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The impact of yellow stem-borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae), on deepwater rice, with special reference to Bangladesh

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Abstract

Using several methods, claims that stem-borers, especially *Scirpophaga incertulas* (Walker), cause serious crop loss in deepwater rice were tested in Bangladesh. Insecticides were used to control different borer broods. Early season, pre-flood applications reduced infestation, but did not affect yield. One to three mid- to late-season applications of monocrotophos at 250 g a.i./ha significantly reduced infestation and/or whitehead numbers, with yield savings (7–10%) similar to those which earlier workers obtained by applying diazinon 20 times in a season. In each of six years, tiller populations peaked before flooding, then steadily declined until harvest, but stem-borer infestation varied, remaining low until late season in two of the years. In 1981, infestation lower than 24% pre-flood and 42% at harvest did not affect yield. In 1982, eighty-four correlation calculations showed no consistent significant effects of infestation (27–60%, C.V. 40%) on yield (25 000 stems were dissected). Anatomical studies of elongated stems revealed *S. incertulas* feeding neither causes significant structural damage nor seriously interrupts nutrient flow; also, the passage of a larva through a nodal septum is not detrimental. Irrespective of stem-borer attack, the submerged lower internodes commonly die, the fibrous remains anchor the upper stem, and nodal roots take over nutrient uptake. Studies of panicle-bearing stems (n = 838) showed that, even with 97% stem infestation, most yield loss results from infestation of the terminal internode and is manifested predominantly as whiteheads. In a specific study, 94% whiteheads (n = 205) were associated with terminal internode infestation, where larval feeding in the narrow stem had disrupted food conduction, so preventing grain-filling. The apparent tolerance of *S. incertulas* by deepwater rice varieties is consistent with their being a primitive group of cultivated rices.

Introduction

Jackson *et al.* (1982) noted that it was the so-called floating varieties of rice which have the capacity to elongate in response to the rising floodwaters and, thus, can be grown in "very deep water (2–5 m maximum depth)". The term 'deepwater rice' is used here in preference to 'floating rice' and includes all of the many varieties of rice which can be grown where natural flooding of the fields is between 1 and 5 m in depth. A useful general

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review of rice, which contains comparative information on deepwater rice and definitions of the morphological and other terminology, is that of De Datta (1981).

Research on deepwater rice in Bangladesh, then East Bengal, started at Dhaka (Dacca) in 1917, and a specific deepwater rice research station opened at Habiganj in 1934 (Bangladesh Rice Research Institute, 1974). The status of insect pests was not reviewed until the first International Seminar on Deepwater Rice in 1974 (Alam, 1975). At that seminar, a call was made for an immediate systematic survey of pests, to be accompanied by careful crop loss assessment studies. The first specific project to undertake such studies was initiated, in 1977, jointly by the Bangladesh Rice Research Institute (BRRI) and the UK Overseas Development Administration (ODA).

Catling & Islam (1979) surveyed the incidence of the yellow stem-borer, *Scirpophaga incertulas* (Walker), and assessed the proportion of rice stems which it infested through the season. Although dissection of the stems gave figures of up to 47% infestation, direct and irreversible losses of grain as shown by whiteheads (unfilled panicles) were evaluated as a mean of 4·4%, with a maximum of 17·5%. The authors, however, believed "it unlikely that large numbers of badly damaged stems, parts of which commonly decay beneath the water surface, do not reduce the yield". That belief has persisted, with the most recent such assertion being by Catling *et al.* (1987).

A review of the Bangladesh project questioned "the true host-plant relationship leading to yield loss" (H. F. van Emden, S. M. H. Zaman, D. Hocking, A. Hocking & A. Davis. UK-Bangladesh Deep Water Rice Pest Management Project, Report of the Mid-term Review Mission. Unpublished report to ODA, 1979), however, and this gave rise to the studies reported principally in this paper. Initial results of pre-flood trials of a range of insecticides in 1981 coupled with a review of all earlier project results led Taylor *et al.* (1982) to suggest that when *S. incertulas* infests the elongated deepwater rice plant it may achieve a near perfect parasite-host relationship. This implied that the mid-season infestation of elongating stems might not be a serious direct cause of crop loss and, if correct, it could explain why whiteheads seen at harvest often occur on less than 20% of infested stems.

In the present paper, a fuller report is given on the evaluation of insecticides to reduce crop loss in 1981, the results of insecticide trials in 1982 and the results of studies in both years of the actual effect of the infestation of deepwater rice stems by stem-borers, mainly *S. incertulas*. Some of the findings have been briefly reported (Taylor, 1984; Taylor & Islam, 1984), but major changes during editing mean that these reports are inaccurate.

Methods and results

General

Assessment of infestation by stem-borers followed the practice of stem dissection adopted by Catling & Islam (1979). Stem samples were split longitudinally and examined for larvae, pupae and evidence of infestation (frass, exit holes, feeding damage and pupal skins). For some studies, the position of each infestation was recorded by noting the internodes affected, counting downwards from the topmost, or terminal, internode. In the early season, deadhearts and, at harvest, whiteheads, were recorded.

Unless definitively stated, results based on using the rapid, quantitative method of stem dissection indicate infestation by stem-borers without denoting the species involved. Intensive surveys, such as Catling & Islam (1979), confirmed by work reported below, however, have shown that it is only at the beginning and the end of the season, when the fields are not flooded, that species other than *S. incertulas* are present in observable numbers. Thus, in the text and tables, the use of the term stem-borers can be taken as primarily indicating *S. incertulas* infestation.

Panicle weights, for use in calculating yield data, were determined by weighing all filled, healthy grains and standardizing for a 14% moisture content.

General observations of stem-borer incidence

1981.—Field trials carried out at four widely separated sites by the project agronomist were assessed to determine borer infestation before flooding and at harvest. The results obtained for 7 of the 20 varieties evaluated in a trial at Daudkandi on the Meghna floodplain are shown in Table I. At this site, pre-flood infestation levels ranged from 0 to 32% but, in general, the numbers of deadhearts and infested stems in the fertilized plots were double those in the unfertilized plots. At harvest, there were no great or consistent differences in stem infestations, which ranged from 24 to 73% between the fertilized and unfertilized areas. The overall findings were that pre-flood infestation levels below 24% appeared not to affect yield, and the same was true of infestation levels below 42% detected at harvest. At one site, near Narshingdi on the Meghna floodplain, major yield losses were complained of by farmers. A crop-cut from one farmer's field showed 83% infestation, and in two trial plots infestation levels were 64 and 80% in harvested stems.

