

## YIELD AND SIZE DISTRIBUTION OF POTATOES AS INFLUENCED BY SEED RATE<sup>1)</sup>

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### SUMMARY

Five spacing experiments with potatoes (variety Alpha) in which the size of set and the number of plants were varied are discussed. There appears to exist a close relation between the number of stems per unit of soil surface and the yield and in case of wide planting also between the number of stems per seed tuber and the skin surface of the seed. Consequently there is a close relation between the yield and the total skin surface of the tubers planted and the more so if the size distribution of the harvest is included by expressing yield also in surface area of skin.

This latter relation is to a large extent independent of the size of set. However, the largest size appears to be inferior to the smaller sizes, because such a large number of stems develop from one potato that a yield depression due to the irregular distribution of the stems on the field results.

The current opinion that small seed is inferior to large seed is proved to be incorrect for the variety Alpha; this apart from practical arguments in favour of sets of medium size.

A theoretical background for the interpretation of spacing experiments is given.

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### INTRODUCTION

The quantity of potato seed planted per hectare depends on the row width, the spacing of the sets within the row and the size of the seed. The width of the rows in the Netherlands, varying from 50–70 cm, is supposed to be determined to such an extent by the wheel spacing of tractors and implements and by management methods, that this width was not varied in our experiments, but kept at an average distance of 60 cm.

Concerning size of set there appears to be considerable confusion as to the suitability of small seed. REESTMAN (1953) came to the conclusion that the use of small seed may be economically justified, but in practice small seed of 25–28 mm is considered inferior to larger seed. This opinion is mainly based on the markedly slow development during the earlier stages of growth and the supposition that plants of small seeds are at the beginning of growth more affected by adverse conditions.

BOYD and LESSELLS (1954) studied the relation between seed rate expressed in weight per soil surface unit and yield and came to the conclusion that for practical purposes this relation is independent of the size of set, although small sizes planted at the same weight rate showed a distinct advantage. This first conclusion was not corroborated by the practical experience of one of us.

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The effect of distance within the rows at a row width of 60 cm and of size of set on yield was investigated on five field experiments with the variety Alpha of which two were harvested at two dates; details being given in the caption of figure 5. The diameter of the seed was 25–28 mm, 35–45 mm and 45–60 mm (resp.  $> 45$  mm) and the seeds were planted at a rate of 400, 600, 800, 1000 and, on experiment CI 2256 also 1200 sets per are (1 hectare = 100 are).

The experiments were carried out according a block design with three replicates and with plots of about 10 m<sup>2</sup>. As an analysis of variance is of small use, only results averaged over the three replicates are given.

Several aspects of the spacing problem are illustrated by the data of experiment PAW 143, 1st harvest, whereas only the main data for the other experiments are given.

#### YIELD, NUMBER OF PLANTS AND WEIGHT OF SEEDS

The relations between the yield of the tubers expressed in kg/are and the number of plants for experiment PAW 143, 1st harvest, is given in figure 1a for the set-sizes 25–28 mm, 35–45 mm and 45–60 mm. The yield appears to depend to a large extent on the size of the seed, although at high rates of the larger sets the effect of size of set seems small. Indeed, on first sight, small set seems to be inferior to large set.

BOYD and LESSELLS (1954) related the yield not with the plant number but with the total weight of planted seeds, a relation which for the same data is represented in figure 1b.

The arrangement of the three separate curves is such that they may form three parts of one main relation between seed weight and yield. BOYD and LESSELLS showed by statistical analyses that this is not the case, but that the effect of weight of seed on yield is larger when the spacing is varied than when the size of set is varied, a result which was corroborated by an analysis of experi-

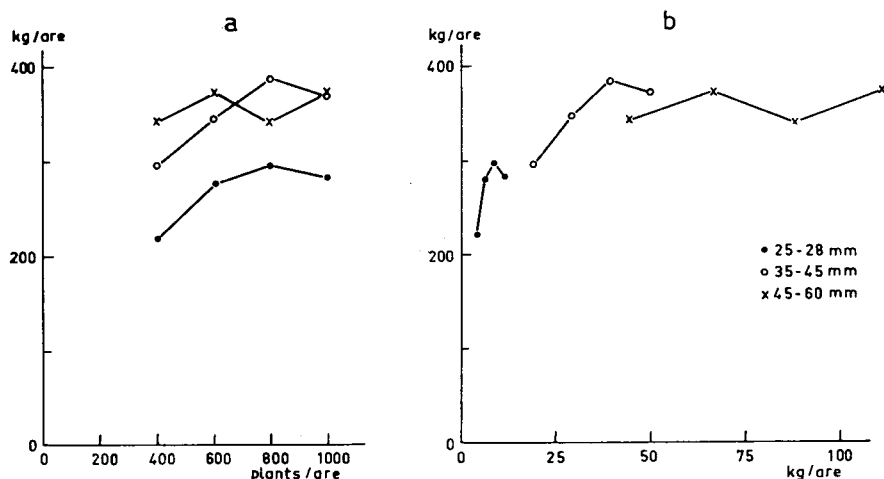


FIG. 1 PAW 143, 1st HARVEST.

