POTATOES AND THEIR CULTIVATION IN THE NETHERLANDS
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Potatoes and their cultivation in the Netherlands
This booklet is mainly for agriculturists who require simple facts about the potato crop in general and are especially interested in potato cultivation in the Netherlands. Those wishing to make a more thorough study of particular aspects of the crop are referred to publications which go more deeply into the subject, such as 'The Potato' by W.G. Burton, or "Introduction to Potato Production" by H.P. Beukema and D.E. van der Zaag, published by Pudoc at Wageningen. Furthermore this booklet does not claim to be exhaustive: for instance, it does not deal with diseases and varieties, nor with the growing of seed potatoes, which is a major enterprise in the Netherlands and for information on which the reader is referred to 'Viruses of potatoes and seed potato production', published by 'Pudoc' at Wageningen.

In preparing this publication the author has made use of various books and scientific papers. To make it easily readable, he has, however, refrained from quoting from the relevant literature, though it could not have been written without information from such sources. The author has also been able to make ample use of unpublished data obtained from various research workers in Wageningen and of information culled from conversations with them.

In revising the text for this third edition it has proved necessary to alter a few sections - these are mainly in the first half of the booklet,
D.E. van der Zaag Wageningen, 1992

Back to content
INTRODUCTION

The potato is an important crop for the Dutch agricultural industry. It occupies almost one quarter of the country's arable land and accounts for almost half of the total value of production from arable farms. Of the 160,000 ha. under potatoes roughly 55,000 are grown especially for the potato-starch industry (Fig. 1 About 75,000 are grown for sale to the consumer as a fresh vegetable or in a processed form (c.g. pre-fried or deep frozen pommes frites and chips, instant mashed-potato powder, flakes or granules). The remaining 30,000 are used for seed production, a large proportion of which (more than 500,000 tonnes a year) is exported. In recent years almost 1,400,000 tonnes of ware and about 1,300,000 tonnes in processed form have also been exported, and about 80% of the starch or its derivates likewise finds its way to other countries. So more than two third of all the potatoes produced in the Netherlands is exported in fresh or processed form. Clearly, therefore, potato growing is closely geared to the international market, a fact which explains the great importance of this crop in the Netherlands.

THE PURPOSE OF THE PRESENT BOOKLET

There are many farmers in the Netherlands who are specialized in potato production. Over the years they have acquired a great deal of know-how and experience and, in addition, the Government has made large sums of money available for potato research. The fairly extensive practical and theoretical knowledge thus gained can be used in other countries, provided that the methods applied are adapted to suit the prevailing conditions. This is possible, if growers are fully acquainted with the background to the methods used in the Netherlands (see also page 76, giving weather data in the Netherlands).

The first four chapters provide general information on factors affecting the growth of the potato crop and on the quality and development of the tubers. Subsequent chapters give a brief description of Dutch potato growing methods, referring back, as necessary, to the first four more or less theoretical chapters. With the help of this background information on the various methods of cultivation used, the reader can decide for himself how best to achieve both high yields and good quality by adapting particular methods to suit his own conditions.

Potato growing in 1990
(afbeelding)
DEVELOPMENT OF THE TUBER

It has been found that the condition of the seed tuber is a very important factor in the growth of the crop. A grower must, therefore, have some idea of what a potato tuber actually is.

MORPHOLOGY OF THE TUBER

Stolons are underground stems; they tend to grow horizontally and have tiny leaves, axillary buds and a terminal bud consisting of a number of leaflets. At a given moment the part just behind the growing tip begins to swell and forms a tuber. The length of the stolon at that moment varies considerably, depending entirely on the variety and such circumstances as daylength, temperature, etc. Fig. 2 shows diagrammatically the formation of a small tuber at the tip of a stolon.

![Fig. 2](image)

Diagram showing the initial development of a small tuber on a stolon (N. Krijthe, Wageningen, Netherlands)

1. Stolon with one side leaflet and five leaflets at the tip.
2. Tip swollen; side leaflet forms first eye and five leaflets at the tip.
3. Two eyes on the tuber and seven at the tip.

The number of eyes in a tuber varies considerably depending on many factors such as variety, size of tuber and growth conditions. Twelve to 15 eyes are quite usual in a 45-mm 'Bintje' tuber. They form a spiral round the tuber, like the side buds on a stem. The sheath surrounding the buds in the eye is a rudiment of a leaf. The eye is, in fact, the axil of a leaf on part of a stem (Fig. 3). In many cases the main bud lies in the middle of the eye, with a bud on either side, often clearly separated by tuber flesh. These side buds may be regarded as the lowest lateral buds of a sprout, which have become separated by the growth of the tuber. Normal sprouts can, and often do, grow from them. The main sprout also bears lateral buds, from which lateral stems or stolons may grow.

![Fig. 3](image)

Crosssection of an eye (from Artschwager, 1924)

If the sprout breaks off but its base remains, there is a fair chance that the bottom lateral buds, which would normally form stolons, will grow into one or more stems, all of which arise from the same eye.

In the case of a sprout which has been allowed to develop in light to an advanced stage the lateral buds will have sprouted far enough for terminal and lateral buds to be visible on them also. For instance, about 30 lateral buds were found at the beginning of April on a sprout of the
variety Eersteling which had been allowed to develop in this way, and these in turn had on average about 13 lateral buds. In well-developed sprouts there are bulges beside the lateral buds. These are root initials (Fig. 4) and when the potatoes are stored in a damp place, the roots begin to grow.

![Figure 4](image_url)

**Fig. 4**
Short compact sprouts formed in light. Small bulges are the beginning of roots.
PHYSIOLOGY OF THE TUBER

DORMANT PERIOD
Under normal conditions the eyes of a potato will not sprout during the first few weeks after harvest, even if temperatures are favourable. This is called the dormant period. Normally it is defined as that between harvesting and the time when, at normal temperatures, the eyes begin to sprout in earnest.
The length of the period depends on:
1. variety
2. degree of maturity when harvested
3. temperatures during the growing season
4. temperature during storage
5. the presence of tuber injury caused mechanically (deliberate cutting or accidental damage) or disease (e.g. blight).

Variety
The variety Alpha has a longer dormant period than Bintje, which in turn has a longer one than Sirtema; it is not, however, necessarily linked with maturity class. A dormant period of 2 to 4 months is quite normal under Dutch conditions.

Degree of maturity
Potatoes harvested immature have a rather longer dormant period, but it must be remembered that such tubers have usually been lifted earlier and will in consequence start to sprout at an earlier date than those harvested when fully mature.

Temperature
Potatoes start to sprout earlier after a warm summer than after a cool summer. Variations due to this factor can be observed even in a small country like the Netherlands. Daylength may also affect dormancy; a short day during the growing season shortens the dormant period. Warm storage speeds up the physiological processes in the tuber and shortens the dormant period but with some varieties a fluctuating temperature or a low temperature for some weeks after harvesting has an even more marked effect in this direction. It follows from the foregoing that the dormant period is far shorter in hot countries than in cooler climates.

Cutting seeds tubers for planting
A tuber cut into seed pieces will sprout earlier than one which is uncut; moreover, more eyes will tend to produce sprouts. Cutting, however, has its drawbacks; the pieces may rot or viruses and bacteria may be transmitted by the knife, so when done, careful precautions must be taken (see page 48).
PERIOD OF APICAL DOMINANCE

The transition from dormancy to active growth is of course not abrupt. There is a fairly long period during which potatoes will sprout when air temperature and humidity are both high but not when the air is dry and the temperature is fairly low. During this transition period, which for some varieties may be long, the apical eye frequently sprouts (Fig. 5) and this holds back the other eyes. Even if conditions for sprouting are improved later, often only the one sprout (or at most two or three) will benefit, the other eyes remaining virtually inactive. However, if the apical sprout or sprouts are removed the other eyes begin to sprout.

![Tubers at different stages of physiological development. From left to right, dormant, apical dominance, normal sprouting, weak thin sprouts.](image)

Apical dominance can be prevented by:

1. Changing very rapidly from cool storage to conditions ideal for sprout growth (approx. 20' C and high humidity) this is particularly necessary if the tuber is still in the transition phase. In some varieties, cool storage may even prolong this phase into early spring.
2. Removing the apical sprout(s) and placing the tuber under conditions favouring sprouting.

It occasionally happens that, even if tubers are stored in a cool place, the apical eyes may produce short sprouts during the autumn or winter. If such seed is then subjected to high temperatures in spring to ensure pre-sprouting, very probably only the top eye and maybe another 1 or 2 sprouts will respond. If more sprouts per tuber are required, then the apical sprout(s) will have to be removed before proceeding with the pre-sprouting treatment.

