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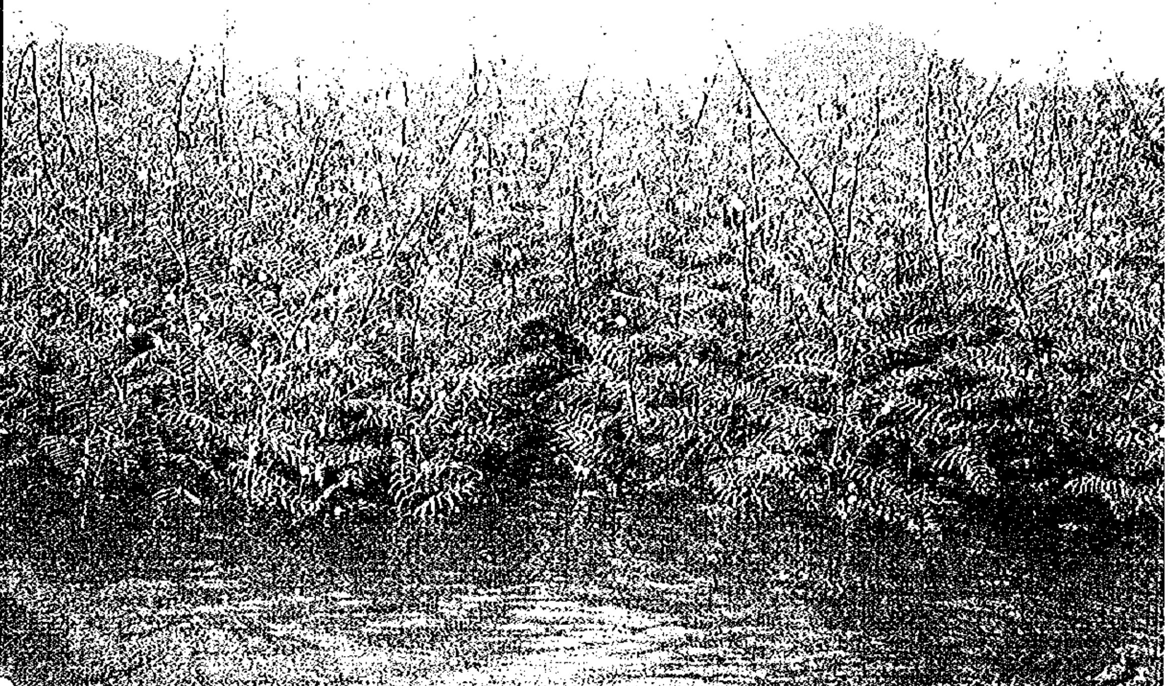
WEEDS AND THE ENVIRONMENT IN THE TROPICS



ASIAN-PACIFIC WEED SCIENCE SOCIETY
JAPAN INTERNATIONAL COOPERATION AGENCY

COVER: ***Mimosa pigra*** **community invading into the reservoir of Doi Tao area, Bhumipol Dam, northern Thailand.**

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WEEDS AND THE ENVIRONMENT IN THE TROPICS

Edited by
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FOREWORD

A symposium on the theme of "Weeds and the Environment in the Tropics" took place during the 10th Conference of the Asian-Pacific Weed Science Society (APWSS) held on November 24 th to 30 th, 1985, in Chiang Mai, Thailand. This symposium was a highlight of the conference. In keeping with this theme, we have strived to relate the content of all sessions and the field-trips to this subject area. Environment and weed ecology have been much published topics in recent decades and will, no doubt, assume even greater importance in the future.

Thailand, is observed to suffer from pollutive weeds throughout the country. In particular, *Mimosa pigra,* known as giant mimosa, is a prevalent pollutive weed around Chiang Mai Province, causing problems on access roads, blocking streams, filling lakes and encroaching on arable lands. Originally, *Mimosa pigra* was imported and planted for the purpose of combating soil erosion on deforested hills, serving as a fire break, and/or fencing out cattle from gardens; however, it has since become a serious problem of increasing magnitude. Besides this weed, we have other serious weeds such as *Eichhornia crassipes* in water areas and *Pennisetum* spp. in terrestrial locations.

The problems of weeds and the environment are urgent and important not only in Thailand but also other countries in the tropics. It is very useful for us to meet at the symposium to pool our knowledge and exchange ideas and to learn ways of solving these problems. Based on the above considerations, the theme of this symposium was established.

Finally, concerning the holding of the symposium, I would sincerely like to acknowledge the contributions of the speakers; Dr. H. Shibayama, Dr. M. Soerjani, Dr. S.K. De Datta, Dr. L.E. Bendixen, Dr. T. Smitinand, Dr. Y.L. Chen and Dr. J. Harada, as well as of Dr. K. Noda, Dr. B.L. Mercado and Dr. K.U. Kim who served as chairmen in the symposium.

Further, I would add our sincere thanks to the Japan International Cooperation Agency who provided partial financial assistance to facilitate the success of this symposium.

November 29th, 1985

Tanongchit WONGSIRI
President and Chairman
APWSS 1983-1985

CONTENTS

PREFACE AND INTRODUCTION

A symposium entitled "Weeds and the Environment in the Tropics" was held on November 29th, 1985, for one day during the 10th Conference of the Asian-Pacific Weed Science Society (APWSS) from November 24th to 30th, 1985, at Chiang Mai, Thailand. Why was this theme determined by the Planning Committee of the 10th Conference of APWSS?

Recently, environment problems have generated much awareness among the public in not only developed countries but also developing countries, probably due to the concern about how to effectively utilize the limited area of the earth with respect to the population explosion in relation to advanced technologies in human life as well as shifting methods of agricultural production of foods and materials. When we consider the impact of weeds on the environment, two aspects can be generally taken into consideration, these are weeds themselves and advanced weed control technologies. They have already provided several environmental problems or potential problems. For instance, Thailand is now suffering from serious infestation of three pollutive weed species, *Mimosa pigra*, *Eichhornia crassipes* and *Pennisetum* spp.

(1) The impact of serious weeds themselves directly and/or indirectly on the environment. Typical, direct impacts are found with *Mimosa pigra*, *Eichhornia crassipes* and *Pennisetum* spp. already described. *Mimosa pigra* was first brought from Indonesia to serve as fire break and to fence out cattle from gardens in Chiang Mai around 30 years ago and promptly spread to the North, Northeast, and South of Thailand in water reservoirs, river banks and/or canals, as well as in wet fields of terrestrial areas. It obstructs water flow, impedes navigation, builds up sediment in water reservoirs and reduces the capacity of water resources and utilization. Much effort has been concentrated on the control and

utilization of this weed.

Eichhornia crassipes, a floating weed called water hyacinth, was also imported from Indonesia as an ornamental plant around a couple of decades ago, and is distributing throughout Thailand. Chao Phya River, Thailand's largest, is somethimes clogged by this weed, impeding navigation. Furthermore, it is considered that recent disastrous flooding in Bangkok was incidentally caused by the reduction of drainage capacity due to the remarkable prolificacy of this weed in rivers and canals on the outskirts of Bangkok. Ineffective efforts at control and utilization have been conducted not only in Thailand but also world-wide.

Further, three species of *Pennisetum,* called communist grasses, have spread all over the country due to the prolific abundance of seeds and their easy distribution by the wind. It is not only a menace in croplands but also often causes traffic accidents because of its height of as much as three meters.

Another aspect of weeds in the environment indirectly affects the environmental situation resulting in disasters associated with the human environment. For instance, weeds which may principally habor microorganisms and insects, may play a role in their dynamic behavior, and may consequently adversely affect agricultural production of crops as well as the well-being of the people.

(2) Another aspect concerning advanced weed control technologies is exemplified by certain herbicides. Excessive application of herbicides induces environmental problems as seen in countries with heavy use such as Japan, the EC countries and the United States. Even in Thailand, increased imports of pesticides including herbicides have aroused the awareness of many persons. Professor An Nimnanbemintr, a member of the Society for the Conservation of National Treasures and Environment, notes that Thailand spent nearly 1,500 million Baht (equivalent to 60 million dollars) on pesticide imports in 1983, and that misuse of these chemicals has caused thousands of injuries and deaths each year, and has said "The government and authorities concerned should try more to keep a good balance between the use of natural predators and of chemicals to control and eradicate weeds".

Recently, in a return to a natural ecosystem, modern technologies based on the development of the chemical industry, such as chemical fertilizers and pesticides including herbicides are tending to be abandoned in agricultural production. However, the use the limited area of the earth for the achievement of a satisfactory and sufficient supply of foods and materials to meet the world population explosion should be the most important and urgent world concern because it is expected by Dr. I. Yamamoto in Japan, that the world's population may reach about eight thousand million in forty years.

According to the introduction by William Inman, of UPI in Dallas, even Dr. Norman Borlaug, the famous Nobel Prize Winner who bred dwarf wheat and high yield crops, criticizes the anti-pesticide movement. He said the movement to ban chemicals is disgraceful. This problem has been grossly exaggerated. Pressing nations to restrict harmful but beneficial chemicals, he says, is like banning the car because of traffic hazards. Ecology activitists reacted incredulously.

Another aspect of advanced weed technology, particularly the use of herbicides, is the impact on the socio-economic situation of farming enterprises. Input into advanced technologies and profits brought by the reduction of labour costs as well as by increased production of crops should be evaluated economically.

In this symposium, seven papers were invited from related professional fields. We do not think, however, that they satisfactorily cover all current aspects of symposium theme. For instance, the relation of weed plants to virus, bacteria, fungus and/or pest insects in the environment is of important significance, and should be given a multidisciplinary approach.

It is very gratifying and significant that a proper recognition and scientific understanding of the situation through the discussions in the symposium will indicate directions towards the solution of the complex environmental problems brought about by weeds themselves and their control technology.

Further, there is a current concept in which the control and utilization of weeds are moving in opposite directions. Dr. K. Ueki said at the water hyacinth meeting in Japan, "Specific biological characteristics of serious weeds such as vigorous growing habits, high adaptability against environmental conditions, high reproductive ability, and strong competitive power cause a weed problem in croplands as well as non-croplands; but these characteristics indicate the future potential of weedy plants for utilization as a biomass. A future strategy for weeds should comprise control and utilization". He also emphasized the growing recognition of the co-existence of humankind and natural resources in the limited area of the globe.

Meanwhile, the symposium is appropriate as one of the objectives of the *National Weed Science Research Institute Project* of the Japan International Cooperation Agency (JICA), that has been implemented under the auspices of the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand, since 1980. I would express our great thanks to JICA for partially sponsoring this symposium.

Finally, the contributions of seven speakers; Dr. H. Shibayama, Dr. M. Soerjani, Dr. S.K. De Datta, Dr. L.E. Bendixen, Dr. T. Smitinand, Dr. J. Harada and Dr. Y.L. Chen, who presented their own papers as well as of Dr. B.L. Mercado and Dr. K.U. Kim who shared the chairmanship of symposium with me are all acknowledged with sincere thanks.

Further, the Symposium Committee Members who cooperated in preparing the symposium, and Mrs. Yupin Kittipong and Miss. Lawan Chaiwiratnukul who helped in processing the editorial work of publication would be also thanked very much.

Kenji NODA
Chairman, Symposium Committee/
Editor

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WEEDS AND THE ENVIRONMENT IN THE TROPICS
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BIOLOGY AND CONTROL OF *MIMOSA PIGRA* L.

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Abstract. *Mimosa pigra* L. has become a serious problem in not only Thailand but also other tropical countries. Regarding habitat, this weed is found at marginal and water-logged places in aquatic areas, abandoned fields, roadsides, etc.

Biological studies on the germination and establishment of this species were conducted in order to learn the causes of serious infestation. *M. pigra* seeds could germinate and establish only under upland conditions, but the seedlings already established became very tolerant against water-flooding, forming spongy tissues on stems and roots.

Low or alternating temperatures, burning by flame, scrubbing by sand and chemical treatments effectively induced seed germination. Scanning electron miscopic observations indicated that the strophiole of seeds might be an important point for water absorption in seed germination after breaking dormancy. Some growth regulators and herbicides were effective in inhibiting seed germination.

Aerial applications of herbicides for controlling *M. pigra* were conducted in northern Thailand. Results from the 1981 experiment indicated that glyphosate gave the best control of the species. Results from the 1982 experiment suggested that glyphosate, picloram, triclopyr and dicamba provided good control. Regrowth from the lower part of plants was found from 120 days after treatments when applied at low spray volumes. Deep flooding at the end of the rainy season provided complete control of regrowth.

INTRODUCTION

Mimosa pigra L. is a thorny and sensitive leguminous shrub species, which recently became one of the most serious weeds, especially in aquatic areas, of certain tropical countries. Although commonly referred to as "giant mimosa", some scientists do not accept this name because there are several other local names such as "catclaw", "giant sensitive plant", "maiyarap yak" in Thai, etc. (Miller *et al.*, 1981; Ooi, 1982; Robert, 1982; Royal Irrigation Dept., 1982; Thammasara and Simagri., 1979). *M. pigra* was introduced to Thailand from Indonesia as a green manure crop in 1952 (Kittipong, 1980). Because of its high adaptability to Thai conditions, this plant has become a noxious weed along rivers, streams and swamp areas in the northern part of Thailand. The presence of *M. pigra* in aquatic areas has caused serious concern because of the disturbance of water flow in rivers and dam reservoirs and the decrease in the volume of reserved water. Further, *M. pigra* plants have invaded waste fields or roadsides along aquatic areas and have formed thick vegetation there. Owing to the shrubby, thorny characters of all stems, branches and petioles, *M. pigra* has made these lands useless.

Control measures involving both mechanical and hand methods have given poor results (Kittipong, 1980; Royal Irrigation Dept., 1982). Chemical control was first introduced in 1975 in an effort to improve efficiency. Foliar applications of several systemic and nonsystemic herbicides on *M. pigra* were evaluated under field conditions in Chiang Mai and Lamphun provinces. Systemic herbicides such as 2,4-D and 2, 4,5,-TP showed a higher efficacy in controlling *M. pigra* and other woody species than contact herbicides such as paraquat (Morton, 1966; Kittipong, 1980).

This paper deals with the investigation of certain biological characteristics of *M. pigra* (Shibayama *et al.*, 1983) as well as evaluation tests on promising herbicides in large scale aerial application.

DISTRIBUTION, HABITAT AND GROWTH

Distribution and Habitat

The distribution of *M. pigra* was investigated world-wide by Habeck, Harley and others, and was reported to include Texas, Central and South America, Central Africa, Southeast Asia, Northern Australia and other countries (Habeck, 1982; Harley, 1982; Miller *et al.*, 1981; Robert, 1982; Wiroatmodjo, 1982). Among these areas, Central and South America were considered to be the origin of this species. However, the countries most seriously infested with *M. pigra* are currently Thailand and Australia.

With regard to the distribution of *M. pigra* in Thailand, Royal Irrigation Dept. (1982), Nopompeth (1982), Robert (1982) and others have collected interesting information from local people and reported the distribution mainly on a provincial basis. The authors made visual surveys of distribution and habitat in northern Thailand from 1981 to 1983 (Fig. 1), because *M. pigra* became one of the most serious weeds,

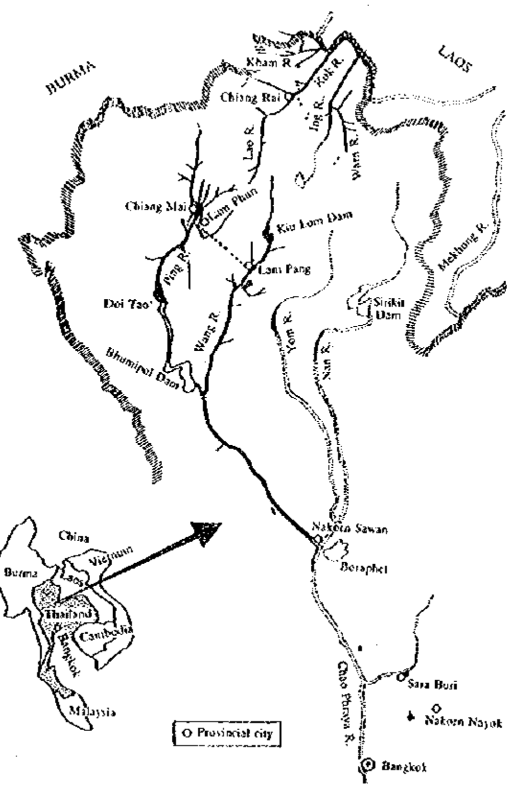

Fig. 1. Distribution of *Mimosa pigra* in northern Thailand (black area).

especially in aquatic areas of northern Thailand, in recent years. With regard to habitat, the plants grow mainly in marginal areas along banks of canals, rivers and lakes, and also inhabit water-logged areas as seen in Kiu Lom Dam and Doi Tao area of Bhumipol Dam Reservoirs (Plate 1). From greenhouse experiments mentioned in another chapter, it is certain that *M. pigra* can germinate from the soil even under upland conditions, where water levels are low during the dry season. As an example, the water level of Kiu Lom Dam Reservoir fluctuated about seven meters during one year in 1980, according to the data of the dam control office. After germination, however, young plants of *M. pigra* were able to grow up in flooded conditions, as water levels rose up month by month (plate 2).

M. pigra has infested many abandoned paddy fields and roadsides, especially in Chiang Mai province. This species shows high adaptability to upland conditions, though its infestation is not so great in other provinces. Abandoned fields were once inundated by water from the *Mimosa*-infested Ping River several years ago when there was heavy flooding around the city. As much of the river basin sand and soil from *Mimosa*-infested areas was widely used for road construction, *Mimosa* seeds were spread along these new roads. The wheels of cars running over roads also carried *Mimosa* seeds elsewhere along roads. Therefore, major *Mimosa* vegetation should be considered to be aquatic or aquatic-originated (Allen *et al.*, 1980). Vegetation under upland conditions as in road-sides, however, does not seem to be vigorous, because the authors could not find any dense *Mimosa* vegetation in upland fields or in mountain areas along these roads, except in wet places like ponds or streams in valleys. *Mimosa* plants do not seem to have the ability to invade in mountains and establish wide vegetation.

In farming areas, *Mimosa* plants usually grow densely only in and along aquatic places like streams, rivers or lakes, and they do not seem to establish in wet paddy fields. If farmers cultivate their arable lands and make weeding thoroughly, *M. pigra* plants do not seem to invade agricultural areas. In aquatic areas, it is interesting to observe that *M. pigra* could not infest deep water areas in rivers, lakes or reservoirs, and it is found only in shallow water river basins along banks and upstream areas in reservoirs. Only a few plants can be found near dam areas. These observations and our experiments show that *Mimosa* plants cannot germinate in deep, permanently water-logged areas. *Mimosa* seeds can germinate only in soils under upland conditions during the dry season as mentioned above. Even *M. pigra* vegetation already established is sometimes killed by deep flooding as seen at the Doi Tao area of Bhumipol Dam Reservoir.

A computer-analyzed colour picture of "Landsat" data on Kiu Lom Dam Reservoir area shows the usefulness of this method in surveying future changes of *M. pigra* vegetation by satellite. This survey and greenhouse experiments suggest the *M. pigra* has the potential to infest many other water areas of Thailand and other tropical countries in the future. However, this species cannot grow in aquatic areas where land is flooded throughout the year. Therefore, it is certain that *M. pigra* plants cannot infest downstream of the Chao Phraya River to Bangkok or the Mekong River to Vietnam, where the rivers are covered by deep water throughout the year.

Growth in Water-flooded Conditions
The growth and development of *Mimosa pigra*, including flowering and seed production, were extensively studied by Wanichanantakul *et al.*, (1979), Wara-Aswapati (1981), and others. However, its growth adaptability to flooded conditions has been barely investigated. Therefore, the anatomical structure of *M. pigra* roots from seedlings grown under upland and water-flooded conditions were investigated in order to discover the adaptability of *Mimosa* plants to both conditions.

Water-flooding provides the formation of spongy tissue from the periderm of *Mimosa* roots. As primary tissues, the epidermis and cortex are usually crushed by the secondary growth of the stele in seedlings from upland soil, but still exist at early stages of secondary growth in those from flooded conditions. Cork cell layers were found in the roots under flooded conditions, but were peeled off under upland conditions (Plates 3 and 4). Morphological differences of roots in both conditions may show physiological differences in adaptation of *Mimosa* roots to aquatic and upland conditions, though the mechanism of adaptation is not yet clear.

SEED GERMINATION AND ESTABLISHMENT

Effect of Soil Conditions
Mimosa pigra seeds could germinate well in all kinds of tested upland and paddy soils as seen in Table 1, although there were slight differences among them.

In sowing depth experiments, the hard seeds of *M. pigra* could swell by imbibing water, and germinate even in 20 *cm* depths of soil under

Table 1. Effects of soils* collected from different locations of Thailand on seed germination of *Mimosa pigra*.

Soil type	Germination rate		
	1 week	2 weeks	3 weeks**
(Test from Sept. 18th, 1981)			
Sand	85%	85%	85%
Upland soil, sandy[1)]	3	61	61
Upland soil, black[2)]	78	78	78
Upland soil, red[3)]	84	84	84
Mountain soil, Marl[4)]	79	82	82
Paddy soil, dried[5)]	34	49	57
Paddy soil, wet[5)]	64	68	69
(Test from June 21st, 1982)			
Sand	75	75	75
Paddy soil, dried[6)]	80	83	83
Wasteland soil, dried[7)]	63	73	78

Remarks: * In an upland condition
** No germination after 3 weeks

Locations of soil sampling;
1) Pakchong, Nakorn Ratchasima
2) Pattananikom, Lopburi
3) Muang, Mahasarakam
4) Tara, Saraburi
5) Bangkhen, Bangkok
6) Chiang Mai
7) Doi-Tao, Chiang Mai

upland conditions, though emerging up to the soil surface was possible only from 7 *cm* depth or less (Table 2). When seeds were placed deeper than 7 *cm* in the soil, they could germinate and grow, but the cotyledons could not reach the soil surface owing to the cessation of elongation and all of these underground seedlings died and later decayed. On the other hand, in water-flooded conditions seeds scarified with boiling hot water could swell by imbibing water when buried below the soil surface, but could not germinate at all, probably due to seed dormancy induced again by the anaerobic soil conditions. These swollen seeds, black in color, could germinate when dug out of flooded soil and put into the aerobic conditions.

These results, similar to Bhanthumnavin's (1977), show that *M. pigra* plants can probably grow on any kind of soil, but cannot emerge to the soil surface if seeds are placed deeper than 7 *cm* by cultivation or other practices.

Table 2. Effect of sowing depth* on seed germination of *Mimosa pigra*.

Sowing depth		Germination rate	
		1 week	2 weeks**
		%	%
Sandy upland Soil	1 *cm*	71	75
	3	40	44
	5	43	45
	7	34	36
	10	–	–
	15	–	–
	20	–	–
Sand	1 *cm*	86	87
	3	82	84
	5	67	69
	7	32	48
	10	–	–
	15	–	–
	20	–	–

Remarks: * In an upland condition
**No germination after 2 weeks

Effect of Water Flooding

Flooding at depths of 0 to 20 *cm* over soil surface after *M. pigra* seeds were sown, allowed imbibition of water and consequently germination. Radicles and cotyledons developed to some extent. Cotyledons were green under flooded conditions and then seemed to be normal. Germinated seedlings, however, could not establish on the bottom of soil under flooded conditions, and their radicles could not elongate into the soil, curved upwards or wound in the water without anchoring to the soil. These seedlings were detached from the swollen seed coats, usually floated up to the water surface and finally died. In our observations, *M. pigra* plants which germinated under flooded water could not establish in the soil, even if they were marginally attached to the soil surface after floating up. Only a few seedlings survived in 0 *cm* flooding in this experiment, and their growth was very limited. As the results of three tests were alomost identical, only the results of the first are shown in Fig. 2.

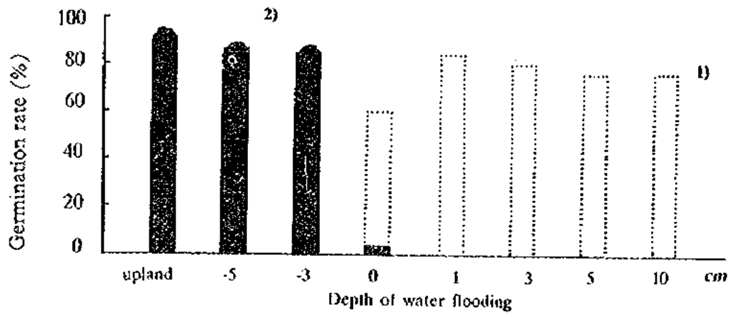

Fig. 2. Effects of water levels on seed germination of *Mimosa pigra.*

1) In a flooded condition (water level 0-10 *cm*), the majority of seeds decayed (0 *cm*) or floated up on the water surface and could not grow at all (1-10 *cm*) (dotted line), though some seeds could germinate.

2) Levels of -5 and -3 show the water level of 5 and 3 *cm* below the soil surface, respectively.

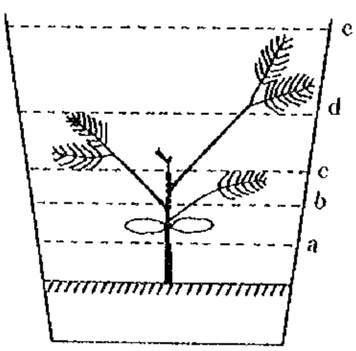

Fig. 3. Levels of water flooding for the seedling of *Mimosa pigra.*

a: under cotyledon, d: under 3rd leaf,
b: under 1st leaf, e: all leaves (complete flooding)
c: under 2nd leaf,

The effects of water flooding on the growth and establishment of *M. pigra* seedlings are shown in Fig. 3 and Table 3. Complete flooding (all leaves, in Table 3) of *M. pigra* seedlings for 2 weeks (flooded at cotyledon stage), 3 weeks (flooded at 1st leaf stage), 4 weeks (flooded at 2nd leaf stage), and 5 weeks (flooded at 3rd leaf stage) killed all plants in treated pots, but flooding for 2 weeks at 2nd leaf stage and for 1 and 3 weeks at 3rd leaf stage did not kill any seedlings, and regrowth began quickly when plants were returned to upland conditions. On the other hand, flooding for 3 months was found to kill even large vegetation in Doi Tao area of Bhumipol Dam Reservoir in 1981. In this experiment, tap water which is clearer than natural river or canal water, was used as the flooding water. Natural water contains many soil particles which reduce the light intensity in water. Therefore, completely submerged plants in this experiment could probably survive more days than plants flooded by river water in natural conditions. Flooding below the cotyledon or flooding below other leaves did not kill *Mimosa* seedlings, although root development was considerably inhibited in these seedlings as shown in a top-root ratio of below 4.7 in the untreated control plants (Table 3).

Table 3. Effect of water-flooding on growth of seedlings of *Mimosa pigra*.

Leaf stage of *Mimosa* at flooding	Depth of flooding*	Number of survived plants	Fresh weight per plant	Top-root ratio (T = 1)
		%	%	
Cotyledon	All leaves (2 weeks)	0	0	0
	Under cotyledon	85	76	3.6
1st leaf	All leaves (3 weeks)	0	0	0
	Under 1st leaf	31	60	2.6
	Under cotyledon	98	39	3.0
2nd leaf	All leaves (4 weeks)	0	0	0
	All leaves (2 weeks)	86	66	3.5
	Under 2nd leaf	88	42	2.2
	Under 1st leaf	92	57	2.9
	Under cotyledon	89	48	3.8
3rd leaf	All leaves (5 weeks)	0	0	0
	All leaves (3 weeks)	46	20	1.9
	All leaves (1 week)	95	107	3.9
	Under 3rd leaf	80	29	1.7
	Under 2nd leaf	86	75	3.1
	Under 1st leaf	96	67	4.0
Untreated Control		100	100	4.7

Remark: * Shown in Fig. 3

From these experiments, it can be concluded that, although non-dormant *M. pigra* seeds can germinate even in water-flooded conditions,, they cannot grow and establish because germinated seedlings will float up to the water surface without anchoring to the soil and will later die. *M. pigra* seedlings, which germinate on the soil where water is below saturation, can establish and withstand water-flooding provided upper leaves remain above the water surface. Even complete flooding in the rainy season will take a few weeks to kill the submerged seedlings of *M. pigra*.

Effects of Temperature and Light

With regard to constant temperature experiments, hot water was effective for breaking the dormancy of *Mimosa* seeds (Premasthira, 1981) by 1 sec to 1 week treatments and the germination rate increased as temperatures were raised to 98°C (Figs. 4 and 5).

In each temperature, the germination rates were tended to increase and then decrease as the treatment time became longer (Fig. 4).

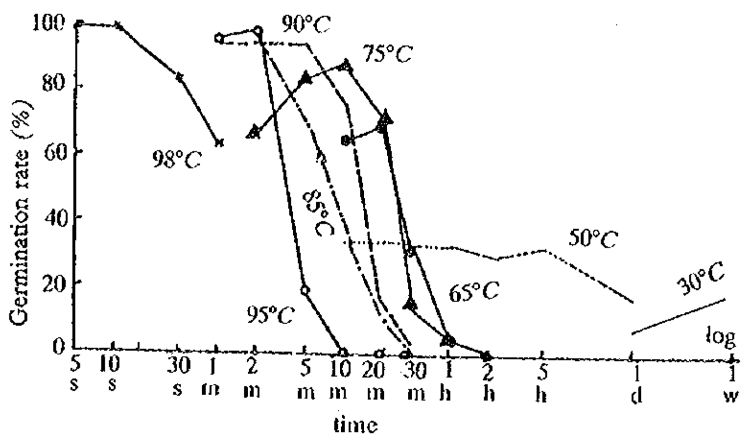

Fig. 4. Effect of periods of constant temperature treatment by hot water bath on germination of old seeds of *Mimosa pigra*.
Experiment was conducted in August to October, 1982. Seeds were moved to room temperature after treatment. Old seeds were collected in 1981.
s : second, m : minute, h : hour, d : day, w : week

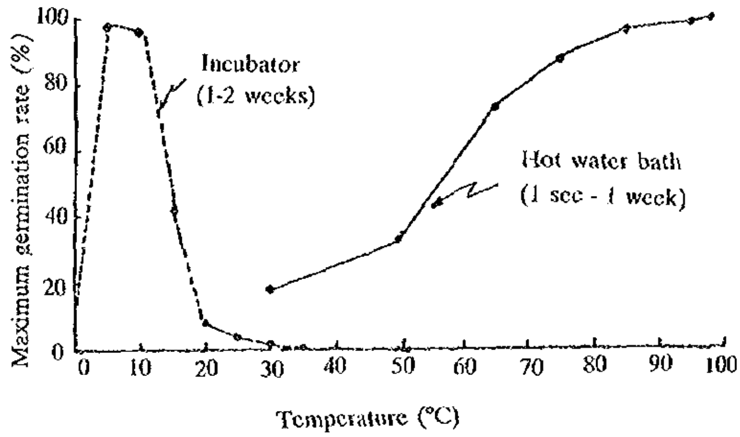

Fig. 5. Effects of constant temperatures on maximum germination rate of old seeds of *Mimosa pigra*.
Experiment was conducted in August to October, 1982. Seeds were moved to room temperature after treatment. Old seeds were collected in 1981.

One week treatment of low temperatures of 5 and 10°*C* was very effective in breaking the dormancy of old seeds collected in 1981, but as temperatures were raised the germination rate decreased (Fig. 5). With regard to alternating temperature experiments, 10 to 20°*C* differences between day and night temperatures for 1 or 2 weeks gave the high rates of breaking dormancy. At day temperatures of 30 or 35°*C*, a 15°*C* difference was necessary to get high germination rates, but at day temperatures of 25°*C* or less, even 10°*C* difference was enough to get high germination rates. Moreover, in the test of 1982, old seeds collected in 1981 showed higher germination rates than new sseds collected in 1982 (Fig. 6).

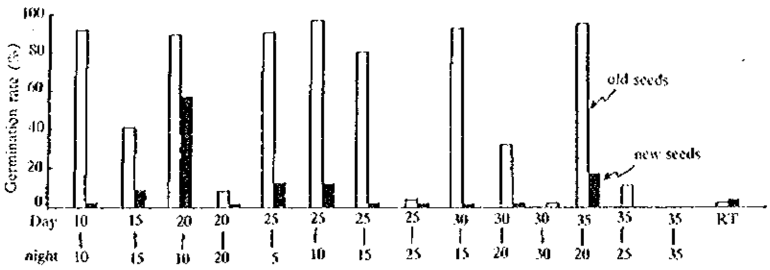

Fig. 6. Effects of alternating temperatures on germination of old and new seeds of *Mimosa pigra*.
Experiment was conducted in August to October, 1982. Temperatures were treated one or two weeks (day temperature 25 C only), and then seeds were moved to room temperature. Old and new seeds were collected in 1981 and 1982, respectively. Day (light) : 6.00 *a.m.* - 6.00 *p.m.*, Night (dark) : 6.00 *p.m.* - 6.00 *a.m.* RT : room temperature.

Under natural conditions, seeds of *M. pigra* seem to germinate more as they become the older. In our experiments, old seeds which had been stored for more than one year after collecting showed better germination rates than new seeds. Bhanthumnavin (1977) got better germination rates than ours when she used four or five years old *Mimosa* seeds, and reported that 64% of such seeds germinated when incubated at 32°*C* room temperature for 10 days. These results suggest that the germination rate of *M. pigra* seeds increases year by year after ripening and shedding in the soil surface or at the bottom of water in aquatic areas.

Seed germination of *M. pigra* was enhanced strikingly when low temperatures such as 5 to 20°*C* were used in constant or alternating temperatures. According to the data of the Meteorological Department, Thailand (1981), mean maximum and minimum temperatures during the winter season in Chiang Mai are around 29 and 15°*C*, respectively. Therefore, one of the reasons for *Mimosa*'s serious invasion in northern Thailand is considered to be the low temperatures in this region.

Light-dark (day-night) and continuous dark conditions did not show any differences in seed germination (Fig. 7). Seeds stored in water germinated more than those in an air dry condition under alternating or constant temperatures.

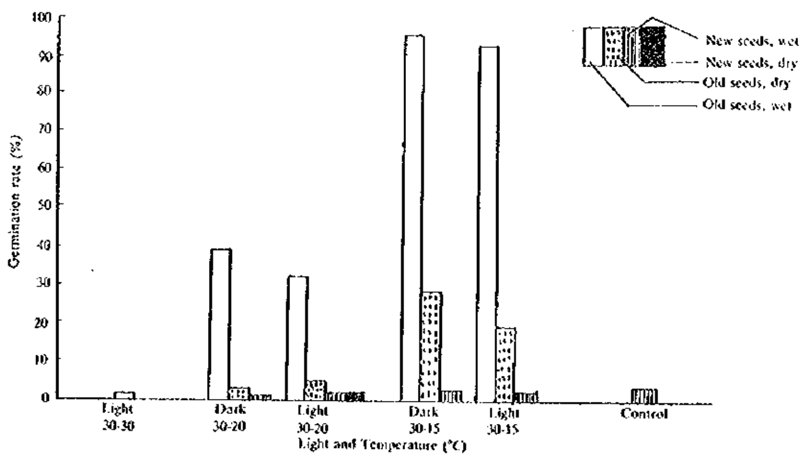

Fig. 7. Effects of light and storage conditions on seed germination of *Mimosa pigra*.

Experiment was conducted in September to October, 1982, at alternating temperatures of 30-20 or 30-15 C. Old and new seeds were collected in 1981 and 1982, respectively.

Light: day time (6.00 *a.m.* - 6.00 *p.m.*) only and night time was dark.

Dark: whole day dark

Wet: stored in water

Dry: stored in an air-dry condition

Effects of Other Factors

Seeds collected in 1982 were subjected to burning by flame and scrubbing with sand paper to confirm that *Mimosa* seeds germinate in large numbers after vegetation along roadsides is burned or after river sand containing numerous *Mimosa* seeds is used for road construction.

Burning was effective for breaking the dormancy of new seeds of *M. pigra* (Fig. 8), but flaming of more than 10 or 20 seconds was usually too long because almost all burned seeds were popped and did not germinate at all. Scrubbing seeds with sand paper was also effective for

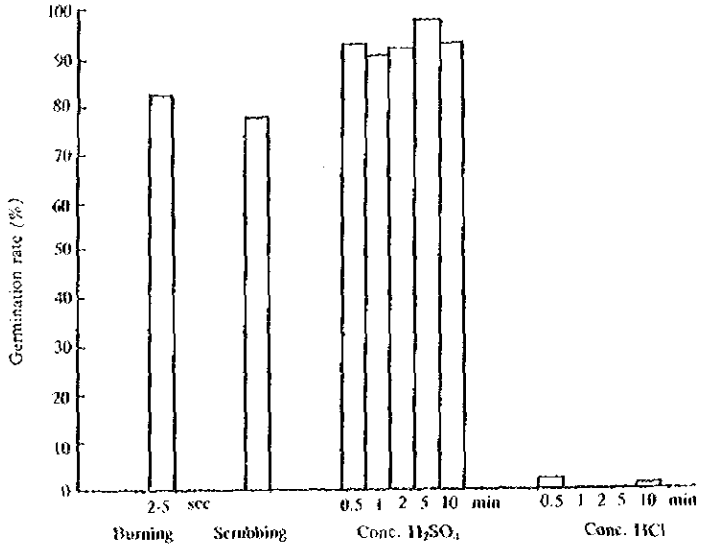

Fig. 8. Effects of burning by flame, scrubbing by sand paper, conc. H_2SO_4 and conc. HCl on germination of new seeds of *Mimosa pigra*.
Experiment was conducted in 1982. New seeds were collected in the same year.

germination (Fig. 8). However, when seeds were mixed with sand in a small bag and scrubbed strongly by hand or beaten several times on the ground, germination was not enhanced at all. Burning *M. pigra* plants and agitating sand or soil mixed with seeds were largely confirmed experimentally to induce the awakening of *M. pigra* seeds from dormancy, although the mixing of seeds with sand for scrubbing by hand or beating on the ground did not give any effect.

To break the dormancy of new seeds, treatments with conc. H_2SO_4 and conc. HCl for 0.5 to 10 *min* and with organic chemicals such as acetone (99.5% and 98%), ethyl alcohol (100%, 99.8% and 70%), ethyl ether (99% and 95%), benzene (100%), xylene (96%), toluene (97.5%) and chloroform (99%) for 10 *min*, 1 *hr* and 1 day were made. A conc. H_2SO_4 treatment for 0.5 to 10 *min* was very effective, but conc. HCl did not break seed dormancy (Fig. 8). Among the organic solvents, only 99.5% acetone (Analytical grade) was effective in awakening dormant *Mimosa* seeds, no other treatments showing any effect (Fig. 9).

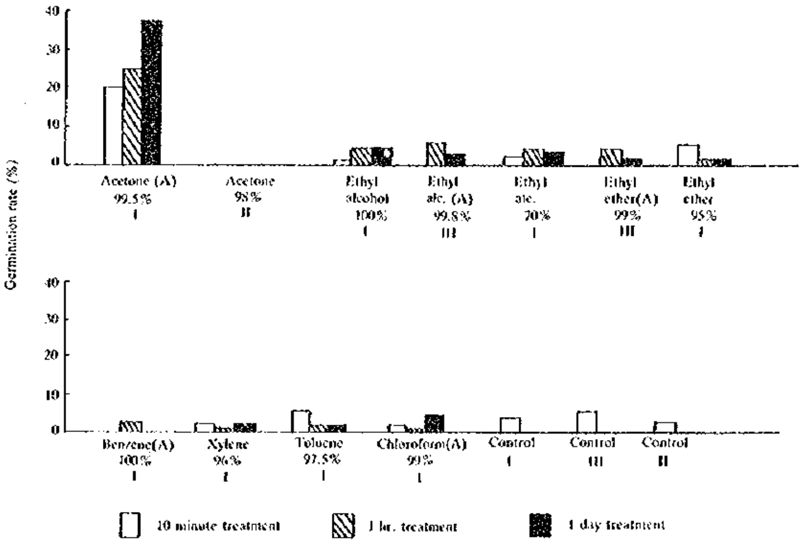

Fig. 9. Effects of organic chemicals on seed germination of *Mimosa pigra*.

Experiments were conducted three times in November (I), December(II), of 1982 and February(III) of 1983. New seeds collected in 1982 were used.

(A) were "analytical grade", others were "extra pure grade"

Scanning Electron Microscopic Observations on Seed Coats

Regarding environmental or artificial factors which affect the seed germination of *M. pigra*, it was considered that seed coat dormancy was broken by these factors (Bhanthumnavin, 1977). On the other hand, changes of water permeability of the strophiole or hilum area of the seed (Fig. 10) was found to be important for water imbibition and then for dormancy breaking of some leguminous seeds, and most parts of the seed coat were found not to be the primary site of water entry (Egley, 1979).

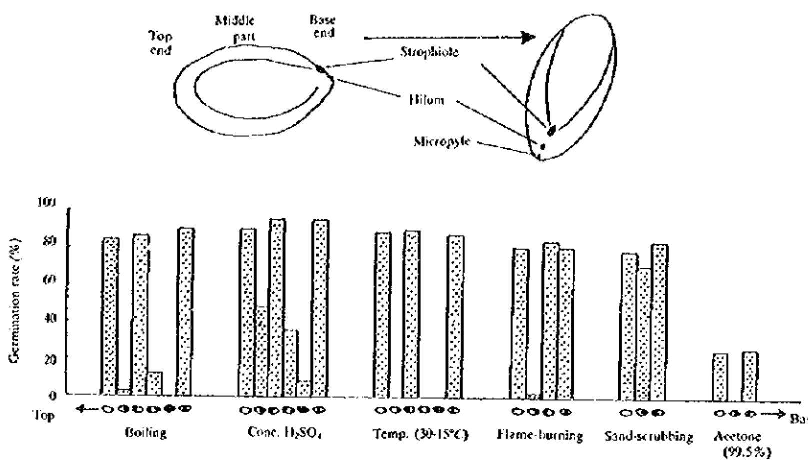

Fig. 10. Effect of vaselline coating on seed germination of *Mimosa pigra*.