- THE RELATION BETWEEN THE PLANTNUMBER PER ARE AND YIELD IN KG/ARE FOR THREE SIZES OF SET.
- THE RELATION BETWEEN SEED RATE (HOR.) IN KG/ARE AND YIELD (VERT.) IN KG/ARE FOR THREE SIZES OF SET.

ments in which both were varied independently. In other words, the yield effect of 1 kg seed is the largest for the smallest set.

On the other hand, they concluded that for practical purposes the effect of seed size on the relation between yield and seed weight can be neglected. This seems not to be the case for our experiments but a definite conclusion cannot be arrived at since there is not sufficient overlap of curves and there is no theoretical background which enables an extrapolation of fitted curves, as yet.

As for experiment CI 2256, a series was included where the seed consisted out of pieces, cut from potatoes with a diameter of 45–60 mm, so as to be of about the same weight as potatoes with a diameter of 25–28 mm. The yield of this series was, as will be seen later, considerably lower than the yield of the series with seed of the size 25–28 mm. It was mainly for this reason that we tried to find another measure than seed weight for the seed rate of potatoes.

#### YIELD AND NUMBER OF STEMS

On all experimental plots the number of stems were counted in the middle of the season. A main stem is a stem sprouting directly from the seed. Such a main stem may already branch below the soil surface. As for the variety "Alpha" in our experiments, this branching below the soil surface hardly occurred.

The relation between yield in kg/are and the number of main stems per are is given in figure 2a for experiment PAW 143, 1st harvest. There is now some overlap and it appears that, as far as the experiment goes, there is small reason to suppose that the curves for the three sizes of set are not a part of one main curve. This conclusion is corroborated by the results of the other experiments. Obviously the number of stems is a measure of some sorts for the plant density. Unfortunately the number of stems is, as the yield itself, a result of the experiment and not of large practical importance as long as it is not known how the number of stems depends on seed number and size of set, stage of dormancy and conditions during emergence.

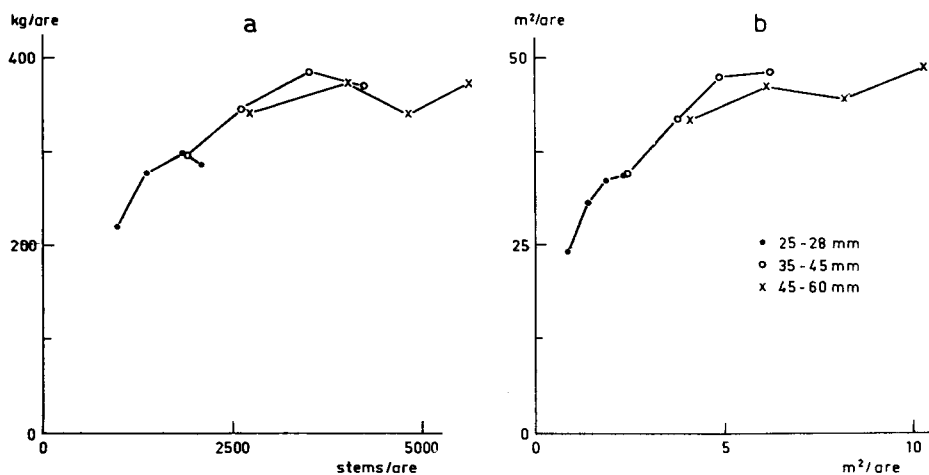


FIG. 2 PAW 143, 1st HARVEST.

- THE RELATION BETWEEN NUMBER OF STEMS PER ARE AND YIELD IN KG/ARE FOR THREE SIZES OF SET.
- THE RELATION BETWEEN SEED RATE (HOR.) IN M<sup>2</sup> SKIN SURFACE PER ARE AND THE YIELD (VERT.) IN M<sup>2</sup> SKIN SURFACE PER ARE FOR THREE SIZES OF SET.