TABLE I. *Results of a deepwater rice varietal trial at Daudkandi, Bangladesh, in 1981*

Variety		No. of tillers $/m^2$ 27.iv	No. of tillers $/m^2$ 3.vi	No. of tillers $/m^2$ 29.vii	No. of panicles $/m^2$ 18–27.xi	Yield (t/ha)	Stem-borer infestation %	
							15.vi pre-flood	18–27.xi harvest
BR 224-2B-2-5	F	245	226	204	113	2·170	8	24
	UF	221	201	188	97	1·893	4	30
BR 311-B-5-4	F	169	237	166	89	2·050	16	32
	UF	288	161	191	61	1·456	12	38
Gilamite	F	238	231	182	126	2·164	16	73
	UF	253	218	149	67	1·304	8	39
DWCB-B-112-3-B	F	179	165	168	101	2·025	12	32
	UF	204	185	166	64	1·270	4	40
BR 232-2B-3-4/A	F	232	203	169	84	1·807	12	39
	UF	196	176	128	61	1·404	12	41
Habiganj A.II	F	159	170	114	99	1·920	20	36
	UF	190	183	107	65	1·236	4	36
Sada Pankaish	F	133	134	169	55	1·640	12	56
	UF	165	167	58	36	0·984	8	58

Unreplicated trial; plot size 6 × 7·2 m, split, with half fertilized (F) (55 kg/ha N, 34 kg/ha P_2O_5) and half unfertilized (UF), line sown on 6 April. Site flooded to 1·70 m by mid-July.
Stem-borer infestation determined by dissection of 25 stems/split plot.

1982.—Field trips to several areas of Bangladesh were made before flooding and between flowering and harvest. The pre-flood stem-borer activity was very low, with around 3% of stems infested. Although *S. incertulas* was predominant, *Chilo polychrysus* (Meyrick) and *Sesamia inferens* (Walker) also were found. After flowering, infestation had risen to 31%, but *Scirpophaga incertulas* was found almost exclusively. At harvest, an arbitrary threshold of 40% stems infested was exceeded in 27% of the fields sampled.

Evaluation of the use of insecticides

Pre-flood insecticide applications in 1981.—Eleven insecticides, supplied by their manufacturers, were tested in a replicated trial (three replicates), with an unsprayed control treatment. At Bastia, Manikganj, an area of 90 × 30 m within a field of the deepwater rice variety Digha, was divided into 36 plots, each 15 × 6 m. Four applications were made (13–14 May, 27–28 May, 10–11 June and 24–25 June), using a knapsack sprayer, at dose rates recommended by the manufacturers and a spray volume of 600 litres/ha. Thirty-five stem samples per plot were taken for dissection on four dates pre-flood (the last being on 1 July when there was 30 cm of water in the field) and at harvest. At harvest, on 12 November, three 1-m^2 crop-cuts were taken from each plot. From them, panicle numbers, panicle weights, grain weights and yield were measured. The results are presented in Table II.

A one-way analysis of variance showed no significant variation between treatments; in

TABLE II. *Results of an insecticide evaluation trial in deepwater rice, variety Digha, in a farmer's field at Bastia, Manikganj, Bangladesh, in 1981*

Insecticide	Dose rate[A] (g a.i./ha)	Stem-borer infestation (%) 22.v	4.vi	17.vi	1.vii	12.xi	No. of panicles /m²	Yield[B] (t/ha)
Formothion	336–560	11	8	10	5	22·9	194	3·899[a]
Dicrotophos	500–1000	8	2	3	4	17·1	177	3·370[ab]
Monocrotophos	250	6	3	5	1	18·1	179	3·249[abc]
Control	0	19	11	6	9	24·8	156	3·154[abc]
Fenvalerate	100–200	5	4	6	3	26·7	151	2·921[abc]
Dicrotophos	300–500	13	13	4	3	15·2	143	2·892[abc]
Profenofos	500–750	9	2	7	2	22·9	142	2·779[abc]
Cypermethrin	50–100	11	7	6	5	23·8	117	2·729[abc]
Dimethoate	240	5	8	5	7	22·9	139	2·606[abc]
Quinalphos	250–375	5	1	1	0	30·5	131	2·506[bc]
Diazinon	1000–1500	8	2	9	2	18·1	141	2·446[bc]
Fenitrothion	300–1000	11	2	7	8	21·0	110	2·041[c]

All the results are means of three replicates.
[A] Dose rates were those recommended by the manufacturer; with lower rates on young plants.
[B] Means followed by a common letter are not significantly different at 5% level (Duncan's multiple range test).

part, this appeared to be due to soil heterogeneity. A two-way analysis of variance, performed after arranging the treatment data in blocks (viz, Block 1 with the highest values in each treatment, Block 2 with the median values and Block 3 with the lowest values) showed significant variations at the 1% level between blocks and between treatments. A Duncan's multiple range test showed that the fourth ranked treatment was the unsprayed control (Table II). Only formothion appeared to give a markedly better result in terms of yield than the other treatments, and three products, quinalphos, diazinon and fenitrothion, gave markedly poorer results. Assessment of the efficacy of the treatments according to the infestation by stem-borers did not prove meaningful.

Analysis of the data on panicle numbers per square metre (mean 148·4, s.d. ± 36·52, C.V. 24·65%), panicle weights (mean 2·72 g, s.d. ± 0·368, C.V. 13·50%) and grain yield (mean 288·3 g/m², s.d. ± 73·16, C.V. 25·37%) showed that there was no correlation between panicle numbers and panicle weights (r = 0·035), but there was a highly significant correlation (r = 0·93, P<0·01) between panicle numbers and grain yield.

