Effects of Soil Temperature on the Vegetative Growth of Rice

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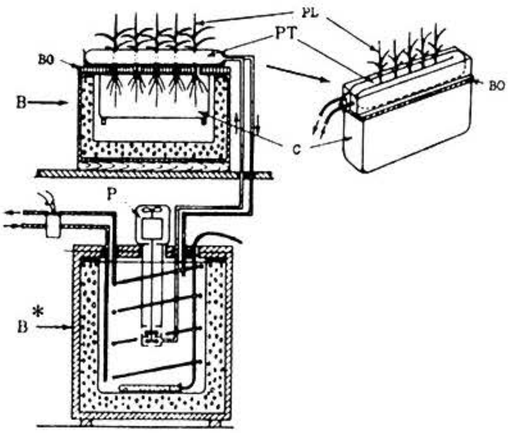
The development of large-scale water storage to allow dry-season cropping together with the increasing use of high-yielding, photoperiod-insensitive, semi-dwarf indica varieties[1,4] has presented the problem of low soil and water temperatures in tropical and subtropical lowland rice cultivation, as used to be the case in the temperate climate.

Much information has been accumulated on the effects of soil and water temperatures on rice, some of which suggesting that the growth during vegetative and early reproductive stages is influenced by the temperature near the shoot-bases enclosing shoot apices and leaf buds[2]. However, with one exception[5], little attempt has been made to elucidate how the cooling of individual plant organs lying buried in the submerged soil, namely shoot-bases and roots, is responsible for the growth retardation of the entire plant, possibly because of the technical difficulties.

The present paper reports the results of such a study, which was undertaken to evaluate the respective roles of shoot-base and root temperatures in the vegetative growth of rice, as judged from their influences on growth attributes, photosynthetic ^{14}C assimilation, and distribution pattern of assimilated ^{14}C.

Experimental materials and method of temperature regulation

A system was developed to impose 4 temperature regimes upon the shoot-base and the root independently. Temperature was regulated at 28°C on shoot-base/28°C on root (H/H), 18°/28° (L/H), 28°/18° (H/L) and 18°/18° (L/L), under usual glasshouse conditions. A batch of 5 to 10 plants of a japonica variety of rice, Norin No. 29 was planted in each plot. An expanded polystyrene board was used to support the rice plants in such a manner as to keep the shoot-bases emerged above the board surface to be placed between a folded polythene tubing of 4 cm diameter, through which temperature-controlled water was circulated. Regulation of root temperature was performed by immersing the con-



B and B* : temperature-controlled water bath, BO : expanded polystyrene board for insulation, C : enameled container filled with nutrient solution, P : pump, PL : rice plants, PT : polythene tubing through which water circulates to regulate the shoot-base temperature.

Fig. 1. Diagram of the system used to separately regulate shoot-base temperature and root temperature of young rice plants

Table 1. Growth attributes and growth patterns of rice plants as affected by shoot-base and/or root temperatures

Plot	Growth analysis			Growth pattern			
	RGR1)	NAR2)	LAR3)	Leafing rate4)	T/R ratio5)	B/S ratio6)	SLW7)
H/H	1.41	0.971	1.45	0.25	5.9	1.16	3.42
L/L	1.26	0.993	1.27	0.14	4.5	0.88	3.61
H/L	1.32	0.966	1.37	0.23	4.6	1.05	3.43
L/L	1.17	0.978	1.20	0.11	3.8	0.83	3.77

1) Relative growth rate (g/g/10 days)
2) Net assimilation rate (g/100 cm^2/10 days)
3) Leaf area ratio (100 cm^2/g)
4) Increase in leaf number on the main stem per day
5) Dry weight of shoots to that of roots
6) Relative dry weight of leaf-blades to that of leaf-sheaths on the main stem
7) Specific leaf weight (dry weight per unit area of leaf-blade, mg/cm^2)
For each plot 8 plants of 7th leaf-stage were subjected to an 8-day temperature treatment.

tainer of nutrient solution in a temperature-controlled water bath (Fig. 1).