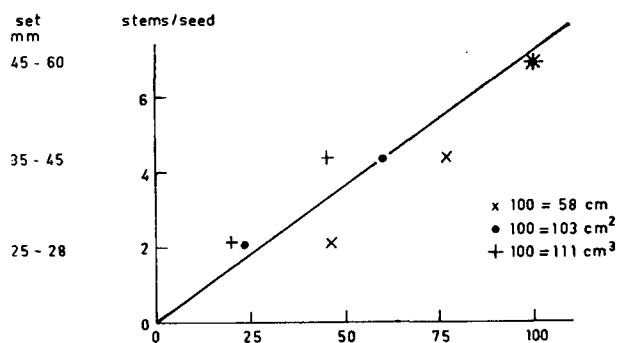


FIG. 3 PAW 143, 1st HARVEST.

THE RELATION BETWEEN NUMBER OF STEMS PER SEED AND THE DIAMETER, SURFACE AND VOLUME ON A RELATIVE SCALE OF THE SEEDS WHEN PLANTED WIDE APART.

A rough survey of the available data showed that, under otherwise the same conditions the number of stems depends on plant number and size of set. There existed, at least at relatively low seed rates, a linear relation between the number of stems and the number of planted sets which enabled to calculate the number of stems, sprouting from one tuber of a given size, when planted wide apart from other tubers. As for experiment PAW 143 these numbers appeared to be 2.1, 4.4 and 6.8 stems per seed for set-sizes of 25–28 mm, 34–45 mm and 45–60 mm, respectively.

This number is in figure 3 plotted against the average diameter, the surface area of skin and the volume of the tubers, which three characteristics are placed along the horizontal axis on a relative scale. The method of estimating volume, surface area and diameter of the seeds is given further on.

The results indicate that there is a linear relation between the number of stems per tuber (planted wide) and the surface area of the skin of the tubers, a result which is again confirmed by the data of other experiments where a linear relation existed between plant number and number of stems. The actual number of stems per unit of skin surface is of course not the same for the different experiments because this number depends to a large extent on the pre-treatment of the seeds and growing conditions in the earlier stages.

#### YIELD, SIZE DISTRIBUTION AND SURFACE AREA OF SKIN

Taking in account the reasonably close relation between yield and number of stems, it must be concluded that it is worthwhile to express the seed rate as the total skin surface of the tubers and not as the total weight per unit surface of the field.

It is well known that the percentage of smaller tubers in the yield increases with increasing plant density. Consequently, accounting for the distribution of tuber sizes in the harvested crop, it is logical to express the size distribution of the tubers in the harvest as the m<sup>2</sup> of skin surface per kg of potatoes. The yield is to be expressed in m<sup>2</sup> of skin surface per are (m<sup>2</sup>/are), which is calculated by multiplying the yield in kg per are and the skin surface in m<sup>2</sup> per kg.

The surface area of skin is estimated as follows. The yield was passed over riddels of 28, 35, 45 and sometimes 55 mm and the weight and number of tubers of each size of set was recorded. The average weight of the potatoes within

each size was calculated from the data and, supposing the specific weight to be 1.085, the average volume of the potatoes of each size.

It may be supposed, that the tubers of the variety Alpha are spherical and given this volume, this enables to calculate the surface of skin and the diameter of the potatoes. The estimated diameters of potatoes within the set-sizes 25–28, 28–35, 35–45, 45–55, 45–60 mm and larger than 45 mm are 2.7, 3.4, 4.45, 5.3, 5.8 and 5.85 cm. The calculated diameters are so large that the estimates are undoubtedly biased, a bias which may due to a wrong estimate of the average specific gravity or to the simplifying assumption that the tubers are spherical. For practical purposes and as a relative measure these estimates may do.

The relation between the surface area of skin planted in m<sup>2</sup>/are and the yield of skin surface in m<sup>2</sup>/are is given in figure 2b. The separate curves arrange fairly well around one common curve. The largest size of set seems to be somewhat inferior to the other. For the time being, this difference is neglected, although it will be shown later on that it is significant and of some practical importance.

#### A THEORETICAL BACKGROUND

Analyzing the results of field experiments on mixed cultivation of barley and oats, DE WIT and ENNINK (1958) found that the yield of each of two plant species which compete only by crowding for the same space may be represented by

$$O_1 = \frac{k_{1,2}z_1}{k_{1,2}z_1 + z_2} M_1 \quad O_2 = \frac{z_1}{k_{1,2}z_1 + z_2} M_2 \quad (1)$$

in which  $O_1$  and  $O_2$  are the yields in mixed and  $M_1$  and  $M_2$  the yields in mono culture, of species  $S_1$  and  $S_2$ , respectively. The seed rates  $z_1$  and  $z_2$  of both species are expressed as fractions of the seed rates of the corresponding mono cultures and chosen such that the sum of both is one. The relative crowding coefficient  $k_{1,2}$  is independent of the composition of the seed mixture.

