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INFLUENCE OF DIFFERENT DAYLENGTHS ON DEVELOPMENT AND TUBER FORMATION OF THE POTATO PLANT

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INTRODUCTION

Growth and yield of the potato plant is determined by light intensity, duration of illumination, and temperature. The influence of daylength only will be discussed in this paper.

There is a general agreement in the published work on photoperiodism that top growth is prolonged and much greater top growth occurs with increased daylength in both early and late varieties (WASSINK and STOLWIJK, 1953; CAESER and KRUG, 1965). It had been also proved that long day had a positive effect on tuber yield if the growing season was sufficiently long.

The efficiency of tuber formation which may be defined as the ratio of the weight of tubers to that of foliage, is greater under short day conditions. Such evidence as there is on the time of tuber formation indicates that this is earlier under short day than under long day conditions. This conclusion is in accordance with results obtained by WASSINK and STOLWIJK, 1953; BODLAENDER, 1958; ALVEY 1963, and KRUG, 1965.

Short day will, on the one hand, cause the early formation of tubers but will on the other hand limit the length and effectiveness of the tuber growing period by restricting the size and lifetime of the foliage. This was also observed by CAESER and KRUG, (1965).

However, most of these investigators have usually applied a limited range of daylength treatments. Information was, therefore, sought on the effects of daylengths over the range of 10 to 24 hours, with two intermediate values.

MATERIAL AND METHODS

Potato tubers of the variety 'Alpha' (a late variety) were planted in the experimental garden of the Laboratory on 18-4-1967 in four plots of 2 × 2.5 meters. Each plot contained 20 plants at distances of 46 × 46 cm. and could be screened by light tight houses with artificial ventilation as described by WASSINK and STOLWIJK (1953).

Another plot with 25 plants was planted at the same distances receiving the natural daylength. This plot was included to have normal plants in hand as a basis of comparison, but ist must be kept in mind that these plants could not be directly compared with the plants of the other treatments since they received much more light energy per daily cycle. Two side rows of the same variety were surrounding each plot. The soil was a loamy sand with artificial manure.

To allow an adequate time for all the shoots to emerge, all plants received natural daylength for the first four weeks after planting. After 28 days the following light treatments started:

a. 10 hrs. of daylight,
b. 10 hrs. of daylight + 3 hrs. of supplementary light,
c. 10 hrs. of daylight + 8 hrs. of supplementary light,
d. 10 hrs. of daylight + 14 hrs. of supplementary light,
e. Natural daylength.

The additional light was provided by fluorescent tubes at an intensity of about 1000/ergs/cm^2/sec. which intensity was so low that no appreciable photosynthesis can have occurred during the additional period. So, the differences between the treatments can be attributed to the differences in daylength only.

After 4 weeks (28 days) from the date of planting, just before starting the light treatments, five plants from plot (e) were lifted to be analized (the initial point). Then, after 8 weeks (56 days) from the planting date, and subsequently until senescence of the foliage, from all the plots, a group of 4 plants were lifted at intervals to be examined for total fresh weight, dry weight, and the distribution of the growth in weight over the plant.

Moreover, the following observations and determinations per plant have been made: 1) number of developed green leaves, 2) total green leaf area, 3) stem length, 4) number of stems, 5) number of stolons, 6) length of stolons, 7) number of new tubers.

RESULTS AND DISCUSSION

a. Growth in weight

1. Total dry and fresh weight per plant

Under the conditions of the experiment, as shown graphically in fig. 1, total dry weight of the potato plant at the early stages of growth (until 56–70 days old) appeared to decrease slightly with increasing daylength. As the plant advanced in age, total dry weight started to increase with increasing daylength. The differences between the treatments became more pronounced towards the end of the growing season.

Similar results were obtained for total fresh weight.

Short day treatment also caused a considerable decrease in the duration of the growing season. With the extension of daylength until a certain limit (18 hrs.), the growing season of the plant was also prolonged.

