A HANDBOOK FOR WEED CONTROL IN RICE

Kwesi Ampong-Nyarko and **S.K. De Datta**

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IRRI
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P.O. Box 933, 1099 Manila, Philippines

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Foreword

Farmers everywhere search for ways to widen the narrow margin of profit between production costs and crop returns. Weeds cause more yield losses in ricefields than any other pest. Cost-effective methods for controlling weeds could help preserve profits and increase yields.

The authors have designed this book to provide practical information on controlling weeds in the many different rice cultural systems, using an integrated management approach. It is exceptionally comprehensive, and can be used as a textbook, as a field guide, and as a manual for making decisions in crop management.

The handbook has been especially designed to facilitate inexpensive translation and copublication. Contact Communication and Publications Services, IRRI Information Center, for permission and assistance, at no charge, in any activities to extend its benefits to rice workers who read languages other than English.

Klaus Lampe
Director General

Preface

Weeds are an important constraint to increasing yields wherever rice is grown, and rice researchers have created a great amount of useful scientific information on weed control. That information, however, is scattered among many journals, books, and reports that are not always accessible in tropical countries. The result is no readily-available source of practical information on weed control for many national agricultural development program workers.

This handbook summarizes important information on weed control in rice. Our intent was to provide essential, practical, up-to-date information for use by rice researchers, extension workers, farmers, teachers, and students.

Publication of this handbook would have been impossible without the assistance and sustaining interest of so many people, it is impossible to mention them all here. It is with profound gratitude that we acknowledge those who helped us compile the material and those who contributed to improving the presentation.

We specifically thank Dr. James E. Hill, extension agronomist, University of California at Davis, USA; Dr. Shooichi Matsunaka, professor of pesticide science, Kobe University, Japan; Dr. Marcos R. Vega, visiting professor in weed science, University of the Philippines at Los Baños (UPLB); Dr. Aurora M. Baltazar, affiliate assistant professor in weed science, UPLB; and Dr. D. H. Drennan, Department of Agricultural Botany, University of Reading, U. K., for extensive reviews of the manuscript and for their valuable suggestions for its improvement.

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We are greatly appreciative of Bill B. Fischer, farm advisor, Fresno, California, USA, author of *Growers Weed Identification Handbook*, and Dr. Hill for their help in securing photographs of important weeds.

Our sincere appreciation goes to Mr. Walter Rockwood for the final editing of the manuscript and for insightful suggestions that made the handbook more readable.

We also acknowledge the help of Gemma Q. Lucero for initial editing and proofreading; Corazon Bambase and Rosalina Gabriel for careful typing through several drafts; and Ramon Quizon for preparing the illustrations.

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Kwesi Ampong-Nyarko
S. K. De Datta
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Chapter 1

Significance of weeds in rice farming

Weeds are plants growing where they are not wanted. A weed in one place may be a useful food, feed, or medicine in another. Thus, a plant species cannot be classified as a weed under all conditions. Many plants, however, are classified as weeds everywhere they occur, because they commonly grow on regularly tilled areas such as ricefields.

Many weeds co-evolved with crops and, in some cases, were ancestors of cultivated plant species. For example, the wild rices *Oryza barthii* and *O. longistaminata* are ancestors of cultivated *O. glaberrima* in Africa. The wild rices *O. rufipogon* and *O. nivara* are ancestors of cultivated *O. sativa* in Asia (Table 1.1).

The prevalent weeds in ricefields are often legacies of previous years' crops—seeds, rhizomes, tubers, and bulbs surviving in the soil. The weed flora in a ricefield is greatly influenced by the rice culture practiced. Continuous rice with an unchanged cultural system encourages the buildup of weeds adapted to that system. In contrast, where crop rotation is practiced, a diverse weed flora will result. Perennial weeds increase in nontilled ricefields.

Table 1.1. Cultivated species of rice evolved from weedy wild species (adapted from Chang 1976).

	South and Southeast Asia	Tropical Africa
Wild perennial	*O. rufipogon* Griff.	*O. longistaminata* A. Chev. & Roehr.
Wild annual	*O. nivara* Sharma & Shastry	*O. barthii* A. Chev.
Cultivated annual	*O. sativa*	*O. glaberrima*

Table 1.2. Yield losses due to uncontrolled weed growth in different types of rice culture in the Philippines (sources: IRRI 1977 to 1988).

