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稻水象甲种群增长规律初探

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摘要：扣笼接虫观测稻水象甲不同接虫密度所产下代虫量。结果表明，稻水象甲种群增长具有明显密度依赖性，接虫密度 X 越大，代间增殖倍率 Y_2 越低。$X-Y_2$ 关系用 $Y_2=1/(0.836+0.421X)$ 的双曲线拟合良好。以水稻移栽后稻田成虫密度 N 为指标，越冬成虫存活率为 S_0，防治后成虫残存率为 S_1，则第 t 和 $t+1$ 年种群密度关系可表述为：$N_{t+1}=S_0S_1N_t/(0.0836+0.0421S_0S_1N_t)$。模型参数值稳定，拟合度好，模型描述的种群增长规律与稻水象甲侵入辽宁省以来种群增长的实际情况相吻合。用该模型预测辽宁省不同地区稻水象甲的发生趋势其准确率高，并可指导稻水象甲的综合防治。

关键词：稻水象甲；种群增长规律；害虫发生趋势预测；综合防治

Preliminary Researches on the Population Increasing Regulation of Rice Water Weevil *Lissorhoptrus oryzophilus* Kuschel

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Abstract: In China, rice water weevil (*Lissorhoptrus oryzophilus*) is a quarantine pest. which was first discovered in Dandong City, Liaoning Province in 1991. Then it was found in 5 cities of Liaoning Province in 1995. The wide occurrence and severe damage of it were spreading quickly in whole Liaoning Province. From 1995 to 1997, this study was carried out at Yiquan town, Donggang City, Liaoning Province where it occurred seriously.

The cage used in this study has a steel skeleton screen covering (1m×1m×1.5m in size and 25 holes/inch^2) that can prevent the adult pest from going in and out freely. The output population densities of pest were measured from different artificial input population densities. A black-box model used to analyze increasing population growth regulation is established. After rice transplanting, the experiment was carried out in paddy field. There were 20 hills of rice in a cage. Different population of the adult pest (collected on maize, not oviposited) was put in every cage and 4 repeat tests of different input densities were made from July when the new adults emerged to early October before rice cut. The adults were picked out from every cage at 3 days' interval and the number of produced adults was counted. Using one-variable analysis method, the relationship between input population density X and output population density Y_1 as well as input population density X and increasing times of population Y_2 could be analyzed. Using mathematical method of insect population increasing calculation, the pest population-increasing model can be built to analyze the tendency of pest population. At last, the controlling program of pest is made. In 1997～2000, the forecasting accuracy of the model was checked by the data that were got from the study of the pest in Liaoning Province.

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The result of the experiment proved that in the increasing of pest population there was remarkably density dependence. It showed that the higher the input population densities X the lower the population increasing times y_2. A hyperbolic line equation gives a good fit to X-Y_2 relation. The Process of experiment in different years was the same and the model was similar. In the model of X-Y_2 relation, N was the population density of adult on early of June in paddy field, S_0 was the survival rate of overwinter adult, S_1 was the survival rate of adult after spraying pesticide, and the preproduction of the survival adult was not affected by chemical control. Then the adult density of this year N_t and it of the next year N_{t+1} could by expressed by the following black-box model.

$$N_{t+1} = S_0S_1N_t/(0.0836 + 0.0421S_0S_1N_t)$$

Using this model for analysis, the pest density increasing from 0.0001 to 1 adult/hill needed only 5 years. Ths values from the model were identical with the observation in the paddy field in Liaoning Province. It could be seen that the rapid increasing population of pest could cause heavy yield loss. As for the current population density of pest in Liaoning Province, in order to check the population density increasing, the efficiency of chemical control should be over 90%. Using the data of observation from different areas in Liaoning Province one could predict the insect population of second year or the next three years in different areas. As contracted with the results of real occurrence in the paddy field, the rate of forecast accuracy could reach 80%. This model was also suited to make control decision. In order to ensure the larva density of the next generation below the economic threshold, the erriciency of chemical control should reach more than 81%. As the current controlling measures were considered, the efficiency of control by agricultural method could only reach 60%. For this reason, enhancing chemical control measures could reduce the yield loss caused by the pest, and a long term IPM strategy with continuing chemical control as chief method must be upheld in Liaoning Province.

