Submergence as a Control Measure for the Rice-Borer, *Chilo simplex* Butler.

By

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The efficiency of submergence as a control measure for the rice-borer, *Chilo simplex* Butler, had been tested at several prefectural agricultural experiment stations in Japan before the writer published the first report[1] of his studies on this method of control in 1920.

The writer believes that the results of his previous experiments have shown how submergence kills the rice-borer and what conditions are important in order that submergence is effective.

However, neither the experiments which were conducted by the writer nor those which were carried out by other entomologists can yet be considered to be conclusive as to the degree of the efficiency of submergence. The records in Table I will confirm this statement.

Table I.

Results of Some Experiments on Submergence.

Experiments	Duration of Submergence (Hours)	Percentage of Killing
at Kagawa Station	19.5	69
„ „ „	15	92
„ Mié „	24	33.3
„ „ „	48	40.0
„ Okayama „	16	45.5
by the writer	24	22.4
„ „ „	29	35.3
„ „ „	32	40.6

The record in Table I shows that there is a conspicuous variation in the

percentage of killing among the experiments, so that it is difficult to estimate the efficiency of submergence from these results. The writer, therefore, desired to determine the efficiency of submergence as a practical method of controlling the rice-borer, and the experiments were conducted in three seasons from 1923 to 1925. The results obtained are reported in the present paper.

Efficiency of Submergence.

It was shown by the previous experiments that the temperature of water in the rice-field plays an important rôle in killing the rice-borer when the rice-field is submerged. Accordingly, the experiments were carried out on a fine and warm day. Sometimes it happened that the weather changed cloudy or windy in course of experiment and the temperature of the water in the rice-field did not rise sufficiently high.

Submergence was started early in the morning and the rice-field was left submerged for twenty-two to thirty hours. The water in the rice-field was kept at the depth of fifteen to eighteen centimeters during the submergence. This depth corresponds to the maximum amount of water that can be flooded in the rice-field of the Ōhara Institute, and the water almost reached the base of the highest blade of the rice-plant.

Two methods were used in submergence. The one is simply to flood the rice-field for a certain duration, and the other is to flood the field and at the same time to bend down the rice-plant at its base to the bottom of water so that the whole plant is kept under the water surface during the submergence. For the sake of convenience, the former is called *the first method* of submergence and the latter, *the second method.* It is expected that there must be difference in effectiveness between these two methods for various reasons, and they were tested as to the difference in efficiency.

According to the writer's experience there are a few dead rice-borers in the rice-stalk even before the rice-field is submerged. The percentage of these dead worms is usually not very uniform in different experimental plots. Thus, in a certain plot it was about three percent, while it was more than eleven in another. Therefore, it is necessary to know the percentage of the dead worms before submergence to make it the check on the result of experiment.

The rice-field which is to be submerged is divided into four sections by assuming two straight lines, the one dividing the rice-field in the middle transversely and the other longitudinally. Of these four small sections, two plots which are opposing diagonally were employed as check plots, and the other two sections as experimental plots.

The results of the experiments in 1923 to 1925 are shown in Table II.

Table II.

Submergence Experiments in 1923—1925.

The First Method of Submergence				The Second Method of Submergence				Year
Plot	Duration of Submergence	Percentage of Killing	Check (Per cent. Dead Worms)	Plot	Duration of Submergence	Percentage of Killing	Check (Per cent. Dead Worms)	
	Hours				Hours			
I	22	24.0	1.7	II	22	88.0	6.6	1923
VI	24	39.6	5.8	IV	24	87.8	10.0	
A—I	24	72.9	7.0	—	—	—	—	1924
A—II	24	70.1	5.4	—	—	—	—	
B—I	24	67.7	3.7	B—II	24	97.4	3.4	
C—I	30	71.4	8.4	C—II	30	98.8	11.1	
II	24	39.7	6.2	I	24	100	4.6	1925
IV	30	46.1	6.7	V	30	95.2	6.8	

Remark: 1) Most of the larvae were in the second or the third stage. But there were a few of the first or the fourth stage.

2) In plots I and II of 1923 the exact duration of submergence was unknown, since the water in the field was drained during the night. The total length of submergence on two days was about twenty-two hours.

3) In order to compare the efficiency of the two kinds of submergence, the results of experiments recorded in the same line should be considered.

Table III.

