PESTICIDE USE IN TAIWAN —PRESENT AND FUTURE—

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Abstract

Both the existence of a subtropical climate and intensive agricultural system provide favorable conditions for pest prevalence in Taiwan. Agricultural pest control is almost exclusively carried out by the use of chemicals leading to excessive applications of pesticides, as evidenced by the consumption of 370 kinds of pesticides totalling 36,000 tons in 1981.

Improvement of the present situation is under way. In this paper, the following three topics are being dealt with: 1) Brown planthopper control, 2) Studies on insecticidal resistance and 3) Grub control.

Taiwan is situated between 21 45′ and 25 48′ NL. It is an island 380 km long from North to South, and about 140 km wide from East to West at its widest part. The island is leaf-shaped with an acreage of 36,000 km^2. The Tropic of Cancer runs at about the 2/3 of the southern part of the island. Therefore, Taiwan is generally considered to belong to the tropics or subtropics by geographers. There is a large chain of mountains running from North to South, which forms the backbone of the island and high mountains of above 3,000 m can be seen all over the island. The highest mountain, Mt. Morrison, culminates at an altitude of 3,997 m. Based on the distribution of the forests, the climate of Taiwan can be divided into the following 4 zones (Table 1).

Table 1 Climatic zones of Taiwan classified according to the distribution of forests.

Climatic zone	Area (%)	Altitude (m) (northern area)	Altitude (m) (southern area)
Tropical	56	0– 300	0– 600
Sub-tropical	31	300–1,500	600–2,000
Temperate	11	1,500–2,500	2,000–3,000
Sub-frigid	2	>2,500	>3,000

As mentioned above, Taiwan has a surface of 36,000 km^2 with 70% of the island being covered by mountains. The percentage of arable land which amounts to only 24%, namely about 90,000 ha, is almost completely confined to the lowland areas. Therefore, agriculture in Taiwan is essentially of the subtropical type. Recently reclamation of mountain areas has made evident progress and large expanses of deciduous orchards, consisting of apple, peach and pear trees as well as cruciferous vegetable gardens in the summer are located in the zone ranging from 2,000–2,500 m in altitude. Besides, the introduction of some new crops, such as onion, asparagus,

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mushroom, various kinds of ornamental plants and flowers makes the crop component more diversified. In addition, the presence of high temperature and moist subtropical climate, along with the intensive agricultural system, are conducive to the existence of a diversity of agricultural pests. For instance, more than 110 species of insects are listed as pests on paddy plants. According to the data from the Department of Agriculture and Forestry, Taiwan Provincial Government, on the average about 30% of the crops sustain losses due to pests unless suitable pest control operations are carried out. It is also stated that, during the paddy cultivation period, if proper chemical control is not implemented, loss due to the pests will total 15.4 and 27.7% for the 1st and 2nd paddy crops on the average, respectively. Especially in the case of the 2nd crop, the loss is estimated to zoom up to 54.2% at the worst. In Taiwan paddy production of rough rice for the 1st and 2nd crops amounts to 3.8 and 3.1 ton/ha, respectively, which corresponds to a very high level of production in the world, and also indicates that plant protection in Taiwan operates fairly well.

It is also important to review the past use of pesticides in Taiwan. In the 6th edition of the Farmer's Handbook of Taiwan (1944), the following pesticides are listed as being commonly used: arsenate, pyrethrum, nicotine sulfate, Bordeaux mixtures, lime sulfur, Derris, machine oils etc. Among them, Derris which is a domestic product, enjoyed a wide popularity at the time.

