BIOLOGICAL CONTROL OF MULBERRY SPIDER MITES, *TETRANYCHUS KANZAWAI*, WITH AUGMENTATION OF *AMBLYSEIUS WOMERSLEYI*

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Tetranychus kanzawai was one of the most polyphagous and notorious spider mites occurring in most of crop systems in Taiwan and far east Asia. Among the crop systems, economic injury caused by kanzawa spider mites was found mainly in mulberry, pear, tea, strawberry, carambola, and papaya through discoloration and wilting and dropping of leaves and fruits. Failure to control the kanzawa spider mites through chemical application necessitated the development of biological control and integrated control strategies in Taiwan.

According to the literature, spider mites have no parasitoid but have many predatory insects and mites. There are limited reports on successful manipulation of them. But predatory mites of *Phytoseiulus, Typhlodromus*, and *Amblyseius* mites have been mass reared and released mostly in orchards and strawberry in temperate area (Oatman 1965, Hoy *et al.* 1982). In Taiwan, the biology of two indigenous species, *Amblyseius womersleyi* and *Amblyseius ovalis* and their control of a kanzawa spider mite were conducted during the past five years (unpublished data). The mass rearing technique and release ratio of the predator to the spider mites and processes of *A. womersleyi* were developed for the mulberry field releases. The results were evaluated on the basis of the population density of spider mite, and the value and cost/benefit of silkworm cocoon production from the field.

PREDACEOUS MITES SPECIES AND ITS POPULATION DENSITIES ASSOCIATED WITH *TETRANYCHUS KANZAWAI* IN TAIWAN

There are five major *Amblyseius* spp. occurring with kanzawa spider mite population in the mulberry groves. They are *Amblyseius deleoni, A. maai, A. okinowanus, A. ovalis*, and *A. womersleyi.* The seasonal population densities of kanzawa spider mites, *Eotetranychus banki* and their *Amblyseius* predators, the life history and reproduction pattern of adults of the last two species of mite predator and the kanzawa spider mite were studied by Chang (1981) and Hsu (1983). *A. womersleyi* was shown as a delay density dependent factor for *kanzawai* and *banki* spider mite population. However, the *A. womersleyi* populations were mostly dependent on the population of *T. kanzawai.* Chang (1981) also reported that both *T. kanzawai* and *A. womersleyi* inhabited the lower leaves. The latter occurred only when the population density of the former was high.

The data on seasonal density of both prey and predators showed that the predators, although had a high searching ability or a high reproductive rate, had little suppression effect over the spider mite population, i.e. the naturally occurring predaceous mites were not sufficient to control the spider mites. Therefore, augmentation would be needed for the biocontrol of the spider mite in the mulberry system, and mass rearing and mass release of *A. womersleyi* were attempted.

MASS REARING OF *A. WOMERSLEYI*

Phaseolus vulgaris was selected as the host plant of spider mite after testing more than 70 host plant species. The process and techniques of host-plant planting, spider mite rearing, and colony conservation and mass rearing of *A. womersleyi* were illustrated in Fig. 1.

DAMAGE THRESHOLD AND CONTROL THRESHOLD OF SPIDER MITE DENSITY

Changes in color of mulberry leaves due to spider mite feeding were determined on potted mulberry trees. The leaves were fed to silkworm larvae to evaluate the damage threshold of spider mites. The leaf-color differences by National Bureau of Standard (NBS) and the weight of the 1st instar of silkworm larva had a positive and a negative natural logarithmic linear correlation with mite damage, respectively (Fig. 2 & 3). Five percent of larval weight loss was arbitrarily assumed for damage threshold of spider mites on mulberry. The damage threshold was hypothetically estimated at 0.42 mite-day/cm^2 which was equivalent to 9.24 mite-day/leaf at an average leaf area of 110 cm^2 for 5-day injury duration [(1.42-1) mite-day/cm^2 x (110 cm^2/leaf ÷ 5 days)]. An upper limit of mite damage for 15-20% of larval weight loss was set for the requirement of acaricide application. An upper limit of 28.5 - 44.6 mite/leaf was also calculated by the same process.