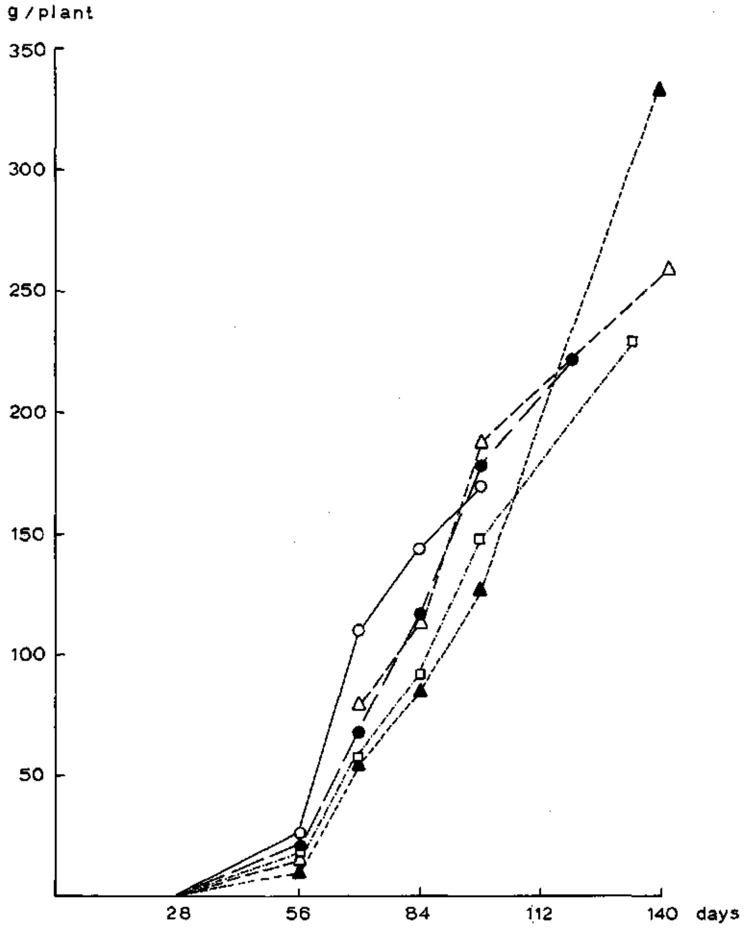

FIG. 1. Total dry matter weight per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △– – – △ 18 hours, ▲- - - ▲ 24 hours and □– . – . – . □ Natural daylength.

2. Dry and fresh weight of above-ground part, per plant

Fig. 2 presents changes in dry weight of the above ground part, per plant, as a function of daylength at different developmental stages. First, the dry weight of the above ground part, in all treatments, showed an increase until the age between 70 and 84 days, then a decrease due to the death of the foliage of the plant at the end of the season. The short day treatment had a marked effect in decreasing leaf and stem weight, especially stem weight was strongly affected. Up to the age of 56 days, the leaf/stem weight ratio per plant was about the same under all the different daylengths, but as the plants advanced in age (until 70 days old), it started to increase with decreasing daylength. This increase is due to the strong effect of short day treatment in decreasing stem weight per plant

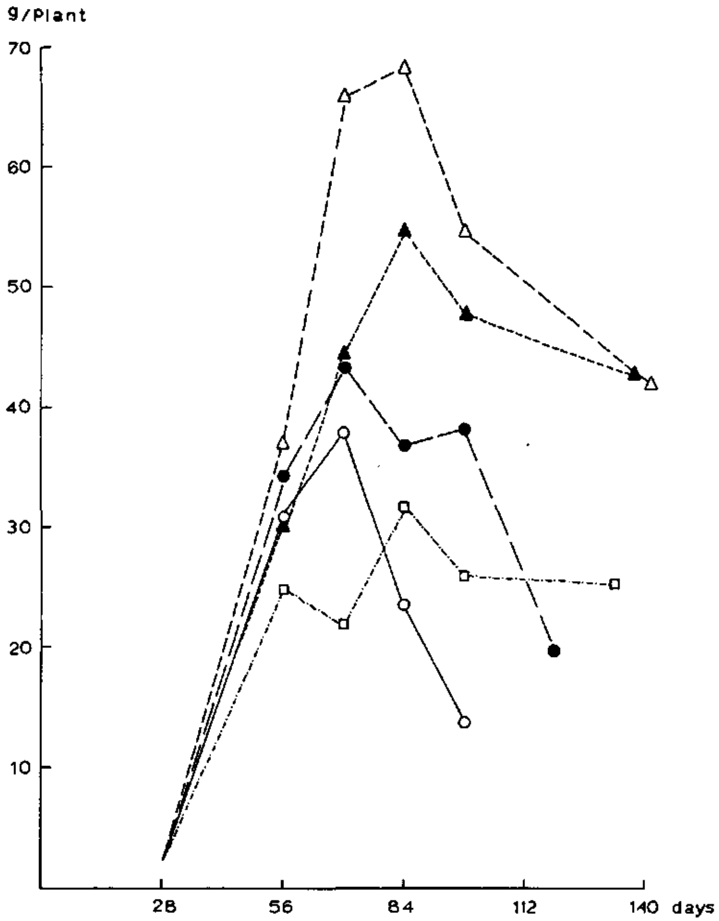

FIG. 2. Dry matter weight of above ground part per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △- - -△ 18 hours, ▲- - -▲ 24 hours and □-.-.-.□ Natural daylength.

as has been mentioned before. Then, at the end of the growing season, this ratio again became equal in all treatments.

The above -ground part under short day conditions reached the maximum weight per plant early (after about 70 days from planting), and started to die early also. Plants grown under 18 hours daylength showed the highest dry weight of the above-ground part at the end of the season. The same trend was found for above-ground part fresh weight per plant.