It was in 1949 that the first organosynthetic pesticide, DDT, was introduced to Taiwan followed by BHC and in 1951, holidol and aldrin were imported. The former showed a remarkable control effect on rice stem borers (*Tryporyza incertulas, Chilo suppressalis*) and other various species of insect pests, while the latter afforded effective control of ants which, as the carriers of pineapple mealybug (*Dysmicoccus brevipes*), cause condiderable hardship to the farmers. Also aldrin is extensively applied as soil insect control agent along with another organic insecticide, heptachlor. In 1953, malathion and endrin were imported. Malathion is widely used for the control of rice insects and aphids, and endrin is used against cotton and soybean insect pests. It was in 1958 that dieldrin was used practically in Taiwan. The chemical showed a significant effect on the control of the banana stem borer weevil (*Odoiporus longicollis*), which has caused severe damage to banana orchards since 1954. DDT was also extensively used for the control of *Anopheles*. Then, Taiwan became a malaria-free area in 1965 according to WHO. Due to the residual toxicity and hazard to the environment, the use of these organic hydrochlorinated insecticides became prohibited around 1975.

Despite the prohibition of the use of several pesticides, the utilization and dependency on pesticides have increased gradually in Taiwan. Nowadays, more than 370 kinds of pesticides are registered by the government. Although these pesticides are undoubtedly contributing to the control of agricultural pests including pathogenic agents, insects, weeds, rodents, the number of registered pesticides has a tendency to increase year by year, along with their dosage. According to the data from the Taiwan Agricultural Pesticides Industry Association, 36,000 tons of pesticides worth US$100 million were consumed in 1981, and paddy is the largest target for the application of pesticides. It is estimated that about 20–30% of the pesticides are used for the control of paddy pests (Tables 2, 3, 4).

Table 2 Use of pesticides in Taiwan in 1981.*

Pesticides	Annual consumption (kg.l)	Target crop and amount consumed (kg.l)			
		Paddy	Vegetables and fruit trees	Rats, stored products and other fumigation procedures	Weeds (paddy fields and upland areas)
Insecticides	13,863,000	8,419,000	5,444,000		
Fungicides	3,826,000	2,481,000	1,345,000		
Herbicides	17,389,000				17,389,000
Others	1,367,000			1,367,000	
Total	(100%) 36,445,000	(29.9%) 10,900,000	(18.6%) 6,789,000	(3.9%) 1,367,000	(47.6%) 17,389,000

* From the data of "Domestic Manufacturer Production and Sales of Pesticides in 1981", Taiwan Agricultural Pesticide Industry Association.

Table 3-A Pesticides used in Taiwan for the control of paddy insect pests in 1981.

Unit: kg.l
NT$ (US$1,000)

Pesticides	Amount sold (kg.l)	Price (NT$) (US$1,000)	Pesticides	Amount sold (kg.l)	Price (NT$) (US$1,000)
Monocrotophos	2,120,552	404,417	Meobal®	1,000	85
Quinalphos	2,001	12	MIPC	836,764	112,064
BPMC	300,687	43,420	MIPC + Bio®	299,312	5,388
Dicrotophos	14,055	3,614	MIPC + Carbophenothion	130,000	37,700
Carbaryl	236,519	100,910			
Phenthoate	60,621	13,672	MTMC	14,540	2,086
Carbamint	1,222	1,223	Acephate	51,125	31,308
CPMC	3,716	285	Ofunak-M®	1,880	639
Mephosfolan	85,087	27,221	Cartap	46,496	8,064
Dimethioate	216,752	41,011	Phosmac	2,420	48
Chlorpyrifos	61,722	7,615	Fenvalerate	14,040	13,871
Diazinon	103,701	5,105	Fenitrothion	69,208	18,459
Dyflonip	425,019	5,525	Cyanofenphos	38,456	22,312
Disulfoton	11,473	384	Dialifos	4,620	878
Ethoprophos	30,120	7,324	Methamidophos	25,000	8,512
Hokbal®	274,865	53,259	Tribassa-G®	10,000	230
Imip	1,066	266	Trimip	17,910	5,373
Phosmet	23,357	5,490	Propoxur	1,890	1,365
Kayaphosbassa®	20,158	6,865	Wellcide-B®	23,121	3,643
Fenthion	52,821	18,340	Total	8,419,337	128,803
Malathion	123,235	12,400			

Add. 1) Data from Taiwan Agricultural Pesticide Industry Association, Domestic Manufacturer Production and Sales of Pesticides in 1981 (the cost of imported products is calculated at the commercial rate of 1:80 in US$ and NT$).

