# Jerusalem Artichoke *(Helianthus Tuberosus* L.) – A Potential Root Crop for the Tropics

**R. Delhey**
Crop Science Institute Technical University,
Berline, Germany

## Abstract

Four cultivars of Jerusalem artichoke were treated with different photoperiods (12 hrs, 12/18 hrs, 18 hrs, normal day) in the open. Short-day treated plants compared with long-day plants are characterized by an acceleration in development, shortening of life time, reduction in plant height, branching, stolen length, tuber number, total dry matter production and final tuber yield. Harvest index is higher in short-day than in long-day plants. Normal-day plants are intermediate in most respects. Long-day plants, though receiving less photosynthetically effective light than normal-day plants, produced twice as much dry matter. The reaction of the cultivars to photoperiod was essentially the same, but differed in their reaction to light intensity.

The short day effect can be compensated largely by a high temperature treatment (30°/24°C compared with 22°/16°C), as revealed by growth chamber experiments with one of the cultivars. High light intensity had an additional effect.

Flowering varied greatly with the cultivar involved. Short day treatment in combination with low temperatures prevented flowering, whereas at higher temperatures, flower heads developed, at least with the one cultivar tested. At long and normal days, only the earliest cultivar formed flowers.

The possibilities of Jerusalem artichoke as a potential crop for lower latitudes are exposed and discussed.

## Introduction

Jerusalem artichoke, grown in eastern and central North America since pre-Columbian times, is a highly neglected crop. It was introduced in Europe in the early 17th century, where it has been cultivated since then, especially in France.

*Helianthus tuberosus* belongs to the same genus as sunflower (*H. annuus*). Although the latter is diploid (2n = 34) and *H. tuberosus* is hexaploid (2n = 102), fertile hybrids may be obtained. Sunflower breeders make use of Jerusalem artichoke as a source of genes resistant to diseases. As the genus *Helianthus* comprises about 70 species which many can form interspecific hybrids, there is a very broad basis for breeding work with sunflower as well as with Jerusalem artichoke (Heiser 1976). The situation can be compared to that of potato.

Jerusalem artichoke plants produce tubers on underground stems, like potato. Tuber yields are comparable to those of potatoes (Patzold 1957), in spite of the little attention Jerusalem artichoke has received from breeders and agronomists. An average analysis of the tubers is as follows: dry matter, 20 to 25 percent; carbohydrates, 13 to 18 percent; protein, 1.5 to 2.0 percent; fat, 0.1 to 0.2 percent; ash, 1.0 to 1.5 percent; and crude fiber, 1.0 to 1.5 percent (Conti 1953).

In contrast to the potato, the carbohydrate stored in Jerusalem artichoke tubers is made up of inulin, not starch. Inulin is a polysaccharide composed of 30 to 40 fructose units. A molecule of sucrose acts as a starter for polymerization, so that on hydrolysis some glucose are always present besides the fructose which makes up the bulk of the hydrolysis products.

The high fructose content makes Jerusalem artichoke tubers suitable for dietetic purposes, especially for persons suffering from diabetes. Conti (1953) and Breen (1964) have studied the possibilities to produce pure fructose and a syrup rich in fructose. The agricultural potential for a fructose production on large scale have been investigated recently by Pilnik and Vervelde (1976) in the Netherlands and by Dorrell and Chubey (1977) in Canada, with promising results.

The tubers can also be utilized for the production of alcohol. In France, Jerusalem Artichoke produces more alcohol per hectare than potato, sugar beet or maize (Patzold 1957). In eastern and central Europe, Jerusalem artichoke is used mainly for animal feeding; tubers as well as the foliage can be utilized for this purpose.

Actually, Jerusalem artichoke is grown to a reasonable extent only in some parts of France and eastern Europe. There are many reports on cultivation trials in lower latitudes, which are often very promising (Patzold 1957; Kay 1973).

The reactions of the plant to climatic factors such as temperature, light intensity and rainfall are only partially known; the day length response has been studied more extensively (Garner and Allard 1923; Tinker 1925, 1929; Hackbarth 1937; and others).

