Studies on the Physiology of Crop Plants in Response to the Effect of High Temperature

I. Effect of high temperature on growth and respiration of crop plants*.

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It has long been observed that high temperature gives striking influence on growth of plants and yield of crops. In our country this problem has been posed in particular in relation to what has been known as "akiochi", which literally means autumn decline of lowland rice, and growth retardation of forage crops described as "natsugare", which literally means summer withering.

However, any close physiological and biochemical studies have scarcely been attempted on this serious problem. In the paper of this series, the author tried to approach the problem through investigations on respiratory metabolism of crop plants as affected by high temperature.

METHODS AND RESULTS

Experiment I. Growth of Italian ryegrass in summer season and its variation as influenced by soil temperature.

Methods: Italian ryegrass was sown in Wagner pots of 1/2,000 are in size on April 1st and July 10th respectively. In both cases three pots were used, and 7.5 g of ammonium sulfate, the same amount of super phosphate and 3.0 g of potassium sulfate were applied per pot as basic dressing.

On the one hand, it was also sown on July 10th in the same manner as mentioned above. In this case six pots were used and half of them were cooled by running water in order to lower soil temperature. The rest of them were laid aside without any particular treatments as the control.

Results: The plants sown on April 1st showed a quite normal growth, tillering and elongating vigorously. On the other hand, the growth of plants sown on July 10th showed such a distinctive feature as that the elongation of the plants which had extremely few tillers, being less than half of one sown on April 1st, was completely arrested in the first half of August. (fig. 1) Because the first half of August is the hottest season of the year, this stagnation in growth would be brought about by the effect of high temperature which might be unfavorable to the

Fig. 1. Growth of Italian ryegrass sown at different dates.

Note: -○-○- sown on April 1st,
-●-●- sown on July 10th.

physiological functions of the plants.

Again, the plants, which were sown on July 10th and grown on the pots cooled by running water, attained more vigorous growth in both elongation and tillering as compared to the control which was given no particular treatments. (table 1) In this case, the maximum soil temperatures in the treated pots and control ones were about 26°C and 36°C respectively. (table 2) This may suggest that roots are rather more sensitive to high temperature than tops are.

* Received for publication, Jan. 11, 1965.

Experiment II. Effect of high temperature on the respiration of Italian ryegrass, orchard grass, timothy and rice plant.

Methods: The plants were grown in green house on Wagner pots of 1/5,000 are in size by soil or water culture.

Two kinds of experiment were conducted. In the first experiment, the plant material was exposed to the successively rising temperature and the respiratory rate at the given temperature levels was determined successively by the use of Warburg's manometer.

In the second experiment, the plants grown on pots were placed in the incubator of different temperatures for a night, about 16 hours, just prior to the determination of respiratory rate. Determination of respiratory rate was carried out manometrically by Warburg's apparatus at a constant temperature, 25°C, with all materials. Thus, the effect of pretreatment with different temperatures on respiratory rate was examined.

Results: Fig. 2 shows the relationships between temperature and the respiration of leaves. The respiration in leaves of rice plant was increased with increasing temperature up to at least 44°C, the highest temperature used in the experiment. On the other hand, the rate of increase in respiration of Italian ryegrass, orchard grass and timothy leaves declined at the temperatures above 38°C.

Furthermore, it was recognized that the physiological activity of leaves as expressed in respiratory rate was declined by the pretreatment of rather low temperature. (table. 3) In case of orchard grass, for example, there was a marked disparity between the activities of the leaves treated at 20°C and 28°C.

high temperature.

Methods: Intact rice roots grown on Wagner pots of 1/5,000 are in size by water culture were treated by submerging them for a night in the water of 30°C and 36°C respectively. Immediately after the treatment, their-respiration was determined at 30°C in the presence or absence of glucose at the concentration of 0.075 M.

On the one hand, intact oat plants grown on Wagner pots of 1/5,000 are in size by soil culture

Fig. 2. Effect of temperature on the leaf respiration of rice plant, Italian ryegrass, orchard grass, and timothy.

Note: -□-□- rice plant, -○-○- Italian ryegrass, -●-●- orchard grass, -⊙-⊙- timothy.

Table 1. Effect of soil temperature on the growth of Italian ryegrass

Soil temperature treatment	August 5 th		August 15 th	
	Height of plant cm	Number of tillers*	Height of plant cm	Number of tillers*
high	22.0	3.8	37.0	11.3
low	27.5	4.8	43.0	15.0

* Averaged per plant.

In the meantime, the root respiration seemed to respond more sensitively to high temperature rather than tops did. (fig. 3) The rate of increase in respiration at rising temperature was really diminished at the temperatures above 26°C with orchard grass and timothy. And even with rice root, it was also diminished at the temperatures above 32°C.

Experiment III. Effect of carbohydrate and lipophilic agent on the respiration affected by

Table 2. Maximum soil temperature

Soil temperature treatment	August 2 nd	August 5 th	August 13 th
	°C	°C	°C
high	34.5	36.0	33.5
low	26.0	25.0	24.0

Note: Temperatures at the vicinity of 5 cm beneath the soil surface.

Fig. 3. Effect of temperature on the root respiration of rice plant, Italian ryegrass, and orchard grass.

Note: $\square$ — $\square$ — rice plant, $\circ$ — $\circ$ — Italian ryegrass, $\bullet$ — $\bullet$ — orchard grass.

were subjected to temperature pretreatments at 36°C and 20°C respectively by the same method as in experiment II. Following the temperature pretreatments, the detached leaves were placed in sealed bell jars for 20 minutes together with or without chloroform contained in small Petri dishes. After that their respiration was determined at 30°C.