Type of rice culture	Yield loss (mean %)	Experiments (no.)
Irrigated		
Transplanted	48	42
Water seeded	44	1
Direct seeded	55	28
Rainfed lowland		
Direct seeded (dry seeds)	74	11
Direct seeded on puddled soil	61	7
Transplanted in puddled soil	51	9
Rainfed upland		
Broadcast or drilled	96	16

Effects of weeds

Weed infestations primarily constrain rice production by reducing grain yield. Yield reductions caused by uncontrolled weed growth throughout a crop season have been estimated to be from 44 to 96%, depending on the rice culture (Table 1.2). In practice, almost all farmers control weeds in their ricefields. Worldwide, some 10% loss of rice yield can be attributed just to weeds that grow after weed control. These losses can amount to 46 million t (based on 1987 world rough rice production). There is considerable variation in yield loss to weeds among countries.

There is a need to improve farmers' weed control practices. Improved weed management will contribute significantly to future gains in rice yield in many countries.

Increase in rice production costs

The cost of rice weed control, including herbicides, cultural and mechanical practices, and hand weeding, is estimated to be about 5% of world rice production and amount to US$3.5 billion annually. When the 10% loss of rough rice grain yield is added to this cost, the world's total estimated cost for rice weeds and their control amounts to 15% of total annual production—valued at US$10.5 billion (based on 1987 average export prices at Bangkok, Thailand, for 5% brokens white rice US$230/t, IRRI 1988b).

Table 1.3. Weeds as secondary hosts for diseases, insects, and nematodes of rice.

Disease/insect	*Host weeds*	*Reference*
Rice dwarf disease (vlrus)	*Echinochloa crus-galli*	Ou (1985)
Rice stripe disease (virus)	*E. crus-gall;* *Cynodon dactylon* *Setaria vindis* *Digitaria adscendens*	Ou (1985)
Rice yellow dwarf (virus)	*Paspalum distichum* *Leptochloa chinensis* *Leersia hexandra* *Imperata cylindrica*	Ou (1985)
Rice hoja blanca (virus)	*Leptochloa spp.* *Digitaria spp.*	Ou (1985)
Bacterial leaf blight *(Xanthomonas campestris pv. oryzae)*	*L. chinensis*	Ou (1985)
Brown spot *(Cochliobolus miyabeanus)*	C. *dactylon* *L. hexandra* *Digitaria sanguinalis*	Ou (1985)
Whlte tip *(Aphelenchoides oryzae)*	*S. viridis* *Cyperus iria* *I. cylindrica*	Ou (1985)
Meloidogyne (nematodes)	*Fimbristylis miliacea* *Echinochloa colona*	Ou (1985)
Rlce grassy stunt virus (transmltted by brown planthopper *Nilaparvata lugens)*	*L. hexandra* *C. dactylon* *Cyperus rotundus* *E. colona* *Monochoria vaginalis*	IRRI (1988a)
Rice tungro assoclated viruses	C. *rotundus* *F. miliacea* *Oryza longistaminata* *Oryza barthii*	IRRI (1988a)
Nymphula depunctalis (Avenee) (caseworm)	*L. chinensis* *L. hexandra* *Ischaemum rugosum*	IRRI (1986)

Weeds as secondary hosts for pests

Weeds indirectly limit production by serving as hosts for organisms that adversely affect rice. Weeds provide food, shelter, and reproduction sites for insects, nematodes, pathogens, and rodents. Table 1.3 lists weeds that serve as alternate hosts to rice pests. This indicates the importance of recognizing weeds as secondary hosts for pests and of removing weeds from the margins of ricefields to prevent continued infection of the rice crop.

Effects on harvesting and grain quality

Weeds hamper rice harvesting and increase harvest costs through direct interference with the harvesting operation and by causing lodging. Weed seeds contaminate rough rice, thus reducing grain quality and market value. For example, the weed red rice has a pigmented layer that shatters easily and readily contaminates rough rice. Removing all traces of the pigmented layer requires intense milling and results in decreased grain quality and lower milling rates.