Key words: *Lissorhoptrus oryzophilus*; population increasing regulation; forecast of the occurrence tendency of pest; IPM

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辽宁省于 1991 **年在丹东市首次检出稻水象甲** Rice Water Weevil(RWW) *Lissorhoptrus oryzophiluthe* *preproduction of the survival adult was not affected by chemical control. Then the adult density of this year* N_t *and it of the next year* N_{t+1} *could by expressed by the following black-box model.*

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辽宁省于 1991 年在丹东市首次检出稻水象甲 Rice Water Weevil(RWW) *Lissorhoptrus oryzophilu* 平来检验模型,该模型用于指导稻水象甲防治并检验其结果。

2 结果与分析

2.1 稻水象甲种群增长规律的分析

3*a* 罩笼接虫试验中,不同接虫密度后代成虫密度及代间增殖倍数如表 1。以接虫密度 X 为横座标,分别以后代成虫密度 Y_1 和代间增殖倍数 Y_2 为纵座标所获得的 $X\text{-}Y_1$ 和 $X\text{-}Y_2$ 关系的趋势图如图 1。结果表明,接虫密度越大,累计后代成虫所计算出的成虫密度随之增大;但代间增殖倍数却随之下降,从接虫密度为 0.25 头/丛的增殖倍数 14.5~16.9 降低至接虫密度为 8 头/丛的增殖倍数 2.5 左右。这说明,在稻水象甲种群增长过程中,存在着明显的密度制约作用。

表 1 罩笼条件下接入稻水象甲成虫所产下代成虫量(辽宁东港)

Table 1 RWW next generation population densities from different input population densities in cage condition (Donggang, Liaoning Province)

年度 Year	接虫密度 RWW input density (adults/hill)	各重复下代成虫累计量(头/笼) Amount of next generation adults per cage				新成虫密度 RWW output population density (adults/hill±se)	代间增殖倍率 Increasing times between generations (times±se)
		Ⅰ	Ⅱ	Ⅲ	Ⅳ		
1995	0.25	70	85	68	67	3.625±0.421	14.500±1.685
	0.5	128	105	141	92	5.825±1.105	11.650±2.210
	1	170	190	185	157	8.775±0.749	8.775±0.749
	1.5	145	179	165	220	8.863±1.587	5.908±1.059
	2	183	245	130	179	9.213±2.356	4.606±1.178
	4	310	250	340	287	14.438±1.899	3.709±0.475
	8	410	426	381	376	19.913±1.191	2.489±0.149
1996	0.25	75	90	92	81	4.225±0.397	16.900±1.587
	0.5	137	106	133	108	6.050±0.813	12.100±1.627
	1	175	155	210	168	8.850±1.175	8.850±1.175
	1.5	182	160	150	223	8.938±1.619	5.958±1.080
	2	231	190	160	166	9.338±1.611	4.669±0.806
	4	265	304	316	292	14.713±1.091	3.678±0.273
	8	390	375	422	438	20.313±1.442	2.539±0.180
1997	0.25	80	90	57	88	3.938±0.756	15.750±3.026
	0.5	132	118	126	116	6.150±0.370	12.300±0.739
	1	175	171	180	182	8.850±0.248	8.850±0.248
	2	186	177	177	175	8.938±0.246	4.469±0.123
	4	291	288	297	269	14.313±0.605	3.578±0.151
	8	442	391	397	376	20.075±1.420	2.509±0.178

2.2 稻水象甲种群增长模型建立及分析

$X\text{-}Y_1$ 趋势图类似指数曲线;而 $X\text{-}Y_2$ 趋势图类似双曲线。从理论上讲,当 $X\rightarrow\infty$ 时,Y_1 将趋近于一个固定值,$Y_2\rightarrow 0$。用常用的一元方程:直线、指数曲线、二次方程、对数曲线、双曲线等来拟合 $X\text{-}Y_1$ 和 $X\text{-}Y_2$,结果以双曲线来拟合 $X\text{-}Y_2$ 的关系其拟合度最佳,因此,选用 $Y_2=1/(A+BX)$ 双曲线来拟合 $X\text{-}Y_2$ 的关系。分别用 3a 数据来拟合这一模型所得的方程及其相关系数测验见表 2。

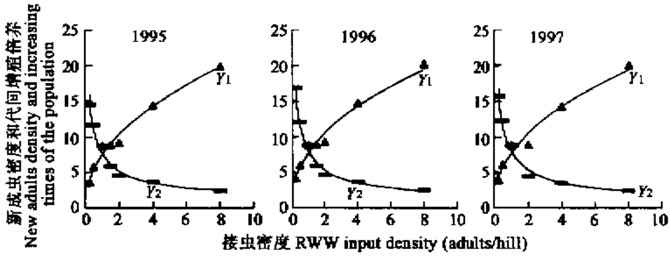

图 1　稻水象甲不同接虫量的种群密度变化趋势和种群增长趋势

Fig. 1　Curve of RWW output population density and increasing times from different input population density