2) Total cost of pesticides consumed in 1981 amounts to NT$354,808 million.
Cost of rice insect pest control totals NT$188,675 million (53%).

Table 3-B Pesticides used in Taiwan for the control of paddy diseases in 1981.

Pesticides	Amount sold (kg.l)	Price (NT$) (US$1,000)
Blestan E. C.	66,287	12,722
Blestan W. P.	500	2,070
Difolatan T. G.	236,683	59,478
Duter W. P.	8,773	1,880
Fuji-1 E. C.	10,000	5,084
Hinosan D. P.	48,968	23,813
Hinosan E. C.	59,139	29,864
Kitazin-P E. C.	62,527	12,118
Kitazin- D. P.	37,042	1,738
Kasumin W. P.	8,344	3,118
Kasumin S.	11,398	2,113
Kasumiron W. P.	46,527	16,628
Mon E. C.	87,042	11,353
Mon T. G.	16,500	4,785
Neo-Asozin S. D.	1,053,271	27,857
Oryzemate G.	479,521	25,430
Polyoxin W. P. S.	40,142	23,772
Rabcide W. P.	62,661	10,060
Tachigaren S.	5,400	6,129
Validacin S.	100,000	24,120
Total	2,480,724	304,457

Table 4 Cost of pest control per hectare for various crops.*

Crop	Gross income/ha	Production cost/ha (A)	Pest control cost (labor/NT$)					Percent of control cost in production cost (B/A × 100)
			Insecticides Fungicides	Herbicides	Labor time (hr)	Wages	Sum (B)	
Paddy (1st crop) *Japonica* type	(66) 44,965	45,559	2,694		51	1,731	4,425	9.9
Paddy (2nd crop) *Japonica* type	(66) 40,387	45,259	3,266		58	2,035	5,301	11.7
Paddy (1st crop) *Indica* type	(66) 44,400	48,229	2,900		48	1,751	4,651	9.7
Paddy (2nd crop) *Indica* type	36,223	45,687	2,934		52	2,044	4,978	10.9
Sweet potato (autumn season)	62,497	66,850	2,125	1,083	73.4	3,583	6,801	10.17
Tea (machine harvesting)	41,057	48,914	2,685	822	54.8	3,824	7,331	14.99
Tea (labor harvesting)	163,839	154,916	5,883	1,352	173.3	8,794	16,029	10.35
Sugarcane (edible)	275,348	224,126	10,570	168	309.5	19,481	30,219	13.48
Banana (spring, summer season)	159,496	159,889	7,330	896	104.1	5,313	13,539	8.47
Banana (autumn, winter season)	100,572	143,121	3,801	853	97.7	5,474	10,128	7.08
Watermelon	133,450	91,252	10,911	122	146.5	8,342	19,375	21.23
Sweetmelon	101,419	90,548	8,592	116	131.5	18,278	26,986	29.80
Muskmelon	100,386	125,535	18,522	–	286.9	13,405	31,927	25.43
Orange (Ponkan)	261,093	199,207	24,503	3,049	308	41,110	68,662	34.47
Orange (Valencia)	195,859	157,020	20,437	606	328.3	19,446	40,489	25.79
Lychee	100,956	105,374	9,195	44	151.1	9,382	18,621	17.67
Pear	198,455	212,847	30,616	–	477.3	19,220	49,836	23.41
Pineapple	229,681	241,963	4,136	800	160.6	6,213	11,149	4.61
Mango	136,751	119,192	21,868	2,257	187.8	12,106	36,231	30.40
Guava	274,536	264,970	17,394	2,190	1,195	45,332	64,916	24.50

* From production cost of agricultural products in 1981 (Dept. Agric. and Forest. Taiwan Prov. Gov.).

