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Eguchi, Toshihiko
Biotron Institute Kyushu University

出版情報：BIOTRONICS. 29, pp.97-107, 2000-12. Biotron Institute, Kyushu University

REVIEW ARTICLE *BIOTRONICS* **29**, 97–107, 2000

SWEETPOTATO STUDIES FOR UNDERSTANDING TUBEROUS ROOT GROWTH HIDDEN BELOW GROUND

T. Eguchi

Biotron Institute, Kyushu University Fukuoka 812–8581, Japan

(Received July 7, 2000; accepted September 29, 2000)

INTRODUCTION

Growth measurement of a plant organ is a basic investigation for plant researches, especially in analyses of environmental effects on crop production. Location of a plant organ has an influence on facility for growth measurement of the organ. We can easily recognize growth of a storage organ when it is located in a terrestrial part; anyone can see changes in tomato fruit size without a special effort. In root and tuber crops, growing storage organs are usually not visible because those exist below ground. This situation has been made researchers to face experimental difficulties on time course measurement of the organ growth and on environment control for the organ. The sweetpotato, *Ipomoea batatas* Lam., is an important root crop in the world, particularly in developing countries. Analyses of environmental effects on the tuberous root growth, however, have been retarded compared with those for fruit crops because of the experimental difficulties mentioned above. The author and coworkers have tried to analyze the relationships between the tuberous root growth and environmental factors since 1994. The present paper summarizes results of our studies (*2–7*) about environment control for growth analysis of the tuberous root and time course measurement of the tuberous root growth in sweetpotato plants. The subject is limited to expansive growth of tuberous roots, although the tuberous root development includes two processes of initiation and the following expansion.

ENVIRONMENT CONTROL FOR SWEETPOTATO STUDY

A plant body of the growing sweetpotato is roughly divided into a terrestrial part and a subterranean part from the viewpoint of photoassimilate translocation. The terrestrial part containing leaves usually acts as a 'source' or a net exporter of photoassimilates, and the subterranean part, i. e. a root system, acts as a 'sink' or a net importer. Many researchers had taken interests in subterranean conditions where the tuberous root grows, and they reported about root temperature effect on tuberous root yield (*9, 16, 19, 23*). In those experiments, however, the root temperature was roughly controlled while the shoot (leaf) temperature was not. Independent control of the respective environments of a 'source' and a 'sink' would be desirable for exact analysis of

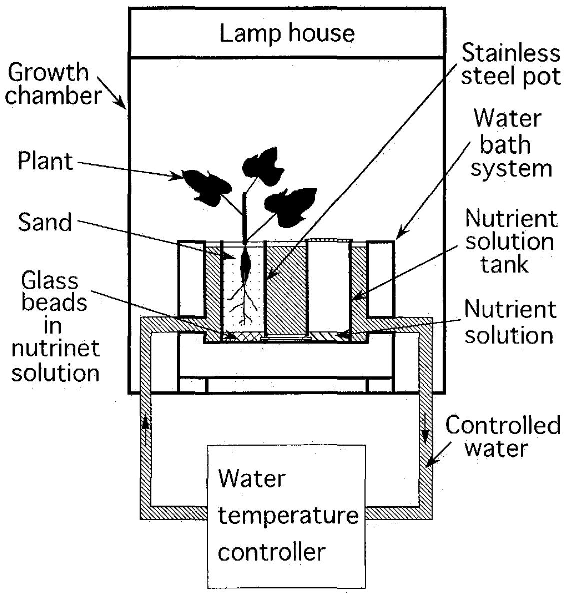

Fig. 1. Schematic diagram of a sweetpotato (*Ipomoea batatas* Lam.) culture system for independent control of shoot and root temperature conditions (Eguchi *et al.*, 1994; ref. *2*).