Social costs of weed control

The drudgery of weeding and labor shortages have made rice farming unattractive. In most tropical countries, farmers spend more time on weeding, by hand or with simple tools, than on any other farming task. Hand weeding 1 ha of rice requires from 100 to 780 labor-hours per crop, depending on the rice culture.

Aquatic weed problems

Nutrient availability and favorable temperatures throughout the year, especially in the tropics, allow luxuriant aquatic weed growth in flooded ricefields. Noxious aquatic weeds have increasingly infested impounded water in the tropics. Heavy aquatic weed infestation causes excessive water loss through evaporation and impedes water flow in irrigation canals. In some cases, aquatic weeds may be a health hazard to persons living near impounded water. For example, the association of the weed *Ceratophyllum demersum* with the intermediate host snail of schistosomiasis (bilharzia) *Bulinus* sp. is well documented.

Rice-weed competition

Weeds interfere with rice growth by competing for one or more growth-limiting resources, such as light, nutrients, and water. Allelopathy (chemical production by living or decaying weed plant tissues) may also adversely affect the growth of a neighboring rice plant.

Rice and rice weeds have similar requirements for growth and development. Competition occurs when one of the limiting resources falls short of the combined requirements of both. The degree of rice-weed competition depends on rainfall, rice variety, soil factors, weed density, duration of rice and weed growth, crop age when weeds started to compete, and nutrient resources, among other variables.

Cultural practices greatly alter the competitive relationship between rice and weeds. Thus, different cultures (irrigated, rainfed lowland, upland, and deepwater) will be subjected to different kinds and degrees of weed competition. To understand this competition, it is essential to know the growth requirements of rice and helpful to know the growth requirements of weeds.

Growth requirements of rice

Rice growth varies with climatic and cultural conditions. Growth during the first 6 wk is slow. Depending on moisture availability and temperature, a seed may take 5-20 d to germinate and 14-22 additional days to reach the 4-leaf seedling stage. The total leaf area of a standing rice crop at flowering determines its photosynthetic capacity for spikelet filling, and thus determines the grain yield. Tillering capacity is also important because number of panicles is a principal component in determining grain yield.

Light

The light requirement of rice varies with crop growth stage. Shading during the seedling stage greatly decreases rice growth. Low light from 10 d before to 20 d after full bloom induces high spikelet sterility, resulting in poor grain yield. Low light after flowering reduces rice dry matter because of decreased photosynthesis—75-80% of grain carbohydrate is photosynthesized after flowering.

Water

The water requirement of rice depends on the soil, climate, variety, growth stage, and duration of plant growth. Plant stress from water shortage at any stage reduces yield, more so if the water shortage occurs during the reproductive phase. Drought stress symptoms include leaf rolling, leaf scorching, reduced tillering, stunted growth, delayed flowering, and spikelet sterility.

C_3 and C_4 photosynthetic pathways

Since its discovery in the late 1960s, interest in the C_4 photosynthetic pathway has been high. The C_4 photosynthetic pathway is a mechanism for concentrating atmospheric CO_2 at the ultimate site of fixation within the leaf before entering the C_3 photosynthetic pathway (Patterson 1985). Some plants are C_4 types, others C_3. Rice is a C_3 plant, as are the weeds *Monochoria vaginalis, Cyperus difformis, Eichhornia crassipes, Ipomoea* spp., and *Ageratum conyzoides.* Examples of C_4 plants are maize, sugarcane, *Sorghum bicolor, Amaranthus* spp., *Brachiaria* spp., *Cynodon dactylon, Cyperus rotundus, Digitaria* spp., *Echinochloa* spp., *Eleusine indica, Leptochloa chinensis, Rottboellia cochinchinensis,* and *lmperata cylindrica.*

It has been suggested that the C_4 photosynthetic pathway provides its greatest advantage under hot, arid, high light conditions. C_4 plants have higher water-use efficiency than C_3 plants, and their nitrogen use efficiency may also be greater.

Competition between C_3 and C_4 weeds has been examined in relation to soil moisture regime (Matsunaka 1983). C_3 plants were dominant in submerged soils; C_4 plants were dominant in dryland soils. This explains why submergence protects rice plants from severe competition with C_4 weeds. On the other hand, upland rice and rainfed lowland rice with limited precipitation face severe competition with C_4 weeds.