It was shown that this formula holds under conditions where the seed of one of the species (i.e.  $S_2$ ) does not germinate ( $M_2 = 0$ ;  $O_2 = 0$ ), under which conditions the competition experiment of the two species degenerates in a spacing experiment of species  $S_1$ . It is shown (DE WIT and ENNINK, 1958; DE WIT, in prep.) that under such conditions the yield of the remaining species is represented by the formula:

$$O_s = \frac{\beta}{\beta + s} \Omega \quad (2)$$

in which  $s$  is the space allotted to one seed unit (one seed, one unit of skin surface, one unit weight of seed and so on),  $O_s$  the yield at a plant spacing  $s$ , and  $\beta$  and  $\Omega$  are constants.

The constant  $\Omega$  represents the yield ceiling which is (theoretically) reached at an endless plant density ( $s \rightarrow 0$ ). This yield is in general not reached because there is a density beyond which the relation breaks down for several reasons. This is not of importance here, because as far as the present spacing experiments with potatoes are concerned, this complication does not occur. The product  $\beta \Omega$  is the yield of one plant (unit) the set being widely spaced.

This spacing formula was found to hold for small grains, fodder beets, peas

and some other crops (DE WIT and ENNINK, 1958; DE WIT, 1959; DE WIT, in prep.).

It is proved (DE WIT, in prep.) that equation (2) is a modified form of the PEARL-VERHULST equation for logistic population growth and that by combining equation (1) and (2), a modified form of the LOTKA-VOLTERRA equations on inter-specific competition is obtained. Equation (2) is of course also one the equations which is often used to describe the effect of a growth factor on yield.

Formula (2) may be rewritten in the following way :

$$\beta + s = \beta \Omega O_s^{-1} \quad (3)$$

so that a straight line is obtained if the inverse of the yield per surface unit is plotted against  $s$  or the inverse of the seed rate.

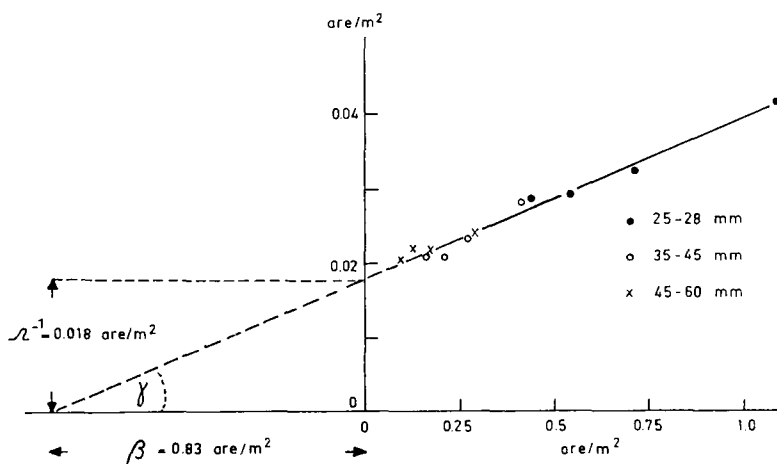


FIG. 4 PAW 143, 1st HARVEST.

THE RELATION BETWEEN THE INVERSE OF THE YIELD (VERT.) AND THE INVERSE OF THE SEED RATE (HOR.) BOTH EXPRESSED IN ARE PER M<sup>2</sup> OF SKIN SURFACE FOR THREE SIZES OF SET.

The inverse of the yield and seed rate for experiment PAW 143, 1st harvest, both expressed in are surface of soil per square meter skin surface (are/m<sup>2</sup>) are plotted against each other in figure 4. The observations appear to be arranged indeed around a straight line, irrespective of the size of set. It is easily understood that the value of  $\Omega$  expressed in m<sup>2</sup>/are is equal to the inverse of the distance between the origin and the intersection of the line with the vertical axis and  $\beta$ , expressed in are/m<sup>2</sup>, equal to the distance between the origin and the intersection with the horizontal axis, whereas  $\cotg \gamma$  is equal to  $\beta \Omega$  or the yield of a single plant unit, the seeds being widely spaced.

It is perfectly understood that this graphical treatment is not completely sound from a statistical point of view, but any disadvantages may be overcome by plotting the data also as is done in figure 2b and check for the course of the resulting curve.