'NORMAL' SPROUTING PERIOD

The 'normal' sprouting period begins when a number of eyes on the tuber start to sprout (Fig. 5). Fortunately, this phase may last for many months. A seed potato which is at the beginning of this period or at the end of the period of apical dominance is said to be physiologically young. One that has reached the end of the 'normal' sprouting period is said to be physiologically old.

PERIOD OF THIN SPROUTS

A seed tuber may become so physiologically old that only thin sprouts are formed which have a market tendency branch. Such tubers are almost exhausted and particularly in some varieties and under certain conditions (e.g. cool weather) are subject to a disorder known as 'little potato' in which new tubers are produced before emergence. Seed from a crop grown in a cool climate, particularly if stored in a cool, dry place after harvesting, has a far 'normal' sprouting period and becomes exhausted much less quickly than one grown in a hot climate and stored under warm conditions. If it is desired to have physiologically young seed tubers in spring, they must be stored at a low temperature; if, on the other hand, physiologically somewhat older seed is preferred, they must be stored under warmer conditions. The effect of the physiological Age of the seed tuber on crop growth is discussed on page 19.
TUBER GROWTH

The sprouts of a seed tuber planted in warm moist soil will form roots and after some weeks the plant will emerge. A few weeks later stolons are formed and the period of tuber initiation starts. Under favourable conditions this can be fairly short (2-3 weeks). The length of the period between emergence and tuber initiation depends on many factors, such as variety, physiological age of seed tuber and sprout, daylength and temperature. Under Dutch conditions tuber initiations usually start 2-5 weeks after emergence. After tuber initiation some of the small tubers start to grow and some weeks later the remainder virtually disappears. The tendency is for only 2-4 tubers per main stem to grow. Fig. 6 shows the development of the various tuber sizes during the growing season in Bintje with 20-25 main stems per m² under favourable conditions. If the number of main stems is increased considerably the weight of tubers smaller than 35 mm and 45 mm increases and that of tubers larger than 55 mm decreases (see also Fig. 16). The weight of tubers smaller than 35-45 or 55 mm is less at the end of the season than it is earlier.

Fig. 6
Diagram illustrating tuber growth (var. Bintje 20-25 main stems per m²).
DEVELOPMENT OF THE HAULM
The leaves and stems collectively called the haulm are needed to intercept light and to use the resultant products of photosynthesis for dry matter production. The haulm can be characterized by four components:
1. the number of steins (main and lateral steins),
2. the number of levels of foliage,
3. the ratio leaf/stem dry weight, and
4. the haulm type pc (open type = erectophile leaf distribution closed type planophile leaf distribution)

NUMBER OF STEINS
The number of main steins is determined by factors such as seed tuber size, number of sprouts per tuber plant density and seed bed preparation (see also Fig. 15). In general, the greater the number of stems the earlier the ground is covered by foliage, but under conditions prevailing in the Netherlands the optimum density of main steins for complete foliage cover is about 25 per m² and higher densities do not achieve materially earlier cover. Lateral stems found on the main stem near or in the ground can help to achieve a closed canopy and so enhance light interception. The number of main steins influences not only haulm development but also tuber size (Fig. 16).

NUMBER OF LEVELS OF FOLIAGE
The steins of a potato plant grow according to a regular pattern. After the formation of 14-19 leaves (1st level) the flower or flower-bud becomes visible (1st flower). Thereafter, two lateral stems usually start to grow from leaf axils below the flower to form the second level, each forming a second flower or flower-bud. In Western Europe, late varieties grown under favourable conditions can produce up to 4 levels but if there is a deficiency of nitrogen or water, even the second level may not be found. One lateral stem under the flower may grow often, one of the may grow in the same direction as the main stein, making it appear as if there is a main stein with one lateral stem (Fig. 7). The formation of some levels of foliage is important for a crop making use of a long growing season, so that even late in the season a closed canopy of fairly young leaves is available to intercept much of the incident radiation and to use it efficiently.

RATIO LEAF/STEM DRY WEIGHT
The ratio of leaf/stem dry weight depends on the stage of crop development variety and growing conditions. Before haulm maximum, leaf dry weight is slightly greater than that of the stem. At haulm maximum leaf/stem dry weight ratios vary from 1/1 to 1/2, but after haulm maximum the ratio decreases.
Haulm Type

In general, a variety with a high leaf/stem dry weight ratio tends to show a more planophile leaf distribution (closed haulm type, as in most Tuberosum varieties) whilst a lower ratio shows more an erectophile leaf distribution (open haulm type, as in most Andigenum varieties). This difference in haulm type may affect light penetration into the foliage and so affect the efficiency with which the foliage uses the intercepted light but there are no data to support this hypothesis.

Fig. 7
Diagram of a main stem with lateral stems as found in the field (Reestman and Schepers).
MAIN YIELD DETERMINING FACTORS

Tuber yield is determined by:
1. cumulative light interception (flight = photosynthetically active radiation (PAR) = 400-700 rim)
2. efficiency- of foliage in utilizing the intercepted light for dry matter production
3. distribution of dry matter (harvest index) 4. dry matter content of tubers.

CUMULATIVE LIGHT INTERCEPTION

Cumulative light interception is determined by the proportion of the ground covered by foliage, the length of the growing period, and global radiation (of which about half is PAR).
Under Dutch conditions a late maturing variety can intercept in total more than 700 MJ/m2.
The proportion of the ground which is covered by foliage is similar to the proportion of the incident PAR intercepted by foliage. For optimal production, the stage of closed canopy should be reached as soon as possible and the leaf canopy should remain closed as long as possible before maturity.

LENGTH OF GROWING PERIOD

Fig. 8 shows the relationship between haulm and tuber growth, at the same time indicating the importance of the length of the growing period. We will call a crop with restricted haulm growth Growth Type 1, and a crop with extensive haulm growth Growth Type 2. If an early crop is desired - i.e. the highest possible yield in a short time - Type 1 should be aimed at, but if tile highest yield attainable is desired type 2 is prefer is clearly evident from Fig. 8.

By Growth Type 2 under Dutch conditions is meant a crop producing about 3 kg fresh of haulm per m2, i.e. approx. 0.3 kg of dry matter (at the point of maximum haulm weight). What then determines whether Growth Type 1 or 2 is obtained? The following list summarizes the more important factors.
### Growth type 1: Growth type 2:

<table>
<thead>
<tr>
<th>Varieties with restricted haulm growth-usually early varieties</th>
<th>Varieties with extensive haulm growth-usually late varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiologically old seed and sprouts</td>
<td>Physiologically young seed and sprouts</td>
</tr>
<tr>
<td>Short day</td>
<td>Long day</td>
</tr>
<tr>
<td>High light intensity</td>
<td>Low light intensity</td>
</tr>
<tr>
<td>Low temperature</td>
<td>High temperature</td>
</tr>
<tr>
<td>Low nitrogen</td>
<td>High nitrogen</td>
</tr>
<tr>
<td>Low soil moisture</td>
<td>High soil moisture</td>
</tr>
</tbody>
</table>

All other factors being equal, variation in a single factor may cause the growth type to change. There is, for instance, a very considerable difference between a crop grown when the days are long and one grown when they are short. The rate of nitrogen application also exercises an important influence and there can be a considerable difference in crops grown from physiologically old and young seed. With the help of the list given, individual factors can be adjusted so as to affect the balance in favour of one or the other growth type as required.

#### Examples:

1. If decreases and the temperature falls during the growing season this must be compensated for, if the maximum attainable yield is required, by planting varieties with extensive haulm growth (fairly late varieties), by applying a large quantity of nitrogen, and by using seed that is not too physiologically old.

2. The opposite must be clot. If daylength increases and a substantial rise in temperature can be expected during the growing season.

3. In order to obtain the same type of crop at high altitudes as at low altitudes it is necessary to apply more nitrogen to the crop and/or to use later varieties and an physiologically younger seed.

4. In areas where the days are inclined to be short and the temperature low early varieties from N.W. Europe usually form too little haulm for high yields. Under these conditions, varieties that produce more haulm should be used, the most popular being later varieties from N.W. Europe although late varieties react stronger on day length than early ones.

It is, therefore, largely the growth type of the crop that determines the length of the growing period and consequently the yield. There are, however, one or two other important factors which also affect the length of the growing period but are not directly connected with the growth type.