## Experiments

Four cultivars have been included in these studies:

cv. B, Bianka, selected from a French breeding clone by G. A. Kuppers-Sonnenberg. Under central European conditions, this is a medium-early cv., which flowers as early as August; low, highly branched bushes; white, knobby tubers.

cv. G, name is unknown; seed tubers were received from Gross-Gerau in West Germany, where this cv. is grown in the forests for game feeding; medium-late; tall, poorly branched; spindle-shaped, reddish tubers.

cv. K, an unnamed clone, which has been selected by us in Berlin out of cv. B. It is not known if we are dealing with a simple admixture or a photoperiodic mutant of cv. B; very late; bushy, with tubers similar to those of cv. B.

cv. R, Rote Zonenkugel, bred by G. A. Kuppers-Sonnenberg; very late; bushy, with club-shaped tubers of pink to violet color.

## Photoperiodical studies

Plants of the four cvs. were exposed to the following treatments:

1. 12 hrs photoperiod continuously;
2. 53 cycles of 12 hrs photoperiod, then shifted to 18 hrs;

3. 18 hrs photoperiod continuously:
4. normal or natural day of Berlin ( (52°28' of n. lat).

In treatments 1 to 3, the plants received a basic light treatment with natural day light of 12 hrs; then they were covered and the 18 hrs plants received an additional 6 hrs illumination with an intensity of 250 Lux, which is photoperiodically effective, but not photosynthetically. The experiments were carried out in the open.

After a sprouting period of about 3 weeks, one-stemmed plants were planted in 10 1-plastic buckets, filled with a mixture of compost, sand and peat. The treatments were started on April 21, 1978. Half of the plants were harvested on June 13, at the age of 75 days. The photoperiodical treatments of the remaining plants were finished on August 29, and the plants were allowed to mature under normal day conditions.

Short day treatment accelerated the development of the plants compared to long or normal day. The plants of treatment 2 (first short, then long day) behaved essentially the same as did those of short day only (Treatment 1). The acceleration of development in the short day is reflected in the life time of the plants, which is considerably reduced compared to the long and normal day (Fig. 1) There is a significant increase of life time also for the plants of treatment 2 compared to those of treatment 1. The cv. B stands out for its relatively short vegetation time even under the normal and long day treatment. This is the cause for its earliness under central European conditions.

In the short day, the late cvs. G, K and R formed flower buds when 70 to 80 days old, but only one flower head opened in cv. G. Much later, the normal and long day plants of cvs. G and R formed some flower buds, although none of them flowered.In comparison to the late cvs., cv. B in the short day did not even develop flower buds; however, under normal and long day conditions, buds and flowers were formed.

Plant height as well is influenced considerably by photoperiod. As shown in Fig. 2, short day plants very soon ceased growing and remained small, whereas normal day and especially long day plants continued to grow over a much longer period. In this respect, B is the most and K the least sensitive cv. to photoperiodical changes.

Photoperiod affects also the branching habit of Jerusalem artichoke. In short day plants, there is only a very limited formation of apical branches, whereas at longer photoperiods ramification is more pronounced and is located at the lower and middle portion of the stems, especially in the cvs. B, K and R. In B and K, stolons can be transformed to secondary stems at long day conditions.

Stolon length is affected in the same way as the length of above-ground stems. Under short day conditions, tubers are inserted almost directly on the stem basis, whereas in normal and long day plants they are formed at the tips of large stolons.

Tubers developed on short day plants have a tendency to become branched and knobby, whereas in the long day plants, tubers are more spindle or club-shaped. The formation of tuber-borne roots is common under short day conditions, but not in the long day. As shown in Table 1, tuber number per plant is higher under long than under short day treatment, being intermediate in the normal day.

There is a very strong effect of day length on total dry matter production, as shown in Fig. 3. In the mean of all cvs., 18 hrs plants yield 3 to 4-times as much dry matter as short day plants, and nearly 2-times as much as normal day plants. The sensitivity to short day treatment differs from cv. to cv., being highest in the early cv. B and lowest in cv. K.

There is a crucial effect of photoperiod on partitioning of the assimilates produced (Table 2). Long photoperiods promote stem growth and, to a lesser extent, also leaf growth. The stems act as a temporary sink for the products of photosynthesis which later are transferred to the tubers, as has been shown first by Incoll and Neales (1970).

Tuberization starts earlier under short day conditions. At the age of 75 days, under the long and normal day conditions, only cv. R had developed some tubers, whereas on the other cvs., only stolons could be found. At the same time, short day plants of all the cvs. had already developed tubers. At maturity, the percentage of total dry matter incorporated in the tubers was much higher in the short day than in long and normal day.

Within a given treatment, there are only small differences among cultivars with respect to partitioning of assimilates; only at long and normal day plants is there a slight differentiation according to the cv. Moreover, long day and normal day plants of each cv. have an identical distribution pattern, although differences in total dry matter production are very obvious.