Temperature of the Water in the Rice-Field. (C°)

1923

Plot	Date	Time of Observation					
		A. M. 8:00	10:00	12:00	P. M. 2:00	4:00	6:00
I	July 19	27.6°	30.5	33.1	35.0	34.6	—
I	July 20	27.2	31.4	35.6	37.2	36.3	34.6
II	July 19	26.5	29.7	33.1	35.5	34.7	—
II	July 20	26.1	30.8	35.5	38.2	37.1	35.4
IV	July 24	25.6	30.2	31.6	34.8	33.6	32.4
VI	July 28	27.5	31.3	34.8	37.4	36.7	34.3

1925 (1)

Plot	Date	Time of Observation					
		A. M. 6:00	8:00	10:00	12:00	P. M. 3:00	5:00
I	July 23	23.6	23.6	27.6	30.7	32.1	30.6
II	July 23	23.6	23.6	27.6	30.7	32.1	30.6

1925 (2)

Plot	Date	Time of Observation							
		A. M. 8:30	10:00	11:00	12:00	P. M. 1:30	2:00	3:20	5:00
IV	Aug. 1	27.1	29.1	30.6	32.7	34.2	34.8	35.1	33.6
V	Aug. 1	27.6	29.2	30.8	32.6	34.1	35.0	35.3	33.7

The maximum temperature of the water flooded in the rice-field did not exceed 38.2°C in any of the experiments in 1923 to 1925. The percentage of larvae killed by the submergence of 24 to 30 hours was from 34 to 39 per cent. after subtracting the percentage of dead worms before submergence. These results agree fairly well with those of the field experiments in 1916 and 1918.

The percentage of killing, obtained in 1924, was markedly higher than those obtained in the other two years, 1923 and 1925. The writer thinks that this better result in 1924 was due to the higher temperature of the water in the rice-field, although the observation of water temperature was not made in the experiment of 1924.

In the first paper on the submergence, the writer stated that the temperature of water in the field is one of the most important factors which govern the efficacy of submergence. In fact it was shown by the experiment that a submergence of only five hours kills 100 per cent. of the larvae when the temperature of water was kept at 40°C. In the field experiment, it has often been observed that the temperature of the water rose to 40°C or a little higher, and that this temperature was maintained for three or four hours on a very fine and warm day.

Taking these facts into consideration, there is no doubt that the excellent result obtained in 1924 was due to the high temperature of the water in the rice-field.

The water in plots I and II in the experiment of 1923 was drained in the evening by an accidence. The plots were again flooded in the next morning. Thus, the total duration of submergence on the two consecutive days was about 22 hours. The killing obtained in plot I by the first method was about 22 per cent. only. This result shows that the efficacy of so-called "*intermit-*

tent submergence" is rather small, and at the same time, that suffocation plays an important rôle in killing the rice-borer by submergence.

By comparing the results obtained by the first method of submergence with those of the second method, it is at once apparent that the efficacy of the second method is much greater than the first. For example, about 65 per cent. at the best was killed with the first method, while at least 77 to 78 per cent., sometimes 100 per cent. was killed with the second method.

There seems to be various causes that make the second method of submergence much more efficacious than the first method. In a previous paper the writer pointed out that a part of the rice-borers which are boring in the stalks bore out of the stalks when the rice-field is submerged, and that they escape from the effect of submergence by crawling up the blade or sometimes by boring up through the mid-rib of the blade and reaching above the water surface in the case where the first method of submergence is used. When the second method is employed, the rice-borers can not escape from the water in the manner just mentioned and succumb under the effect of suffocation within a short time. This must be an important condition which makes the latter method more effective than the former.

Some of the larvae that bore out of the stalk would be attacked by the predatory enemies such as the frog, the spider, the larva of the diving-beetle etc., while they are wandering on the blade or swimming on the water. In the submergence of the second kind, the rice-borers can not find either the stalk or the blade which is above the water surface, even if they escape from the rice-stalk which is in the water. Therefore, most of them would be destroyed by the predatory enemies. For this reason, some investigators maintain the view that this predatory act of the enemies is the essential factor that makes submergence effective.

The writer however found that there were still very many rice-borers in the stalk even after submergence, and that a high percentage, from 80 to 100 per cent. of them were dead. This fact seems to show that suffocation and the high temperature of the water in the rice-field are much more important than the predatory act of the enemies in killing the rice-borer by submergence.

From the results of the experiments in 1917 to 1919 and also from those obtained in 1923 to 1925 the following conclusions can be drawn :—

1. The first method of submergence of 24 hours kills 30 to 40 per cent. of the rice-borers when the maximum temperature of the water in the rice-field is about 35°C.

2. If the duration of submergence is increased to 30 to 32 hours, over 40 per cent. of the borers can be killed.

3. When the maximum temperature of water reaches 41°C or over, about 70 per cent. can be killed by the submergence of 32 hours.

4. The submergence of 30 to 32 hours kills about 20 per cent. only, if the maximum temperature of the water is 32° or 33°C.

5. By the second method of submergence over 80 per cent. can be killed, if it is satisfactorily carried out.

Injurious Effect of Submergence on the Rice-Plant.