These are:

1. Efficient control of diseases and pests, e.g. late blight (Phytophthora infestans).
2. All adequate supply of minerals and water

### CONTROL OF FOLIAGE DISEASES

Under Dutch conditions, efficient and intensive measures to control Phytophthora infestans are all important pre-requisites for a long growing season. The average national yield has risen roughly 25% during the period 1960-1970, a considerable part of this being attributable to a longer growing season achieved by improved Phytophthora control.

In other countries different diseases, such as early blight (Alternaria), and pests, such as aphids, may cause serious damage to the foliage.
SUPPLY OF MINERALS

The most important minerals for the growth of potato plants are N, P, K, and Mg. The following information on the uptake of these minerals is based on knowledge acquired in temperate zones from frequent observations of crops.

Nitrogen has a very marked effect on the growth of the crop: it also affects the growth type. When determining the correct amount to apply, it is necessary to decide first of all what growth type is required (i.e. whether an early- or a late crop) and how much the soil itself can supply. This latter depends not only on the soil type, but also on weather conditions before and during the growing season. Nitrogen is utilized throughout the entire growing season, but intake is particularly rapid when the plants are producing a good deal of foliage which is especially the case after they have reached a height of 15 to 20 cm. In Fig. 9 this is 50 to 80 days after planting.

The nitrogen content of the haulm diminishes fairly rapidly, after tuber initiation. At the time the haulm of a crop in the temperate zone is at its maximum, the quantity of N is often found to amount to 4% of the dry matter or even more. In a well-developed crop the fresh weight of haulm is 3 to 4 kg per m2 with a dry matter content of approximately 10%. The total amount of N in the crop (haulm + tubers) at the time of maximum haulm size is 150-200 kg N per ha. This is obviously, the minimum that had to be available. A fair amount of N is still absorbed even after the point of maximum haulm size is reached, but, as is evident from Fig. 9, the quantity, required gradually diminishes.

Part of the N is transported to the tubers where at harvest time, the total quantity present is roughly 1½ to 2% of the dry matter.

For a yield per ha. of 8 tons of dry matter the total quantity of N removed with the tubers is about 150 kg, and therefore, be less than that absorbed by the crop at an earlier stage. Nitrogen is an important element in protein synthesis. It stimulates the growth of the meristem tissue, which contains many proteins and it also promotes branching. Nitrogen deficiency produces light green plants with a small haulm stiff upright leaves and leads to rapid maturation and a low yield.

Phosphate is absorbed throughout the entire growing season but, like nitrogen, absorption is most rapid when the foliage is in full growth. During the period of maximum haulm size the P₂O₅-content of the haulm of a well-grown crop is often 0.7 % or more of the dry matter; the tubers also usually contain about this amount. The total quantity of P₂O₅ absorbed by a well-grown crop is about 60 kg per ha; of this 50 kg at the most is removed with the mature tubers when they are harvested.
Phosphate is not absorbed very readily by the potato plant, consequently it is important to ensure that it is present in a form readily available. In acid soils P is readily fixed by iron and aluminium lime may make the P better available. However; in calcareous soils lime may make the P less available. Soil analyses must form the basis for determining the correct P-application. It should also be remembered that a satisfactory soil structure is extremely important in assisting absorption. Phosphate deficiency manifest itself in poorly developed dirty green coloured foliage and a generally unsatisfactory level of growth.

Potassium is absorbed in large quantities by potato plants. If there is a K-deficiency the crop dies to the detriment of yield. During the period of maximum haulm size the K-content of the haulm can vary markedly from crop to crop. In well-developed crops it may comprise 3% or as much as 7% of the dry matter. A low content of K in the foliage has a less disturbing effect where the N-content is low than where it is high. To be adequate, the K-content of the plant during the period of maximum haulm size, where the supply of N is normal, must not be below 4% of the dry matter and should preferably be somewhat higher. At that point, if the plants have developed properly the entire crop may have absorbed more than 350 kg K per ha. (i.e. about 420 kg K₂O). At harvest time, mature tubers contain 1.5 to 2.5% of K on a dry weight basis. If therefore the yield is good, about 200 kg K per ha, is removed. This is considerably less than the crop will have absorbed while growing.

A few weeks after the plant emerges it starts to absorb a large amount of K (Fig.9). Since, at about the time when maximum haulm size has been reached or shortly thereafter, there is a fairly sharp decline in the rate of absorption, very large quantities must be provided over a relatively short period. Potassium deficiency manifests itself in a dark green colour and bronze discoloration of the leaves, which, in the later stages, may become necrotic. Tubers with a low K-content bruise easily (bluish-grey discoloration under the skin).

Magnesium. Although not much Mg is required, its absorption is not infrequently impeded and a deficiency may markedly shorten the growth period. It is, therefore, all important constituent of the mineral provision which has to be made. The of the haulm during the period of maximum haulm size can vary considerably. Contents of 0.3 to 0.4 % (on a dry basis) are common ill crops with adequate supplies of the element Mg tell is of approx. 0.1.5 % are often found in the tubers. The total absorption of a well-developed crop at its haulm maximum may be roughly 30 kg Mg per ha. (i.e. approx. 50 kg MgO). This quantity must be available before the haulm maximum is reached.

There are a number of soil conditions which call make Mg relatively unavailable to the plant roots. A high level of acidity does not favour poor soil structure impedes it. Nitrogen usually counteracts symptoms Although the NH₄ ion hinder’s the absorption of the Mg ion, in most cases NH₄ is converted in the soil into NO₃ so N in the form of ammonia also usually counteracts Mg-deficiency symptoms.

Potassium impedes Mg-absorption, and, in consequence, excessive applications of K often results in Mg-deficiency. The symptoms of Mg-deficiency are very characteristic. The oldest leave become more necrotic between the veins while tile edges of the leaves remain.

**WATER SUPPLY**

Insufficient water supply to the crop reduces foliage growth and the efficiency of, that foliage to use intercepted light by reducing the rate of photosynthesis; moreover, water deficiency Stimulates maturity and call even cause death of the leaves. Under Conditions prevailing in the Netherlands, shortage of water has a greater effect on the efficiency of the foliage in producing dry matter than it has on total light interception, although on
light soil early death of crops may happen in dry- summers or on the heavier soils ill dry spring’s there may be incomplete foliage cover early ill the season.

EFFICIENCY OF FOLIAGE
The efficiency of foliage in utilizing intercepted light depends on:
1. temperature
2. light intensity
3. leafage
4. stomatal aperture (as it affects CO₂ concentration in the leaf tissue).

In the Netherlands, the of foliage in utilizing tile intercepted ligth usually varies between 2.0-3.0 g plant dry weight per MJ or 1.5-2.5 g tuber dry weight per MJ light intercepted

TEMPERATURE
In the previous chapter saw that affects the type of growth. High temperatures encourage the growth of the haulm, whereas lower temperatures are more conducive to that of the tubers. The temperature, then, affects the distribution, in one way or the other, of the dry matter formed. For example, temperatures higher than 25 to 30° C are unfavourable for tuber production. It is not only the average temperature that is important; the maxima and minima are even more so. Low night temperature may do a lot to restore the balance. Regions with maxima as high as 30°C and minima of about 15°C are much better for potato growing than regions with temperatures that are fairly constant at around 25°C.

The effect of temperature on photosynthesis and respiration of potato leaves is illustrated in Fig. 10.

Dry matter production is most rapid at about 20°C, at which temperature assimilation is high and respiration still slight.

At about 30° C dry-matter production drops to roughly two thirds of what it is at 20°C. At 10° C it is considerably higher of what it is at 30° C. No wonder then that this crop grows best in temperate climates or at high altitudes in the tropics or sub-tropics.

Needless to say, the temperature given is that in the crop. This may differ considerably from that measured at a height of 2m (i.e. the air temperature).

Fig. 10
Effect on temperature on photosynthesis and respiration (bottom line) for different light intensities (figures compiled by Winkler, published in ‘The Potato’ by W.G. Burton).
LIGHT INTENSITY

Figs. 10 and 11 show that the effective gross assimilation is greater when the light intensity is high than when it is low. Where light intensity is high the optimum temperature is also higher (Fig. 10). Regions with plenty of sunshine, therefore, have a certain advantage over areas where it is often cloudy.

Moreover, an abundance of light tilts the balance of the haulm/tuber growth relationship in favour of the tuber. This is one of the reasons why, in tropical and sub-tropical regions, it is possible to achieve high yields at high altitudes, where there is a high light intensity, even when day temperatures are fairly high, provided that night temperatures are rather low.