## Studies on temperature and light intensity

One experiment was carried out in growth chambers, in order to study the effects of different temperatures and light intensities on Jerusalem artichoke cv, B. The following treatments were applied:

1. 22°C day and 16°C night temperatures, 12,000 to 15,000 Lux (low temp./low light intens.);
2. 30°C day and 24°C night temperatures, 12,000 to 15,000 Lux (high temp./low light intens.);
3. 30°/24°C, 30,000 Lux (high temp./high light intens.).
   The three treatments received a uniform day length of 12 hrs, relative humidity was maintained at 70 to 80 percent.
4. Greenhcuse control.

Four weeks after onset of sprouting, one-stemmed plants were planted in 10 l-buckets as in the previous experiment. The treatments began on March 3, 1978. On June 6, half of the plants were harvested; the other half was transferred outdoors and permitted to finish maturation. Final harvest was on July 19.

The low temperature in combination with the low light intensity inhibited plant growth substantially. Plants remained small, and large chlorotic patches appeared on the leaves. There was a delay in the development of plants of treatment 2 (high temp./low light intens.) compared to those of treatment 3 (high temp./high light intens.), especially with respect to plant height (Fig. 4).

Temperature had a remarkable effect on the reproductive behavior. At low temperatures not even flower buds developed, whereas buds and blossoms appeared at the high temperatures. There was an effect of light intensity, too, as flowering started earlier and more flower heads developed at high light intensity than at low (Table 3).

At low temperatures, stolon length was extremely reduced, fewer tubers developed per plant (Table 3), the tendency of the formation of knobby tubers and of tuber-borne roots was increased, compared to the high temperature treatments.

As shown in Fig. 5, the total dry matter production was lowest at low temperature and low light intensity (treatment 1), highest at high temperature and high light intensity (treatment 3) and intermediate at high temparature and low light intensity (treatment 2). There was no further increase of dry matter between the first and the final harvest, except in treatment 2, demonstrating once more the retardation in the development of plants grown at high temperature and low light intensity.

However, in all the treatments there was a change in the distribution pattern of assimilates, because a considerable amount was transferred from the tops to the tubers during this period (Fig. 5). The greatest harvest index was obtained at low temperature; nevertheless, the absolute tuber yield in this treatment was lower than that of the others.

The greenhouse grown plants (treatment 4) cannot be compared directly to the other treatments, because the climatic conditions could not be controlled. For example, day length was beyond the 12 hrs which were applied to treatments 1 to 3. With respect to plant height and flowering, greenhouse plants were similar to those of treatment 3. The same was true for the final tuber yield; however, the latter is the result of a higher total dry matter production and a lower harvest index of the greenhouse plants.

## Discussion

Since the studies of Garner and Allard (1923), it is known that Jerusalem artichoke is sensible to variations in photoperiod. In our experiments, the results of former authors are confirmed and completed as to the morphological and physiological changes brought about by photoperiod. Short day plants, in comparison with long day plants, can be characterized as follows: There is an acceleration of the development, hence a shortening of life time. Plant height is reduced, as is branching, stolon length, tuber number and especially total dry matter production. The distribution pattern of the assimilates is changed, as the incorporation into the tubers is favored at the expense of leaves and stems. Nevertheless, final tuber yield is much higher in long day than in short day plants, because the high harvest index cannot compensate for the low over-all productivity of short day plants.

Plants grown under the conditions of the normal day during spring and summer in Berlin are intermediate between short day and long day plants in most respects. The distinct difference in total dry matter production between long-day and normal day plants is a striking demonstration of the purely regulatory action of the long day treatment. Long day plants produced twice the dry matter compared to normal day plants, although they received only 12 hrs of photosynthetically effective illumination, whereas the latter received much more hours of light which could be utilized photosynthetically. Apparently, the long day stimulus somehow accomplishes a more effective utilization of sunlight per time unit.

The reaction of the four cultivars to photoperiod was essentially the same, but differed in their intensity. The most sensitive to short day treatment was the earliest cv. B, followed by the medium-late cv. G, whereas the late cvs. R and K were the least.