Nutrients

Nitrogen (N) is the most important nutrient for rice, and N deficiency occurs almost everywhere. Deficiencies of phosphorus (P) and potassium (K) that may also occur greatly reduce rice plant tillering. In the tropics, the harvest of a ton of rice straw and grain removes an average 16 kg N, 3 kg P, and 17 kg K/ha.

Factors of weed competition

The availability of light, water, and nutrients affects the growth and competitiveness of plants. In theory, the amount of these resources in a given rice environment is fixed—whatever is used by one plant species is not available for another. This means that resources taken by weeds are lost to rice, and vice versa. In general, rice dry matter yield will be reduced by 1 kg for every kilogram of weeds produced in the same area.

Light

Competition for light can occur throughout rice growth. Most weeds and rice have maximum photosynthesis and growth in full sunlight. Competition for light occurs when one leaf shades another. Weeds compete with rice by growing faster and by shading rice with large, horizontal leaves. Tall plants have an advantage over short plants. For example, when *Rottboellia cochinchinensis* was allowed to grow with rice, *R. cochinchinensis* was 150 cm tall and rice was 50 cm tall at 8 wk after seeding. The amount of light received at 25 cm within the rice canopy was only 3% of the light at the top of the weed canopy. In this situation, the weed clearly had an advantage.

Water

Rice yield losses from water deficit depend on the severity and duration of the deficit, environmental conditions, cultivar, and growth stage when drought stress occurs. Drought stress reduces photosynthesis by reducing leaf expansion and causing loss of leaf turgor, which leads to stomatal closure. Transpiration and photosynthesis by leaves are greatly reduced when stomata close. Responses to drought stress include wilting and increased leaf mortality. Rice and weeds differ in their tolerance for drought because of differences in their root distribution, root elongation rate, genetic tolerance for low water availability in plant tissue, and control of water loss through transpiration. C_4 weeds have lower water requirements than those of C_3 rice and are able to tolerate more drought stress than rice.

Nutrients

The three most common yield-limiting nutrients are N, P, and K. Competition, however, may occur for any nutrient required for plant growth. Many weed species have a nutrient uptake similar to that of rice, but have higher nutrient-use efficiency than rice. In general, factors that give a plant a competitive advantage in water uptake also give the plant a competitive advantage in nutrient uptake.

Critical period of weed competition

Competition between weed seedlings and direct seeded rice seedlings usually begins as competition for light. The effect of shading on rice growth is most severe during the seedling stage, but rice can recover from weed competition if weeds are eliminated early in the season. Weeds will not further reduce the grain yield of a mature rice crop ready for harvesting.

The so-called critical period lies between the seedling and harvest stages, the 30-45 d when weed competition is most damaging to rice. To avoid grain yield losses, it is important to controI weeds throughout this critical period. At 45- to 60-d-old, well-established, weed-free rice plants are able to suppress later germinating weed seedlings. When herbicides are used, their persistence should be long enough to cover the critical period of competition.

Characteristics of successful weeds

Weeds and crops may have common origins, and hence, may have similar characteristics. Weeds often have evolved adaptive traits that increase their persistence or competitiveness, or both. Traits contributing to successful weeds fall under three categories: 1) weed competitiveness and growth, 2) weed reproduction and dispersal, and 3) similarities between weed and rice.

Weed competitiveness and growth

Some weeds have large seeds which allow for rapid seedling growth. Some weeds are climbers; others are tall. Some weeds have higher rates of photosynthesis, faster growth, larger leaves, and deeper root systems than rice and other crops. Deep root systems enable a weed to exploit nutrients essential for crop growth.

Weeds are highly adaptable to changing environments (phenotypic plasticity). Under favorable conditions, weeds become large and produce many seeds. Under unfavorable conditions, weeds remain small and produce only a few seeds.

Reproduction and dispersal

Many weeds produce large quantities of seed in favorable environments. For example, *Eckinochloa colona* may produce 100,000 seeds/plant; *Eleusine indica,* 50,000 seeds/plant; *Commelina benghalensis,* 1,600 seeds/plant; *Trianthema portulacastrum,* 52,000 seeds/plant; and *Amaranthus* spp., 196,000 seeds/plant. Production of a large number of seeds ensure species survival even in adverse environments. Weed seeds ripen nonsynchronously—viable seeds are produced and shatter before the rice crop matures.

