Implementation of Integrated Weed Management for Sustainable Rice Production

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Abstract

A single method of weed control is not sufficient for sustainable rice production and integration of weed management methods is necessary. Land preparation is the primary method for destroying weeds and inhibiting germination of weed seeds, by land levelling in transplanted rice and pregerminated direct-seeded rice and by repetition of tillage prior to seeding of rice. After the crop is established, the use of rice varieties with long and droopy leaves such as IR 2006-P-3-33-2, Kim Rad F 87, Dular and Hashkalmi will lead to a higher competition for light and reduction of the biomass of the weeds. For transplanted rice, water should be used as a tool to control weeds by maintaining the water level at 5-10 cm one month after transplanting. With pre-germinated direct-seeded rice, water should be drained one week after seeding. Weed control by manual weeding or small machines at 20-30 days after planting is usually necessary. Control of weeds by judicious use of herbicides 2, 4-D butachlor, thiobencarb, pretilachlor, oxadiazon, and fenoxaprop-p-ethyl and the possibility of substitution by other bio-agents such as duck agisting and azolla coverage of weeds are discussed.

Key words: integrated weed management, sustainable rice production, lowland rice, upland rice, deepwater rice

Introduction

A single method of weed control is ususally not successful. Weed management is a combination of practices that lead to sustainable rice production. Weed management is a long-term process aiming of optimizing farm productivity, by maintaining weed levels below levels which compete significantly with the crop. It must maintain a balance between economic, social and environmental considerations (Kon, 1992). Weed management is a combination of several strategies, including selection of rice cultivars, planting methods, land preparation, appropriate irrigation, time of planting, crop rotation, harvesting methods, biological control agents, allelopathic substances, preventive weed control methods and jucidious chemical weed control (Smith Jr., 1993). Sustainable rice production should depend on decreased use of chemicals and other fossil-based inputs, while at the same time securing increase of yield reducing production costs, improving farm profit, reducing risk, and sustaining the productivity of the soil and water resources (Harwood, 1990). In the consideration of each method of weed control for incorporation into weed management, differences in rice cultivation methods are important to achieve sustainable rice production.

Land preparation

Land preparation is an extremely important weed control practice. It can provide weed-free conditions at planting and favourable conditions for the growth and development of the crop. In the past, plowing using draft animals, was carried out when the soil was wet and the majority of weeds had germinated. Weed seedlings were killed because plowing uprooted them and covered them with soil. Now that tractors are being used, plowing can be carried out under dry conditions. As newly shed weed seeds lying on

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the soil surface are buried deep in soil, while buried seeds from the previous season are brought up to the surface to germinate, severe weed infestation occurs especially in upland rice and dry-seeded rice. Soil should be harrowed after the first plowing when weeds have reached the seeding stage to kill the majority of *Echinochloa colona* (L.) Link seeds, since they germinate at 0-1.5 cm soil depth (Vongsaroj and Notaya, 1991). Yingviwatanapong (1986) reported that plowing a deepwater rice field with a three-disc plow to a depth of 3.0-12.5 cm reduced the occurrence of *Eleocharis* as they were brought to the soil surface and killed by drying. Control methods must lower the viability of weed seeds, or alternatively stimulate germination, so that control can easily be achieved (Vongsaroj, 1976). In the case of heavy infestation of wild rice, burning of rice straw after harvest gave good control (Vongsaroj, 1976). Puckridge *et al.* (1988) found that broadcasting of pregerminated rice seeds onto puddled soil reduced the wild rice population because the germination of wild rice seeds was inhibited in saturated soil. For wet-seeded rice, a single plowing followed by puddling and leveling of the soil surface minimized the occurrence of weeds because the water level over the whole field could be controlled at a specific depth to prevent weed germination.