With respect to the agronomically important character of tuber dry weight, there was nearly no difference between short day and normal day plants of cv. K, whereas the other cvs. yielded more at normal day. This does not agree with the results of Garner and Allard (1923), Tinker (1925, 1928) and Hackbarth (1937), who got higher tuber yields at short than at normal day. These differences can be explained partly by varietal reaction, as in our experiments as well as in those of Hackbarth (1937) the sensitivity to photoperiod varied according to the cv. Another reason is perhaps that "normal day" in Berlin is not identical to "normal day" in other places, as Washington, D.C., where Garner and Allard (1923) carried out their experiments. Besides day length temperature also varies from place to place and from season to season (the part of temperature will be discussed later).

Plants which had been treated with 53 cycles of short day and afterwards with long day did not differ from plants which received a continuous short day treatment, except a prolongation of life time. Apparently, after 53 cycles of short day, determination is definite and can only be modified. With respect to flowering, Scheibe and Muller (1955) reported that 8 weeks of short day treatment are more effective than 6 weeks.

In the growth chamber experiments, the influence of different temperatures and light intensities under short day conditions were studied. Treatment 1 (low temp./low light intensity) behaved essentially the same as did the "short-day-treatment" in the previous experiment. This parallelism is expected because the "photoperiod experiment" was carried out in the open, where the mean temperature was even lower than in the "low-temperature-treatment" of the growth chamber experiments; surely, light intensity was quite different.

The short day effect, as described above, can be compensated, at least partly, by high temperatures as revealed by treatment 2 (high temp./low light intensity) of the growth chamber experiment; an additional effect in the same direction is accomplished by a high light intensity (treatment 3). Plants live somewhat longer at high temperatures. Plant height, branching tendency, stolen length and tuber number increase, tubers are less knobby and do not form roots. There is a rise in total dry matter production and in tuber yield. Harvest index is lower than at the low temperature.

Breeding work with Jerusalem artichoke is hampered by the difficulties of flower and fruit formation. The importance of photoperiod for these processes was demonstrated by Garner and Allard (1923). Varietal differences in the response to different day lengths have been reported by Scheibe and Muller (1955).

In our experiments there are two well-defined groups of cvs., according to their reproductive behavior. The first one is represented by the early cv. B, and the second by the later maturing cvs. G, K and R. The latter, in the short day, formed flower buds but no blossoms. This failure to blossom possibly is the consequence of the higher competitive efficiency for assimilates of the growing tubers, as has been discussed already by Garner and Allard (1923).

Not even flower buds were developed by cv. B under short day conditions in the open neither at the low temperature in the growth chamber experiment. It cannot be decided if under these conditions no flower induction has taken place or if the lack of nutrients is the reason why flower buds, could not be realized. Flowers developed when cv. B was grown in the short day at high temperatures; the number of flower heads per plant was increased with the higher light intensity. In contrast to the other group of cvs, B developed flowers under normal day and even under long day conditions.

## Conclusions

As has been pointed out, even under the very limited number of Jerusalem artichoke cvs. actually available, there exist genotypes which in the short day yield the same or even more tuber dry matter than under the normal day conditions of the higher latitudes; in addition, the vegetation period is shortened in the short day. Moreover, high temperatures, in combination with short day, can bring about a further increase in tuber yield of Jerusalem artichoke. On the contrary, three potato cvs. yielded much more at the low temperature treatment compared to the high temperature (Delhey and Carls, unpublished). This is an evidence, that the possibility for adaptation to high temperatures could be greater in Jerusalem artichoke than in potato. Of course, this does not mean that Jerusalem artichoke could replace the potato for human consumption because of the outstanding culinary and keeping qualities of the latter.

Nevertheless, the potential of Jerusalem artichoke as an alternative root crop for tropical and subtropical conditions should not be neglected. The broad genetic basis which is at the disposal of the breeders, offers great possibilities for its genetic improvement. The yielding potential of this crop is comparable to that of potato and without doubt can be increased considerably, if more attention is given to this plant by breeders and agronomists.

Jerusalem artichoke can be cultivated at different levels of intensity, as a permanent crop which needs little care or as a one-season crop, in the home garden or on a large scale in the field, for domestic use or as raw material for the industry. The whole plant, tops and tubers, can be utilized.

In the home garden, it would be an additional vegetable, of special interest for dietetic purposes. Besides, it is accepted easily by small animals like poultry, rabbits, pigs, sheep and goats. As a fodder plant, it can be grown also on a large scale and fed to horses and cattle, either directly or as silage. The possibilities for the production and utilization of air-dried tubers should be studied. Pigs can dig out tubers directly in the field.