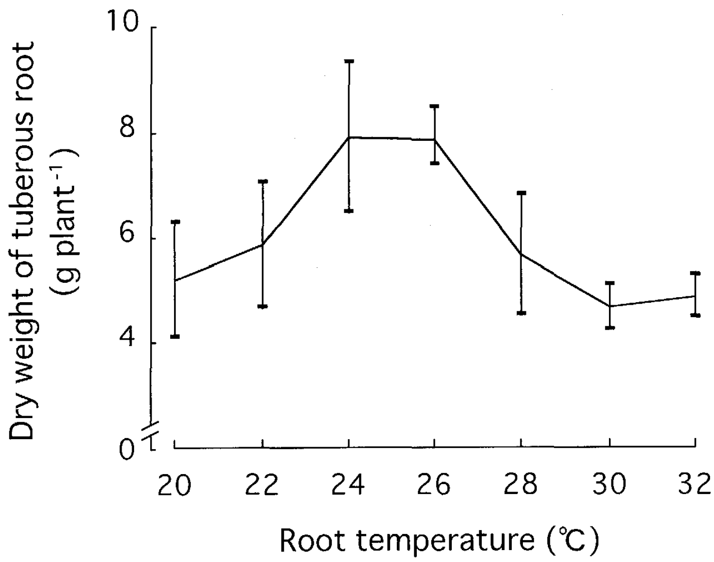

Fig. 2. Effect of root temperature on tuberous root yield (dry weight base) of sweetpotatoes (Eguchi *et al.*, 1994; ref. *2*). Means of four plants grown under exactly controlled root temperature for 40 days are plotted with 95% confidence limits.

environmental effects on growth of the sink organ, because their functions in biomass production are quite different each other. This standpoint may be also applicable to sweetpotato studies. Therefore, we made a sand culture system where the source (shoot) and sink (root) temperatures can be controlled independently and exactly (Fig. 1). Root temperature effect on the tuberous root yield was examined using the culture system, at which root temperature was controlled variously ranged from 20 to 32±0.2℃ under the same condition of the shoot environment (*2*). To obtain experimental results with high reproducibility, the number of leaves in each material plant was unified to minimize the individual variation in source strength, and the number of nodal root, which developed to a tuberous root, was limited to one per plant. The highest tuberous root yield (dry weight basis) was found at 24～26℃ that was a little lower temperature than the shoot condition of 28℃ (Fig. 2), and the highest proportion of dry matter partitioning to the tuberous root was found at 24℃. A root system of a sweetpotato is divided into two types: a tuberous root as a 'storage sink' and a fibrous root as a 'utilization sink' (the classification of sink organs is referred to Ho *et al., 11*). Then, it may well be doubted if the root temperature affected the tuberous root growth only. Temperature effects on fibrous root and indirect contribution of the effect to the tuberous root growth cannot be distinguished from those results. Independent control of the respective environments of a 'storage sink' and a 'utilization sink' would be also desirable if it is possible. As shown in Fig. 3a, source (leaf), storage sink (tuberous root) and utilization sink (fibrous root) are arranged in series in usual