New seeds collected in 1981 were used for treatments except "alternating temperature" in which old seeds collected in 1981 were used. Vaselline was coated at black portions of the above-figured seed. Left end of seed was the top and right one was the base in the above figure. Experiment was conducted in 1982.

This work was conducted to investigate what part of *Mimosa pigra* seeds would be affected by dormancy breaking factors to result in an increase of seed coat permeability. The seed coat of *M. pigra* was affected with various treatments for breaking dormancy as mentioned previously, and many of seeds began to imbibe, swell and germinate. However, when the top, middle and base ends of each seed (Fig. 10) were coated with vaseline after treatments, these coated seeds revealed differences in water absorption and germination.

As seen in Fig. 10, seeds treated with boiling hot water, alternating temperatures, flame burning and acetone had little or no germination when the base end was coated with vaseline, but those in which the middle or top ends were coated, germinated very well as did uncoated seeds. Seeds treated with conc. H_2SO_4 and sand scrubbing could germinate at about the same or half the rate of uncoated seeds, even when the base ends of the seeds were coated with vaseline. The strophiole, hilum and micropyle tissues are at the base end of seed in this experiment. Boiling hot water, alternating temperatures, flame burning and acetone, which induced water imbibition through the base end of the seed, would be mainly effective in changing the water permeability of these tissues (Egley, 1979). However, these treatments seemed to be ineffective in enhancing water imbibition through other parts of the seed coat. On the other hand, conc. H_2SO_4 and sand scrubbing treatments seemed to change water permeability in all parts of the seed coat (Fig. 10).

Thus, scanning electron microscopic observations on seed coats of *Mimosa pigra* were made. Boiling and low temperature treatments produced little change at the top and middle parts of *Mimosa* seeds compared with utreated seeds (Plate 5). However, the strophiloes at the base end which seemed to be sited of water entry to break dormancy (Plate 6, 7) were frequently swollen and cracked after these treatments. No. external morphological change was found at the hilum or micropyle. On the other hand, a conc. H_2SO_4 treatment caused severe damage to the outer layer of the seed cost (Plate 8) in addition to swelling and cracks in the strophioles. This damage would be the reason for the differences in water imbibition after various dormancy breaking treatments and vaseline coating.

In natural conditions, it seems that the dormancy of *M. pigra* seeds will be broken mainly by factors which produce swelling and cracks in the strophiole, although Egley (1979) reported that the hilum was the main site of water permeability for other leguminous species.

CHEMICAL CONTROL BY AERIAL SPRAYING

Materials and Methods

The test site of chemical control by aerial spraying (Plate 9) was located in Kiu Lom Reservoir, Lampang province 642 kilometers north of Bangkok whose elevation is 241 meters above sea level. Average annual rainfall within the area is 1,079 *mm*. The maximum and minimum temperatures are approximately 32.6°*C* and 20.2°*C* respectively. Sunshine averages approximately 8.0 hours per day.

Water depth in the test area reaches a maximum of 3.5-4.0 meters in December or January but the reservoir is completely dry in May and remains in this state for about 4 months before the monsoon flooding begins.

Herbicides used in 1981 were glyphosate 41% [N-(phosphonomethyl) glycine] at 12.5 and 25.0 liters (product)/*ha* and fosamine 42% [ethyl hydrogen (aminocarbonyl) phosphonate] at 18.75 and 31.25 liters (product)/*ha* with 125, 250 and 375 liters of spray solution/*ha*. In 1982, test herbicides included glyphosate, picloram 49.8% (4-amino-3,5,6-trichloropicolinic acid) and triclopyr 48% {[(3,5,6-trichloro-2-pyridinyl) oxy] acetic acid} at 6.25 and 12.5 liters (product)/*ha* and dicamba 40.6% (3,6-dichloro-o-anisic acid) at 12.5 and 25.0 liters (product)/*ha* in 62.5 and 125 liters/*ha* of spray volume.

Age of the natural growth of *M. pigra* within the test area was estimated to be 4-5 years old with heights ranging mostly from 4.0-4.5 meters.

Spraying was conducted with a "Miller 305" helicopter travelling at 20 knots equipped with a 160 liter spray tank and 59 nozzles on a 9.7 meter spray boom which covered 10 meters each swath. All applications were made near plant-top level. Time of application was between 8 *A.M.* to 4 *P.M.* in 1981 and between 8.00-11.00 *A.M.* in 1982.

A randomized block design with two replications was used in this test. Plot size measured 20 × 320 meters or 6,400 square meters. Data were collected from the middle of each plot. Visual observations were made at 30 day intervals using a 0-10 point scale throughout the 12 months study.

Results and Discussion

Data collected in the 1981 wet season are summarized in Table 4. Results show that within the first month after application of fosamine and glyphosate on a natural growth of mimosa in Kiu Lom reservoir more than 90 percent of the giant mimosa was defoliated. Glyphosate showed more effect than fosamine.

At the end of the first 30 days after treatment, glyphosate at 12.5, 25.0 liters (product)/*ha* in 125, 250 and 375 liters of spray solution provided approximately 90-100 percent defoliation when compared with fosamine at 18.75 and 31.25 liters (product)/*ha* in the same amount of spraying volume which resulted in 70 to 90 percent defoliation.

Table 4. Performance of glyphosate and fonsamine for *Mimosa pigra* control by aerial application at Kiu Lom reservoir, Lampang, Thailand, 1981.

Treatments	Rate Lts (mat)/ha	Spray Vol. Lts/ha	Performance (d.a.t.)					
			30	100	120	180	240	365
forsamine	18.75	375	7.0	4.0	2.0	0	0	0
forsamine	31.25	375	9.0	6.0	5.0	3.0	0	0
glyphosate	12.5	375	10.0	9.5	10.0	10.0	10.0	10.0
glyphosate	25.0	375	10.0	10.0	10.0	10.0	10.0	10.0
glyphosate	12.5	125	10.0	9.5	9.5	9.5	9.0	9.0
glyphosate	25.0	125	10.0	10.0	10.0	10.0	10.0	10.0
fosamine	18.75	125	7.0	4.0	3.0	0	0	0
fosamine	31.25	125	8.0	6.0	4.0	3.0	2.0	0
fosamine	18.75	250	7.0	4.0	2.0	0	0	0
fosamine	31.25	250	8.0	6.0	5.0	3.0	0	0
glyphosate	12.5	250	9.0	9.5	7.5	5.0	4.0	4.0
glyphosate	25.0	250	10.0	10.0	8.0	7.0	4.0	4.0

Remarks: Figures are from visual observation using a 0 to 10 scale with 10 being 100% defoliation
d.a.t. = days after treatment

At 100 days after treatment, the killing action of glyphosate appeared to be at a satisfactory level with complete defoliation noted on plants treated at both rates at all three levels of spraying solutions. The killing action of fosamine declined with time.

Regrowth from stems was observed on plants treated with fosamine. The chemical apparently was not mobile within the plants because the tops of the plants were defoliated but the lower branches remained green. Similar results were observed at 120 days following application of fosamine.

At 180 days following treatment continued regrowth was found on fosamine treatments with the lower rate showing almost complete regrowth.

Application of glyphosate at both low and high rates with 125 and 375 liters of water/ha provided satisfactory results but application of the same concentrations in 250 liters of water showed approximately 50 and 30 percent regrowth. Similar results were recorded at 240 days after treatment.

At the final checking, or at 365 days after chemical application, results showed that glyphosate at 12.5 and 25.0 liters (product)/*ha* in 125 and 375 liters of spray volume gave 90-100 percent control of *Mimosa* plants but application of the same rates in 250 liter/*ha* of spraying solution resulted in 60 percent regrowth. All spray treatments with fosamine showed complete regrowth one year after spraying was done.

Results from the 1982 dry season are listed in Table 5. Data indicate that herbicides such as dicamba, glyphosate, picloram and triclopyr showed fast top killing action within 30 days after application under the dry condition of Kiu Lom area. Complete defoliation of the leaves and complete killing of the top plant parts were noted 60 days after treatment. Visual observations indicated no differences among treatments during the 60 days after spraying.

Table 5. Performance of dicamba, glyphosate, picloram and triclopyr for *Mimosa pigra* control by aerial application at Kiu Lom reservoir, Lampang, Thailand, 1982.

Treatments	Rate	Spray Vol.	Performance (d.a.t.)				
	Lts (mat)/*Rai*	*Lts/ha*	60	120	180	240	365
dicamba	12.5	62.5	10.0	9.5	8.0	10.0	10.0
dicamba	12.5	125.0	10.0	10.0	10.0	10.0	10.0
dicamba	25.0	62.5	10.0	10.0	10.0	10.0	10.0
dicamba	25.0	125.0	10.0	10.0	10.0	10.0	10.0
glyphosate	6.25	62.5	10.0	10.0	8.0	10.0	10.0
glyphosate	6.25	125.0	10.0	10.0	10.0	10.0	10.0
glyphosate	12.5	62.5	10.0	9.5	8.5	10.0	10.0
glyphosate	12.5	125.0	10.0	10.0	10.0	10.0	10.0
picloram	6.25	62.5	10.0	8.5	8.0	10.0	10.0
picloram	6.25	125.0	10.0	10.0	9.0	10.0	10.0
picloram	12.5	62.5	10.0	8.5	8.0	10.0	10.0
picloram	12.5	125.0	10.0	10.0	9.0	10.0	10.0
triclopyr	6.25	62.5	10.0	9.0	7.0	10.0	10.0
triclopyr	6.25	125.0	10.0	10.0	8.0	10.0	10.0
triclopyr	12.5	62.5	10.0	9.5	7.5	10.0	10.0
triclopyr	12.5	125.0	10.0	9.5	8.5	10.0	10.0

Remarks: see Table 4

Records at 120 days after application showed slight differences in the degree of efficacy for all four tested compounds compared to 60 days following spraying.

Observations made at 180 days after application indicated that dicamba at 12.5 and 25.0 liters (product)/*ha* and glyphosate at 6.25 and 12.5 liters (product)/*ha* in 125 liters of spraying volume gave complete control similar to the first 30 day checking but application of both herbicides at the same rates using 62.5 liters spray volume gave less control with time and regrowth was observed on the lower parts of the stems. Regrowth was also recorded from plots treated with picloram and triclopyr at 6.25 and 12.5 liters (product)/*ha* in 62.5 and 125 liters of spraying solution.

A better degree of control was detected from all treatments at 240 days after application and absolute control was obtained after 240 days and up to 360 days after application due to the increasing water level in the reservoir at the end of the rainy season.

Visible toxicity to near-by vegetation indicated that glyphosate was highly selective on many broadleaf species other than grasses. Dicamba on the other hand showed high selectivity for grasses while the rest of the tested compounds did not show any selectivity for grasses or broadleaf plants.

Fosamine and glyphosate showed similar defoliation action on natural growth of *Mimosa* plants at 30 days after application, but the effectiveness of glyphosate increased with time and a high water level in the Kiu Lom reservoir. This suggests that high moisture conditions speeded up glyphosate activities (Jordan, 1977). The increase in glyphosate action might relate to its classification as an ambimobile rather than a specific phloem-mobile herbicide (Dewey and Appleby, 1983).

The visible toxicity obtained from application of fosamine indicated that it did not translocate within the plant and its activities decreased with time. Good coverage of all the leaves and green plant parts is important for effectiveness of fosamine. A spray volume less than 200 liters/*ha* is not sufficient for fosamine to control plants taller than 1.5 *m* in height (Niehuss, 1974).

Time of application is also critical for aerial control of *M. pigra*. Treatments applied in the morning allowed plants to absorb more chemical than when applied later in the afternoon of the same day.

Data collected from the dry season experiment indicated that foliar application under dry conditions stimulated absorption and translocation of all four tested compounds. Deep penetration through both apoplast and symplast portions of the plants by dicamba and glyphosate resulted in better control of *M. pigra* when compared with picloram and triclopyr in the first 6 months. The minimum spraying volume for aerial control of natural growth plants is 125 liters/*ha* or more (Niehuss, 1974). Suitable spraying time for best control is from morning up until noon.

The results suggest that *Mimosa pigra* can be controlled if the proper herbicides, spray volume and timing are used (plates 10, 11, 12, 13 and 14). Economics of using the aerial spray procedure have not yet been worked out.

CONCLUSION

With regard to the *Mimosa pigra* problem in not only Thailand but also other countries, there is the danger of future spreading to many other aquatic areas of tropical countries because of the prolific ability of *M. pigra*. This species, however, may be incapable of infesting the main streams of large rivers such as the Chao Phraya river and the Mekong river because *M. pigra* seeds cannot germinate and establish at heavily water-logged places. Further, this species cannot infest natural forest areas in mountains as well as agricultural lands under cultivation.

The management program of *Mimosa pigra* in aquatic areas and their surroundings should be designed based on the following ideas.

1) Application of herbicides such as glyphosate, dicamba, triclopyr and picloram is certainly effective, but the complete eradication of this weed from specific areas by herbicide application alone is not preferable because it would require a large amount of chemicals with the potential of producing adverse effects on the environment.

2) Mechanical and/or manual procedures for eradicating this species are very tedious and expensive because of its stout growth with many acute spines on main and branched stems.

3) This program should not be terminated in a short time, because *Mimosa pigra* is likely to create regrowth and reinfestaion through seeds buried in the soil even when the major part of the vegetation is

controlled. Further, it will take a long time to practice biological control by insects and/or plant pathogens in the future.

4) Integrated control of *Mimosa pigra* should be practised by means of combining chemical control, mechanical control, hand weeding, water level management, biological control, and so on.

5) The utilization of *Mimosa pigra* should be very significant for its long term management. Success, however, depends on various multiple, longterm studies in the future.

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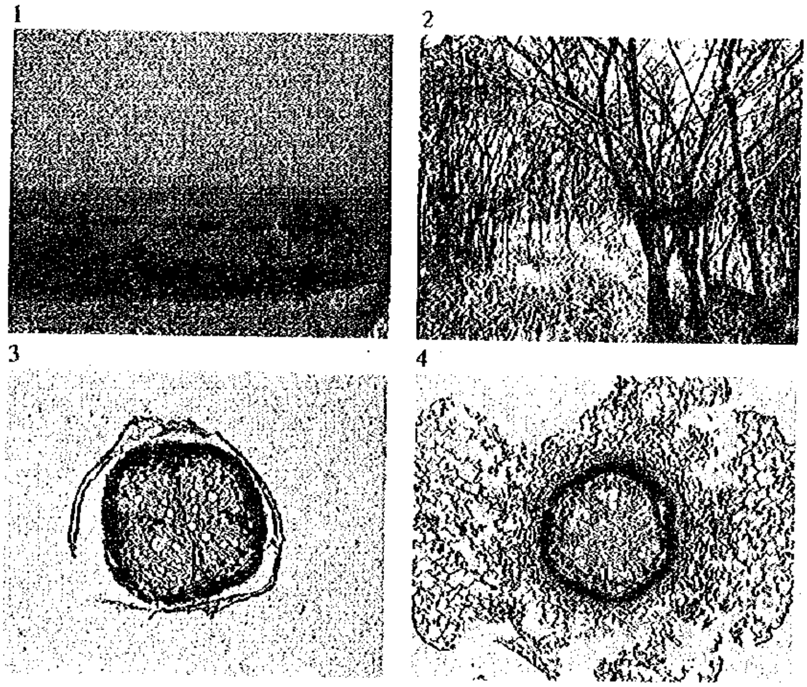

Plate 1. A general view of *Mimosa* vegetation at Doi Tao area of Bhumipol dam reservoir.
2. Big trees of *Mimosa pigra* at Kiu Lom dam reservoir in dry season.
3. Cross section of *Mimosa pigra* root in upland soil.
4. Cross section of *Mimosa pigra* root in flooded water.

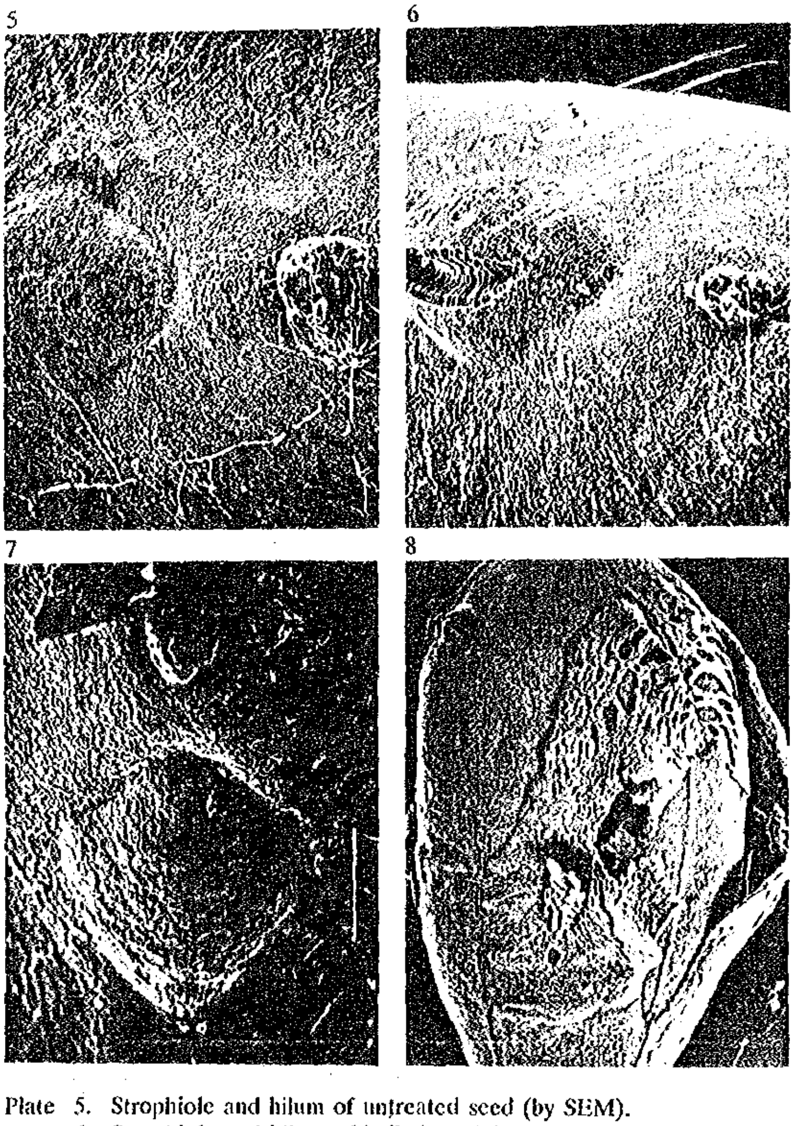

Plate 5. Strophiole and hilum of untreated seed (by SEM).
6. Strophiole and hilum of boiled seed (by SEM).
7. Strophiole and hilum of low temperature treated seed (by SEM).
8. Conc. H_2SO_4 treated seed (by SEM).

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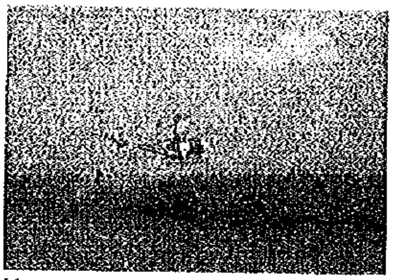

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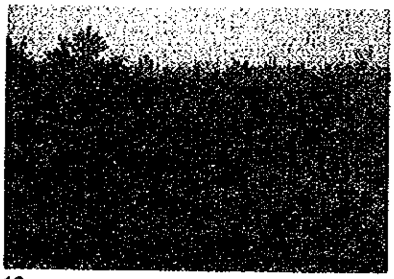

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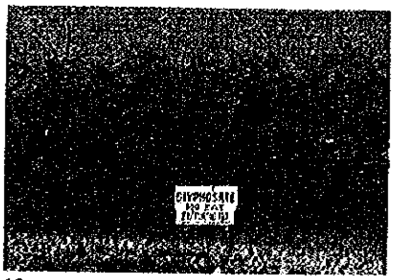

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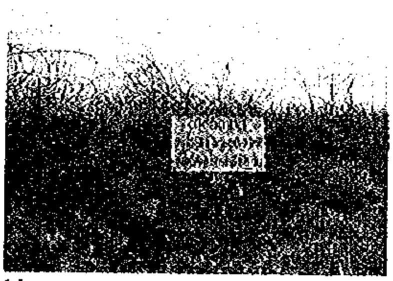

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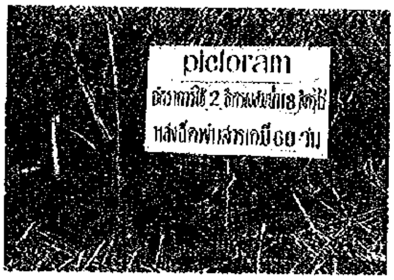

Plate 9. Aerial spraying by Helicoptor "Miller 305".

10. Untreated vegetation of *Mimosa pigra*.

11. Glyphosate 100 days after application at 2 *l/rai*/40 *l* H_2O.

12. Dicamba 60 days after application at 1 *l/rai*/9 *l* H_2O.

13. Triclopyr 60 days after application at 2 *l/rai*/18 *l* H_2O.

14. Picloram 60 days after application at 2 *l/rai*/18 *l* H_2O.

(6.25 *rai* = 1 *ha*)

WEEDS AND THE ENVIRONMENT IN THE TROPICS
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ENVIRONMENTAL CONSIDERATIONS IN THE NOVEL APPROACH OF AQUATIC VEGETATION MANAGEMENT

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Abstract. The growing environmental awareness since the 1960's refers among others to the improvement of measurement techniques, and the rapid increase of the knowledge of dose-response relations. There is also an increasing concern of the fact related to our finite world, the increasing pressure of the human population and the continuous changes of life-style on the limited resources on earth. This creates various problems due to the increasing production of wastes and the increasing disorders in the system in which we live. One of the important impacts of the increased activities of man on aquatic system is the unwanted growth of aquatic vegetation. Under certain tropical conditions this may facilitate an increasing complexity of problems in a proper water resources management. Therefore, an appropriate approach should be developed for an environmentally sound aquatic vegetation management, so that side effects and negative impacts can be mitigated, while the problems are viewed from an optimistic dimension, and considered as opportunities.

Some of the common practices in aquatic vegetation management and some of the shortcomings will be presented and the novel approaches of aquatic vegetation management with environmental considerations will be discussed. These among others considering aquatic vegetation as a potential resource, in which utilization of its biomass will have twofold benefits, namely to get a pay-off from getting rid of the aquatic biomass. There are various opportunities to utilize aquatic vegetation for the direct and indirect benefits for men. In the biological control method of aquatic vegetation the use of herbivorous fauna ending it up beneficially for men, e.g. fish, or competing it with other more beneficial vegetation, *e.g. Ipomoea aquatica* and other hydrophonic plant species. This is better than ending in the trophic pyramids with a top level fauna unknown in its

function in the system. Another novel approach is the use of slow-released formulations of herbicides with polyvinyls, alginates, rubbers, etc. to minimize the potential drift which may pollute the aquatic system. There are, of course, other environmental risks in the development of these methods, among others the potential development of resistance, which will be discussed as potential risks to be considered. It is hoped that with an appropriate environmental consideration the aquatic vegetation management could be implemented properly, that we may achieve a better quality of live in a better and healthy environment.

INTRODUCTION

Since 1960's there have been a growing awareness that the biosphere is anticipating environmental crises. This culminated in 1972 when the Stockholm Declaration on the Human Environment was declared, which gave an empetus to the development of "modern" environmental studies and management. The growing awareness refers also among others to the improvement of measurement techniques, in which *e.g.* trace elements or pollutants can be accurately measured or detected. This has been accompanied with the rapid increase of our knowledge in dose-response relations. Any component in our system is related, interacted, and dependent with other components.

There is only one world, while due to its rapid increase, the human population creates pressures not only by number, but also by the changes in human life-styles. Consequently the study of the human environment must be a complicated one. One aspect of study in environmental science is that often there is no simple answer to any given problem. There is always controversy as an integral part of the study. Therefore, environmental consideration in any effort to manage a system will result in something compromistic in nature, with only optimal results, never something maximal for one and risks for the rests.

This paper is an overview of man's activities that may create impacts on the aquatic environment, particularly in the abundant growth of aquatic vegetation. This vegetation may be considered as an aquatic weed that creates nuisance to the optimal function of an aquatic resource. Finally, the paper will deal with efforts to manage the problem appropriately, with sound environmental consideration, and with an optimal result for all concerned.

AN INCREASING ACTIVITY WITH AN INCREASING RISK

With an increasing number of population and the increasing trend of needs due to continuous changes inlife style, humans tend to get more from the limited resources. This is made possible with the continuous development of technology, which may facilitate more products for human beings, but in turn, may create more wastes and more pollutants. Therefore, there is always an increasing disorder and increasing risk in humanlife (Fig. 1).

Since generally speaking there is always a decreasing quality of our environment, there is a decreasing quality of life. Therefore, there is a need to manage our environment appropriately as shown in Fig. 2, in order to maintain the quality of the environment, by which to maintain the quality of life.

AQUATIC RESOURCE AND AQUATIC VEGETATION

Water is one of the most vital resources to sustain life and the activities of

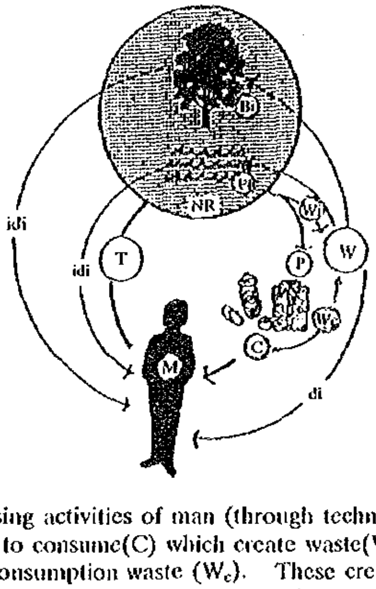

Fig. 1. The increasing activities of man (through technology) will produce product(P) to consume(C) which create waste(W), industrial waste (W_i) and consumption waste (W_c). These create direct(di) and indirect(idi) (through physical and biotic components) impacts to man.

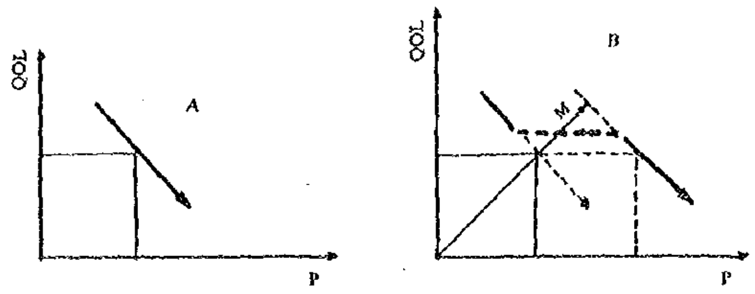

Fig. 2. A. As product(P) increases the quality of life(QOL) is decreasing, therefore: B. Environmental management(M) is needed, that P is still increasing while QOL is maintained (modified from Beale, 1980)

man as well as other living organisms. It dissolves and transports nutrient from the soil into the bodies of plants and animals, dissolves and dilutes many of the wastes, serves as a raw material in all phases of metabolisms, and is major factor in the world climate and weather system (Miller Jr. 1979). Water is not only vital but also unusual because of its physical and chemical characteristics. In the ecosystem, water has a unique hydrological system and with a complicated energy relations in its various stages and phases of existence.

The aquatic system includes distinct parts of the environment such as rivers, streams, lakes, estuaries, and coastal and deep ocean waters (Duke, 1977). It is clear that, by definition, man's interactions with water will cover a vast and complicated area, in addition, these systems represent almost all groups of life-forms. However, man's use of water is dominated by only a small fraction of water called fresh water or sweet water (approximately 3% out of the total water volume of $135.10^{10}\ m^3$). Therefore, man's impact on water is mainly accumulated in fresh water system, *e.g.* rivers, streams, ponds, and lakes. The human needs of water is shown in Table 1.

Those usages of water for irrigation, industry, and domestic purposes determine the impact of man's activities on the water quality, namely the kind and amount of wastes and pollutants dumped into the water. This creates pollution and eutrophication that in turn changes the life-forms in the aquatic habitat.

Table 1. The daily per capita needs of water in the USA and the world in 1975* and the estimated need in Indonesia in 2000**.

Usage	USA(1975)		World (1975)		Indonesia (2000)	
	m^3	%	m^3	%	m^3	%
1. Irrigation	2.52	41.8	1.74	88	1.84	94.1
2. Industry	2.97	49.1	0.14	7	0.01	0.5
3. Domestic	0.55	9.1	0.11	5	0.10	5.4
Total	6.04	100	1.99	100	1.95	100

* Miller Jr. 1979.
** Sutamihardja & Haeruman, 1983

The first to change is the aquatic flora, the macrophytes as well as the microphytes, which will become abundant in a eutrophied system. Under a large majority of lake conditions, the most important factors causing the abundant growth of aquatic macrophytes are phosphorous and nitrogen. The community will be occupied mainly by dominant species or mixtures of several species. The most important ten aquatic weed species in the world are shown in Table 2.

It has to be noted, however, that with the increasing activities of man, there is a considerable change in the composition of aquatic vegetation throughout the world from time to time. In most cases, such as in the case of water hyacinth *(Eichhornia crassipes)* and molesting salvinia *(Salvinia molesta)*, aquatic weed problems arises from exotic species. The aliens seem to reporduce faster and spread more vigorously than in their native ranges, particularly if in their new habitat, resources are not fully utilized by native species (Ikusima, 1983), also if natural enemies in the new area have not yet established in their full balance.

It has to be noted that luxuriant submerged and floating vegetation is not very productive when compared to the marginal or emergent vegetation. The dry weight per unit area of submerged and floating vegetation is low compared with that to communities such as marsh or reed swamps (Sculthorpe in Gaudet, 1974). This is also due to the fact that plants under water will have less availability of oxygen and carbondioxide from the atmosphere (Sastroutomo,1985). In a shallow region to a depth of about one meter, there will be a potentially high

Table 2. The ten most important species of aquatic weeds in the Asia and the world listed in order of their degree of importance.

NO	SOUTHEAST ASIA*		THE WORLD**	
	Species	Family	Species	Family
1.	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae
2.	*Salvinia molesta* D.S. Mitchell	Salviniaceae	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae
3.	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	*Pistia stratiotes* L.	Araceae
4.	*Mimosa pigra* L.	Mimosaceae	*Ceratophyllum demersum* L.	Ceratophyllaceae
5.	*Pistia stratiotes* L.	Araceae	*Salvinia molesta* D.S. Mitchell	Salviniaceae
6.	*Echinochloa stagnina* (Retz.)	Poaceae	*Nelumbo nucifera* Gaertn	Nelumbonaceae
7.	*Ceratophyllum demersum* L.	Ceratophyllaceae	*Typha angustifolia* L.	Typhaceae
8.	*Panicum repens* L.	Poaceae	*Egeria densa* Planch	Hydrocharitaceae
9.	*Typha angustifolia* L.	Typhaceae	*Echinochloa colonum* (L.) Link	Poaceae
10.	*Monochoria vaginalis* (Burm.f.) Presl	Pontederiaceae	*Panicum repens* L.	Poaceae

* Listed based on Soerjani.1975; Pancho & Soerjani.1978; Pancho *et al.*.1985.
** Holm *et al.*.1977, 1980; Soerjani.1983.

productivity of emergent macrophytes that utilize resources from the aqueous sediment and the aquatic habitats.

THE ROLE OF AQUATIC VEGETATION

Aquatic vegetation is a primary producer that sustains other groups of living organisms. It provides direct food for herbivorous organisms and detritus for detritivorous and sapotrophic organisms. It may serves as the habitat for organism living in the phyllosphere, or provide shelter, hiding and breeding place for other living organisms. Some other role of aquatic macrophytes in the system are : as soil stabilizers; in nutrient cycling, as nutrient pump from the soil, and in water purifications; as a source of food for terrestrial organisms, *e.g.* bird and man. Sastroutomo (1985) listed 20 aquatic plant species that are eaten, partly or wholy, by birds, among others those considered as important weed species, *e.g. Ceratophyllum* spp., *Myriophyllum* spp., *Polygonum* spp., *Sagittaria* spp., and *Scirpus* spp.

Further on the list of aquatic plants edible to men is as shown in Table 3.

Table 3. Aquatic plants edible to man (Sastroutomo, 1985).

No.	Species	Part(s) used	Use
1.	*Acorus calamus*	Under ground parts	Medicinal
2.	*Butomus umbellatus*	Under ground parts	Medicinal
3.	*Glyceria fluitans*	Seeds	Food
4.	*Phragmites communis*	Under ground parts	Food
5.	*Rorippa nasturtium-aquaticum*	Shoots	Food
6.	*Sagittaria sagitifolia*	Under ground parts	Food
7.	*Typha* spp.	Pollen, under ground parts	Food
8.	*Zizania latifolia.*	Under ground parts, leaves	Medicinal
9.	*Nelumbo nucifera*	Under ground parts, seeds	Food
10.	*Ipomoea aquatica*	Leaves	Food
11.	*Brasenia* spp.	Young leaves	Food
12.	*Limnocharis flava*	Leaves	Food
13.	*Eichhornia crassipes*	Young leaves, flower buds	Food

For other purposes aquatic plant species may also have other functions, *e.g.* as cattle feed, mulch, green manure, pulp, handicraft, religious and traditional ceremonies, and various source of chemicals. It also serves as ornamentals and add to the beauty and serenity of an aquatic landscape.

The role in causing nuisance to man or decreasing the value of a system is normally due to its abundant growth, so that the plant is in excessive population. This may include loss of water storage, as agricultural and public hazards, as habitat for disease agents and their vectors, etc.

The role of aquatic plants is very much determined by the activities of man affecting the aquatic system as shown in Fig. 3.

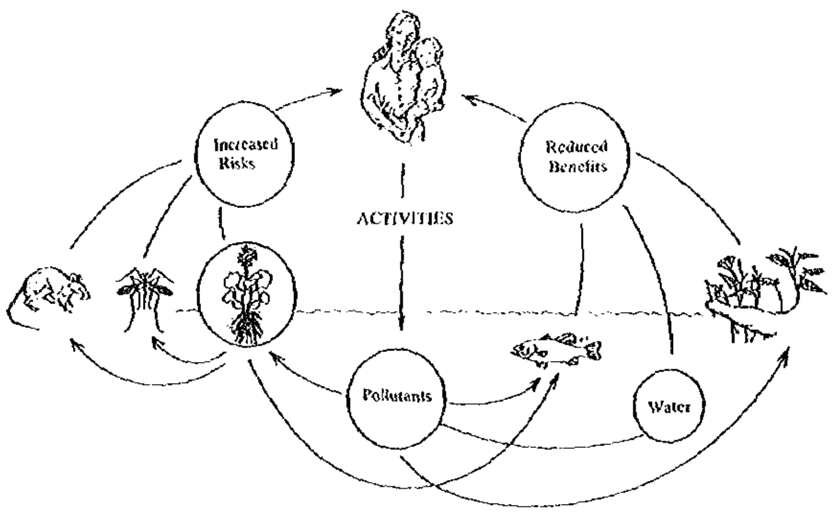

Fig. 3. The activities of man that affect an aquatic system.

The pollutant may enrich water that stimulates excessive growth of aquatic weeds. It may also contain hazardous pollutant that may enter the biotic components, *e.g.* vegetable, or fish that may finally end up to human beings.

AQUATIC VEGETATION MANAGEMENT WITH ENVIRONMENTAL CONSIDERATIONS

The above chapters give a general idea of the place and role of aquatic plants in the holistic system of life and nature, in particular in the aquatic system. Those are the general basis in the development of control measures if environmental quality is taken into serious consideration.

Aquatic weed management is part of aquatic vegetation management which is again part of the whole aquatic resource management, which must be aimed at the development of an amenity fresh water system. This refers to the social and environmental function of a water resource. The system must be developed based on social and environmental agreeableness, social pleasures, or as agreeable pursuits in general. The amenity fresh water system should be defined as a water system with harmonious environmental, economic, recreational, spiritual, and aesthetic values. Priority of the criteria must be in the first instance referred to the social and environmental function of a water body. There are benefits from a water body which are easy to value, e.g. fish production, drinking water supplies, rice field irrigation, or industrial water supplies. In other cases, however, valuation is not easily accomplished, especially for non-marketable items, such as the environmental quality, visual attractiveness, and other spiritual values. Therefore, in general, the strategy must develop a low cost and low maintenance system, relevant to the present day escalating cost of living.

The common model to develop an amenity fresh water system is shown in Fig. 4 (Soerjani 1983).

The following are steps to be considered as a general approach in an appropriate and environmentally sound aquatic weed management.

5.1 Terrestrial and Marginal Plant Gallery

As shown in Fig. 4 the activities of man will produce wastes (W_1) which may by recycled, reutilized, or screened by gallery of plants in the marginal or on the bank of a water body. By so doing a resource R_1, *e.g.* timber, vegetable, flower, and fruits can be harvested. It has only to be taken into consideration that the waste may contain hazardous chemicals that may also pollute or contaminate the products edible to animals or man.

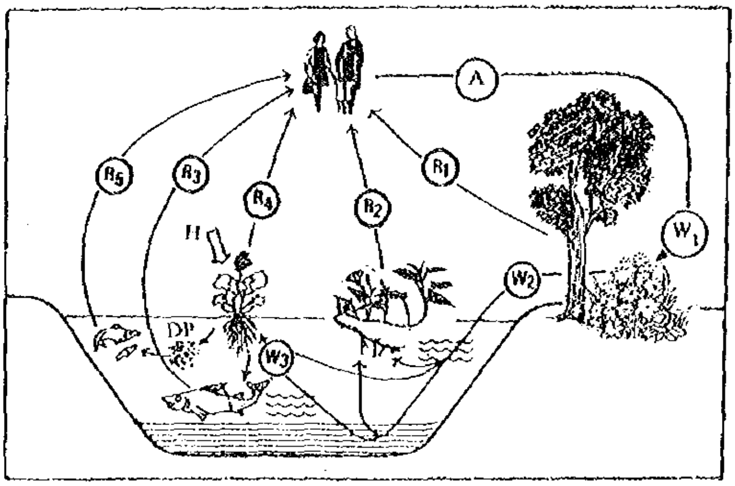

Fig. 4. A model of man's activities(A) that create wastes(W) which can be converted through appropriate management to become useful resources(R) in an amenity fresh water system(Soerjani, 1983).

5.2 Hydrophonic or Aquaculture Plants

To compete for space, and therefore also to compete for nutrient and probably also light, hydrophonic or aquaculture plants can be planted in a bamboo raft or something similar to it. The plants selected must have some beneficial values to humans, *e.g.* floating rice or edible *Ipomoea*. However, again it has to be taken into consideration if there are certain hazardous chemicals contaminating the products.

5.3 Fish Management

Fish management may control or utilize the weed biomass, by the introduction of an appropriate fish, particularly grass carp *(Ctenopharyngodon idella* Val.) which will directly consume the macrophytes. The fish is edible and serves as a good source of protein (R3).

In the fresh water food web, some other fish can also be cultured (Fig. 5). The introduction of silver carp *(Hypophthalmichtys molitrix* Val.) which will consume plankton is one of the appropriate combinations with grass carp. Grass carp will digest only part of the macrophytes

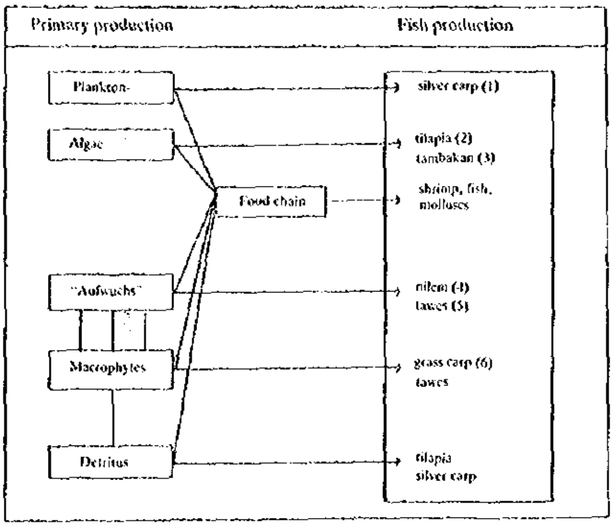

Fig. 5. Primary production as a direct source of fish production or through a food chain in a fresh water system (after Stengel, 1976).

(1) silver carp = *Hypophthalmichtys molitrix* Val.
(2) tilapia = *Sarotherodon mossambicus* (Peters)
(3) tambakan = *Helostoma temmincki* C.V.
(4) nilem = *Osteochilus hasselti* (C.V.)
(5) tawes = *Puntius javanicus* (Blkr.)
(6) grass carp = *Ctenophryngodon idella* Val.

consumed, and the release of the partly digested food will stimulate the growth of plankton, which in turn will be consumed by silver carp.

The use of herbivorous fish to manage weed population has another positive aspect, namely to provide man with certain beneficial resource. The use of fish can also be classified as an appropriate biological control method, since the addition of a component in the trophic level has ended up to something clear in its function in the food web or in the entire web of life. Fig. 6 shows that biological control method of water hyacinth using insect, e.g. water hyacinth weevil (*Neochetina eichhorniae* Warner) will end up at something unknown to our present knowledge (A). Our experience in Indonesia with the weevil showed that the insect has two other hosts, namely the edible canna *(Canna edulis)* and ginger (*Zingiber* spp.) both are secondary economic crops in Indonesia, while the introduction of grass carp *Ctenopharyngodon idella* Val.) may end up beneficially to man (B). It has to be noted, however that the top component in the trophic structure does not necessarily benefit man, but something, for sure, compatible in the entire good and healthy quality of our environment.