COST ANALYSIS OF MASS REARING *A. WOMERSLEYI*

The cost of mass rearing the predators is determined by the cost and efficiency of labor, facilities and flow of processes. The processing flow of mass rearing of predator has been determined as shown in Fig. 1. In view of the limited amount of predator reared per labor, the utilization of facilities, and the turnover time of a cyclic transfer or inoculation of prey and predators, the batch production of 300,000 predators is considered economical. This production will cost NT$0.015 per predator (Table 1). The cost can be reduced to NT$0.01 per predator at 1,000,000 predator rearing.

PACKING AND TRANSPORTATION OF PREDATORS

Predators can be easily packed with host plants, prey and some absorbent paper strips in a PE bag. They are retained for 24 - 48 hrs in dark condition at room temperature. During this period, the spider mites would be either desiccated or consumed by predators, thus none would be distributed into the field. For long distance transportation the bag with predator was aeriated with a pump and put into a carton. The predators can stand this condition for 2-3 days without reduction in survival. The predators are released into the field by simply emptying the bag by hand.

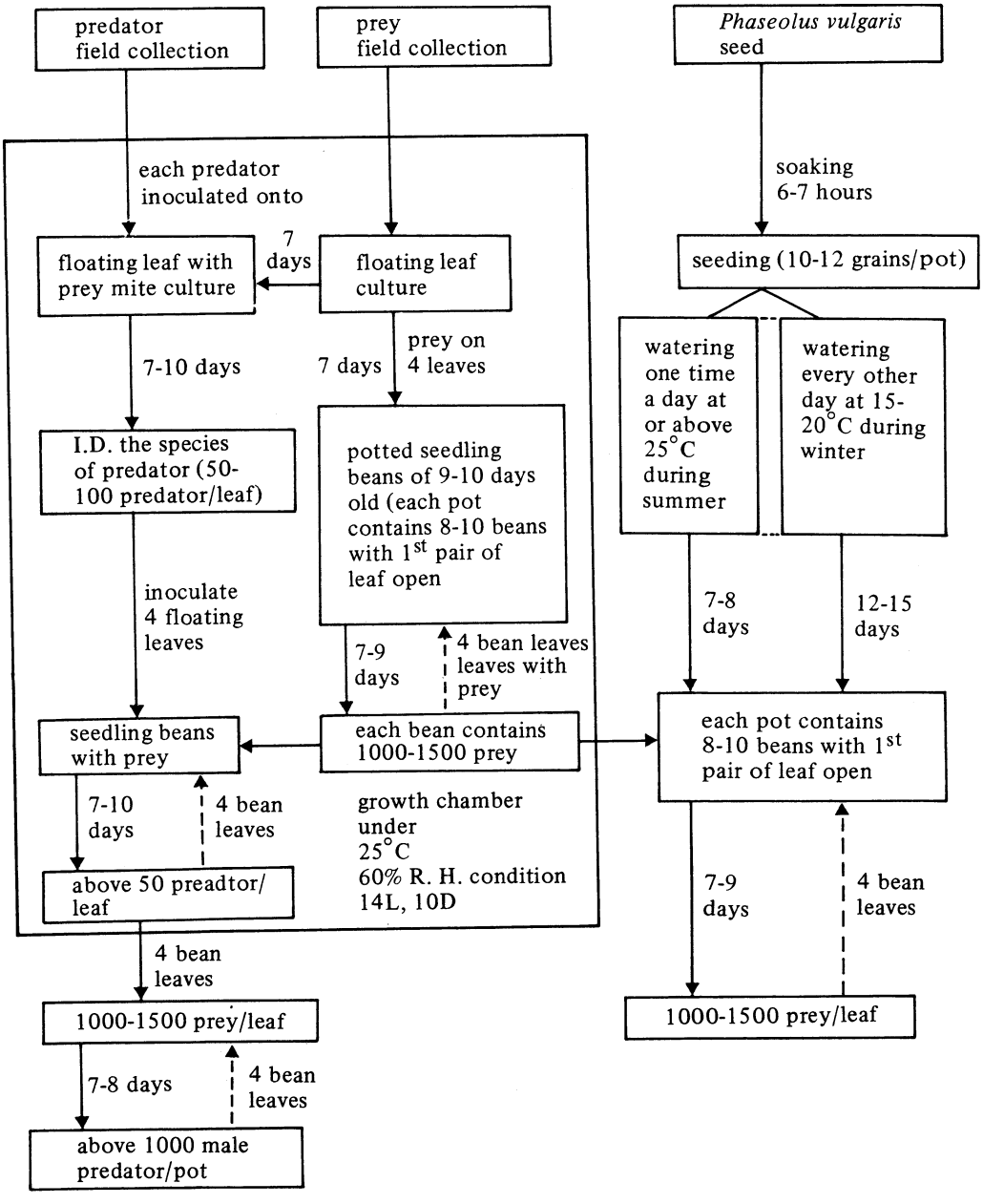

Fig. 1. Flow-chart of mass rearing of *Amblyseius womersleyi.*

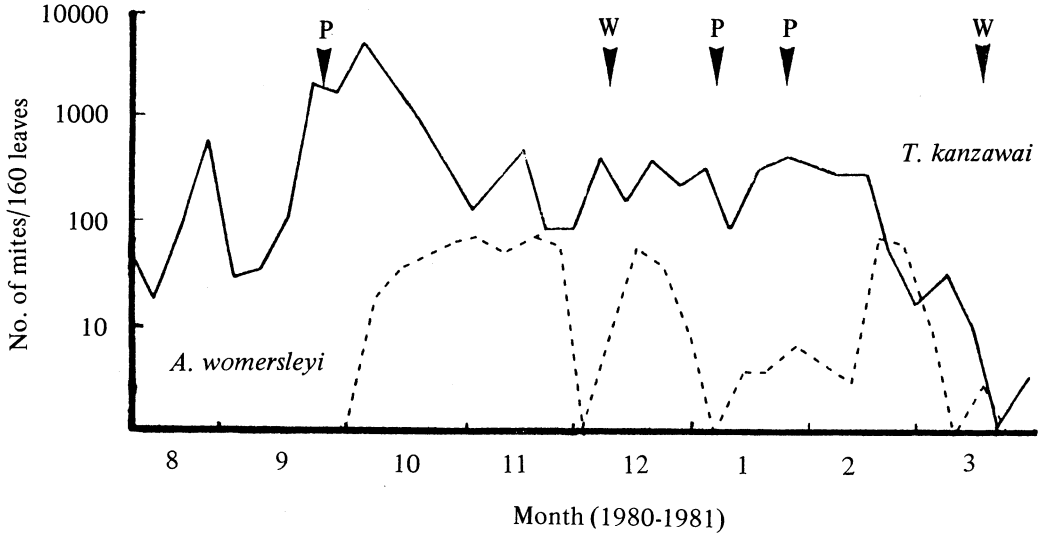

Fig. 2. Population density of *Tetranychus kanzawai* and *Amblyseius womersleyi* in mulberry grove in Taiwan, 1980-1981. (P: Prunning, W: Weeding.)