Rice crops

Rice seeds should be free of weed seeds. In the Philippines, Rao and Moody (1990) found that most of the rice seeds were contaminated with weed seeds. Rice seeds should be made free of weed seeds by winnowing, floating the rice seeds, and cleaning the equipment used for land preparation and threshing before its use. Cultivars of rice that will have advantage in competition with weeds should be tall and show an extensive leaf display with many long, wide horizontally disposed leaves to shade weeds, exhibit early rapid root growth, and be free-tillering (Moody, 1979). Vongsaroj *et al.* (1977 b) compared 10 rice varieties in transplanted rice and found that tall rice cultivars namely Khaodokmali, Puangnak 16, Nanfmol 34, Leung Pratew 123 and Kaokaew were associated with fewer weeds than short cultivars. Biswas *et al.* (1992) found that in upland rice plots with Hashikalmi weed weight was lower than in the case of other cultivars (Table 2). Hassan *et al.* (1994) reported that the use of the rice cultivars Arabi, Sakha, UPK 82-1-7, Bala, IET 144 and Dular reduced barnyardgrass fresh weight by 92 to 96% while that of Giza 176 reduced weeds only by 5% (Table 2) because these cultivars released allelopathic substances inhibiting weed growth. Many rice cultivars (Table 3) controlled signalgrass, ducksalad and purple ammania (60-90%) while Rexmont and Palmyra did not provide any control (Dillday *et al.*, 1990). and minimized the occurrence of *Cyperus difformis* L. (Table 4) (Hassan *et al.*, 1994).

In upland rice fields, weeds and rice seeds germinate at the same time. Most of upland rice cultivation is practiced in deforested areas where there are no weeds during the first year, but during the second and third years heavy weed infestation occurs. There are no barriers to the spread of weeds from adjacent clear areas and intense sunlight on the exposed soil induces the germination of weed seeds. The upland farmer solves weed problems by moving on to a new site every few years.

Table 1 Effect of upland rice cultivars on weed weight and percentage of light interception and grain yield (Biswas, Sattar and Bashar, 1992)

Entry	Number of rice plants	Weed weight	Radiation interception (%)	Grain yield (kg/ha)
BR 4290-3-35	176	215b	27.10	374b
BR 4290-3-1-10	181	203b	31.19	442ab
IR 255-88-7-3-1	193	200b	28.01	259b
BR 20	130	225b	29.64	357b
BR 21	167	201b	34.18	407ab
Hashikalmi	296	132a	36.37	647a

Table 2 Allelopathic activity of different rice genotypes on growth of barnyardgrass in the greenhouse (Hassan *et al*., 1994)

Rice genotype	Barnyardgrass (BYG) (plant height) cm	Barnyardgrass fresh wt. (g/pot)	% Reduction in BYG fresh wt.
Barnyardgrass	36.3	34.65	0
Giza 176	34.7	33.01	5
Arabi	23.8	2.65	92
Sakha-2	15.3	2.60	92
Ratna	19.5	1.34	96
UPR 82-1-7	15.5	1.48	96
Bala	8.3	1.50	96
IET 1444	6.5	1.49	96
Dular	8.1	1.50	96

Table 3 Rice germination accessions with potential allelopathic activity to broadleaved signalgrass, ducksalad, and purple ammania, 1988-1991. (Dilday *et al*., 1990)

Weed species	Germination designation	Country of origin	Radius (cm) of activity	Weed control (%)
Broadleaved	Daudzai	Pakistan	25.0	90
Signal grass	IR 329 19522	Philippines	25.0	90
		Indonesia	25.0	80
		Japan	12.5	60
Ducksalad	AC 1423	India	17.8	85
	Tono Brea 439	Dominican Republic	16.5	85
	Tsai Yuan Chon	Taiwan	15.2	90
	Donduni	Afghanistan	1.52	85
Purple ammania	IR 104456	Philippines	17.5	77
	Cuba 65 V 58	United States	17.5	72
	Cuba 6558 A	United States	17.5	70
	IR 75 693	Philippines	14.0	80
	IR 52 1673	Philippines	14.0	80

Check cultivars (Rexmont and Palmyra) did not exhibit any allelopathic activity

Table 4 Allelopathic activity of different rice genotypes on growth of *Cyperus difformis* in the greenhouse (Hassan *et al*., 1994)