However an even more extensive use of pesticides is made in orchards, and for some vegetables and ornamental plants. Such considerable consumption of pesticides which reflects the progress of agriculture, also symbolizes the modernization of agriculture in Taiwan. On the other hand, it is inevitable that such a use would bring about problems from both the agricultural and social standpoints. At first, the high cost of pest control caused considerable hardship to the farmers. Due to the industrialization of Taiwan, labor cost has increased markedly recently, and wages always exceed the cost of pesticides themselves. However wages vary with the kind of pesticide and target crop. It is estimated that pesticides account for about 55–60% of the total expenditure for pest control. If the cost of the applicators is taken into account, the total expenditure for pest control amounted to about US$250 million in 1981, which also corresponds to approximately 10–30% of the total production cost. Especially, for several fruit trees, the expenditure for pest control accounts for more than 30%, totalling US$1,000–1,300. The average cost for a crop is estimated at US$650–800. From these data, it is apparent that compared with other countries, pesticide use in Taiwan is excessive. Furthermore, farmers find it difficult to select among the various pesticides the most effective one. The "Plant Protection Manual", a guide-book for farmers, is published annually by The Department of Agriculture and Forestry, Taiwan Provincial Government. According to the manual of the 1982 edition, 28, 68 and 32 formulations of various pesticides are recommended officially for the control of rice blast (*Pyricularia oryzae*), the brown planthopper (*Nilaparvata lugens*) and the diamond back moth (*Plutella xylostella*), respectively.

Such an abundance of recommended pesticides is often criticized by the farmers. The reassessment of the recommended pesticides for some important pests has already been carried out for the past years but it will take several more years to complete the whole work.

It is nonetheless evident that agriculture in Taiwan has made remarkable progress following the application of pesticides. On the other hand, serious problems are being experienced. Nowadays, specialists are making strenuous efforts for improving the situation. The following studies on insect pests, will be presented with a view to considering future prospects for the use of pesticides in Taiwan.

1 Brown planthopper (BPH) control

BPH is recognized as the most destructive insect pest of paddy. Presently, a BPH working group comprising more than 10 entomologists is being organized, to carry out fundamental and applied studies.

At first, basic aspects are being taken up, such as the design of sampling methods, studies on population dynamics, damage analysis and estimation, followed by the determination of the economic threshold. At last criteria for economic control are defined as shown in Table 5.

Table 5 Criteria for economic control of brown planthopper. (No. of BPH/Stab.: before heading stage/after heading stage).

Control cost (NT$1,000/ha)	Rice price (NT$/kg)					
	10	12	14	16	18	20
3	3.6/5.2	3.2/4.4	2.8/4.0	2.7/3.8	2.6/3.6	2.4/3.4
4	4.8/6.4	4.0/5.2	3.6/4.8	3.2/4.4	3.0/4.2	2.8/4.0
5	6.0/8.0	4.8/6.8	4.0/5.6	3.6/5.2	3.2/4.8	3.0/4.4
6	8.0/9.6	6.0/8.0	4.8/7.2	4.4/6.4	4.0/5.2	3.6/5.0
7	9.6/14.4	8.0/9.2	6.0/8.0	4.8/7.2	4.6/6.4	4.0/6.0

Thereafter, studies will be almost exclusively based on these data. Due to the increase of labor wages, the application of granular pesticides is considered to be the soundest method. Then, the improvement of applications of granular pesticides will be evaluated in using 3% furadan G. Chemicals are applied to the paddy fields at the rate of 40 kg/ha with 3–5 cm standing water. The control effect on BPH is compared in paddy fields with or without the water being removed (Fig. 1).