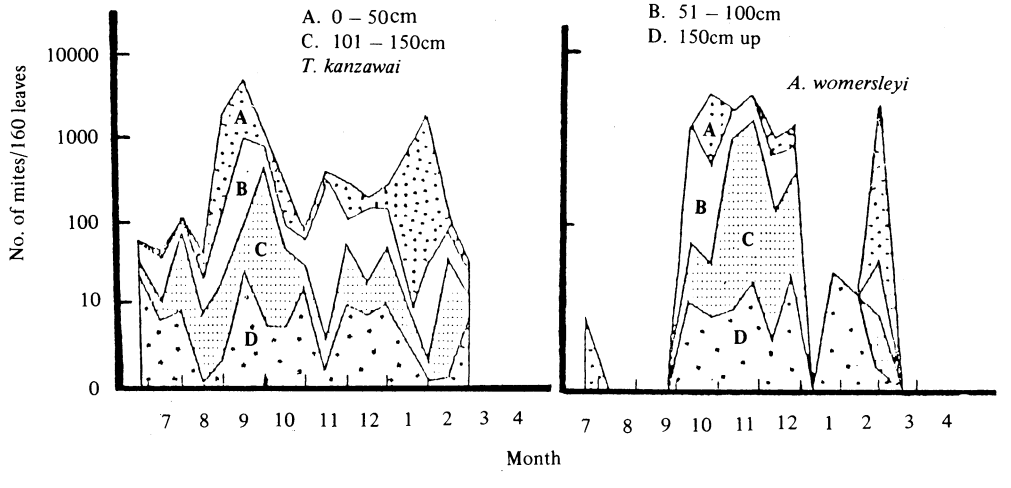

Fig. 3. Vertical distribution of population of *Tetranychus kanzawai* and its predator *Amblyseius womersleyi* on two mulberry groves in Taiwan, 1980-1981.

Table 1. Cost analyses for mass rearing of 300,000 *A. womersleyi*

Items	Cost (NT$)	Note
Labor cost	750	300,000 at 600 predators/pot = 500 pots. 500 pots at 200 pots/labor-day = 2.5 labor-day. 2.5 labor-day at $300/labor-day = $750.
Seeds	400	500 pots at 12 seeds/pot = 6,000 seeds. 6,000 seeds at 600 seeds/kg = 10 kg. 10 kg at $40/kg = $400.
Soil	940	500 pots at 0.00471 m^3/pot = 2.35 m^3. 2.35 m^3 at $400/$m^3$ = $940.
Fertilizer	250	500 pots at 100 pots/bag = 5 bags. 5 bags at $50/bag = $250.
Electricity	1,920	Two 0.08 kw lights x 12 hrs /25 pots = 0.0768 kw/day/pot. 0.0768 kw/day/pot x 25 day x 500 pots = 960 kw-hrs. 960 kw-hrs at $2 kw-hr = $1,920.
Total	4,362	

The expenses of pots, rearing facilities, predator colony maintenance, and miscellaneous items were not in the analysis.

COMPARISON OF COST OF SPIDER MITE CONTROL WITH PREDATOR RELEASE AND ACARICIDE APPLICATIONS

At population density of 5 spider mites per leaf in mulberry field, the biocontrol with *A. womersleyi* and acaricide applications were conducted in different groves. One release of predators (release ratio between predator and prey was 1:30) at 100,000 individuals per hectare was sufficient to control spider mite population for at least one month, and resulted in a 95 out of 100 times of success. On the other hand, chemical alternates required weekly sprays to achieve an equal suppression of spider mite population. The ratio of cost of biological and chemical control was 1 to 3 (Table 2).

EVALUATION OF MASS RELEASE OF *A. WOMERSLEYI* IN MULBERRY GROVES

Spider Mite Control with Mass Release of *A. womersleyi*: During the spring season (Mar.–Apr.) of 1983 and 1984, 100,000 predaceous mites per hectare were released into the mulberry field and a significant reduction of spider mite population was obtained in fields with initial spider mite population of less than 22 mites/leaf (Table 4). However, when initial mite population was high, the effect of releasing predators was lower, but still higher than chemical applications (Table 3). In 1984,

Table 2. Comparison of cost and benefit index between chemical control and biological control of mulberry kanzawa spider mites

Items	Expenses (per hectare)	
	Biological	Chemical
Cost of control		
Predator or chemical	$2,908	$800
Effective duration	30 days	7 days
Labor	$300	$600
Average cost/ha/day	$107 (2,908 + 300)/30	$200 (800 + 600)/7 days
Average of successful* control in 4 weeks	0.95	0.65
Actual cost per hectare per day	$112.6 (107/0.95)	$308 (200/0.65)
Economical benefit index of control**	3 (1/113 = 0.01)	1 (1/308 = 0.03)

*Results were calculated from release and nonrelease plots in which the spider mite density was reduced to 1.0 or less per leaf within 2 weeks after the treatment in 1983 and 1984.
**The economical benefit index of biological control to chemical control was 3 to 1 from the calculation of the item 4.

