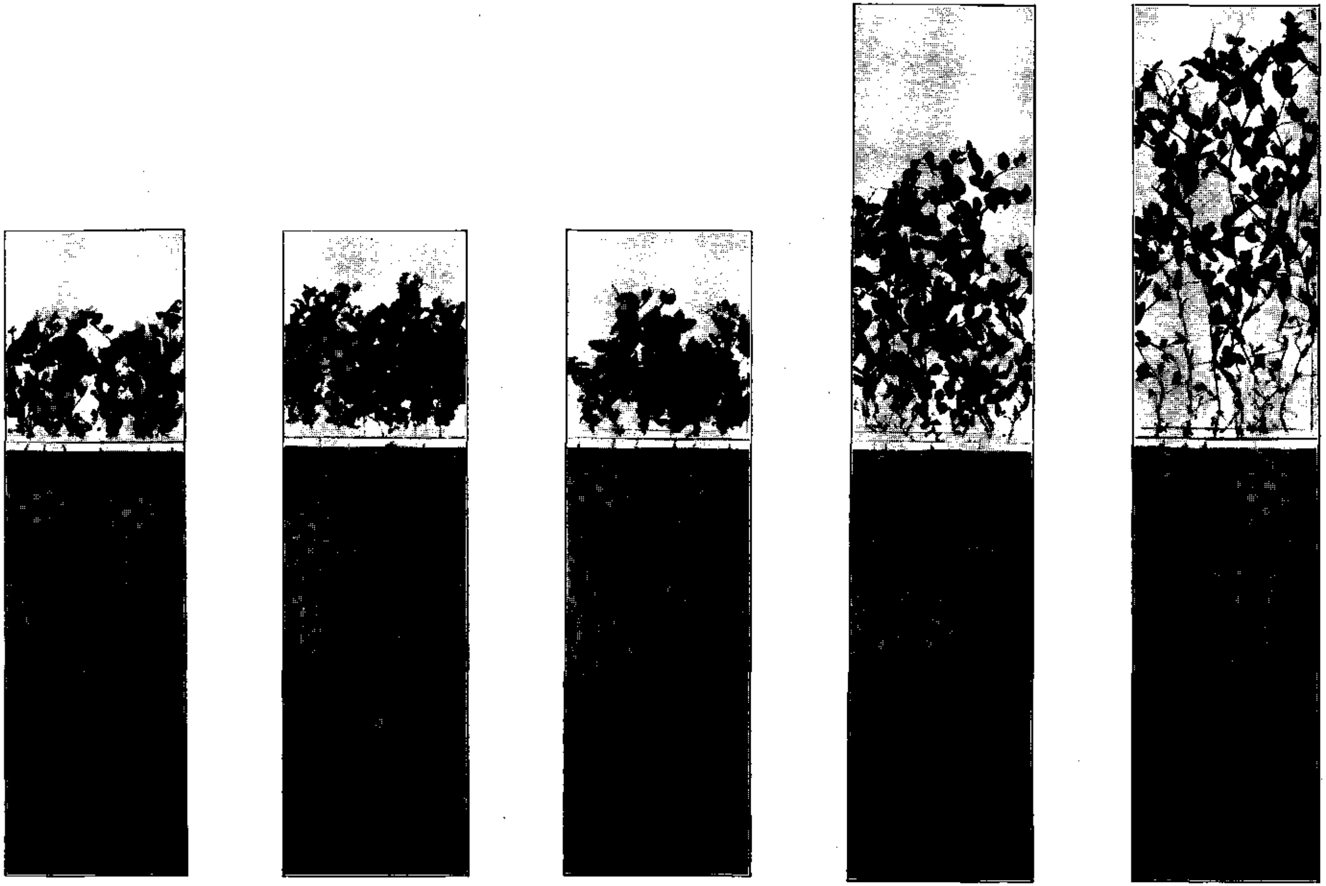

photo 5