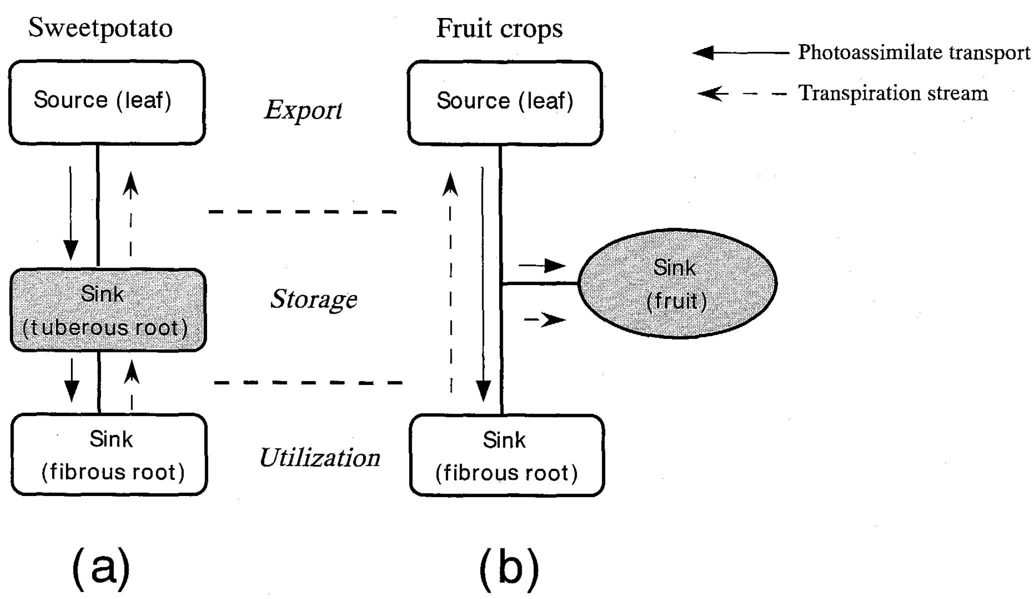

Fig. 3. Arrangement of source, storage sink and utilization sink in a wholeplant of sweetpotatoes (a) and fruit crops (b).

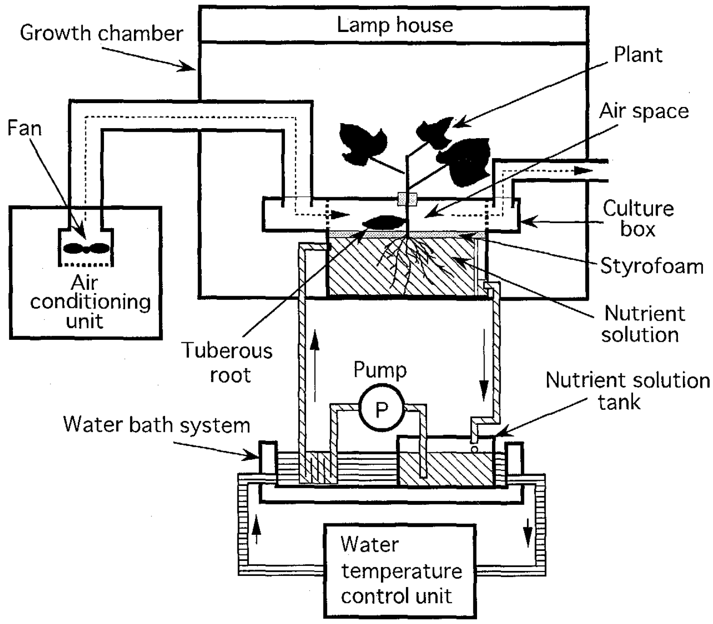

Fig. 4. Schematic diagram of a hydroponic system for sweetpotatoes (Eguchi *et al.*, 1996 ; ref. *3*). Environmental conditions of shoot, tuberous root and fibrous root can be controlled independently.

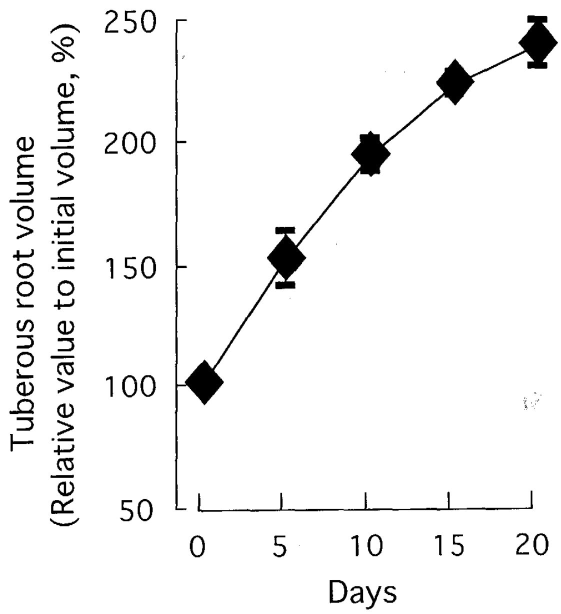

Fig. 5. Volume changes in tuberous roots grown in the sweetpotato hydroponic system shown in Fig. 4 (Eguchi *et al.*, 1996 ; data not published). Means of relative values for four plants are plotted with 95% confidence limits.