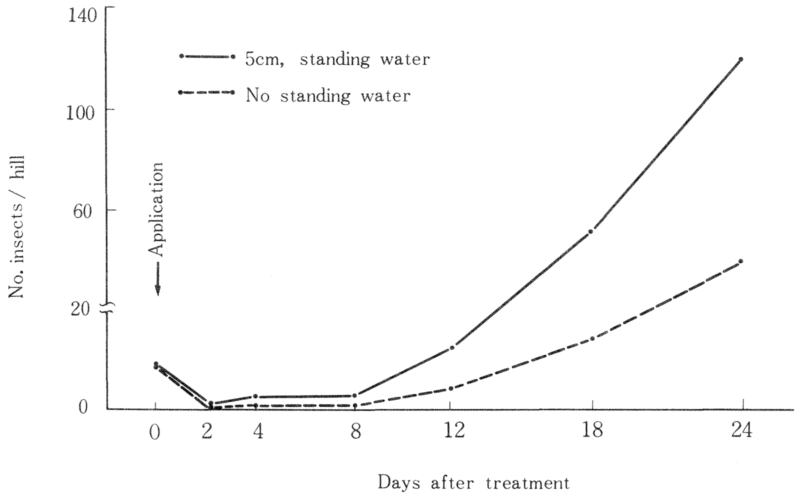

Fig. 1 Influence of water regime of rice field on the efficacy of furadan G against rice brown planthopper.

The results of the tests obviously indicate that it is preferable to remove water in the fields if long-term control by the granular insecticides is to be achieved.

In order to determine the proper timing for insecticidal application, 3.5% Ofunak-M. D., 3% furadan G. and 40.64% furadan F. were applied twice or 3 times during various intervals between the early booting stage and heading stage of paddy plant, and the effect of control against BPH was estimated.

As shown in Figs. 2 and 3, the most effective control was achieved by two applications of the pesticide within 1-week interval, both of them being targeted to the booting stage which is the most sensitive stage of the paddy plant to the damage by the BPH. The application resulted in a very effective control and brought about high yield and high net income.

Comparison of the effect among the various chemical formulations is also being made. The results of the experiments showed the advantages of applying the pesticide twice under the form of dust at the booting stage. Both from the standpoint of control effect and economy such an application was found to be superior to liquid spraying. As for the net income, 3-time spraying, twice at the booting stage and once at heading stage, is less advantageous than dusting treatment applied twice at the booting stage (Table 6).

The work is also aimed at designing labor saving applications, along with improving the spraying methods and nozzle structure.

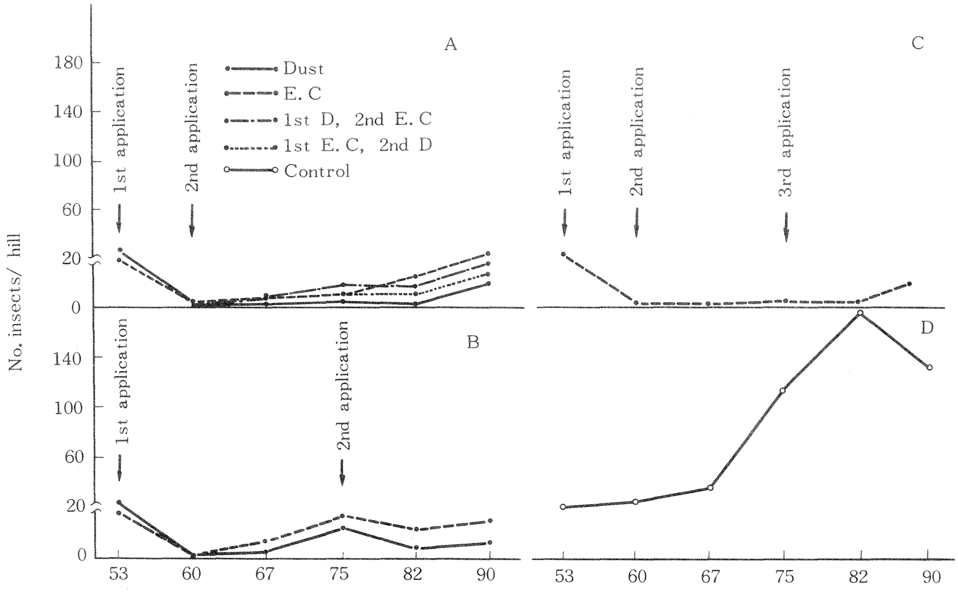

Fig. 2 Effect of the frequency of insecticide application and interval during booting and full-heading stages on the population of brown planthopper for the 2nd crop of rice (1980).