On an industrial scale, Jerusalem artichoke tubers can be processed into fructose. The economic possibilities of this product are estimated very optimistically (Pilnuk and Vervelde 1976, Dorrell and Chubey 1977). More promising are perhaps the possibilities for the production of industrial alcohol with regards to the increasing shortage of energy in many places. Actually, manioc and sugar cane are utilized for this purpose. The much wider ecological range of Jerusalem artichoke would offer possibilities for the production of bio-energy also in regions where the above-mentioned crops cannot be grown.

Additional possibilities are offered for the regeneration of soils infested with weeds, as Jerusalem artichoke plants form a canopy dense enough to suffocate any other plant. Moreover, once established, the crop regenerates itself every season, as the tuber fragments remaining in the soil generally are sufficient for the formation of a new stand. First experiences with the control of *Cynodon dactylon* in Argentina have been made by Montaldi (1971). On the other hand, it should not be omitted to mention the invasive character which Jerusalem artichoke has shown in some parts of central Europe.

As has been pointed out already, the special demands of Jerusalem artichoke are poorly investigated. According to our experiments, it tolerates a wide range of day lengths and temperatures. The limiting factor for many regions is possibly its fairly high water requirement.

The greatest problem of this crop is connected with the storage and shipping of the tubers, the tubers lack a protective suberin layer and therefore are subject to bruising resulting to infections, as well as to a rapid loss of water. This problem remains to be solved by the collaboration of breeders, agronomists and storage experts.

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Table 1. Influence of photoperiod on tuber number per plant of four cultivars of Jerusalem artichoke.

| Photoperiod | B | G | K | R | Mean |
|---|---|---|---|---|---|
| | | Cultivar | | | |
| 12 hrs | 3.5 a[x] | 9.0 a | 7.0 a | 7.5 ab | 6.8 a |
| 12/18 hrs | 5.0 ab | 8.0 a | 9.0 ab | 6.0 a | 7.0 a |
| 18 hrs | 14.0 c | 20.0 b | 17.5 c | 10.5 b | 15.5 c |
| normal day | 7.5 b | 8.0 a | 11.5 b | 8.5 ab | 9.8 b |

x) 1
Values in the same column followed by different letters are significantly different (p = 0.05).

Table 2. Influence of photoperiod on Harvest Index (percentage of tuber plus stolon dry matter on total dry matter) at the age of 75 days (1. H.) and at maturity (2. H.) of four cultivars of Jerusalem artichoke.

| | Cultivar | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | | G | | K | | R | | Mean | |
| Photoperiod | 1.H. | 2.H. | 1.H. | 2.H. | 1.H. | 2.H. | 1.H. | 2.H. | 1.H. | 2.H. |
| 12 hrs | 59 b[x)] | 87 b | 51 b | 86 b | 37 b | 88 b | 46 b | 88 b | 48 b | 87 b |
| 12/18 hrs | – | 90 b | – | 87b | – | 91 b | – | 93 c | – | 90 c |
| 18 hrs | 6 a | 73 a | 10 a | 63 a | 7 a | 67 a | 8 a | 71 a | 8 a | 69 a |
| normal day | 7 a | 77 a | 7 a | 63 a | 6 a | 68 a | 8 a | 72 a | 7 a | 70 a |

x) 1
Values in the same column followed by different letters are significantly different (p = 0.05)

Table 3. Influence of temperature and light intensity on number of flower heads and tubers per plant and of stolon length (the three largest stolons of each plant were measured) of Jerusalem artichoke cultivar Bianka.

| Treatment | Flower heads | Tubers | Stolon length |
|---|---|---|---|
| low temp. low light intens. | none | 5.5 a | 0.1 a |
| high temp. low light intens. | 5.0 a[x)] | 10.0 b | 3.9 b |
| high temp. high light intens. | 13.5 b | 9.5 b | 3.0b |
| greenhouse control | 13.5 b | 12.0 b | 8.0 c |

x)[1] Values in the same column followed by different letters are significantly different ($p = 0.05$)

Fig. 1. Influence of photoperiod on life time of four cultivars of Jerusalem artichoke.