▲Y_1 Y-axes are New adults density ；▬Y_2 increasing times of the population

表 2　稻水象甲代间增殖倍率与接虫密度之间关系的数学模型拟合

Table 2　The mathematical model fitting to the relationship between increasing times and input density of RWW

年 份 Year	拟合模型 Model	相关系数及其显著性 Correlative coefficient and its significance
1995	$Y_2 = 1/(0.08635+0.04186X)$	$0.9716^{**} > r_{5,0.01} = 0.874$
1996	$Y_2 = 1/(0.08338+0.04168X)$	$0.9664^{**} > r_{5,0.01} = 0.874$
1997	$Y_2 = 1/(0.08106+0.04275X)$	$0.9647^{**} > r_{4,0.01} = 0.917$

因不同年度的试验过程相同，且模型参数数值相近，故参数按平均值合并。代间增殖倍率 Y_2 表示为：

$$Y_2 = 1/(0.0836 + 0.0421X)$$

显然，当 $X \to \infty$ 时，$Y_2 \to 0$，即接虫密度足够大时，种群不再增长；当 $X \to 0$ 时，$Y_2 \to 11.96$，即种群密度极低时，代间增殖倍数达最大，约为 12 倍。

根据稻水象甲的生物学特性，首先，该虫在辽宁每年发生 1 代，以成虫越冬，其越冬自然死亡率较低，只有 10% 左右，即，越冬成虫平均存活率 $S_0 = 0.9$；其次，水稻移栽后越冬成虫迁入稻田，稻田无对成虫具有明显影响的寄生性或捕食性天敌，稻田成虫产卵前存活率为 100%；再次，按一般防治操作规程来考虑化学防治，通常，在成虫产卵前施药防治成虫，假设 1 次防治，平均防治效果为 C，防治后成虫残存率 $S_1 = 1 - C$，设化学防治对残存成虫的生育无影响。在此 3 个假设条件下，设当年水稻移栽后稻田种群平均密度为 N_t，下年同期成虫平均密度 $N_t + 1$ 可表示为：

$$N_{t+1} = S_0 N_t S_1 [1/(0.0836 + 0.0421 S_0 N_t S_1)] = S_0 S_1 N_t / (0.0836 + 0.0421 S_0 S_1 N_t)$$

以此模型进行分析：

(1)稻水象甲侵入初期　可检测出的密度为数十头/hm^2，即 0.0001 头/丛；常规条件下成虫越冬死亡率低，$S_0 = 0.9$；无化学防治，$S_1 = 1$。则今后几年内，以水稻移栽后稻田成虫量为标志的种群数量由 0.0001 头/丛，经 $1.0765 \times 10^{-3} \to 1.1584 \times 10^{-2} \to 0.1241 \to 1.2644$，历时 5a 种群密度便上升至 1 头/丛以上。这说明稻水象甲种群增长迅速、易于积累成灾。事实上，在辽东南丹东、大连等地，稻水象甲检出年为 1991～1992 年，到 1996 年(此期间只有较少的示范性化学防治)，平均种群密度达 1.2 头/丛左右的高水平，种群增长模型反映了种群增长的实际情况。

(2)种群不再增长的化学防治强度　设越冬成虫存活率仍为 0.9；因为成虫的其他自然致死因子极少，化学防治是影响成虫存活的唯一关键因子；在不计种群迁入迁出的条件下，要使种群不增长($N_t + 1 = N_t = N$)的化学防治后成虫残存率必须满足：

$$S_1 \leqslant 0.0836/(S_0 - 0.0421 S_0 N) \text{ 即}, C \geqslant 1 - [0.0836/(0.9 - 0.0378N)]$$

当前代表辽东南、辽河下游及沈阳地区的稻水象甲平均种群密度分别为 1.00、0.65 和 0.35 头/丛，使种群不至增长的化学防治后成虫残存率分别应小于：9.70%、9.55% 和 9.43%，即化学防治平均防效应分

别大于 90.30%、90.45%和 90.57%。

2.3 稻水象甲种群增长模型检测及其应用效果

1997 年以来，分别在辽宁省稻水象甲老疫区及新发生区用种群增长模型进行其发生趋势预测，用实际调查数据来检测模型。当预测值与实际调查值的偏差为 5%以内，视为符合，而大于 5%视为不符合。结果见表 3。