Rice genotype	*Cyperus difformis*	
	Fresh wt. (g/pot)	% Reduction
Cyperus difformis-Check	1.288a	—
Giza 172-check	4.424a	8
Giza 175-check	4.654a	5
IR 2006-P 3-33-2	0.132b	94
Kim Rad F 87	0.432b	91
Dular	0.232b	95

Method of planting

There are several types of rice cultivation, upland rice, dry-seeded rice, deepwater rice, transplanted rice and wet-seeded rice. The level of weed infestation varies with the methods of planting. Upland rice shows the worst weed infestation and transplanted rice the least. Dry-seeded rice and wet-seeded rice display intermediate levels of weed infestation (Kittipong, 1983).

Water control

Water is widely recognized as an effective means of suppressing weeds. Flooding of transplanted rice for 30 days suppresses weed growth (Publico and Moody, 1993). Dry-seeded rice is sown under dry conditions, but when the field is flooded, weeds at some growth stages are killed. Nakkaew *et al*. (1991) found that all the *Echinochloa colona* plants were killed when the field was submerged for two weeks at a depth greater than 30 cm at 10 or 20 days after emergence and farmers have a good stand of rice because before they flood the field, most weeds are suppressed. In wet-seeded rice, farmers drain water 10 days after seeding. The population of *Echinochloa crus-galli* (L.) Beauv, *Cyperus difformis* (L.) will then be reduced under dry conditions, but be replaced by *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees and *Ischaemum rugosum* Salisb. which are then partly killed when the field is flooded again. *Leptochloa chinensis* (L.) Nees was completely controlled by flooding 15-20 days after sowing (Drost and Moody, 1981) (Table 5). In irrigated areas, farmers grow wet-seeded rice as an upland crop to induce upland weeds to germinate. The land is gradually flooded from 5-10 days after crop emergence until the flowering stage to a depth of 15-20 cm. This practice controls some weeds (Vongsaroj *et al*., 1977 a).

Transplanted rice

Transplanting was introduced to minimize weed problems. Flooding at 5-10 cm depth after transplanting prevents the germination of some weeds. Even if some weed species germinate under submerged conditions, the height of the rice seedlings is 20-30 cm as the weeds just start to germinate. Rice has an advantage in competition with the weeds.

Direct-seeded rice

Direct seeding consists of either dry-seeded rice or wet-seeded rice using pregerminated seeds. Although transplanting reduces weeds, it involves a high production cost in terms of nursery bed for the seedlings, and the labour cost of gathering seedlings and hand transplanting. Wet-seeded rice was developed in order to reduce costs (Kanchanomai, 1981). Both wet and dry direct-seeded rice are associated with weed problems, because rice and weeds germinate at the same time. After direct seeding has been used for a few years, it is recommended that farmers change temporarily to transplanting, which was particularly effective in controlling *Echinochloa crus-galli* (L.) Beauv. and *Leptochloa chinensis* (L.) Nees in the central plain of Thailand (Vongsaroj, 1987).

Table 5 Weed density and biomass of *Leptochloa chinensis* growing in association with wet-seeded rice as effected by time of flooding (Drost and Moody, 1981)

Time of flooding (DS)	Weed density no/m^2	Weed wt. (g/m^2)
5	0a	0a
10	2a	0a
15	42b	25.0b
20	72b	25.0b

Plant density

Seeding rate plays an important role in weed control. Farmers normally sow seeds in dense stands to help the rice compete with weeds. In dry-seeded rice, a seed rate of 125-162.50 kg/ha was very effective in suppressing weeds. For wet-seeded rice, a rate of 100 kg/ha was suitable for competition with weeds (Kanchanomai, 1981). In transplanted rice, spacing of hills at 25×25 cm with 1, 3, 6, 9 and 15 plants/hill gave a dry weight of *Marsilea crenata* Presl. of 197.60, 188.40, 108.00, 111.20, 120.80, or 114.80 g/m^2, respectively (Supatakul and Khomvilai, 1986). Transplanting at a spacing of 8×8 cm with one plant/hill minimized infestation with *Chara zeylanica* Willd in Northeast Thailand (Vongsaroj *et al*., 1977 a).