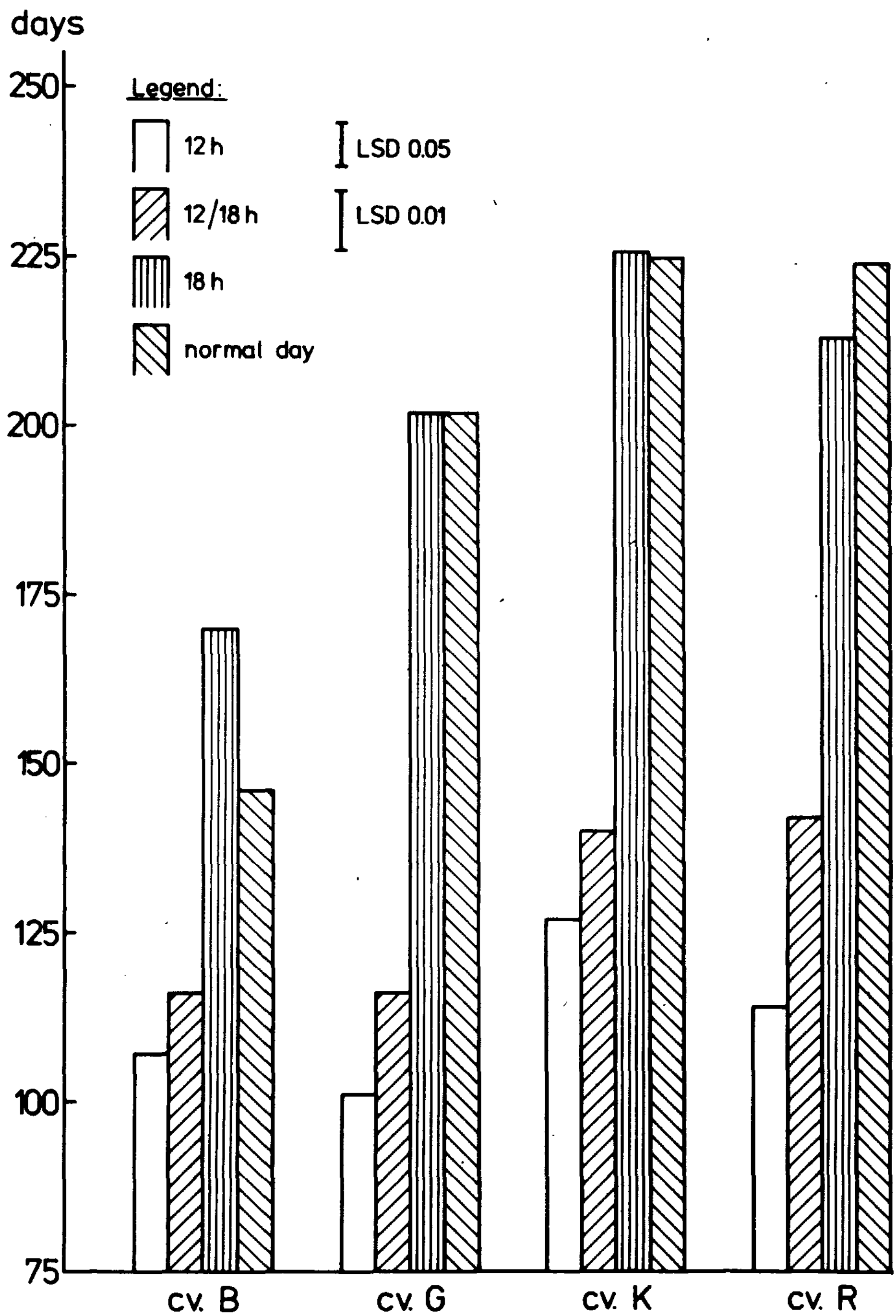

Fig. 2. Influence of photoperiod on plant height of four cultivars of Jerusalem artichoke.