Some annual weeds have short life cycles and may produce several generations a year when moisture is not limiting, particularly in the tropics.

Perennial weeds reproduce both sexually and vegetatively. Vegetative reproduction includes rhizomes, tubers, corms, bulbs, and stolons. Such weeds are highly adaptive. Vegetative organs depend on the parent plant for their supply of nutrients and water during development and use stored reserves to support later establishment. Vegetative structures, which are normally larger and contain more stored food than seeds, grow fast and emerge from greater soil depths than seeds. Examples of these weeds are *Cynodon dactylon, lmperata cyclindrica, Cyperus rotundus,* and *Commelina benghalensis.*

Many viable weed seeds remain dormant even under favorable conditions, and dormancy prevents weed seeds from germinating under unfavorable conditions. Seed dormancy may be genetic or arise from environmental conditions such as deep burial, unfavorable temperatures, low oxygen supply, or waterlogging. Weed seeds in the soil may be in different states of dormancy and may germinate at different times, making weed eradication through weed control practices difficult. The high seed production ability and long dormancy periods result in large reserves of viable weed seeds in the soil, including many seeds that can survive for several years.

Weed seed dispersal also contributes to the survival of weed species. Mature seeds and fruits of weeds are dispersed by wind and water, and by animals and man. Moving water is an important pathway in the spread of weed seeds, particularly in the interconnected canals of irrigated and rainfed lowland ricefields.

Similarities between weeds and rice

The growth requirements and habits of many weeds resemble those of rice. These adaptations include similarities in seed size, seed maturity, morphology, and physiology. Wild rice species, for example, are very similar to cultivated rice species. A classic example is the rice mimic *Echinochloa oryzoides* (Ard.) Fritsch; hundreds of years of hand weeding is thought to be the selective agent responsible for its vegetative mimicry. It is rarely found outside the rice environment.

Chapter 2

Rice weeds of worldwide importance

National and regional methods of classifying rice cultures can vary widely, depending on rice-growing conditions and purposes of the classification system. A classification system may be based on general surface hydrology, source of water, landform and soil units, ecological factors, or crop season. For weed control, general surface hydrology and rice seeding method are more important than other factors (De Datta 1981).

A classification based on surface hydrology and seeding method is used here to discuss weed problems and the integrated methods available for weed control in each type of rice culture. Rice culture is classified on the basis of water management as lowland, upland, or deepwater; it may be irrigated or rainfed. This is further subdivided on the basis of rice establishment method.

This chapter covers weeds of worldwide importance in lowland, upland, and deepwater ricefields. The weeds in each ecosystem are arranged alphabetically on the basis of family. Photographs show seed, seedling, mature plant, and flower for each weed, and each weed's characteristics and agricultural importance are described. Local names of weeds in the countries where they are of major concern are provided to compliment the photographs for weed identification. (We know the list of local names is not complete, and the spelling used for the local names may not be the one preferred. Readers are invited to send the authors the correct local names.)

Weeds in rice are classified by their life cycle, habitat, and morphological characteristics.

Life cycles

Weeds are classified as annual or perennial, or both. Where moisture or temperature is not limiting and life cycle is short, an annual weed may complete more than one life cycle in a year. Annuals produce many seeds, some of which remain dormant and buffer a species against weed control measures.

Perennial weeds propagate by vegetative structures such as bulbs, corms, rhizomes, stolons, and tubers. A bulb is an underground bud. Rhizomes are underground shoots with short, thick internodes buried in the soil. They have specialized buds that can remain dormant. These shoots are rich in stored food and enable plants to survive from year to year. *Imperata cylindrica* and *Cynodon dactylon* are rhizomatous weeds.

Stolons are horizontally growing stems with long slender internodes; adventitious roots form at the nodes when in contact with soil. *Paspalum distichum* is a weed with stolons.

A tuber is a specialized structure that results from the swelling of the terminal portion of an underground stem or root; it contains stored food. *Cyperus rotundus* produces tubers.

Morphology

Weeds are also classified as monocotyledonous or dicotyledonous.