sweetpotatoes. The tuberous root is not only 'sink' but also 'path' for transport system. On the other hand, fruit crops such as tomatoes and apples have parallel arrangement of transport system as Fig. 3b. Storage sink (Fruit) and utilization sink (fibrous root) are connected in parallel to source (leaf) for photoassimilate translocation through phloem, and leaf and fruit are connected in parallel to fibrous root for transpiration stream through xylem. Transport system in a potato, *Solanum tuberosum* L., is also the parallel type. Independent control of the respective environments of those organs appears to be difficult in the sweetpotato of the serial system. When fibrous root temperature is artificially lowered in a growth experiment, temperature of storage sink in the serial system may be fluctuated for temperature-lowered transpiration stream flow through the organ, whereas storage organ in the parallel system may be little affected. Thus, the parallel system appeared to be preferable to examine environmental effects on sweetpotato growth. This means that the tuberous root is required to act simply as a storage sink like a potato tuber does, and not act as path. We considered that the tuberous root could be released from the 'path' role by excising all fibrous roots extended from the organ. Then, we tried to develop a new sweetpotato culture system where environments of a shoot, a tuberous root and a fibrous root can be controlled independently. As shown in Fig. 4, we designed a new culture system for sweetpotato, where shoot, tuberous root and fibrous root environments can be controlled independently. Here, the tuberous root is enclosed in a box and exposed to controlled air, as some researchers had already demonstrated that the tuberous root can grow in air (*10, 24*). Fibrous roots emerged from basal nodes are totally immersed in a temperature-controlled nutrient solution. Figure 5 shows volume changes of tuberous root grown in the new culture system we developed. Volume increase of the tuberous root was observed clearly. Exact control of growth conditions resulted in high reproducibility of the outcome as the data showed small variances. Thus, each of shoot, tuberous root and fibrous root were able to grow in independently controlled conditions of environmental factors. I note, however, that the sweetpotato culture system is for a 'short-term' experiment only. The tuberous root growing in the system can not extend its length because the distal nodal root is excised, and active growth may cease sooner than that of field grown tuberous root. The sand culture system mentioned above prefer to a long-term experiment in which tuberous root yield is the main subject of interest.

TIME COURSE MEASUREMENT OF TUBEROUS ROOT GROWTH

Various techniques have been used for time course measurement of storage organ growth (Table 1). Manual measurement using a scale or a caliper is a simple method but is not favor to chase changes in minute or second bases, which are usually occurred in storage organs. Electric devices such as a linear variable transformer (*8, 13, 18, 21, 22*), a potentiometer (*12*) and a strain gauge (*17*) have been applied for continuous measurement of fruit diameter in various fruit crops. In recent years measuring devices applying laser beam are widely utilized in industry. The laser device can accurately measure width, length or thickness of the object without direct attachment. Kitano *et al.* (*14*) applied a laser displacement sensor to measure fruit diameter of tomato, and they successfully evaluated volume changes of growing tomato fruit. For growth measurement of sweetpotato tuberous root, we applied a laser micrometer (LM) to evaluation of tuberous root volume (*5*). The LM is a device for non-contact measurement of diameter of an object. As shown in Fig. 6, diameters of the tuberous root were scanned by moving the LM along the longitudinal axis of the tuberous root at constant speed, and tuberous root volume was evaluated as an aggregation of thin disks. Conventional methods listed in Table 1 evaluate the storage organ growth by measuring partial change, i. e. change in maximum diameter, whereas the LM system scans the whole contours of the organ. By using the LM system, the volume measurement was done with high accuracy of ± 0.4 mm^3. It should be also noteworthy that the drift induced by temperature changes in the LM system was negligibly low (less than $\pm 0.01 \mu m$ $℃^{-1}$). Figure 7 shows the typical pattern of the tuberous root growth measured using the LM system installed in the sweetpotato culture system (*4*). The tuberous root growth showed diurnal change synchronizing with changes in light condition of the shoot environment. Thus, the LM system was proved to be an effective tool for measuring volume changes in growing tuberous root. By using the LM system, I found that the tuberous root growth was affected by leaf transpiration

Table 1. Various techniques for evaluation of time course change in storage organ size.