Weed control

Manual weeding which is the primary direct weed control method should be performed at the early stages of rice growth. However it is labour-intensive, and labour costs are rising with the alternative demands for labour both on and off farm. It is recommended that hand weeding of transplanted rice be carried out for the first time 20-30 days after transplanting. It should be carried out 20-30 days after seeding in the case of upland rice, dry-seeded rice and deepwater rice (Anon., 1988). Manual weeding can be replaced by a rotary weeder or a small machine, if available. Most farmers do hand weeding whenever they are free from other work. If weeding is delayed until the initiation of rice panicle primordia, the rice yield will be markedly reduced.

Judicious use of herbicides

1. Herbicides

They can eradicate recalcitrant weeds in a rotation, promote more efficient use of land, reduce the need for cultivation, can be used as harvesting aid, can maintain a small weed seed number in soil and increase the efficiency of external production factors (Zoschke, 1994). All these processes increase rice yield and quality due to the reduction of competition. Herbicides also ease working conditions by minimizing hand labor, increase human efficiency, promote pride in clean field, give more leisure time, better education, and reduce costs, provide time for alternate weeding operations and maximize income and net profit (Zoschke, 1994). Herbicides have been introduced to control weeds and minimize the possible hazards to non-target organisms of all sorts from micro-organisms to mammals (Hance, 1990). Herbicides should only be used when really needed and must be applied at the right rate and right time. Butachlor, (Machete EC 60% a.i.), propanil (Stam F EC 35% a.i.) oxadiazon, (Ronstar EC 25%) and thiobencarb + propanil (Saturnil EC 60% a.i.) at 0.8, 1 0.0-0.5, 3.0, 0.75 and 2.4-1.2 kg a.i./ha for weed control and higher yield respectively were found to be most effective (IRRI, 1981).

2. Possibility of substitution

Herbicides that are widely used in paddy fields, may be acutely or chronically toxic to other organisms, man included (Hance, 1990). Substitution by other methods or materials is often desirable. For example plant allelopathic substances such as extracts of *Eupatorium adenophorum* Spreng. inhibited germination of 9 weed species e.g., *Amaranthus spinosus* L., *Amaranthus viridis* L., *Bidens pilosa* L. and *Borreria alata* DC. by 90-100% (Zungsontiporn and Premassthira, 1994). Other bioagents for weed control were reported, *Azolla* suppressed 69-100% of weeds in transplanted rice (Janiya and Moody, 1984) and controlled *Monochoria vaginalis* in transplanted rice in Thailand (Table 6) (Vongsaroj *et al*., 1944). When combined with fish, rice-*Azolla*-fish system minimized weed density and weed weight (Table 7) (Liu Chung -chu, 1987). For fish, Tubb (1961) reported that during early rice growth, a field containing milk fish (*Chanos chanos*) required less weeding than a field without fish. The water level should be 20-30 cm. Ducks were also found to minimize weed number and weed weight (Table 8) (Komson *et al*., 1995 ; Manda, 1992) and reduced the occurrence of red rice grain in U.S.A. (Smith, Jr. and Sullivan, 1980). Utilization of weeds is another means of weed control and many weed species can be used as vegetables (Table 9) (Prachasaisoradcj, 1989 ; Jackquat and Bertussa, 1990) while *Marsilea crenata* showed a high nutritional value

Table 6 ***Azolla* and *Lemna* for control of some weeds in dry season (Vongsaroj, 1994)**