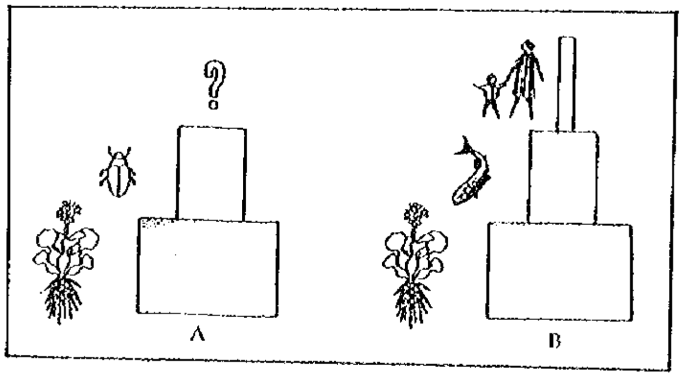

Fig. 6. Schematic situation of the trophic structure in a biological control of water hyacinth. (Soerjani, 1985).
A. With the weevil; B. With grass carp

5.4 *Utilization of the Aquatic Weeds*

A further option is to harvest the weed biomass and utilize it as a resource (R_4) for various purposes (Soerjani, 1982; 1983; Wolverton and McDonald,1979*a*). Most fresh water weeds can be directly consumed by pigs and ducks, or other livestock, *e.g.* cattle (Kashem *et al.*, 1983), chicken and rabbit after certain processes. It can be utilized as supplementary feed for the pen culture of carp and tilapia(Edward,1980; Hiranwat, 1983). Other uses of fresh water weeds are for biogas production, fuel, fertilizer, soil additives or mulch, mushroom culture, paints (Vedanayagam *et al.*,1983) the reduction of water pollutants from pulp/paper mills, tanneries (Haider *et al.*, 1983), rubber and oil palm industries (John,1983) and human waste (Wolverton and McDonald,1979 b). Water hyacinth and some other aquatic plants are harvested to produce handicrafts, *e.g.* shoes, bags, trays, carpets, vase, ropes, decorations, and picture frames. The most promising use of water hyacinth and *S. grossus* if for pulp, carton and paper production. In various parts of South and South-east Asia cartons from water hyacinth manufactured in some rural areas by an appropriately simple technology have become a promising marketable product. Efforts are still continuing to produce particle boards and cement boards from water hyacinth biomass.

5.5 The Use of Herbicides

In special cases when all the efforts do not work well due to certain constraints, the plant population or community may temporarily have to be suppressed by known control methods, *i.e.* mechanically or chemically (H).

The use of an appropriate chemical (herbicides H) with an appropriate dose may convert the noxious plant biomass into certain beneficial components, *e.g.* detritus (D) for detribivorous animals or fish, or the dead mass will be converted into nutrient to stimulate the growth of phytoplankton and zooplankton (P) for planktonivorous animals or fish.

The use of herbicides can also be implemented to reduce the extremely abundant growth of the weed that utilization can not cope with.

Furthermore, the safe use of herbicides can be improved through various recent methods developed, *e.g.* the use of a slow-released herbicide. This started in 1970 with several forms of 2,4-D and silvex were formulated in polyvinyl acetate, polyvinyl chloride and palamyd plastics and evaluated against watermilfoil *(Myriophyllum demersum)* with reasonable results (Cardarelli & Cardarelli,1982). A number of aquatic herbicidal materials utilizing a thermoplastic binder with a porosigen additive and one of several agents were developed in 1980. Herbicides evaluated were diuron, simazine, diquat, fenac, bromacil, atrazine, dichlobenil, and several forms of 2,4-D. Recently alginate, crumb rubber, and latex have been used to formulate slow-released herbicides with considerable success.

5.6 Combination

It is to be noted that no single method will guarantee the success of any effort in aquatic weed management. It has to be evaluated carefully in a limited scale if a novel method is to be introduced as an alternative for the less effective conventional method. In general it can be concluded that a combination of several appropriate methods is in many cases recommended.

The integration of compatible efforts is hopefully the most appropriate answer to the question of how to manage fresh water vegetation optimally for all forms of life including mankind.

CONCLUSIONS

It is concluded that aquatic weed problems has to be viewed as an opportunity, which means that the structure and function of the species concerned in the environment have to be appropriately taken into consideration before any control measure is implemented.

The ultimate results of any cultural method and any potential side effect or risk have to be studied carefully if energy is not to be wasted and potential resource is not to be converted into detrimental wastes or pollutants.

The use of herbicide and any other conventional control method is not excluded in an environmentally sound aquatic vegetation management. As in any other effort, detrimental impact has to be eliminated at least mitigated, while the residual impact is to be compensated with other beneficial pay-offs. In the use of herbicide some of the recently known impact to be taken into consideration are among others the development of resistance of plant species after being repeatedly treated with the same herbicide.

It is obvious that to be able to exist happily in a healthy environment, men must understand their appropriate niche in the ecosystem, and able to maintain their interrelationship and interdependency with other components in it. They have to know and understand the other companions in the system. Since aquatic weeds or aquatic vegetation is part of their companion, knowing and understanding the biology of aquatic weed flora is part of knowing and understanding their own niche. This will be part of men's effort to be able to develop aquatic vegetation management appropriately for the benefit of all.

Since men are part of nature, as Ernest Partridge (1984) said, human beings have a genetic need for natural environments. They also have a fundamental need to care for things outside themselves, and human life will be enriched by a transcending concern and responsibility for the wellbeing of natural species, habitats, and ecosystem. By so doing, men enrich the quality of moral life. Persons with genuine reverence and respect for a healthy environment have to control and reduce their demands, but hopefully they will enjoy greater fulfilment in their own lives and be better companions to each other.

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WEEDS AND THE ENVIRONMENT IN THE TROPICS
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TECHNOLOGY AND ECONOMICS OF WEED CONTROL IN BROADCAST-SEEDED FLOODED TROPICAL RICE

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Abstract. Increases in labor cost, irrigated area, the development of modern early-maturing varieties, and improved weed management techniques have encouraged many farmers in Thailand, Malaysia, and the Philippines to switch from transplanted to direct-seeded flooded rice culture.

Based on research at IRRI during the late sixties, butachlor and thiobencarb are now marketed in 22 and 56 rice-growing countries, respectively, in the world. Farm-level constraints research demonstrates that the benefit cost ratio from using chemical weed control technology is high in irrigated rice culture.

Alternative weed control technology is being developed for direct-seeded flooded rice to reduce cost, minimize herbicide toxicity, and increase grain yield and income. The use of these alternative technologies, however, will depend largely on the weed situation, and the relationships between labor and herbicide prices.

INTRODUCTION

Direct seeding of rice is extensively practiced in temperate rice-growing countries such as the United States, Australia, Italy, and Portugal (De Datta, 1981). However, in most tropical Asian countries, direct seeding was not widely practiced before the late seventies due to difficulties in weed control, extensive rat and bird damage, snail infestations, and poor irrigation water control (Mabbayad and Obordo, 1971). Direct seeding of rice in tropical Asia is performed either by broadcasting or drilling seed onto puddled wet (wet seeding) or dry soil (dry seeding). Wet seeding requires 2-3 labor days per hectare. This practice is labor saving and cost-reducing compared to the 15 or more days necessary to transplant a hectare of rice seedlings.

Historically, the weed problem was a dominant constraint to the widespread adoption of broadcast-seeding. It is for this reason that this paper focuses on advances in weed control technology in broadcast-seeded rice; a necessary condition for the current, rapid adoption of this practice in Asia.

Research conducted by IRRI in the early seventies showed that shallow (less than 2.5 *cm*) continuous flooding contributed to weed growth and so increased weeding costs. Under shallow but continuous flooding, there were more sedges and broadleaf weeds and grasses, while with 15 *cm* of standing water, grasses and sedges were practically suppressed (De Datta *et al.*, 1973). According to a recent survey, about 34 species in 18 genera under 14 families are important weeds in the Muda rice-growing area of Malaysia where broadcast seeding is extensively practiced (Ho, 1984). *Monochoria vaginalis* (Burm. f.) Presl was the dominant weed species followed by *Fimbristylis miliacea* (L.) Vahl, *Leersia hexandra* Sw., *Jussiaea repens* L., *Scirpus grossus* L.f., *Isachne globosa* (Thunb.) O.K., and *Scirpus juncoides* Roxb. These together with *Cyperus haspan* L. and *Marsilea crenata* Presl infested not less than 75% of the rice-growing areas in Muda area (Ho, 1984). With the recent increase in mechanization in Muda, weed seed contamination in the rice fields has led to widespread emergence of *Echinochloa crus-galli* (L.) Beauv. ssp. *hispidula* (Retz.) Honda, *Echinochloa glabrescens* Munro ex Hook.f., and *Leptochloa chinensis* (L.) Nees.

In Thailand, weeds in broadcast-seeded flooded rice areas are similar to transplanted rice areas except the infestation is more severe with pre-germinated rice (Vongsaroj, 1985). The major weeds in broadcast-seeded flooded rice are: *E. crus-galli* ssp. *hispidula*, *L. chinensis*, *Echinochloa colona* (L.) Link, *Sphenoclea zeylanica* Gaertn., *Mimulus orbicularis* Benth, *M. vaginalis*, *Cyperus difformis* L., *F. miliacea*, *Eleocharis dulcis* (Burm.f.) Henschel, *M. crenata*, *Chara zeylanica* KL. ex. Wild.

In the Philippines, the principal weed species are *E. glabrescens*, *E. crus-galli* ssp. *hispidula*, *C. difformis*, *M. vaginalis*, and *S. zeylanica*.

REVIEW OF LITERATURE

Chemical weed control combined with other cultural practices is now a practical way to reduce weed competition, crop losses, and labor costs. In most instances, the use of herbicides is a practical, effective, and economical means of reducing weed competition and production losses.

The recent expansion in broadcast-seeded flooded rice culture in Malaysia, Thailand, and the Philippines resulted from a combination of technical and economic factors. Technical changes included a) the release of modern rice varieties with high seedling vigor and tillering capacity which increased the crop's competitiveness with weeds, b) improved water control, and c) the availability of selective herbicides such as butachlor and thiobencarb which effectively control weeds in wet-seeded rice (De Datta, 1981; Moody and Cordova, 1985). Long-term trends in the Asian rice farmer's economic environment which facilitated direct seeding included a) falling real prices of rice and herbicides and b) increasing labor costs for transplanting and weeding. Thus, the adoption of wet seeding is a rational response by rice farmers to a cost-price squeeze in rice production (Flinn and Mandac, 1985).

Wet seeding has become an increasingly important method of rice crop establishment in South-East Asia since the late seventies. In Central Luzon -- the "rice bowl" of the Philippines where most of the rice crop is irrigated -- the percentage of farmers adopting wet-seeded rice increased from less than 2% in 1979 to possibly over 80% by 1984 (Coxhead, 1984; Moody and Cordova, 1985). Also the adoption of wet seeding has been similarly spectacular in both favorable and unfavorable rainfed rice environments of the Philippines; it has contributed to early first-crop establishment and increased rice crop intensification (De Datta, 1981; Mandac *et al.*, 1982). The most widely used herbicides in broadcast-seeded flooded rice in the Philippines are now butachlor and thiobencarb.

In Thailand, at least 0.8 *million ha* was planted to broadcast-seeded rice in 1985, in Malaysia the area under direct seeding possibly exceeds 40,000 *ha* (De Datta, 1985). Some commonly used herbicides in broadcast-seeded flooded rice in Thailand are butachlor, thiobencarb, oxadiazon, and piperophos + dimethymetryn (Vongsaroj, 1985). Nearly 40% of the Muda rice area alone was direct-seeded by 1983 (De Datta, 1985). Practically all farmers used herbicides in direct-seeded rice in the Muda area (Ho, 1984). The most common herbicide was 2, 4-D butyl ester applied 25-30 days after seeding (DAS) which controls only annual broadleaved weeds and sedges. Other herbicides currently being tested are trifluralin, piperophos, pyrazolate, molinate, fluazifop-butyl, butachlor, thiobencarb, and oxadiazon.

IRRI results show that several herbicides were effective in controlling weeds and increasing grain yield of broadcast-seeded flooded rice. In 1968, IRRI began herbicide testing with national programs. The results of IRRI research and with cooperating countries encouraged broad usage of butachlor (22 countries) selected at IRRI in 1968 (IRRI, 1969), and thiobencarb (56 countries) selected in 1969 (IRRI, 1970). Butachlor and thiobencarb, earlier reported as highly selective on broadcast-seeded flooded rice (De Datta and Bernasor, 1971, 1973; De Datta, 1981; De Datta and Herdt, 1983), were occasionally moderately toxic to rice when combined with 2, 4-D. This symptom occurred most frequently when plants had too much water or when the herbicides were applied during cold weather. However, rice plants often recovered from this herbicide injury.

Other cultural practices that minimize weed competition in broadcast-seeded flooded rice are the degree of puddling and land leveling, fertilizer and water management (Bernasor and De Datta, 1983; Vongsaroj, 1985).

MATERIALS AND METHODS

Preliminary Herbicide Screening

Three screening trials were conducted at IRRI during the 1982 dry and wet seasons and the 1984 wet season to identify herbicides that would complement other weed control methods in direct-seeded flooded rice. Each experiment was laid out in a randomized complete block design replicated three times. Most of the herbicides were applied at early postemergence of weeds (2-3 leaf stage).

Advanced Herbicide Screening

Advanced screening trials were conducted at IRRI, and at Maligaya and

Bicol Rice Research Stations during the dry season, and at these sites and the Visayas Rice Research Station during the wet season. The experiments at each site were laid out in a randomized complete block design replicated four times. The herbicides were applied 6-8 DAS. *E. crus-galli* ssp. *hispidula*, *E.glabrescens*, *M. vaginalis*, and *C. difformis* were common at all sites.

Time of Herbicide Application

The effect of application time and rate of three postemergence herbicides on weed control and on direct-seeded flooded IR36 yield was studied at IRRI during the 1983 dry season. Propanil at 1.5 and 3.0 *kg/ha*, bentazon at 1.0 and 2.0 *kg/ha*, and fluazifop-butyl at 0.05 and 0.10 *kg/ha* were applied at the 2-3 and 5-7 leaf stages, and at the tillering stage of the rice crop.

Chemical Control of Scirpus maritimus

Time of application. Effect of application time of bentazon and 2,4-D was examined at IRRI in the 1982 wet season. Bentazon at 1.0 *kg/ha* and 2,4-D at 0.75 *kg/ha* were applied 15 and 25 DAS in randomized complete block design. Each treatment was replicated four times. Butachlor at 1.0 *kg/ha* was applied to all plots 6 DAS to control annual weeds.

Single vs combined herbicide application. An experiment conducted during the 1983 dry season compared the effects of single and combined herbicide treatments on *S. maritimus* control in direct-seeded flooded IR36. Bentazon, propanil, and 2,4-D were applied singly and combined with each other as tank mixtures 25 DAS. The treatments were arranged in a randomized complete block design and replicated four times. Butachlor at 1.0 *kg/ha* was applied to all plots 6 DAS to control annual weeds.

Integrated Weed Control

The long-term effect of tillage, cultivar, and herbicides are being examined in an experiment initiated in the 1984 dry season. The experiment was laid out in a factorial randomized complete block design replicated three times on an area kept in weedy fallow for 3 months. Tillage levels were 1 harrowing, 2 harrowings, and 3 harrowings, each preceded by 1 plowing. The cultivars used were IR36, a semidwarf, and IR29723-143-3-2-1, an intermediate tall. The herbicide treatments consisted of bensulfuron-methyl (0.05 *kg a.i/ha*) applied 10 DAS, propanil + 2,4-D (1.5 + 0.5 *kg a.i./ha*) applied tank-mixed 15 DAS, and an untreated check. There were 17 weed species present before the start of the trial.

Farm-level Constraints Trial
During the 1984 dry season, experiments were conducted in farmers' fields in Nueva Ecija, Bulacan, and Camarines Sur provinces, Philippines to evaluate IRRI-developed weed control technology against farmers' current weed control practices.

Farmer-application of Wet Seeding/Herbicide Technology
Farmer's use of wet seeding and herbicides were evaluated through farmer surveys in Central Luzon and the Bicol region of the Philippines. These two sites were chosen as contrasts in wetland rice culture as Central Luzon is the highest yielding region of the Philippines and Bicol among the lowest. Yet wet seeding is widely used by farmers in both regions, in the former case with irrigation, in the latter case under irrigated and shallow rainfed conditions.

RESULTS AND DISCUSSION

Preliminary Herbicide Screening
The major weeds present during the preliminary herbicide screening were *E. crus-galli* ssp. *hispidula*, *E. glabrescens*, *M. vaginalis*, *C. difformis*, and *S. maritimus*.

In the 1982 dry season trial, the molinate/R-24216, molinate/2,4-D EPTC/2,4-D treatments, and the butachlor check gave similar yields which were significantly higher than the yield in the untreated control (Table 1). Yield in other treatments did not differ from the untreated check.

In the wet season, all herbicide treatments gave significantly higher yields than the untreated check (Table 2). The granular formulation of a new herbicide, bensulfuron-methyl, applied at 0.05 *kg/ha* 6 DAS, provided excellent control of broadleaf and grassy weeds and very good control of the perennial sedge *S. maritimus* without affecting the rice crop. Oxyfluorfen and thiobencarb/2,4-D also provided excellent

Table 1. Effect of early postemergence (6 days after seeding) application of promising granular herbicides on weed control, crop tolerance, and yield of broadcast-seeded flooded IR36.[a] IRRI, 1982 DS.

Treatment[b]	Rate (kg ai/ha)	Weed biomass (g/m^2)	Toxicity rating[c]	Yield (t/ha)
Molinate/R-24216	2.0/1.0	0 a	0	3.8 ab
EPTC/2,4-D	1.8/0.45	29 a	3	3.7 ab
Molinate/2,4-D	2.1/0.45	12 a	0	3.6 abc
Chlornitrofen/2,4-D	1.25/0.5	130 a	3	2.8 bcd
PPG 844	1.0	92 a	0	2.4 cd
Butachlor check	1.0	0 a	0	4.2 a
Untreated check	-	130 a	0	2.2 d

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]A slash bar (/) means the chemicals were applied as a proprietary mixture. [c]Rated 1 week after herbicide application on a 0-10 scale: 0 = no toxicity and 10 = complete kill.

control of the annual weeds but did not control *S. maritimus*. These herbicides were slightly toxic to rice.

Five herbicides and herbicide combinations gave significantly higher yields than those in the untreated control in the 1984 wet season trial (Table 3). Quinchlorac controlled weeds effectively, caused only slight crop injury, and produced significantly higher yields than did the thiobencarb/2,4-D check and other herbicide treatments. Naproanilide/butachlor, SC-0254, and the pyridate compounds were highly toxic to rice.

In the advanced herbicide screening trials conducted during the dry and wet seasons, the average yield over 3 years and 3/4 sites with all the herbicide treatments were significantly higher than the untreated check (Table 4). Plots treated with naproanilide/thiobencarb yielded significantly higher than plots treated with pendimethalin, butachlor, and butachlor + 2,4-D. Butachlor with or without 2,4-D was occasionally toxic to rice in some sites. Pendimethalin poorly controlled *C. difformis* and *Cyperus iria* L.

Table 2. Effect of early postemergence (6DAS) application of promising granular herbicides on weed control, crop tolerance, and yield of broadcast-seeded flooded IR42.[a] IRRI, 1982 WS.

Treatment	Rate (*kg ai/ha*)	Weed biomass[b] (*g/m*^{2})			Toxicity rating[c]	Yield (*t/ha*)
		Broadleaf weeds	Grasses	Sedges		
Bensulfuron-methyl	0.05	0 a	0 a	4 a	0	5.0 a
Oxyfluorfen	0.10	3 ab	0 a	41 b	4	3.8 a
Thiobencarb/2,4-D check	1.0/0.5	0 a	0 a	49 b	2	3.9 a
Untreated check	-	17 b	11 b	36 b	0	2.2 b

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]The major broadleaf weed was *Monochoria vaginalis*, grasses were *Echinochloa crus-galli* spp. *hispidula* and *Echinochloa glabrescens*, and sedge was *Scirpus maritimus*. [c]Rated 20 days after seeding (DAS) on a scale of 0-10 : 0 = no toxicity and 10 = complete kill.

Table 3. Effect of early postemergence (6DAS) application on new herbicides on weed control, crop tolerance, and yield of broadcast-seeded flooded IR58.[a] IRRI, 1984 WS.

Treatment[b]	Rate (kg ai/ha)	Weed biomass (g/m^2)			Toxicity rating[c]	Yield (t/ha)
		Broadleaf weeds	Grasses	Sedges		
Quinchlorac G	.0.3	0 a	0 a	2 a	2	4.3 a
Thiobencarb/2,4-D check	1.5	0 a	6 ab	54 b	3	3.3 b
MO/butachlor EC	1.0	34 bc	13 ab	10 ab	4	3.1 b
Naproanilide/butachlor G	2.0	5 ab	27 bc	52 b	6	2.6 b
SC-0254 G	2.0	38 c	6 ab	12 ab	6	2.6 b
Pyridate/MCPA WP[d]	2.0	0 a	134 d	0 a	5	1.3 c
Pyridate EC[d]	1.0	0 a	94 cd	0 a	6	0.6 cd
Untreated check	-	43 c	69 cd	57 b	0	0 d

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]G = granule. A slash bar (/) means the chemicals were applied as a proprietary mixture. EC = emulsifiable concentrate. WP = wettable powder. [c]Rated 2 weeks after herbicide application on a 0-10 scale: 0 = no toxicty, 10 = complete kill. [d]Applied 29 days after seeding (DAS).

Table 4. Effect of early postemergence (6-8 days after seeding) application of granular herbicides on yield of broadcast-seeded flooded IR36.

Treatment[a]	Rate (kg ai/ha)	Grain yield (t/ha)		
		Dry season[b]	Wet season[c]	Mean
Naproanilide/thiobencarb	1.0/0.7	4.8 a	3.3 a	4.1 a
Piperophos/2,4-D	0.3/0.2	4.4 ab	3.3 a	3.9 ab
Thiobencarb/2,4-D	1.0/0.5	4.5 ab	3.2 a	3.9 ab
Butachlor	1.0	4.4 ab	2.9 bc	3.7 bc
Butachlor + 2,4-D	0.75+0.5	4.1 b	3.1 ab	3.6 bc
Pendimethalin	0.75	4.2 b	2.7 c	3.5 c
Untreated check	-	2.9 c	2.1 d	2.5 d

[a]A slash bar (/) means the chemicals were applied as a proprietary mixture. A plus (+) means the chemicals were applied separately. [b]Av of 4 replications, 4 years (1982-1985) at IRRI, and 3 years (1982-1984) at Maligaya and Bicol. [c]Av of 4 replications, 3 years (1982-1984), and 4 sites (IRRI, Maligaya, Bicol, and Visayas).

Table 5. Effect of rate and time[a] of herbicide application on weed control and yield of direct-seeded flooded IR36.[b] IRRI, 1983 DS.

Treatment	Rate (kg ai/ha)	Weed biomass[c] (g/m^2)			Mean	Grain yield (t/ha)			Mean
		S_1	S_2	S_3		S_1	S_2	S_3	
Bentazon	1.0	56 bc	36 abc	34 b	42 b	2.3 a	0.4 b	2.4 a	1.7 a
Bentazon	2.0	41 b	70 cd	21 ab	44 b	1.5 ab	1.8 ab	1.0 ab	1.4 ab
Propanil	1.5	82 bc	48 bcd	25 b	52 b	1.5 ab	1.2 ab	0.4 b	1.0 abc
Propanil	3.0	82 bc	25 ab	32 ab	46 b	1.9 ab	2.1 a	0.8 b	1.6 a
Fluazifop-butyl	0.05	146 cd	69 cd	131 c	115 c	1.1 ab	1.1 ab	0.5 b	0.9 abc
Fluazifop-butyl	0.10	216 d	78 cd	51 b	115 c	1.0 ab	0.5 b	0.7 b	0.7 bc
Hand weeded check[d]	–	7 a	13 a	7 a	9 a	1.9 ab	1.8 ab	0.9 b	1.5 ab
Untreated check	–	103 bcd	142 d	95 c	113 c	0.5 b	0.8 ab	0.4 b	0.6 c

[a] Growth stage of rice: S_1 = 2-3 leaf stage; S_2 = 5-7 leaf stage; S_3 = tillering stage. [b] Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [c]Sampled at 60 days after seeding (DAS). [d]Weeded at 15, 30, and 45 DAS.

Time of Herbicide Application

In the study of herbicide application time, most herbicides applied at 2-3 leaf stage controlled weeds (predominantly *S. maritimus* and *C. iria*) but not as effectively as three hand weedings (Table 5). Bentazon (1.0) and propanil (3.0) applied at 5-7 leaf stage were as effective; they significantly reduced weed biomass when sprayed at tillering stage at both rates. They were more effective when applied toward the tillering stage when weeds were older and had more top growth. Fluazifop-butyl was consistently poor in controlling weeds regardless of application time. Bentazon at both rates and propanil at a higher rate yielded significantly higher than the untreated check. The highest average yield of 1.7 *t/ha* obtained from bentazon-treated (1.0) plots was comparable with those of other treatments except with fluazifop-butyl at 0.1 *kg/ha* which was significantly lower.

Chemical Control of Scirpus maritimus

In the study of chemical control of *S. maritimus*, bentazon and 2,4-D were superior in controlling weeds when applied at 25 DAS (Table 6). Bentazon controlled *S. maritimus* better than 2,4-D because it gave significantly less weed biomass than the untreated check applied 15 DAS, which was comparable with 2,4-D applied 25 DAS. Weed biomass with 2,4-D applied 15 DAS and the untreated were similar. However, both herbicides were safe on rice and gave significantly higher yields than the untreated control regardless of application time.

Table 6. Effect of time of application of bentazon and 2,4-D on the control of *Scirpus maritimus* and yield of broadcast-seeded flooded IR36.[a] IRRI, 1982 WS.

Treatment[b]	Application		*S. maritimus* biomass	Grain yield
	Rate (*kg ai/ha*)	Time (DAS)	(*g/m²*)	(*t/ha*)
Bentazon	1.0	15	41 b	3.9 a
Bentazon	1.0	25	6 a	3.8 a
2,4-D	0.75	15	80 c	4.1 a
2,4-D	0.75	25	20 ab	4.2 a
Untreated check	-	-	201 c	1.8 b

[a]Av of four replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Butachlor was applied at 1.0 *kg ai/ha* 6 days after seeding (DAS) to all treatments to control annual weeds.

In the single and combined herbicide application trial, most of the herbicide treatments did not significantly reduce *S. maritimus* stand (Table 7). However, all herbicides, except propanil, applied alone (poorest weed control) yielded significantly higher than the untreated check.

Table 7. Effect of herbicide combination applied 25 DAS on the control of *Scirpus maritimus* and yield of broadcast-seeded flooded IR36.[a] IRRI, 1983 DS.

Treatment[b]	Rate (*kg ai/ha*)	*S. maritimus* biomass (g/m^2)	Grain yield (*t/ha*)
Bentazon + 2,4-D	0.5 + 0.5	30 a	4.1 a
Propanil + 2,4-D	1.5 + 0.5	69 abc	3.5 ab
Bentazon	1.0	81 abc	3.3 ab
2,4-D	0.75	118 bc	3.1 ab
Bentazon + propanil	0.5 + 1.5	62 abc	2.9 bc
Propanil	2.0	132 bc	2.1 cd
Untreated check	-	188 c	1.8 d

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]A plus (+) means the herbicides were tank-mixed. Butachlor was applied at 1.0 *kg a.i./ha* 6 days after seeding (DAS) to all plots to control annual weeds.

Integrated Weed Control

In the integrated weed control experiment, the cultivars did not affect weed stand in the first crop (DS) (Fig. 1). Approximately the same number of *P. distichum*, *S. maritimus*, and annual weeds was observed in the short IR36 and tall IR29723. However, there was a slight decrease in *P. distichum* and an increase in *S. maritimus* and annual weeds when tillage was increased from 1 to 3 harrowings. *S. maritimus* and the annual weeds were controlled only with bensulfuron-methyl and propanil +2,4-D application (Fig. 1) resulting in significant yield increases in IR36 plots that received 1 and 3 harrowings and in IR29723 plots the received 2 and 3 harrowings (Table 8).

In the second crop (WS), 3 harrowings gave the lowest *P. distichum* stand, but again did not minimize *S. maritimus* and annual weed

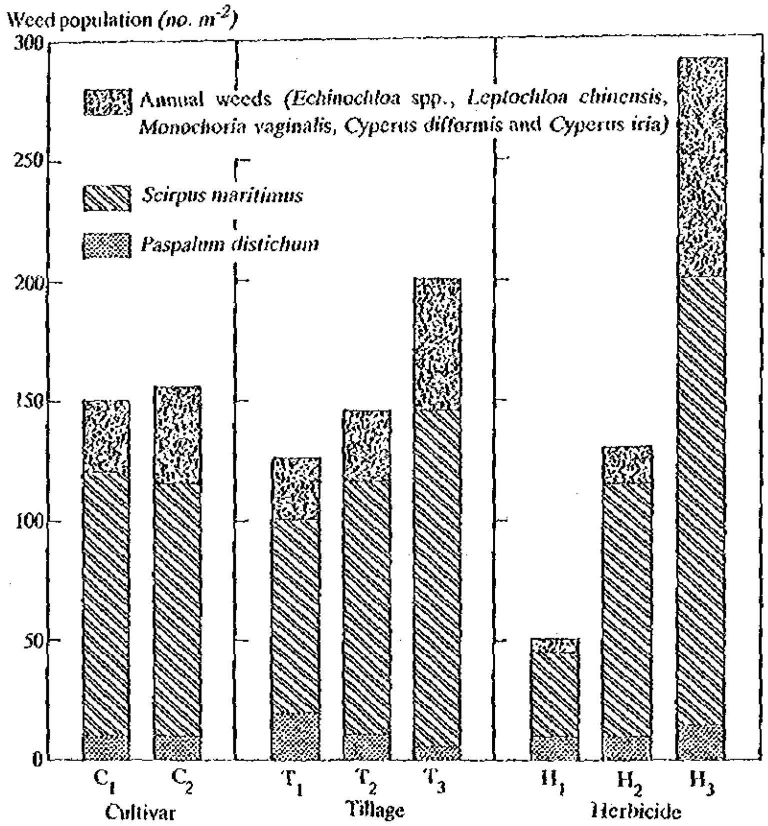

Fig. 1. Weed population in the first crop as affected by cultivar (C_1 = IR35, C_2 = IR29723-143-3-2-1), tillage (T_1 = 1 harrowing, T_2 = 2 harrowings, T_3 = 3 harrowings), and herbicide (H_1 = bensulfuron-methyl, H_2 = propanil+2,4-D, H_3 = untreated) in broadcast-seeded flooded rice, IRRI, 1984 DS.

Table 8. Effect of herbicide treatments on the yield of the first continuous broadcast-seeded rice crop planted under 3 tillage levels.[a] IRRI, 1984 DS.

Treatment[b]	Application		Grain yield (t/ha)		
	Rate (kg ai/ha)	Time (DAS)[c]	One harrowing	Two harrowings	Three harrowings
			IR 36		
Bensulfuron-methyl	0.05	10	4.3 a	3.3 a	3.7 a
Propanil EC + 2,4-D EC	1.5 + 0.5	15	4.0 a	3.1 a	3.7 a
Untreated check	–	–	1.6 b	3.1 a	1.6 b
			IR29723-143-3-2-1		
Bensulfuron-methyl	0.05	10	4.8 a	5.4 a	5.8 a
Propanil EC + 2,4-D EC	1.5 + 0.5	15	4.8 a	5.0 a	5.9 a
Untreated check	–	–	4.3 a	3.1 b	3.5 b

[a]Av of 3 replications. In a column/cultivar, means followed by a common letter are not significantly different at the 5% level. [b]G = granule. EC = emulsifiable concentrate. + = tank mixture. [c]Days after seeding.

infestations better than with either 1 or 2 harrowings (Fig. 2). The IR29723 plots were only slightly less weedy than the IR36 plots. Herbicide-treated plots had substantially less *S. maritimus* and annual weeds regardless of tillage level. Yields with both herbicide treatments were significantly higher than in untreated IR36 plots harrowed once and thrice and in IR29723 plots harrowed twice and thrice (Table 9).

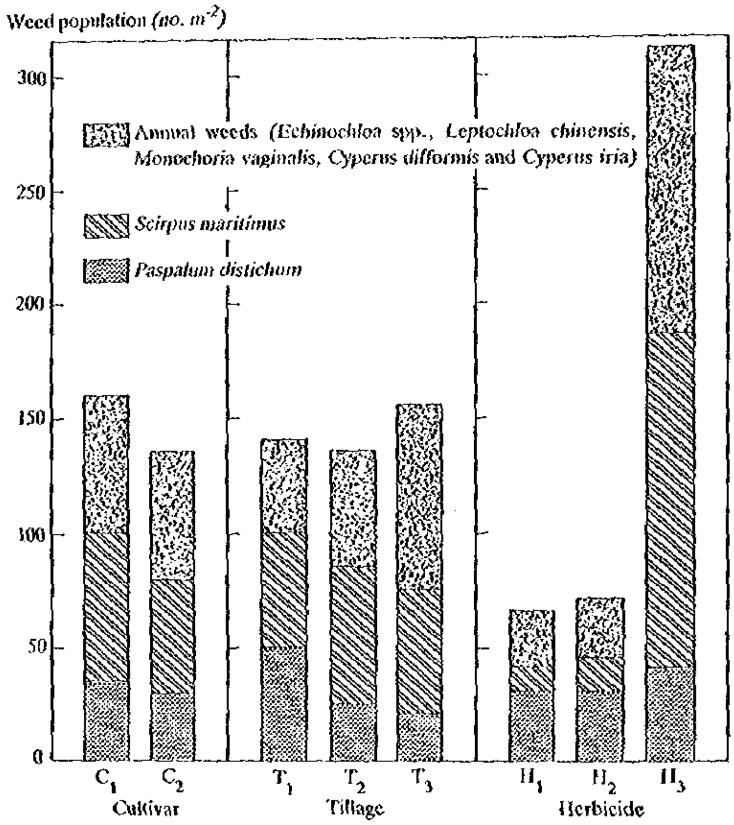

Fig. 2. Weed population in the second crop as affected by cultivar (C_1 = IR36, C_2 = IR29723-143-3-2-1), tillage (T_1 = 1 harrowing, T_2 = 2 harrowings, T_3 = 3 harrowings), and herbicide (H_1 = bensulfuron-methyl, H_2 = propanil+2,4-D, H_3 = untreated) in broadcast-seeded rice. IRRI, 1984 WS.

Table 9. Effect of herbicide treatments on the yield of the second continuous broadcast-seeded flooded rice crop planted under 3 tillage levels.[a] IRRI, 1984 WS.

Treatment[b]	Application		Grain Yield (t/ha)		
	Rate (kg ai/ha)	Time (DAS)[c]	One harrowing	Two harrowings	Three harrowings
			IR 36		
Bensulfuron-methyl	0.05	10	1.9 a	2.2 a	3.4 a
Propanil EC+2,4-D EC	1.5 + 0.5	15	2.4 a	2.4 a	2.1 b
Untreated check	-	-	0.4 b	1.4 a	0.6 c
			IR29723-143-3-2-1		
Bensulfuron-methyl	0.05	10	2.7 a	2.5 a	3.1 a
Propanil EC+2,4-D EC	1.5 + 0.5	15	2.3 ab	2.7 a	3.1 a
Untreated check	-	-	1.2 b	1.1 b	1.3 b

[a]Av of 3 replications. In a column/cultivar, means followed by a common letter are not significantly different at the 5 % level.
[b]G = granule. EC = emulsifiable concentrate. + = tank mixture. [c]Days after seeding.

Results from both crops indicate that cultivar type had no effect in minimizing weed competition. However, a slight decrease in *P. distichum* was observed with an increase in tillage level. Bensulfuron-methyl and propanil + 2,4-D application effectively controlled *S. maritimus* and the annual weeds which consequently resulted to higher yields.

Farm-level Constraints Trial
On-farm experiments showed that herbicides in combination were not necessary to control single weed vegetation for optimum rice yields. IRRI constraints research data show that the contribution of improved herbicide weed control accounted, on average, for about 30% of the yield gap over farmers' weed control practices, but that actual contributions varied enormously across sites and over years (Fig. 3). The benefit to cost ratio of the researcher's weed control, when compared to farmer's practices, were extremely high in the dry season, and on average, exceeding 20 : 1, except for Bulacan in 1985.

Farmer Management of Broadcast-Seeding
Farmer's rice yields in Central Luzon are essentially double that recorded in the Bicol region (Table 10). In the irrigated sites in Central Luzon, mean rice yields, over 4 *t/ha*, did not differ between methods of crop establishment. However, in the rainfed rice systems in Bicol, yields were significantly higher in the transplanted (2.4 *t/ha*) than the wet-seeded (1.9 *t/ha*) sites. The yield difference in Bicol was ascribed in part to differences in fertilizer use and, while not reported, in the higher incidence of weed infestation and moisture stress in wet-seeded parcels (Mandac *et al.*, 1982).

Farmers in both Central Luzon and Bicol who direct-seeded used significantly higher seed rates than those who transplanted their rice. Seeding rates were well in excess of those recommended for transplanted (40 *kg/ha*) or for wet-seeded (60-90 *kg/ha*) rice in the Philippines. Farmer's high seeding rates with direct seeding are in effect a substitute for herbicides and hand weeding. High seeding rates also compensate for uneven seed distribution and stand loss due for example to birds, rats or uneven land preparation. The Central Luzon farmers on average applied almost twice as much herbicide to direct-seeded compared to transplanted rice. However, in Bicol, the opposite was the

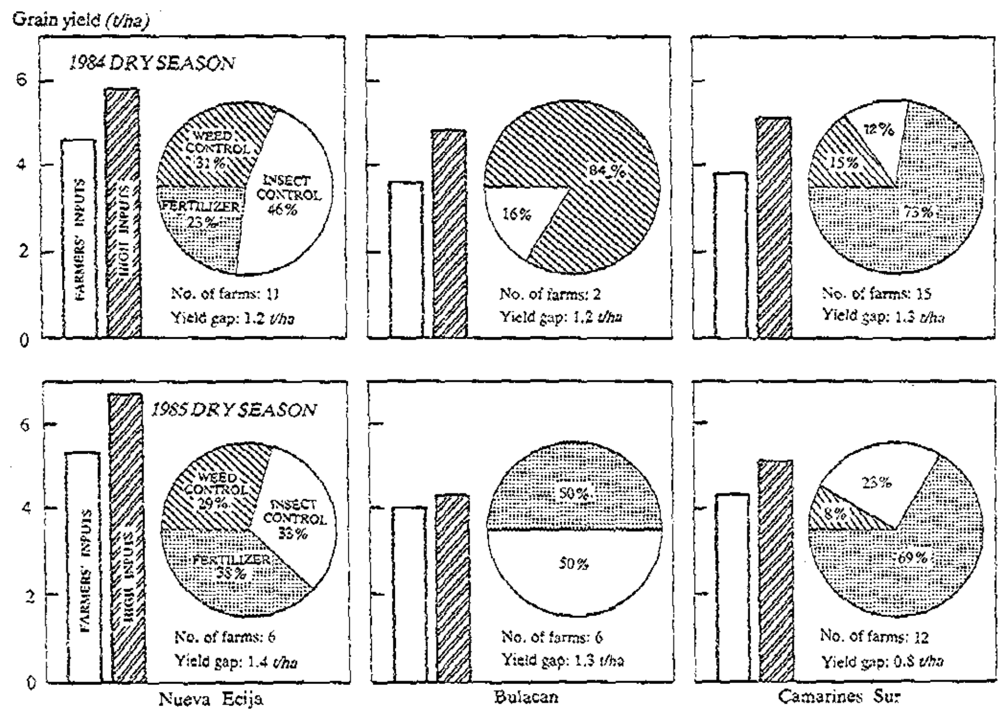

Fig. 3. Average yields with farmers and high inputs and relative contributions of fertilizer, weed control, and insect control toward improvement of rice yields on broadcast-seeded irrigated farms in 3 provinces in the Philippines. 1984 and 1985 dry seasons.

Table 10. Comparative yields and inputs in transplanted and wet-seeded rice in Central Luzon (irrigated rice) and Bicol (rainfed rice) regions of the Philippines.

	Luzon-irrigated			Bicol-rainfed		
	TPR	WSR	Diff.	TPR	WSR	Diff.
Output						
Grain yield *(t/ha)*	4.0	4.3	0.3^{ns}	2.4	1.9	0.5
Inputs						
Seed *(kg/ha)*	113	203	90**	104	135	31**
Herbicide *(₱/ha)*[a]	71	144	73**	41	28	13**
Nitrogen *(kg/ha)*	66	70	4^{ns}	24	17	7*
Labor *(days/ha)*	95	75	20**	84	54	29**

Source: (Moody and Cordova, 1985; Flinn and Mandac, 1985).
**, * and ^{ns} imply means significantly differed at the 1%, 5% and not significantly differed.
[a]1 US $ = 18 Philippine pesos.

case, partly a reflection of the fact that the most resource-poor farmers adopted wet seeding most widely in an attempt to reduce production costs (Flinn and Mandac, 1985).

The greatest saving from wet seeding is reduced labor inputs which saved farmers 20 labor days/*ha* or more, or over ₱400/*ha* (US$22/*ha*) mainly for transplanting. This saving, even after the cost of higher seed rates and possibly herbicides are allowed for, substantially reduces rice production costs and so helped sustain the profitability of rice production.

DISCUSSION

Innovations in weed management based on judicious use of recently identified herbicides have resulted in wet seeding emerging as a viable alternative to transplanting in areas with reasonable water control during crop establishment. Important technical issues which may influence the sustainability of this technique include whether yields are maintained and whether herbicides continue to control weed species which may become dominant as wet seeding is adopted on a sustained basis. Another is whether water control at seeding time will constrain expanded use of this technology. Future economic circumstances will also determine the expanded use of this technology.

The emerging Asian rice scenario seems to be that rice supplies are increasing at a more rapid rate than is effective demand, and as a result, real rice prices are tending to fall (IRRI 1985). Yet the real cost of inputs has not decreased in a similar manner. Thus, the Asian rice farmer is facing a cost-price squeeze -- and so seeks alternative practices which will enable him to maintain productivity and profitability in rice production. Among these strategies are direct seeding and herbicide use, which helped reduce production costs by reducing labor inputs for crop establishment and for weeding.