3. Dry and fresh weight of under-ground part, per plant

a. The effect of daylength on dry tuber weight per plant at different developmental stages is presented in fig. 3. Tuber formation occurred under all daylengths applied. Only in the early stages of development (until the first harvest), tuber dry weight per plant was higher in treatment (a) than in all other treatments, showing that tuber formation had started earlier under short days than under long days conditions. However, owing to larger tops and longer life, plants grown under long day conditions surpassed those grown under short day, and reached a higher final production despite their delayed onset of tuber formation. Plants grown under continuous light had the highest final tuber weight, followed by 18 hours and 13 hours respectively.

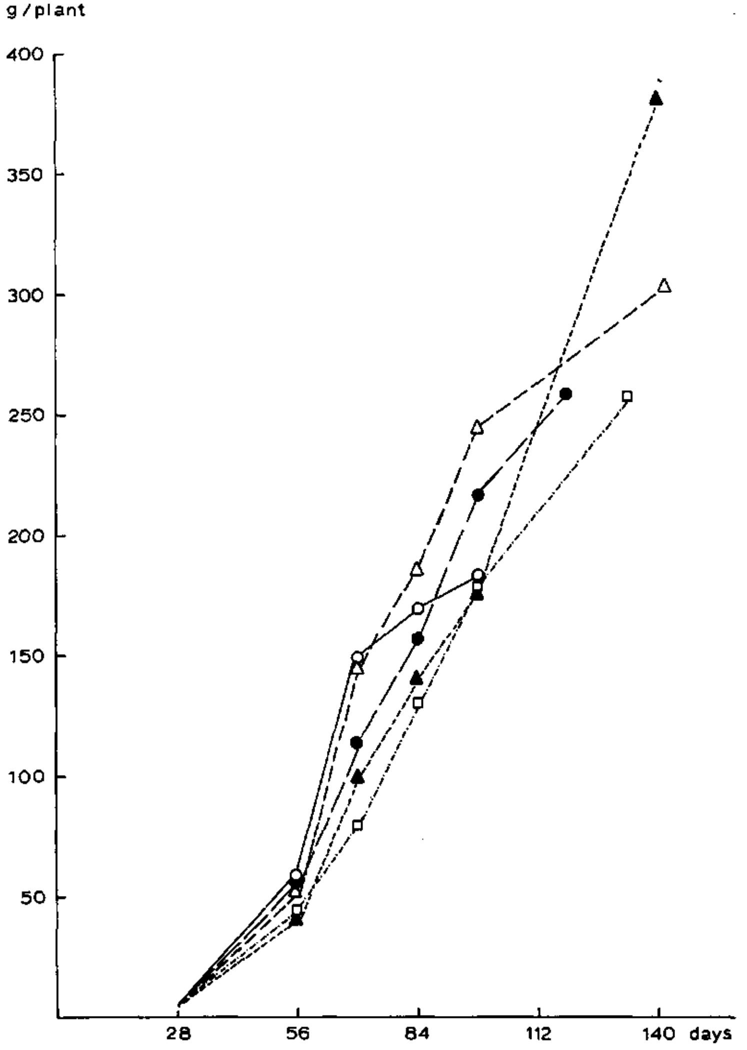

FIG. 3. Dry matter weight of new tubers per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △- - - △ 18 hours, ▲- - - ▲ 24 hours and □- . - . - . □ Natural daylength.

b. Stolon weight per plant was strongly affected by daylength, there was a linear correlation between the extension of daylength and the dry weight of stolons per plant as represented in fig. 4. It was very marked that plants grown under short day conditions arrived at the maximum weight of stolons much earlier (after 56 days from planting date) and remained at lower values for this weight than those grown under long day conditions which reached their optimum weight later. Under all daylengths applied, stolon dry weight per plant first showed an increase (until 56–84 days old), and then a decrease in the advanced stages, owing to senescence of the plants.

c. As illustrated in fig. 5, daylength had a marked effect on dry weight of roots per plant. Root dry weight also appeared favoured by exposure to long day, it increased with time until a maximum was reached after 70–84 days from planting date, and then decreased. This decrease in weight of roots per plant may be attributed to the continuous decay of old roots in the soil while no new roots are formed.