Electric device	Subject	Crop	Reference
Linear variable differential transformer	Fruit diameter	Apple, Cucumber, Tomato	Tukey, 1964 (*22*)
	Fruit diameter	Citrus	Elfving and Kaufmann, 1972 (*8*)
	Fruit diameter	Apple	Tromp, 1984 (*21*)
	Tuber diameter	Potato	Stark and Halderson, 1987 (*20*)
	Fruit diameter	Tomato	Johnson *et al.*, 1992 (*13*)
	Fruit diameter	Tomato	Pearce *et al.*, 1993 (*18*)
Strain gauge	Fruit diameter	Apple	Link *et al.*, 1998 (*17*)
Dendrograph	Fruit diameter	Montmorency cherry	Kozlowski, 1968 (*15*)
Potentiometer	Fruit diameter	Tomato	Huang, 1974 (*12*)
Laser displacement sensor	Fruit diameter	Tomato	Kitano *et al.*, 1996 (*14*)

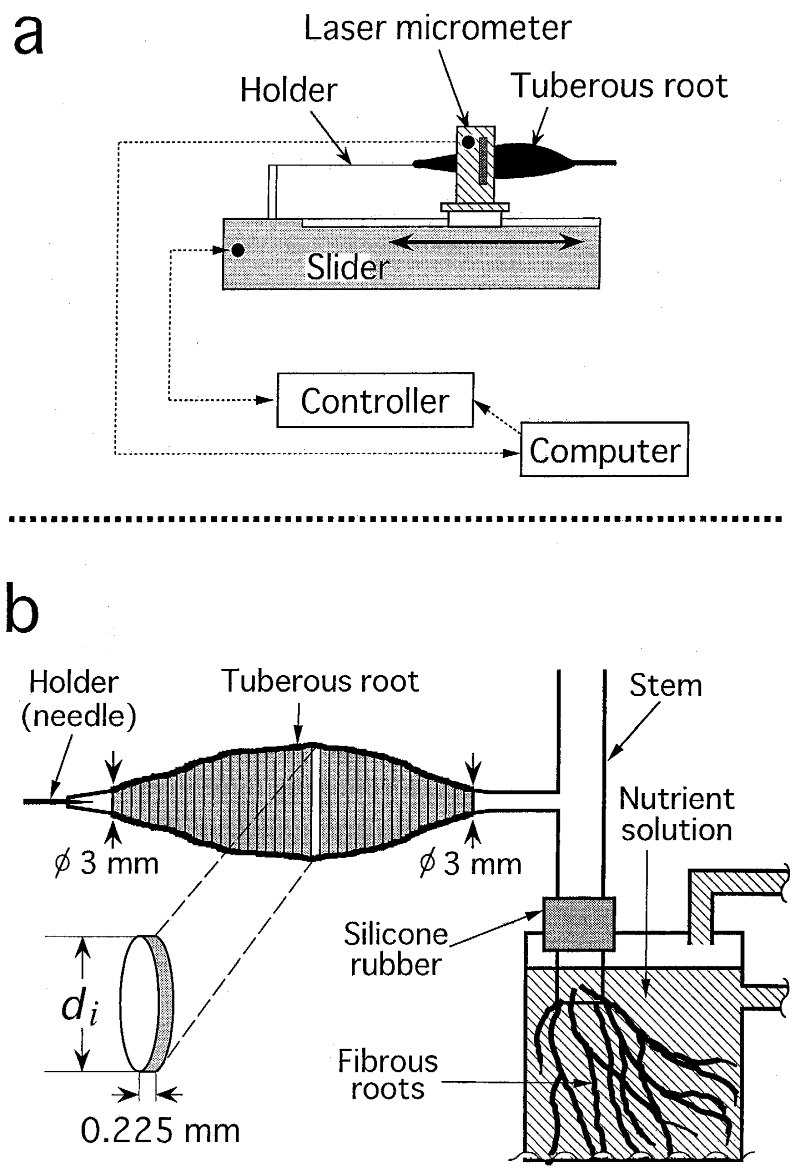