The adoption of wet seeding in the Philippines was facilitated as herbicides have become cheaper compared to labor (Fig. 4). Whether this incentive for broadcast-seeding continues will in part depend on government policies with respect to trade controls and monetary and exchange rate policies which will help determine herbicide prices as most Southeast Asian countries now import the active ingredients of herbicides. This, together with the level of market competition, will in aggregate help determine the market prices of herbicides, and the competitiveness of herbicides and labor. A second determinant of the

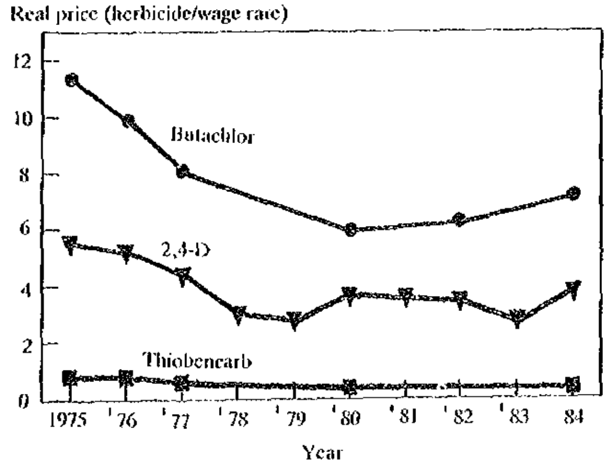

Fig. 4. Long-term trends in real prices of herbicides in the Philippines, 1975-1983.

long-term profitability of broadcast-seeding is the trend in real wages (Fig. 5). In Malaysia, North Sumatra, and the Central Plain of Thailand where real wages are rising, direct-seeding is likely to expand more rapidly than for example in Central Java or South Sulawesi where real wages are comparatively low. Indonesia, however, provides an interesting contrast. In Central Java there appears to be little incentive to shift towards broadcast seeding, yet in North Sumatra, the financial incentive appears high. In Thailand, mechanization is rapidly taking place in land preparation and community threshing. Broadcast-seeding and herbicide usage are steadily increasing to decrease cost of production and labor usage. Alternatively, stagnation in real wages may act as a deterrent to the current rapid rate of adoption of this practice in the Philippines.

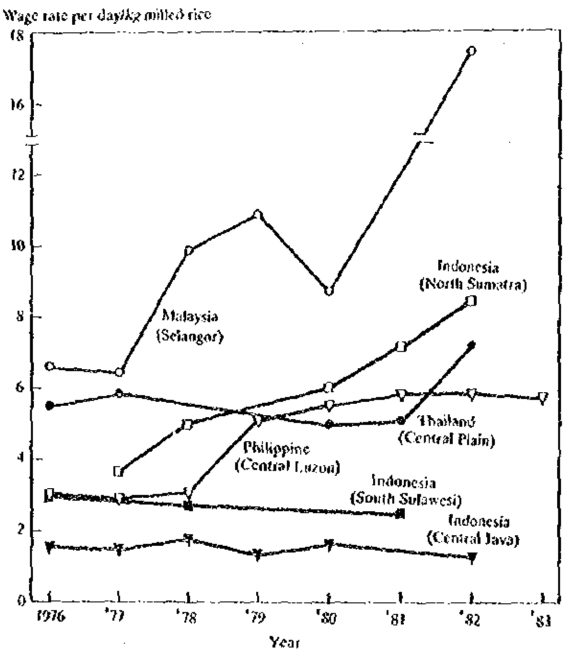

Fig. 5. Long-term trends in real agricultural wages in Indonesia, Malaysia, the Philippines, and Thailand.
Real wage derived at wage rate per day divided by the price per *kg* of milled rice.

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DISCUSSION OF THE PAPERS OF H.SHIBAYAMA, M. SOERJANI AND S.K. DE DATTA

(Chaired by K. Noda)

Dr. M. Blacklow (Australia): Dr. Y.K. De Datta, your comparison of direct seeded and transplanted rice were based on single crops. Are there any differences in the conclusions when the comparisons are made on the basis of cropping systems?

Dr. S.K. De Datta (Philippines): The switch is much larger in the dry season than in the wet season. If we examine crop establishment technique on an annual basis, most of the farmers are using the broadcast seeding in the dry season than growing a transplanted crop in the wet season.

In the rainfed rice areas, depending on the initial rainfall, farmers would decide to grow either transplanted crop or broadcast seeding into dry or moist soils. The switch to broadcast seeding is greater where a rice-rice system is used. The switch to broadcast seeding is more in irrigated rice on puddled fields and is less in rainfed rice.

Dr. S.K. Mukhopadhayay (India): No doubt the direct seeded flooded rice system has the distinct advantage of saving considerable labor cost, yet there are many people who have problems on toxicity-injury of herbicides in direct-seeded flooded rice crop as compared to transplanted rice crop. When herbicides are applied, transplanted seedlings being older are less prone to herbicide injury.

Dr. S.K. De Datta : No herbicides would be recommended when the toxicity is consistent and also persistent. Our recent results suggested that when the herbicide application is made before seeding, the toxicity is considerably reduced. At the time of herbicide application if the seedlings of broadcast-seeded rice are mostly submerged under water, then the herbicide injury will be high. Therefore, proper water control at the time of herbicide application is important to minimize seedling injury and maximize weed control.

Mrs. Rajanee Virabalin (Thailand): Dr. M. Soerjani, is it possible that 'by choosing an appropriate technology to use aquatic weeds as a raw material, the aquatic weeds will be changed to be economic crops?

Dr. M. Soerjani (Indonesia): Yes, it might be. A typical example is wild rice. Some of the species of wild rice now become cultivated crops, while the rest (e.g. *Oryza perennis* and *O. rufipogon*) still have status as weeds.

Dr. M. Blacklow (Australia): Dr. M. Soerjani, you seemed to be advocating constraints with the expansion of the biological control of aquatic weeds and concluded that control with herbicides is localised and would, therefore, allow any advantages of aquatic weeds to be exploited. Would you care to emphasis this advice?

Dr. M. Soerjani : I have no objection to the implementation of conventional bioligical control. However, I am questioning: when you add a component in the trophic structure, namely by releasing an insect as a biological control agent to control a weed, you have to know what will be the end of the trophic pyramid. If you don't know what will happen with the insect or what will be the top component of the new trophic pyramid, there will be an unknown risk.

In most biological control efforts with insect for instance, the other role of an insect except as a phytophagous agent is mostly unknown. Since actually the insect may also serve as pollinators of crops or other economic plants. This is a beneficial side effect of a control agent.

The use of herbicides in aquatic weed control may offer a broader opportunity by converting the biomass into others, e.g. detritus, phytoplanktons and zooplanktons, that can be utilized by a variety of fish in a more proper way. Furthermore, if aquatic weed utilization is not feasible because of the small amount of the biomass, preventive control measure might be more appropriate by using herbicides.

Dr. Lee Soo Ann (Malaysia): Dr. M. Soerjani, you mentioned that aquatic weeds harbour mosquito larvae, which may spread malaria. I have heard of reports of strains of malaria parasites resistant to the usual doing in Sabah and perhaps Indonesia. Can you please comment on the aquatic weed species which specifically harbour this parasite and what are your views on their control?

Dr. M. Soerjani: In general, water is a living place for mosquito larvae, and since they are high in the trophic level, they need certain support from the lower level of the trophic structure, including primary producers, e.g. aquatic plants.

Dr. K. Noda : We had many papers on *Mimosa pigra* in the concurrent session, and Dr. Onnop, Chiang Mai University have new, current information on it around these areas,I think. Please give us any comment.

Dr. Onnop Wara-Aswapati (Thaialnd): We had many papers and reviews on *Mimosa pigra* in the concurrent session including Dr. Shibayama's paper in this Symposium and observation on a field trip to infested areas. I think, there is no need to add any comment on current situations. But I would like to ask two points: 1) what is the best method of *Mimosa pigra's* control and/or managements?, 2) what should be emphasized in future research for *Mimosa pigra?*

Dr. H. Shibayama (Japan) : In a long term sense, biological control is useful, but in a short term one, combination of herbicides and manual methods is necessary, I would say. As for research programme, the utilization of landsat will be interested to know the change of *Mimosa pigra* vegetation. Biological works such as seed germination presented by Dr. W.H. Lonsdale in natural conditions are very important to know how it propagates and spreads to new other areas. Further, physiological analysis of how *Mimosa pigra* adapts to flooding conditions, and biological works to find weak points of *Mimosa pigra* for control are very important, I think.

WEEDS AND THE ENVIRONMENT IN THE TROPICS
(Eds. K. NODA & B.L. MERCADO), pp. 79-99, 1986

WEEDS IN SHIFTING CULTIVATION IN THAILAND

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Abstract. Shifting cultivation under customary practice is undertaken into 2 forms: annual and rotary. Under both practices weeds are constantly encroached during and after cultivation.

The most noxious weeds in the annual cultivation, commonly practised by the hill tribes; i.e. Maeo, Musoe and Yao are Saap ma, *(Ageratina adenophora* (Spreng.) R.M. King & M. Robins., Phak hai *(Artemisia dubia* Wall. ex DC.) and Thaan tawan nuu or Bua tong *(Tithonia diversifolia* Gray), which become gregarious all over the area after such cultivation.

The rotary shifting cultivation causes less noxious weeds, as the land was left to fallow for a period of 5-9 years: the most noxious weeds are Saap suea *(Chromolaena odorata* (Linn.) R.M. King & B. Robins) and Khaem *(Saccharum arundinaceum* Retz.).

However, Ya khaa *(Imperata cylindrica* Beauv.) is the noxious weed in both types of shifting cultivation.

INTRODUCTION

The First Tropical Weed Science Conference was held at Haad Yai, Songkhla, Thailand during 22-25 October 1984, of which many topics on weeds were discussed, especially in the lowland, with only a mere touch on the highland. It appears that among the ten top weeds, the Lallang grass *(Imperata cylindrica)*, Purple nutsedge *(Cyperus rotundus)*, and Saap suea *(Chromolaena odorata)* occur both in lowland and highland. The aim of this paper is to enumerate weeds in the shifting cultivation among the highland.

Weeds can be defined as plants out of place or unwanted plants, or plants with a negative value, or plants which compete with man for the soil. They can be classified into 2 categories: obligate and facultative (SEN, 1981). The obligate weeds are occuring only in association with man and never in wild form, such as Ngon kai or Dok daai *(Celosia argentea)*, Saap ma *(Ageratina adenophorum)*, Saap suea *(Chromolaema odorata)*, Maiyaraap ton *(Mimosa pigra)*, Thaan tawan nuu *(Tithonia diversifolia)*, etc. The facultative weeds are found both wild in primary habitats and with man in cultivated habitats, such as, Saap raeng saap ka *(Ageratum conyzoides)*, Phaak hia *(Artemisia dubia)*, Yaa khi thut *(Artemisia roxburghiana)*, Khaem *(Saccharum arundinaceum)*, Yaa tong kong *(Thysanolaena maxima)*, etc.

Shifting cultivation practised in Thailand is undertaken into two forms: annual and rotary. The annual shifting cultivation is done by hill tribes in Northeastern Highland, namely Maeo or Hmong, Yao, Musoe or Lissu living at higher elevations from 1,000 *m* upwards, they are half nomads. These people grow their crops annually, such as corn for their staple food, and opium poppy as cash crop. Under their practice the land is properly cleared and continually cleaned to ensure the highest yield; thus except the crops cultivated, the land is almost without any other ground cover. During the time of cultivation the soil is exposed to the sun and rain, causing rather high evapotranspiration and water run off. After harvest the soil is totally barren, and subject to very high evapotranspiration and surface erosion, caused either by wind or water run-off.

Plant succession under this trying condition is subject to noxious weeds such as Saap ma *(Ageratina adenophora)*, Phak hia *(Artemisia dubia)*, and Yaa khi thut *(Artemisia roxburghiana)*, gregariously occupying the open ridges and slopes; whereas along the rather humid valleys Thaan tawan nuu or Bua thong *(Tithonia diversifolia)* is preponderate. If such areas are continually subject to annual fire, the above mentioned weeds might be encroached by grasses such as : *Arundinaria setosa, Capillipedium assimile, C. parviflorum, Cymbopogon flexuosus, Heteropogon triticeus, Imperata cylindrica, Saccharum arundinaceum, Themeda arundinacea, T. triandra, Thysanolaena maxima*, etc.; the ferns, *Dicranopteris linearis* and *Pteridium aquilinum*, become widespread. The full list of species is given in Table 1.

The rotary shifting cultivation is practised by other hill tribes inhabiting lower elevations from 600*m* upwards, such as : Karen and Lawa or Lua. These people are stationary and grow wet-rice for their staple food with additional shifting cultivation to supplement their income. The rotary system of shifting cultivation has a rotation from 5-9 years; after harvest the land is left to fallow between the rotation. Under this system the land is not properly cleaned, stumps are left around, which will coppice after the harvest. Plant succession in these areas is subject to hardy tree species lately coppiced, shrubs and other annual herbs such as Saap raeng saap ka *(Ageratum conyzoides)* Phak kaat chang *(Crassocephalum crepidioides)*, and Yaa tom tok *(Physalis minima)*, which later are superseded by the perennial herbs, Saap suea *(Chromolaena odorata)* (Nemoto & Pongskuk, 1985) and other perennials such as Yaa khai luang *(Arundinella hispida)*, Yaa saeng kham *(Hyparrhenia* rufa), Yaa kha *(Imperata cylindrica)*, Khaem *Saccharum arundinaceum)*, and Yaa tong kong *(Thysanolaena maxima)*. The full list of species is given in Table 2.

MAJOR WEEDS IN HIGHLAND SHIFTING CULTIVATION

The major weeds in highland shifting cultivation in Thailand belong to two groups of plants, i.e. Pteridophyta or vascular ferns and Spermatophyta or seed plants.

PTERIDOPHYTA.– Only two species of vascular ferns, Kut pit *(Dicranopteris linearis)* of the family Gleicheniaceae and Kut kin *(Pteridium aquilinum)* of the family Dennstaedtiaceae are recognized as noxious weeds.

Dicranopteris linearis (Burm.f.) Underw. is very widespread all over the country in old clearings, usually at edge of forests, in open or half-shaded places at low to medium altitudes.

Pteridium aquilinum (Linn.) Kuhn is found all over the country in open areas, upto 2,000 *m* alt. It is one of the acidiphilous plants, usually forms a big thicket at edge of forests, or recent clearings in sunny places, and frequent in the pine forests. The young fronds are cooked to substitute vegetable, and starch is available from rhizome.

SPERMATOPHYTA.– Quite a number of seed plants are identified as weeds, but the majority belongs to families Gramineae, Acanthaceae, and Compositae.

Gramineae or the grass plant. Grasses are either annual or perennial. The annual species are not noxious weeds, only the perennials ones play an important role in weed science. Annual species such as Yaa khon kratai *(Aristida cumingiana)*, Yaa yung *(Capillipedium assimile, C. parviflorum)*, Yaa paak khwaai *(Digitaria violascens)*, *Dimeria ornithopoda*, Yaa kon hep *(Eragrostis capensis)*, Yaa khai puu *(Eragrostis unioloides)*, Yaa khanaeng *(Rytilix granulare)*, etc. are found after the harvest of crops, but later will be suppressed by the perennial ones. such as *Arundinella setosa*, *Cymbopogon flexuosus*, *Eulalia siamensis*, Yaa saeng kham *(Hyparrhenia rufa)*, Khaem *(Neyraudia reynaudiana)*, Khaem luang *(Themeda arundinacea)*, and Yaa tong kong *(Thysanolaena maxima)*.

Among these grasses *Imperata cylindrica* is well established becoming the most noxious weed difficult to eradicate. It is subject to fire and is a check against any pioneer species to establish. Even tall grasses such as *Arundinella setosa*, *Themeda arundinacea* and *Saccharum arundinacum* hardly exist.

Acanthaceae weeds, mostly annuals, namely *Rostrellularia chiangmaiensis*, *R. cradengensis*, *R. neglecta*, *Rungia maculata*, and *Barleria cristata* although established after harvesting of crops are superseded by *Imperata cylindrica* and other grasses, except *Barleria cristata* that exists scatterlingly owing to its having fasciculate roots.

Compositae weeds, mostly annuals, i.e. *Anaphalis adnata*, *A. margaritaceum*, *Ageratum conyzoides*, *Blumea fistulosa*, *B. lacera*, *Crassocephalum crepidioides*, etc. are also superseded by *Imperata cylindrica*, and other perennial tall grasses. Except in certain moister areas perennials such as *Artemisia dubia*, *Chromolaena odorata*, and *Tithonia diversifolia* become preponderate. The annual *Ageratina adenophylla* is also forming dense masses in moister localities. It is worthwhile to note that among these weeds the exotic species, i.e. *Ageratina adenophylla*, *Chromolaena odorata*, and *Tithonia diversifolia*, which belong to the family Compositae become widespread due to the gregarious flowering in suitable condition. Only the native *Imperata cylindrica* is forming dense stands owing to its matted underground rhizomes and gregarious flowering due to annual fire.

Table 1. Weeds in the annual shifting cultivation

Botanical names	Vernacular names
PTERIDOPHYTA	
DENNSTAEDTIACEAE	
Pteridium aquilinum (Linn.) Kunth	Kut kin
DRYOPTERIDACEAE	
Dryopteris cochleata C.Chr.	
GLEICHENIACEAE	
Dicranopteris linearis (Burm.f.) Underw.	Kut pit
SELAGINELIACEAE	
Selaginella chrysorrhizos Spring	
S. helferi Warb.	Yaa roug hai
S. monospora Spring	
S. ostenfeldii Hieron.	Phak khwa
S. repanda (Desv.) Spring	
S. siamensis Hieron.	Phak nok yung
SPERMATOPHYTA	
(ANGIOSPERMAE - MONOCOTYLEDONES)	
COMMELINACEAE	
Commelina benghalensis Linn.	Phak plap
C. diffusa Burm.f.	Phak plap
Cyanotis axillaris Roem. & Schultes	Phak plap naa
Murdannia gigantea Brueck.	Yaa ngon ngueak
CYPERACEAE	
Carex indica Linn.	Yaa kom bang lek
C. tricephala Boeck.	Yaa dok din
Cyperus cyperinus Suringar	Yaa liam
C. leucocephala Retz.	Yaa faek mai
Fimbristylis dichotoma Vahl	Yaa niu nuu
F. monostachyos Hassk.	Yaa kuk muu
Scleria levis Retz.	Yaa saam khom
S. pergracilis Kunth	Khaa hom
GRAMINEAE	
Aristida cumingiana Trin. & Rupr.	Yaa khon kataai
Arundinella hispida Hack.	Yaa khaai luang
A. setosa Trin.	
Bothriochloa pertusa (Linn.) A. Camus	Yaa hom
Capillipedium assimile (Steud.) A. Camus	Yaa yung
C. parviflorum (R.Br.) Stapf	Yaa yung
Centotheca lappacea Desv.	Yaa ee nieo
Cymbopogon flexuosus (Linn. Nees) Wats.	

Table 1 (continued)

Botanical names	Vernacular names
Digitaria adscendens (H.B.K.) Henr.	Yaa plong khaao nok
D. sanguinalis (Linn.) Scop.	Yaa teen ka
D. violascens Link	Yaa paak khwaai
Dimeria ornithopoda Trin.	
Eragrostis burmanica Bor	Yaa krok
E. capensis Trin.	Yaa kon hep
E. nutans (Retz.) Nees ex Steud.	Yaa khaem
E. unioloides (Retz.) Nees	Yaa khai puu
E. zeylanica Nees & Mey	Yaa waai
Hyparrhenia bracteata (Humb. & Bonpl.) Stapf.	Yaa khon taa chang
H. rufa (Nees) Stapf	Yaa saeng kham
Imperata cylindrica (Linn.) P. Beauv.	Yaa khaa
Ischaemum barbatum Retz.	Yaa waai
I. rugosum Salisb.	Yaa daeng
Microstegium vagans (Nees) A. Camus	
Oplismenus compositus (Linn.) P. Beauv.	Yaa khai maengda
Panicum notatum Retz.	Yaa khai haao luang
Rytilix granularis Skeels	Yaa khanaeng
Saccharum arundinaceum Retz.	Khaem
Setaria plicata (Lamk.) T. Cooke	Yaa kong kaai
Sorghum nitidum (Vahl) Pers.	Yaa haang maa
Spodiopogon lacei Hole	
Sporobolus kerrii Bor	
Themeda arundinacea (Roxb.) Ridl.	Khaem luang
T. triandra Forssk.	Yaa faek
Thysanolaena maxima (Roxb.) O. Ktze.	Yaa tong kong
(ANGIOSPERMAE - DICOTYLEDONES)	
ACANTHACEAE	
Andrographis laxiflora (Bl.) Lindau	
A. paniculata (Burm.) Wall. ex Nees	Faa thalaai
Barleria cristata Linn.	Angkaap
Dyschoriste depressa Nees	Yaa saam chan
Eriostrobilus bombycinus (Imlay) Brem.	
Golfussia anfractuosa (Clarke) Brem.	
G. rex (Clarke) Brem.	
Lepidagathis chiangmaiensis Brem.	
L. incurva Ham. ex Don	Yaa khon kai
L. fasciculata Nees	
L. thyrsiflora Brem.	Yaa haep
Parasympagis garettii Brem.	

Table 1 (continued)

Botanical names	Vernacular names
Pseuderanthemum andersonii (Mast.) Lindau	Thao lang laai
Rostrellularia chiengmaiensis Brem.	
R. cradengensis Brem.	
R. neglecta Brem.	
Rungia parviflora Nees	
COMPOSITAE	
Anaphalis adnata DC.	Naat khao
A. margaritaceum (Linn.) Benth.	Naat doi
Ageratina adenophylla (Spreng) R.M.King & M. Robins	Saap maa
Ageratum conyzoides Linn.	Saap raeng saap ka
Blumea aurita DC.	Saap raeng saap ka
B. balsamifera (Linn.) DC.	Naat yai
B. fistulosa Kurz	Phak kaat khi maa
B. lacera (Burm.f.) DC.	Naat wua
B. oxydonta DC.	Pat nam
Blumeopsis falcata (O.Ktze.) Merr.	Phak kaat khok
Chromolaena odorata (Linn.) R.M.King & M. Robins.	Saap suea
Cosmos caudatus H.B.K.	Dao rueang phamaa
C. sulfureus Cav.	Dao krachaai
Crassocephalum crepidioides (Benth.) S. Moore	Phak kaat chaang
Cyathocline purpurea (Ham. ex D.Don) O.Ktze.	
Eupatorium cannabinum Linn.	
Gnaphalium affine D.Don	
G. hypoleucum DC.	
Inula cappa (Ham. ex D.Don) DC.	Naat kham
I. crassifolia Coll. ex Hemsl.	Naat khok
I. eupatorioides DC.	Naat khon
I. nervosa Wall. ex DC.	Deelamon
Laggera alata (D.Don) Sch. Bip. ex Oliv.	Naat wua
Piloselloides hirsuta (Forssk.) C. Jeffrey	Waan khaang khok
Saussurea deltoidea (DC.) C.B. Clarke	
S. peguensis C.B. Clarke	
S. venosa Kerr	
Senecio nagensium C.B. Clarke	Khaang haang lek
Spilanthes iabadicensis A.H. Moore	Phak khraat
Tithonia diversifolia (Hemsl.) A.Gray	Thaan tawan nuu
Tricholepis karensium Kurz	Kham doi
Vernonia cinerea (Linn.) Less.	Suea saam kha
V. squarrosa Less.	Naat kham

Table 1 (continued)

Botanical names	Vernacular names
EUPHORBIACEAE	
Acalypha kerrii Craib	Khaang poi
Cnesmone javanica Bl.	Tamyae khruea
C. laotica (Gagnep.) Croiz.	Haan salit
Euphorbia capillaris Gagnep.	Pom daeng
E. hypericifolia Linn.	Nam nom ratchasi
Phyllanthus amarus Schum. & Thonn.	Luuk tai bai
LABIATAE	
Achyrospermum wallichiaum Benth. ex Hook.f.	Saa hom
Acrocephalus indicus (Burm.f.) O.Ktze.	
Anisochilus pallidus Wall.	
A. siamensis Ridl.	
Anisomeles candicans Benth.	
Epimeredi indica (Linn.) Roth	Komko huai
Geniosperum siamense Murata	Hom paa
Hyptis suaveolens Poit.	Maenglak kaa
Leucas ciliata Benth.	Yaa hua suea
L. mollissima Wall.	
Teucrium quadrifarium Buch. – Ham.	
LEGUMINOSAE – CAESALPINIOIDEAE	
Cassia pumila Lamk.	Ma khaam bia
C. mimosoides Linn.	Sano noi
LEGUMINOSAE – MIMOSOIDEAE	
Archidendron glomeriflorum I.Niels.	Yaa poh
Mimosa invisa Mart.	Mai yaraap ton
M. pigra Linn.	Mai yaraap naam
LEGUMINOSAE – PAPILIOIDEAE	
Crotalaria assamica Benth.	Ma hing nam
C. chinensis Linn.	Ma hing phae
C. montana Heyne ex Roth	Hing men foi
C. verrucosa Linn.	Hing haai bai yai
Indigofera sutepensis Craib	Khraam pa
I. squalida Prain	Baa bing men
POLYGALACEAE	
Polygala longifolia Poir.	Yaa lueat nai
Salomonia cantoniensis Lour.	Niam nok khao
S. ciliata DC.	Yaa raak hom
POLYGONACEAE	
Polygonum chinense Linn.	Phak bang bai
P. paleaceum Wall.	

Table 1 (continued)

Botanical names	Vernacular names
SOLANACEAE	
Physalis minima Linn.	Yaa tom tok
UMBELLIFERAE	
Heracleum siamicum Craib	Ma laep
URTICACEAE	
Boehmeria chiangmaiensis Yahara	Khiang khaeng maa
B. macrophylla D.Don	Chaa paan
B. platyphylla D.Don	Paan
VERBENACEAE	
Verbena officinalis Linn.	

Table 2. Weeds in the rotary shifting cultivation

Botanical names	Vernacular names
PTERIDOPHYTA	
DENNSTAEDTIACEAE	
Microlepia speluncae (Linn.) Moor	Kuut phee or kuut yee
Hypolepis punctata (Thunb.) Mett. ex Kuhn	Kuut kin or kuut kia
Histiopteris incisa (Thunb.) J. Smith	
DRYOPTERIDACEAE	
Dryopteris cochleata C.Chr.	
D. mollis Hiern	Kuut khon
Pleocnemia winitii Holtt.	Kuut dam
Pteridrys syrmatica C. Chr.	Kuut kham
GLEICHENIACEAE	
Dicranopteris curranii Copel.	
D. linearis (Burm.f.) Underw.	Kuut pit
Gleichenia longissima Bl.	
OPHIOGLOSSACEAE	
Botrychium lanuginosum Wall. ex Hook. & Grev.	
Helminthostachys zeylanica (Linn.) Hook.	Kuut teen hung
Ophioglossum petiolatum Hook.	
PARKERIACEAE	
Pityrogramma calomelanos Link.	Foen ngoen
PTERIDACEAE	
Pteris biaurita Linn.	Kuut haang khaang
P. heteromorpha Fée	Kuut phee
P. vittata Linn.	Kuut maak

Table 2. (continued)

Botanical names	Vernacular names
SCHIZAECEAE	
Lygodium flexuosum (Linn.) Sw.	Kuut kong
L. giganteum Tagawa & K. Iwats.	
L. japonicum (Thunb.) Sw.	Ngo ngae
L. microphyllum (Gav.) R. Br.	Kachot nuu
L. polystachyum Wall. ex Moore	Kuut khruea
L. salicifolium Presl	Kuut khue
SELAGINELLACEAE	
Selaginella biformis A. Br. ex Kuhn	Kuut pha
Selaginella delicatula (Desv.) Alst.	
S. helferi Warb.	Yaa rong hai
S. intermedia (Bl.) Spring	Hee moi sao kae
S. involevens (SW.) Spring	Foen phaeng
S. kurzii Bak.	
S. minutifolia Spring	Kuut yee
S. ostenfeldii Hieron.	Phak khwaa
S. pubescens (Wall. ex Hook. & Grev.) Spring	Fueai nok
S. roxburghii (Hook. & Grev.) Spring	
S. siamensis Hieron.	Phak nok yuung.
S. tenuifolia Spring	
THELYPTERIDACEAE	
Thelypteris cylindrothrix (Rosenst.) K. Iwats.	
T. dentata (Forsk.) St. John	
T. hirsutipes (Clarke) Ching	
T. interrupta (Willd.) K. Iwats.	Kuut yaang
T. truncata (Poir.) K. Iwats.	Kuut kaan daeng
SPERMATOPHYTA	
(ANGIOSPERMAE – MONOCOTYLEDONES)	
COMMELINACEAE	
Aneilema scaberrimum Kunth	Phak plaap khieo
Commelina bengalensis Linn.	Phak plaap
C. diffusa Burm. f.	Phak plaap
Cyanotis axillaris Roem. & Schultes.	Phak plaap naa
C. cristata Roem. & Schultes	Yaa hua raak noi
Murdannia gigantea (R. Br.) Brueck.	Yaa ngon ngueak
M. nudiflora (R.Br.) Brennan	Kin kung noi
CYPERACEAE	
Carex baccans Nees	Yaa khom baang
Carex cruciata Vahl	Yaa hom baang khaao
C. indica Linn.	Yaa khom baang lek

Table 2. (continued)

Botanical names	Vernacular names
C. continua C.B. Clarke	
C. stramentita Boott & Boeck.	Yaa khom baang
C. tricephala Boeck.	Yaa dok din
Cyperus compactus Retz.	Yaa bai khom
C. cuspidatus Kunth	Kok rang ka paa
C. cyperoides O. Ktze.	Yaa rang kaa
C. iria Linn.	Yaa rang kaa khaao
C. leucocephalus Retz.	Yaa faek mai
C. rotundus Linn.	Yaa haew muu
C. sesquiflorus Mattf.	Yaa dok khaao
C. tenuiculmis Boeck.	Yaa dok daeng
Fimbristylis dichotoma Vahl	Yaa niu nuu
F. eragrostis Hance	Yaa dok khaao
F. fusca Benth.	Yaa bai bit
F. hookeriana Boeck.	Yaa hua bo
F. junciflorus Kunth	Yaa dok khaao
F. monostachyos Hassk.	Yaa kuk muu
F. rigidula Nees	Yaa fan fuem
F. savannicola Kern	Yaa nuat maeo
F. thomsonii Boeck.	Yaa haeo muu
Scleria ciliaris Nees	Yaa rang kaa
S. kerrii Turrill	Yaa puum paao
S. levis Retz.	Yaa saam khom
S. lithosperma Sw.	Yaa khom baang lek
S. pergracilis Kunth	Khaa hom
S. terrestris Fassett	Yaa khom baang khao
S. tonkinensis C.B. Clarke	Yaa kom bao
GRAMINEAE	
Acroceras tonkinense (Balansa) C.E. Hubb. ex Bor	
Apocopis paleacea (Trin.) Hochr.	
A. siamensis A. Camus	
Aristida balansae Henr.	Yaa haang suea
Arundinella hispida Hack.	Yaa kaai luang
A. setosa Trin.	
Bothriochloa pertusa (Linn.) A. Camus	Yaa hom
Capillipedium assimile (Steud.) A. Camus	Yaa yung
C. parviflorum (R.Br.) Stapf	Yaa yung
Centotheca lappacea Desv.	Yaa ee nieo
Cymbopogon flexuosus (Linn. ex Nees) Wats.	
Digitaria adscendens (H.B.K.) Henr.	Yaa plong khaao nok
D. sanguinalis (Linn.) Scop.	Yaa teen kaa

Table 2. (continued)

Botanical names	Vernacular names
D. violascens Link	Yaa paak khwaai
Dimeria ornithopoda Trin.	
Eleusine indica (Linn.) Gaertn.	Yaa teen kaa
Eragrostis burmanica Bor	Yaa krok
E. capensis Trin.	Yaa kon hep
E. japonica (Thunb.) Trin.	
E. nutans (Retz.) Nees ex Steud	Yaa khaem
E. unioloides (Retz.) Nees	Yaa khai puu
E. zeylanica Nees & Mey.	Yaa waai
Eremochloa bimaculata Hack.	Yaa haang nok yuung
E. eriopoda C.E. Hubb.	Yaa haang karok
Eulalia bicornuta Bor	
E. birmanica (Hook.f.) A. Camus	
E. phaeothrix (Hook.) O. Ktze.	Yaa kaai
E. siamensis Bor.	
E. smitinandiana Bor.	Yaa ra ruen
Germainia balansae	
G. khasiana Hack.	
G. lanipes Hook.f.,	
Heteropogon contortus (Linn.) P. Beauv.	Yaa lem
H. triticeus (R.Br.) Stapf	Yaa nong
Hyparrhenia bracteata (Humb. & Bonpl.) Stapf	Yaa khon taa chaang
H. rufa (Nees) Stapf	Yaa saeng kham
Ischaemum barbatum Retz.	
I. rugosum Salisb.	
Leptaspis urceolata (Roxb.) R. Br.	Nieo 'maa
Lepturus repens (G.Forst.) R.Br.	
Lophatherum gracile Brongn.	Yaa khui mai phai
Massia triseta (Nees) Balansa	
Microstegium vagans (Nees) A. Camus	
Neyraudia arundinacea (Linn.) Henr.	Khaem
N. reynaudiana (Kunth) Keng	Khaem
Oplismenus compositus (Linn.) P. Beauv ex Steud.	Yaa khai maengda
Oryza granulata Nees & Arn.	Khaao nok
Ottochloa nodosa (Kunth) Dandy	Yaa khui phai khon
Panicum auritum Presl	Yaa plong
P. incomtum Trin.	Yaa khai hao
P. notatum Retz.	Yaa khai hao luang
Paspalidium flavidum Stapf	Yaa nok see chomphuu
Paspalum conjugatum Berg.	Yaa nom non
P. longifolium Roxb.	Yaa phraek haang chaang

Table 2. (continued)

Botanical names	Vernacular names
P. scrobiculatum Linn.	Yaa phong hin
Pennisetum pedicellatum Trin.	Yaa khachon chop
P. polystachyon (Linn.) Schultes	Yaa khachon chop
P. purpureum Schumach.	Yaa nepia
Perotis indica (Linn.) O. Ktze.	Yaa waen
Phragmites australis Trin. ex Steud.	O lek
Pogonatherum crinitum Kunth	Yaa phai yong
Polytoca digitata Benth.	Khaao phot phee
P. wallichiana (Nees) Benth.	
Pseudopogonatherum contortum (Brogn.) A. Camus	
Rhynchelytrum repens (Willd.) C.E. Hubb.	
Rottboellia exaltata Linn.f.	Yaa prong khaai
Saccharum arundinaceum Retz.	Khaem
S. procerum Linn.	Yaa khamong
S. spontaneum Linn.	Lao
Sacciolepis indica (Linn.) A. Camus	
S. myosuroides (R.Br.) A. Camus	
Schizachyrium brevifolium (SW) Nees ex Buse	
Sclerostachya fusca (Roxb.) A. Camus	Khaem doi
Sehima nervosum (Rptte.) Stapf	
Setaria glauca (Linn.) P. Beauv.	Yaa haang maa noi
S. pallide-fusca (Schumach.) Stapf & C.E.Hubb.	Yaa maa ching chok
S. palmifolia (Koen.) Stapf	Yaa kaap phai
S. plicata (Lamk.) T. Cooke	Yaa kong kaai
S. verticillata (Linn.) P. Beauv	Yaa khaai
Sorghum halepense (Linn.) Per.	Yaa phong
S. nitidum (Vahl) Pers.	Yaa haang maa
Spodiopogon lacei Hole	
Sporobolus diander (Retz.) P. Beauv.	
S. kerrii Bor	
Themeda arundinacea (Roxb.) Ridl.	Khaem luang
T. quadrivalvis (Linn.) O. Ktze.	Yaa kai
T. triandra Forssk.	Yaa faek
Thysanolaena maxima O. Ktze.	Yaa tong kong
Vetiveria zizanioides (Linn.) Nahs	Faek or Kaeng hom
JUNCACEAE	
Juncus effusus Linn.	
J. prismatocarpus R. Br.	
LILIACEAE	
Dianella ensifolia Red.	See khan chai

Table 2. (continued)

Botanical names	Vernacular names
RESTIONACEAE	
Leptocarpus disjunctus Mast.	See maa ho
(ANGIOSPERMAE – DICOTYLEDONES)	
ACANTHACEAE	
Andrographis glomeruliflora Brem.	
A. laxiflora (Bl.) Lindau	
A. paniculata (Burm.) Wall. ex Nees.	Faa thalaai
Asystasia salicifolia Craib	Khok maa taek
Barleria cristata Linn.	Angkaap
B. siamensis Craib	Ra-ngap
Dyschoriste depressa Nees	Yaa saam chan
Eranthemum ciliata A. Benoit	Chaa hom
Lepidagathis incurva Ham. ex D.Don	Yaa khon kai
L. thyrsiflora Brem.	Yaa haep
Perilepta auriculata (Nees) Brem.	Chaa hom
P. siamensis Brem.	Kok maa taek
Peristrophe lanceolaria Nees	Waa cha-am
Rostrellularia spp.	
Rungia spp.	
Sericocalyx quadrifarius Brem.	Tin tang tia
Strobilanthes spp.	
AMARANTHACEAE	
Achyranthes aspera Linn.	Phan nguu
A. bidentata Bl.	Phan nguu noi
Aerva sanguinolenta Bl.	Khruea khaao tok
Amaranthus blitum Linn.	Phak khom
A. spinosus Linn.	Phak khom naam
Cyathula prostata Bl.	Yaa phan ngu daeng
BORAGINACEAE	
Heliotropium indicum Brongn.	Yaa nguang chaang
CAPPARIDACEAE	
Cleome viscosa Linn.	Phak sian phee
CARDIOPTERIDACEAE	
Cardiopteris quinqueloba (Hassk.) Hassk.	Khaao saan khaang
COMPOSITAE	
Ageratum conyzoides Linn.	Saap raeng saap kaa
Anaphalis adnata DC.	Naat khao
Blumea aurita DC.	Saap raeng saap kaa
B. balsaminifera (Linn.) DC.	Naat yai
B. fistulosa Kurz	Phak kaat khi maa
B. lacera (Brum.f.) DC.	Naat wua

Table 2. (continued)

Botanical names	Vernacular names
B. oxydonta DC.	Pat nam
Blumeopsis falcata (O.Ktze.) Merr.	Phak kaat khok
Chromolaena odorata (Linn.) R.M.King & M.Robins	Saap suea
Cosmos caudatus H.B.K.	Dao rueng pha maa
C. sulfureus Cav.	Daa krachaai
Crassocephalum crepidioides (Benth.) S. Moore	Phak kaat chaang
Elephantopus scaber Linn.	Do mai ru lom
Gnaphalium affine D.Don	
G. hypoleucum DC.	
Inula cappa (Ham. ex D.Con) DC.	Naat kham
I. eupatorioides DC.	Naat khon
I. indica Linn.	
Laggera alata (D.Don) Sch. Bip. ex Oliv.	Naat wua
Pluchea eupatorioides Kurz	Naat noi
P. polygonata (DC.) Gagnep	Saap raeng khaao
Siegesbeckia orientalis Linn.	Saphaan kon
Spilanthes acmella Murr.	Phak khraat
Tridax procumbens Linn.	Teen tuk kae
Vernonia cinerea (Linn.) Less.	Suea saam kha
V. elliptica DC.	Taan mon
V. silhetensis Craib ex Kerr	Phak phet khaao kam
V. spirei Gand.	Yaa haang nok khieo
CONVOLVULACEAE	
Evolvulus alsinoides Linn.	
Merremia umbellata Hall. f. Ching	Ching cho khaao
M. vitifolia Hall.f.	Ching cho lueang
EUPHORBIACEAE	
Acalypha indica Linn.	Tamyae maeo
A. kerrii Craib	Khaang poi
A. mairei (Livl.) Schneid.	
A. siamensis Oliv. ex Gage	Chaa khoi
Baliospermum moitanum (Willd.) Muell. Arg.	Tong taek
Breynia angustifolia Hook.f.	Kaang plaa khaao
B. retusa (Dennst.) Alst.	Khraam nam
B. vitis-idaea (Burm.f.) C.E. Fisch.	
Cnesmone javanica Bl.	Tamyae khruea
C. laotica (Gagnep.) Croiz.	Haan salit
Croton cascarilloides Raeusch.	Plao nam ngoen
C. crassifolius Geisel.	Phang khee
C. kerrii Airy Shaw	
C. kongensis Gagnep.	

Table 2. (continued)

Botanical names	Vernacular names
Euphorbia capillaris Gagnep.	Pom daeng
E. coudercii Gagnep.	Muuk biae
E. hirta Linn.	Namnom ratchasi
E. hypericifolia Linn.	Buea daeng
E. prolifera Buch-Ham. ex D.Don	
Mallotus barbatus Muell. Arg.	Tong tao
M. garrettii Ary Shao	
M. khasianus Hook.f.	
M. repandus (Willd.) Muell. Arg.	Ma kaai khruea
Phyllanthus acutissimus Miq.	Pha waan chaang khlong
P. amarus Schumach. ex Thonn.	Luuk ta i bai
P. clarkei Hook.	
P. elegans Wall. ex Muell. Arg.	Phak waan dong
P. sootepensis Craib	Ma khaam pom din
P. virgatus Forst.f.	Khaang amphai
Sauropus androgynus (Linn.) Merr.	Phak waan baan
S. bicolor Craib	Phaak waan daeng
S. hirsutus Beille	Phak waan nok
S. orbicularis Craib	
S. quadrangularis (Willd.) Muell. Arg.	Ma yom thuean
S. similis Craib	
Securinega virosa (Roxb ex. Willd.) Bail	Kaang plaa khaao
Trigonostemon reidioides Kurz) Craib	Lot thanong
LABIATAE	
Achyrospermum wallichianum Benth. & Hook.f.	Saa hom
Acrocephalus indicus (Burm.f.) O. Kuntze	
Anisochilus pallidus Wall.	
A. siamensis Ridl.	
Anisomeles candicans Benth.	
Dysophylla auriculatia (Linn.) Bl.	Saap raeng saap ka
Epimeredi indicus (Linn.) Roth	Kom ko huai
Elscholtzia blanda (Benth.) Benth.	
E. kachinensis Raain	Phak luean
E. winitiana Craib	
Geniosporum coloratum O. Kuntze	Hom paa
G. siamense Murata	
Hyptis suaveolens Poit.	Maeng lak khaa
Leucas aspera (Willd.) Link.	Yaa nok khao
L. ciliata Benth.	Yaa hua suea
L. lanata Benth.	
L. mollissima Wall.	