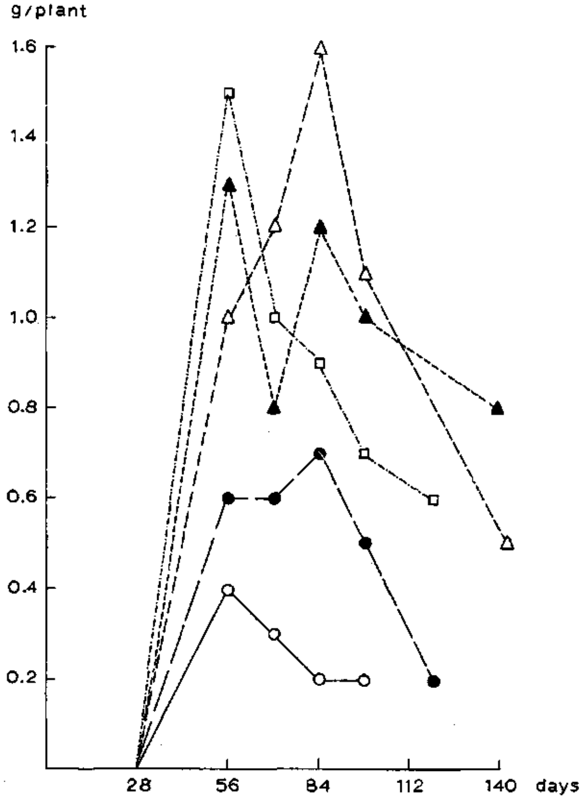

FIG. 4. Dry matter weight of stolons per plant at periodic harvests. ○——○ 10 hours, ●—— ● 13 hours, △- - - △ 18 hours, ▲- - - ▲ 24 hours and □- . - . - . - . □ Natural daylength.

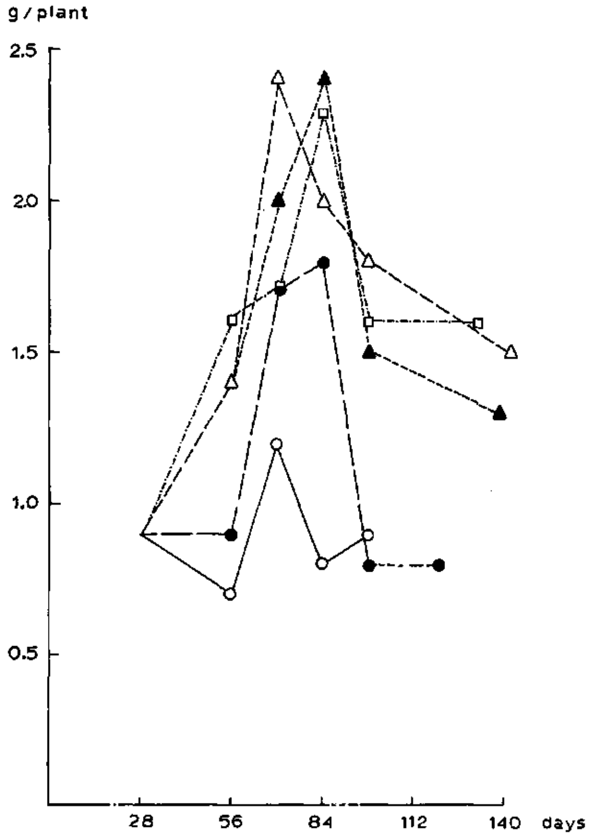

FIG. 5. Dry matter weight of roots per plant at periodic harvests. ○——○ 10 hours, ●——● 13 hours, △- - -△ 18 hours, ▲- - -▲ 24 hours and □- . - . - . - .□ Natural daylength.

More or less the same results were obtained for fresh weight of new tubers, stolons, and roots per plant.

b. Some morphogenetic features

1. Number of developed green leaves per plant

As shown in fig. 6, up to the first harvest (after 56 days from planting), the number of developed green leaves found on the plant tended to be slightly higher in (SD) treatment. As the plants proceeded in age, the green leaf number per plant showed a greater increase with extending daylengths. Leaflets were larger and thinner under short day conditions. This difference in green leaf number per plant between short and long day plants may be attributed to the fact that the short day plant reaches its maximum development earlier and thus at a lower number of leaves. All plants grown under the different daylengths

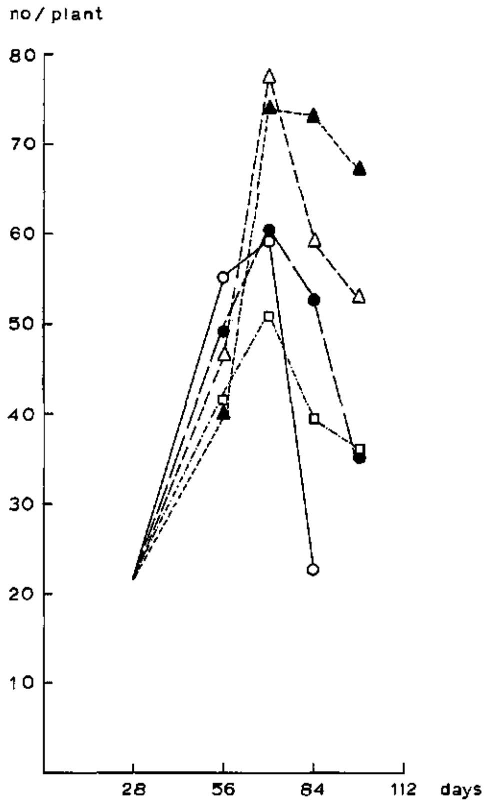

FIG. 6. Number of developed green leaves per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △– – – △ 18 hours, ▲- - -▲ 24 hours, and □- . - . - . □ Natural daylength.

applied, showed an increase in number of green leaves until the age of 70 days, and then a decrease towards the end of the growing season of the plant which was markedly earlier under short day conditions.