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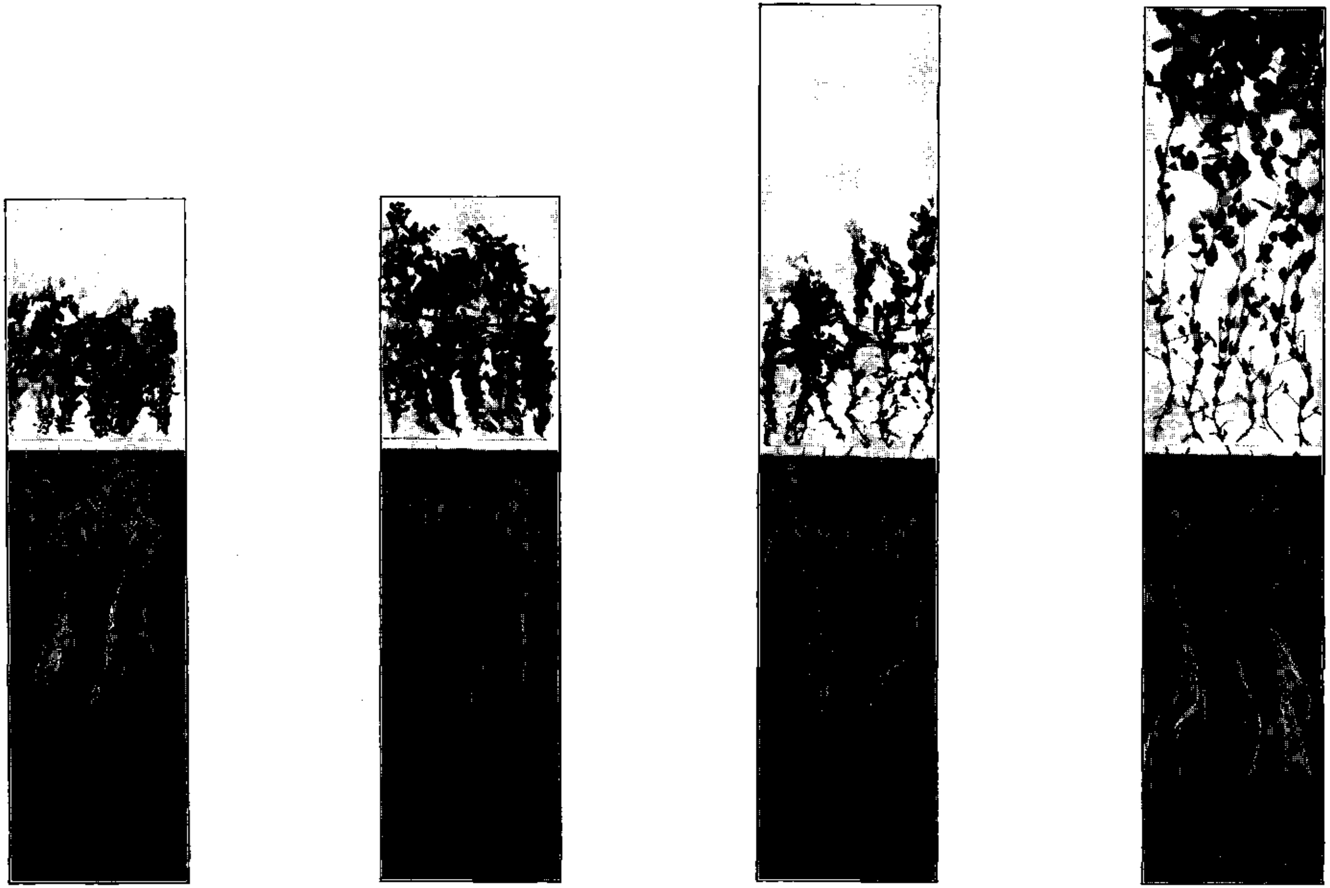

photo 6