Results: It is shown in fig. 4 that the high temperature pretreatment lowered the respiratory activity of roots, and that the addition of glucose could not virtually recover the declined activity. This would be interpreted as that the decline of respiratory activity did not merely result from the exhaustion of respiratory substrate.

In understanding the physiological significance of high temperature effect the fact that the respiration of oat leaves responded differently to the chloroform treatment depending upon the difference in temperature pretreatment should be noticed. As shown in table 4, the respiration of the leaves pretreated at 36°C was evidently stimu-

Table 3. Effect of temperature pretreatment on respiration of leaves of Italian ryegrass and orchard grass.

Temperature of pretreatment	O ₂ uptake at 25°C, ml/d. w./hr.	
	Italian ryegrass	Orchard grass
20°C	1.50	2.00
28°C	1.43	1.54
36°C	1.26	1.18

Fig. 4. Effect of glucose addition on the respiration of rice roots pretreated by high temperature.

Note: high temp. treat-

ment (36°C)..... { glucose addn. $\circ$ — $\circ$ —
none $\bullet$ — $\bullet$ —
control (30°C)..... { glucose addn. $\square$ — $\square$ —
none $\blacksquare$ — $\blacksquare$ —

lated by chloroform treatment in contrast to the respiration of the leaves pretreated at 20°C which was markedly retarded by chloroform treatment. In the light of the lipophilic nature of chloroform, it is conceivable that high temperature might exert an influence on the cellular lipid component which may be playing an important role in regulating the physico-chemical properties of protoplasm.

DISCUSSION

It seems to be noteworthy that the temperature pretreatment at 28°C actually retarded the respiratory activity of orchard grass leaves. It is generally known that protein undergoes heat coagulation or denaturation under the temperatures higher than 50°C. In this connection, Aratani¹⁾ who investigated the characteristics of heat denaturation of protein making use of sulfhydryl radical reaction of protein as an indicator of denaturation carried out heat treatment of egg albumin at 65°C and determined its sulfhydryl reactions under the treated and room temperatures respectively. Thus he observed that the changes by heat of sulfhydryl reactions in egg albumin were completely restored by cooling, and presumed that changes in configurations in the structure of protein molecule were reversible to a

Table 4. Effect of chloroform application on respiration of oat leaves pretreated with the temperature of 36°C and 20°C.

Temperature and chloroform pretreatment	O ₂ uptake at 30°C ml/d. w./hr.	Percentage of no chloroform treatment
36°C {chloroform	1.55	125
{none	1.24	100
20°C {chloroform	1.81	75
{none	2.43	100

certain extent.

It is further known that protoplasm undergoes heat coaguration under considerably low temperatures, often at 30°C, at which protoplasmic lipid is apt to suffer from injurious effect of the temperature²⁾. In fact, the results of experiment III could be taken as indication that there were some interrelations between the cellular lipids and the effect of high temperature on the respiratory activity.

In this sense, it will be essential to make further investigations on the cellular lipid component and its physiological functions to solve the high temperature problem.

SUMMARY

Studies were conducted on the changes in growth and in respiration of several species of winter crops and rice plant caused by high tem-

perature.

The roots were affected more sensitively by high temperature than tops. In case of roots of orchard grass and timothy, rate of respiratory increase due to rise of temperature was diminished above 26°C. In case of rice roots, it was declined above 32°C.

The decline in respiratory activities of rice roots caused by the pretreatment of 36°C was not restored by the addition of glucose as respiratory substrate. On the one hand, the respiration of oat leaves affected by the treatment of 36°C was enhanced by the addition of lipophilic reagent such as chloroform, though the respiration of the control leaves was inhibited by chloroform.

Discussion was made on the physiological mode of the changes in respiratory activity caused by high temperature.

ACKNOWLEDGMENT

The author wishes to express his deep appreciation to Dr. I. Baba, chief of the division of physiology and genetics, National Institute of Agricultural Sciences, for his cordial guidance and valuable advice.

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〔和 文 摘 要〕

作物に対する高温の影響に関する生理的研究

I. 作物の生育および呼吸に対する高温の影響

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作物の高温障害に関する基礎的研究として、牧草および水稻の生育および呼吸に対する高温の影響をしらべた。夏期高温時に播種したイタリアンライグラスの生育は地温を低下することにより、ある程度促進されるのがみとめられた。地上部と地下部の呼吸に対する温度の影響をしらべたところ、水稻葉身では実験範囲(20°C~44°C)の内では温度の上昇にしたがって呼吸も増加したが、イタリアンライグラス、オーチャードグラス、チモシーの葉身では 32°C 以上では温度上昇に対する呼吸増加率が低下した。一方根の呼吸は水稻では 32°C 以上で呼吸増加率が低下し、イタリアンライグラス、オーチャードグラスでは 26°C 以上で呼吸増加率が低下するのがみとめられ、地上部にくらべて根は高温障害に対して弱いようであった。つぎにこれら高温による呼吸活性の低下の原因を明らかにするため、呼吸基質としてのグルコース、あるいは原形質の主要な構成成分である脂質に作用すると考えられるクロロフォルムの影響と高温の影響との関係をしらべ、高温による呼吸活性の低下は、呼吸基質の消耗以外にも原因があることを推定した。