Pre-flood insecticide application in 1982.—Plans were made to follow the 1981 work by incorporating a superimposed insecticide treatment in agronomic factorial trials at five geographically separated sites (Daudkandi, Comilla District; Dubail, Tangail District; Rajbari, Joydebpur, Dhaka District; Manikganj, Dhaka District; and Narshingdi, Dhaka District) representative of the major river floodplains. The timing and frequency of spraying would have been determined from a long-term stem-borer population monitoring study initiated at Dubail. The early season, however, was notable for an almost total absence of stem-borers. Stem samples taken from all 64 plots at each of the factorial trials in the period 21 June to 10 July, coinciding with the first build-up of floodwaters, revealed mean infestation rates of no more than 2·5% at four of the sites. At the fifth site, infestation was higher, 7·3%, but this was due primarily to *C. polychrysus*. In 1981, the comparable levels had shown a peak of infestation in May of 19%, with an associated deadheart level of 18%. Thus, there was no justification for any pre-flood applications of insecticide in 1982.

Insecticide application during flooded conditions.—When both the monitoring study and field surveys showed considerable increases in adult *S. incertulas* numbers in mid-August, it was decided that application of insecticide, as a means of increasing the mortality of egg masses and first-instar larvae (before they penetrated the rice stems), should be evaluated. Part of each of five farmers' fields at Dubail and three fields in the uncontrolled flooding area of the Dhaka-Narayanganj-Demra (DND) Project were sprayed during September and October. The spraying was done from a boat punted through the field. In most instances, a motorized mist-blower was used, but on one occasion a spray boom with spinning disc applicators (Herbi) (Catling *et al.*, 1980) was used. Both methods gave a spray swathe some 12 m wide. Monocrotophos (Azodrin 40 WSC) was applied at a dose rate of 250 g a.i./ha.

About one week before harvest was expected, panicle and whitehead densities were estimated in the sprayed and unsprayed areas of each field by making 20 counts of 1-m^2 quadrats in each area. Between 100 and 200 stems were sampled from each area and dissected.

The effect of insecticide application on borer infestation and on whitehead numbers is shown in Table III. Because there were two sites and four rice varieties, the data were not grouped for analysis, but the whitehead and infestation levels in the sprayed and unsprayed areas of each field were compared by *t* test. In six of the eight fields and for three of the four varieties, whitehead numbers were significantly higher in the unsprayed areas. There were significantly higher levels of infestation in the unsprayed areas of six of the eight fields. Only four of the fields had significant reductions in both infestation and whiteheads.

Yield estimation, by harvesting two 16-m^2 portions, was possible in only two of the fields. Both of these were at Dubail and both were of the variety Boron Bawalia. In Field 3 (Table III), the results were: yield from unsprayed area 1·756 t/ha, yield from sprayed area 1·894 t/ha, yield saved 0·138 t/ha or 7·3%. In Field 5, the results were: yield from unsprayed area 2·081 t/ha, yield from sprayed area 2·311 t/ha, yield saved 0·230 t/ha or 10.0%. These yield savings were of the same order as the reductions in whitehead numbers of 8·3% and 7·4%, respectively.

TABLE III. *Effect of monocrotophos insecticide on* Scirpophaga incertulas *infestation in deepwater rice in Bangladesh in 1982*

Field no.	Variety	Whitehead (%)		Infested stems (%)		Spraying method^A & application date		
		Unsprayed	Sprayed	Unsprayed	Sprayed	1	2	3
At Dubail								
1	Sonna Digha	8·64	8·59†	74·63	50·49**	S.7.ix	M.26.ix	—
2	Chamara	5·86	2·11**	58·00	28·19**	S.7.ix	M.26.ix	M.10.x
3	Boron Bawalia	10·79	2·44**	54·00	21·00**	M.7.ix	M.26.ix	M.10.x
4	Sonna Digha	8·17	6·13†	48·00	33·33*	M.7.ix	M.26.ix	—
5	Boron Bawalia	10·97	3·55**	63·00	38·00**	M.7.ix	M.26.ix	M.10.x
At DND Project								
6	Khama	10·26	4·69**	57·00	45·00†	M.9.ix	M.7.x	—
7	Khama	12·68	4·64**	52·80	32·00**	M.9.ix	—	—
8	Khama	11·80	6·35**	70·00	59·13†	M.9.ix	—	—

^A S. = spinning disc spray boom; M. = motorized mist-blower.
* significant at 5% level, ** significant at 1% level, † not significant (*t* test).

Evaluation of the effect of infestation by Scirpophaga incertulas *on deepwater rice panicles*

1981 studies.—A total of 100 deepwater rice plants was sampled at harvest from a farmer's field. Stems were dissected, and the position of any infestation was recorded. Grain sterility was assessed for each panicle, and panicle weights were determined. One or more nodal tillers were found on 33% of the plants. Five per cent. of the main stems were grossly damaged and rotten, each of them having been badly infested by borer larvae. Panicles on infested and uninfested main stems were similar in weight. A significant panicle weight difference occurred between basal (main stem) and nodal tillers. The relations between grain sterility, panicle weight or mean grain weight and the position of the infestation were examined, but none of the relationships was significant. The highest grain sterility or number of whiteheads or both were associated with infestation in the terminal internode. The data showed that infestation in the immediately lower internodes also caused some increase in grain sterility, but the low sample numbers precluded detailed determination of whether there was a straight line relationship or if the slope of the relationship changed abruptly between the terminal internode and the third internode.

1982 studies.—Data were obtained to evaluate the correlation, if any, between the extent of stem-borer infestation and crop yield in project agronomy trials. The five factorial trials (listed above) were assessed for infestation before flooding and at harvest. Other trials were assessed only at harvest. The sample size for each experimental plot was 25 stems, and a total of over 25 000 stems was dissected, requiring some 1250 man-hours of work.

In the factorial trials, the level of infestation before flooding (around 2·5%) was too low to warrant any calculation of the correlation coefficients for infestation and yield. The results obtained at harvest from each of the sites, are shown in Table IV. There were eight randomized complete blocks at each site. The correlation between yield and infestation was examined for both of the rice varieties at each site. In only one instance, for the variety Ejuli Digha at Dubail, was there a significant correlation between infestation and yield. This was positive, indicating that the higher infestation gave a higher yield.