Monocotyledons

The seeds of monocotyledonous weeds have a single cotyledon (seed leaf). A monocotyledon's mature leaves are long and narrow with parallel veins. The stem or culm is cylindrical and the growing point is protected by a sheath. The root systems arise adventitiously and are usually fibrous. Examples of families of monocotyledoneae are Potamogetonaceae, Pontederiaceae, Cyperaceae, Poaceae, and Commelinaceae. Sedges (Cyperaceae) resemble grasses but differ from grasses in that their stems are unjointed, solid, and often triangular in cross section.

Dicotyledons

The seeds of dicotyledonous weeds have two cotyledons. Mature leaves are broad and usually net-veined. The root systems have tap roots. The dicotyledons have a branched growth form. Not all broadleaf weeds however, are dicotyledonous. *Commelina benghalensis, Monochoria vaginalis,* and *Eichhornia crassipes* have broad leaves but are monocotyledonous weeds.

Habitat

Weeds in rice can be grouped on the basis of their adaptation to submerged conditions as lowland or upland weeds. Lowland weeds may be semiaquatic or aquatic; upland weeds are adapted to dry sites.

Information on yield loss from uncontrolled weeds from different experiments around the world is given when available to indicate the weed's potential competitive ability. The losses will differ from one locality to another because they are affected by environmental factors such as nutrient, moisture, temperature, time of weed emergence, and density. The yield loss information is not meant to show the relative competitiveness among the different weeds, and the yield loss figures should not be used to target particular weeds for control, leaving others to compete with the crop.

For further information on the biology of the weeds listed in this chapter, and on other weeds that may be of interest, readers can refer to the book *The world's worst weeds - distribution and biology* (1977) by L.G. Holm and colleagues. Other references include Krantz et al (1977), Moody (1981), and Moody et al (1984).

Approved computer codes for weeds

Computer codes for weeds now available (Bayer Agrochemicals Division 1986) are useful for universal identification in bibliographies and data bases. An approved computer code is a five-letter abbreviation based on the scientific name of each plant. In general, the first three letters refer to the genus and the last two denote the species, the subspecies, or the variety. For example, the code for *Echinochloa colona* is ECHCO; for *Echinochloa crus-galli,* ECHCG; and for *Echinochloa crus-galli* P.B. var. *kasaharae* Ohwi, ECHCK.

Lowland rice weeds

ASTERACEAE (Compositae, sunflower family)

Weed name: *Eclipta prostrata* (L.) L.
Synonyms: *Eclipta alba* (L.) Hassk., *Eclipta erecta* L., *Verbesina alba, Verbesina prostrata* L.
Local names:

Country	*Common name*
Argentina	yerba de tago (Spanish)
Bangladesh	keshuti (Bengali)
France	*eclipte blanche*
India	bhangra, kesadura, ghuzi
Indonesia	urang-aring (Javanese)
Japan	takasaburo
Malaysia	aring-aring
Mexico	hierba-prieta (Spanish)
Myanmar	kyeik-hman
Pakistan	daryai buti
Peru	florcita (Spanish)
Philippines	higis manok (Tagalog)
Sri Lanka	sindu kirindi (Sinhalese) kaikechi (Tamil)
Sudan	tamar el ghanam
Thailand	ka-meng (Thai)
USA	eclipta
Vietnam	co muc

Life cycle: An annual or perennial broadleaf weed that can grow as tall as 90 cm. Propagates by seeds, which show no dormancy. In the tropics, the seed germinates throughout the year.

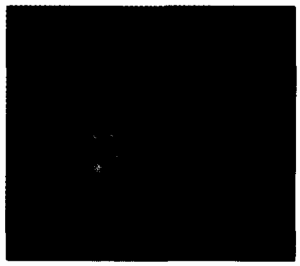
Habitat: Thrives in continuously wet soils but can grow at dry sites. Also found in poorly drained wet areas.

Weedy nature: An adaptable weed with fast vegetative growth.

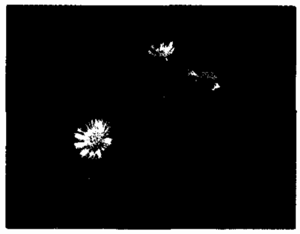
Agricultural concern: Prevalent in lowland and upland ricefields. Rice yield losses of 25% have been recorded in the Philippines.