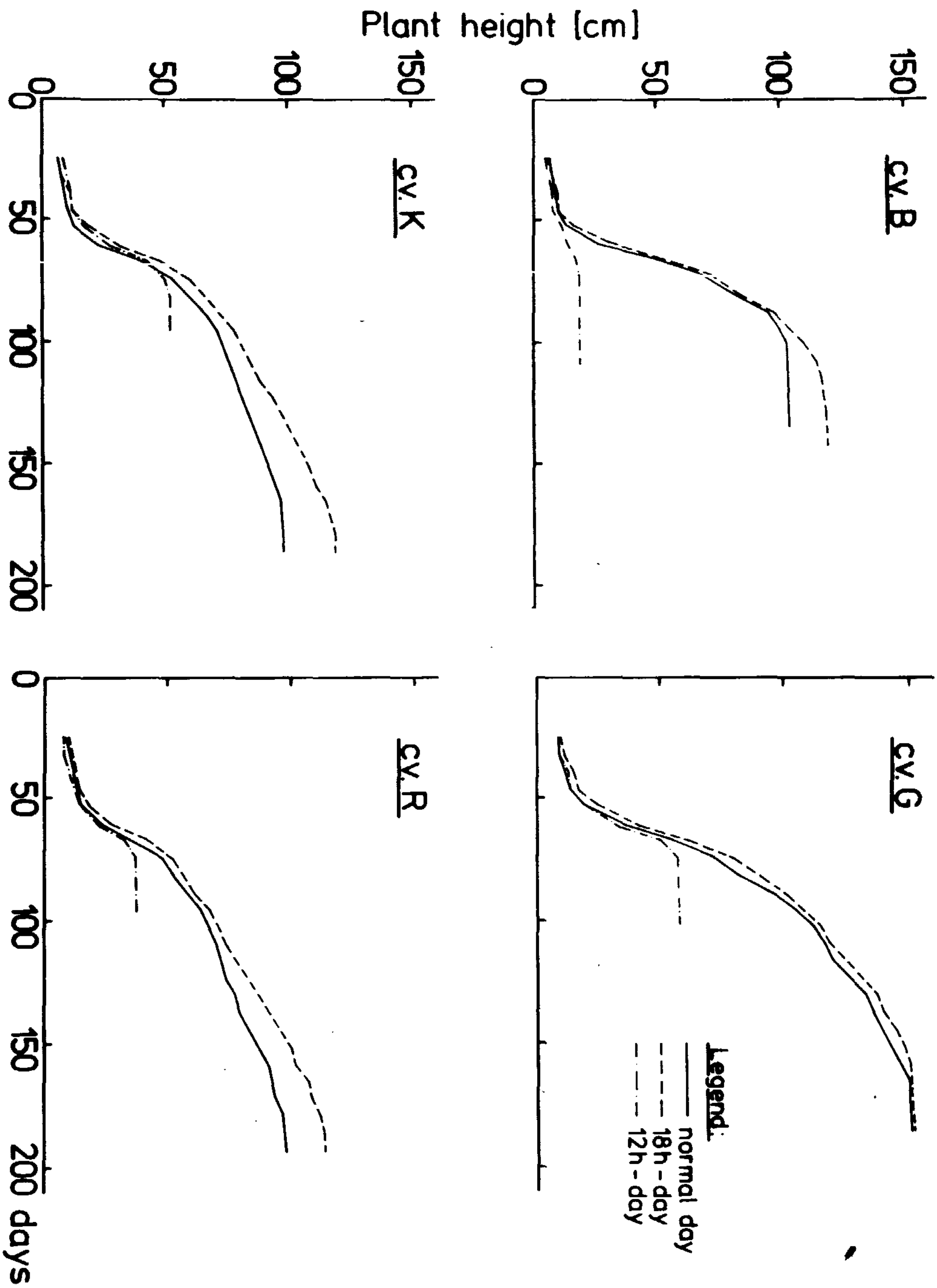

Fig. 3. Influence of photoperiod on total and tuber dry matter production of four cultivars of Jerusalem artichoke.