Transplanted variety trials at three sites, Dubail, Rajbari and Narshingdi, with nine varieties and four replicates at each site, were sampled. The results are summarised in Table V. The mean infestations for the sites were 38·5, 36·2 and 36·0%, respectively. Only one variety, Gilamite, showed a significant correlation between the collective data for infestation and yield from all three sites, with a negative correlation ($r = -0{\cdot}69$, $t = 3{\cdot}018$, t at 5% level $= 2{\cdot}23$, d.f. $= 10$), indicating that a higher infestation gave a lower yield. Of the 27 correlations for the nine varieties at each of the three sites, nine correlations were reasonably strong but only two were significant; the variety Kartiksail at Dubail ($r = -1{\cdot}00$) and the variety BR 306-B-3-2 at Rajbari ($r = 0{\cdot}99$ at 5% level, $t = 4{\cdot}30$, d.f. $= 2$).

Four fertilizer response trials, laid down to evaluate a range of agronomic practices (fertilizer types, levels and timing, seed rates, seed treatments and mixed cropping) and using different varieties, were sampled. Forty correlation coefficients were calculated for yield: infestation (in the various treatments and site means); only two correlations were significant, both being positive.

The main constraints on the interpretation of the results from agronomy trials were first, that the yields were site- or field-dependent to a very high degree, and second, that there was very high variability in the levels of borer infestation (C.V. for mean infestation averaged around 40% in all the trials), but it was not feasible to sample more than 25 stems from each plot, that is less than 1% of the total.

Direct evaluation of the effect of borer infestation on grain filling

At harvest in 1982, all the deepwater rice plants were sampled from a 4-m^2 area at Dubail (variety Chamara) and from a 5-m^2 area at Daudkandi (variety Sada Pankaish). Individual records were made of stem dissection (borer infested or damaged internodes, numbering from the top downwards) and the amount of grain sterility (% grains unfilled) of the associated panicle. The results are given in Table VI.

The level of stem infestation in Chamara (90%) was much higher than in Sada Pankaish (37%). Grain sterility associated with infestation in the terminal internode, however, was similar in both varieties and was significantly higher than in panicles on uninfested stems in both cases. In Chamara, infestations below the terminal internode were not shown to have increased grain sterility. The situation in Sada Pankaish differed in that infestation in the third and fourth internodes was significantly associated with increased grain sterility but not with infestation in the second internode. Separate consideration of infested stems without whiteheads showed that, in Chamara, grain sterility was highest when the terminal internode was infested, but this was not significant, and in Sada Pankaish, the only significant increase in grain sterility was when infestation was in the fourth internode.

At Dubail in late September 1982, 205 rice stems each bearing a whitehead, were collected from either the variety Chamara or Boron Bawalia. In the laboratory, the stems

TABLE IV. *Yield and stem-borer data from multi-site factorial trials in Bangladesh in 1982*

	Fertilized^				Unfertilized				Overall means			
	Broadcast		Line sown		Broadcast		Line sown		Yield		Inf.	
Site & plot size Variety	Yield (t/ha)	Inf. (%)	Yield (t/ha)	Inf. (%)	Yield (t/ha)	Inf. (%)	Yield (t/ha)	Inf. (%)	(t/ha)	C.V.(%)	(%)	C.V.(%)
Daudkandi, 32 m²												
Sada Pankaish	1·44	23	1·56	26	1·90	39	1·23	23	1·53	18	28	53
Gilamite	1·53	31	1·15	27	1·56	25	1·01	32	1·31	21	29	46
Tangail, 32 m²												
Ejuli Digha	1·25	45	1·13	31	0·98	48	0·97	41	1·08	25	42	42
Kartiksail	0·98	32	1·02	31	0·93	41	0·76	33	0·92	22	34	48
Narshingdi, 27 m²												
Til Bazal	0·95	49	0·95	37	0·91	49	0·95	48	0·94	39	45	36
Sada Pankaish	0·90	42	0·84	49	0·78	47	1·09	59	0·90	38	52	46
Rajbari, 19 m²												
Habiganj Aman IV	2·67	30	2·42	27	2·38	27	2·38	32	2·46	16	29	44
Gilamite	2·66	26	2·65	28	2·16	18	1·63	34	2·28	25	27	42
Manikganj, 32 m²												
Kartiksail	3·05	50	2·84	58	3·17	52	2·39	45	2·86	12	51	10
Choto Bawalia	2·14	—	2·06	—	2·54	—	2·49	—	2·31	16	—	—

^ Fertilizer; 40 kg/ha N, 40 kg/ha P_2O_5, 30 kg/ha K_2O, top dressed before flooding.
Seed rate, line sown and broadcast = 92 kg/ha.
Inf. = infestation rate.
Layout: Eight randomized complete blocks at each site.
* Significant at 5% level ($t = 2{\cdot}169$, t at 5% level = 2·04, d.f. = 30).

were dissected to determine which internodes were infested and the number and species of borer larvae present. The results showed that borer infestation down to the sixth internode may be associated with whiteheads, but 94% of the whiteheads were associated with infestation in the terminal internode. *S. incertulas* was associated with 84% of the whiteheads, *Sesamia inferens* with 2% and *C. polychrysus* with 6%; mixed infestations accounted for the balance. In most of the other studies, larvae usually were present singly, but in this instance the majority of infestations were by two or more larvae. The highest

TABLE V. *Correlation between stem-borer infestation and yield of deepwater rice, multi-site varietal trials in Bangladesh in 1982*

Variety[A] (Site)		Replicate 1	2	3	4	C.V.(%)	Correlation coefficient, yield:inf.
Higher infestation: lower yield							
Gilamite	Inf. (%)	68	44	32	—	38·2	−0·86
(Tangail)	Yield (t/ha)	1·76	1·89	2·43	—	17·5	
Gilamite	Inf. (%)	48	36	32	24	28·6	−0·78
(Rajbari)	Yield (t/ha)	2·43	2·38	2·72	2·77	7·7	
Kartiksail	Inf. (%)	48	36	28	24	31·1	−1·00*
(Tangail)	Yield (t/ha)	2·10	2·38	2·60	2·69	10·8	
Sada Pankaish	Inf. (%)	64	44	36	16	49·7	−0·80
(Rajbari)	Yield (t/ha)	1·52	2·77	2·60	2·72	24·7	
BR 232-2B-3-4/A	Inf. (%)	40	40	32	20	28·6	−0·87
(Narshingdi)	Yield (t/ha)	1·36	1·86	1·92	2·38	22·2	
BR 308-B-2-3	Inf. (%)	72	52	20	16	66·8	−0·75
(Narshingdi)	Yield (t/ha)	0·73	0·42	0·68	1·36	50·0	
Higher infestation: higher yield							
BR 224-2B-2-5	Inf. (%)	32	32	28	16	28·0	+0·93
(Tangail)	Yield (t/ha)	3·08	2·77	2·96	1·95	18·9	
BR 306-B-3-2	Inf. (%)	52	32	24	—	40·1	+0·99*
(Rajbari)	Yield (t/ha)	2·87	2·54	2·47	—	8·1	
BR 306-B-3-2	Inf. (%)	56	48	16	—	52·9	+0·74
(Narshingdi)	Yield (t/ha)	1·85	2·07	1·65	—	11·3	