Fig. 6. Schematic diagrams of a laser micrometer (LM) system for on-line measurement of sweetpotato tuberous root volume (a), and method of tuberous root volume evaluation (b) (Eguchi *et al.*, 1997 ; ref. *5*).

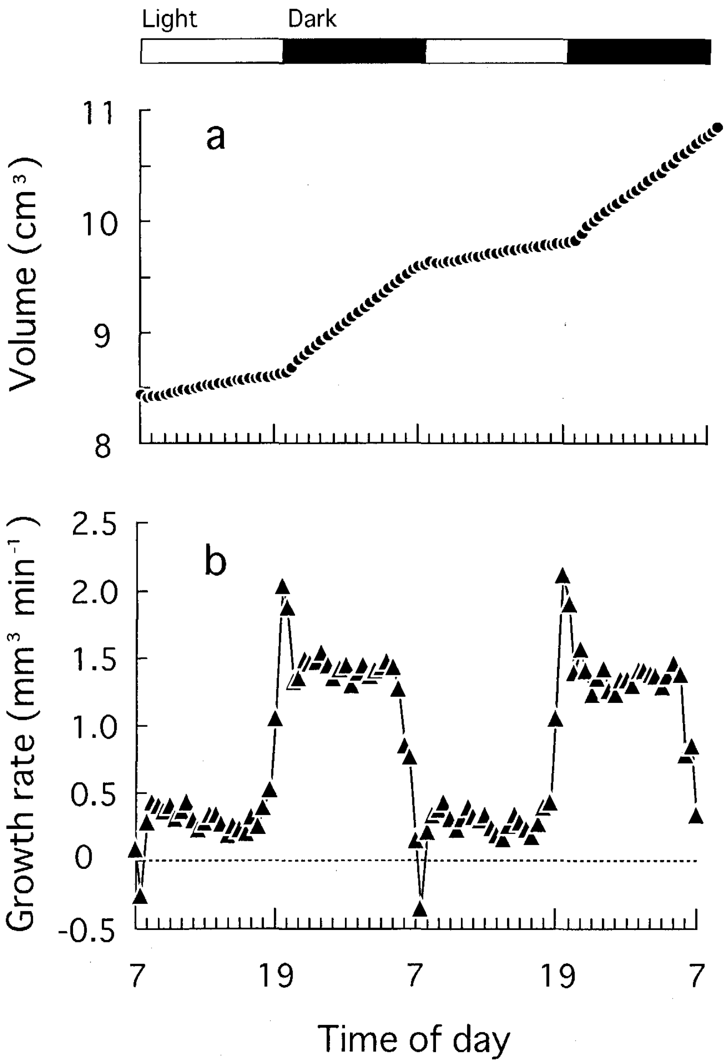

Fig. 7. Time course pattern of diurnal changes in tuberous root growth of sweetpotatoes (Eguchi *et al.*, 1997 ; ref. *4*).

(*6*) and humidity condition around the tuberous root (*7*). Furthermore, it was considered that the LM method could be also used for evaluation of diurnal changes in potato tuber growth. The system was modified for potato plants (Fig. 8), and diurnal change in the tuber growth was successfully calculated as shown in Figure 9 (*1*).