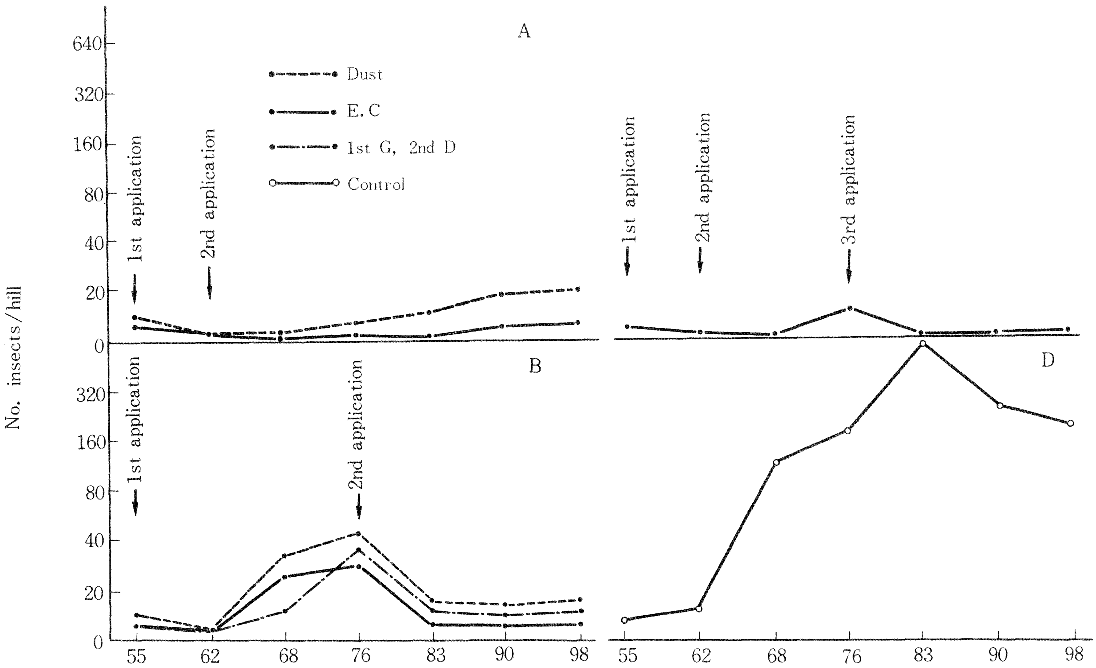

Fig. 3 Effect of the frequency of insecticide application and interval during booting and full-heading stages on the population of brown planthopper for the 2nd crop of rice (1981).

Table 6 Effect of various insecticidal applications on paddy yield and profit (1980).

Application	Yield kg/ha	Cost of application NT$/ha	Profit NT$/ha
1. Liquid spraying each at early booting and heading stages (twice).	5,895.0 ab	4.06	106.8
2. Dusting each at early booting and heading stages (twice).	5,773.5 c	3.60	104.9
3. Spraying at early booting stage each 7 days (twice).	5,943.6 a	3.72	108.0
4. Dusting at early booting stage each 7 days (twice).	5,884.2 b	3.60	107.0
5. Granular application at early booting stage (once), dusting at heading stage (once).	5,806.8 bc	6.10	103.1
6. Dusting at early booting stage (twice), additional one at heading stage.	5,996.7 a	5.40	107.3
7. Untreated.	3,971.7 d	0.00	74.7

Cost for control = price of pesticide + wages.
Pesticide (kl) = 40.64% furadan F NT$800, 3% furadan G NT$70, 3.5% Ofunak-M.D. NT$35.
Wage (per ha) = spraying, NT$900–1,000; dusting, NT$400; granular application NT$100.