[A] Nine varieties and four randomized complete blocks at each of the three sites; infestation assessed from 25 stems per plot (100 stems/variety/site); 18 other correlations were calculated but were less extreme than those shown.
Inf. = Infestation rate.
* Significant at 5% level (t = 4·30, d.f. = 2).

TABLE VI. *Effect of stem-borer infestation on grain filling in deepwater rice in Bangladesh in 1982*

Highest infested internode	Variety Chamara: No. of stems	% Grain sterility	Whitehead nos.	Variety Sada Pankaish: No. of stems	% Grain sterility	Whitehead nos.
1	132	51·0**	30	21	55·7**	10
2	33	31·0†	0	6	20·1†	0
3	25	30·0†	0	6	29·5**	1
4	21	24·0†	0	14	39·6**	2
5	18	31·1†	1	171	16·1†	5
Uninfested	25	26·4	0	376	15·9	4

t test for comparison of mean sterility in sample and in uninfested stems; ** significant at 1% level; † not significant.

numbers of larvae found in multiple infestations were 23 of *Scirpophaga incertulas* and 47 of *Sesamia inferens*.

Anatomy of deepwater rice plants and the feeding of Scirpophaga incertulas *larvae*

A literature search showed that there was little published information on the anatomy of deepwater rice plants and no recorded study of the actual effect of feeding by *S. incertulas* larvae. So, in a series of simple experiments, the bases of some 200 elongated stems of the variety Chamara collected during September and October 1982 were immersed in a weak solution of aniline blue dye for 2–3 days. The stems then were dissected and/or sectioned to investigate the effect of feeding by stem-borer larvae. The vascular tissue of the stems was clearly stained blue. Photographs were taken of several examples and drawings made from these are shown in Figs 1 & 2.

Several instances were found of *S. incertulas* larvae actively feeding in the fourth and

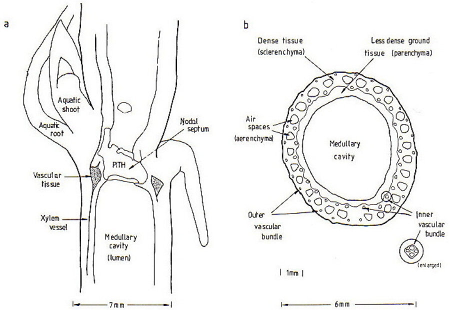

Fig. 1.—The internal structure of a basal tiller of an elongated deepwater rice plant, Bangladesh variety Chamara, drawn from life, vascular tissue being stained with aniline blue. (*a*) Longitudinal section of fifth node down from the stem apex; (*b*) transverse section of fourth internode down from the stem apex.

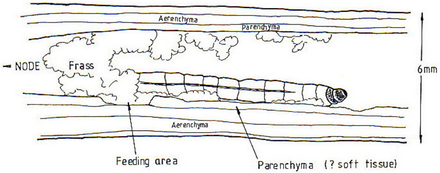

Fig. 2.—Simplified drawing of a dissected deepwater rice stem, Bangladesh variety Chamara, showing a third-instar larva of *Scirpophaga incertulas* and its feeding damage to parenchyma tissue at the fourth internode down from the stem apex.

fifth internodes down from the growing point, or apex, of the stem. In no case had this led to obvious interruption of the xylem flow to the apex, as in all instances the xylem tissues were stained above the feeding damage. Even when larval feeding occurred in the internode immediately below the terminal internode the flow to the upper xylem was not interrupted and the panicle appeared to be normal. Feeding in the internodes rarely was found to have penetrated as far into the parenchyma as the inner ring of vascular bundles. Even when this had occurred, disruption of conduction was limited to a few of the many bundles. In one instance, a live pupating larva was found with accompanying pronounced feeding damage to the inner ring of vascular bundles, but the outer ring remained intact, with its xylem flow uninterrupted.

At the nodes, the vascular tissue appeared to form a dense continuous ring connecting all the incoming bundles from the internode. The nodal septum was unstained and was made up solely of undifferentiated ground tissue with no vascular tissue. Passage of larvae through the nodal septum was not found to have affected disruption of conduction or to have led to obvious reduction in growth above the penetrated node.

Evidence of larval feeding earlier in the season was shown in several stems in which the lower part, at least one internode, had died. This particular variety normally shows profuse development of aquatic or nodal roots approximating to the height of the plant at maximum flooding. Larval feeding damage lower than these roots was not found to have affected the development of the upper plant. A schematic drawing of the mature plant and the positions of larval feeding is shown in Fig. 3. The stem at this stage would have been growing for some four to five months and the following evidence of infestation by four separate *S. incertulas* broods is indicated: in internodes 9 and 10, mainly exit holes in decayed stems; in internodes 5–7, relatively intact dead pupae and pupal skins; in internode 4, fourth- to sixth-instar larvae and pupae; and, in internodes 1–3, small, first- or second-instar larvae.

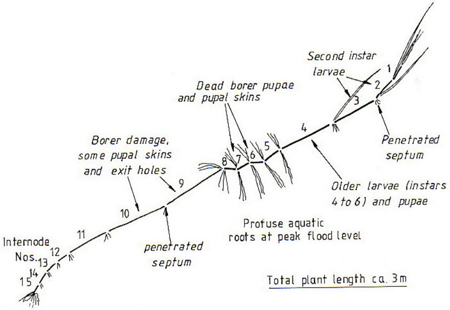

Fig. 3.—Stylized representation of a flowering elongated deepwater rice plant, Bangladesh variety Chamara, showing sites of infestation by successive broods of *Scirpophaga incertulas* in 1982.