#### THE RESULTS OF FIVE EXPERIMENTS

The results of the five experiments are graphically represented in figure 5 and 6. The observations are, irrespective of size of set reasonably well arranged

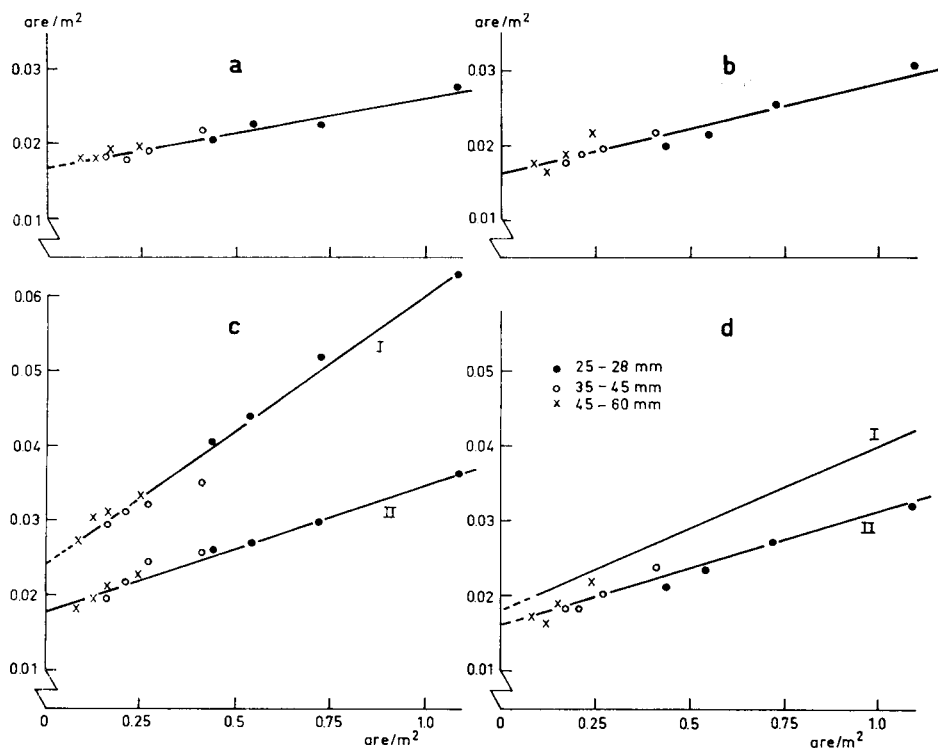


FIG. 5 THE RELATION BETWEEN THE INVERSE OF THE YIELD (VERT.) AND THE INVERSE OF THE SEED RATE (HOR.) BOTH EXPRESSED IN ARE PER M<sup>2</sup> SKIN SURFACE, FOR THREE SIZES OF SET.

| figure | number  | place    | soil | year | harvest date | $\beta$<br>are/m <sup>2</sup> | $\Omega$<br>m <sup>2</sup> /are |
|--------|---------|----------|------|------|--------------|-------------------------------|---------------------------------|
| 5a     | PAW 28  | De Steeg | löss | 1957 | 15 Oct.      | 1.8                           | 59                              |
| 5b     | PAW 29  | Randwijk | clay | 1957 | ±5 Oct.      | 1.4                           | 63                              |
| 5c I   | PAW 142 | "        | "    | 1958 | 1 Aug.       | 0.67                          | 42                              |
| 5c II  | PAW 142 | "        | "    | 1958 | 25 Sept.     | 0.98                          | 57                              |
| 5d I   | PAW 143 | De Steeg | löss | 1958 | 29 July      | 0.83                          | 55                              |
| 5d II  | PAW 143 | "        | "    | 1958 | 13 Sept.     | 1.1                           | 63                              |
| 6      | CI 2256 | "        | "    | 1956 | 16 Oct.      | 2.8                           | 48                              |

around straight lines, although it may be that the crosses which concern the largest size of set are situated somewhat above the average. The cause of this small, but significant deviation will be discussed later on.

The data of experiment PAW 142 and 143 refer to one harvest at the end of July and another harvest at the beginning of October. In both cases of the value of  $\beta$  and  $\Omega$ , both, are smaller for the first harvest. The curves for experiment PAW 142, as calculated by means of the constants  $\beta$  and  $\Omega$  are represented in figure 7a in a more customary way, with the yield in m<sup>2</sup>/are along the vertical axis and the seed rate in m<sup>2</sup>/are along the horizontal axis. The yields, expressed as percentages of the yield at a seed rate of 10 m<sup>2</sup>/are are represented by curves 1 and 2 in figure 7b for the 2nd and 1st harvest. The percentage effect of increasing plant rate on yield appears to be the highest for the first harvest.