Table 2. (continued)

Botanical names	Vernacular names
L. zeylanica (Linn.) R. Br.	Yaa prik
Nosema cochinchinensis (Lour.) Merr.	Haang suea
Teucrium quadrifarium Buch.-Ham.	
LEGUMINOSAE - CAESALPINIOIDEAE	
Cassia hirsuta Linn.	Phong pheng
C. mimosoides Linn.	Sano noi
C. occidentalis Linn.	Chumhet lek
C. pumila Lamk.	Ma khaam bia
C. tora Linn.	Chumhet thai
LEGUMINOSAE - PAPILIONOIDEAE	
Aeschynomene aspera Linn.	Sano khang khok
Atylosia scarabaeoides Benth.	Maeo khee non
A. siamensis Craib	Paep phee
Crotalaria acicularis Ham. ex Benth.	
C. alata D.Don	Ma hing men doi
C. albida Heyne ex Roth	Hing men maa
C. bracteata Roxb. ex DC.	Yaa hing men
C. calycina Schrank	Phrayaa muuin
C. montana Heyn ex Roth	
C. sessiliflora Linn.	
C. spectabilis Roth.	
C. verrucosa Linn.	Hing haai bai yai
Desmodium gangeticum DC.	Ee nieo
D. gyroides DC.	
D. oblongum Benth.	Naat kham
D. renifolium Schnidl. var. *oblatum* (Bak. ex kurz) /Ohashi	Sieo
D. velutinum DC.	Yaa song plong
Dunbaria longeracemosa Craib	Khaang khrang
D. podocarpa Kurz	Ma bae kwaang
Flemingia kerrii Craib	
F. macrophylla O.Ktze ex Prain	Khamin naang
F. strobilifera R. Br. ex Ait.	Nuut phra
Mucuna pruriens DC.	Maa mui
Phyllodium pulchellum Desv.	Klet plaa chon
Pueraria candollei Grah.	Khruea khao puu
P. thomsonii Benth.	Phak pheet
Tadehagi triquetrum (DC.) Ohashi	
Uraria lagopodioides D sf.	Yaa haang on
U. macrostachya Wall.	Yaa haang suea

Table 2. (continued)

Botanical names	Vernacular names
LINACEAE	
Reinwardtia trigyna Planch.	Kham paa
LOGANIACEAE	
Buddleja asiatica Lour.	Dok daai
MALVACEAE	
Abutilon hirtum Sweet	Khrop chakrawaan
A. indicum Sweet	Ma kong khaao
Hibiscus surattensis Linn.	Cha mot
Pavonia rigida Hochr.	Khee on
Sida acuta Burm.	Yaa khat bai yaao
S. rhombifolia Linn.	Yaa khat
MELASTOMATACEAE	
Melastoma malabathricum Linn.	Khlong khleng khee nok
M. normale D.Don	Chuk naree
Osbeckia chinensis Linn.	En aa noi
O. pulchra Geddes	Thao nang hung
O. stellata Ham. ex Ker-Gawl	En aa khon
MENISPERMACEAE	
Pericampylus glaucus Merr.	Yaan huu suea
P. incanus Miers	
NYCTAGINACEAE	
Boehavia diffusa Linn.	Phak khom hin
B. repanda Benth.	Phak miak
PASSIFLORACEAE	
Passiflora foetida Linn.	Ka thok rok
POLYGALACEAE	
Polygala crotalarioides Ham.	Maa mae kham
P. glomerata Lour.	Kham tia
P. longifolia Poir.	Yaa lueat nai
P. tricholoph Chodat	Khuea chae din
Salomonia cantoniensis Lour.	Niem nok khao
S. ciliata DC.	Yaa raak hom
POLYGONACEAE	
Polygonum chinense Linn.	Phaya dong
P. hydropiper Linn.	Phak phai nam
P. strigosum R.Br.	Phak phot daeng
Rumex crispus Linn.	Phak kaat som
R. vesicarius Linn.	Phak buak
ROSACEAE	
Rubus alceifolius Poir.	Khai puu yai
R. ellipticus J.E. Sm.	Naam khai kung

Table 2. (continued)

Botanical names	Vernacular names
R. rufus Focke	Baa huu ngoen
R. rugosus J.E.Sm.	Naam khai puu
RUBIACEAE	
Borreria stricta G.F.W. Mey	Chat saam chan
Hedyotis capitellata Wall. ex G.Don	Duuk kai yaan
H. coronaria Craib	Wang ot
H. fulva Hook.f.	Chaam doi
H. rosmarifolia	
Knoxia corymbosa Willd.	Tong laai
Paederia foetida Linn.	Phang hom
P. linearis Hook.f.	Tot muj tot maa
P. tomentosa Bl.	Yaan phaa hom
SCROPHULARIACEAE	
Alectra arvensis (Benth.) Merr.	
Buchnera cruciata Ham.	Yaa khaao kam
Scoparia dulcis Linn.	Krot nam
Striga lutea Lour.	Yaa mae mot
SOLANACEAE	
Physalis minima Linn.	Yaa tom tok
Solanum erianthum D. Don	Dap yaang
S. nigrum Linn.	Ma waeng nok
S. torvum Sw.	Ma khuea phuang
STERCULIACEAE	
Helicteres angustifolia Linn.	Khee tun
H. hirsuta Lour.	Po tao hai
H. isora Linn.	Po bit
H. obtusa Wall.	Pa heio mong
H. viscida Bl.	Po khee on
Melochia corchorifolia Linn.	Seng lek
Triumfetta annua Linn.	Yaa phom yung doi
T. pilosa Roxb.	Po yum yuu
T. pseudo-cana Spraque & Craib	Paa chaa mong
T. rhomboidea Jacq.	Seng
URTICACEAE	
Boehmeria chiangmaiensis Yahara	
B. clidemoides Miq.	
B. diffusa Wedd.	Mae khoei thee
B. macrophylla D.Don	Chaa paan
B. malabarica Wedd.	
B. pilosiuscula (Bl.) Hassk.	
B. platyphylla D.Don	

Table 2. (continued)

Botanical names	Vernacular names
B. pseudotomentosa Yahara	
B. thailandica Yahara	
B. zollingeriana Wedd.	
Girardinia heterophylla Decne.	Tam yae chaang
Maoutia puya Wedd.	Chaa paan
Pouzolzia pentandra Benn.	Yaa non tai
VERBENACEAE	
Lantana camara Linn.	Phaka krong
L. trifolia Linn.	Phaka krong
Stachytarpheta indica Vahl	Phan nguu khieo
Verbena officinalis Linn.	Nang dong laang
VIOLACEAE	
Rinorea virgata O. Kuntze	Khoi yong

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WEEDS AND THE ENVIRONMENT IN THE TROPICS
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WEED HOSTS OF *MELOIDOGYNE*, *THE* ROOT-KNOT NEMATODES.

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Abstract. Weeds impact on crop production directly through interference and indirectly through hosting other crop pests. The root-knot nematodes are among the most serious pests hosted by weeds. A literature search produced over 2200 entries of weed hosts of root-knot nematodes. They are listed in tables representing 19 nematode species of the genus *Meloidogyne*. These weed hosts represent 113 plant families. The greatest numbers of weed host entries were from the families Leguminosae, Compositae, and Gramineae, followed by Solanaceae, Amaranthaceae, Labiatae, Cruciferae, Malvaceae, Polygonaceae, and Euphorbiaceae. *Solanum* was the genus with the greatest number of entries, followed by *Amaranthus, Trifolium, Nicotiana, Chenopodium, Euphorbia, Rumex, Hibiscus, Ipomoea,* and *Vicia*. Dicotyledons are better hosts than monocotyledons of most *Meloidogyne* species. *M. javanica* was hosted by the most weed species, followed by *M. hapla, M. acrita, M. incognita,* and *M. arenaria*. The objectives of the weed hosts as pest reservoirs activities are to emphasize the overall impact of weeds in crop production, to offer another criterion in defining the importance of weeds, and to promote effective control of weeds.

INTRODUCTION

Weeds are perceived variously. They may be ground cover for erosion control. They may be grazed or harvested for animal feed. They may be medicinal plants or a source of fiber. They may be admired and collected as wild flowers. They may be competitors with crops and reduce crop yield. They may have no effect on the cosmetic value of crop products. Thus, for many reasons, the image of weeds may not be unfavorable. However, the impact of weeds may be great, yet difficult to judge unless carefully researched.

Several direct and indirect influences of weeds may be responsible for reductions in crop yield. One of the direct influences may result from interference. Competition for light, water, and mineral nutrients is one aspect of interference. Another aspect of interference is allelopathy, resulting from chemical exudations or degradation products which may restrict seed germination, plant establishment, or plant growth. It may be very difficult to distinguish between the effects of competition and allelopathy in crop yield reductions.

Competition from weeds results because of their trophic status, like crops, of being *primary producers*. They are thus involved in the flow of energy and matter. Therefore, they compete, and often vigorously, with crops and other plants for limited supplies of light, water, and mineral nutrients.

As primary producers, weeds may also provide energy, nutrients, and shelter for insects and mites, nematodes, pathogens, and vertebrates, which are primary or secondary *consumers*. In this relationship, weeds serve as hosts of these other organisms. As hosts, they may also serve as reservoirs by maintaining populations of those organisms. This is an example of an indirect influence of weeds on crop production. Whether the influence is positive or negative is determined by whether the species hosted is beneficial or a pest.

Microclimate modification may be an indirect influence of weed canopies on crops. Among other things, their physical stature and density might alter air movement and relative humidity. In modifying the microclimate, weeds may not only have a direct effect on crop growth, but also an indirect effect. This indirect effect may result from the responses of crop pests to those changes in the microclimate. Pest populations may thus be reduced or enhanced.

The integrated pest management (IPM) concept is usually interpreted as vertical integration for management of one pest species. Use is made of appropriate combinations of preventive, biological, physical-mechanical, and chemical methods or tools in crop cultural practices. In the IPM concept, one utilizes the interacting effects of climate, soil, and crop, in addition to the four tools listed above, in regulating pest populations. If

IPM is to achieve its ultimate goal, it must be perceived also as horizontal integration, integrating control of all classes of pests -- weeds, insects and mites, nematodes, pathogens, and vertebrates. The interrelationships of these five classes of pests might be illustrated as a "pest pentagon" (246). Biological control of pests and biological infection by pests are implicit in the concept of the horizontal integration of IPM and of the pest pentagon. Biological control of pests has been illustrated by many classical and non-classical examples. Biological infection may also be illustrated by many examples. It relates to the infection of one organism by another as a result of the activity of a third organism. One example is the infection of corn (*Zea mays* L.) with maize dwarf mosaic virus by aphids.

The "Weed Hosts as Pest Reservoirs" concept is one approach toward horizontal integration in pest management. The premise is that, if the weed hosts of specific pests -- insect, nematode, pathogen, or vertebrate -- are controlled, the populations of those pests will be reduced. Literature on weed hosts as pest reservoirs and the importance of weed hosts of pests in crop production has been reviewed (38,39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 104, 147, 205, 206, 207, 276, 353). The difficulty of assigning the relative effects of the direct influence of competition and the indirect influence of pests hosted by weeds on crop yield is akin to the difficulty of distinguishing between competition and allelopathy on crop growth.

ROOT-KNOT NEMATODES

Among the plant-parasitic nematodes, the root-knot *(Meloidogyne)*, cyst *(Heterodera)*, and lesion *(Pratylenchus)* nematodes may by considered to be the most serious genera, in that order, affecting worldwide crop production. Over 54 species of the genus *Meloidogyne* have been described and named (143a). Of these, *M. incognita*, with four widespread races, *M. javanica*, with one race, *M. hapla*, with one race, and *M. arenaria*, with two races, in that order, were most widely distributed and caused the most crop damage. They very probably cause more damage to farm crops than all other *Meloidogyne* species combined (295).

The first report on *Meloidogyne* may have been that of Berkeley (49) in England in 1855. Subsequently, Jobert (165) reported on root galls of diseased coffee trees in Brazil, which was researched further by Goeldi (121). The presence of the root-knot nematode in the United States was first reported by Atkinson (25) and Neal (243) in 1889.

M. hapla, a cool climate species often referred to as the northern root-knot nematode, has an optimum temperature range of 15° to 25°*C* (330). It can survive in frozen soils and regions where the average temperature of the coldest month is near or below 0°*C*. The upper limit of its tolerance range is about 27°*C*. It is found where these conditions are met in North and South America, Africa, and Australia. It is the most common *Meloidogyne* species found north of 35°*N* latitude.

M. incognita, *M. javanica*, and *M. arenaria* are tropical zone nematodes. *M. javanica* does not survive where the isotherm of the coldest month is below 7°*C*. The lower limit for *M. incognita* is about -1 °*C*. The optimum temperature range for these three species is 25° to 30°*C*. They are found between 35°*N* and 35°*S* latitude and adapted to continuous existence in these warm areas of Africa, Asia, Australia, and the Americas. However, *M. javanica* is seldom found above 30°*N* latitude. Very little activity occurs in any of these species below 5°*C* or above 40°*C*.

Meloidogyne species are obligate plant parasites. Reproduction occurs only when second-stage infective larvae enter roots or other underground parts of suitable host plants, initiate giant cells on which to feed, and develop to egg-laying females (330). Females may continue to produce eggs for 2 to 3 months. Hatching is dependent on suitable soil temperature and soil moisture. The hatched larvae may survive from a few days to a few months. Their migrations in the soil are random until they come within a couple of *cm* of a root, when their movement is then directed toward the root. Each female may produce many eggs and several generations per year may develop, depending upon favorable temperature and moisture conditions. Infection causes various degrees of stunting, wilting, and malformation which may cause death of the host plant.

As a genus, the root-knot nematodes affect a wide range of vegetable, fruit, grain, forage, and tree crops. Crop losses in technologically developed countries may range from 5% to 10%, while crop losses for small farmers of less developed countries may range from 25% to 50% (330). Root-knot is considered to be one of the most widespread plant diseases of the world.

WEED HOSTS AS PEST RESERVOIRS

The purpose of research on the weed hosts as pest reservoirs concept is to emphasize the role of weeds and the importance of weed control in crop production. The use of weeds for erosion control or for animal feed may be counter productive if those weeds maintain populations of crop-destroying pests. The weed hosts as pest reservoirs concept offers another criterion, in addition to interference by competition or allelopathy, in defining the significance of weeds in crop production (47).

The following section contains over 2200 entries of weeds reported to host specific *Meloidogyne* species. These weed hosts are distributed non-uniformly among 113 plant families. They host one or more of the 19 *Meloidogyne* species included. The publication by Goodey *et al.* (130) was used as a chief source of plant host information to 1965. The weed survey by Holm *et al.* (146) was used to identify which host plants to classify as weeds. For this reason, plants considered by others to be weeds may have been omitted. Only the earliest available report of a plant as a host is included in the tables.

There are 20 weed hosts tables, arranged alphabetically by *Meloidogyne* species hosted. Within each table, the weed hosts are listed alphabetically by plant family, which are also arranged alphabetically. Since uncertainty seemed to exist in the literature in identifying some nematode species, those species identified as *M. incognita acrita* or *M. incognita* and/or *acrita* were arbitrarily listed with *M. acrita* in Table 1. Those species identified as *M. javanica bauruensis* were listed with *M. bauruensis* in Table 5, and those identified as *M. arenaria thamesi* were listed with *M. thamesi* in Table 19.

On the basis of these groupings, there were considerably more weed host entries listed for *M. javanica* than any other nematode species (Table 14). Furthermore, those entries represented more plant families, genera, and species listed as weed hosts of *M. javanica* than for any of the other nematode species. *M. hapla* (Table 11) is in second place, *M. acrita* (Table 1) in third, *M. incognita* (Table 12) in fourth, and *M. arenaria* (Table 3) in fifth place in number of weed host entries, number of species, and number of genera. The order for the number of plant families represented differs in that *M. incognita* is second, *M. acrita* is third, *M. arenaria* is fourth, and *M. hapla* is fifth. In the remaining 14 nematode species, the number of entries in these four categories is appreciably less than in the five species named.

Turning to a consideration of the weed hosts of the nematodes, the total numbers of host species entries were greatest for the families Leguminosae, with 308; Compositae, with 267; and Gramineae, with 248. Solanaceae ranked fourth, with 155 Then Amaranthaceae, with 89; Labiatae, with 73; Cruciferae, with 62; Malvaceae, with 61; Polygonaceae, with 54; and Euphorbiaceae, with 52 host entries, completes the list of the ten worst host families from the 113 plant families included in this review. These data are a summation from entries in all 20 tables.

The genus *Solanum* had more entries, with 61, than any other. *Amaranthus*, 40; *Trifolium*, 36; *Nicotiana*, 30; *Chenopodium*, 28; *Euphorbia*, 28; *Rumex*, 25; *Hibiscus*, 23; *Ipomoea*, 22; and *Vicia*, 21, completes the list of ten genera with the greatest number of host species entries. These data are also a summation from entries in all 20 tables.

Since plants differ in acceptability as hosts of nematodes, hosts of each of the five species of root-knot nematode previously identified as having the most hosts will be discussed separately. Within each of these sets of entries, there is no duplication of species as occurred in the two previous summations of entries from all 20 tables.

There are 394 species entries of weed hosts of *M. javanica* (Table 14). They are distributed non-uniformly among 227 genera in 64 plant families. The genus *Solanum* had the most host species entries, with 13; *Nicotiana* ranked second, with 8 entries. *Trifolium* and *Amaranthus* each had 7 entries. *Chenopodium*, *Hibiscus*, *Cassia*, *Indigofera*, and *Setaria* each had 6 entries. Note a two-fold spread in number of entries between the first and last named genera.

M. hapla has the second most species entries of weed hosts, with 305 (Table 11). They are also distributed non-uniformly among 173 genera in 48 plant families. In this case, *Rumex* is in first place, with 8 host entries. *Nicotiana* retains second place, with 7 entries. *Solanum* and *Chenopodium* each have 6 species entries. *Trifolium* and *Ipomoea* each have 4 entries. A two-fold spread in number of entries is also noted here between the first and last named genera.

The third most numerous weed host species was for *M. acrita*, with 283 entries in 181 genera and 54 plant families (Table 1). There are 12 host entries for *Trifolium* and 11 for *Solanum*. There are 7 entries for *Amaranthus*, 6 for *Polygonum*, and 5 each for *Hibiscus* and *Eragrostis*.

A spread greater than two-fold is found in this set.

M. incognita, the root-knot nematode species identified as being most widely distributed and causing the most damage to crops worldwide (330), ranks fourth in the number of weed host species (Table 12). There are 252 entries among 164 genera in 59 families. *Amaranthus* heads the list of host genera with 9 species. *Solanum* and *Nicotiana* each have 7 entries. There are 5 entries for each of *Chenopodium* and *Rumex*.

The number of entries for fifth ranking *M. arenaria* is only about 40% of the number of entries for first-ranking *M. javanica* and less than 70% of the number of entries for fourth-ranking *M. incognita*. There are 170 weed host entries in 130 genera of 51 families (Table 3). There are over twice as many entries for the first-ranking genus Solanum, with 7, as for the next group. *Amaranthus, Nicotiana, Hibiscus, Ipomoea, Indigofera,* and *Digitaria*, each have 3 weed species entries.

It may be deduced from the data presented that many genera, and also families, are represented by only one or two weed host entries. Furthermore, it may be noted that, although the Gramineae ranked third among the plant families in the number of weed host entries, only 3 of the 33 genera identified as being the most frequent hosts were Gramineae. Those three genera were *Eragrostis, Digitaria*, and *Setaria*. They ranked lowest in their respective lists. Among the 10 genera identified previously as having the most entries of host species, none were Gramineae. All were dicotyledons. This relates to the fact that dicotyledons are better hosts to most species of *Meloidogyne*. However, differences exist among *Meloidogyne* species. For example, 68% of the host entries for *M. naasi* (Table 17), 57% of the host entries for *M. acronea* (Table 2), 46% of the host entries for *M. microtyla* (Table 16), and all of the few entries for *M. graminicola* (Table 9), *M. graminis* (Table 10), and *M. kikuyensis* (Table 15) are monocotyledons. Similar differences also exist among nematode genera. While dicotyledons are the preferred hosts of *Meloidogyne*, monocotyledons are the preferred hosts of the lesion nematode *Pratylenchus* and some other genera.

A long-standing means of nematode control is crop rotation from susceptible to non-host crops. Nematode populations decrease during the periods of non-host crop culture in the rotation. Length of the intervals between culture of susceptible crops is determined by the time required for nematode populations to diminish below the economic threshold level.

The practice of crop rotation for nematode control is functional if, during the intervals between culture of susceptible crops, weed hosts are not permitted to grow and maintain nematode populations. When weed hosts are permitted to grow, they serve as reservoirs for nematode populations, obviously available to infect susceptible crops whenever they are planted. This negates that purpose of crop rotation.

If used, the weed hosts as pest reservoirs concept might achieve several worthwhile objectives. It might facilitate multidisciplinary research in pest management. This a team would be approach to solution of crop production problems. It might improve the economic aspect of crop production if, by controlling weeds, other pest populations were reduced. This has a multiple advantage in that competition from weeds is reduced concurrent with reduction in populations of the pests they host. It might increase the options among alternative crops which might be grown. The weed hosts as pest reservoirs concept is an example of horizontal integration in pest management.

It seems that much research has been done throughout the world which has not been made accessible to the worldwide scientific community. Much of it has been published only for local use. If a worldwide collaborative network on the weed hosts as pest reservoirs concept were created, it may be possible to disseminate more of this useful information (41). This might be done through regional and multinational conferences, with the proceedings being published. Conference and planning sessions might be used to correlate research as well as to exchange information. Weed scientists and weed science organizations might take a more active leadership role in this multidisciplinary activity. Global and local increases in crop yields and production might be achieved by such a cooperative effort.

The objectives of the weed hosts as pest reservoirs activities are: 1) to emphasize the overall impact of weeds in crop production; 2) to offer another criterion in defining the significance of weeds; and 3) to promote effective control of weeds, thereby reducing their interference with crops and hosting other pests.

This report has presented information on weed hosts of but one significant group of pests -- the root-knot nematodes.

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APPENDIX

Table 1. Weed hosts of *Meloidogyne acrita* or *M. incognita acrita* or *M.incognita* and/or *acrita*.

Family & Weed Species	References
Acanthaceae	
Thunbergia sp.	236
Aizoaceae	
Mollugo nudicaulis Lam.	194
Amaranthaceae	
Aerva lanata (L.) Juss.	194
Alternanthera sp.	194
Amaranthus albus L.	113
Amaranthus caudatus L.	227
Amaranthus graecizans L.	113
Amaranthus hybridus L.	214
Amaranthus retroflexus L.	294
Amaranthus spinosus L.	113, 214
Amaranthus thunbergii Moq.	214
Amaranthus sp.	219
Celosia cristata L.	229
Celosia trigyna L.	214
Celosia sp.	in 133
Cyathula prostrata (L.) Blume	194
Gomphrena celosioides Mart.	218
Apocynaceae	
Apocynum cannabinum L.	113
Nerium oleander L.	294
Araceae	
Caladium sp.	238
Asclepiadaceae	
Asclepias syriaca L.	113
Asparagaceae	
Asparagus officinalis L.	84
Balsaminaceae	
Impatiens balsamina L.	303
Impatiens sultani Hook. f.	294
Berberidaceae	
Berberis sp.	164
Cannaceae	
Canna sp.	153
Capparidaceae	
Cleome ciliata Schum. & Thonn.	194
Caryophyllaceae	
Stellaria media (L.) Vill.	113
Chenopodiaceae	
Beta vulgaris L.	294
Chenopodium album L.	113, 203
Chenopodium ambrosioides L.	113
Chenopodium murale L.	352
Commelinaceae	
Commelina spp.	194
Cyanothis sp.	194
Compositae	
Ageratum conyzoides L.	214
Calendula sp.	294
Carthamnus tinctorius L.	282
Centaurea maculosa Lam.	113
Chrysanthemum coronarium L.	211
Chrysanthemum sp.	228
Cichorium sp.	154
Cirsium arvense (L.) Scop.	113
Cirsium vulgare (Savi) Ten.	113
Emilia sonchifolia (L.) Wight	194
Erigeron canadensis L.	113
Erlangea cordifolia S. Moore	352
Eupatorium cannabinum L.	230
Galinsoga parviflora Cav.	213
Gnaphalium luteo-album L.	214
Helianthus annuus L.	228
Lactuca canadensis L.	113
Lactuca pulchella DC.	113
Lactuca serriola L.	113
Matricaria sp.	203
Mikania scandens Willd.	194
Sonchus arvensis L.	113
Sonchus oleraceus L.	113
Spilanthes acmella (L.) Murr.	194
Syndrella nodiflora (L.) Gaertn.	194
Taraxacum officinale L.	113
Tragopogon pratensis L.	113
Vernonia altissima Nutt.	113
Xanthium pensylvanicum Wallr.	113

Vitis rupestris Scheele	184
Vitis sp.	184
Zygophyllaceae	
Tribulus terrestris L.	215

Total Family : 54; Genera : 181; Species (Entries) : 283

Table 2. Weed hosts of *Meloidogyne acronea.*

Family & Weed Species	References
Gramineae	
Chloris gayana Kunth	in 130
Eragrostis curvula Nees	in 130
Setaria glauca (L.) Beauv.	in 130
Sorghum vulgare Pers.	77
Leguminosae	
Phaseolus sp.	77
Portulacaceae	
Portulaca oleracea L.	265
Solanaceae	
Lycopersicon esculentum Mill.	77

Total Family : 4; Genera : 7; Species (Entries) : 7

Table 3. Weed hosts of *Meloidogyne arenaria.*

Family & Weed Species	References
Amaranthaceae	
Achyranthes aspera L.	214
Amaranthus caudatus L.	227
Amaranthus hybridus L.	214
Amaranthus retroflexus L.	294
Celosia argentea L.	78
Celosia cristata L.	214
Apocynaceae	
Alstonia constricta F. Muell.	152
Nerium oleander L.	294
Araceae	
Caladium sp.	235
Colocasia sp.	154
Balsaminaceae	
Impatiens balsamina L.	227
Impatiens sultani Hook. f.	294
Impatiens sp.	216
Berberidaceae	
Berberis sp.	30
Berberis thunbergii DC.	154
Bignoniaceae	
Catalpa sp.	30
Cannaceae	
Canna sp.	218
Capparidaceae	
Cleome monophylla L.	214
Chenopodiaceae	
Beta vulgaris L.	235
Chenopodium album L.	214
Chenopodium murale L.	229
Compositae	
Acanthospermum australe (Loefl.) O. Kzte	102
Ageratum conyzoides L.	357
Bidens biternata Merrill & Sherff	216
Bidens sp.	216
Calendula sp.	294
Chrysanthemum sp.	228
Cichorium endivia L.	78
Cichorium intybus L.	203
Emilia coccinea Sweet	215
Epaltes australis Less.	78
Erlangea laxa S. Moore	216
Eupatorium cannabinum L.	230
Galinsoga parviflora Cav.	213
Helianthus annuus L.	216
Sonchus oleraceus L.	78
Tagetes minuta L.	214
Convolvulaceae	
Convolvulus tricolor L.	117

Umbelliferae	
Ammi majus L.	215
Daucus carota L.	294
Pastinaca sativa L.	203
Verbenaceae	
Clerodendron sp.	215
Lippia sp.	336
Verbena bonariensis L.	78
Verbena officinalis L.	55
Zingiberaceae	
Hedychium sp.	238

Total Family : 51; Genera : 130; Species (Entries) : 170

Table 4. Weed hosts of *Meloidogyne artiellia.*

Family & Weed Species	References
Cruciferae	
Brassica napus L.	110
Gramineae	
Hordeum vulgare L.	110
Leguminosae	
Medicago lupulina L.	110
Medicago sativa L.	110
Trifolium pratense L.	110
Vicia faba L.	110

Total Families : 3; Genera : 5; Species:6

Table 5. Weed hosts of *Meloidogyne bauruensis* or *M. javanica bauruensis.*

Family & Weed Species	References
Amaranthaceae	
Celosia cristata L.	228
Compositae	
Helianthus annuus L.	228
Leguminosae	
Cajanus cajan Mill.	190
Glycine hispida Max.	188a
Salicaceae	
Salix sp.	228

Total Families : 4; Genera : 5; Species (Entries) : 5

Table 6. Weed hosts of *Meloidogyne coffeicola.*

Family & Weed Species	References
Compositae	
Eupatorium pauciflorum H.B.K.	357

Total Families : 1; Genera : 1;Species : 1

Table 7. Weed hosts of *Meloidogyne elegans.*

Family & Weed Species	References
Cucurbitaceae	
Momordica charantia L.	268
Leguminosae	
Schrankia leptocarpa DC.	268

Total Families:2; Genera:2; Species:2

Table 8. Weed Hosts of *Meloidogyne exigua.*

Family & Weed Species	References
Solanaceae	
Solanum nigrum L.	87

Total Families:1; General:1; Species:1

Table 9. Weed hosts of *Meloidogyne graminicola*.

Family & Weed Species	References
Cyperaceae	
Cyperus compressus L.	354
Gramineae	
Echinochloa colona (L.) Link	354

Total Families:2; Genera:2; Species:2

Table 10. Weed hosts of *Meloidogyne graminis*.

Family & Weed Species	References
Gramineae	
Ammophila arenaria (L.) Link	324

Total Families:1; Genera:1; Species:1

Table 11. Weed hosts of *Meloidogyne hapla*.

Family & Weed Species	References
Amaranthaceae	
Amaranthus retroflexus L.	264
Celosia argentea L.	292
Celosia cristata L.	214
Apocynaceae	
Vinca major L.	129
Vinca minor L.	203
Balsaminaceae	
Impatiens balsamina L.	203
Impatiens sultani Hook. f.	294
Berberidaceae	
Berberis thunbergii DC.	203
Berberis sp.	71
Boraginaceae	
Lycopsis arvensis L.	187
Myosotis collina Hoffm.	187
Campanulaceae	
Campanula rapunculoides L.	264
Lobelia cardinalis L.	310
Cannabaceae	
Humulus lupulus L.	202
Capparidaceae	
Cleome viscosa L.	292
Gynandropsis gynandra (L.) Briq.	352
Caprifoliaceae	
Lonicera sp.	23
Symphoricarpus sp.	23
Viburnum sp.	13
Caryophyllaceae	
Cerastium vulgatum L.	340
Lychnis alba Mill.	340
Spergula arvensis L.	187
Stellaria media (L.) Vill.	157
Chenopodiaceae	
Atriplex hastata L.	187
Atriplex sp.	94
Beta vulgaris L.	294
Chenopodium album L.	114
Chenopodium album L. or *C. opulifolium* Schrad.	214
Chenopodium ambrosioides L.	270
Chenopodium glaucum L.	296
Chenopodium murale L.	229
Chenopodium polyspermum L.	117
Compositae	
Achillea millefolium L.	126
Ageratum conyzoides L.	214
Anthemis arvensis L.	187
Anthemis cotula L.	340
Arctium lappa L.	303
Arctium minus (Hill) Bernh.	340
Artemisia biennis Willd.	340
Artemisia dracunculus L.	335
Artemisia vulgaris L.	187
Bellis perennis L.	118
Bidens biternata Merrill & Sherff.	216
Bidens cynapiifolia H.B.K.	272
Bidens pilosa L.	210

Anoda cristata (L.) Schlecht.	98
Hibiscus cannabinus L.	186
Moraceae	
Morus sp.	71
Oleaceae	
Jasminum sp.	230
Ligustrum sp.	16
Onagraceae	
Epilobium sp.	340
Fuchsia sp.	117
Oenothera lamarckiana Ser.	157
Oenothera sp.	214
Oxalidaceae	
Biophytum sp.	118
Oxalis stricta L.	117
Oxalis sp.	228
Papaveraceae	
Chelidonium majus L.	157
Papaver argemone L.	117
Papaver rhoeas L.	117
Papaver sp.	118
Phytolaccaceae	
Phytolacca americana L.	98
Piperaceae	
Piper sp.	203
Plantaginaceae	
Plantago lanceolata L.	114
Plantago major L.	114
Plantago rugelii Decne	157
Polygonaceae	
Emex spinosa (L.) Campd.	230
Polygonum aviculare L.	170
Polygonum convolvulus L.	126
Polygonum persicaria L.	126
Rumex acetosa L.	114
Rumex acetosella L.	157
Rumex alpinus L.	264
Rumex angiocarpus Murb.	214
Rumex crispus L.	117
Rumex hydrolapathum Huds.	324
Rumex japonicus Houtt.	157
Rumex obtusifolius L.	in 90
Rumex sp.	in 90
Portulacaceae	
Portulaca oleracea L.	214
Ranunculaceae	
Aconitum napellus L.	235
Aconitum sp.	235
Anemone pulsatilla L.	251
Anemone sp.	236
Delphinium ajacis L.	332
Delphinium sp.	150
Ranunculus repens L.	187
Thalictrum minus L.	264
Rosaceae	
Alchemilla sp.	214
Fragaria vesca L.	11
Fragaria virginiana Decne.	127
Fragaria spp.	238
Geum sp.	238
Potentilla intermedia L.	296
Prunus cerasus L.	203
Rosa canina L.	251
Rosa multiflora Murr.	216
Rosa sp.	248
Spiraea sp.	71
Rubiaceae	
Borreria sp.	214
Richardia sp.	214
Scrophulariaceae	
Antirrhinum majus L.	325
Buchnera sp.	216
Digitalis purpurea L.	187
Linaria vulgaris Mill.	187
Odontites rubra Gil.	187
Veronica arvensis L.	340
Veronica peregrina L.	340
Veronica serphyllifolia L.	187
Solanaceae	
Capsicum annuum L.	293
Capsicum frutescens L.	294
Datura stramonium L.	214
Lycopersicon esculentum Mill.	71
Lycopersicon peruvianum (L.) Mill.	329
Nicandra physalodes (L.) Gaertn.	214

Nicotiana glauca Grah.	69
Nicotiana glutinosa L.	134
Nicotiana longiflora Cav.	134
Nicotiana paniculata L.	69
Nicotiana suaveolens Lehm.	69
Nicotiana tabacum L.	134
Nicotiana trigonophylla Dun.	69
Physalis peruviana L.	214
Solanum capsicastrum Link	214
Solanum dulcamara L.	340
Solanum melongena L.	294
Solanum nigrum L.	157
Solanum tuberosum L.	71
Solanum villosum Willd.	228
Tetragoniaceae	
Tetragonia expansa Murr.	114
Umbelliferae	
Cryptotaenia canadensis (L.) DC.	157
Daucus carota L.	210
Foeniculum vulgare Mill.	114
Pastinaca sativa L.	71
Pimpinella saxifraga L.	264
Urticaceae	
Urtica dioica L.	264
Valerianaceae	
Valerianella locusta (L.) Betcke	114
Verbenaceae	
Callicarpa sp.	236
Verbena bonariensis L.	214
Verbena officinalis L.	264
Verbena peruviana (L.) Britt.	215
Violaceae	
Viola arvensis Murr.	187
Viola tricolor L.	214

Total Families : 48; Genera : 173; Species (Entries) : 305

Table 12. Weed hosts of *Meloidogyne incognita*.

Family & Weed Species	References
Agavaceae	
Agave sp.	17
Aizoaceae	
Mollugo verticillata Roxb.	266
Amaranthaceae	
Achyranthes aspera L.	241
Alternanthera ficoidea (L.) Griseb.	102
Alternanthera nana R.Br.	78
Alternanthera repens (L.) O. Kuntze	78
Alternanthera sp.	148
Amaranthus caudatus L.	112
Amaranthus cruentus L.	112
Amaranthus gracilis	241
Amaranthus graecizans L.	264
Amaranthus hybridus L.	357
Amaranthus paniculatus L.	78
Amaranthus retroflexus L.	294
Amaranthus tricolor L.	78
Amaranthus sp.	219
Amaranthus spp.	101
Amaranthus viridis L.	266
Celosia argentea L.	152
Celosia cristata L.	241
Apocynaceae	
Nerium oleander L.	294
Araceae	
Anthurium sp.	238
Caladium sp.	23
Colocasia antiquorum Schott	238
Araliaceae	
Brassaia actinophylla F.V. Muller	78
Asclepiadaceae	
Asclepias curassavica L.	130
Asparagaceae	
Asparagus sp.	237
Balsaminaceae	
Impatiens sultani Hook. f.	294
Impatiens sp.	148
Boraginaceae	
Symphytum officinale L.	22
Campanulaceae	
Lobelia purpurascens R. Br.	78

Sida rhombifolia L.	55
Urena lobata L.	266
Moraceae	
Ficus pumila L.	78
Morus alba L.	155
Morus sp.	228
Musaceae	
Heliconia spp.	238
Myrsinaceae	
Ardisia sp.	13
Nyctaginaceae	
Boerhavia coccinea Mill.	269
Mirabilis jalapa L.	270
Oleaceae	
Ligustrum sp.	16
Onagraceae	
Fuchsia sp.	251
Papaveraceae	
Papaver rhoeas L.	78
Passifloraceae	
Passiflora edulis Sims	78
Passiflora sp.	14
Phytolaccaceae	
Phytolacca decandra L.	203
Phytolacca octandra L.	78
Polygonaceae	
Emex australis Steinh.	78
Polygonum plebeium R. Br.	78
Rumex acetosella L.	78
Rumex crispus L.	264
Rumex dentatus L.	241
Rumex hastatulus Ell	4
Rumex hymenosepalus Torr.	283
Portulacaceae	
Portulaca grandiflora Hook.	266
Portulaca oleracea L.	78
Primulaceae	
Anagallis arvensis L.	78
Rosaceae	
Rosa multiflora Murr.	281
Rosa sp.	61
Rubus rosaefolius Sm.	78
Rubiaceae	
Borreria latifolia (Aubl.) Schum.	111
Borreria verticillata (L.) G.F.W. Mey.	270
Salicaceae	
Populus sp.	228
Salix babylonica L.	155
Salix sp.	233
Scrophulariaceae	
Antirrhinum majus L.	325
Centranthera muticum (H.B.K.) Less.	78
Scoparia dulcis L.	78
Solanaceae	
Capsicum annuum L.	71
Capsicum frutescens L.	294
Datura stramonium L.	291
Lycopersicon esculentum Mill.	325
Nicotiana glauca Grah.	55
Nicotiana glutinosa (L.)	69
Nicotiana longiflora Cav.	134
Nicotiana paniculata L.	69
Nicotiana suaveolens Lehm.	69
Nicotiana tabacum L.	134
Nicotiana trigonophylla Dun.	69
Physalis angulata L.	270
Physalis minima L.	78
Physalis peruviana L.	2
Solanum auricullatum Ait.	112
Solanum melongena L.	294
Solanum nigrum L.	78
Solanum paniculatum L.	266
Solanum sisymbriifolium Lam.	68
Solanum tuberosum L.	133
Solanum villosum Willd.	229
Sterculiaceae	
Melochia melissaefolia Benth.	111
Melochia pyramidata L.	269
Waltheria indica L.	269
Tiliaceae	
Corchorus acutangulus Lam.	2
Corchorus capsularis L.	70

Corchorus olitorius L.	70
Turneraceae	
Turnera ulmifolia L.	266
Umbelliferae	
Daucus carota L.	71
Pastinaca sativa L.	in 90
Valerianaceae	
Valeriana officinalis L.	326
Verbenaceae	
Lantana montevidensis (Spreng.) Briq.	78
Lippia nodiflora L.	2
Stachytarpheta cayennensis (L.C. Rich.) Vahl	266
Verbena bonariensis L.	78
Verbena officinalis L.	78
Violaceae	
Viola sp.	13
Vitaceae	
Vitis sp.	61

Total Families : 59; Genera : 164; Species (Entries) : 252

Table 13. Weed hosts of *Meloidogyne inornata*.

Family & Weed Species	References
Leguminosae	
Glysine hispida Max.	188a
Solanaceae	
Nicotiana tabacum L.	105

Total Families:2; Genera:2; Species:2

Table 14. Weed hosts of *Meloidogyne javanica*.

