

Effect of Root Temperature on the Rate of Water and Nutrient Absorption in Cucumber Cultivars and Figleaf Gourd¹

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Summary

A comparative study was made of the effect of root temperature on water and nutrient absorption in cucumber (*Cucumis sativus* L.) cultivars and figleaf gourd (*Cucurbita ficifolia* Bouché). These plants were preincubated at root temperatures of 12, 14, 17, 20 and 30°C for 1 or 5 days, then the rate of water and nutrient absorption was determined for the following 24 hours at the each same root temperature.

In cucumber cultivars, absorption of both water and nutrients was greatly inhibited at temperatures lower than 17 or 20°C, depending on nutrient elements. Absorption of nutrients was more severely inhibited than that of water, particularly when the plants were preincubated at lower temperatures for 5 days. The difference in rates between cultivars was relatively insignificant except for P absorption, which was more significantly inhibited at 12~17°C in a chilling sensitive summer cultivar 'Suyō' than in a less sensitive spring one 'Kurume-ochiai H'.

In figleaf gourd, which is more tolerant of chilling temperatures than cucumber, both water and nutrients were absorbed at similar rates at all temperatures, being irrespective of preincubation periods. P absorption was exceptionally inhibited at 12°C after 1 day preincubation, but it became unaffected after 5 days preincubation.

Introduction

Cucumber cultivars in Japan are roughly classified into 2 ecotypes; the summer cultivars and the spring ones.

It was found previously(19) that a summer cultivar 'Suyō' was more sensitive to chilling root temperatures than a spring one 'Kurume-ochiai H'. Growth of 'Suyō' was significantly improved by grafting it on figleaf gourd roots. Figleaf gourd *per se* was highly tolerant of chilling root temperatures. Significant correlations were observed between the degree of growth inhibition and that of decrease in water and nutrient concentrations of leaves at lower root temperatures.

The results are indicative of the sensitivity of absorbing capacity of roots to chilling being one of the primary factors that deter-

mine the root-chilling tolerance of the plants. However, the decrease of leaf nutrient concentrations could be caused by reduced translocation of absorbed nutrients from roots to tops(17), and possibly by increased top-root dry weight ratios(19), in addition to reduced absorption by the roots.

Present paper will report the effect of root temperature on water and nutrient absorption by intact roots of cucumber cultivars and figleaf gourd following preincubation at various root temperatures for different periods.

Materials and Methods

Seedlings of cucumber 'Suyō' and 'Kurume-ochiai H' and figleaf gourd with 2 expanded leaves were planted in 110 l culture tanks filled with a third strength Hoagland No.2 solution. Solution (=root) temperatures were established 2 days after planting at 12, 14, 17, 20 and 30°C. The plants were

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cultured at these root temperatures for 1 or 5 days before the absorption experiment. These pretreatments are expressed as 1 day and 5 days preincubation, respectively. Thereafter, the plants were transplanted in a plastic bottle containing 250 ml of a third strength Hoagland No.2 solution at the each same temperature, and cultured with continuous aeration for 24 hours.

Air temperatures were controlled at 28°C for day and 22°C for night. Day length was 12 hours supplied with fluorescent lamps (Toshiba FL 20 BRF) as a single light source (340 W·m⁻² day⁻¹ at plant level).

The rate of water and nutrient absorption was determined by measuring the decrease of solution volume and nutrient contents at the end of the experiment, and it was expressed on the basis of dry weight of a whole plant harvesting.

Results

Rates of water and nutrient absorption are summarized in Figs.1 to 8. Generally, the effects of low root temperature on absorption processes depended on kinds of nutrient elements and crop plants.

Water absorption rate reduced significantly at lower than 14°C in both cultivars of cucumber, whereas it reduced only at 12°C in figleaf gourd. Longer period of preincubation did not result in greater reduction in rates except 'Kurume-ochiai H' at 12°C.

A great difference in nutrient absorption rates was found between cucumber and fig-

leaf gourd at lower temperatures. In general, the rates were slightly affected by temperature in figleaf gourd for most elements, except P. On the other hand, in cucumber the rate of nutrient absorption reduced great-

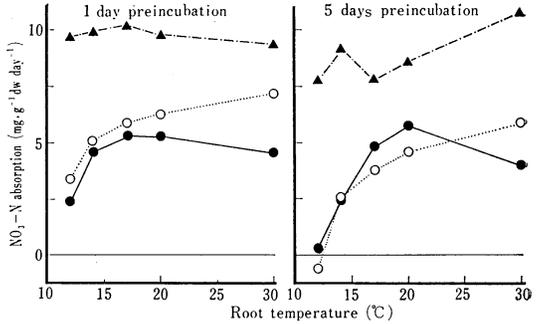


Fig. 2. Effect of root temperature on NO₃-N absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