An example of the course of  $\beta$  and  $\Omega$  throughout the season cannot be given

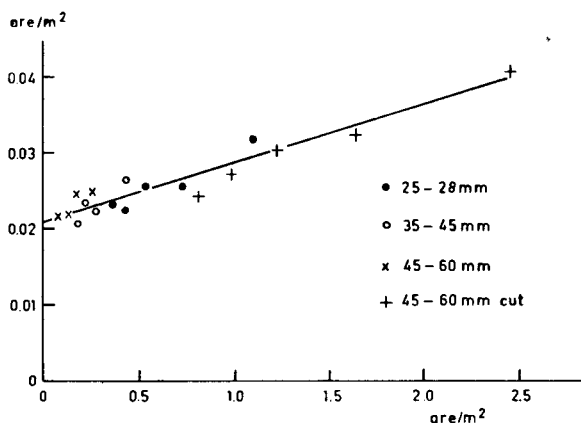


FIG. 6 CI 2256.

THE RELATION BETWEEN THE INVERSE OF THE YIELD (VERT.) AND THE INVERSE OF THE SEED RATE (HOR.) BOTH EXPRESSED IN ARE PER  $M^2$  OF SKIN SURFACE FOR THREE SIZES OF SET AND FOR POTATOES OF SET 45-60 MM CUT TO THE WEIGHT OF POTATOES OF THE SET 25-28 MM.

because no periodic harvests of a spacing experiment with potatoes are available. It was, however, possible to calculate this course for sugar beets (DE WIT, in prep.) from the result of an experiment of VAN GINNEKEN (1934). This course is represented in figure 8; the crosses and the full line concern the value of  $\beta$  and the open dots and the broken line the value of  $\Omega$ . It appears that  $\Omega$  increases up to the end of the growing season, but that  $\beta$  remains constant from the middle of August onwards. The value of  $\beta$  appears to be closely correlated with the leaf

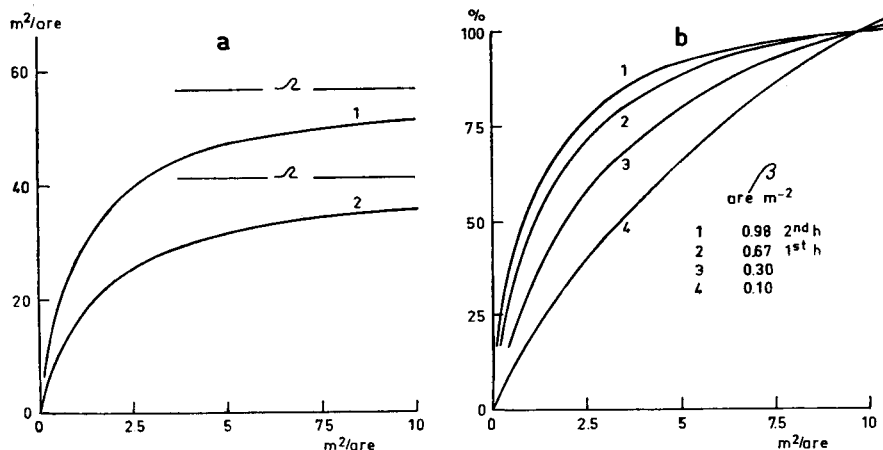


FIG. 7 a THE RELATION BETWEEN YIELD (VERT.) AND SEED RATE (HOR.) BOTH EXPRESSED IN  $M^2$ /ARE FOR TWO HARVEST DATES (SUMMER AND AUTUMN) AS CALCULATED FROM THE STRAIGHT LINES IN FIGURE 5c.

b THE RELATION BETWEEN SEED RATE AND YIELD EXPRESSED AS A PERCENTAGE OF THE YIELD AT A SEED RATE OF 10  $M^2$ /ARE FOR VALUES OF  $\beta$  EQUAL TO 0.98, 0.67, 0.30 AND 0.10 ARE/ $M^2$ .

THE CURVES (1) AND (2) HOLD FOR PAW 142, 2nd AND 1st HARVEST.