LEAFAGE

Most research workers assume that the rate of photosynthesis decreases considerably as the leaves age, for example, when they are older than, say 50 days. The higher the temperature the quicker the leaves age. Because young leaves respire faster than old leaves, the most efficient leaves are those which have just fully expanded. A crop which can make use of a long growing season, as can most crops in the Netherlands, has to form a lot of foliage to ensure that at the end of the season sufficient green leaves are still available to maintain an adequate rate of dry matter production.

Fig. 11
Effect of light intensity on photosynthesis. When the sky is overcast light intensity is $1 \times 10^5$-$2 \times 10^5$ Ergs per sq. Cm. Per second. On sunny days it is $6 \times 10^5$-$7 \times 10^5$ ergs per sq.cm. per second ('The Potato' by W.G. Burton)
STOMATAL APERTURE

There is a very strong positive relation between carbon dioxide concentration and assimilation ($CO_2 + H_2O + sun energy \rightarrow carbohydrates + O_2$) (Fig. 12). The CO$_2$ concentration outside the leaves cannot be influenced appreciably in practice. What matters, in any case, is the concentration inside the leaves. This is governed by the concentration of CO$_2$ around the leaves and the degree to which their pores (stomata) are open, which in turn is determined by the degree of evaporation from the leaves, the supply of water to the roots and the radiation. On hot days, when air humidity is low and the rate of evaporation is high, water must be made available in large quantities via the roots, otherwise the stomata close, causing a rapid drop in the concentration of CO$_2$ in the leaves and consequently in the rate of photosynthesis. This often occurs in the afternoon when the other conditions happen to favour optimal photosynthesis. We can put it another way: when conditions are conducive to a high rate of evaporation and the supply of water is inadequate, suction pressure increases not only in the roots, but also in the leaf, tissue.

Fig. 12
Effect of carbon dioxide concentration on photosynthesis. In the crop, the concentration is approx. 0.03% (‘The Potato’ by W.G. Burton)

Unlike the stomata in the leaves other agricultural crops, those in the potato leaf have been found to close at relatively low suction pressures. It is assumed by some research workers that they do so at a suction pressure of little as -4 bars (0.4 MB). It is not known if photosynthesis begins to decline at the same time but it seems to be that at -7 to -10 bars photosynthesis declines rapidly.

Under the conditions prevailing in the Netherlands, a dense crop in full growth gives off 25 to 30 mm of water per week. Precipitation in July and August averages 80-90 mm a month (see page 76). This means that if the crop is to continue growing well, the remaining moisture has to come from the soil reserves. During the growing season as a whole, the soil has to provide a total of 130-150 mm of moisture to compensate for the shortfall in precipitation. On average, the soils in the Netherlands retain, per cm of depth, about 2 mm of moisture that is accessible for plant growth of which 50% is readily available. Even if between 40 and 80 mm of moisture reach the root zone by means of capillary action, the roots still have to go down to a depth least 80 cm if there is not to be a moisture deficiency.

In countries where air humidity is low during the potato growing season, a well-developed crop may give off more than 50 mm of water per week. Such a high evapotranspiration rate calls for both frequent irrigation and a very well-developed root system. The amount of moisture evaporating in a day or two under these conditions is far more than the amount available to the plants in a well-shaped potato ridge after irrigation. This means that on subsequent days it must be possible for moisture to be from the soil beneath the ridge, and that will only be possible if the penetrate deeply into the soil.

Potatoes and their cultivation in the Netherlands
In many tropical and sub-tropical countries, where evaporation is often extremely rapid, it is, therefore, essential that good irrigation is backed by a deep, developed root system. A good, deep root system is, therefore, of the greatest importance if interruption in the growth of the plants is to be avoided. The potato root is not strong and has difficulty in penetrating caked or heavy soils. Sharp transitions from one soil type to another (e.g. from clay to sand) also severely curtail root growth. For an extensive root system, there must be no obstructive layers in the soil profile and the creation of hard layers at depths of between 10 and 30 cm by cultivations must be avoided. Hard layers of this sort may not only occur as a result of ploughing, but also during preparation of the seed bed.

They may be caused either by implements (e.g. power-driven implements closing up a moist layer as they slide over it), or by tractor wheels. If a good yield is to be obtained, it is extremely important to avoid this. The fact that good root development does not occur in by any means all soils, is evident from Fig. 13. This sketch was made on old, reasonably good potato land, in the Netherlands. Roots are only found in fairly substantial quantities to a depth of 30 to 35 cm and, even above that depth, many areas are without roots. These are hard areas. At depths greater than 35 cm, roots are found only occasionally (see also Fig. 14B).

Comparing this with the root pattern in Fig. 14A, which shows the growth of potato roots in a young polder¹ soil, it can be seen that the root systems are far better developed, because this soil contains fathard areas in the root zone. This greater suitability for root growth is one of the reasons why potato yields in the new polders are appreciably higher than in the old.

As, has been made clear, root development is dependent on whether or not the soil contains hard and obstructive layers. Another important point is the ratio of oxygen to carbon dioxide in the air pores. The respiration rate of roots is high and they, therefore, require a great deal of oxygen. Suffocation of the roots is most likely to occur when tile water cannot drain away fast enough during heavy rain.

¹ polder = a tract of low land reclaimed from the water, protected by dykes and where the water level is mechanically controlled.
After a period of waterlogging, particularly when the temperature is high, symptoms of water deficiency quickly become apparent, although the soil is still damp. In no such cases the majority of the roots will have been suffocated and no longer be able to absorb moisture. American investigations have shown that potato roots are particularly sensitive to oxygen deficiency or an excess of carbon dioxide. Suffocation may also occur if the top layer of soil has become compacted and, as a result, insufficient diffusion takes place between the air above ground and that in the soil. Diffusion can be improved by breaking up the compacted taking care to avoid damaging roots lying near the surface. A more common trouble is suffocation of the roots due to water accumulating on the surface of impervious soils during heavy rain or irrigation. Good drainage is, therefore, as important for satisfactory rooting and root activity as a good profile free from obstructive layers.

It can be seen from the above, that high standards have to be set for land used for potato-growing and growers must prepare it with particular care if the soil is to be in the right condition for the plants to grow properly without interruption, even when weather conditions are not ideal.
In practice the average tuber growth per day in the Netherlands is about 700 kg per ha., although, under favourable conditions, figures of 900 kg per day per ha. have been recorded by many commercial growers over periods of several weeks.

In experimental fields, tuber growths of as much as 1,200 kg per day per ha. have repeatedly been recorded. This means that, when the growing period is long, yields of 70 to 80 tons per ha. are a practical possibility, and in some years such yields are indeed obtained here and there on very good soils. Fortunately, yields of 60 tons per ha. are no longer exceptional. The conclusion can, therefore, be drawn that if all conditions are favourable the potato is a crop that can provide very high yields.

**DRY MATTER DISTRIBUTION**

Dry matter distribution during growth is clearly shown in Fig. 8. In a late maturing variety more dry matter must be invested in foliage growth than is necessary in one that matures early. The harvest index is also important; it is defined as the ratio of the total tuber dry matter at harvest to the total dry matter that has been produced by the crop and its numerical value depends on variety and growing conditions. In the Netherlands, the index varies between 0.75 and 0.85.

**DRY MATTER CONTENT OF TUBERS**

A yield of 50 tonnes/ha. of tubers with dry matter content of 20% is, from the point of production capacity, comparable with a yield of 40 tonnes/ha tubers with dry matter content of 25%. Factors influencing the dry matter content of tubers are set out in Fig. 19.

**ESTIMATING THE YIELD OF A POTATO CROP**

There is a simple method (described in the "Introduction to Potato Production" by H. P. Beukema and D. E. van der Zaag) by which the yield of a crop can be estimated from weekly measurements of the amount of ground covered with green foliage. A similar calculation can be done with a so called 'ideal' crop (with optimal water and mineral supply and no diseases or pests) to estimate the potential in a region. Under Dutch conditions such an 'ideal' crop would be planted in the beginning.
of April, emerge in the beginning of May, have a closed canopy from the beginning of June until the end of August and would mature at the end. Such a crop could intercept about 800 MJ PAR and, theoretically, produce about 22 tonnes tuber dry per ha. (utilization efficiency of 2.75 g tuber dry weight per MJ PAR intercepted) which is about 100 tonnes tuber fresh weight per ha suming a tuber dry matter content of 22%. A well-developed main crop of ware potatoes on good silt soil in the Netherlands produces about 60 tonnes per ha. (22% dry matter content). Its cumulative light interception would lie between 500 and 700 MJ/m² and so the foliage efficiency would vary from 2.0 to 2.5 g tuber dry weight per MJ PAR intercepted.