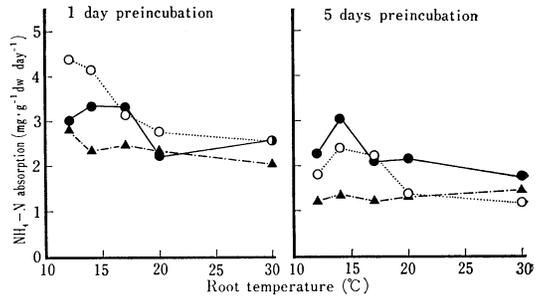


Fig. 3. Effect of root temperature on NH₄-N absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

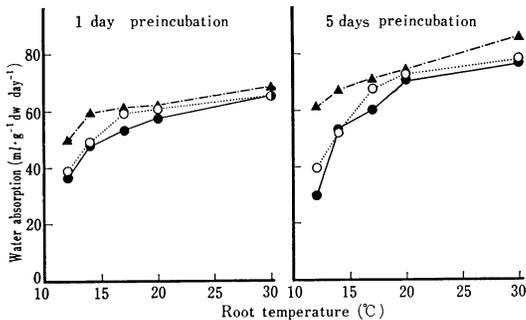


Fig. 1. Effect of root temperature on the water absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

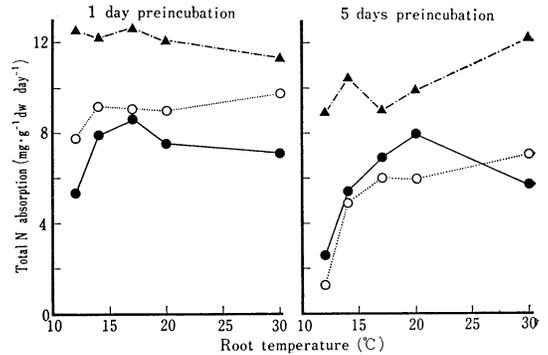


Fig. 4. Effect of root temperature on total N absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after 1 and 5 days incubation at respective temperatures for 1 and 5 days.

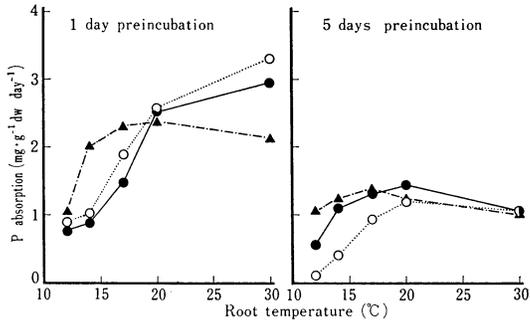


Fig. 5. Effect of root temperature on P absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

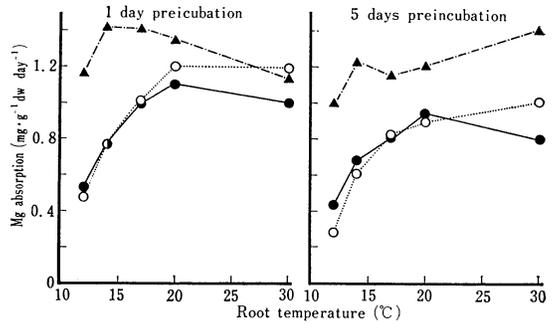


Fig. 8. Effect of root temperature on Mg absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

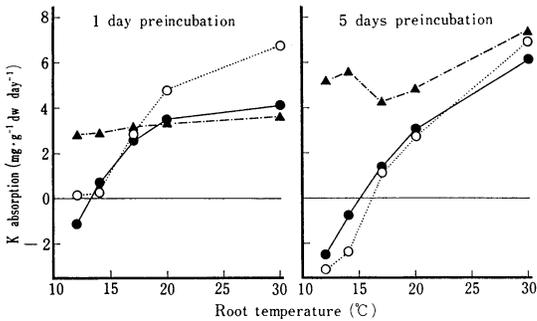


Fig. 6. Effect of root temperature on K absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

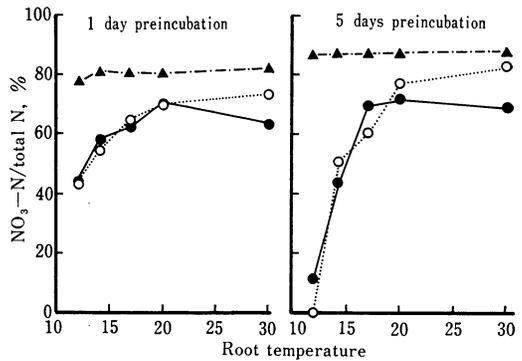


Fig. 9. NO₃-N absorption in percent of total N absorption at different root temperatures after incubation at respective temperatures for 1 and 5 days in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲).