Growth analysis and growth pattern

As given in Table 1, greater RGRs and LARs were resulted from higher shoot-base or root temperature of which the former had greater influence than did the latter. Greater NARs were brought about by higher root temperature, and by lower shoot-base temperature irrespective of root temperature. It is thus assumed that cooling of shoot-bases is the primary causal factor of the growth retardation in the vegetative stage, whereas cooling of roots is of comparatively less importance although the effect on NAR is apparent. Declined leafing rate, T/R and B/S ratios as well as increased SLW due to lowered shoot-base temperature suggest that the slow rates of both initiation and expansion of new leaves are primarily concerned in declined LAR, and hence decrease in dry matter production (RGR).

Photosynthetic ^{14}C assimilation

When rice plants at the vegetative stage were subjected to the short-term temperature treatment (5 hrs) and allowed to feed $^{14}CO_2$, cooling of shoot-base and/or roots resulted in decreased assimilation rate of the whole leaf-blade. With the plants subjected to the long-term temperature treatment (8 days), however, larger assimilation rates were found at either lower shoot-base or higher root temperature, showing a sharp constrast to the result of shoot-term treatment of shoot-base temperature3).

Fig. 2 shows the relative pattern of the rate of ^{14}C assimilation in relation to the leaf position on the main stems. The mature leaves at the uppermost position (the top leaf) showed the highest rate of assimilation except for the plot H/L. Among the different temperature treatments, assimilation rate of the top leaf was greatest in the plot L/H, followed by the plots H/H, L/L and H/L in that order. It was in a close relationship to that of all leaves of a plant (Fig. 3). Thus the effects of shoot-base and/or root temperature on ^{14}C assimilation at the vegetative stage are most strikingly reflected on the top leaves. In this connection, Fig. 4 illustrates a parallel relationship between the assimilation rate and the total nitrogen content in the top leaves and the elongating leaves locating next to them. Hence, local temperature seems to affect pri-

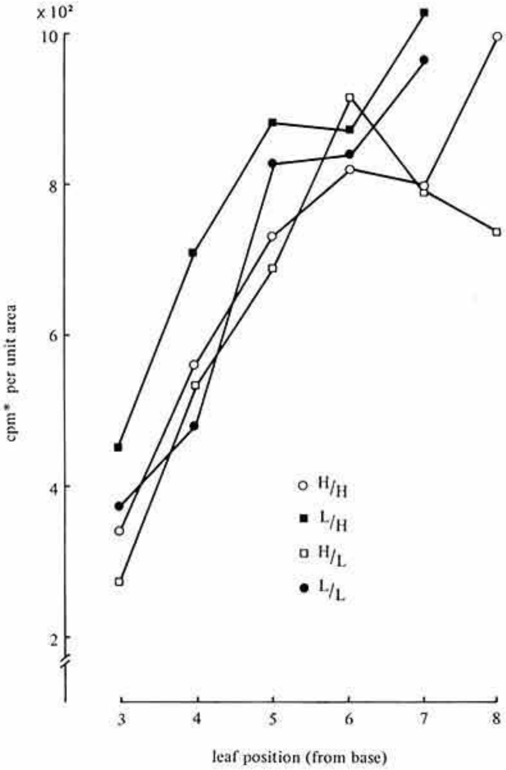


Fig. 2. Photosynthetic activity in successive leaves on the main stem

* counts per minute

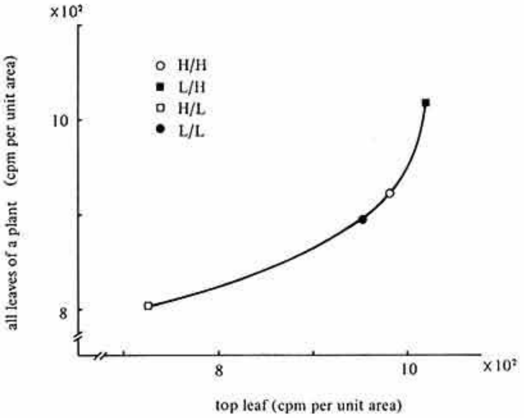


Fig. 3. Relation of photosynthetic activity of top leaf to that of all leaves

marily the nitrogen accumulation in elongating leaves, thus resulting in varied photosynthetic activities after their full expansion.