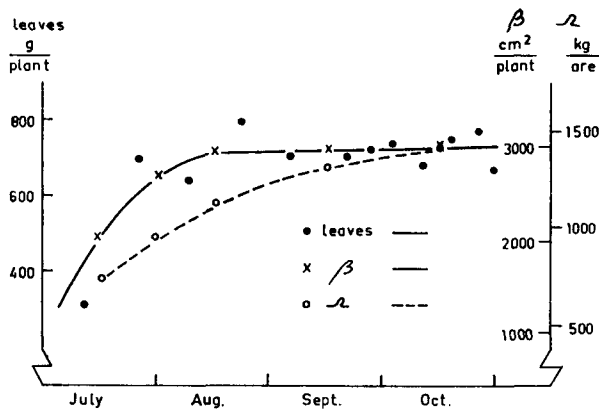


FIG. 8 THE VALUES OF  $\beta$ ,  $\Omega$  AND THE WEIGHT OF THE LEAFMASS PER PLANT IN COURSE OF TIME FOR SUGAR BEETS, AS CALCULATED FROM THE DATA OF AN EXPERIMENT OF VAN GINNEKEN (1934).

weight per plant (averaged over all spacings), which is represented in the figure by full dots. At some earlier stage, when the plants were very small, the value of  $\beta$  must have been practically zero.

In view of the above results, it must be supposed also for potatoes that in the first part of the growing season,  $\beta$  increases rapidly with time, but remains practically constant at some later stage. A stage, where only the tubers gain in weight, but the plant does not occupy more space. The value of  $\beta$  may be very low, where producers of seed or early potatoes harvest at a very early stage.

The percentage effects of spacing on yield for  $\beta$  equal to 0.3 are/m<sup>2</sup> and 0.10 are/m<sup>2</sup>, calculated as an example, are represented by the curves 3 and 4 in figure 7 b. It is seen that for low values of  $\beta$  this percentage effect increases very rapidly with decreasing  $\beta$ , so that the importance of dense planting for seed producers must be stressed. It is worthwhile to harvest some spacing experiments at intervals in order to obtain more information on the quantitative aspects of this effect.

As for experiment CI 2256 a series with pieces of potatoes of the same weight of whole tubers of set 25–28 mm, but cut from potatoes of size 45–60 mm was included. If the weight of the pieces should determine the yield, the yield of these pieces should be the same as the yield for whole tubers of the size of 25–28 mm. If, on the other hand, the surface area of skin determines the yield, the yield of the pieces should be smaller, because the surface area of skin of each piece is only about half that of a whole tuber of set-size 25–28 mm.

The results of the experiment are given in figure 6. The surface area of skin of the series with cut pieces is estimated by multiplying the surface of the large potatoes by the volume ratio of the small and large potatoes. It appears that the yield of the cut pieces is lower than the yield of potatoes within the size of 25–28 mm, and that to an extent as may be estimated from the reduction of surface area of skin.

Likewise the number of stems were 1.7 per piece and 2.6 per tuber of size 25–28 mm.

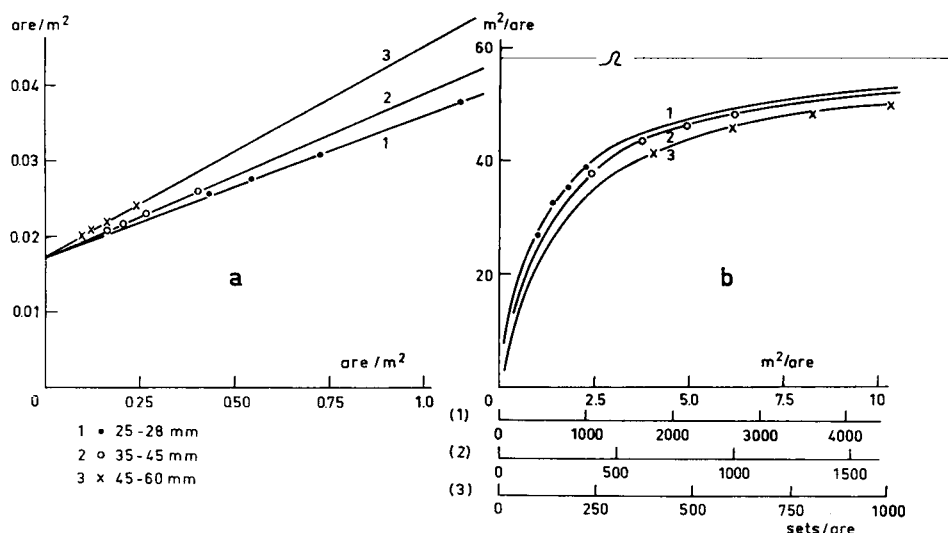


FIG. 9 THE RELATIONS BETWEEN YIELD (VERT.) AND SEED RATE (HOR.) BOTH EXPRESSED IN  $M^2$  OF SKIN SURFACE PER ARE IN GRAPHS WITH A NORMAL (b) AND INVERTED SCALE (a) FOR THREE SIZES OF SET.