These calculations show that the average main crop intercepts considerably less light and utilizes this intercepted light less efficiently than the "ideal", crop producing a calculated yield of about 100 tonnes/ha. Some farmers have obtained yields of 85 tonnes/ha. and on experimental plots yields of 95 tonnes/ha. have been achieved.

In warmer climates, both the growing period and the daylength are usually shorter than in the Netherlands which means that there will be a lower total cumulative intercepted light. Moreover, at higher temperatures the intercepted light is used less efficiently and the harvest index is lower. The overall result is that the potential yield in most tropical and sub-tropical regions is considerably less than in temperate zones.

Figu 15
Factors influencing tuber size (effect of disease attack or second growth has not been included).
QUALITY

Quality\(^2\) can be divided into external aspects, such as shape and size of tuber, surface defects, visible damage etc., and internal aspects, such as dry matter content, sugar content, and internal defects and diseases. All these quality characteristics are governed by both the variety of potato and the conditions under which it is grown. The effect of variety can be ascertained from any good descriptive list; we shall confine ourselves here to explaining the effect of various growth factors on quality and thus show how the grower can work towards a specific quality. Not all aspects of quality can be covered here; we shall deal only with tuber size and shape, second growth, colour of skin and flesh, dry matter content, internal brown discoloration and common scab. A very important consideration in the case of seed potatoes is their freedom from certain diseases (virus, fungal & bacterial), which is not dealt with here since it would necessitate going into the whole background of the seed potato growing industry of the Netherlands, which, as has already been pointed out, is not the purpose of this booklet.

TUBER SIZE

Tuber size of the harvested product depends on the total tuber yield and the number of tuber per \(m^2\). The total yield depends on the length of the tuber growing period and the average growth of the tubers per day. The number of tubers per \(m^2\) depends on the number of main steins per \(m^2\) and on the number of tubers per main stein, which, in turn, decreases with the number of main steins. Number of tubers per main stem are also influenced by variety. In addition, it should be noted that fewer tubers are usually formed in heavy hard soil than on light soil. Conditions during the period of tuber formation also play an important role although really do not know exactly are the best conditions for the formation of a large number of tubers. In any case it would seem that neither extreme dryness nor undue moisture would flavour it. Very high temperatures and long clays would also seem unfavourable. The number of main steins is logically determined by the number of sprouts planted, but the firmness of the sprouts and the method of planting (which may result in breaking off sprouts) are important. Occasionally also, when the seed bed is very dry and cloddy the sprouts will not root. The number of Sprouts planted depends on the number of sprouts per seed tuber and the number of tubers planted. The number of sprouts per seed tuber is determined by the size of the tuber and by the pre-germination treatment adopted.

The foregoing is shown schematically in Fig. 15, is not, of course, exhaustive. For example, the growth per day also depends to some extent on the number of tubers per \(m^2\) and the number of main stems. Moreover, it should be borne in mind that by no means all the factors affect it to the same degree. The factors that have the most direct bearing on tuber size are the yield and the number of main stems per \(m^2\).

Fig. 16 shows that the number of main stems may also affect the yield and, what is even more important, the size grading. It also shows that the yield of tubers larger than \(28\ mm\) is highest where there are \(30\) to \(35\) main stems per \(m^2\) and that the maximum yield of tubers larger than \(50\ mm\) is obtained where there are approximately \(15\).

\(^2\) The term ‘quality’ covers all the characteristics of a potato consignment that make it suitable for the purpose for which it is intended.
It would seem that the relationship shown in Fig. 16 applies fairly generally. It will, of course, be to adjust the height of the x-axis and with it the tuber yield, to the actual yield while the y-axis must be moved all an appropriate distance to left or right according to soil type and variety. For example, on good, light, sandy-clay soil, or in the case of varieties with with many tubers per stem the number of main stems corresponding to the maximum weight of tubers above 55mm will be somewhat smaller than on heavy soil or in the case of varieties with few tuber per main stem. To obtain the same proportions of the different sizes of tubers in a long growing season (high yield) as in a short (low yield) more stems will be needed.

It will already have been gathered from what has been said that more tubers are often formed per stem on light, pervious soils than on firm, heavy soils.

During the period of tuber initiation (usually lasting a few weeks), the plants form quite a large number of tubers per stem, but as a rule only two to four of them develop into tubers that can be harvested; the rest disappears.

We do not know all the factors that bear on this. It has been found that in some years more tubers are formed per stem than in others. Fortunately, the grower can to a certain extent control the number of main stems produced. Fig. 15 shows schematically all the factors he has to take into account. The principal means of achieving the desired number of stems are:

1. good pre-germination.
2. determination of the most suitable distance between the seed tubers in the row, which, in turn, depends on the number of well-developed sprouts, the number of stems desired per m², and the distance between rows
3. provision of a good, moist seed bed.
4. avoidance of damage to sprouts during planting.

By these means Dutch growers try to obtain about 20 main stems per m² when growing a ware crop and at least 30 main stems when growing seed. In the case of the latter their aim is to harvest tubers measuring between 28 and 50 mm and, in the case of the ware, tubers larger than 35 mm or 40mm.

**TUBER SHAPE**

This is a varietal characteristic. In unfavourable growing conditions, tubers are liable to be misshapen, exhibiting such defects as growth cracks, swollen protusions of the eyes prolongation and swelling of the rose end etc. Such deformities occur when after a growth check (e.g. due to drought) the crop suddenly begins to grow rapidly again. Some X varieties seem to be more prone to this than others and care has to be taken that the crop always has enough moisture particularly.
by adopting appropriate methods of cultivation. The primary requirement is, that the root system must penetrate the soil extensively and deeply. As stated previously, this can be brought about by seeing that the soil is not compacted by the pressure of tractor wheels or by using implements in moist soil and by loosening any obstructive layers in the subsoil. In districts where there is insufficient rainfall, irrigation will have to be resorted to, though even then good root development is important. Deformities are caused by checks in growth, especially if this is accompanied by high temperatures, the presence of quantities of nitrogen, small numbers of main stems m$^2$ or distribution of the main stems. The first two factors stimulate the upsurge in growth after a drought and the last two stimulate an increase in tuber she after resumption because when there are few main stems the haulm/tuber ratio is high.

SECOND GROWTH

Deformation of the tubers can be considered as a mild form of second growth. Secondary tuber initiation on newly formed stolons or on the sprouts of the young primary (first formed) tubers is another form of second growth (Fig 17). When harvest time arrives there are then two distinct types of tubers, those with old skins (the tubers) and those with thin skins (the secondary tubers). The starch in the primary tubers is sometimes broken into sugars which then pass to the secondary tubers, the flesh of the former becoming glassy as a result (Fig. 18). This not only detracts from the quality of the tuber but also may cause it to rot. This may also occur at the stolon ends of tubers that have become excessively elongated and can sometimes lead to a condition known as jelly-end rot.

Fig. 17
Second growth. You can see very well the big tubers are the primary tubers, the little ones newly formed secondary tubers.
COLOUR OF SKIN AND FLESH
The skin of a potato tuber is usually yellow sometimes red but less frequently purple or mottled. The flesh ranges from white to yellow British and American varieties are mainly white, Dutch varieties usually light-yellow and the German varieties mainly yellow. Neither the colour of the skin nor the colour of the flesh bears a relation to quality British and American varieties generally have a lower dry matter content than those from the Netherlands but this is more a matter of the type of potato a country chooses to breed rather than correlation between flesh colour and dry matter content.

![Glassy tuber](image)

DRY MATTER CONTENT
A potato tuber with a high dry matter content is more floury boiled than one with a low content. The former also gives better yields when processed into potato starch, instant mashed-potato powder etc., chips or pommes frites than does the latter. Several factors influence the dry matter content of the tubers these are shown schematically in Fig. 19. It is well-known that the dry matter content of the tuber increases with maturity except in so far that some decrease may occur right at the end of the growing season, at which time it is assumed that respiration losses exceed assimilation gains. Such a decrease however be more than offset in a dry season by water loss from the tubers which, of course, lead to all apparent though not real increase in dry matter. Tuber maturity depends on variety date of harvest and growth type. Growth type affects dry matter content not only through the degree of maturity of the tubers but also through interaction with other factors such as, nitrogen supply, daylength, temperature, etc (Fig. 19). Many research workers have found that small applications of nitrogen increase the dry matter content of the tubers, whereas large applications tend to have the opposite effect. This would seem to imply that if haulm development is either poor or massive, the dry matter content of the tubers will rarely be high. Between these two extremes lies the optimal haulm development for high dry matter.
Haulm growth is not only affected by nitrogen supply but also by other factors (Fig. 19) To what extent, for example, irrigation will increase or decrease tuber dry matter depends on the level of haulm growth without it. Thus, if without irrigation haulm development would be pool and with it not too abundant, it is likely to increase the dry matter content. If on the other hand irrigation is likely to induce excessive haulm growth, it may decrease the dry matter content. The same can be said for daylength physiological age of the tuber and for the other factors mentioned.