2. Total green leaf area per plant

Fig. 7 shows that the green leaf area per plant increased with increasing daylength. The increase is mainly due to the greater leaf number per plant produced under long day conditions. It must be mentioned also here that, in the first harvest, the green leaf area per plant tended to be higher under short day conditions. This is mainly due to the relatively high number of green leaves formed per plant in this treatment at that age (56 days) and also to the larger leaflets of the plant under (SD) conditions.

3. Stem length

The average length of the main stem at periodic harvests as influenced by daylength is illustrated in fig. 8. Due to the differences in the rate of development under the various daylengths, the final stem length of plants grown under short days was greatly decreased as compared with those grown under long day conditions. The differences between the treatments became more pronounced as the plants advanced in age. Plants grown under 18 hours daylength reached the

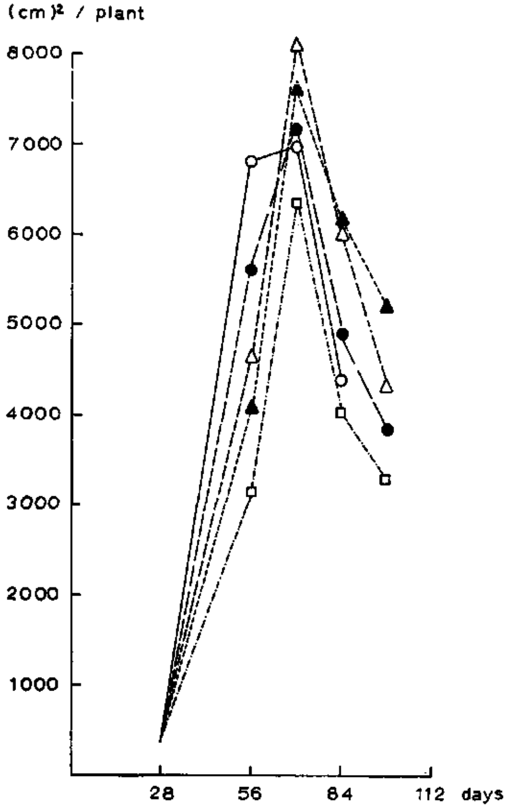

FIG. 7. Total green leaf area per plant at periodic harvests.
○——○ 10 hours,
●— — ● 13 hours,
△- - -△ 18 hours,
▲- - -▲ 24 hours
□- . - . - . □ Natural daylength.

greatest stem length, followed by 24 hours, and then 13 hours. The shortest stems were formed under 10 hours daylength.

4. Number of stems per plant

Under the conditions of the experiment, daylength seemed to have no influence of the number of stems per plant. No regular differences could be observed between the different treatments applied.

5. Number of stolons per plant

As shown in fig. 9, until the age 28 days, no stolons were seen on the plants. Later, as the plants advanced in age, it was found that the number of stolons per plant tended to be higher with increasing daylength. Up to the second harvest (after 70 days from planting), in all treatment applied, all the plants showed an increase in the number of stolons. Thereafter, a decrease was observed which was due to the decay of most of the stolons in the soil, especially those which had no tubers at their tips.

6. Stolon length per plant

Stolon length per plant was strongly affected by daylength as is presented in fig. 10. Up to the second harvest (after 70 days from planting) there was a linear relation between daylength and the length of stolons per plant. Thereafter, there

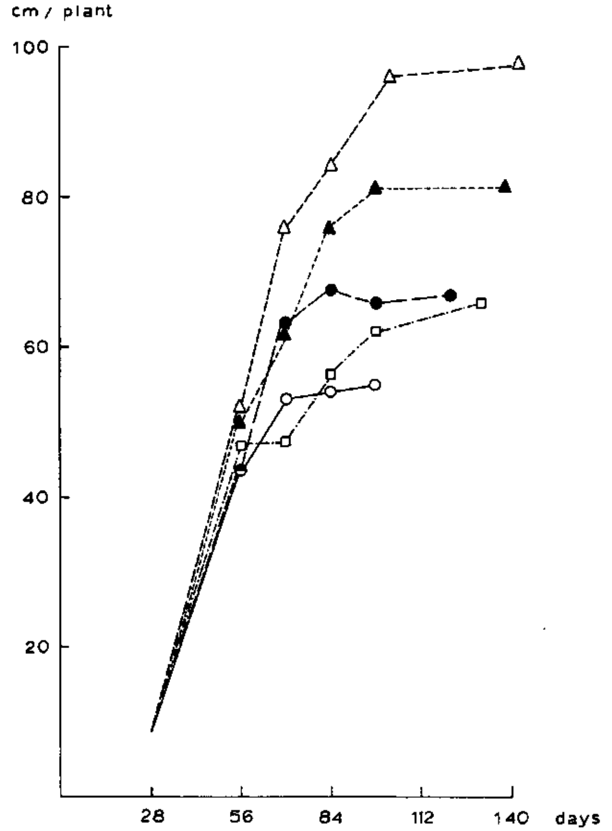

FIG. 8. Length of main stem per plant at periodic harvests. ○——○ 10 hours, ●—— ● 13 hours, △- - - △ 18 hours, ▲- - - ▲ 24 hours and □- . - . - . □ Natural daylength.