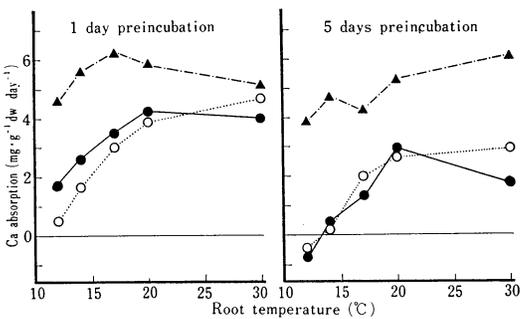


Fig. 7. Effect of root temperature on Ca absorption in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲) after incubation at respective temperatures for 1 and 5 days.

ly at temperatures lower than 17 or 20°C, depending on elements. Furthermore, the reduction in rates became greater when the preincubation period extended to 5 days, and the negative absorption, i. e., the leakage of nutrients to external solution was noted

in NO₃-N and Ca at 12°C and in K at 12~14°C. The trend was more remarkable in 'Suyō' than in 'Kurume-ochiai H'. The difference in the rate of nutrient absorption between the cultivars was relatively small at 14~20°C, but 'Suyō' showed higher rates than 'Kurume-ochiai H' at 30°C.

P absorption was greatly inhibited at 17°C and lower in cucumber cultivars and at 12°C in figleaf gourd after 1 day preincubation. Although the rate reduced as a whole after 5 days preincubation, the inhibitory effect of low root temperature augmented in 'Suyō', while lessened in figleaf gourd. Relative rates at 12~17°C among the 3 crops followed the order of root chilling tolerance of the plants.

Unlike other nutrients, NH₄-N absorption

Table 1. Effect of root temperature on the ratio of nutrient absorption to water absorption ($\text{me}\cdot\text{l}^{-1}$).

A. 1 day preincubation

Crop	Root temp. (°C)	NO ₃ -N	NH ₄ -N	P	K	Ca	Mg
Suyō	12	4.75	6.12	1.60	0.14	0.49	0.78
	14	6.27	4.86	1.67	0.10	1.34	1.04
	17	5.75	3.08	2.59	0.99	2.07	1.16
	20	5.90	2.63	3.40	1.63	2.58	1.35
	30	6.43	2.24	4.04	2.14	2.87	1.21
Kurume-ochiai H	12	4.53	4.80	1.66	<0	1.90	0.97
	14	5.54	3.99	1.46	0.28	2.21	1.07
	17	5.82	3.53	2.23	0.98	2.64	1.24
	20	5.24	2.22	3.55	1.24	2.93	1.27
	30	4.02	2.24	3.66	1.30	2.44	1.02
Fingleaf gourd	12	11.09	3.25	1.66	1.15	3.74	1.56
	14	9.54	2.25	2.72	1.20	3.72	1.59
	17	9.96	2.43	3.16	1.26	4.27	1.60
	20	8.95	2.16	3.05	1.08	3.78	1.44
	30	7.74	1.67	2.46	1.07	2.97	1.09
B. 5 days preincubation							
Suyō	12	<0	2.73	0.20	<0	<0	0.48
	14	2.71	2.62	0.62	<0	0.35	0.79
	17	3.28	1.89	1.11	0.35	1.21	0.81
	20	3.62	1.12	1.32	0.76	1.48	0.83
	30	4.33	0.86	1.07	1.83	1.52	0.88
Kurume-ochiai H	12	0.61	4.35	1.50	<0	<0	0.95
	14	2.58	3.27	1.68	<0	0.34	0.84
	17	4.58	1.99	1.77	0.48	0.92	0.89
	20	4.67	1.74	1.63	0.82	1.67	0.88
	30	2.98	1.31	1.09	0.83	0.93	0.69
Fingleaf gourd	12	7.22	1.12	1.36	1.73	2.52	1.11
	14	7.76	1.14	1.51	1.71	2.80	1.21
	17	6.29	0.98	1.54	1.24	2.40	1.08
	20	6.63	1.01	1.21	1.33	2.86	1.08
	30	7.22	0.98	0.96	1.74	2.84	1.10

rate increased with lowering of root temperature. This trend was noted particularly in 'Suyō' after 1 day preincubation, but to the least extent in fingleaf gourd. As a result, total N absorption rate was positive even in 'Suyō' at 12°C where the leakage of NO₃-N occurred. Fig. 9 shows the ratio of NO₃-N absorption in percent of total N absorption. The ratio decreased greatly with lowering root temperatures in cucumber, and most of N absorbed was NH₄-N at 12°C. On the other hand, in fingleaf gourd the ratio was hardly affected by root temperature, and it was nearly the same with that of the

nutrient solution (87.5%).