#### THE DISADVANTAGE OF IRREGULAR DISTRIBUTION OF STEMS

It has been shown that the relation between seed rate and yield, both expressed in  $m^2$  of skin surface per are, is in first approximation independent of the size of set, although there is some indication that the yield from plots planted with large tubers is lower than the yield from plots planted with medium and small tubers, both being planted at the same skin surface rate.

The inverse values of the yields of the experiments are averaged to obtain an average relation between the inverse of the yield and the space per plant unit, both expressed in  $are/m^2$ . The resulting values are plotted in the graph of figure 9a. The observations for each size of set produce linear relationships very neatly, but it appears now clearly that the relation between planted and yielded surface depends to some extent on the set-size. The same relations are represented in figure 9b in a more customary way.

The value of  $\Omega$  is the same for all three sizes of set. The values of  $\beta$  are, however, 0.93, 0.80 and 0.63  $are/m^2$  for the set-sizes 25-28 mm, 35-45 mm and 45-60 mm, respectively. Hence, the space which is occupied by plants growing from one unit of skin surface of small tubers, planted wide apart, is larger than the space occupied by plants growing from one unit of skin surface of large tubers, planted wide apart. On the other hand, it is found, as may be seen in figure 2a, that the yield per main stem from large tubers is also smaller.

The relatively low yield from fields planted with large sets is therefore not due to a relatively low number of stems per unit skin surface. Apparently, it makes some difference whether the stems are developing in groups of five to ten, as is the case on plots planted with large tubers or in groups of one to three as is the case on plots planted with small tubers. The stems appear not to be able to overcome this disadvantage of irregular distribution.

It is to be expected that this difference between large and small set disappears

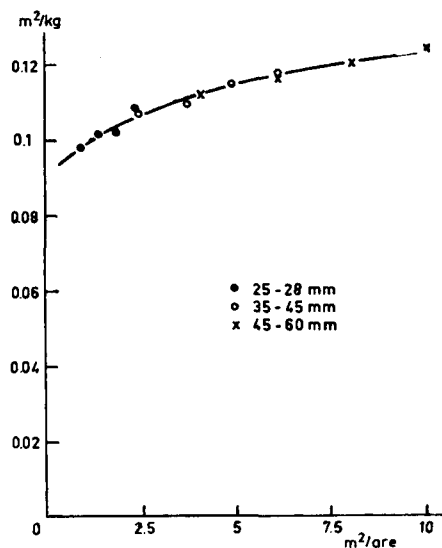


FIG. 10 THE RELATION BETWEEN THE  $m^2$  SURFACE AREA OF SKIN PER KG OF POTATOES AS A MEASURE FOR THE SIZE DISTRIBUTION, AND THE YIELD IN  $m^2$  OF SKIN SURFACE PER ARE.

if the large tubers are cut into pieces and these pieces are distributed regularly within the row. It is read in the figure that the yield from large seed planted at a rate of 4  $m^2/are$  increases from about 42  $m^2/are$  to 45.5  $m^2/are$  if this seed should be cut in pieces having a skin surface equal to those of the sets 25–28 mm, that is in five pieces. An experiment on this effect of cutting will be carried out, although it is realised that cutting large seeds is probably not worth the trouble under European conditions.

The distance of the tubers in the row, planted at a rate of 1000 sets per are is 16.7 cm. The yield of large tubers planted at this rate is lower than the yield of small tubers planted at the same skin surface rate, so that a distance of 16.7 cm is, in spite of the large reserve of large tubers, too wide. Hence, the current row width of 60 cm must lead also to a yield depression which cannot overcome by dense planting within the row. Especially as far as seed production is concerned, it may be that husbandry methods are at present too much governed by the limitations of existing machinery.

#### THE SIZE DISTRIBUTION

The effect of yield on the size distribution is represented in figure 10; the size distribution along the vertical axis being expressed in  $m^2$  of skin surface per kg of potatoes and the yield along the horizontal axis in  $m^2$  of skin surface per are. The relation appears to be independent of the size of set. The skin surface per unit weight increases with increasing yield due to dense planting, so that the yield in  $m^2/are$  may still be increased by increasing the seed rate in a region where the yield expressed in kg/are does hardly increase.

The yield in kg/ha may be calculated from the yield in  $m^2/are$  by dividing the latter by the value read along the vertical axis of figure 10. This is of practical importance, since potatoes are sold by weight.

The number of sets per are necessary to obtain an arbitrary surface of skin are given in figure 9 b in auxiliary scales for the three sizes of set. It is read here that to obtain a surface area of 5 m<sup>2</sup>/are requires about 500 large tubers, but about 2200 small tubers per are. Existing machinery is not very well suited to planting such a large number of potato sets, so that farmers who use small sets, generally plant too few.

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