was a decrease, owing to the decrease in number of stolons per plant in the later stages of the season. Plants, grown under 18 hours daylength, had the greatest stolon length per plant, followed by those grown under 24 hours and then those under 13 hours. Plants grown under 10 hours daylength had the smallest stolon length per plant.

7. Number of new tubers per plant

The number of new tubers per plant was also affected by daylength as is shown in fig. 11. Up to the second harvest (after 70 days from planting), the number of tubers found per plant tended to be slightly higher in the short day (10 hrs) treatment. As the plants proceeded in age (84 days old), it seemed that the number of tubers started to increase, relatively, with extended daylength. This increase in number of tubers per plant grown under long day over that produced under short day conditions is due to the larger number of stolons formed in long days.

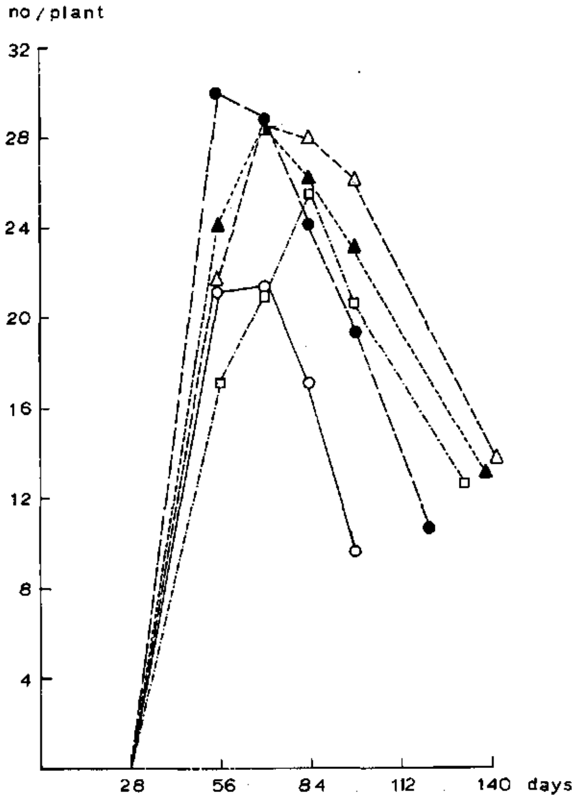

FIG. 9. Number of stolons per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △- - -△ 18 hours, ▲- - -▲ 24 hours and □- . - . - . □ Natural daylength.

The tuber/stolon number ratio was always very high under short day conditions. This ratio decreased with increasing daylength until a certain limit (18 hours). The average ratio per plant (in percents) was 95.2, 93.9, 86.8, 88.5 for the treatments 10, 13, 18, and 24 hours daylength respectively.

CONCLUSION

A general phenomenon is that under 10 hours daylength (SD), the development of the potato plant is accelerated, especially at the early stages of development. Stem elongation ends early, tuber formation starts early and the plant also starts to die early (after 98 days from planting). Under such circumstances, short stems, short stolons and large leaflets are formed, tuber initiation also is stimulated.

Extending the daylength, the elongation is stimulated, but tuber initiation is delayed especially when daylength is prolonged to 24 hours. But, despite the

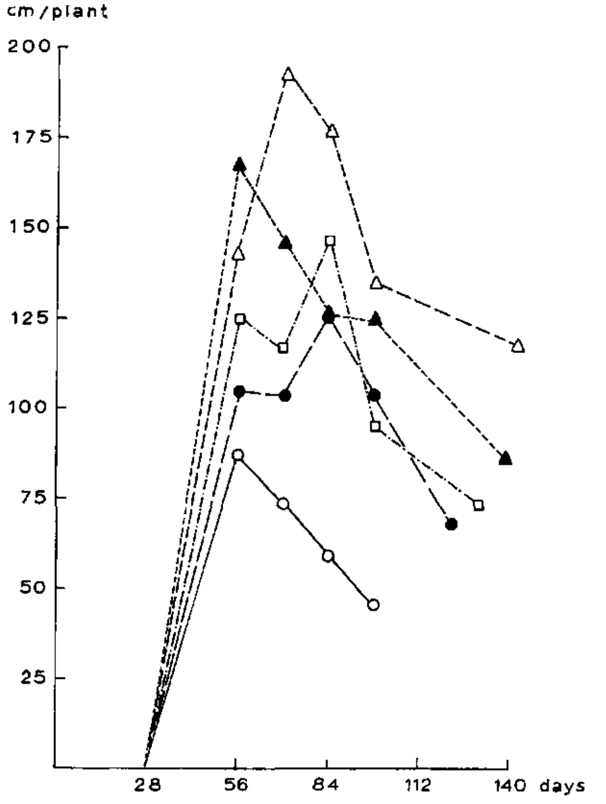

FIG. 10. Stolon length per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours △- - - △ 18 hours, ▲- - - ▲ 24 hours and □- . - . - . □ Natural daylength.