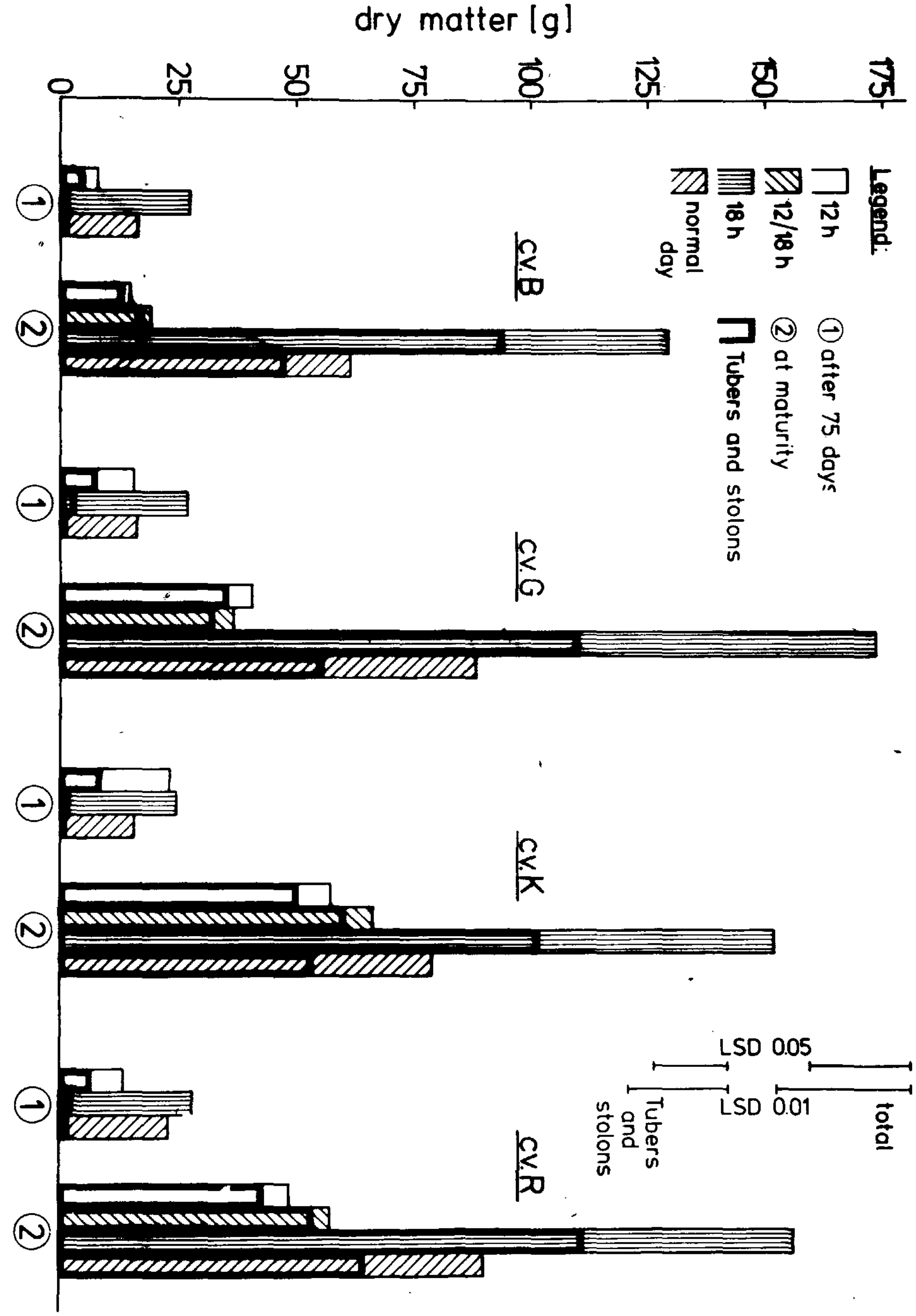

Fig. 4. Influence of temperature and light intensity on plant height of Jerusalem artichoke cv. Bianka.

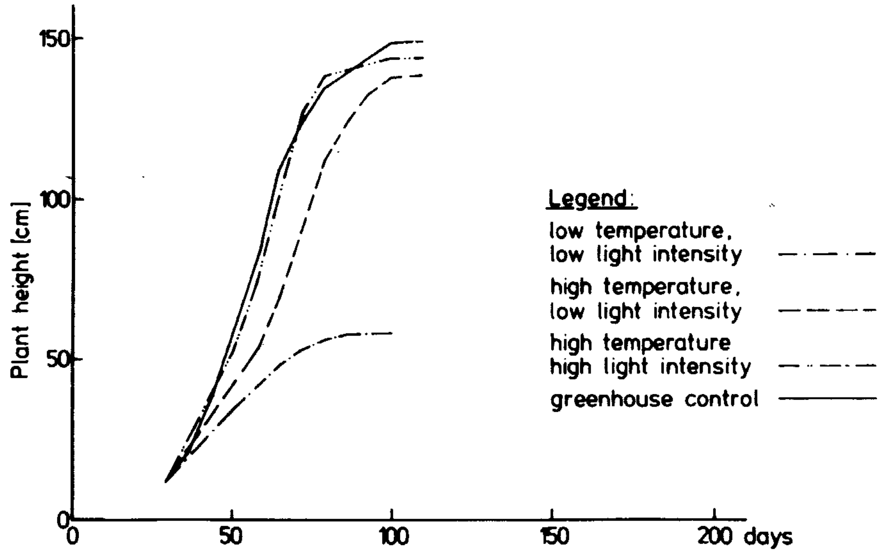

Fig. 5. Influence of temperature and light intensity on total and tuber dry matter production of Jerusalem artichoke cv, Bianka.