Water and mineral uptake can affect growth type but also have a direct effect on tuber dry matter, as has been shown in the case of potassium and chloride. Potassium, when given in large quantities, tends to reduce the dry matter content, this being more marked on light than on heavy soils and increased by the presence of chloride in the potassium salts. Phosphorus has no marked effect on tuber dry matter, only when given in extremely high doses does it tend to induce some slight increase.
Soil and weather conditions can affect tuber dry matter through their influence on growth type, or possibly also through an effect on mineral uptake. In Fig. 19 it is assumed that the varietal effect on the dry matter content of the tubers operates mainly through maturity growth type and water and mineral uptake. As long as we have no clear data on differences between varieties in the distribution of dry matter within the plant or in tuber anatomy that may affect dry matter content of the tubers we may explain varietal effect in the way stated.

The level of dry matter required naturally depends on the purpose for which the crop is being grown, the principles outlined should enable the grower to achieve the result required.

INTERNAL BROWN DISCOLORATIONS

In some varieties and particularly in hot summers, small brown patches may appear in the flesh of the tubers, particularly if they are large. This defect is probably the same as one which, in some sub-tropical countries, is called 'chocolate disease'. It is regarded as a physiological disorder and is not transmitted via the seed tubers. Probably this phenomenon is associated with poor calcium transport. It appears to be linked with high temperatures when growth is, spasmodic, especially as a consequence of inadequate irrigation. Rapidly growing tubers (at harvest time usually the large ones) are the worst affected. To avoid damage of this type it is necessary both to improve irrigation and a dense stem population to prevent the formation of excessive numbers of large tubers. It is even better, of course to grow the crop at a time of year when temperatures are lower.

INTERNAL BRUISING - BLACK SPOT

Black spot is a blue-grey discoloration in the vascular tissue found 1-3 days after impact damage (harvester, grading machine). The skill often shows no visible sign of damage. The pigments responsible for the discoloration are produced by the oxidation of phenolic substrates (tyrosine by phenolase).

The susceptibility of tubers to black spot is determined by;
1. the potential of the tissue to oxidation products;
2. susceptibility of the tissue to damage

It seems that in the main commercial varieties the most important factor is the of the tissue to damage. This is influenced by;
1. temperature of the tubers - at low temperatures they are much more susceptible than at tell;
   temperatures above 12-15°C;
2. dry matter content of the tubers - the higher the dry matter content the more they are susceptible;
3. turgidity of the tubers - tubers with high turgor (low are more susceptible than those with normal turgor;
4. variety - some variety arc more susceptible to damage than others

The influence of the potassium content of the tuber oil black spot susceptibility is not clear. It call it via the dry matter content but it may have also a direct effect.

COMMON SCAB

Although, under Dutch conditions, there is no of scab via the seed, many growers demand seed tubers that are relatively free of the disease and the consumer does not like scabby potatoes. The incidence of scab is closely linked with soil conditions. It has been found that if the soil is kept moist during the period of tuber (about 3 weeks), the incidence of scab is greatly reduced. Where there is irrigation, this method of control can be used with success.
Organic fertilizers are mainly used to keep the soil in good condition, with particular emphasis on its structure. Since many arable farms in the Netherlands no longer keep cattle, there is no farmyard manure available.

Organic manuring primarily takes the form of ploughing back a green crop such as grass or clover. Potatoes are fairly heavily dependent on fertilizers for their mineral supply. As Fig. 9 shows, a large proportion of the minerals is absorbed at the beginning of the growing period. So they must be readily available to the young plants at all stages. The quantity of fertilizer required depends on the soil and the purpose for which the crop is intended. As sandy soils containing humus often supply more nitrogen than do clay soils, potatoes grown on these latter must be given more nitrogen. The soil in new polders is very rich in potash, making it for crops to be given any potassium at all for the first few years. If an early crop (Type 1, Fig. 8) is required (e.g. one for seed or early ware) considerably less nitrogen should be given than to one intended for late harvesting. Potatoes that are required to have a high dry matter content should be given considerably less potassium (and certainly no potassic fertilizer containing chloride) than potatoes the dry matter content of which is less important.

In order to make a recommendation on fertilizer requirements, it is necessary to know what the soil itself will supply, what the crop desired needs, and how much is likely to be leached from the soil.

To estimate the correct amount of nitrogen to apply the amount of available nitrogen in the soil in spring should be known. Nowadays growers can obtain this information.

The following is a rough guide to the quantities normally given in the Netherlands:

<table>
<thead>
<tr>
<th>GROWTH TYPE 1 (Fig. 8)</th>
<th>GROWTH TYPE 2 (Fig. 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 100-150 kg per ha.</td>
<td>N 200-300 kg per ha.</td>
</tr>
<tr>
<td>P₂O₅ 100-150 kg per ha.</td>
<td>P₂O₅ 100-200 kg per ha.</td>
</tr>
<tr>
<td>K₂O 100-300 kg per ha.</td>
<td>K₂O 200-500 kg per ha.</td>
</tr>
</tbody>
</table>

The lowest doses of nitrogen apply in the main to sandy soils and the lowest doses of potassium to crops which must have a high dry matter content or which are grown in soils rich in potassium.

Fig. 20
Relation between nitrogen supply and tuber yield at full maturity on sandy clay soil.
Under the conditions prevailing in the Netherlands, nitrogen usually has a far more marked effect on yield than do either phosphorus or potassium. Fig. 20 shows the relationship between nitrogen application and tuber yield.

Two thirds of the required nitrogen, as ammonium nitrate, is usually applied before planting and the remaining one third 3-5 weeks after emergence; all phosphorus is applied as super phosphate before planting, commonly as compound fertilizer with nitrogen (23:23); potassium is applied on silt soils in the autumn as potassium chloride, whilst on sandy soils and on crops where a high dry matter content is essential it is applied in spring as potassium sulphate.

Although placement does effect some saving in fertilizer, it is a method that has not found general acceptance in the Netherlands.

Soils that are deficient in magnesium are given this as well as the nitrogen, phosphorus and potassium fertilizers in summer when the first deficiency symptoms appear, they may be sprayed with MgSO₄ solution at a rate equivalent to 24 kg MgO in 600 litres of water per ha.

PRE-TREATMENT OF SEED POTATOES

When growing potatoes for seed, ware and starch production which are to be harvested early, the aim is to produce Growth Type 1 (Fig. 8). The seed for this crop should be physiologically fairly old and should also have well-developed sprouts. Crops that need riot be harvested until late and from which maximum yields are required should be grown from fairly young seed.

If possible, therefore, growers of seed and early potatoes should store their seed at temperatures just below that necessary for sprouting, subsequently placing them in sprouting trays (Fig. 22) at fairly high temperatures with a good deal of light for at least 2 months before planting, to enable them to form good sprouts. For early potatoes, a plant with not too many sterns is preferred, which means that there should not be too many sprouts per tuber. The transition from the low temperature at which the potatoes are stored to the higher temperature at which they are placed to sprout should, therefore, be made gradually. When handling seed for seed production, on the other hand, the practice is to apply a sharp increase in temperature by raising it rapidly to about 20°C so that as many eyes as possible will sprout. Formerly, seed was stored at a fairly high temperature, the sprouts (often apical sprouts), which appeared in January, being removed by fraud. More eyes then began to sprout.
This method is now too laborious for many farms. Glass seed stores (Fig. 23) are still used for both winter storage and pre-sprouting. Artificial light is also used for pre-sprouting.

To produce short sturdy sprouts and thus ensure minimal damage, the trays are placed out-of-doors for the last few weeks (Fig. 22 and 25).

In recent years large stores for pre-sprouting seed potatoes have been built in which several handling operations can be done mechanically (Fig. 24).

For late crops there is an increasing tendency to go over to a simpler system which need not be detrimental to the yield, provided the grower has sufficient time to allow the crop to mature. The seed is stored in a cool place (2°C to 4°C) in sacks or in bulk. About a month before planting the seed in sacks is transferred to a shed (in which the temperature should be between about 4°C and 12°C). In this way, by the time of planting the eyes are usually well open. Another method of stimulating growth is to subject the seed to a temperature of about 20°C in the cool storage shed a week or so prior to planting and then to plant it when it has cooled down. Whichever of the two methods is used, the seed is still physiologically fairly young, which is conducive to the production of growth Type 2.