delayed onset of tuber formation, plants grown under 24 hours daylength, with different day and night temperatures, have the highest final tuber weight per plant followed by 18 hours and then 13 hours respectively. This increase in tuber weight is mainly due to the larger tops and the longer life of plants grown under long days than those grown under short day conditions.

Under both long and short day conditions, a fraction of the photosynthetic products is directed to the under ground part of the plant to be stored in the form of tubers, but under shortday conditions, this downward current appears more pronounced and becomes manifest earlier, connected with an earlier standstill in growth and a quicker senescence of the foliage of the plant.

Stolon length, as well as stem length, are promoted by increase in daylength, up to 18 hours.

At the early stages of development (after 56 days from planting), the leaf/ stem weight ratio is almost the same under short and long day conditions. As the plants advanced in age (about 70 days old), it becomes lower for the plants

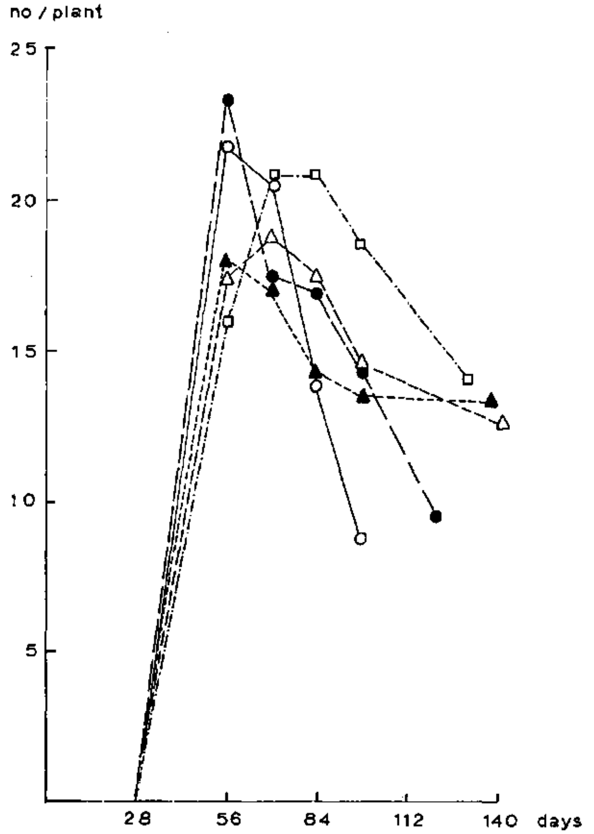

FIG. 11. Number of new tubers per plant at periodic harvests. ○——○ 10 hours, ●— — ● 13 hours, △- - - △ 18 hours, ▲- - - ▲ 24 hours and □- . - . - . □ Natural daylength.

which are growing under long days especially under 18 hours daylength. But at the end of the growing season, this ratio returnes to become equal again under short and long day conditions.

Lastly, it must be kept in mind, as has been mentioned before, that the photoperiodic response is not the whole story in connection with the potato plant, also temperature, light intensity, and may be light quality, as well as daylength, all of these factors, together or separately, have a marked effect on the development and tuber formation of the potato plant.

Four plots planted with potato tubers of the variety Alpha (a late variety) have been exposed to four different daylengths in the field. All the plants received 10 hours of daylight plus 0, 3, 8, and 14 hours of supplementary light, provided by fluorescent tubes at a low light intensity of about 1000 ergs/cm^2/sec. In addition, plants were also grown, from the same variety, receiving natural daylength.

At the early stages of growth, the total weight of the plant first showed a

Summary

decrease with increasing daylength, but as the plants advanced in age, it started to increase, especially when the daylength was prolonged to 24 hours.

Increase in daylength stimulates the vegetative growth of the plants until a certain limit,. Plants, grown under 18 hours daylength, had the highest weight of the above ground part, per plant.

Leaf/stem weight ratio was higher under short day treatment at the middle of the season.

Tuber formation occurred under all the different daylengths applied. Only, in the early stages of development, tuber weight per plant was higher in short day treatment than in long days, but later on, owing to larger tops and longer life, plants grown under long days surpassed those grown under short days, and reached a higher final production despite the delayed onset of tuber formation.