Table 1 shows the ratio of nutrient absorption to water absorption expressed in $\text{me}\cdot\text{l}^{-1}$. From this, it may be seen which of the water and nutrient absorption was more strongly inhibited by lower temperatures. In cucumber, the values for NO₃-N were the same at all temperatures after 1 day preincubation, showing that the absorption of NO₃-N and water was inhibited similarly by lower temperatures. After 5 days preincubation, however, the values decreased markedly with lowering of root temperature, which indicates that NO₃-N absorption was more sensi-

tive to low temperatures than water absorption. The table also shows that low root temperature affected greatly on P, K and Ca absorption than on water absorption, particularly after 5 days preincubation. On the other hand, the values in figleaf gourd were relatively unchanged at all temperatures. Rather, they tended to increase with lowering root temperatures for $\text{NO}_3\text{-N}$ and K. Only exception was for P after 1 day preincubation.

Discussion

The rate of nutrient absorption by intact roots differed greatly between cucumber and figleaf gourd at root temperatures lower than 17 or 20°C, depending on elements and preincubation periods. The difference may be primarily responsible for the previously observed difference in the nutrient concentrations of leaves at lower root temperatures (19). However, the difference in absorption rate between cucumber cultivars was small as compared with that in nutrient concentrations of leaves.

Many investigations have been reported on the effect of root temperature upon water and nutrient absorption by plants (2, 4, 5, 7, 8, 14, 16). The mechanisms involved in root temperature effects on absorption processes in intact roots are rather intricate. In addition to the direct effect on respiratory activities, membrane permeability, electrochemical potential gradients and carrier functionings of the roots, more indirect effects on transpiration, upward transport of nutrients and photosynthate translocation to roots could be causal factors of reduced absorption rates at lower root temperatures.

Root respiration is undoubtedly affected by temperature. Generally, hardy plants can maintain high rates of root respiration at low temperature as compared with less hardy plants (10). Masuda and Gomi (12) found the respiration rate of figleaf gourd roots to be higher than cucumber roots at 12°C, the rate being equal in 2 plant species at 16°C and higher. Presumably, root respiration rate was a rate-limiting factor for absorption process at low root temperature. However, according to Masuda and Gomi, low tempera-

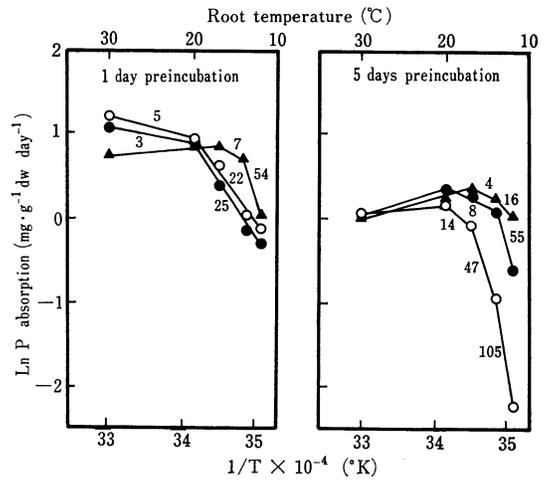


Fig. 10. Arrhenius plots of P absorption after incubation at respective temperatures for 1 and 5 days in Suyō (○), Kurume-ochiai H (●) and figleaf gourd (▲). Numbers in the figures indicate activation energies in $\text{kcal}\cdot\text{mol}^{-1}$.

ture greatly suppressed root respiration rate even in figleaf gourd, which was hardly affected in nutrient absorption by low temperature except P after 1 day preincubation in the present experiment.