In one or two instances, deadhearts were found. In these, the damage was due to small, first- or second-instar larvae which, after boring down between the flag leaf sheath and the stem, had entered just above the top node. The larval feeding had cut a ring right around the narrow apical stem, almost severing the stem. The result had been a total interruption of the vascular system and the apex had died. Later in the season, examination of many whiteheads showed just this near excision of the apical stem.

Discussion

The objectives of the above studies were to assess the actual crop loss attributable to *S. incertulas* and the potential for controlling this and other borer species. While crop loss could be observed directly as deadhearts and whiteheads (both denoting death of the apical internode, the latter term being used for unfilled panicles), the loss caused by the feeding activity of borer larvae in parts of the stem other than the terminal, panicle-bearing internode was not felt to have been properly resolved.

In 1979, Catling wrote "The yellow rice borer was consistently found to be a severe pest, especially in the stem elongation phase when very high levels of stem infestation were recorded. Larval feeding damages and destroys main stems and basal tillers which then stimulates compensatory branching. Notwithstanding this, stem density is lowered and much yield is lost" (H. D. Catling, Deepwater Rice Pest Management Project, mid-term technical report, Unpublished report to BRRI and ODA, 1979). After further experiments, he added that "There was some evidence that early borer attacks (in June and July) cause greater yield loss. In the pot experiments and the 1978 field experiment most yield loss was due to early attack, whereas in the two 1979 field experiments, where the loss was considerably less, the outbreaks occurred in August and September" (H. D. Catling, Deepwater rice in Bangladesh, final report of entomologist. Unpublished report to BRRI and ODA, 1981). Catling *et al.* (1982) and Catling & Islam (1982*a*) held to the basic precept that larval feeding causes 'damage' and as a consequence high numbers of larvae lead to considerable 'damage'. Catling & Islam (1982*b*) asserted that there is a damaged stems:yield loss ratio of about 1:1. This was modified by Catling *et al.* (1987), who claimed that, assuming a linear relationship, there is an approximate ratio of 1% yield loss from every 2% increment of stem damage in deepwater rice, and thus, in Bangladesh and Thailand, from the average rates of 38–44% damaged stems at maturity it follows that a yield loss >20% is common in many fields.

Use of insecticides

A major part of the evidence leading to the above claim stemmed from the results of field experiments in 1978 and 1979 in which attempts were made to secure an insect-free crop and so to determine crop loss. The use of insecticide treatment at regular intervals throughout the season, however, must have precluded the determination of when borer attacks had the most effect on the crop. Re-examination of the data by the present author showed that, at harvest in both years, some 75% of the infestations were at the top of the stems.

Population dynamics studies had shown that the *S. incertulas* populations in Bangladesh displayed the characteristic succession of distinct broods throughout the season (H. D. Catling, *op. cit.*, unpublished report, 1981; Torii, 1971). This offered a possibility for control by insecticide application at distinct points in time, and the 1981 study at Bastia, therefore, was designed to evaluate the effect of pre-flood use of insecticides. The last application of the series, on 24–25 June, was just before the first floodwater entered the fields. Although some reduction in infestation appeared to be achieved by use of certain insecticides, the yield data showed no related significant differences between treatments (Table II). The study, together with an experiment in a deepwater pond, facilitated the construction of a population model for *S. incertulas* (Taylor *et al.*, 1982). What emerged also was that, because there are successive broods, stem dissections over a period of time may show an apparent decline in the borer larval population, but this could be simply a consequence of the increasing tiller numbers so that there are more tillers but no more larvae.

In 1982, a repetition of the pre-flood application of insecticides was planned as a factor in multi-factorial trials at several sites. Light trap results and stem dissections both showed very low *S. incertulas* populations. The adult numbers crashed after a late April peak and almost no live larvae were found from mid-May to late July (Z. Islam & B. Taylor, *In*

Research work conducted by the ODA/BRRI Deepwater Rice Project. Unpublished report to the BRRI internal review meeting, 1983). High temperatures (up to 37·9°C) appeared to have been the main factor in this crash.

In mid-August, a considerable increase in *S. incertulas* moths in light traps gave the opportunity to study the impact of insecticide application on a specific borer brood. Not only were significant reductions in infestation and in whitehead numbers achieved (Table III) but also yield savings of some 8·6% in the variety Boron Bawalia. In two fields of the variety Khama, a significant reduction in whiteheads (around 7%) resulted from a single insecticide application. Of the four rice varieties treated, the variety Sonna Digha had no reduction in whiteheads although a significant reduction in stem infestation was recorded. A possible explanation is that this variety matured earlier and, thus, the panicle development was more advanced, making it susceptible earlier than the other varieties to damage to the terminal internode.

The level of yield saving in this trial, involving one to three applications of monocrotophos, was very similar to that achieved by the 1979 series of 20 applications of diazinon (H. D. Catling, *op. cit.*, unpublished report, 1981; Catling *et al.*, 1987). The yield saving in 1982, moreover, was of the same order as the reduction in whiteheads.

Effect of Scirpophaga incertulas *infestation on stem density*

Data on crop stand and borer infestation obtained in six consecutive seasons by the ODA-BRRI project in Bangladesh are given in Table VII (unpublished results from project records and project reports to BRRI annual review meetings). As can be seen, the drop in stem density (tillers/m^2) was of the same order in all six years, but in two of the years, 1979 and 1982, there were no great numbers of stem-borers until the late season. In 1982, moreover, weekly counts of tiller numbers showed that a decline set in before the onset of flooding and continued at an even rate right through to harvest.

TABLE VII. *Data on crop stand and stem-borer infestation in deepwater rice in Bangladesh in 1977–1982†*

Year	Pre-flood		Elongation		Harvest		Panicles as % of pre-flood tillers
	Tiller nos. /m^2	Stem-borer infestation (%)	Tiller nos. /m^2	Stem-borer infestation (%)	Panicle nos. /m^2	Stem-borer infestation (%)	
1977	196	5–10	149	31–40	103	54·0	52·6
1978	323	2–6	153	8–28	98	44·5	30·3
1979	213	0	130	2–15	110	31·7	51·6
1980	253	2–4	163	10–13	123	80·3	48·6
1981	192	7	142	17–28	64	43·3	33·3
1982	350	2	315	2·5	190	25·0	54·3

† The data are representative of the overall situation in each year and do not all come from one site or one deepwater rice variety.