Fig. 22
Trays for presprouting seed potatoes.

Fig. 23
Glass shed for storage and presprouting seed potatoes.
A sensible potato-grower will rarely plant seed tubers without sprouts, with eyes that are not properly open, or with long weak sprouts. Good pre-treatment of seed is vital for rapid and even emergence and high yield. Fortunately, most Dutch potato-growers are well aware of this fact (Fig 26). Although proper pre-treatment of the seed is most important for the achievement of a good harvest, the use of healthy seed is even more so. Cutting of seed is hardly ever practised in Western Europe. Investigations have, indeed, shown clearly that under Dutch conditions no advantage is to be gained from cutting tubers that are smaller than 55 mm. The same result can be achieved by ensuring good pre-sprouting (many shuns per seed tuber) and planting wider apart. At normal plant densities there may be advantages in cutting tubers larger than 55 mm into two, provided it is done properly.

This means that:

1. the knife must be disinfected each time so that no virus or bacterial diseases are transmitted;
2. the halves of the tubers are suberized, in a humid atmosphere. This can be done by placing the two halves together best done by not cutting the tuber right through (Fig. 27). The two halves are then not separated until they are planted.

At low plant densities cutting tubers smaller than 55 mm may have advantages to
PLANTING

PREPARING THE SEED BED

To obtain rapid growth, the well-prepared seed tubers should be planted in fairly moist soil. If they are planted in very loose or cloddy soil, there is a probability that they will dry out. Buds or sprouts grow very slowly if at all under such conditions; roots are also formed extremely slowly. As sprout elongation does not start until the roots appear the overall result is usually slow and irregular. Furthermore, the final number of stems produced per plant is frequently much lower than it would have been had the seed tubers been planted in fine moist soil.

Silt soils should be ploughed before the winter and in spring, when the soil has dried sufficiently, the soil should be prepared for planting with great care. Properly prepared soil should consist of a fairly fine, some what moist top at least ± 6-8cm deep. If this is achieved, not only will sprouting of the seed and emergence of the plants be rapid but it will also be possible to make a clod-free ridge, a factor of great importance for mechanical harvesting. The two essential points in preparing a seed bed on silt soils are:

1. Wait until the ground is dry enough. This is vital and many growers still find it difficult and to wait long enough.
2. Use the right implements to make the soil loose and fine. Harrows with a depth adjuster and power-driven implements are in common use for this purpose. Figs. 28 and 29 show a harrow which is very popular, although also many growers prefer more old-fashioned harrows with a depth adjuster.

On silt soils the seed bed should preferably be prepared on the day of planting. When planting, it is very important to ensure that the top layer of firm earth under the furrow is not smoothed down, as this can hinder downward root growth.

On sandy and peaty soils, ploughing is done both during and after the winter. It is not so difficult to work this type of soil to a consistency that is sufficiently loose and fine for planting. Indeed care has to be taken to see that the ground is not too loose, otherwise it will dry out quickly. Growers, in fact, usually like to let the loose earth settle a litte before planting. The best results are obtained by planting in fairly firm, moist soil.
DEPTH OF PLANTING

Dutch growers do not plant deep. If the condition of the seed bed is satisfactory; the tubers are planted at a depth of only a few centimetres. This means that, if the soil were levelled off after planting, the top of the seed tubers would be roughly, level with the surface. This facilitates lifting and also ensures that the newly-formed tubers are above the level of the bottom of the furrow (Fig. 38). The advantage of this latter is that, if the growing season is wet, the tubers never lie for long in water-logged soil, which might lead to wet rot.

If the top layer of soil is dry, the tubers must be planted somewhat deeper, to ensure that they are lying in moist earth. In many countries seed is normally, planted rather deeper than it is in the Netherlands.

ROW AND PLANT SPACING

Whereas, in former times, a row spacing of 66 cm was customary, 75 cm is now commonly, used. Wide row spacing has many advantages, for example:

1. more earth is available to make a good ridge;
2. the sides of the ridges are less likely to be compacted by wide tractor tyres;
3. less time is needed per hectare for cultivations.

The distance between seed tubers in the row depends on the size of tuber it is desired to harvest. Figs. 15 and 16 indicate the factors governing tuber size. Bearing in mind present-day market requirements, about 20 main stems per m² seem to be optimal for ware production under Dutch conditions. Some growers, however, prefer about 15 stems/m² to obtain a high proportion of large tubers to be sold to the processing industry for pommes frites. The percentage of irregular tubers is then usually somewhat higher. A 35 to 45 mm seed tuber, given the right pre-treatment, should produce approx. 5 main stems and most growers, therefore, plant about 4 seed tubers per m². If the rows are 75 cm apart, this implies a spacing of 33 cm between the plants in the row, requiring about 2,000-2,500 kg of seed per hectare. If fewer stems are expected per plant, because, for instance, small seed is being used, plant spacing within the row must be reduced.

If the aim is to harvest a large number of tubers of between 28 and 45 mm, at least 30 main stems per m² are required; seed growers indeed sometimes go as high as 45 stems per m². If large seed (45 to 55 mm), properly prepared for pre-sprouting, is used, an average of 6 main stems per plant can be expected. If the rows are 75 cm apart, the distance between plants in the row must then be 20 to 25 cm. For seed production this is often done. This involves the planting of 4-5 tons of seed per ha. Fig. 30 shows the relation between tuber size and tuber weight for round and long oval tubers. From this can be concluded that 60,000 long oval seed tubers of 45 to 55 mm weigh almost 6 tons.
METHODS OF PLANTING

Seed potatoes are no longer planted by hand in prepared furrows, as this calls for far too much labour. Nevertheless it is still a good method, provided the furrows are not allowed to dry out.

Once, semi-automatic planters were in common use. The pre-sprouted seed was put into the planting cups by hand (Fig. 31). Although still practised on some seed-producing farms, even this method calls for excessive labour. Therefore, a 2- and 4-row planter were developed that kept sprout damage to a minimum (Fig. 32). Trays are emptied by hand during planting. Recently machines have been developed where this is also mechanised. The distance between the seed tubers in the row tends to be somewhat irregular. Most growers, however, now use fully automatic planters (Fig. 33), which enable the work to be done quickly and accurately. However, they have one drawback: they tend to damage the sprouts of pre-sprouted seed. Every effort must, therefore, be made to keep sprout damage to a minimum by taking the following precautions:

1. Sprouts should be short and well hardened off. It is for this reason that growers like to leave the pre-sprouted seed out-of-doors, exposed to the weather, for several weeks before planting.
2. Care must be exercised when emptying the sprouting-trays into the hopper of the planter and it is essential to use slow forward speeds when planting.

Most varieties can be handled satisfactorily in this way, and, despite the drawbacks, the crop comes up reasonably, quickly and evenly, (Fig. 34). The majority of growers of ware potatoes for the starch industry do not pre-sprout the seed, but plant seed tubers of which the eyes are well open. The seed is transported to the field in bags or in bulk. In the latter case the trailer is loaded in the store with a self-fed conveyor and unloaded into the planter (Fig. 35).

Transport of the seed and planting with a 4 row-planter takes about 2-3 manhours per ha.
Fig. 33
Planting presprouted seed with fully automatic planter.
EARTHING-UP AND WEEDCONTROL

In order to get sufficient earth low forming a well-shaped ridge on silt soils, it is often necessary to loosen the subsoil between the rows. On light soil this presents no difficulties but on heavier soils it may do so, and, in the Netherlands, many growers use a rotary row-crop cultivator (Fig. 36) for the purpose.

In addition to having sufficient loose soil, good ridging bodies are needed and these must be used correctly. That shown in Fig. 37 is widely used in the Netherlands.

Fig. 38 shows the shape of ridge required. It must be fairly high and have a wide rounded top so that it can contain a large number of tubers. In such a ridge, moreover, the newly-formed tubers are all above the bottom of the furrow. If, after rain, water remains standing in the furrow for some time, most, if not all, of the tubers will be above the level of the soil.

Fig. 36
A row-crop cultivator used to loosen the earth between the rows and then to build up the ridge.

Fig. 38
Diagram of a well-shaped potato ridge.
Broadly speaking, the following two methods of earthing-up and weed control are practised.

1. Some days after planting, the ground is gone over once, or perhaps twice, in order to form good ridges. Shortly before the plants emerge, the ground is sprayed with a herbicide. On sandy and peaty soils this, in the majority of cases, are contact herbicides such as paraquat which kill only the weeds that have emerged.