Although it is apparent, from what has been stated above, that the submergence is effective in killing the rice-borer, there is a question which should be answered before this method of control is employed for the practical purpose. The question is, "*Is there any injurious effect of the submergence on the rice-plant?*"

It often happens in Japan that the rice-field is flooded as a result of a heavy rainfall in a short period or of a continued rainfall for several days, and that the rice-plants are submerged in a muddy water for several days. It is generally accepted that the rice-plant would be affected to some extent under such conditions. In spite of this circumstance existing in Japan, there seems to have been very few experiments conducted to determine the extent of injury done on the rice-plant by a submergence of one or two days.

The only report which was available to the writer was that[2] published by the Mié Agricultural Experiment Station where the experiment was conducted in a rather small scale. The average of the results of experiments for six years showed that the decrease in the yield of the unhulled rice was about four per cent. when the rice-plant was submerged for twenty-four hours in the case where the tip of the blade of the rice-plant was about ten centimeters above the water surface, and that the yield decreased was about 13.3 per cent. when the rice-plant was completely immersed in water. To ascertain the results of their experiments the writer conducted the following experiments.

Determination of the yield in the experimental plots was made for two-fold purposes, i. e., first, to know the extent of injury, and second, to compare two methods of submergence in regard to their damages on the rice-plant.

The results of the experiment are shown in Table IV.

Table IV.

The Yield of the Unhulled Rice in the Plots Submerged.

Year	The First Method of Submergence		The Second Method of Submergence		Check Plot (No Submergence)
	24 hours	30 hours	24 hours	30 hours	
	Kan *	Kan	Kan	Kan	Kan
1923	22.140	19.660	19.700	18.500	—
1924	18.240	19.431	16.240	17.992	19.140
	—	—	—	—	19.239
Average	20.190	19.545	17.970	18.246	19.189

* One *kan* = 3.75 kilograms.

The number of experiments made by the writer is limited so that definite conclusion can not be drawn from the results. However, it can be safely stated, considering the results obtained by the writer and those by the Mié Agricultural Experiment Station, that the first method of submergence of 24 to 30 hours hardly affect the yield of rice.

The results obtained by the writer by the second method of submergence may be considered to correspond to the experiment of the Mié Agricultural Experiment Station, in which the rice-plant was completely immersed in water.

According to the result obtained by the writer, the second kind of submergence of 24 hours decreased about 6 per cent. of the yield. Judging from the result obtained by the Mié Agricultural Experiment Station and that of the writer, we may conclude that the yield is diminished by 6 to 13 per cent. by a submergence of 24 hours when the rice-plant is completely in water.

The rice-plant attains a considerable height by the twentieth or the twenty-fifth of July when submergence is to be carried out. If we bend the rice-stalk completely in the water at this time, the stalk and the blade are injured to some extent. In addition to this mechanical injury due to bending, some of the blades are injured on account of the high temperature if the temperature of water rises to 35°C or over, and this injury can be easily observed when the water is drained off. Therefore, it is expected, without the determination of the yield, that the second method of submergence would diminish the yield to some extent.

Conclusion.

Various factors such as the weather, the depth and the temperature of the flooded water etc. affect the efficacy of submergence, so that it is not possible to draw a conclusion which is valid in every case regarding the effectiveness of submergence. However, it is apparent that submergence is fairly effective in combatting the rice-borer, *Chilo simplex* Butler, under the conditions prevailing in Okayama Prefecture.

If this method is satisfactorily carried out towards the middle or the end of July, it is possible to kill 50 to 60 per cent. by a submergence of 24 hours. 80 to 90 per cent. can be killed if the rice-field is submerged and at the same time the rice-plants are bent down and brought completely under the water surface.

An important question which demands consideration is, "*What is the increase in the yield when this method of control is employed in the rice-field?*".

Suppose that a plot in the rice-field is left unsubmerged as a check for the experimental plot, and that 60 to 70 per cent. of the first brood larvae are killed by submerging the experimental plot. If there were only one generation of the rice-borer, there would be an increase in yield corresponding to the

percentage of larvae killed. As a matter of fact the rice-borer, *Chilo simplex* Butler, appears twice a year, and the moths which appear from the surviving larvae of the first brood lay their eggs in the experimental plot as well as in the check. Thus, the increase in the yield in the experimental plot, which would have been obtained by submergence at the time of the first generation, is decreased by the second brood of the rice-borer. Moreover submergence of long duration is a little injurious to the rice-plant and slightly diminishes the yield. Therefore, it is quite a difficult matter to determine, by the field experiment, the true benefit of submergence.

However, it can not be argued that it is advisable to employ the first method of submergence when there is an abundant appearance of the rice-borer and the injury is expected to be fairly great, as the submergence of 24 hours exerts very slight injurious effect on the yield of rice and kills about 50 per cent. of the rice-borer.

The second method of submergence may be employed only in such a serious outbreak of the rice-borer that more than 50 or 60 per cent. of the rice-plant in the field would be killed if no control measure is taken. Even in such a case it is doubtful if this method is more profitable than cutting off the injured rice-stalks, since the second method of submergence requires a considerable labour in carrying it out.

Literature Cited.

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