Treatment	Dry weight of weeds			Yield of rice t/ha
	1	2	3	
Azolla 62.5kg/ha	3.72 b	1.2 b	2.7 ab	3.3 bc
Azolla 125.0kg/ha	3.27 b	0.4 a	2.3 ab	3.9 a
Azolla 197.5kg/ha	2.11 b	0.3 a	3.0 ab	3.9 a
Azolla 250kg/ha	2.35 b	0.2 a	0.9 a	4.1 a
Lemna 62.5kg/ha	0.62 ab	1.1 ab	2.5 ab	3.9 a
Lemna 125.0kg/ha	0.37 a	0.1 ab	2.3 ab	3.7 b
Lemna 197.5kg/ha	1.25 ab	0.3 a	2.7 ab	3.7 b
Lemna 250kg/ha	0 a	0.5 a	1.5 a	3.7 b
Oxadiazon	0 a	0.3 a	0 a	3.9 a
Untreated check	8.08 c	1.5 b	7.5 c	3.1 c

1. 1 = ***Cyperus difformis***
   2 = ***Monochoria vaginalis***
   3 = ***Sphenoclea zeylanica***
2. Values in the same column followed by the same letter are not significantly different at 5% level by DMRT.

Table 7 **Effect of rice-*Azolla*-fish systems on weed growth (Liu Chung-chu, 1987)**

Treatment	Weed density no./m²	Weed weight g/m²
Rice	48.2	450
Rice-*Azolla*	9.3	63
Rice-*Azolla*-fish	1.8	11

Table 8 **Frequency of duck agisting in the field as compared to hand weeding and chemical control at 8 weeks after transplanting (Komoson *et al*., 1995)**

Treatment	Height of rice plant (cm)	Number of rice tillers/hill	Dry weight of weeds (g/0.5 m²)
Untreated check	84.1	25.9	19.8
Pretilachlor (Sofit EC 30%)	84.6	28.8	18.4
Hand weeding	83.5	30.1	10.3
Duck agisting 1 time	83.3	27.1	22.5
Duck agisting 2 times	83.4	28.7	17.4
Duck agisting 3 times	82.8	30.9	15.6
Duck agisting 4 times	84.6	29.6	14.4
Duck agisting 5 times	83.5	29.4	9.4

(Anon., 1992)

3. Carry-over effectiveness of herbicides

Oxadiazon and oxyfluorfen were used to control weeds in rice crop and after rice had been harvested, soybean was immediately planted in rice straw without any tillage. Weed control in rice crop had a residual effect on the soybean crop, reducing the incidence of broadleaved weeds (Vongsaroj and Price, 1987).

Table 9 Edible weeds from paddy fields (Prachasaisorade, 1989; Jackquat and Bertussa, 1990)

Weeds	Family	Edible parts of plant
Ceratopteris thalictroides Brown.	Parkeriaceae	Young fronds
Marsilea crenata Presl.	Marsileaceae	Tender shoots and leaves
Nelumbo nucifera Gaertn.	Nelumbonaceae	Young leaves
Nymphaea lotus Linn.	Nymphaeaceae	Stalk of flowers
Nymphaea nouchali Burm.	Nymphaeaceae	Stalks of leaves
Jussiaea repens Linn.	Onagraceae	Shoots and leaves
Crassocephalum crepidiodes S. Moore	Compositae	Tuber
Spilanthes acmella Murr.	Compositae	Leaves
Ipomoea aquatica Forsk	Convolvulaceae	Shoots young leaves, fruits
Sphenoclea zeylanica Gaertn.	Sphenocleaceae	Young plants
Limnocharis flava Buch.	Linnocharitaceae	Stalks of young leaves
Blyxa echinosperma Hook. F.	Hydrocharitaceae	Young leaves
Blyxa japonica Maxim. Es Aschers + Guerke	Hydrocharitaceae	Leaves
Ottelia alismoides Pers.	Hydrocharitaceae	Young leaves
Monochoria hastata Solms	Pontederiaceae	Young leaves
Monochoria vaginalis (Burm. f.)	Pontederiaceae	Young shoots and leaves
Mollugo pentaphylla Linn.	Aizoaceae	Young shoots, leaves and flowers
Plantago major Linn.	Plantaginaeae	Young shoots

Table 10 Gross margin of weed control treatment in dry seeded rice in Northeast Thailand (Vongsaroj, 1995)