Family & Weed Species	References
Acanthaceae	
Andrographis echioides Nees	93
Peristrophe bicalyculata Nees	in 130
Thunbergia alata Sims	214
Thunbergia sp.	63
Agavaceae	
Agave sp.	238
Aizoaceae	
Gisekia pharnaceoides L.	214
Amaranthaceae	
Achyranthes aspera L.	214
Alternanthera denticulata R.Br.	78
Alternanthera ficoidea (L.) R & S	78
Alternanthera polygonoides R. Br.	271
Alternanthera pungens H.B.K.	216
Alternanthera repens (L.) O. Kuntze	214
Amaranthus caudatus L.	326
Amaranthus gracilis Desf.	3
Amaranthus graecizans L.	264
Amaranthus hybridus L.	214
Amaranthus retroflexus L.	294
Amaranthus thunbergii Moq.	209
Amaranthus viridis L.	78
Celosia argentea L.	78
Celosia cristata L.	78
Celosia trigyna L.	211
Cyathula cylindrica Moq.	216
Digera arvensis Forsk.	245
Gomphrena decumbens Jacq.	277
Gomphrena globosa L.	78
Gomphrena sp.	227
Apocynaceae	
Nerium oleander L.	294
Vinca major L.	228
Araceae	
Arum sp.	235
Caladium sp.	153
Colocasia antiquorum Schott	152
Colocasia sp.	129
Xanthosoma sp.	153
Asclepiadaceae	
Asclepias curassavica L.	78
Asclepias fruticosa L.	78
Calotropis gigantea (Willd.) Ait.	266
Calotropis sp.	52

Balsaminaceae	
Impatiens balsamina L.	71
Impatiens sultani Hook f.	294
Impatiens sp.	216
Bignoniaceae	
Tecoma sp.	153
Buddlejaceae	
Buddleia sp.	214
Cactaceae	
Mammillaria sp.	209
Opuntia sp.	215
Cannabaceae	
Cannabis sativa L.	264
Humulus lupulus L.	229
Cannaceae	
Canna sp.	215
Capparidaceae	
Cleome aculeata L.	78
Cleome monophylla L.	209
Cleome spinosa Jacq.	214
Cleome viscosa L.	278
Gynandropsis gynandra (L.) Briq.	352
Gynandropsis pentaphylla (L.) DC.	278
Caprifoliaceae	
Viburnum sp.	238
Caryophyllaceae	
Corrigiola littoralis L.	214
Polycarpaea corymbosa Lam.	214
Saponaria officinalis L.	214
Chenopodiaceae	
Beta vulgaris L.	326
Chenopodium album L.	218
Chenopodium album L. or *C. opulifolium* Schrad.	214
Chenopodium ambrosoides L.	3
Chenopodium murale L.	352
Chenopodium opulifolium Schrad.	352
Chenopodium rubrum L.	264
Chenopodium sp.	326
Commelinaceae	
Commelina benghalensis L.	214
Commelina subulata Roth	214
Commelina spp.	214
Compositae	
Acanthospermum australe (Loefl.) O. Ktze	24
Acanthospermum hispidum DC.	214
Ageratum conyzoides L.	292
Ageratum houstonianum Mill.	78
Aspilia sp.	214
Aster subulatus Michx.	78
Bidens biternata Sherff	211
Bidens cynapiifolia H.B.K.	111
Bidens pilosa L.	78
Bidens schimperi Walp	214
Bidens steppia (Steetz) Sherff	218
Bidens sp.	218
Calendula sp.	209
Carthamnus tinctorius L.	282
Centaurea cyanus L.	214
Chrysanthemum leucanthemum L.	228
Cichorium endivia L.	191
Cichorium intybus L.	214
Cichorium sp.	154
Conyza aegyptiaca Ait.	214
Cosmos caudatus H.B.K.	193
Crassocephalum sp.	214
Crepis parviflora Desf.	264
Eclipta alba (L.) Hassk.	78
Emilia coccinea Sweet	215
Emilia sonchifolia DC	78
Erechtites valerianaefolia DC.	78
Erigeron floribundus (H.B.K.) Sch.-Bip.	214
Erlangea cordifolia S. Moore	352
Erlangea laxa S. Moore	214
Eupatorium cannabinum L.	230
Galinsoga parviflora Cav.	209
Gnaphalium indicum L.	78
Helianthus annuus L.	210
Pluchea sericea Coville	334
Senecio discifolius Oliv.	214
Tagetes minuta L.	214
Tragopogon porrifolius L.	78
Vernonia cinerea (L.) Less	78
Vernonia poskeana Vatke & Hildebr.	214
Convolvulaceae	

Convolvulus arvensis L.	277
Dichondra repens Forst.	227
Ipomoea batatas (L.) Lam.	227
Ipomoea sp.	227
Cruciferae	
Brassica napus L.	78
Brassica rapa L.	214
Capsella bursa-pastoris (L.) Medic.	264
Lepidium sativum L.	78
Raphanus sativus L.	294
Cucurbitaceae	
Citrullus vulgaris Schrad	293
Cucumis melo L.	337
Cucumis myriocarpus Naud.	214
Cucumis sativus L.	326
Cucumis spp.	218
Cucurbita pepo L.	209
Luffa aegyptiaca Mill.	227
Luffa cylindrica (L.) M. Roem	245
Momordica charantia L.	266
Cyperaceae	
Bulbostylis sp.	215
Cyperus amabilis Vahl	214
Cyperus esculentus L.	214
Cyperus rotundus L.	78
Fimbristylis sp.	215
Dioscoreaceae	
Dioscorea sp.	214
Dipsacaceae	
Scabiosa sp.	227
Euphorbiaceae	
Acalypha indica L.	278
Croton sparsiflorus Morong	245
Euphorbia geniculata Orteg.	78
Euphorbia hirta L.	216
Euphorbia prostrata Ait.	78
Euphorbia prunifolia Jacq.	4
Euphorbia thymifolia L.	51
Euphorbia sp.	154
Phyllanthus niruri L.	193
Ricinus communis L.	326
Sapium sebiferum (L.) Roxb.	227
Gramineae	
Arrhenatherum elatius (L.) J. & C. Presl	199
Avena sativa L.	294
Brachiaria miliiformis (Presl) Chase	78
Brachiaria plantaginea (Link.) Hitchc.	357
Cenchrus ciliaris Fig. & De Not.	212
Chloris gayana Kunth	185
Chloris virgata Sw.	214
Cynodon dactylon (L.) Pers.	137a
Cynodon plectostachyum Pilger	212
Cynodon sp.	285
Dactylis glomerata L.	199
Digitaria adscendens (H.B.K.) Henr.	78
Digitaria decumbens Stent	192
Digitaria sanguinalis (L.) Scop.	199
Digitaria ternata (Hochst) Stapf	214
Digitaria velutina (Forsk) Beauv.	214
Echinochloa crus-galli (L.) Beauv.	78
Eleusine africana K. O'Byrne	214
Eleusine indica (L.) Gaertn	185
Eragrostis aspera (Jacq.) Nees	214
Eragrostis curvula Nees	185
Eragrostis viscosa Trin.	214
Festuca arundinacea Schreb	214
Hordeum vulgare L.	293
Lolium multiflorum Lam.	214
Melinis minutiflora Beauv.	189a
Oryza sativa L.	185
Panicum colonum L.	214
Panicum coloratum L.	214
Paspalum notatum Fluegge	199
Pennisetum purpureum Schumach.	212
Pennisetum sp.	in 130
Phalaris tuberosa L.	185
Poa pratensis L.	199
Rhynchelytrum repens (Willd.) C.E. Hubb.	214
Rottboellia exaltata L.	216
Saccharum officinarum L.	341a
Secale cereale L.	294
Setaria glauca (L.) Beauv.	3
Setaria homonyma (Steud.) Chiov.	214
Setaria pallide-fusca Stapf & Hubb.	209
Setaria sphacelata Stapf & Hubb.	185
Setaria verticillata (L.) Beauv.	214

Setaria viridis (L.) Beauv.	291
Setaria sp.	214
Sorghum almum L.	185
Sorghum vulgare Pers.	185
Triticum aestivum L.	293
Zoysia matrella (L.) Merr.	199
Iridaceae	
Gladiolus sp.	227
Iris spp.	229
Labiatae	
Coleus blumei Benth.	215
Hyptis capitata Jacq.	78
Leonurus sibiricus L.	232
Leucas linifolia Spreng	78
Leucas martinicensis R. Br.	214
Ocimum americanum L.	215
Ocimum basilicum L.	186
Ocimum sanctum L.	277
Plectranthus sp.	215
Salvia sp.	209
Leguminosae	
Acacia cyanophylla Lindl.	115
Acacia dealbata Link	218
Acacia decurrens (Wendl.) Willd.	193
Acacia mearnsii de Wild	214
Acacia melanoxylon R.Br.	55
Albizia chinensis (Osbeck) Merr.	215
Albizia lebbek Benth	215
Alysicarpus rugosus (Willd.) DC.	214
Arachis hypogaea L.	212
Cajanus cajan Mill.	78
Cassia absus L.	214
Cassia alata L.	111a
Cassia mimosoides L.	78
Cassia obtusifolia L.	232
Cassia occidentalis L.	111
Cassia tora L.	245
Clitoria ternatea L.	189
Crotalaria intermedia Kotschy	92
Crotalaria juncea L.	92
Crotalaria lanceolata E. Mey.	186
Crotalaria spectabilis Roth	216
Desmodium triflorum (L.) DC.	78
Desmodium uncinatum DC.	78
Dolichos Lablab L.	214
Glycine hispida Max. & *G. soja* Sieb. & Zucc.	294
Indigofera arrecta A. Rich.	352
Indigofera australis Willd.	78
Indigofera endecaphylla Jacq.	78
Indigofera hirsuta L.	78
Indigofera subulata Pait.	216
Indigofera suffruticosa Mill.	266
Lespedeza stipulacea Maxim.	351
Lespedeza striata Hook	351
Leucaena glauca Benth.	338
Lotus corniculatus L.	178
Lupinus albus L.	214
Lupinus angustifolius L.	78
Lupinus luteus L.	186
Lupinus sp.	in 133
Medicago sativa L.	294
Medicago scutellata (L.) Mill.	78
Melilotus alba Desr.	215
Mimosa invisa Mart.	78
Mimosa sensitiva L.	266
Mucuna pruriens (L.) DC.	216
Phaseolus lunatus L.	214
Phaseolus sp.	154
Pueraria phaseoloides (Roxb.) Benth	129
Pueraria triloba Benth	186
Rhynchosia minima (L.) DC.	215
Schrankia leptocarpa DC.	266
Sesbania exaltata (Rafin.) Cory	305a
Spartium sp.	228
Stizolobium sp.	78
Stylosanthes sundaica Taub.	78
Tephrosia candida (Roxb.) DC.	78
Trifolium hybridum L.	217
Trifolium incarnatum L.	217
Trifolium lappaceum L.	217
Trifolium pratense L.	178
Trifolium repens L.	178
Trifolium resupinatum L.	217
Trifolium subterraneum L.	214
Vicia faba L.	211
Vicia sativa L.	228
Liliaceae	
Allium cepa L.	294
Ornithogalum sp.	153

Scoparia dulcis L.	270
Verbascum thapsus L.	227
Solanaceae	
Capsicum frutescens L.	78
Datura stramonium L.	214
Duboisia myoporoides R.Br.	78
Lycopersicon esculentum Mill.	325
Lycopersicon peruvianum (L.) Mill.	293
Nicandra physalodes (L.) Gaertn.	209
Nicotiana alata Link & Otto	65
Nicotiana glauca Grah.	69
Nicotiana glutinosa L.	134
Nicotiana longiflora Cav.	65
Nicotiana paniculata L.	65
Nicotiana suaveolens Lehm.	69
Nicotiana tabacum L.	134
Nicotiana trigonophylla Dun.	65
Nierembergia hippomanica Miers	214
Physalis angulata L.	215
Physalis minima L.	78
Physalis peruviana L.	78
Solanum auriculatum Ait.	78
Solanum capsicastrum Link	214
Solanum indicum L.	214
Solanum laciniatum Ruiz & Pav.	54
Solanum mammosum L.	216
Solanum melongena L.	326
Solanum nigrum L.	326
Solanum paniculatum L.	357
Solanum pseudocapsicum L.	331
Solanum seaforthianum Andr.	78
Solanum sisymbriifolium Lam.	357
Solanum tuberosum L.	71
Solanum villosum Willd.	227
Solanum spp.	218
Withania somnifera (L.) Dun.	51
Sterculaceae	
Melochia pyramidata L.	78
Pentapetes phoenica L.	52
Tamariscaceae	
Tamarix gallica L.	138
Tetragoniaceae	
Tetragonia expansa Murr.	214
Tiliaceae	
Corchorus acutangulus Lam.	78
Corchorus capsularis L.	339
Corchorus olitorius L.	339
Corchorus trilocularis L.	215
Turneraceae	
Turnera ulmifolia L.	266
Umbelliferae	
Ammi majus L.	215
Angelica archangelica L.	in 130
Apium leptophyllum (Pers.) Benth.	78
Coriandrum sativum L.	115
Daucus carota L.	209
Daucus sp.	238
Foeniculum vulgare Mill.	352
Pastinaca sativa L.	211
Verbenaceae	
Lantana camara L.	78
Lippia javanica (Burm.f.) Spreng.	214
Phyla nodiflora (L.) Greene	215
Verbena officinalis L.	264
Verbena peruviana (L.) Britt	215
Violaceae	
Viola tricolor L.	215
Viola sp.	154
Vitaceae	
Vitis sp.	299
Zingiberaceae	
Hedychium coronarium Koenig	253

Total Families : 64; Genera : 227; Species (Entries) : 394

Table 15. Weed hosts of *Meloidogyne kikuyensis*.

Family & Weed Species	References
Gramineae	
Pennisetum clandestinum Hochst	137

Total Families: 1; Genera : 1; Species: 1

Table 16. Weed hosts of *Meloidogyne microtyla*.

Family & Weed Species	References
Amaranthaceae	
Amaranthus hybridus L.	341
Asclepiadaceae	
Asclepias syriaca L.	341
Caryophyllaceae	
Cerastium vulgatum L.	341
Silene cucubalus Wibel	341
Compositae	
Erigeron canadensis L.	341
Galinsoga ciliata (Raf.) Blake	341
Lactuca scariola L.	341
Senecio vulgaris L.	341
Taxacum officinale Weber	341
Cruciferae	
Barbarea vulgaris R. Br.	341
Lepidium virginicum L.	341
Sinapsis arvensis L.	341
Sisymbrium altissimum L.	341
Dipsacaceae	
Dipsacus sylvestris Huds.	341
Gramineae	
Agropyron repens (L.) Beauv.	341
Agrostis alba L.	341
Agrostis tenuis Sibth.	341
Arrhenatherum elatius (L.)	341
Avena fatua L.	341
Briza maxima L.	341
Bromus inermis Leyss.	341
Bromus secalinus L.	341
Bromus tectorum L.	341
Dactylis glomerata L.	341
Digitaria sanguinalis (L.) Scop.	341
Echinochloa crus-galli (L.) Beauv.	341
Echinochloa pungens (Poir.) Rybd.	341
Eragrostis pectinacea (Michx.) Nees	341
Hordeum jubatum L.	341
Leersia oryzoides (L.) Sw.	341
Lolium multiflorum Lam.	341
Panicum capillare L.	341
Panicum miliaceum L.	341
Phalaris arundinacea L.	341
Phleum pratense L.	341
Poa pratensis L.	341
Setaria glauca (L.) Beauv.	341
Setaria virdis (L.) Beauv.	341
Labiatae	
Leonurus cardiaca L.	341
Nepeta cataria L.	341
Prunella vulgaris L.	341
Leguminosae	
Medicago lupulina L.	341
Malvaceae	
Malva neglecta Wallr.	341
Onagraceae	
Oenothera biennis L.	341
Plantaginaceae	
Plantago major L.	341
Polygonaceae	
Rumex crispus L.	341
Rosaceae	
Potentilla norvegica L.	341
Scrophulariaceae	
Verbascum thapsus L.	341
Solanaceae	
Datura stramonium L.	341
Nicotiana tabacum L.	341
Solanum dulcamara L.	341
Umbelliferae	
Daucus carota L.	341

Total Families : 17; Genera : 45; Species (Entries) : 52

Table 17. Weed hosts of *Meloidogyne naasi*.

Family & Weed Species	References
Caryophyllaceae	

Stellaria media (L.) Vill.	222
Gramineae	
Agropyron repens (L.) Beauv.	222
Agrostis alba Amer. auctt.	222
Agrostis tenuis Sibth	222
Avena sativa L.	222
Dactylis glomerata L.	222
Digitaria sanguinalis (L.) Scop.	222
Lolium multiflorum Lam.	222
Lolium perenne L.	222
Oryza sativa L.	222
Poa annua L.	222
Poa pratensis L.	222
Poa trivialis L.	222
Sorghum bicolor (L.) Moench.	222
Leguminosae	
Coronilla scropiodes (L.) Koch	347a
Medicago hispida Gaertn.	347a
Melilotus sulcata Desf.	347a
Vicia villosa Roth	347a
Polygonaceae	
Rumex crispus L.	222

Total Families:4; Genera:15; Species:19

Table 18. Weed hosts of *Meloidogyne ovalis.*

Family & Weed Species	References
Aceraceae	
Acer negundo L.	284
Acer platanoides L.	284
Acer rubrum L.	284
Acer saccharum Marsh.	284
Betulaceae	
Betula alleghaniensis Britt.	284
Betula papyrifera Marsh.	284
Oleaceae	
Fraxinus americana L.	284
Ulmaceae	
Ulmus americana L.	284

Total Families:4; Genera:4; Species:8

Table 19. Weed hosts of *Meloidogyne thamesi* or *M. arenaria thamesi.*

Family & Weed Species	References
Chenopodiaceae	
Beta vulgaris L.	126
Compositae	
Helianthus annuus L.	186
Cucurbitaceae	
Momordica charantia L.	189b
Euphorbiaceae	
Ricinus communis L.	186
Iridaceae	
Gladiolus sp.	153
Labiatae	
Leonurus sibiricus L.	189b
Ocimum basilicum L.	186
Leguminosae	
Crotalaria juncea L.	185
Crotalaria lanceolata E. Mey.	186
Desmodium tortuosum (Sw.) DC.	186
Lupinus albus L.	186
Lupinus angustifolius L.	186
Lupinus luteus L.	186
Pueraria triloba Benth.	186
Liliaceae	
Allium cepa L.	179
Linaceae	
Linum usitatissimum	185
Malvaceae	
Hibiscus cannabinus L.	186
Solanaceae	
Lycopersicon esculentum Mill.	185
Lycopersicon peruvianum (L.) Mill.	185
Nicotiana tabacum L.	126
Solanum tuberosum L.	133
Turneraceae	
Turnera ulmifolia L.	266

Total Families : 12; Genera : 18; Species (Entries) : 22

Table 20. Weed hosts of Unidentified *Meloidogyne* Species.

Family & Weed Species	References
Acanthaceae	
Acanthus mollis L.	10
Thunbergia alata Sims	225
Thunbergia fragrans Roxb.	50
Aceraceae	
Acer macrophyllum Pursh	322
Acer negundo L.	345
Aizoaceae	
Mollugo cerviana Seringe	161
Mollugo pentaphylla L.	34
Mollugo verticillata L.	50
Sesuvium portulacastrum L.	50
Trianthema portulacastrum L.	96
Amaranthaceae	
Achyranthes aspera L.	275
Alternanthera philoxeroides Griseb.	262
Alternanthera repens (L.) O. Kuntze	162
Alternanthera sessilis DC.	106
Amaranthus blitum L.	80
Amaranthus caudatus L.	50
Amaranthus gangeticus L.	63
Amaranthus gracilis Desf.	123
Amaranthus graecizans L.	50
Amaranthus hybridus L.	50
Amaranthus mangostenus L.	182
Amaranthus palmeri S. Wats	50
Amaranthus paniculatus L.	64
Amaranthus retroflexus L.	25
Amaranthus spinosus L.	243
Amaranthus thunbergii Moq.	161
Amaranthus tricolor L.	50
Amaranthus viridis L.	298
Amaranthus sp.	64
Celosia argentea L.	122
Celosia cristata L.	239
Celosia trigyna L.	307
Gomphrena decumbens Jacq.	160
Gomphrena globosa L.	254
Amaryllidaceae	
Narcissus tazetta L.	182
Anacardiaceae	
Schinus molle L.	328
Spondias lutea L.	50
Apocynaceae	
Vinca major L.	63
Vinca minor L.	63
Vinca rosea L.	64
Araceae	
Caladium bicolor Vent.	53
Caladium sp.	64
Colocasia antiquorum Schott	239
Araliaceae	
Brassaia actinophylla F. Muell.	188
Hedera helix L.	66
Aristolochiaceae	
Aristolochia clematitis L.	109
Asclepiadaceae	
Gomphocarpus physocarpus Meyer	119
Asparagaceae	
Asparagus officinalis L.	50
Balsaminaceae	
Impatiens balsamina L.	108
Impatiens sultani Hook. f.	244
Impatiens sp.	289
Basellaceae	
Basella rubra L.	50
Boussingaultia baseloides H.B.K.	243
Begoniaceae	
Begonia spp.	64
Berberidaceae	
Berberis thunbergii DC.	66
Berberis vulgaris L.	108
Berberis sp.	63
Bignoniaceae	
Bignonia capreolata L.	317
Catalpa bignonioides Walt.	345
Catalpa speciosa Warder	50
Boraginaceae	
Anchusa italica Retz.	64
Heliotropium indicum L.	266
Lappula echinata Gilib.	133

Trichodesma zeylanicum R. Br. 160

Buddlejaceae

Buddleia asiatica Lour. 63

Buddleia sp. 243

Cactaceae

Opuntia monocantha Haw. 228

Opuntia sp. (Prickly pear) 58

Campanulaceae

Lobelia cardinalis L. 64

Cannaceae

Canna indica L. 26

Canna sp. 64

Cannabaceae

Cannabis sativa L. 64

Humulus lupulus L. 240

Capparidaceae

Cleome ciliata Schum. & Thonn. 96

Cleome gynandra L. 119

Cleome monophylla L. 80

Cleome spinosa Jacq. 239

Gynandropsis pentaphylla DC. 160

Caprifoliaceae

Lonicera japonica Thunb. 50

Lonicera tartarica L. 345

Lonicera sp. 345

Caryophyllaceae

Cerastium glomeratum Thuill. 261

Melandrium album (Mill.) Garcke 133

Polycarpaea corymbosa Lam. 160

Saponaria officinalis L. in 133

Silene anglica L. 119

Silene cucubalus Wibel 133

Spergula arvensis L. 50

Stellaria media (L.) Vill. 342

Chenopodiaceae

Atriplex semibaccata R. Br. 50

Atriplex sp. 345

Beta vulgaris L. 108

Chenopodium album L. 50

Chenopodium ambrosioides L. 162

Chenopodium anthelminticum L. 25

Chenopodium botrys L. 243

Chenopodium glaucum L. 124

Chenopodium murale L. 63

Chenopodium sp. 50

Commelinaceae

Commelina lagosensis C.B. Clarke 97

Commelina nudiflora L. 119

Commelina spp. 307

Tradescantia fluminensis Vell. 322

Compositae

Acanthospermum australe Kuntze 257

Acanthospermum hispidum DC. 160

Achillea lanulosa Nutt. 63

Achillea millefolium L. 125

Ageratum conyzoides L. 59

Ageratum mexicanum Sims 345

Ambrosia elatior L. 64

Anthemis arvensis L. 345

Anthemis cotula L. 50

Anthemis nobilis L. in 133

Arctium minus (Mill) Bernh. 29

Artemisia absinthium L. in 133

Artemisia annua L. 301

Artemisia vulgaris L. 345

Bellis perennis L. 50

Bidens pilosa L. 307

Bidens tripartita L. 64

Bidens sp. 257

Calendula sp. 64

Carthamnus tinctorius L. 50

Cassinia leptophylla R. Br. 63

Centaurea cyanus L. 50

Centaurea pallascens Delile 63

Centaurea sp. 63

Chrysanthemum coronarium L. 122

Chrysanthemum indicum L. 63

Chrysanthemum leucanthemum L. 32

Chrysanthemum sp. 50

Cichorium endivia L. 167

Cichorium intybus L. 183

Cichorium pumilum Jacq. 224

Cirsium arvense (L.) Scop. 221

Cirsium oleraceum (L.) Scop. 174

Cirsium vulgare (Savi) Tenore 196

Cirsium sp. 345

Conyza aegyptiaca Ait. 80

Sinapis arvensis L.	288
Cucurbitaceae	
Citrullus colocynthis Schrad.	64
Citrullus vulgaris Schrad.	243
Citrullus spp.	64
Cucumis dipsaceus Spach.	64
Cucumis melo L.	243
Cucumis metuliferus Schrad.	161
Cucumis myriocarpus Naud.	64
Cucumis sativus L.	49
Cucurbita pepo L.	50
Luffa cylindrica (L.) M. Roem	50
Momordica balsamina L.	64
Momordica charantia L.	50
Cyperaceae	
Cyperus alternifolius L.	63
Cyperus amabilis Vahl	160
Cyperus aristata Rottb.	160
Cyperus compressus L.	318
Cyperus esculentus L.	50
Cyperus rotundus L.	63
Cyperus strigosus L.	119
Eleocharis palustris R.Br.	176
Kyllinga monocephala Rottb.	100
Scirpus sylvaticus L.	247
Dioscoraceae	
Dioscorea sp.	313
Dipsacaceae	
Dipsacus fullonum L.	108
Scabiosa atropurpurea L.	64
Scabiosa sp.	345
Ebenaceae	
Diospyros virginiana L.	50
Euphorbiaceae	
Acalypha wilkesiana Muell.	126
Acalypha australis L.	345
Acalypha ciliata Forsk.	in 130
Acalypha indica L.	345
Acalypha ostryaefolia Riddell	223
Acalypha virginica L.	64
Chrozophora rottleri A. Juss.	63
Chrozophora tinctoria A. Juss.	345
Cnidoscolus stimulosus (Michx.) Gray	58
Croton glandulosus L.	50
Croton hirtus L'Herit	166
Euphorbia cyparissias L.	183
Euphorbia dentata Michx.	in 131
Euphorbia exigua L.	in 131
Euphorbia falcata L.	in 131
Euphorbia fulgens Klotzsch	66
Euphorbia geniculata Orteg.	in 131
Euphorbia heterophylla L.	in 131
Euphorbia lathyrus L.	344
Euphorbia peplus L.	in 131
Euphorbia pilulifera L.	50
Euphorbia platyphyllos L.	in 131
Euphorbia prostrata Ait.	in 131
Euphorbia pterococca Brot.	in 131
Euphorbia splendens Hook.	in 131
Euphorbia stricta L.	in 131
Euphorbia terracina L.	in 131
Euphorbia sp.	64
Mercurialis annua L.	171
Phyllanthus corcovadensis Muell.-Arg.	24
Ricinus communis L.	63
Fagaceae	
Quercus agrifolia Nee	63
Fumariaceae	
Fumaria vaillantii Lois.	301
Geraniaceae	
Erodium cicutarium (L.) Ait.	63
Erodium malacoides Willd.	83
Geranium maculatum L.	237
Geranium molle L.	168
Geranium sp.	153
Gramineae	
Agropyron repens (L.) Beauv.	133
Agrostis stolonifera L.	358
Ammophila arenaria (L.) Link	133
Ammophila breviligulata Fern	355
Arrhenatherum elatius (L.) J. & C. Presl	50
Avena barbata (?)	63
Avena fatua L.	119
Avena sativa L.	139
Axonopus affinis Chase	197

Lauraceae	
Cinnamomum zeylanicum Nees	125
Leguminosae	
Abrus precatorius L.	50
Acacia dealbata Link	50
Acacia longifolia Willd.	63
Acacia melanoxylon R.Br.	63
Albizia moluccana Miq.	356
Canavalia ensiformis (L.) DC.	50
Cassia floribunda Cav.	63
Cassia mimosoides L.	34
Cassia obovata Collad.	301
Cassia tora L.	25
Centrosema plumieri Benth.	64
Centrosema pubescens Benth.	36
Centrosema virginianum (L.) Benth.	58
Clitoria ternatea L.	97
Coronilla varia L.	314
Crotalaria anagyroides H.B.K.	99
Crotalaria juncea L.	50
Crotalaria saltiana Andr.	119
Crotalaria striata Schrank	63
Crotalaria usaramoensis Baker	79
Desmodium tortuosum (Sw.) DC.	58
Desmodium triflorum (L.) DC.	119
Dolichos lablab L.	50
Gleditschia triancanthos L.	345
Indigofera anil L.	257
Indigofera arrecta A. Rich.	160
Indigofera endecaphylla Jacq.	33
Indigofera cuneaphylla L.	12
Indigofera hirsuta L.	161
Lathyrus cicera L.	50
Lathyrus latifolius L.	122
Lathyrus ochrus DC.	224
Lathyrus sativus L.	50
Lathyrus tingitanus L.	50
Lathyrus sp.	172
Lespedeza cuneata G. Don	8
Lespedeza stipulacea Maxim.	316
Lespedeza striata Hook.	25
Leucaena glauca Benth.	50
Lotus corniculatus L.	25
Lupinus albus L.	50
Lupinus angustifolius L.	50
Lupinus hirsutus L.	256
Lupinus luteus L.	50
Medicago arabica (L.) All.	307
Medicago falcata L.	345
Medicago hispida Gaertn.	204
Medicago sativa L.	107
Melilotus alba Desr.	25
Melilotus indica (L.) All.	50
Melilotus officinalis (L.) Lam.	345
Mimosa invisa Mart.	252
Mimosa pudica L.	64
Mucuna pruriens (L.) DC.	50
Phaseolus acontifolius Jacq.	50
Phaseolus angularis W.F. Wight	50
Phaseolus lunatus L.	57
Phaseolus sp.	64
Prosopis juliflora DC.	119
Pueraria phaseoloides Benth.	36
Pueraria triloba Benth.	312
Robinia pseudoacacia L.	63
Schrankia leptocarpa DC.	267
Sesbania aculeata Poir.	50
Sesbania grandiflora Poir.	26
Spartium junceum L.	64
Tephrosia candida (Roxb.) DC.	306
Tephrosia purpurea (L.) Pers.	36
Trifolium arvense L.	345
Trifolium hybridum L.	63
Trifolium incarnatum L.	108
Trifolium medium L.	63
Trifolium pratense L.	108
Trifolium repens L.	302
Trifolium resupinatum L.	73
Trifolium subterraneum L.	64
Trigonella foenum-graecum L.	50
Uraria lagopoides DC.	in 129
Vicia angustifolia (L.) Reichard	125
Vicia atropurpurea Desf.	50
Vicia faba L.	50
Vicia hirsuta (L.) S.F. Gray	50
Vicia hybrida L.	204
Vicia monanthos Desf.	50
Vicia narbonensis L.	50
Vicia peregrina L.	204
Vicia sativa L.	50
Vicia villosa Roth	50
Vicia sp.	63

Passiflora incarnata L.	50
Passiflora sp.	308
Pedaliaceae	
Ceratotheca sesamoides Endl.	97
Sesamum indicum L.	27
Phytolaccaceae	
Phytolacca decandra L.	25
Phytolacca octandra L.	10
Phytolacca rigida Small.	123
Pinaceae	
Pinus palustris Mill.	63
Pinus strobus L.	203
Piperaceae	
Peperomia pellucida (L.) H.B.K.	100
Piper betle L.	359
Piper umbellatum L.	120
Pittosporaceae	
Pittosporum sp.	154
Plantaginaceae	
Plantago lanceolata L.	183
Plantago major L.	108
Plantago media L.	64
Plumbaginaceae	
Plumbago zeylanica L.	140
Polygalaceae	
Polygala arenaria Willd.	160
Polygonaceae	
Fagopyrum esculentum Moench	50
Fagopyrum tataricum (L.) Gaertn.	73
Polygonum acre H.B.K.	62
Polygonum aviculare L.	64
Polygonum capitatum Buch.-Ham.	258
Polygonum convolvulus L.	141
Polygonum hydropiperoides Michx.	50
Polygonum lapathifolium L.	64
Polygonum persicaria L.	64
Rumex acetosa L.	50
Rumex acetosella L.	63
Rumex crispus L.	124
Rumex hymenosepalus Torr.	63
Rumex obtusifolius L.	64
Rumex patientia L.	208
Portulacaceae	
Portulaca grandiflora Hook.	50
Portulaca oleracea L.	243
Portulaca pilosa L.	123
Portulaca quadrifida L.	307
Portulaca sp.	255
Talinum triangulare (Jacq.) Willd.	97
Primulaceae	
Anagallis arvensis L.	119
Lysimachia punctata L.	64
Proteaceae	
Grevillea robusta R.Br.	254
Ranunculaceae	
Aconitum napellus L.	153
Aconitum sp.	35
Anemone cernua Thunb.	63
Anemone coronaria L.	135
Anemone nemorosa L.	321
Anemone pulsatilla L.	244
Delphinium ajacis L.	182
Delphinium sp.	64
Ranunculus bulbosus L.	345
Rhamnaceae	
Ziziphus mucronata Willd.	160
Rosaceae	
Fragaria indica Andr.	64
Fragaria vesca L.	343
Fragaria spp.	64
Potentilla anserina L.	345
Prunus avium L.	63
Prunus cerasus L.	64
Prunus virginiana L.	50
Rosa laevigata Michx.	50
Rosa multiflora Dum.-Cours.	6
Rosa sp.	139
Rubus idaeus L.	300
Rubus trivialis Michx.	243
Rubiaceae	
Diodia teres Walt.	123
Paederia foetida L.	119
Richardia brasiliensis Gomez	123
Richardia sp.	64

Total Families : 102; Genera : 363; Species (Entries) : 717

DISCUSSION OF THE PAPERS OF TEM SMITINAND AND L.E. BENDIXEN

(Chaired by K.U. Kim)

Mr. Teoh Cheng Hai (Malaysia): Two questions for Dr. L.E. Bendixen. 1) When assessing the status of weeds as potential reservoirs of nematodes, I find it would be more appropriate to consider the susceptibility of weeds to *Meloidogyne* as well as *Pratylenchus* as both are ubiquitous. 2) If we have a weed and a crop plant of the same genus growing together, which is more likely to be susceptible to nematode infestation?

Dr. L.E. Bendixen (U.S.A.) : We have done a rather limited literature search on weed hosts of *Pratylenchus,* the lesion nematodes. Dr. Juliana S. Manuel at the University of the Philippines, Los Banos, is senior author of that publication. We also share authorship of a publication on one of the species of *Heterodera -- Heterodera glycines,* the soybean cyst nematode. As I indicated earlier, the three nematode genera of greatest agricultural significance are *Meloidogyne, Pratylenchus,*, and *Heterodera,* in that order. Because of the magnitude of the literature, I decided to discuss the weed hosts of but one genus.

I choose the root-knot nematodes for several reasons. On a worldwide agricultural basis, they are the most significant. Another impelling reason is that Dr.Joseph N. Sasser at North Carolina State University organized and has directed the International Meloidogyne Project for several years. It is a worldwide collaborative network on root-knot nematode biology and control. I felt it would be desirable to review the literature and identify the specific weed hosts of this most important genus of nematodes to facilitate collaborative research between weed scientists and nematologists. Such collaborative research would be desirable because of the expected increase in effectiveness of crop rotations as a means of depleting nematode populations when weed hosts are controlled concurrently.

The next question is that, if we have host weeds and crops growing together, which one will be the better host. Plants differ in their acceptability as hosts of nematodes. As an example, Dr. R.M. Riedel, nematologist at the Ohio State University, went to Columbia to consult on problems of dry bean (*Phaseolus* sp.) production. The beans used were the best nematode tolerant varieties available. The bean fields were infested with high populations of *Bidens pilosa* which is a better host than *Phasaeolus* of the root-knot nematodes. He pulled bean plants out of the ground and drew attention to the nodules of the nitrogen-fixing Rhizobium and galls of the root-knot nematodes. The massive nematode populations procuded on *Bidens pilosa* had overcome the tolerance capacity of the beans. His recommendation was that *Bidens pilosa* must be controlled. The beans would then be able to overcome the nematode problem. To repeat the generalization, plants differ in their acceptability as hosts of nematodes. Whether a crop or a weed is the better host is dependent upon the species being compared.

Dr. J. Harada (Thailand): To Dr. T. Smitinand. Which types of weeds are more serious in shifting cultivation areas. Naturalized or native species?

Dr. T. Smitinand (Thailand) : I think, the most serious weed is naturalised species.

Dr. M. Nemoto (Japan) : To Dr. T. Smitinand. I would like to ask a question about the difinition of the term, shifting cultivation. It is important to survey the areas in shifting cultivation because I also investigate weed species in shifting cultivation in Thailand.

Dr. T. Smitinand: I guess, shifting cultivation is not permanent. It has been underpractised after cleared the lands or forests of the primary or the secondary ones and then grows crops; after the harvest, moving to another areas, leaving the area to fallow, becoming secondary growth. I say, in Thailand We have two types of shifting cultivation, one is annual being under practised in the highland by the hill tribes. Then rotary one has been under practised by another tribes in the lower elevation.

Dr. K.U. Kim: Dr. T. Smitinand, what is the means used in the shifting cultivation; by hand or rotary? The meaning of shift cultivation is strange to us. First of all, it may be necessary to define the term of shifting cultivation. Then it should be explained what the factors are to induce the shift and why it should happen. Otherwise, it would be difficult to meet the requirement of title.

Dr. T. Smitinand: Shifting cultivation mostly has been done by hand annually, and leaving the land after harvest, but they will return after five or ten years. That makes a rotation.

Dr. M. Blacklow (Australia) : A question for Dr. Bendixen. You provided us with an impressive catalogue of weed-hosts for nematodes. However, if we are to proceed to the horizontal integration of pest management that you advocate, then weed scientists will need to know the nematode density/weed density relationships and the longevity of nematodes in the soil following a given level of weed control in a crop. Can you tell us if such information is available?

Dr. L.E. Bendixen: Your comment is most important. It relates to the time required for a nematode population to decrease below the economic threshold level. There are biological differences among the genera of nematodes. The time will vary from one nematode genus to another. Probably 2 or 3 years may be sufficient for some species of root-knot nematode, while it may take 4 to 6 years for cyst nematodes. However, if the land is not kept free of weed hosts during the non-host cropping time, that is, if a weed population is allowed to exist, the nematode population will be maintained. The time required for nematode populations to diminish below the economic threshold level presupposes a genuine host-free rotation.

Dr. M. Blacklow: Currently our efforts at weed control are determined by the relationships between crop yield and weed density. However, this may not be adequaté for the control of nematodes hosted by the weeds. For example, we may be satisfied with a weed density of ten plants per square metre for crop yield but the density of nematodes may not be decreased unless there are less than two weeds per square metre. Have there been any investigations of the relationships between nematode densities and weed densities.

Dr. L.E. Bendixen: My literature search related to the weed hosts of species of root-knot nematodes. It did not include the important question you have raised on the relationship of weed host density and consequent nematode density on crop yield. Therefore, I do not have any literature addressing your question directly. I have indicated that the movement of nematodes is rather random until they come within a couple of centimeters of a root, when their movement becomes directed. The effect of nematodes on crops depends very much on level of infestation. The weed populatin which might be tolerable as related to competition may not be acceptable as related to hosting nematodes. The example I used of the impact on nematode tolerant beans of the massive populations of nematodes maintained by *Bidens pilosa* gives some clues. Dr. Riedel's conclusion was that if the weed were controlled the nematode tolerance of the beans would be adequate. But there was no indication of an acceptable level of weed population in maintaining nematode populations below a threshold level.

WEEDS AND THE ENVIRONMENT IN THE TROPICS
(Eds. K. NODA & B.L. MERCADO), pp. 173-200, 1986

ALLELOPATHY AND FISH-TOXICITY OF WEEDS

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Abstract. Some plants contain toxic substances, release them into the environment and affect the growth of other plants. This phenomenon is known as an allelopathy. Many allelochemics have been isolated from various plant species and are reviewed in this paper. Moreover, two researches dealing with *Polygonaccae* weeds and *Oenanthe javanica* are introduced in detail. Some problems on allelopathy in the tropics are also discussed.

Piscicidal plants have been widely used in the world by native tribes or in old times to catch fish. Various types of piscicidal substances have been isolated from these plants and are reviewed in this paper. It was found recently that some aquatic weeds contained piscicidal substances which might affect the aquatic environment. Research on the identification of the piscicidal substance from *Ammannia baccifera*, an aquatic weed is introduced here in detail.

INTRODUCTION

Chemical substances contained in weeds often play an important role as one of the environmental factors which affect the growth of other weeds or crops.

It was found recently that some aquatic weeds contained piscicidal substances which might affect the aquatic environment.

These biologically active substances contained in weeds will be discussed in this paper, mainly based on our own research works.

ALLELOPATHY

Historical Review

Allelopathy as first proposed by Molish in 1937 with higher plants is the production and release of some toxic substances by plants into the environment. As a result, the growth of other plants is affected. Since then, many workers reported this phenomenon with various plants and now allelopathy is extensively used not only in the relations among higher plants but also between higher plants and microorganisms or even among microorganisms (Table 1).

Table 1. Relation between producer of chemicals and sufferer in allelopathy. (Koshimizu, 1978).

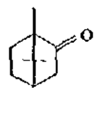
Producer	Sufferer	General name
Higher plant	→ Higher plant	koline phytotoxin
Higher plant	→ Microorganism	phytoncide phytoalexin
Microorganism	→ Higher plant	marasmine pathotoxin phytotoxin
Microorganism	→ Microorganism	antibiotic

Allelopathy has attracted the interest of not only ecologists but also chemists. Moreover, the rapid development of analytical equipment has made it easier to characterize chemically the substances involved in allelopathy. With such reasons, many allelochemics have been isolated and identified from various plant species (chemical structures are listed in Fig. 1 with numbers). Volatile monoterpenoids such as camphor (1) and cineole (2) were identified by Muller in 1964 from *Salvia leucophylla* which invades the grassland in California. Crow *et al.* (1971) isolated sesquiterpenes (3, 4, 5) from *Eucalyptus grandis*. Norditerpenelactones such as nagilactone A (6), inumakiloctone A (7), ponalactone (8) and podolactone A (9) were isolated from *Podocarpus* spp. These substances are believed to be related to the pure forest formation of *Podocarpus* spp. Bode clarified in 1958 that

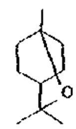
1,4,5-trihydroxy naphthalene contained in *Juglans nigera* is oxidized into juglone (10), then inhibits the growth of other plants. 3-acetyl-6-methoxybenzaldehyde (11) was isolated from *Encelia forinosa* (Gray and Bonner, 1948). *Parthenium argentatum* contained *t*-cinnamic acid (12) which was believed to be related to "fairy ring" formation in the community of this plant (Bonner and Galston, 1944). Polyacetylene compound, cis-dehydromatricaria ester (13) was isolated from *Solidago altissima,* which possesses a high competitive ability against other weeds and quickly infested all over the non-agricultural area in Japan (Kawazu *et al.*, 1969). Another polyacetylene compounds, matricaria ester (14), lachnophyllum ester (15) and 2-trans, 8-cis-matricaria ester (16) were isolated from *Erigeron annuus* (Kobayashi *et al.,* 1974). Barley *(Hordeum sativum)* is known as a "smoother crop", which releases toxic substances and inhibits the emergence of weeds. Hordenine (17) and gramin (18) were isolated from barley plants (Overland, 1966). They are believed to be involved in this phenomenon. It is well known that if upland rice plants are cultivated in the same field continuously, the yield decreases year by year. Munakata *et al.* (1959) revealed that the *p*-hydroxycinnamic acid (19) was released from rice plants, accumulated in the soil and reduced rice yield. But in the case of lowland paddy field, irrigation water washes away such substance hence no problem occurs (Above-mentioned example reviewed by Koshimizu, 1978). Red clover *(Trifolum pratense)* is known to cause "clover sickness"; that is, the second crops did not grow well in the field where red clover was cultivated (Tamura *et al.*, 1969). Chang *et al.* (1969) isolated many kinds of isoflavonoids (20-27) from this plant. These substances decompose into phenolcarboxylic acid which causes "clover sickness".