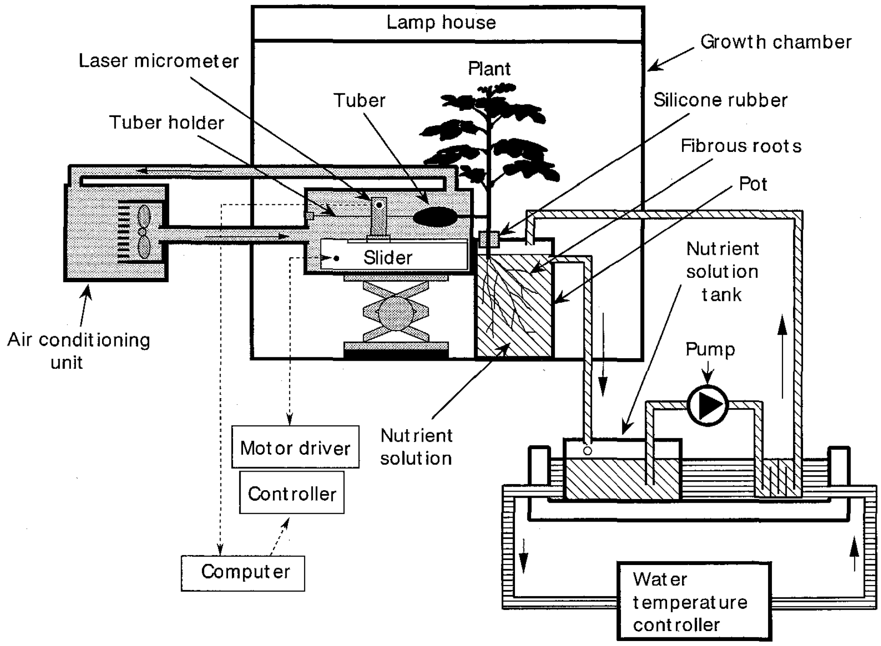

Fig. 8. Schematic diagram of a hydroponic system for on-line measurement of potato tuber growth under the controlled environments (Eguchi, 2000 ; ref. *1*).

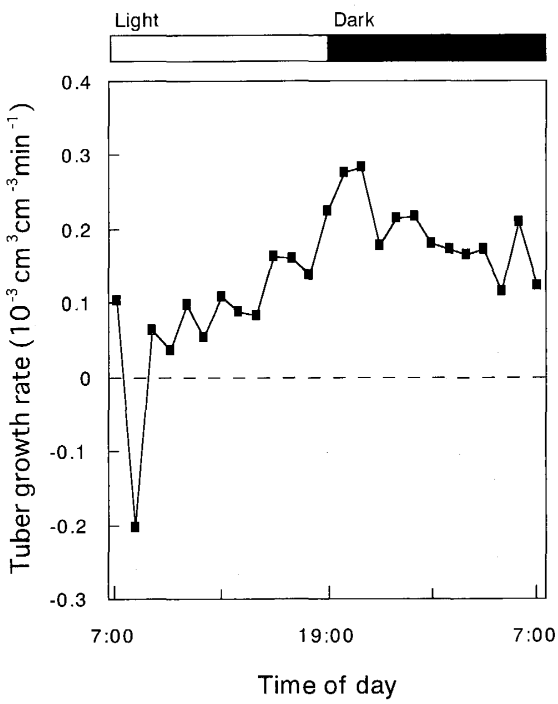

Fig. 9. Diurnal change in relative growth rate of potato tuber grown under the controlled environments (Eguchi, 2000 ; ref. *1*).

CONCLUSION

In sweetpotatoes, the optimum temperature for tuberous root growth may be not necessarily the same for fibrous root growth and also for leaf photosynthesis. Then, it may be an important idea that growth experiment for examination of environmental effects should be done under independent control of environments of the respective organs which differ in roles for dry matter production. The idea had, however, been difficult to do in practice, because the tuberous root is a localized thickening part of a nodal root and is usually hidden below ground. At the present state of sweetpotato studies, we found barely that tuberous root expansion responds rapidly to changes in shoot environments related to leaf transpiration. However, it is interesting that those responses, which occur under the ground, had been similarly found in fruits (*8, 12, 15, 21, 22*) grow above ground. We are now starting to understanding how environmental factors affect tuberous root growth in sweetpotatoes.

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