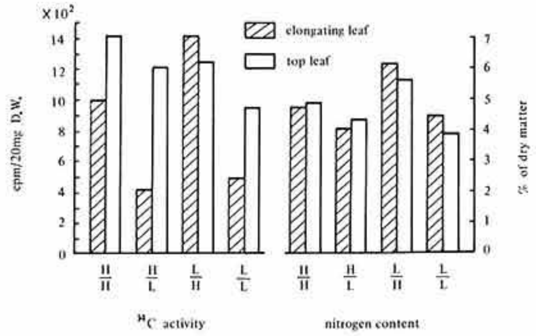


Fig. 4. Photosynthetic activity and nitrogen content in elongating leaf and youngest fully matured leaf (top leaf)

In addition, RuDP carboxylase activities of top leaves behaved in the same manner as did their total nitrogen content[3]. Hence, such a difference in ^{14}C assimilation rates seems to be attributed to that in levels of Fraction I Protein in comparable leaves.

Distribution pattern of assimilated ^{14}C

Fig. 5 shows the distribution pattern immediately after and 26 hrs after a 1-hr exposure to $^{14}CO_2$ of the entire plants subjected to long-term temperature treatment (8 days). It is noted that the short-term (0 hr) distribution pattern differs much from the long-term one (26 hr) in both the elongating leaves and the roots. In the latter case, however, the accumulation pattern of ^{14}C-assimilate highly correlates with leafing rate and T/R ratio as demonstrated in Table 1, Therefore the distribution pattern of ^{14}C-assimilate in at least 1-day period following application of $^{14}CO_2$ appears to characterize the growth pattern of rice as affected by shoot-base and/or root temperature.