2. In the second method, which is applied sometimes on silt soils and does not involve the use of chemicals for weed control, the ridges are formed in one or two operations with an interval of a week or two between each. These provide a form of weed control. If necessary, a further cultivation which consists of harrowing and earthing up in one operation may be carried out later to keep down the weeds.

It is hard to say which method is the better. The first is labour-saving but costs more. The second may result in additional loss of moisture and possibly, also in damage to the roots of the potato plants. The first is preferred when planting is done late, because of the likelihood of drought.

Fig. 39
Spraying a field of potatoes to control late blight.
CONTROL OF LATE BLIGHT

PHYTOPHTHORA INFESTANS

Hardly a year passes without an outbreak of late blight caused by the fungus phytophthora infestans. Twenty or thirty years ago it was not unusual for yields to be low as a result of potato blight, or for there to be a high proportion of diseased tubers in the crop. More effective control has prevented this happening now.

The quite substantial improvement in the yield that has taken place in the case of ware potatoes and potatoes grown for starch is primarily due to better blight control, which has made a longer growing season possible.

In the Netherlands the following points receive particular attention:

1. Diseased plants developing from diseased tubers on refuse dumps or in the field provide highly dangerous foci of infection and are destroyed as soon as possible.
2. Where susceptible varieties are involved, chemical control is begun as soon as plants meet in the rows.
3. A regular programme of spraying is maintained. Most growers spray every ten days and, when the weather favours the disease, every seven days.
4. The right fungicides must be used. Maneb-fentin combinations are widely used and give very good results.
5. Should the foliage be at all seriously affected by the disease, the leaves are immediately killed off by spraying in order to prevent infection of the tuber. The last decades, control has been so efficient that this is very rarely done.
6. Where tubers have nevertheless become infected, it is essential for the crop to be dried quickly and then stored in a well-ventilated store.

Potatoes are sprayed both from the air and with ground-operated machines (Fig. 39), the latter method being the more common. It is no exception for a susceptible variety like Bintje to be sprayed 12 to 15 times in one season. Dutch growers have come to appreciate that efficient Phytophthora control always pays.
**HARVESTING**

The seed crop is generally harvested in August and the ware crop mainly in September. In the case of seed, the haulm is usually killed at the end of July or the beginning of August, to prevent the tubers from becoming infected with virus diseases spread by aphids. Haulm is destroyed by chemical or mechanical means. In the first method, now etiquet is the chemical principally used. Mechanical destruction consists of mechanical pulling and then shredding of the haulm (Fig. 40 and 41). This method is becoming more popular. Seed growers like to start lifting the crop as soon as possible after the haulm has been destroyed so as to prevent infection of the tubers with *Rhizoctonia solani* (black scurf).

All potatoes are lifted mechanically. Two-row harvesters convey the tubers straight into an accompanying trailer (Fig. 42 and 43). So it is possible to harvest 1 ha., or 50 to 60 tons potatoes, in, say, 3 hours.

If a harvester is correctly adjusted, the tubers can be harvested without sustaining any damage worth mentioning, provided that the soil is in good condition and has been properly prepared in the early part of the season. The last decades Dutch growers have paid increasing attention to cultivation with highly successful results. Fortunately there are many areas of the country with soils that are very suitable for potato growing. After lifting the potatoes are transported to stores in 8 to 12 ton vehicles. Usually these are tipping trailers. Before actually entering the store, the potatoes often undergo a cleaning process to remove earth and haulm debris. (Fig. 44).
Fig. 43
Soil on the web protects the tuber from damage.

Fig. 44
Potatoes are often unloaded into a hopper from which they are transferred to a precleaner which removes still more earth and small tubers.
STORING, GRADING AND MARKETING

STORING
A potato tuber is a living piece of stem containing a great deal of moisture. All manner of processes take place in the tuber; it breathes, i.e. uses oxygen. Respiration is at its lowest and there is remarkably little spread of any, fungal or bacterial infection present if the storage temperature is kept at about 4-5°C and the potatoes will keep for a long time. Moisture-loss is at its minimum at a relative humidity above 92%. In very dry air water-loss is excessive and the tubers soon become spongy, and wrinkled. On the other hand, the tuber must not get too damp, since that may cause it to rot or sprout prematurely. A temperature of 4-5°C and a relative humidity of 92%-95% are ideal conditions for prolonged storage. If sprouting is held in check by, using a growth-inhibiting agent, ware potatoes will keep satisfactorily for 7-9 months. It has, however, been found that the reducing sugar content increases gradually at this temperature. These sugars are the chief cause of the brown discoloration of pre-fried frites and of chips, so for these purposes, only potatoes should be used that have been stored at a higher temperature, e.g. 7 to 10°C.

Since the majority of the larger tubers are used for pommes frites, most ware potatoes in the Netherlands are stored at 6 to 7°C. Those intended especially for the chips industry should, in fact, be stored at 8 to 10°C and germination checked by using a growth-inhibitor (CIPC + IPC).
Seed potatoes, particularly when they are to be planted as late as April or exported early in the year, should be stored at 3 or 4°C; they will then be in the best possible condition for planting in March or April. The storage temperature must be entirely geared to the purpose for which the product is intended.

Nearly all seeds and ware potatoes are stored in accordance with modern methods, i.e. in insulated stores controlled ventilation (Fig. 46).

A high capacity fan (100 m³ of air per m³ of potatoes at a static-pressure of 15 mm water gauge) blows fresh air upwards through the stack, the air escaping through automatic dampers in the ceiling. A system of surface or underground ducts below the stack (Fig. 47) ensures that the air is evenly distributed. The walls of the store are sufficiently well-insulated to ensure that the indoor temperature is reasonably independent of the outdoor temperature.

Experience has shown that the heat penetration coefficient must not exceed 0.5 kcal/M²/h/°C. (almost 0.6 W/M²/°C).

When the potatoes are brought in, they are always somewhat damp. They can be dried in a few days by ventilating them with fresh air from outside This helps to prevent the spread of fungi and bacteria and is essential if the tubers are brought in at all wet. As soon as the minimum night temperature starts to drop in autumn, ventilating is done at night using the cold air, which means that the ventilating system is then being used to cool the tubers. The insulated walls ensure that the temperature in the store does not rise much during the day.

In this way the potato can be stored from the middle of October until the beginning of May at temperatures below 6°C (Fig. 48).

Under the climatic conditions prevailing in the Netherlands these requirements can easily be met in modern stores and it is essential that they are if the high quality of the product is to be maintained; this applies by no means least to the seed crop.
Fig. 48
Maximum, minimum and average temperature in the Netherlands (30 year average)
GRADING

Before the potatoes are delivered, they must be graded according to size and the diseased, misshapen and damaged tubers removed. Before grading the tubers are warmed to about 12°C to prevent internal bruising.

Grading machines (Fig. 49) are used for size separation. Most work is entailed in picking out the rejects. For this purpose, all the potatoes are passed slowly over a roller conveyor (Fig. 50) which causes each tuber to revolve around its longitudinal axis, thus enabling the whole surface to be properly inspected. Sonic growers do their own grading but others leave this work to the co-operatives or merchants selling their potatoes. These co-operatives or merchants have large, centrally situated grading areas (Fig. 50). In the Netherlands, considerable attention has been devoted to the storage and grading of potatoes; in fact, the cost involved in these two operations represents nearly a quarter of the total cost of production.

Fig. 49
Grading machine

Fig. 50
Roller conveyor to facilitate removal of rejects, at a central grading area.
MARKETING

It is not the purpose of this booklet to get into the details of marketing. The entire process of cultivation and storage must be geared to marketing if potato growing is to be a profitable undertaking. Sales can be stimulated if growers make real efforts to satisfy their customers’ requirements. They can do this:

a. By choosing their varieties carefully. The variety chosen should be the one that has the most favourable characteristics for the purpose for which it is being grown.

b. By employing the correct cultivation techniques. Most methods of cultivation affect not only the yield but also the quality of a consignment. Manuring is a major factor and can have quite a marked effect on the dry matter content as can the time of planting, the pre-treatment of the seed and the time of lifting the crop. As we have seen, the grower himself can regulate the size of the tubers harvested, one method being to ensure the correct number of main stems per m2. Many more examples of the effect of cultivation methods could be given.

c. By adopting the appropriate method of storage. If the customer cannot take receipt of the potatoes until several months after harvest, they will have to be properly stored so that a good quality product can be supplied at the right time. Good storage facilities are essential to potato production.

The purpose of the foregoing is to make clear that there is a close connection between potato growing and marketing.

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