According to Bravo-F and Uribe (2), K and P absorption were more temperature-dependent than respiration in corn roots. They supposed that in addition to limitation of energy the low temperature decreased the fluidity of carrier proteins in catalyzing ion transport. It is known that membrane phase transition temperature is higher in chilling sensitive plants than in less sensitive plants (15). It shifts to lower temperatures when grown at lower temperatures in plants with high acclimation capacities to low temperature (11). Chapin (5) found that the capacity for P absorption by marsh plants was negatively correlated with the soil temperature of the habitat of origin. It was found in this experiment that the 3 crop plants responded differently in P absorption rate to extended period of preincubation at lower root temperatures. Arrhenius plots of P absorption rates are shown in Fig. 10. The numbers in the figure are the activation energies (E_a) of P absorption for the corresponding straight segments of the

plots. When the plots for the 2 preincubation periods are compared, it is seen that the values of E_a decreased after 5 days preincubation at 12~14°C in figleaf gourd, at 14~20°C in 'Kurume-ochiai H' and at 17~20°C in 'Suyō', respectively. However, the values increased further at 12~14°C in 'Kurume-ochiai H' and at 12~17°C in 'Suyō'. These results may indicate that figleaf gourd could acclimate at least at 12°C in membrane-associated metabolic activities in the roots. Presumably, 'Suyō' roots is less adaptable to low temperatures than 'Kurume-ochiai H' roots. Leakage of nutrients to external solution was probably caused by dysfunction of membrane systems.

It has been noted that $\text{NH}_4\text{-N}$ absorption is less temperature-dependent than $\text{NO}_3\text{-N}$ absorption. Clarkson and Warner (6) assumed $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ to be absorbed across the cell membrane at sites spacially different from each other, the site involved in $\text{NH}_4\text{-N}$ absorption being fluid region of the membrane.

Recently Ikeda *et al.* (9) found that a high ratio of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$ in the nutrient solution caused ammonium toxicity in Japanese hornwort when combined with low solution temperature. In the present experiment, ammonium toxicity was not observed even in 'Suyō' at 12°C after 5 days preincubation, where all of N was absorbed as $\text{NH}_4\text{-N}$. Solution-pH was higher than 4.3, notwithstanding it tended to decrease with lowering temperatures. Cucumber grows well with $\text{NH}_4\text{-N}$ as a single N source, provided that the solution pH is higher than 4.0(13), therefore, increased absorption of $\text{NH}_4\text{-N}$ probably compensated partly for the reduced absorption of $\text{NO}_3\text{-N}$.

Relationships between water and nutrient absorption have been a subject of study for decades(1, 3, 18). A distinct increase in nutrient absorption often takes place with enhanced transpiration. However, their causal relations are left unrevealed. From the data on the ratio of nutrient absorption to water absorption, it is assumed that the low root temperature inhibits nutrient absorption largely through its effects on root func-

tions directly associated with absorption processes, rather than through effects on transpiration. In this respect, it is of interest to note that Ca absorption, which has been thought to be largely related to transpiration (18), was more temperature-sensitive than water absorption.

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キュウリ品種とクロダネカボチャの養水分吸収に及ぼす根温の影響

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摘 要

低根温耐性を異にするキュウリ2品種(‘四葉’と‘久留米落合H型’)及びクロダネカボチャを根温12, 14, 17, 20, 30°Cで1日及び5日間前培養したあと、ホーグランド液(第2液, 1/3倍)250mlの入ったポリびんに移して、それぞれの根温における24時間の養水分吸収速度を測定した。

吸水速度は低根温によって抑制されたが、その程度はキュウリにおいて著しく、クロダネカボチャは顕著な抑制を受けなかった。キュウリにおいては、2品種ともに前培養日数の増加によって低根温下での吸水速度の低下程度が増大した。

一方、養分吸収速度は、キュウリ2品種においては、養分によって違いがあったが、概ね14~17°C以下の低根温で低下がみられ、前培養日数の増加によりその程度が増大した。また、NO₃-N, K, Caでは12~14°Cで

外液への漏出が起こった。これらの傾向は‘四葉’の方が‘久留米落合H型’より顕著であった。なお、NH₄-Nに限って、低根温下で吸収速度の増大する傾向が認められた。

これに対して、クロダネカボチャではPを除いて両前培養区ともに根温の影響をほとんど受けなかった。P吸収速度は前培養1日区では12°C区でのみ低下したが、前培養5日区では12°Cにおいても低下はみられなかった。また、低根温によるNH₄-N吸収速度の増大は顕著ではなかった。

水分吸収速度に対する養分吸収速度の比率(養水分吸収比)はキュウリ2品種では根温の低下に伴って低下し、5日間の前培養によってこの傾向は一層増大した。しかし、クロダネカボチャでは養水分吸収比は全体的に低根温によってむしろ高くなる傾向がみられた。