表 3 稻水象甲种群增长模型的检验

Table 3 Test for the RWW population increasing model

地点 Place	年度 Year	当年虫口基数 Population density (adults/hill)	平均防效 Average controlling effectiveness (%)	下期虫量预测 Next period population density (prediction) (adults/hill)	下期实查虫量 Next period population density (actually) (adults/hill)	符合情况 Correctness /Error
丹东东港	1997～1998	1.150	89.50	1.232	1.250	C
Donggang	1998～1999	1.250	93.00	0.906	0.870	C
Dandong	1999～2000	0.870	85.00	1.326	1.150	E
大连庄河	1998～1999	1.450	89.00	1.601	1.653	C
Zhuanghe Dalian	1999～2000	1.653	92.50	1.264	1.306	C
营口大石桥 Dashiqiao Yingkou	1997～2000	0.005	00.00 15.00 65.00	1.686	1.615	C
鞍山海城	1998～1999	0.125	73.50	0.351	0.355	C
Haicheng Anshan	1999～2000	0.355	85.00	0.560	0.532	C
沈阳东陵	1997～1998	0.008	00.00	0.086	0.090	C
Dongling	1998～1999	0.095	40.00	0.598	0.570	C
Shenyang	1999～2000	0.570	75.00	1.441	0.752	E

上述结果表明，用该模型预测稻水象甲的发生趋势准确率达 80%，其中，在大石桥的 3a 超长期预测亦极为准确。2 个不准确的预测中，在东陵用 1999 年的发生量预测 2000 年的发生量偏差较大，另一个在东港用 1999 年发生量预测 2000 年的发生量与实查值偏差甚小。

另一方面，可用该模型进行防治决策。首先，稻水象甲种群增长迅速，其经济危害水平较低，为 0.3 头/丛。在选择防治措施上，当前，栽培防治和化学防治最为有效。栽培防治主要靠成虫产卵高峰期浅水管理、干湿交替灌水来减少田间落卵量，一般防治效果可达为 60%，如虫口密度刚达到经济危害水平，仅依靠栽培防治，当前幼虫即能造成危害，来年成虫密度将达到 1.225 头/丛，因此，仅靠栽培防治措施来控制稻水象甲不可行。若使来年虫口密度仍在经济危害水平以下，区域性总体防治效果必需在 90.59%以上，只有化学防治方可达到此效果。因此，目前条件下，稻水象甲综合防治的关键性措施是化学防治。其次，已知种群平均密度，利用模型可计算出应实施的化学防治平均强度。设防治后残存成虫正常繁殖，残存成虫至少可以产生：$L=S_1N_t/(0.0836+0.0421S_1N_t)$的幼虫量。幼虫的经济危害水平 2 头/丛。要使 $L\leqslant 2$ 的防治后成虫残存率 S_1 必须满足：$S_1\leqslant 0.1672/(0.9158N_t)$。当前辽东、南平均种群密度为 1 头成虫/丛左右，必须 $S_1\leqslant 18.25\%$，即总体平均防治效果必须至少达 81.75%以上方可保证当年稻水象甲危害损失在经济危害水平以下。尽管多数防治药剂可以达到这一防治效果，但区域性防治不普遍、施药期不适宜，总体防治效果很难达到这一水平。因此，稻水象甲对本省的水稻生产存在长期的、严重的威胁，以化学防治为主体的综合治理策略必须长期坚持。

3 讨论

稻水象甲种群增长存在着明显的密度制约，低密度时种群增长迅速。用双曲线模型来拟合代间增长倍数与种群密度的关系其拟合度良好，所得的年(代)间种群增长模型反映了本地稻水象甲积累的实际情况。用该模型进行稻水象甲的发生趋势预测准确度较高，能进行防治决策、指导综合防治的实施。

美国、日本等国家有关稻水象甲种群消长、种群积累迅速的研究报道较多[2,9],但未见用数学模型描述种群增长规律的报道。截止到 2000 年,辽宁省除朝阳、阜新水稻面积小、未调查稻水象甲发生为害与否外,其余 12 个市均有发生,全省 600 000hm^2 水稻有近 400 000hm^2 罹害、需要防治。Kiritani,翟保平、张孝羲预警了稻水象甲对日本、中国及亚洲水稻生产的严重威胁和研究其生物学、生理学、生态学的重要性[10,11]。本研究针对辽宁省稻水象甲发生危害的严峻形势,本着实用的目的,用简明的数学模型描述该虫种群增长规律,已在生产实践中得到了广泛应用。昆虫种群增长模型常用 Logistic 方程等具有明确理论意义的数学模型来描述[4,5],本文的双曲线模型虽能很好地拟合种群实际增长过程,但这一模型参数的生物学意义不明确。因此,它仍属黑箱模型。稻水象甲实验种群生命过程研究逐渐明确后,利用昆虫种群增长的常规理论模型来描述其种群增长过程,不仅可在生产实践中应用,而且还对昆虫种群变动理论研究具有重要意义。

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