Agronomic studies in Bangladesh have shown that neither use of differing seed rates (30, 50, 70 and 90 kg/ha) nor use of transplanting to achieve a known high initial plant stand have significant effects on final yield. In 1981 moreover, a very precise transplanted spacing trial was laid down to study the effect of seedling number per hill with a constant seedling population of 200/m^2. The results showed that despite a very high variation in early tiller populations (626/m^2 with a 10 × 10-cm spacing and 419/m^2 with a 20 × 20-cm spacing) the final panicle numbers were similar (234 and 208/m^2, respectively). The wider spacing had fewer panicles but, nevertheless, gave a higher yield due directly to higher panicle weights (P. Francis, *In* Research work conducted by the ODA/BRRI Deepwater Rice Pest Management Project. Unpublished reports to the BRRI Internal Review meetings, 1981 and 1982).

A wide range of agronomic studies at Habiganj Deepwater Research Station also have shown that high seed rates may give high early tiller populations and high panicle numbers but often do not give consistently higher yields. For instance, a seed rate of 134 kg/ha gave 404 tillers/m^2 (at 30 days after sowing) and 194 panicles/m^2 with yield of 2·44 t/ha, but a seed rate of 68 kg/ha gave 211 tillers/m^2 and 147 panicles/m^2 with a yield of 2·52 t/ha (Agronomy Division reports to BRRI internal deepwater rice seminar, unpublished, 1983).

Francis & Griffin (1982) ascribe the high seed rate (92 kg/ha) habitually used by Bangladesh deepwater rice farmers to be due to allowance for considerable loss of the rice plants during raking and hand weeding and for considerable mortality of tillers during flooding. Similar studies in Thailand (Sittiyos *et al.*, 1982) gave identical results.

This drop in tiller numbers is not unique to deepwater rice but is characteristic of all rice crops; for example, Tanaka (1976) shows a 50% drop in conventional rice tiller numbers. The factors which affect crop establishment and tiller numbers are so numerous and complex in their interaction that stand reduction should not be ascribed to any single factor. For instance, Hutchings (1983) reviewed natural thinning in plant populations and showed that plant density commonly declines with increasing size of individual plants.

Effects of feeding by Scirpophaga incertulas *larvae*

As an internal parasite, which enters the rice stem as a first-instar larva and does not leave until it emerges as an adult, *S. incertulas* depends for its survival on larvae not destroying the stem which they inhabit. The anatomical studies reported above show that in deepwater rice, except in seedlings and in the panicle-bearing internode, larval feeding does not cause significant structural damage or interruption to the flow of nutrients. The passage of a larva through the nodal septum also appears not to have any detrimental effect. This is because the septum is composed solely of pith, i.e. undifferentiated ground tissue; penetration cannot affect nutrient conduction and, the stem being cylindrical, it should not affect the structural strength of the node.

The exit hole bored prior to pupation by the last instar larva is a potential weak point, but it is small relative to the large stems characteristic of deepwater rice. Entry by bacterial or fungal rot organisms is conceivable, although the hole is sealed with silk. The large elongated stems are fibrous, and it is common for the lower submerged internodes to die without loss of the stem as a connection between the original soil roots and the upper stem. Deepwater rice varieties are characterized also by the development of nodal roots which assimilate nutrients from the water and thus counteract this death of the lower stem. In the open flooded fields, uprooting of deepwater rice plants is not uncommon, but it has been shown that yields may still be near that of non-uprooted plants (Alim & Zaman, 1958).

Larval feeding in young plants, with commensurately narrow tillers, can cause tiller death (deadhearts), but two natural factors reduce this problem in deepwater rice. First, dry sowing is the norm and the young plants usually get their moisture from residual soil moisture or sparse spring rainfall, whereas *S. incertulas* prefers wetland conditions and high humidity. Second, being the end of the dry season, *S. incertulas* adult populations are at the annual minimum.

In the mature crop, whiteheads, or unfilled dead panicles, are an obvious direct loss of yield. Again the borer larva is feeding in a narrow stem, and serious to total interruption of nutrient conduction is almost inevitable.

The above findings are contrary to the statements by Catling & Islam (1982*b*), but the apparent tolerance of *S. incertulas* by deepwater rice is consistent with the opinion that deepwater rice varieties form a primitive group of cultivated rices. Chowdhury & Zaman (1970) described this group as probably a direct descendant of the most prevalent wild rice species of Bangladesh, *Oryza sativa* var. *fatua*. The selection of paddy rice varieties with shorter, narrower stems could have led to inherently greater damage to vascular tissues by larval feeding and, thus, to the formation of deadhearts throughout the growth of the crop.

Correlation between infestation and yield

The evaluation of the correlation between infestation and yield in 1981, using data from agronomy trials (Table I, for example) suggested that pre-flood infestation levels below

24% and infestation levels from harvested stems below 42% had not affected yield. Detailed dissections of 100 panicle-bearing stems showed no difference in panicle weights on infested or uninfested stems. The highest grain sterility and most whiteheads were associated with infestation in the terminal, panicle-bearing internode.

This was followed up, in 1982, by sampling all the project trials, and some 25 000 stems were collected for dissection. Taken as a whole, with a range of mean infestation levels (27–60%) and variability in the levels of natural borer infestation (C.V. around 40%), the results showed no consistent correlation between stem infestation and yield (84 separate correlations were calculated, in some cases with *d.f.*>30). For instance, in the factorial and variety trials at four sites (Tables IV & V), only three correlations were significant. For the varieties Ejuli Digha and BR 306-B-3-2 they were positive, indicating higher infestation leading to higher yield, and for Kartiksail the correlation was negative, indicating higher infestation had reduced yield. Results for these three varieties from other sites showed no significant correlations. The combined data for the variety Gilamite, from three transplanted trials, showed a significant negative correlation. The previous year, Gilamite had been heavily infested (Table I) but the yield had been sustained by a compensatory production of high numbers of secondary, or nodal tillers which counterbalanced their lower individual panicle weights.