Table 3. Mass releases of 100,000 *Amblyseius womersleyi* per hectare against kanzawa spider mites in mulberry groves in spring of 1983

Area	Releasing date		Prereleasing density of spider mites (individuals per leaf)	Average density of mites in predator released plots (mites per leaf)[2]		Average density of mites in predator non-released plots (mites per leaf)[2]	
	Re-leasing day	Last sampling day		Spider mite	Predators	Spider mite	Predator
Nantou	0304	0415	17.50± 7.27	6.13± 1.17*b*	0.80±0.09*b*	15.16±1.18*a*	0.65±0.09*a*
Yuanlin[3]	0321	0419	218.03±312.35	288.67±81.62*a*	2.45±0.12*a*	348.69±5.66*b*	0
Tainan	0324	0422	21.90± 38.07	1.35± 0.94*c*	0.35±0.18*c*	7.40±6.82*c*	0.20±0.17*b*
Taitung	0322	0419	2.73± 0.67	0.40± 0.49*d*	0.13±0.13*d*	–	–
Nantou[1]	0304	0415	1.00± 0.04	7.24± 0.49*b*	0.16±0.04*d*	15.16±1.18*a*	0.65±0.09*a*

[1]Chemical sprayed plots with 25.5% chlorobenzen E.C. at 1,000 × diluting solution at 1.5 liter/ha. Chemicals were sprayed once every week.
[2]Means followed by the same letter in each column were not significantly different at 0.01 level by Duncan multiple range test (p = 0.01).
[3]Predators were released at the rate of 100,000/ha in previous year in the same plots.

when 16 million predators were released into 160 hectares in 4 different areas of mulberry groves, the spider mite population was checked by predators for the whole season (Table 4).

Table 4. Mass releases of 100,000 *Amblyseius womersleyi* per hectare against kanzawa spider mites in mulberry groves in spring 1984

Area	No. of samples	Prerelease density of mites (mites/10 leaves)[1]		Post release density of mites (mites/10 leaves)[1]			
				Predator non-released plots		Predator released plots	
		Spider mites	Predators	Spider mites	Predators	Spider mites	Predators
Hualien	200	4.14±1.18A	2.29±0.79*b*	–	–	1.48± 0.06B	3.55±0.09*a*
Pingtung	200	4.11±3.54B	0.35±0.57*a*	6.43± 0.35A	0 *b*	1.49± 0.21C	0.43±0.05*a*
Nantou	200	126.68B	5.77*a*	167.59±30.91A	3.08±6.16*b*	33.83±22.85C	5.51±0.81*a*
Taitung	200	0.13A	0.38*c*	0.50± 0.58A	3.13±2.16*b*	0.19±0.512A	4.78±2.22*a*
Over all		33.74 B	2.11 *c*	58.18 A	2.26 *b*	9.25 C	3.57 *a*

[1]Means followed by different letters in capitalized or italic showed significant difference by student t-test between pre- and post-releases of predator, respectively.

Net Income of Mass Releases of *A. womersleyi*: Predator release resulted in a better quality and a higher yield of silkworm cocoons. The mulberry leaves produced per hectare each spring are sufficient to raise 20 boxes of silkworms at 25,000 eggs/box. The total gross income of spring season from predator released plots were NT$145,285/ha compared to NT$129,524/ha from non-released plots. Profit of biological control of spider mites with mass release of *A. womersleyi* was NT$14,861/ha over non-control program.

In conclusion, mass release of predators against spider mites in mulberry groves at 100,000 predators per hectare resulted in a promising control and a benefit of NT$14,861/ha. Therefore, based on the economic benefit index, biological control is three times better in controlling spider mite population than chemical control.