Treatment	1990		1991	
	Yield of rice (t/ha)	Gross margin $	Yield of rice (t/ha)	Gross margin $
Weedy check	2.62 b	422	2.25 b	360
HW 30 DAE	2.63 b	383	2.66 ab	387
HW 45 DAE	2.66 a	485	3.18 a	411
HW 30 + 45 DAE	3.57 a	497	3.14 a	490
2,4-D	3.83 a	601	3.29 a	514
Propanil	3.78 a	568	3.51 a	526
2,4-D + HW 45 DAE	3.74 a	529	3.52 a	514
Propanil + HW 45 DAE	3.70 a	519	3.00 a	341
2,4-D + propanil	3.84 a	566	3.01 a	441
2,4-D + propanil +HW 45 DAE	3.70 a	511	3.59 a	433

The same results were found in 1992, 1993 and 1994 when soybean was grown after rice treated with pretilachlor (Kanchapan *et al*., 1995). Similar effects were found when soybean, mungbean and sunflower were grown after rice treated with thiobencarb, butachlor and piperophos/dimethametryn (Vongsaroj, 1993).

4. Environmental considerations

Weed control methods must pay attention to the user and the environment. Herbicides should not be toxic to human beings, e.g., 2, 4, 5-T, or to fish, e.g., PCP in Japan. Regulations should be set for the safe

Table 11 Return to weed control affected by weed control treatments (IRRI, 1981)

Treatment	Rate (kg a.i./ha)	Yield (t/ha)	Output ($)	Cost of weed control ($)	Return of weed control
Butachlor	0.8	3.1	508	12	414
Thiobencarb+2,4-D	1.0-0.5	2.6	426	19	325
Propanil	3.0	3.9	640	34	524
Oxadiazon	0.75	3.2	525	55	388
Thiobencarb+propanil	2.4-1.2	4.0	656	49	525
Unweeded	–	0.5	82	–	–

use or handling of herbicides in addition to those dealing with health and safety at work. Poisoning and pollution are wider in scope and continue to have implications. Civil liabilities of the user of herbicides, employees, duty to neighbour, duty to public, contractor's duty to occupier and insurance should be set.

5. Economic aspects and sustainability

Cost of different methods of weed control varies: hand weeding is labour-consuming and wages are increasing year by year, and also difficult to achieve while herbicide cost is almost fixed. Vongsaroj (1995) found that weed control with herbicide application tended to have higher gross margin than hand weeding (Table 10). In the Philippines a higher return was obtained from weed control (Table 11) (IRRI, 1981). If there is no risk for integrated weed management, then technology will be sustained.

6. Replacement of labour

Due to the high wages and shortage of labour, replacement of labour should be attempted. No tillage systems, optimum plant population, models of water control, shedding rice cultivars, allelopathic substances from rice cultivar or from weeds, biological control with available bio-agents in the country and safe herbicides can be used. Small machines to hoe weeds must adopt planting methods with rice in rows.

7. Effect on crop production

Crop production may be low in the case of integrated weed management for sustainable rice production in the short-term but it will increase if practiced over a long-term. When economic aspects are concerned, profits are high enough to adopt this strategy. In addition to environment of aspects, integrated weed management will be far more beneficial because weed control is not harmful to the user and environment.

8. What is needed to continue

The technique of growing rice has been changed from transplanting to wet-seeded rice. Integrated weed management for sustainable rice production must also be improved by researchers and the technology should be easy to adopt, require less input, be associated with maximum profit and not harmful to the environment, as well as conveniently implemented by farmers.

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Discussion

Duong Van Chin (Vietnam) : How do you plan to reduce herbicide use to promote sustainable production of rice when there is a shortage of labour due to the competition between the industry and agriculture ?

Answer : As I mentioned in my presentation, wet-seeded rice can be grown as an upland crop to induce upland weeds to germinate and thereafter proceed to flooding to control some of the weeds. Herbicides can be applied randomly and also emphasis should be placed on the use of postemergence herbicides.