The two detailed studies of stems bearing panicles showed that it was primarily infestation of the terminal, panicle-bearing internode that led to loss in grain weight (Table VI). This was particularly marked in the variety Chamara where, despite an infestation level of 97% in the 254 stems dissected, no significant grain loss had occurred unless the terminal internode was infested. Dissection of 594 stems of Sada Pankaish (overall infestation 37%) showed infestation in the terminal, third and fourth internodes to affect grain filling. In both varieties, whiteheads associated with infestation in the terminal internode were the predominant cause of grain loss. In this study, the varieties were collected from widely separated locations but samples of Sada Pankaish from fields at the Chamara location showed 41% infestation. The difference may be that Chamara with thicker stems is more susceptible to borer attack but, to compensate, having thicker, tougher stems could enable it to better withstand larval feeding. Catling found in 1978 that thicker stemmed varieties had higher infestations but this was not true in 1979 (H. D. Catling, *op. cit.*, unpublished report, 1981).

Finally, the specific study of rice stems with whiteheads showed that, although borer infestation down to the sixth internode may be associated with whiteheads, 94% of the 205 whiteheads were associated with infestation in the terminal internode. In this study, the majority of infestations were by two or more larvae whereas in earlier findings larvae usually were present singly. Presumably, this was due to a late season population explosion as the highest numbers of larvae found in multiple infestations were 23 of *S. incertulas* and 47 of *Sesamia inferens*.

Recently published results from West Bengal, India (Datta *et al.*, 1985; Datta *et al.*, 1985), from Vietnam (Van Huynh *et al.*, 1986) and from Thailand (Catling *et al.*, 1987) showed the same pattern of whiteheads as the main source of crop loss. In Vietnam, about 5% whiteheads and 30–44% stem infestation were found in 1984 (data from 150 plants). In West Bengal, there was no yield when the terminal internode was infested and somewhat lower yield when the 2nd to 12th internodes (as a group) were infested (data from 20 plants per group); infestation in 1983 related to high borer incidence in late September and was restricted mostly to the top three internodes. In Thailand, when whiteheads were omitted, the mean panicle weights on infested stems were higher than in uninfested stems. Similar studies in Bangladesh in 1978 (unpublished ODA-BRRI project records) found no relationship between infestation and yield in samples from crop-cut surveys. A panicle weight assessment, with dissections of some 180–200 stems from each of four fields, showed that in three fields panicles from infested stems were lighter by 4·5–12·7%, but in the fourth field such panicles were heavier by 21·7%.

The results cited by Catling *et al.* (1987) from small-scale pot and cage experiments in Bangladesh do appear to suggest that stem infestation has an effect on yield, but careful examination of the original records by the present author showed that a different interpretation of the results is possible. For instance, the 1978 pot study with Habiganj Aman gave a yield reduction in the infested pots of 9·6 g/pot (36·7%). This could have been accounted for by the initial deadhearts in the infested pots, which at 4·3 per pot (each being direct loss of a primary panicle weighing 2·2 g), amounted to 9·5 g. This initial loss was offset by the development of secondary tillers, but these typically had lighter panicles. The subsequent 20% stem infestation may well have had no effect on the final yield. Also, in the small-scale experiments, the depth of water never exceeded 1 m, thus precluding the normal elongation of the plants which would occur under field conditions of water 2–3 m deep.

Conclusions

The evidence obtained does not support the concept that *Scirpophaga incertulas* larvae feeding in the massive stem lumens of elongated deepwater rice cause significant damage and consequently seriously affect crop yield. At this stage, *S. incertulas* probably approaches a near perfect parasite-host relationship in many deepwater rice varieties. The large hollow stems provide a safe stable environment for the larvae which can feed on the parenchyma tissue without damaging vascular tissue.

The peak tiller numbers in deepwater rice occur in late May to early June. A steady decline then commences with the final tiller and panicle numbers being around 50% of the peak numbers. This takes place irrespective of the numbers of *S. incertulas* larvae present.

Taking the combination of all the trials evaluated, detailed observations were made of 18 deepwater rice varieties and many others were examined in resistance studies and crop-cuts. The trials also encompassed three methods of crop establishment (broadcast dry seeding, line sowing and transplanting), variations in seed rate and spacing, several different forms, application rates and timings of fertilizer, and varying seed treatments. The four floodplains of Bangladesh have widely differing soil characteristics, largely due to major differences in the water quality and silt content of the rivers which flood over them. Thus, the crop environment is extremely complex, and consideration of any one crop factor in isolation of knowledge of the others is inadvisable.

The results of the evaluations of the possibility for reducing crop loss in deepwater rice due to *S. incertulas* by use of insecticides clearly indicate the importance of the mid- to late-season brood(s) of the insect. Although the logistic difficulties of insecticide application to the deepwater rice fields at peak flooding, when the water is up to 3 m or more deep, are considerable, they would not be insuperable. Selection of the insecticide would have to take into account the need to prevent loss of the fish populations.

The following general conclusions, although derived primarily from work in Bangladesh, would seem to be applicable to all the deepwater rice areas of South and South-East Asia.

(1) At the beginning of the season (April–May), deepwater rice can be regarded as being the same as dryland rice. Deadheart incidence will give a reasonable indication of stem-borer infestation and, if unusually severe, the loss of primary tillers could lead to crop loss. In Bangladesh at least, this is not a common problem.

(2) If there are substantial pre-monsoon rains and moderate temperatures in late May to early July, *S. incertulas* larvae will survive in sufficient numbers to give a noticeable second brood before the onset of flooding.

(3) The onset of flooding leads to rapid plant growth and then to stem elongation. A third brood of *S. incertulas*, or an extended second brood, may be observed during this period (mid-July to late August). At this time, *S. incertulas* may become numerous because of emergence from conventional summer wetland rice.

(4) Light-trap results in the peak flood period, from August to mid-September, can be expected to show a potential *S. incertulas* population explosion in deepwater rice. Spraying at this time could give a significant saving in yield of some 10% or more. The abundant larvae entering the maturing crop may well penetrate the terminal inter-

nodes, leading to the formation of whiteheads and total grain loss from the affected panicles. This is the major source of crop loss in deepwater rice due to *S. incertulas*.

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