Incorporation of assimilated ^{14}C into protein of the elongating leaves

To understand more fully the pattern of

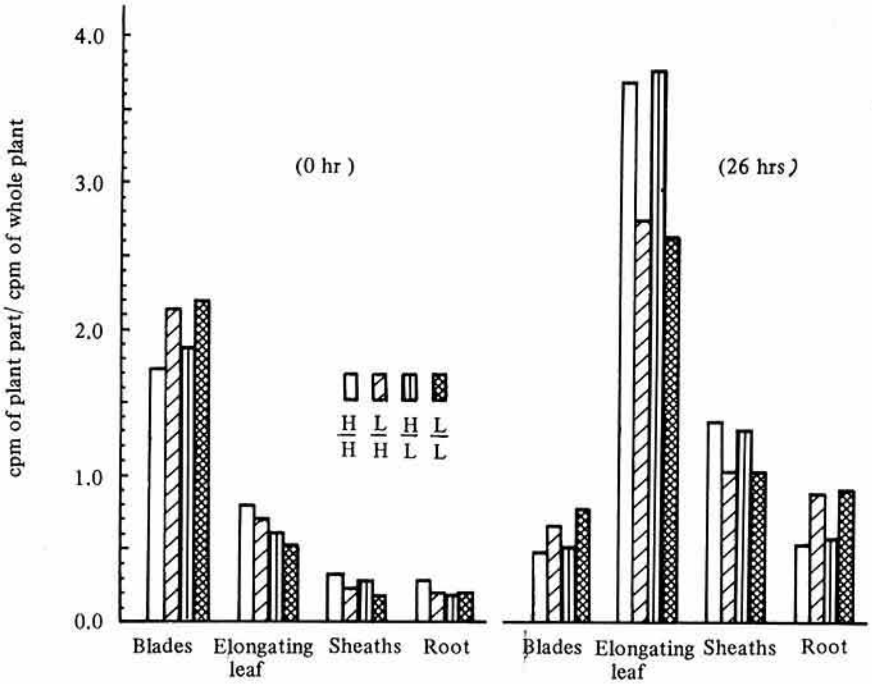


Fig. 5. Distribution of ^{14}C fed via entire leaves of a plant

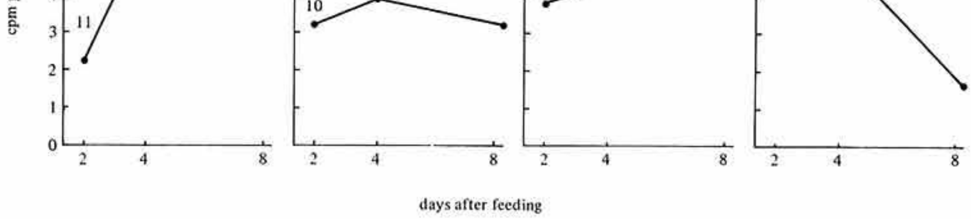


Fig. 6. Changes with time in total ^{14}C activity of protein in elongating leaves following photosynthesis with $^{14}CO_2$

Numbers 10 and 11, refer to leaf-positions of elongating leaves on the main stem at the time of feeding $^{14}CO_2$

Table 2. Increase in amount of protein and cell-wall constituents in upper leaves on main stem over a 6-day period following $^{14}CO_2$ feeding

Plot	Days after feeding				Difference between 2 and 8 days	
	2		8			
	Protein	Cell-wall constituents	Protein	Cell-wall constituents	Protein	Cell-wall constituents
	mg	mg	mg	mg	mg	mg
H/H	14.8	18.0	97.3	328.6	82.5	310.6
L/H	28.7	45.6	80.6	204.1	51.9	158.5
H/L	12.3	23.0	76.3	193.5	64.0	170.5
L/L	21.8	42.3	54.7	132.6	32.9	90.3

The elongating leaves on the main stem at the time of feeding $^{14}CO_2$ were at the 11th leaf-position in plots H/H and H/L, and the 10th in plots L/H and L/L, respectively.

protein synthesis in the upper leaves on the main stems as affected by the temperature at shoot-bases and/or roots, whole plants subjected to the long-term treatment were exposed to $^{14}CO_2$. Feeding was carried out for 20 min under sunlight 10 days after the commencement of temperature treatment and subsequently the elongating leaves on the main stems were successively harvested 2, 4 and 8 days after feeding, and ^{14}C incorporation into protein was measured. These leaves had nearly attained their full size and the fresh weight was almost unchanged during the 8 day experimental period. Therefore, protein-^{14}C based on fresh weight (cpm/g FW) seemed not only to represent its concentration but also to be parallel to the total amount in a single leaf-blade.

Worth while to note in the results represented in Fig. 6 is that the incorporation of fed ^{14}C into protein of the elongating leaves was rapid during the 2-day period following feeding but subsequently it showed abrupt depressions in rice plants grown with their shoot-bases and/or roots cooled. It may be thus concluded that turnover rate of protein is higher when the shoot-bases or roots, especially the former, is cooled. On the contrary, newly fed ^{14}C was incorporated into the leaf protein at a slower rate initially and at the increasing rate thereafter when temperature of either shoot-bases or roots, particularly of the former, was kept favorable for rice growth.

Rice plants subjected to the long-term temperature treatment, as in this study, seem to have varied metabolic systems according to the organ treated and the degree of the treatment.

By considering all these observations, it is suggested that when shoot-bases or roots are kept under favorable thermal conditions a considerable amount of previously assimilated carbon might be in available forms for protein synthesis in the elongating leaves at the time of feeding with $^{14}CO_2$. Only a little proportion of newly fed ^{14}C might be incorporated into protein during the initial period following feeding. Moreover, it seems likely that the incorporation pattern of fed ^{14}C into protein of the elongating leaves observed 8 days after feeding is associated with neither fresh weight nor protein content of the leaves, but with the rate of leaf production on the main stems or the growth rate of the whole plant illustrated in Table 1.

Increased amounts of protein and cell-wall constituents in the upper leaves on the main stems over a 6-day period following feeding are given in Table 2. Upper leaves, which included a newly developed leaf, shoot apices and leaf buds, showed a great accumulation when shoot-bases or roots were kept under favorable thermal conditions.

Consequently the incorporation pattern of assimilated carbon into protein of the elongating leaves was closely associated with the synthetic rate of both protein and cell-wall constituents in the upper young leaves and hence growth rate of individual whole plants as affected by shoot-base and/or root temperature.

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