In the old days when shifting cultivation was widely practiced in Japan, farmers cultivated *Perilla frutescense* var. *japonica* for the purpose of reducing the emergence of weeds in the field (Sugawara, 1982). The same species but different variety, *P. frutescense* var. *crispa* is also known to show strong allelopathy. Two plant growth inhibiting substances, perilla ketone (28) and perilla aldehyde (29) were identified from these plants, respectively (Harada, 1984).

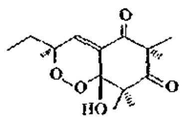
Witchweed *(Striga lutea)* is an angiospermous root-parasitic weed indigenous to several tropical and subtropical agricultural areas in the world. Seeds of this plant remain dormant until germination is



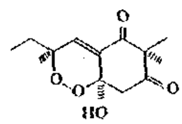
(1) camphor



(2) cineole



(3)



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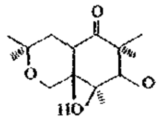

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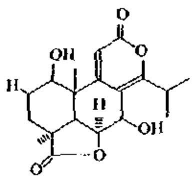
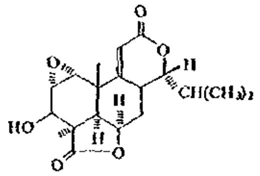
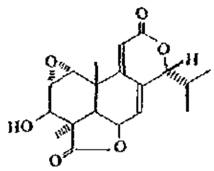


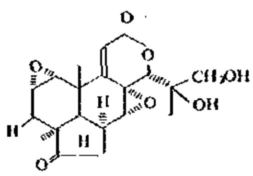
(6) nagilactone A



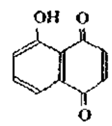
(7) inumakilactone A



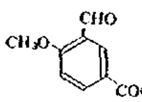
(8) ponalactone



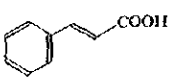
(9) podolactone A



(10) juglone



(11) 3-acethyl-6-methoxybenzaldehyde



(12) *trans*-cinnamic acid

$$CH_3(C{\equiv}C)_3{-}\overset{H}{C}{=}\overset{H}{C}{-}COOCH_3$$

(13) *cis*-dehydromatricaria ester

$$CH_3\overset{H}{C}{=}\overset{H}{C}{-}C{\equiv}C{-}C{\equiv}C{-}\overset{H}{C}{=}\overset{H}{C}{-}COOCH_3$$

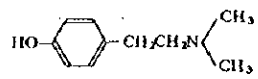
(14) matricaria ester

$$CH_3CH_2CH_2{-}C{\equiv}C{-}C{\equiv}C{-}\overset{H}{C}{=}\overset{H}{C}{-}COOCH_3$$

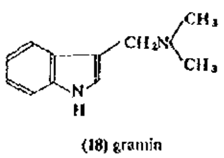
(15) lachnophyllum ester

$$CH_3{-}\overset{H}{C}{=}\overset{H}{C}{-}C{\equiv}C{-}C{\equiv}C{-}\overset{H}{C}{=}\underset{H}{C}{-}COOCH_3$$

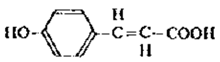
(16) 2-*trans*, 8-*cis*-matricaria ester



(17) hordenine

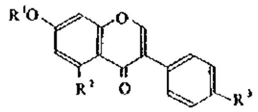


(18) gramin

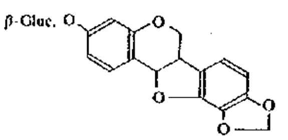


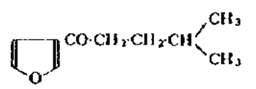
(19) p-hydroxycinnamic acid

	R^1	R^2	R^3	
(20)	H	H	OCH_3	formononetin
(21)	H	H	OH	daidzein
(22)	β-Gluc.	H	OH	daidzein glucoside
(23)	β-Gluc.	H	OCH_3	ononin
(24)	H	OH	H	genestein
(25)	H	OH	OCH_3	biochanin A
(26)	β-Gluc.		OCH_3	
	$OCOCH_2CO_2H$			

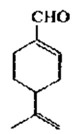


(27) trifolirhizin

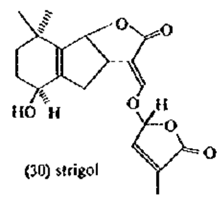




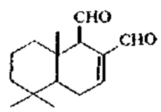
(28) perilla ketone



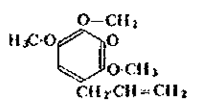
(29) perillaldehyde



(30) strigol



(31) polygodial



(32) apiole

Fig. 1. Chemical structures of allelochemics isolated from plants.

stimulated by a chemical produced by the host plant or by certain other plant species. Cook *et al.* (1966, 1972) isolated strigol (30), the stimulant from cotton root exudates and determined its complete structure by X-ray crystallographic analysis of a single crystal. Strigol causes germination of *S. lutea* at concentrations less than 10^{-5} *ppm*. This substance which shows a promoting effect seems to be very peculiar from the point that most allelochemics show a plant growth inhibitory activity.

Thus, various types of allelochemics have been isolated and reported with many plant species. From them, two researches which were carried out by the author's group and published already (Harada and Yano, 1983; Harada, 1986) will be introduced in detail hereafter.

Plant Growth Inhibiting Substance Contained in Polygonaceae Weeds (Example 1)

Family *Polygonaceae* includes important weed species in Japan, such as *Polygonum hydropiper*, *P. japonicum*, *P. conspicuum*, *P. thunbergii*, *P. nipponense*, *P. sagittatum* var. *sieboldii*, etc. in lowlands and *P. longisetum*, *P. lapathifolium* subsp. *japonicus*, *Rumex obtusifolius*, etc. in upland fields (Numata *et al.*, 1975).

These weed species often form a pure community and severely cause weed damage to crops. From such observation, we presumed that these *Polygonaceae* weeds might contain allelochemics which inhibit the growth of other weeds or crops. These experiments deal with some *Polygonaceae* weed species in Japan and showed the possible existence of plant growth inhibiting substance in these plants.

Plant growth inhibiting activity of the methanolic extracts from 22 *Polygonaceae* weed species was examined by rice seedling bioassay. The results are shown in Fig. 2. Root growth in rice seedlings was strongly inhibited by the extracts from most weeds, while the growth of the second leaf sheath was inhibited by the extracts from some species in higher concentration only. These results clearly showed the existence of plant growth inhibiting substance(s) in *Polygonaceae* weeds.

To identify the substance(s), further experiments were conducted using *P. hydropiper* plants which possess both piscicidal and plant growth inhibiting activities (Harada and Yano, 1983). Preliminary experiments revealed that this substance was extractable with hot

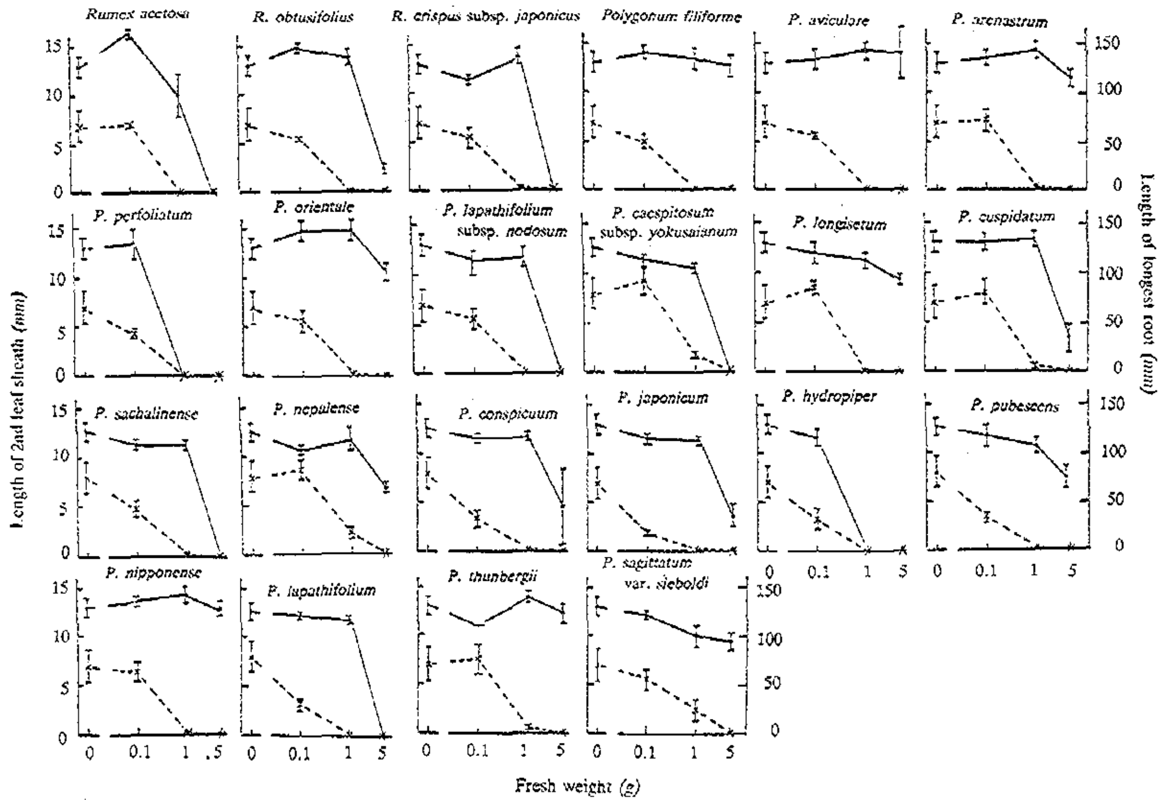


Fig. 2. Effect of the methanolic extracts from 0.1, 1 and 5 *g* fresh weight of *Polygonaceae* weeds on the growth of rice seedling cv. Tan-ginbozu (Harada and Yano, 1983).

water, methanol, acetone, ethylacetate, ether, chloroform, benzene or *n*-hexane (Table 2), and easily partitioned from aqueous solution into organic solvent at both pH 3 and 8 (Table 3). From these data, the substance was considered neutral. Methanolic extract was purified by charcoal-celite column chromatography with water/acetone step elution system. Both activities were mainly shown in the same 10/90 (v/v) eluate (Table 4), suggesting that a single substance might possess both biological activities. Biologically active eluate was concentrated in vacuo and further purified by TLC with benzene/ethylacetate (4/1, v/v) solvent system. A single spot at Rf 0.59 was detected as a dark color under UV light and deep yellow color with aldehyde reagent (0.5% 2,4-dinitrophenyl-hydrazine in 2N HCl) spray (Fig. 3). Spotted area was scraped off and eluted with methanol, then biological activity and UV, IR absorbing spectra were determined. It showed a very strong piscicidal and plant growth inhibiting activities and pungency. Also, its spectrum data were as follows: UV λ_{max}^{MeOH} 228 *nm* (Fig. 4), IR $\nu_{max}^{CCl_4}$ 2700 (-CHO), 1715 (satur. C=O) 1975 (α, β -unsatur. C=O,) 1640 (conj. C=C), 825 ($>=<^{H}$) cm^{-1} (Fig. 5). From these data, biologically active substance contained in *P. hydropiper* was identified as polygodial (31), which was already reported in the same plant independently of the biological activity (Barnes and Loder, 1962).

To estimate the existence of polygodial in other *Polygonaceae* weeds, piscicidal activity of the methanolic extracts was examined. All the *Polygonaceae* plants showed the activity as shown in Fig. 6. These results suggest that plant growth inhibiting substance contained in *Polygonaceae* weeds is polygodial.

Although roles of polygodial in the growth and allelopathy of *Polygonaceae* weed species are not clarified yet, Sukul (1970) reported that the growth of wheat and the infestation of wheat gall nematode (*Anguina tritici*) were greatly inhibited when they were grown together with *P. hydropiper* and presumed that this inhibition was caused not only by competition for light, water and nutrients but also by toxic root diffusates. A polygodial might be responsible for this phenomenon.

Plant Growth Inhibiting Substance Contained in Oenanthe javanica (Blume) DC. (Example 2)

O. javanica which belongs to family *Umbelliferae* is a serious perennial paddy weed in Japan (Numata *et al.*, 1975). This weed often

Table 2. Biological activity of the extracts with various solvents from air-dried leaves of *Polygonum hydropiper* (Harada and Yano, 1983).

Solvents	Plant growth inhibiting activity*	Piscicidal activity**
Water (0° C)	–	–
Water (80° C)	+	+
Acetone	+	+
Ethyl acetate	+	+
Ether	+	+
Chloroform	+	+
Benzene	+	+
n-Hexane	+	+

* Rice seedling cv. Tan-ginbozu
** *Oryzias latipes*

Table 3. Biological activity of ether fractions partitioned at different *pH* from hot water extract of *Polygonum hydropiper* (Harada and Yano, 1983).

pH	Plant growth inhibiting activity*	Piscicidal activity**
Original solvent	+	+
3	+	+
7	+	+
8	+	+

* Rice seedling cv. Tan-ginbozu
** *Oryzias latipes*

Table 4. Separation of biologically active substance contained in *Polygonum hydropiper* by charcoal-celite column chromatography (Harada and Yano, 1983).

Eluate Water : Acetone (v/v)	Growth inhibiting activity*	Piscicidal activity**
50 50	–	–
40 60	–	–
30 70	–	–
20 80	++	++
10 90	+++	+++
0 100	+	+

* Rice seedling cv. Tan-ginbozu
** *Oryzias latipes*

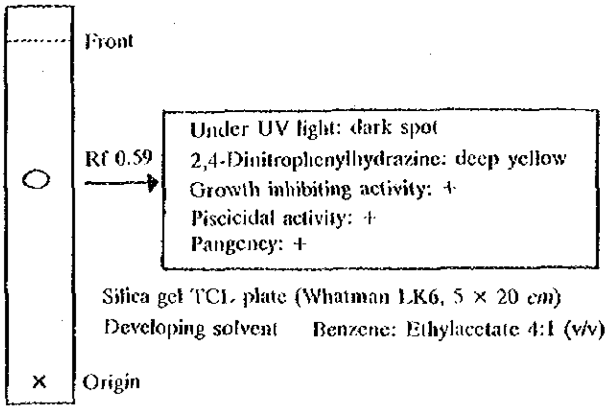


Fig. 3. Thin-layer chromatogram of biologically active substance contained in *Polygonum hydropiper* (Harada and Yano, 1983).

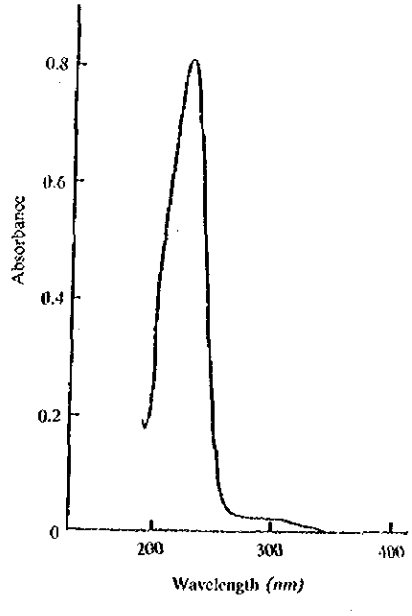


Fig. 4. UV-absorption spectrum of methanol solution of biologically active substance isolated from *Polygonum hydropiper* (Harada and Yano, 1983).

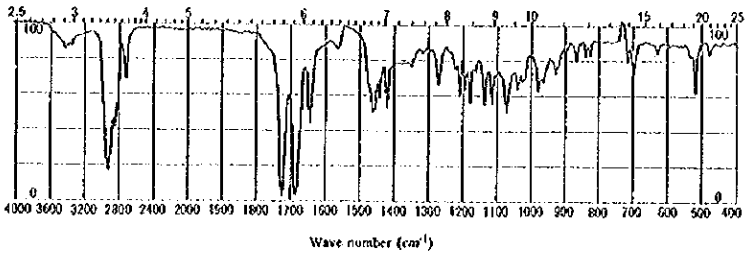


Fig. 5. IR spectrum of biologically active substance isolated from *Polygonum hydropiper* (in carbon tetrachloride) (Harada and Yano, 1983).

forms a pure community in paddy field or paddy levee and severely causes weed damage to rice plants. It is often observed in direct-sown paddy field with heavy infestation of this weed that rice seedlings are extremely retarded in their growth and are not able to emerge from the soil surface.From such observation, we presumed that *O. javanica* plants might contain allelochemics which inhibit the growth of other weeds or crops. This experiment was initiated to identify the plant growth inhibiting substance contained in *O. javanica* plants.

Effects of the original methanolic extract, n-hexane and aqueous phase of *O. javanica* plants on the growth of rice seedlings were examined and results are shown in Fig. 7. Methanolic extract inhibited sheath growth linearly but it inhibited root growth only at higher concentration. Sheath growth inhibitor(s) was partitioned from aqueous phase into n-hexane phase, however root growth inhibitor(s) remained in aqueous residue. Data indicate that the former substance(s) is less polar than the latter.

Methanolic extract was purified by charcoal-celite column chromatography with water/acetone/ethyl acetate step elution system. As a result (Table 5), root growth inhibiting activity was shown in the first eluate (water/acetone/ethyl acetate, 40/60/0, v/v/v) and sheath growth inhibiting activity was shown in the second and third eluates (20/80/0 and 0/100/0).

The sheath growth inhibitory eluates were combined, concentrated in vacuo, and further purified by TLC with n-hexane/ether (5/1, v/v) solvent system. As a result, four spots at Rf 0.14, 0.22, 0.36 and 0.51 were detected under UV light. Among them, only a substance which

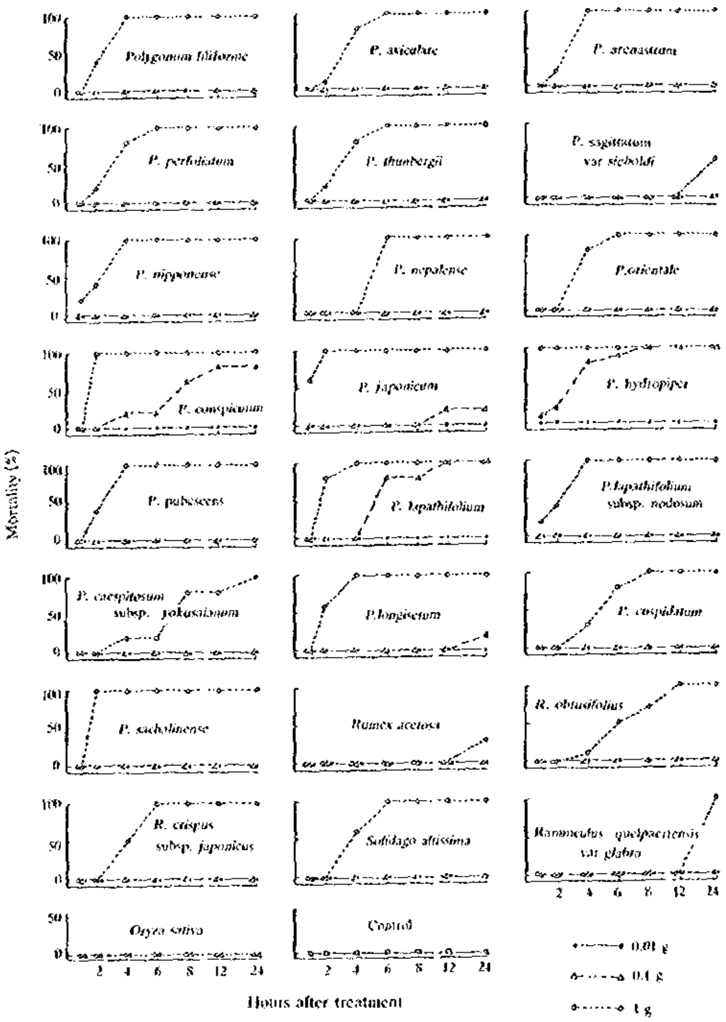


Fig. 6. Piscicidal activity of the methanolic extracts from 0.01, 0.1 and 1 *g* fresh weight of *Polygonaceae* weeds, *Solidago altissima*, *Ranunculus quelpaertensis* var. *glabra* (Harada and Yano, 1983).

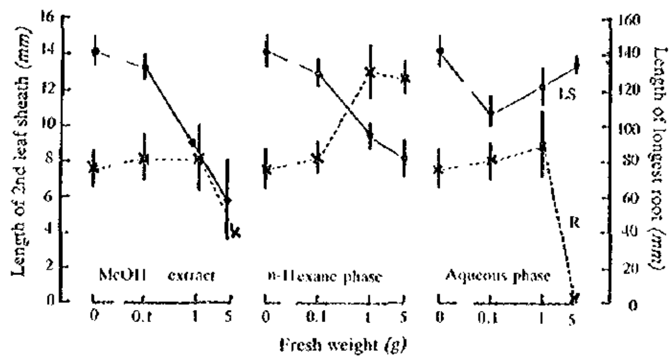


Fig. 7. Effects of the methanolic extract, n-hexane or aqueous phase from 0.1, 1 and 5 *g* fresh weight of *Oenanthe javanica* on the growth of rice seedling cv. Tan-ginbozu (Harada, 1986).
LS: Length of 2nd leaf sheath, R: Length of longest root

Table 5. Separation of plant growth inhibiting substance contained in *Oenanthe javanica* by charcoal-celite column chromatography (Harada, 1986).

Eluate Water:Acetone:EtOAc (v/v/v)			Length of 2nd leaf sheath (*mm*)		Length of longest root (*mm*)	
			1 *g*	5 *g*	1 *g*	5 *g*
40	60	0	16.2±0.4	12.7±0.9	67.8±10.5	19.7± 4.7
20	80	0	9.5±0.5	9.0±1.2	66.2±12.0	58.7±11.7
0	100	0	12.8±1.3	8.2±2.0	102.2± 5.9	84.7±25.0
0	80	20	17.2±0.7	15.8±0.9	80.5± 8.7	76.8±14.8
0	60	40	14.2±0.7	14.2±1.1	60.7± 7.0	69.0±10.4
0	40	60	12.5±0.8	12.2±0.9	63.5±13.9	77.8±16.4
0	20	80	10.5±0.5	10.8±0.9	59.2± 7.7	56.0±12.7
0	0	100	11.5±1.0	12.5±1.1	59.7± 6.1	56.7± 6.3
Control			15.7±1.0		65.5±13.2	

Bioassay: rice seedling cv. Tan-ginbozu
Samples extracted from 1 and 5 *g* fresh materials were used.

appeared at Rf 0.51 showed a strong growth inhibiting activity (Fig. 8).

To identify the biologically active substance, UV absorption spectrum and GC-MS analysis were carried out. As a result, UV: λ_{max}^{MeOH} 230, 280 *nm* (shown in Fig. 9) and fragment peaks of MS: *m/e* $222M^+$, 207, 195, 191, 177, 149, 121, 106, 91, 77, 65 (shown in Fig. 10) were obtained respectively. From these data, sheath growth inhibitory substance contained in *O. javanica* was identified as an apiole, 1-allyl-2, 5-dimethoxy-3, 4-methylene dioxybenzene (32).

Recently the author isolated myristicin which possesses a similar chemical structure as apiole from parsley plants (Harada, 1984) and also both myristicin and apiole from parsley seed oil as plant growth regulators (Harada, 1984). By using this isolated apiole from parsley seed oil, effect on the growth of rice seedlings was examined. As shown in Fig. 11, apiole inhibited only leaf sheath growth at lower concentration although it inhibited both sheath and root growth at higher concentration. This characteristic seems to be desirable to consider the practical use of the chemical as a plant growth regulator in agriculture.

One of the plant growth inhibiting substances contained in *O. javanica* was identified as apiole although root growth inhibitory substance remained unknown. Apiole seems to be closely related to allelopathy of this weed species. Further study, however, is essential to clarify the phenomenon.

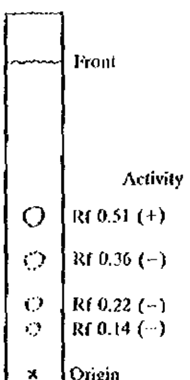


Fig. 8. Thin-layer chromatogram of the active fraction from charcoal-celite column chromatography (Harada, 1986).
Silica gel TLC plate --- Whatman LK6, 5 × 20 cm
Developing solvent --- n-Hexane : Ether 5:1 (v/v)

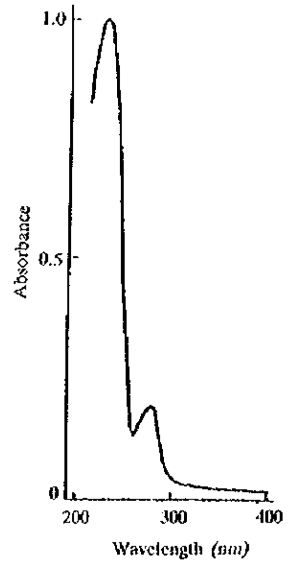


Fig. 9. UV-absorption spectrum of methanol solution of plant growth inhibiting substance isolated from *Oenanthe javanica* (Harada, 1986).

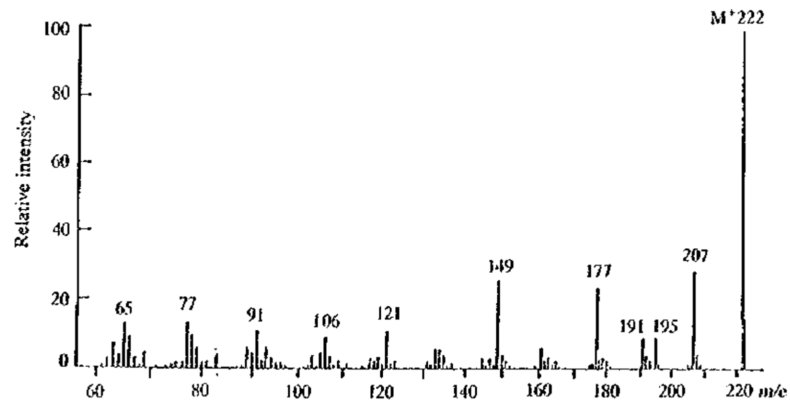


Fig. 10. Mass spectrogram of plant growth inhibiting substance isolated from *Oenanthe javanica* (Harada, 1986).

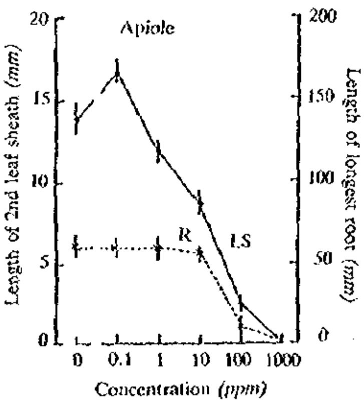


Fig. 11. Effect of apiole on the growth of rice seedling cv. Tan-ginbozu (Harada, 1986).
LS: Length of 2nd leaf sheath, R: Length of longest root

Problems in the Tropics

The author has described in this paper about two examples of allelopathy researches which were carried out in Japan, a temperate country. In the tropics, however, there are many kinds of weeds showing high competitive ability with other weeds or crops, some of which might be due to allelopathic effects besides the competition for light, water, nutrients, etc. From this point of view, the existence of plant growth inhibiting substances in certain tropical weed species was investigated and reported partially (Fig. 12; Premasthira *et al.*, 1986). Methanolic extracts of most weeds strongly inhibited the rice seedling growth and this clearly indicates the possible existence of plant growth inhibiting substances in the plants, although these substances are not always related to allelopathy. Further investigation and identification of these substances, however, will be a stepping stone to reveal allelopathy. Moreover, mechanical weed control is a popular method in agricultural area of most tropical countries. Generally after eradication weeds are always mixed in the soil as a green manure or

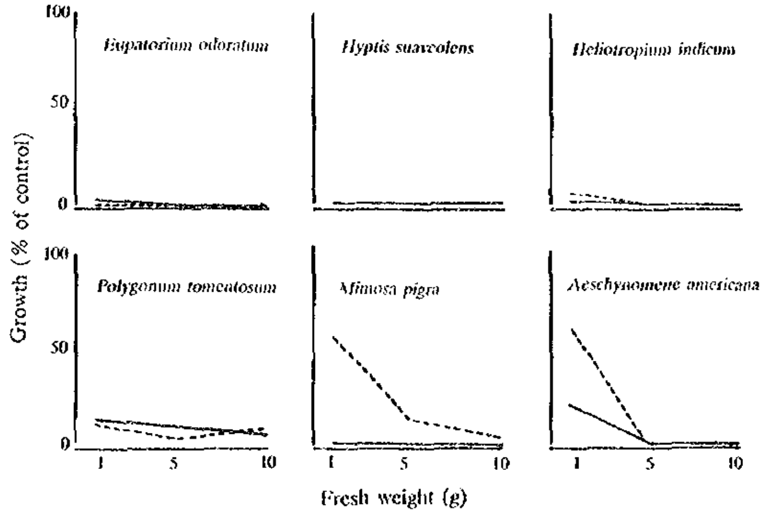


Fig. 12. Effect of the methanolic extracts from 1, 5, and 10 g fresh weight of some weed species on the growth of rice seedlings (Premasthira *et al.*, 1986).
Broken line: 2nd leaf sheath, Solid line: root

sometimes weeds are dried and mixed in the soil during land preparation. Horowitz and Friedman (1971) revealed that fresh or dried plant material can produce toxic substance during their decomposition. From this point of view, we must avoid to incorporate weeds which contain strong plant growth inhibiting substances, into the soil.

Further researches are under way through the cooperation between Thai and Japanese researchers in the National Weed Science Research Institute Project.

FISH-TOXICITY OF WEEDS

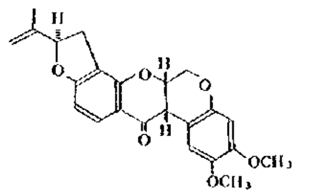
Piscicidal Plants

Piscicidal plants have been widely used in the world to catch fish in old times or by native tribes at present. From these plants, various types of piscicidal substances have been isolated and reported (Fig. 13 with numbers). Rotenone (33) was isolated from *Derris elliptica*, *D. montana* or *D. pubipetala* (belong to *Leguminosae*), root of which were widely used in Southeast Asia, juglone (5-hydroxynaphthoquinone) (34) from *Juglans mandshurica (Juglandaceae)*, roots or fruits of which were used in Japan, justicidin A (35) and B (36) from *Justicia hayatai* var. *decumbens (Acanthaceae)*, whole plants were used in Taiwan (Ohta *et al.*, 1969, 1971), Callicarpone (37) from *Callicarpa candicans (Verbenaceae)*, leaves of which were used in Caroline and Philippine islands, maingayic acid (38) from *Callicarpa maingayi (Verbenaceae)* (Nishino *et al.*, 1971), huratoxin (39) from *Hura crepitans (Euphorbiaceae)*, latex of which was used in South America (Sakata *et al.*, 1971), vibsanine A (40) from *Viburnum awabuki (Caprifoliaceae)*, leaves of which were used in Okinawa, Japan (Kawazu and Mitsui, 1974), inophyllolide (41) from *Calophyllum inophyllum (Guttiferae)*, leaves or seeds of which were used in Malay peninsula, ichthyothereol (42) from *Ichthyothere terminalis (Compositae)*, leaves of which were used in the Amazon (Reports without citation: reviewed by Kawazu, 1972). The plants mentioned show a very strong piscicidal activity but seem to possess no possibility to pollute the aquatic environment because most of them grow far from the area.

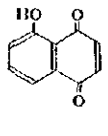
Piscicidal Aquatic Weeds

Recently it was found and earlier mentioned in this paper that *P. hydropiper*, a weed in aquatic environment contained polygodial which shows a strong piscicidal activity (Harada and Yano, 1983). However, we were not aware of the importance of this fact, because aquatic environment such as rivers, lakes or paddy fields are well polluted in Japan with a large amount of agrochemicals and exhausts from factories or houses. In most Southeast Asian countries, aquatic environment is very important as a site of protein production. Farmers control aquatic weeds by plowing and flooding the land, where fish culture is commonly practiced. In addition, large number of fish often die with unknown cause in the area, although no agrochemical has been used at all.

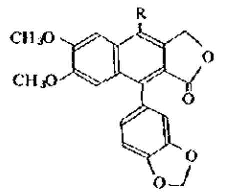
From these facts, we considered that piscicidal substances contained in aquatic weeds might be related to the cause of fish killing. Hence, we examined the piscicidal activity of 54 weed species grown in tropical



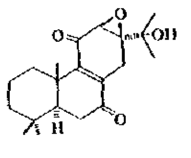
(33) rotenone



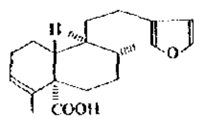
(34) juglone



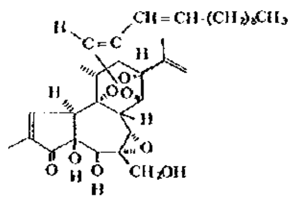
(35) R = OCH_3 justicidin A
(36) R = H justicidin B



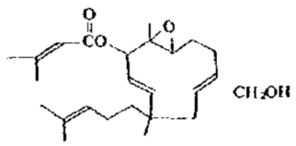
(37) callicarpone



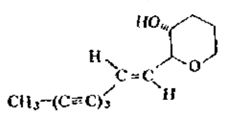
(38) maingayic acid



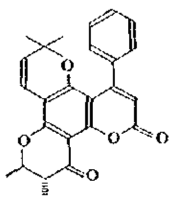
(39) huratoxin



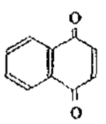
(40) vibsanine A



(42) ichthyothercol



(41) inophyllolide



(43) α-naphthoquinone

Fig. 13. Chemical structures of piscicidal substances isolated from plants.

aquatic environment with guppy fish and found that twelve species among them showed the activity as shown in Table 6 (Zungsonthiporn *et al.*, unpublished).

Table 6. Piscicidal weeds grown in aquatic environment (Zungsonthiporn *et al.*, unpublished).

Weed Species	Family
Ammannia baccifera	*Lythraceae*
Polygonum tomentosum	*Polygonaceae*
Dysophylla stellata	*Labiatae*
Sphenoclea zeylanica	*Sphenocleaceae*
Bacopa monnieri	*Scrophulariaceae*
Mimosa pigra	*Mimosaceae*
Neptunia natans	*Mimosaceae*
Sesbania javanica	*Papilionaceae*
Ipomoea aquatica	*Convolvulaceae*
Centrostachys aquatica	*Amaranthaceae*
Potamogeton malaianus	*Potamogetonaceae*
Pistia stratiotes	*Araceae*

Piscicidal substance(s) was extracted from shoots of *Ammannia baccifera* which showed the strongest activity with various solvents (Table 7). Most extracts except water showed strong activity. It is clearly understood that the active substance(s) is widely soluble in non-polar to polar organic solvents. Methanol extract, however, killed

Table 7. Piscicidal activity of various extracts from 0.1, 0.5 and 1.0 *g* fresh weight of *Ammannia baccifera* shoots (Zungsonthiporn *et al.*, 1986).

Solvent	Mortality (%)		
	0.1	0.5	1.0
Cold water	0	0	0
Hot water (80° C)	0	0	20
Methanol	100	100	100
Ethyl acetate	100	100	100
Benzene	100	100	100
n-Hexane	100	100	100

the fish earlier than the other extracts. Hence we used methanol for extraction thereafter.

Purification of the active substance(s) was carried out by a charcoal-celite column chromatography with water/acetone step elution system. As a result, the active substance(s) came out in 0/100 (water/acetone, v/v) fraction. One *g* (equivalent to fresh material) of the active fraction was developed on TLC plate with n-hexane/ethylacetate mixture (9/1, v/v). The dark violet band was found at Rf 0.65 under UV light as shown in Fig. 14. This zone was scraped off and eluted with methanol for piscicidal activity and further analysis. The substance(s) at Rf 0.65 apparently showed a strong piscicidal activity.

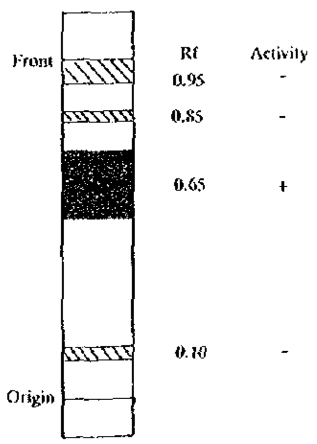


Fig. 14. Thin layer chromatogram of the active fraction from charcoal-celite column chromatography (Zungsonthiporn *et al.*, 1986).
Silica gel plate --- Whatman LK 6, 5×20 *cm*
Developing solvent -- n-Hexane : Ethyl acetate 9:1 (v/v)

UV-absorption spectrum of the active zone is shown in Fig. 15. λ max in methanol was 244 *nm*. The pattern resembled to that of α-naphthoquinone. GC and GC-MS analyses, however, were carried out for identification of the substance.

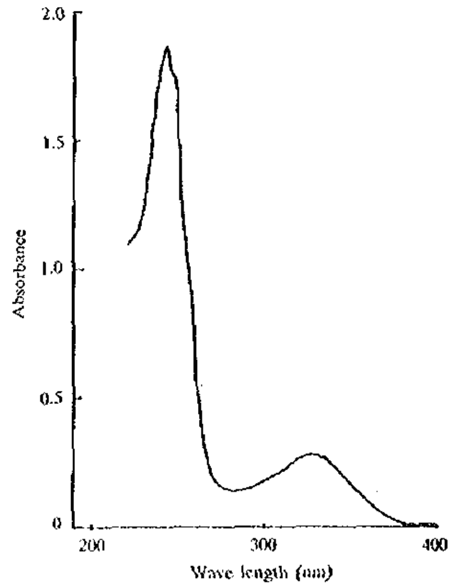


Fig. 15. UV-absorption spectrum of methanol solution of piscicidal substance isolated from *Ammannia baccifera* (Zungsonthiporn *et al.*, 1986).

GC pattern is shown in Fig. 16. The active zone gave three peaks, one major and two minor. Mass spectrogram of major substance (A) gave fragment peaks; $158M^+$, 130, 104, 102, 76 as shown in Fig. 17. Fragment peaks of the first (B) and the second (C) minor substances were $174M^+$, 158, 146, 130, 118, 105, 102, 89, 76, and $188M^+$, 174, 158, 130, 116, 102, 89, 76, respectively. From the results, major active substance contained in *A. baccifera* was identified as α -naphthoquinone (43). Two minor substances, however, still remain unknown.

To ascertain the activity, piscicidal effect of synthetic α -naphthoquinone was examined by using guppy. As a result (Fig. 18), TLm (24 *h*) was about 0.09 *ppm*. This value is just moderate compared with other piscicidal substances; *i.e.* huratoxin : 0.0014, justicidin A and B : 0.02 and 0.04, callicarpone : 0.04, vibsanine : 0.1, cis-dehydromatricaria ester : 2, maingayic acid : 4.7 and inophyllolide : 5 *ppm* (reviewed by Kawazu, 1972).

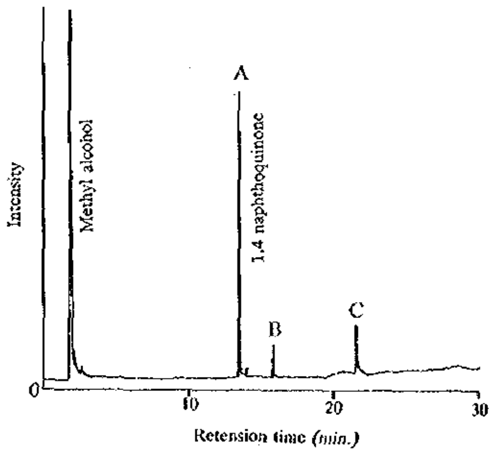


Fig. 16 Gas-chromatogram of active fraction from TLC (Zungsonthiporn *et al.*, 1986).
Column : 25 *m L*, 0.2 *mm* I.D.
Temp : 100 – 280°C (6°C/min)
Liquid phase : 5% phenylmethyl silicone
Carrier Gas : He.
Flow rate : 50 ml/min, column 0.5 ml/min
Vent : 50 *ml/min*, spilt ratio : 1:100

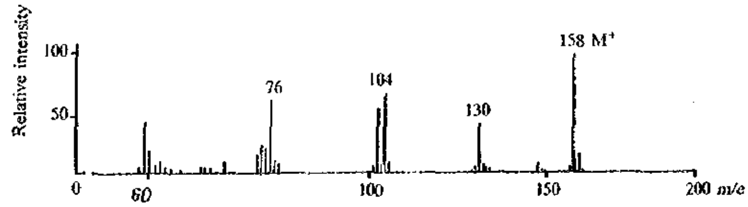


Fig. 17. Mass spectrogram of piscicidal substance isolated from Ammannia baccifera (Zungsonthiporn *et al.*, 1986).

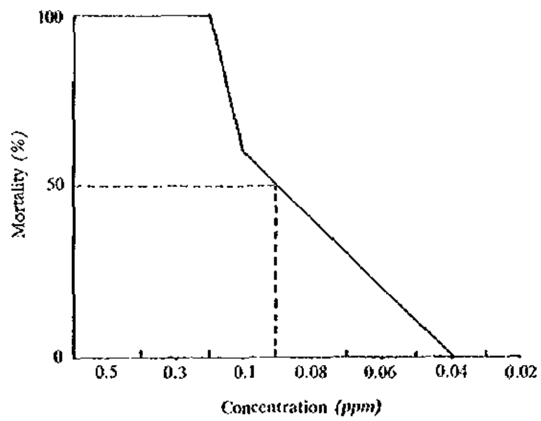


Fig. 18. Effect of synthetic α-naphthoquinone to the guppy fish (Zungsonthiporn *et al.*, 1986).