The final stem length of the plants, grown under short days, was greatly shortened compared with those grown under long day conditions, especially those grown under 18 hours daylength.

Stolon length was also strongly affected by daylength; there was a direct relation between the extension of daylength and the length of stolons per plant.

The number of new tubers per plant was slightly higher under short day conditions at the beginning of the growing season, but later on it started to increase with increasing daylength.

Daylength also had a marked effect on the tuber/stolon number ratio per ulant; it was always high under short days and increasing daylength decreased it pntil a certain limit.

Acknowledgements

The present study has been carried out at the Laboratory of Plant Physiological Research, Agricultural University, Wageningen, the Netherlands, under the supervision of Professor Dr. E. C. Wassink, director of the laboratory, to whom I wish to express my deeply felt thanks for his continuous help and guidance during this study.

I am also grateful to all the staff members of the laboratory for their readiness to give advice and help whenever they have been asked for.

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POSTSCRIPT (added in proof, 10-XI-'69). – Mr. EL HAK had to leave rather hurriedly after finishing his manuscript so that there was no time for elaborate discussion of the material. Perusal of the proofs induced me to attempt a few comparisons between different data, in relation to daylength. Results are given in Fig. P1, a–c. Fig. P1a shows the proportion of tuber to above ground dry weight (data of Fig. 3/Fig. 2), and shows that, up to the end of the season, shortening of the day increases the relative tuber weight. The gradual shift shows that, in this respect, the difference between short and long days is a gradual one.

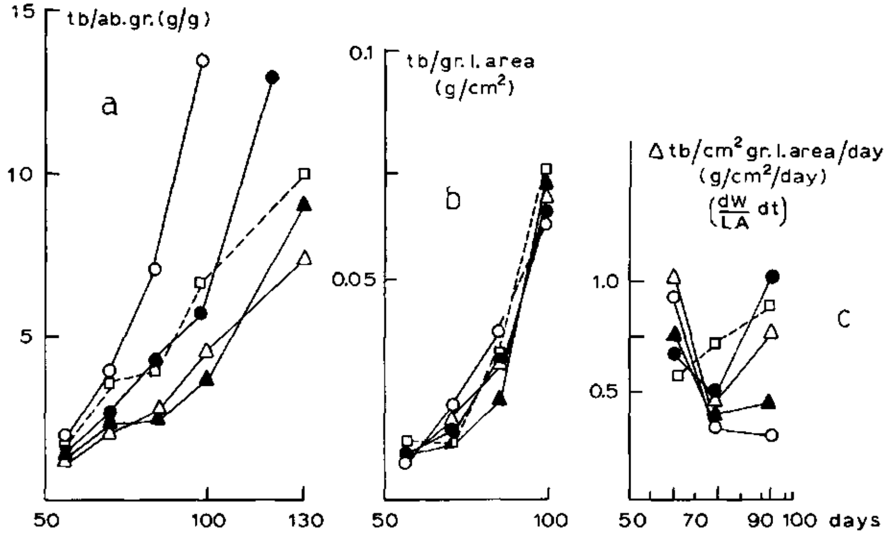

FIG. P1, a–c. Some relationships between various data, cf. POSTSCRIPT

a, Tuber dry weight in relation to above ground dry weight; *b*, tuber dry weight in relation to green leaf area; *c*, increase in tuber dry weight per cm² green leaf area, per period between two successive harvests.

○ = 10h, ● = 13h, △ = 18h, ▲ = 24h, □ = natural daylength (as in textfigures).

Fig. P1b shows the relation tuber dry weight/green leaf area (data of Fig. 3/Fig. 7). As long as the leaves are still green, the picture is rather similar to that of Fig. P1a; at the end of the season the increased vitality of the above ground parts in the longer days reduces the differences. Fig. P1c attempted to bring about the most interesting relationship, viz., the daily increase in tuber dry weight per cm² leaf area present as average during each period between two harvests. The result, however, is not very satisfactory, evidently since minor deviations in the slopes of the curves, especially of Fig. 3, heavily affect the outcome. Thus, the dip in most curves for the period 70–84 days probably is not of essential significance, except perhaps for the 10h. curve. Similarly, the 84–98 days point in the 24h. curve probably is exceptionally low, it being followed, in Fig. 3, by a relatively very high point at the final harvest, the effect of which has not been weighed. The average daily increase in dry weight of the tubers is between 0.5 and 1.0 mg/cm² leaf area, and extends further into the season for the longer day lengths. The results in Figs P1b and c are less clear than those in Fig. P1a which suggests that also the formation of stems is a considerable task for the leaves, increasing with increasing daylengths, and that the transport of material to the tubers per unit leaf area is not that much different as long as the leaves are there and still green. The essential formative daylength effect thus seems to be, besides the regulation of the duration of the annual cycle, that of the relation between above and below ground parts as a whole, which seems plausible since the tips of the stems are the spots at which new leaves are initiated.

E. C. WASSINK