2 Studies on insecticidal resistance

This is an important topic related to insecticidal applications worldwide. Insecticidal resistance of the BPH has been studied since 1976. In 1978, studies were carried out in using BPH collected in the field with regard to the resistance to the following 14 insecticides: BPMC, carbofuran, carbaryl, Hokbal, methomyl, MIPC, MTMC, propoxur, aceptate, parathion, malathion, parathion-methyl, monocrotophos and vamidothion. Comparison of the LD_{50} determined in 1976, showed that the resistance ratio (RR) for carbofuran and malathion was 1.9 and 4.2 times higher respectively and there was no difference in the susceptibility of the insect, compared with other insecticides. In 1979, however, the situation changed markedly. The RR of carbaryl, MIPC, monocrotophos, parathion, malathion increased 3.5–12.5 fold, with the highest ratio for malathion. In 1980 and 1981, except for propoxur, vamidothion, aceptate, there was a 2–21.5 fold increase of resistance to the other 11 insecticides. In particular the increase of resistance to carbaryl, carbofuran, MIPC, monocrotophos was conspicuous. In the laboratory, strains becoming 1183 fold resistant to malathion and 41 fold resistant to MIPC were developed throughout 9 and 16 generations of selection respectively. Both resistant strains were equally and significantly resistant to propoxur and permethrin, but still remained susceptible to fenvalerate.

Synergists, such as S,S,S-tributyl phosphorotrithioate (DFF) and piperonyl butoxide (p.b.) were tested to determine their effect on malathion and MIPC resistant BPH. Then it was found that DEF enhanced the toxicity of malathion about 20 fold, and that of parathion and methyl parathion 11 and 6 fold, respectively.

The insecticidal resistance of the diamond back moth is also being investigated. The resistance has been tested for the following 7 insecticides: diazinon, mevinphos, carbofuran, padan, pyrethrin, cypermethrin, decamethrin and fenvalerate. Besides, cross-resistance to the synthetic pyrethrin chemicals was developed by the diazinon-resistant strain.

3 Chemical control of grubs

Since the prohibition of the use of organochlorine insecticides, the activity of subterranean insect pests has become prominent again. In Taiwan, the grub is one of the most important pests of the sugarcane plantations and forestry nurseries. About 20 species of scarabaeid beetles have been recorded as sugarcane pests. One of the dominant species, the red-legged cupreous chafer, *Anomala cupripes*, is being studied intensively. Of the 3 instar larval stages, the 1st and 2nd instar stages are considered to be the easiest to be controlled by chemicals.

The age groups with their seasonal successions are investigated both under field and laboratory conditions. The survival rate of the overwintering population in various larval instar stages is also being calculated. In addition, to determine the ovipositional succession, adult collection is made both in the daytime and at night on host plants and in light traps. The individuals collected are dissected and seasonal changes in the reproductive activity are being investigated. The results obtained suggest that May and July are the most suitable months for soil application of insecticides.

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Discussion

Fuhr, F. (Federal Republic of Germany): Did I understand correctly that Taiwan has only 90,000 ha under cultivation? You mentioned that the annual consumption of pesticides in Taiwan amounts to about 36,000 tons. Is this in terms of active ingredients or formulated products?

Answer: In Taiwan the surface of arable land accounts for 24% of the total area, i.e. 90,000 hectares. The consumption of 36,000 tons of pesticides refers to formulated products (corresponding to 1/3 of active ingredients).

Ishikura, H. (Japan): You estimated the economic injury level in relation to the cost of control and the price of rice. I believe that the absolute yield level should also be taken into consideration.

Answer: Of course the yield level is important and was considered. The price production level was set at 5.5 and 4.0 ton/ha for the first and second crops respectively.

Kajiwara, T. (Japan): In Taiwan it seems that you use a large amount of fungicides to control orange diseases. What is the most important disease?

Answer: I cannot give you a precise answer because I am not a plant pathologist.

Kohli, A. (Switzerland): It is interesting to note that the cost of pesticide application you indicated accounts for a very high percentage of the total treatment cost, i.e. for paddy it amounted to almost 40% and for oranges for more than 50%. What assumptions did you make when you calculated the cost of application? Did it include water and labor charges? What equipment was used to make it so expensive?

Answer: The control cost must be divided into two parts: 1. the cost of pesticides and 2. expenses covering labor charges, machinery and water use as well as rice itself. The use of semi-automatic sprayer and duster is most popular in Taiwan.