Quantitative analysis by using UV absorption spectrum revealed that 1.0 *g* fresh weight of *A. baccifera* shoots contained 78 *μg* of α-naphthoquinone. From this point, an enough amount of pollutant can be found in aquatic environment all over the country.

Our field observation in Buri Ram, Surin and Si Sa Ket, Northeastern Thailand on December 11 to 13, 1984 revealed that heavy proliferation of piscicidal aquatic weeds as well as *A. baccifera* was found in the area where large number of fish died. Further studies, however, are essential to clarify the relation between piscicidal aquatic weeds and the cause of fish killing in natural condition.

CONCLUSION

Isolation and identification of allelochemics or piscicidal substances from weeds seem to be very important not only to reveal allelopathy or environmental pollution but also to find new biologically active substances for future practical use. Such interest must be focused in the tropics where abundant plant resources exist.

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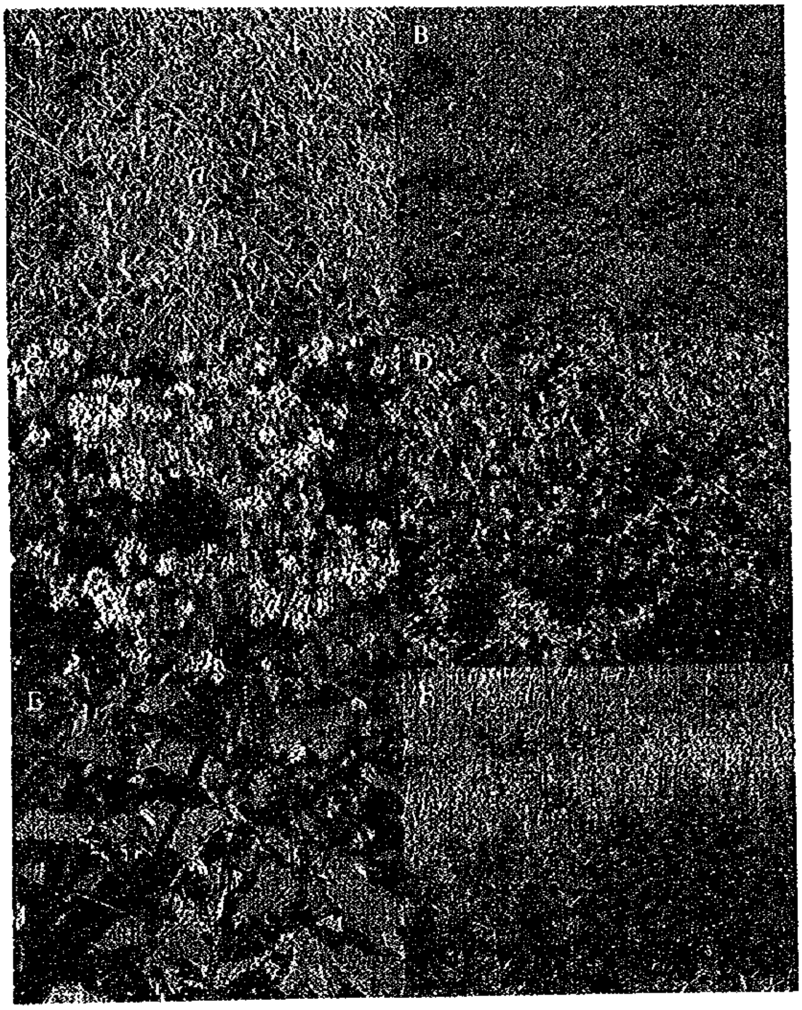

Plate 1. Some weed species which contain strong plant growth inhibiting substances.
A : *Polygonum hydropiper*, B : *Oenanthe javanica*,
C : *Eupatorium odoratum*, D : *Hyptis suaveolens*,
E : *Heliotropium indicum*, F : *Aeschynomene americana*

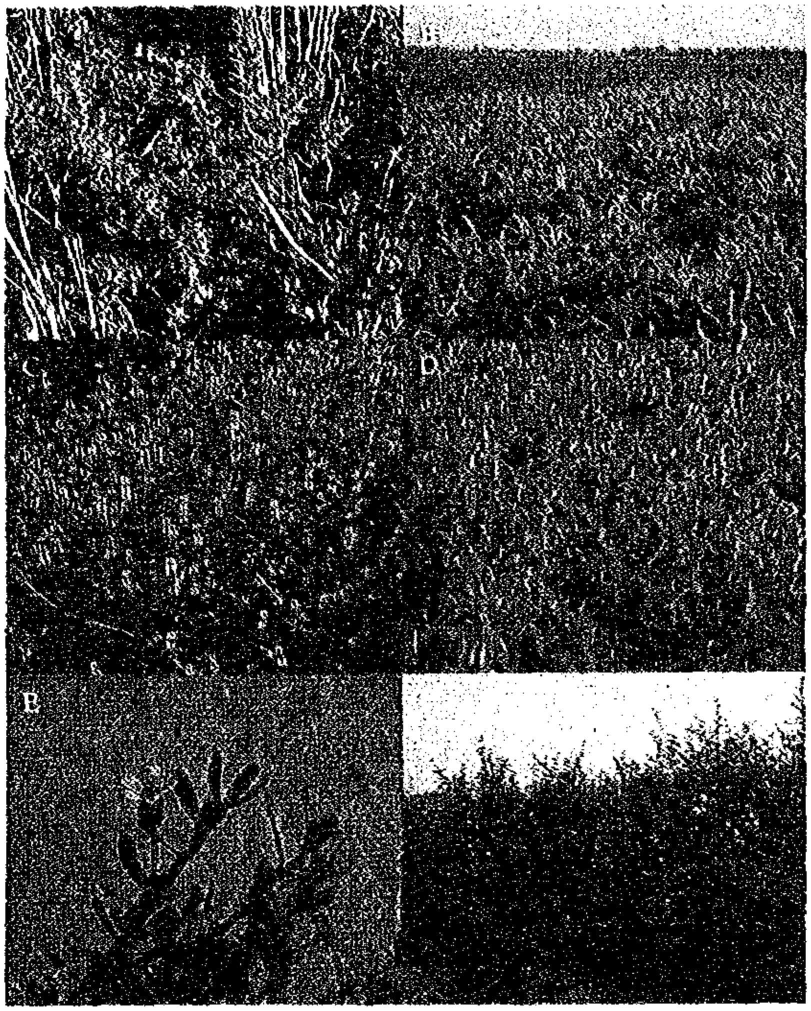

Plate 2 Piscicidal weeds grown in aquatic environment.
A : *Ammannia baccifera*, B : *Polygonum tomentosum*,
C : *Dysophylla stellata*, D : *Sphenoclea zeylanica*,
E : *Bacopa monnieri*, F : *Mimosa pigra*

WEEDS AND THE ENVIRONMENT IN THE TROPICS
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HERBICIDES IN THE ENVIRONMENT

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Abstract. Herbicides play a very important role in modern agriculture. In spite of some significant advantages in the use of herbicides, they also have several important disadvantages that must be considered carefully when these herbicides are applied in the fields. In this paper, fate and behavior of herbicides in the environment after their application are reviewed particularly with herbicides currently used in Taiwan and in Japan. Emphases are made on the herbicides used in paddy fields, because rice is a big crop ranking second to wheat in terms of area harvested, and is mainly cultivated in Asian countries by the method of transplanting in paddy fields. The flooded soil is characteristically different from non-flooded soil in its physical, chemical and microbiological properties. Therefore, the fate, dissipation and mechanism of degradation of herbicides applied to the paddy fields may differ from those in non-flooded soils. Many factors may affect the behavior and fate of herbicides after their application. Climatic conditions and soil properties seem to be critical.

The present review is primarily concerned with recent progress on the herbicides in the environments after their use. Studies with the rice paddy model ecosystem, which seemed to be very effective and useful for studying the fate of herbicides in the environment are also included.

HERBICIDES USED IN PADDY FIELDS

At present time, 89 kinds of herbicides with different chemical structures have been registered in Taiwan. Of these chemicals, 25 compounds were used in paddy fields either as a single component or as component(s) in the mixed herbicides (Table 1). Besides these herbicides, additional 14

Table 1. Herbicides registered for use in paddy fields in Taiwan and in Japan.

Common name	Chemical name	Year registered	
		Taiwan	Japan
Dichlobenil (DBN)	2,6-Dichlorobenznitrile	1965	1963
Propanil (DCPA)	*N*-(3,4-Dichlorophenyl) propionamide	1966	1961
Molinate	*S*-Ethyl-*N*,*N*-hexamethylene thiolcarbamate	1967	1972
MCPA*	2-Methyl-4-chlorophenoxyacetic acid	1970	1953
Chlornitrofen (CNP)	2,4,6-Trichlorophenyl-4′-nitrophenylether	1970	1963
Benthiocarb (Thiobencarb)	*S*-(4-Chlorobenzyl)*N*,*N*-diethylthiolcarbamate	1971	1969
Butachlor	*N*-(Butoxymethyl)-2-chloro-2′,6′-diethylacetanilide	1971	1973
Credazine*	3(2-Methylphenoxy) pridazine	1971	-**
Chlomethoxynil	2,4-Dichlorophenyl 3-methoxy-4-nitrophenylether	1972	1973
Oxadiazon	2-*tert*-Butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-Δ^2-1,3,4-oxadiazolin-5-one	1972	1972
Phenopylate	2,4-Dichlorophenyl-1-pyrrolidinecarboxylate	1973	1977***
Piperophos*	*S*-(2-Methyl-1-piperidylcarboxymethyl)-*O*,*O*-di-*n*-propylphosphorodithioate	1974	1976
Dimethametryn*	2-(1′-2′-Dimethylpropylamino-4-ethyl-amino-6-methyl-thio-*s*-triazine	1974	1976
Methoxyphenone	3,3′-Dimethyl-4-methoxybenzophenone	1976	1976
Bensulide (SAP)*	*S*-(*O*,*O*-Diisopropyl phosphorothioate) ester of *N*-(2-mercaptoethyl) benzene sulfonamide	1976	1982
Bifenox	Methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate	1976	1982
Trifluralin*	α, α, α-Trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine	1976	1970

Table 1. (continued)

Common name	Chemical name	Year registered	
		Taiwan	Japan
Bentazone	3-Isopropyl-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide	1976	1975
Pendimethalin	*N*-(1-Ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine	1976	–**
Naproanilide*	α-(β-Naphthoxy) propionanilide	1976	1980
Fluothiuron (Thiochlormethyl)	3-(4-Difluorochloromethylmercapto-3-chlorophenyl)-1,1-dimethylurea	1977	1979***
Dymron*	1-(α,α-Dimethylbenzyl)-3-(4-methylphenyl) urea	1979	1975
Oxyflurfen*	2-Chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene	1980	–**
Trichlopyr*	[(3,5,6-Trichloro-2-pyridinyl)oxy] acetic acid	1982	–**
Bromobutide*	*N*-(α,α-Dimethylbenzyl)-α-bromo-*tert*-butyl acetanilide	1983	–**

* Used as a component of mixed herbicide only.
** Not registered for use in paddy fields in Japan.
*** In the year registration was withdrawn in Japan.

different chemicals have been also registered as herbicides for use in paddy fields in Japan (Table 2).

Although the method of cultivation of rice in paddy fields is pretty close between Taiwan and Japan, owing to the quite different climatic conditions and cultivation system, herbicides used for the control of weeds in paddy fields are not always be quite the same. For example, Taiwan located in the tropical and subtropical zones, but Japan in temperate zones. Movcover, rice is cultivated once a year in Japan but it is two crops in Taiwan. Soil properties and weed flora are also different somewhat in detail. From these reasons, some herbicides such as simetryn and several phenoxy-type compounds which are very popular in Japan, could not be used in Taiwan because these herbicides are very sensitive to temperature. Simetryn alone or combined with other herbicides such as benthiocarb, MCPB, molinate, phenothiol, bentazone, bensulide, ACN or methoxyphenone are officially registered in Japan for control of weeds in paddy fields. But serious injuries to rice were found even after the rate of simetryn was reduced to minimum amounts when these combined herbicides were tested in Taiwan. Other examples are the phenoxy-type herbicides such as 2,4-D, MCPA, MCPB and their salts or esters which were extensively used in Japan. Because of the unusual low temperature in early spring in southern part of Taiwan, occasional cases of injury to rice like onion-leaf phenomenon were observed in the first crops at the temperature of below 15°C when these herbicides alone or mixed herbicides containing these phenoxy-type compounds were used. Another case is benthiocarb. Dwarfing of rice plants in the paddy field by the application of benthiocarb, especially under the reductive soil conditions with a larger amount of organic substances such as raw straws, was widely reported everywhere in Japan since 1976. *S*-Benzyl *N*, *N*-diethylthiocarbamate, the dechlorination product of benthiocarb, found to be associated with the phytotoxic action and believed to be the cause of the dwarfing of rice plants, was identified from the soil of paddy field by Ishikawa *et al.* (1980).Neither the dechlorination of benthiocarb nor the degradation of dechlorinated benthiocarb occurred in the sterilized soil, indicating that soil microbes were involved in this dechlorination reaction (Tatsuyama *et al.*, 1981). Properties and conditions of soils causing the dechlorination of benthiocarb in flooded soils were carefully examined in the laboratory by Moon and Kuwatsuka (1984, 1985). But dwarfing of rice plants in

Table 2. Herbicides registered for use in paddy fields in Japan but not in Taiwan.

Common name	Chemical name	Year registered
2,4-D (Sodium salt) (2,4-PA)	Sodium (2,4-dichlorophenoxy) acetate	1950
2,4-D (Ethyl ester)	Ethyl (2,4-dichlorophenoxy) acetate	1957
PCP (Sodium salt)	Sodium pentachlorophenolate	1957
MCP (Ethyl ester)	Ethyl 2-methyl-4-chlorophenoxyacetate	1957
MCPB (Ethyl ester)	Ethyl 4(4-chloro-2-methylphenoxy) butylate	1959
Allyl MCP	Allyl 2-methyl-4-chlorophenoxyacetate	1961
Prometryn	2,4-Bis (isopropylamino)-6-(methylthio)-*s*-triazine	1963
Chlorthiamid (DCBN)	2,6-Dichlorothiobenzamide	1964
Swep (MCC)	Methyl-*N*-(3,4-dichlorophenyl) carbamate	1966
2,4-D (Amine salt)	Dimethylamine salt of (2,4-dichlorophenoxy) acetic acid	1967
ACN	3-Chloro-2-amino-1,4-naphthoquinone	1968
Simetryn	2,4-Bis-(ethylamino)-6-methylthio-*s*-triazine	1969
Phenothiol*	*S*-Ethyl-4-chloro-2-methylphenoxythioacetate	1971
Pyrazolate	4-(2,4-Dichlorobenzoyl) 1, 3-dimethyl-5-pyrazolyl-*p*-toluene-sulphonate	1980

*Used as a component of mixed herbicide only.

the paddy fields, by the application of benthiocarb, was never reported in Taiwan so far probably due to the different cultivating systems and difference in the climatic condition and soil properties.

Several review papers concerning the herbicides and the environment were published. Environmental problems related to herbicidal use in Japan were reviewed by Matsunaka and Kuwatsuka (1975). The fate and behavior of herbicides in the soil environment, with special emphasis on the fate of principal paddy herbicides in flooded soils in Japan were reviewed by Kuwatsuka and Niki (1976). Kuwatsuka (1983) also reviewed the fate of herbicides in flooded paddy soils. The effects of temperature, photodecomposition, microbial degradation, and soil properties on the herbicides used in paddy fields and effects of some herbicides on fish, mussel, seaweed, and *Chlorella* were reviewed by Chen (1983). Chen (1983) also reviewed the behavior and fate of pesticides in paddy ecosystems in which 17 herbicides used in paddy fields were included. Recently, residue problems of herbicides in paddy fields and aquatic environments were reviewed by Yamada (1985).

FACTORS AFFECTING DEGRADATION OF HERBICIDES

Many factors may affect the behavior and fate of herbicides after their application in the environment. Undoubtedly almost all of herbicides are applied to the soils. Even with a foliage spray, a great majority of the herbicides will fall to the soils eventually. Thus, interactions between herbicides and soils are indispensable. All herbicides decompose and metabolize in soils to a varying degree. The extent and nature of the degradation vary with environmental conditions and chemicals. Certain herbicides are metabolized or degraded completely in a matter of hours, but on the contrary, other chemicals require weeks or months. Moreover, some complex herbicides are readily metabolized by soil microbes, while some relatively simple ones are amazingly resistant to biodegradation. Of course, a great majority of degradation results from biotransformation by different enzymatic actions by soil microbes, but a minor degradation may also take place by normal chemical reactions.

Minor change of the chemical structure may change the nature and effect in the environment. For example, butachlor differs from alachlor only by butyl group instead of methyl group. Butachlor is one of the most popular herbicides used in paddy fields, but alachlor is only used in the upland crops. Sodium salt of 2,4-D and esters of 2,4-D are quite different in their volatility. Thus, the effects of these compounds to the environment will be different too. The amount of herbicide residues that can accumulate in soils depends on factors such as the nature of the chemical, soil type and texture, moisture, soil microbes, cation exchange capacity, content and nature of organic matter and clay minerals, pH of the soil and so on. Photodecomposition is also an important phenomenon related to residue dissipation.

Some factors related to the degradation and dissipation of herbicides after application include temperature, photodecomposition, microbial degradation, and soil properties.

Temperature

Some herbicides such as simetryn and the phenoxy-type herbicides are very sensitive to temperature as they were already mentioned before.

In laboratory tests by Chen and Chen (1979), the volatilization of butachlor from aqueous solution and its adsorption in soils were significantly influenced by temperature. The loss of butachlor by volatilization from 0.05 *M* $CaCl_2$ solution was demonstrated to be 4.5% at 21.5°*C* (room temperature), and 30% at 40° *C*. Raising the temperature from 20 to 40°*C* resulted in decreased adsorption by soils.

In field experiments, some differences were observed between the first crop (March) and the second crop (August). Degradation and dissipation of butachlor were more rapid in the second crop (Table 3) (Chen and Chen, 1979).

Although simazine [2-chloro-4, 6-bis (ethylamino)-*s*-triazine] is not used in paddy fields, in the collaborative experiment on simazine persistence in soils initiated by the European Weed Research Society (EWRS) (Walker *et al.* 1983) the effects of soil temperature and soil moisture content on the rate of simazine degradation were measured in the laboratory in soils from 21 sites located in 11 countries. First-order half-lives under standard incubation conditions were significantly correlated with clay content, organic carbon content and soil pH in a multiple linear regression. The temperature dependence of degradation was similar in the different soils whereas the moisture dependence showed considerable variation between soils.

The field experiments performed in Taiwan by Chen *et al.* (1983) with

Table 3. Residue of butachlor in paddy field(*ppm*).

Date	Time (day)	Water	Soil			Rice plant	
			0-3 *cm*	3-6 *cm*	0-6 *cm*	Shoot	Root
1st Crop							
Mar. 3	-1	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Mar. 4	0	0.29	4.00	0.51	0.76	2.03	1.62
Mar. 5	1	0.30	2.76	0.24	1.07	2.54	2.88
Mar. 6	2	0.25	1.72	0.06	0.33	3.43	2.86
Mar. 8	4	0.19	1.17	0.06	0.38	2.98	2.37
Mar. 12	8	0.11	2.23	0.48	2.43	0.44	5.98
Mar. 20	16	0.04	0.53	0.06	1.09	0.74	0.93
Apr. 5	32	0.01	1.25	0.001	0.50	< 0.001	< 0.001
2nd Crop							
Aug. 2	-1	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Aug. 3	0	2.16	9.17	0.58	4.59	31.20	< 0.001
Aug. 4	1	0.46	2.00	0.15	3.44	12.74	0.81
Aug. 5	2	0.24	0.87	0.10	2.38	30.46	0.46
Aug. 7	4	0.09	0.44	0.06	0.23	< 0.001	< 0.001
Aug. 11	8	0.02	0.23	0.12	0.45	< 0.001	< 0.001
Aug. 19	16	0.02	0.17	0.05	0.07	< 0.001	< 0.001
Sept. 4	32	0.02	0.03	0.06	0.07	< 0.001	< 0.001

Taichung clay loam in different seasons and Taipei loam soils showed a significant difference between climate and degradation rate. Simazine had a half-life of 18 days in the summer which is relatively hot and wet, a half-life of 24 days in the cooler and dryer winter season of the Taichung area, but in the medium temperature and medium precipitation of the autumn season of the Taipei area, the half-life was found to be 14 days (Table 4).

These results indicate that climate was not the only factor affecting degradation of simazine, but soil properties may also be related to the degradation rate. Laboratory studies of degradation rates performed with 3 different temperatures at soil moisture content of 90% field capacity and 4 different soil moisture contents at 20°*C* on different types of soil texture showed a significant relationship between the temperature and the residues of simazine in soils, and also a positive tendency was observed between soil moisture content and degradation (Table 5) (Walker *et al.*, 1983)

Photodecomposition

Photodecomposition is an important route of degradation and dissipation of herbicides from crops and soils. Such studies are useful in establishing residue tolerance and residue levels considered to be negligible. These studies are also important in establishing non-effect levels and waiting periods for crops. Butachlor was photodecomposed rapidly under UV light as a thin film on glass. The half-life was found to be about 1.5 *hr.* At least 7 photodecomposition products were observed (Chen and Chen, 1978). Photodecomposition of butachlor in aqueous solution was very fast and more complicated than that as a thin film on a glass surface. The half-lives were demonstrated to be about 0.8 *hr.* under UV light and 5.4 *hr.* under sunlight irradiation, respectively. As many as 24 compounds were detected and the partial pathways involved in the photodecomposition in aqueous solution was proposed (Chen *et al.*, 1982).

Among the herbicides used in paddy fields, photodecomposition of many compounds were already investigated. These herbicides include PCP (Kawahara *et al.*, 1965, 1966, 1969), benthiocarb (Chen *et al.*, 1976, Ishikawa *et al.*, 1977, Ishikawa *et al.*, 1980), bifenox (Ohyama and Kuwatsuka, 1976), molinate (Soderquist *et al.*, 1977), credazine (Nakagawa and Tamari, 1974), propanil (Moilanen and Crosby, 1972), methoxyphenone (Fujii *et al.*, 1979), bentazone (Nilles and Zabik, 1975)

Table 4. Soil properties and standard half-lives at different location of sites.

Location of site	Organic carbon (%)	Soil properties: Clay (%)	Sand (%)	Silt (%)	pH	Field capacity (%, w/w)	Standard half-life (days)
Regina, Saskatchewan, Canada	4.00	69	5	26	7.7	40.0	101
Uppsala, Sweden	3.60	42	28	30	6.5	28.7	88
Alberta, Canada	1.26	32	41	27	7.8	24.9	88
Harrow, Ontario, Canada (I)	0.52	5	88	7	5.2	14.0	63
Harrow, Ontario, Canada (II)	1.50	8	78	14	5.6	23.0	63
Braunschweig, West Germany	0.99	12	49	39	6.5	23.9	54
Wageningen, Holland	2.38	3	89	8	5.6	18.3	51
Warwick, England	1.30	20	75	5	6.6	17.0	46
Firenze, Italy	0.98	14	59	27	6.7	23.0	39
Summerland, British Columbia, Canada	0.71	5	79	16	7.5	10.0	38
Harpenden, England	1.75	35	31	34	7.5	28.2	37
Oxford, England	2.10	15	66	19	5.8	18.0	31
Taichung, Taiwan, ROC (Winter)	0.83	31	42	27	5.2	30.3	24
Maarn, Holland	1.40	3	93	4	5.6	8.0	21
Taichung, Taiwan, ROC (Summer)	0.83	31	42	27	5.2	30.3	18
Taipei, Taiwan, ROC (Autumn)	1.04	21	32	47	4.3	27.5	14
Los Banos, Laguna, Philippines	1.74	31	18	51	5.6	26.0	-

Table 5. First-order half-lives(days) in the laboratory studies.

Temperature (°C) Moisture (% FC)	20 20	20 40	20 60	20 90	10 90	30 90
Warwick	137	92	75	50	120	29
Saskatchewan	–	230	156	114	274	78
Firenze	53	48	45	39	147	31
Uppsala	157	125	88	102	230	76
Braunschweig	82	73	58	58	214	42
Alberta	237	160	140	125	283	59**
Oxford	229	113	62	34	55	26
Ontario I	77	69	59	62	134	30
Ontario II	71	60	68	71	123	33
Wageningen	67	62	57	50	74	27
Maarn	26	26	24	21	44	17
British Columbia	90	57	49	42	190	28
Harpenden	–	75	59	46	112	190*
Taipei	73	66	75	39	108	25
Taichung	64	67	53	55	153	31
Laguna	476***	28***	25***	24***	67**	11****

* 5°C; ** 25°C; *** 35°C; **** 45°C.

and bromobutide (Takahashi *et al.*, 1985).

Microbial Degradation

Soil microbes undoubtedly play a very important role in the degradation and dissipation of herbicides in soils. Microbial decomposition was proved to be the major avenue of dissipation of butachlor from soils (Beestman and Demming, 1974). Several soil microbes effectively degraded butachlor. Some of the metabolites by a soil microbe *Mucor sufui* NTU-358 were identified and the pathways involved in the degradation of butachlor were proposed (Chen and Wu, 1978). Degradation of butachlor by a soil fungus *Chaetomium globosum* was also studied. More than 10 metabolites were isolated and some of these were characterized (Lee, 1978). About 20 metabolites were detected from the degradation products of benthiocarb by soil microbes (Ishikawa *et al.*, 1976).

Microbial degradation can be rapid and complete. For example, 2,4-D is degraded completely to CO_2, H_2O and chlorine, and has an average half-life in paddy field of only several weeks. Half-lives of the herbicides used in paddy fields in Japan are shown in Table 6 (Kuwatsuka, 1983).

Degradation of some herbicides in soils used in paddy fields were also reported. These herbicides included PCP (Kuwatsuka and Igarashi, 1975), bifenox (Ohyama and Kuwatsuka, 1976, 1978, 1983), chlornitrofen (Niki and Kuwatsuka, 1976, Oyamada and Kuwatsuka, 1979, Yamada, 1983, Yamada and Suzuki, 1983), chlomethoxynil (Niki and Kuwatsuka, 1976), molinate (Imai and Kuwatsuka, 1982), naproanilide (Oyamada *et al.*, 1980), methoxyphenone (Izawa and Asaka, 1979, Izawa *et al.*, 1981, Kurozumi *et al.*, 1980), simetryn (Izawa *et al.*, 1981) and MCPB-ethyl (Asaka and Izawa, 1982, Izawa *et al.*, 1981).

Populations of fungi, actinomycetes and bacteria increased 1 week after the addition of butachlor to the soil. Higher doses of butachlor kept the population of soil microbes higher than that in the control up to 4 weeks after incubation (Chen *et al.*, 1981). The effect of PCP on bacterial flora in reductive layers of water-logged soil was studied. PCP was applied to the surface water of water-logged soil at the recommended rate and at 100 times the recommended rate. Changes in total numbers of aerobic bacteria were not clear. However, the effects on the changes in numbers of PCP-tolerant bacteria and gram-negative bacteria were clear (Kato *et al.*, 1981).

Table 6. Half-lives(days) of paddy herbicides in flooded soils*.

Herbicide	In laboratory experiments**	In paddy fields***
2,4-D	30-40	35,48
2,4-D ethyl	< 1 hr	
MCPA	3, 4, 7, 7, 15, 20	7, 7
MCPA ethyl	7-14	
Phenothiol	< 1	< 5
PCP	5, 10-17, 12-70 (average 30), 60	3-4, 6-7, 10-17
Benthiocarb	7-100 (average 40)	3-8, 7, 8, 14, 62
Molinate	7, 15, 18, 30	< 1, < 5, < 5, < 5, < 9, 11
Swep	2-9, 10-11, 7-14	< 10
Propanil	< 1-1, 1, < 5	< 1-1
Naproanilide	5, 6	2, < 4, 4
Butachlor	9-30	6, 8
Credazin	90-150	22, 45
Trifluralin	9, 10, 22, 45	10, 45
Chlornitrofen	7-35 (average 15), 17, 35	7, 9, 12, 13, ca. 14
Chlomethoxynil	7-35 (average 15), 30	7-8
Bifenox	4, 4	4, 4
Oxadiazon	75, 93-98	
Bentazone	5, 33, 45	15, 15
Simetryn	< 37, 63	
Prometryn	100, 120	

* Data were collected from various sources.

** Each chemical was mixed with soil and incubated at 25-30°C in dark.

*** Persistence in soils in paddy fields in Japan. Most herbicides were applied in May or June.

STUDIES WITH RICE PADDY MODEL ECOSYSTEM

The rice paddy model ecosystem, replacing the original sorghum plant by rice seedling with other biota unchanges, was introduced by Lee *et al.*, (1976). The fate of three diphenyl ether-type herbicides, nitrofen, chlomethoxynil, and bifenox was studied by this system. Nitrofen was found to be relatively stable under the model ecosystem. It was bioconcentrated and stored over a 33-day period in the tissues of alga, snail, mosquito larva, and fish. When the carbomethoxy group of bifenox was used as a degradophore, tissue storage of the parent compound was minimal. The methoxy group of chlomethoxynil was not an effective degradophore. This system was further modified by substituting the organisms involved in food chains to fit an actual rice paddy field condition in Taiwan. The environmental fate of benthiocarb was studied with this system (Chen *et al.*, 1982). With their low ecological magnification values and high biodegradability indices, the use of benthiocarb in paddy field was found to be very safe. This rice paddy model ecosystem seemed to be very effective and useful for studying the environmental fate of pesticides especially those to be used in rice paddy fields.

CONCLUSION

It is not the intention of the authors to review all of the literatures on the behavior of herbicides in the environment. Emphases are made on the herbicides used in paddy fields because rice is mainly cultivated in Asian countries by the method of tranplanting in paddy fields. It fact, more than one half of the population in the world is consuming rice as their staple food. The consumption of herbicides is still increasing year by year. Although the herbicides currently used are relatively non-persistent, and with rather low mammalian toxicities in general, the effects of these chemicals, which has been produced only by man, on the environment should be carefully considered before their application. More attention should be paid on the environmental quality. It is our responsibility to prevent possible pollution from our environment which might be occurred by the misuse of these herbicides.

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DISCUSSION OF THE PAPERS OF J. HARADA AND Y.L. CHEN
(Chaired by B.L. Mercado)

Dr. M. Blacklow (Australia) : To Dr. J. Harada, a question of terminology. You showed a classification of allelopathy that operated at the level of higher plants and below. However, you discussed plant chemicals that were piscicidal and you also showed chemicals extracted from red clovers *(T. pratense)* that are precursors of oestrogens that cause reproduction problems in sheep. Do you suggest that we expand allelopathy to include effects on higher organisms, even drugs used by man?

Dr. J. Harada (Thailand): I can't answer. I think it maybe changed year by year as situations change. The effect on fishes and animals should be called allelopathy in future.

Mr. David T.K. Wang (Taiwan, ROC): Dr. Y.L. Chen, regarding the herbicides, a herbicide is used in granular type. This granular type is anything reflected or effected by the soil of flooded rice or its physical and/or chemical properties of the soil?

Dr. B.L. Mercado: Is your question the relation of soil properties and herbicide degradation?

Dr. Y.L. Chen (Taiwan, ROC) : Of course, the soil properties affect herbicide degradation in the environment. But I think herbicides may not affect so much the soil properties.

Dr. Somchai Khomvilai (Thailand): Dr. Chen, why do you use % F.C. instead of moisture content? Because the moisture content of F.C. will change with soil texture, *e.g.* the clay soil will have high moisture content at F.C. than the sandy soil.

Dr. Y.L. Chen: It is true. Because this collaborative work was designed by European Weed Research Society. We just follow their method. The detail of data will be shown in the proceeding of the Symposium.

Dr. M. Blacklow: Dr. J. Harada, you showed us an impressive range of chemical structures you extracted from a wide range of plants that were allelopathic in the rice seedling bioassay. However, to be of ecological significance those chemicals need to be released and persist in the environments. Do you consider all of the compounds you showed us are likely to be of ecological significance?

Dr. J. Harada : I don't have enough data at the laboratory level, but we can find such phenomena in the field. We can presume that some chemicals from roots, or dead plant materials , will appear in the soil, although I didn't examine this on all the substances. But we grew some plants in water culture mixed with active carbon. After some days, substances adsorbed by the active carbon were eluted and identified. We could find some inhibitory substances.

Dr. B.L. Mercado: Dr. Y.L. Chen, as for herbicides in rice, does either a granular type or any other type affect the properties of soils?

Dr. Y.L. Chen: I am sure that the soil property does not change so much by the use of different type of herbicides, but a granule type is popular. Different processing of granular preparation will give some different effects on the effectiveness because of being slowly or fastly released.

Dr. Lii-Sin Leu (Taiwan, ROC): Dr. Harada, I wonder if any chemicals secreted or produced by weeds are beneficial to the growth of crop plants.

Dr. M. Soerjani (Indonesia) : With regard to the question whether allelopathic substances are also released from the leaves, *Juglans nigra* releases hydroxyjuglone from the leaves and oxydised in the air to become juglane which has an inhibiting capacity to nearby plants. Recent work, *e.g.* of Eussen in Indonesia and others showed that *Imperata cylindrica* also releases allelopathic substances (the phenolic compounds) from the leaves, both from the intact leaves as well as from dead leaves. There are also allelopathic substances released to stimulate the growth of other plants. For instance, the release of strigol by host plants of *Striga lutea* which stimulate the germination of striga seeds.

Dr. J. Harada : I think, corn, sorghum or any other host plants produce strigol. It was originally identified in cotton plants, and stimulates the seed germination of *Striga*. It is very rare case.

GENERAL DISCUSSION

(Chaired by B.L. Mercado)

Dr. S. Matsunaka (Japan) : I will talk about air pollution, another viewpoint of the symposium titled "Weeds and the Environment in the Tropics". Air pollution is an important environmental problem even in the developing countries. I felt some smell of ozone, a component of photochemical oxidants in Bangkok. In a highly crowed city you may face the air pollution problem soon. In the case of such pollution, herbicide researchers can contribute to manage this problem. One point is to estimate the injury of these pollutants to the crop plants. Another is the utilization of indicator plants to estimate how the states of air pollutions are with a lot of higher plants including weeds themselves. In this case the idea of selectivity mechanism of herbicides is very important. So, air pollution is one kind of environmental problems to which we, weed scientists, can contribute. I have published already two books related to the indicator plants for air pollution in Japan.

Another is related to the sleeping sickness. It is called Japanese encephalitis caused by virus which is mediated by mosquito born in the paddy fields. By the statistics the usage of diphenylether herbicides such as nitrofen or chloronitrofen in the paddy fields and the number of patients of this sickness in Japan have a close negative correlation each other. These diphenylether herbicides can kill mosquito larvae at the practical dosage even though these are useful for the safety to fish. These mosquito larvae killers were applied just after transplanting. At this time overwintered adult mosquitoes came to oviposit in paddy fields. Then hatched young mosquito larvae were killed timely by the application of the diphenylether herbicides. One time almost all of paddy fields in Japan were treated with such herbicides. Therefore, this is a possibility that these applications were so effective to decrease the patient number of Japanese encephalitis. This sickness is also very important in tropical countries. Also for the malaria control, this idea will be utilized.

Unfortunately nitrofen was over and chlornitrofen is not familiar. New diphenylether herbicides having a substituent next to nitro group have little activity to kill the mosquito larvae. However this information may be paid attention.

Dr. M. Soerjani (Indonesia) : A comment on Dr. Matsunaka's comment. There are some important species of plants that are used as biological indicators of air pollution, *e.g. Lichenes* and *Pinus* spp. to indicate pollution of SO_2. Are there more sensitive weed species to be used as bio-indicators for air pollution. In my opinion, it can be also very important to develop aquatic plants or terrestrial plants as bio-indicators for water or soil pollution.

Mr. Sener Buranapawang (Thailand) (via Dr. J.T. Swarbrick) :*Mimosa pigra* is a very important food source for honey bees in the Chiang Mai area in the wet season when few other major pollen sources are available. The Thai bee-keeper's industry curren has about 30,000 hives producting honey for home consumption and for export. The other *Mimosa* species are probably also important honey sources, as is *Eupatorium odoratum*.

Dr. M. Blacklow (Australia) : The potential loss to beekeepers in northern Thailand if *Mimosa* spp. is controlled, is analogous to the concern by Australian beekeepers should *Echium* spp. be controlled by biological control agents.

There has been a long and, at times, emotional conflict between those who value *Echium* spp., the beekeepers and some pasturelists, and those who want biological control, producers of cereal crops and of livestock on improved pastures.

We now know it is necessary to identify and resolve any potential conflicts before costly research programs into biological control are undertaken. Therefore, we needed to established statutory law, through special legislation, so that biological control can proceed if it is seen to be in the national interest.

The Australian experience with *Echium* spp. is described in the recent issue of the Australian journal, Plant Protection Quarterly.

Dr. B.L. Mercado : It is very difficult to identify the final weeds. There is a lot of conflicts. We should have a workshop on this in the next conference.

CLOSING REMARKS

The topic, "Weeds and environment in the tropics", presents a very broad horizon to weed scientists in the Asian–Pacific region. The severity of weed population is determined largely by the biotic and abiotic environmental forces and the tropics provide an uninterrupted interaction between a weed and its environment. The papers presented created the impression that there are countless ways we can deal with weeds. We can utilize their potentials as useful plants; we can approach their control in more ways than one.

Utilization of weeds has been documented even in very early years. Hence, we have reports of particular weed species being utilized by certain groups of people for medicinal purposes. The use of water hyacinth for pulp and paper manufacture is well supported by the greeting card my family gets from Dr. Soerjani of Indonesia every special occasion. It represents ingenuity and resourcefulness put to good practice.

Allelopathy has been looked at many times in reference to plant interaction. Dr. Harada presented piscicidal activities from some aquatic weeds, an undesirable property that can be harnessed towards a desirable use. Now that the groundwork has been provided by the weed scientists, other biologists can pick it up for further application.

Weeds as alternate hosts of other pests has oftentimes been considered a minor undesirable effect of weeds. Dr. Bendixen, however, who has been working on the weed hosts of nematodes for some years already indicated that the "unseen" effect of weeds on nematode population particularly that of *Meloidogyne,* can contribute a considerable reduction in yield apart from direct competition for environmental resources.

Farming practices have influenced the quality and quantity of weed population. In many parts of Asia, shifting cultivation is a customary practice in forested and hilly areas. Dr. Smitinand stressed the severity of perennial weed problems in this kind of agriculture where weeds are too difficult to control with the conventional methods. The practice itself presents a two-pronged problem that has been the subject of discussion during the 1983 conference in Manila. Shifting cultivation is an undesirable practice itself, bringing about socio-economic and agronomic problems.

The agriculture of rice, the staple food of Asians, has undergone considerable changes since the introduction of the modern high yielding cultivars. Rice has become the guinea pig in technological changes in weed control. The shift from transplanted to broadcast-seeding in flooded rice promises an overall higher yield and less labor cost. As Dr. De Datta has put it, success is largely dependent on the efficacy and selectivity of the herbicide applied.

Interest on the increasing seriousness of introduced species like *Mimosa pigra* in Thailand generated information on its biology that revealed very interesting behavioral characteristics of the weed. Such information will help both in chemical and ecological approaches of control.

Aquatic weeds such as water hyacinth has been the subject of biological control studies for quite some time but the appropriate agent has been very elusive. Dr. Soerjani presented a novel approach to controlling aquatic weeds without depending largely on biological control and considering the total ecosystem.

We have looked at the soil often times as a "dumping ground" but the soil allows chemical and biological reactions that determine the behavior and fate of herbicides. Mother earth nurtures our food, clothing and shelter materials and Dr. Chen stressed the importance of soil-herbicide interaction particularly in rice agriculture.

The papers presented problems and possible solutions in some cases. In anyway we look at the weeds and the environment, there is always that mystery that needs to be unravelled for a better and economical control of weeds.

Beatriz L. Mercado

Beatriz L. MERCADO
Chairman/Editor

PROGRAMME OF SYMPOSIUM: WEEDS AND THE ENVIRONMENT IN THE TROPICS

in the 10th Conference of Asian-Pacific Weed Science Society

Date : November 29, 1985
Location : The Royal Orchid Ballroom, Chiang Mai Orchid Hotel, Chaing Mai, Thailand

Chairman : K. Noda (Thailand)

8:30– 9:00 a.m.	Biology and control of *Mimosa pigra* L. - H. Shibayama (Japan) and P. Kittipong (Thailand)
9:00– 9:30 a.m.	Environmental consideration in the novel approaches of aquatic vegetation management - M. Soerjani (Indonesia)
9:30–10:00 a.m.	Technology and economics of weed control in broadcast-seeded flooded tropical rice - S.K. De Datta and J.C. Flinn (The Philippines)
10:00–10:15 a.m.	Discussion
10:15–10:45 a.m.	Coffee Break

Chairman : K.U. Kim (Korea)

10:45–11:15 a.m.	Weed hosts of *Meloidogyne,* the root-knot nematodes - L.E. Bendixen (U.S.A.)
11:15–11:45 a.m.	Weeds in shifting cultivation in Thailand - T. Smitinand (Thailand)
11:45–12:00 a.m.	Discussion
12:00– 1:30 p.m.	Lunch

Chairman : B.L. Mercado (The Philippines)

1:30– 2:00 p.m.	Allelopathy and fish - toxicity of weeds - J. Harada (Thailand)
2:00– 2:30 p.m.	Herbicides in the environment - Y.L. Chen (Taiwan, R.O.C.) and H. Nakayama (Japan)
2:30– 2:45 p.m.	Discussion
2:45– 3:30 p.m.	General discussion
3:30 p.m.	Closed

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