Mature plant

Seed, magnified



Seedling



Flower

Weed name: *Cyperus difformis* L.
Synonyms: None
Local names:

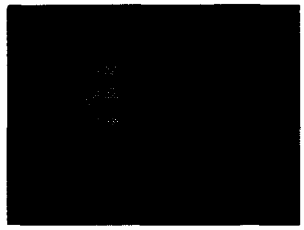
Country	*Common name*
Australia	dirty dora
France	souchet a petites fleurs
Japan	tamagayatsuri
Korea	albang dong sani
Malaysia	rumput air
Nigeria	imeremere (Yoruba)
Philippines	baki-baki (Ilongo)
	ballayang (Tagalog)
Sierra Leone	a-kek-a-pot
Thailand	kok ka-narg
USA	smallflower, umbrella sedge

Life cycle: An annual sedge that can grow as tall as 75 cm. Normally propagates by seeds.

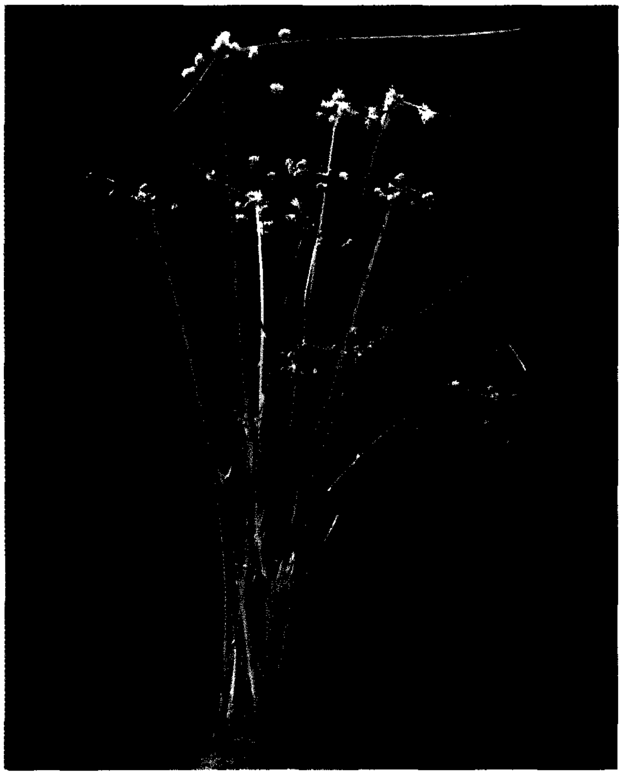
Habitat: Adapted to moist lowland soils or flooded areas.

Weedy nature: A heavy seed producer. Can complete one life cycle in about 30 d. Through high seed production and short life cycle, can spread rapidly to become a dominant weed in a ricefield.

Agricultural concern: Produces a dense stand within a short time, thus competing with rice for moisture and nutrients. Has caused rice yield reductions of 12-50%.



Seed, magnified



Mature plant

Seedling

Inflorescence

Weed name: *Cyperus iria* L.

Synonyms: None

Local names:

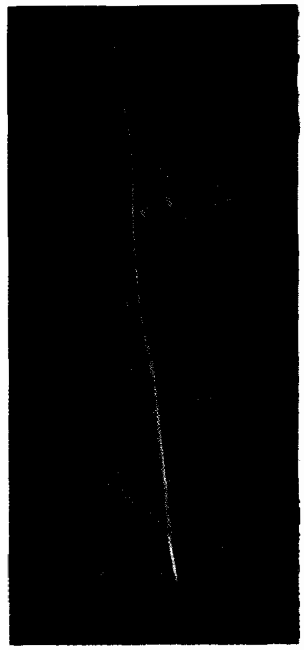
Country	*Common name*
Bangladesh	barachucha (Bengali)
Brazil	tiririca-do-brejo (Portuguese)
Cambodia	kak kangkep (Khmer)
India	morphula (Assamese)
Indonesia	djekeng (Javanese)
Japan	kogomegayatsuri
Korea	chambang-donsani
Pakistan	khana
Philippines	alinang (Bicolano) paiung-paiung (Tagalog)
Thailand	kok huadaeng
USA	rice flatsedge

Life cycle: An annual sedge that grows as tall as 60 cm. Propagates by seeds, which may be dormant but can germinate about 75 d after shedding.

Habitat: Grows well in moist to wet soil.

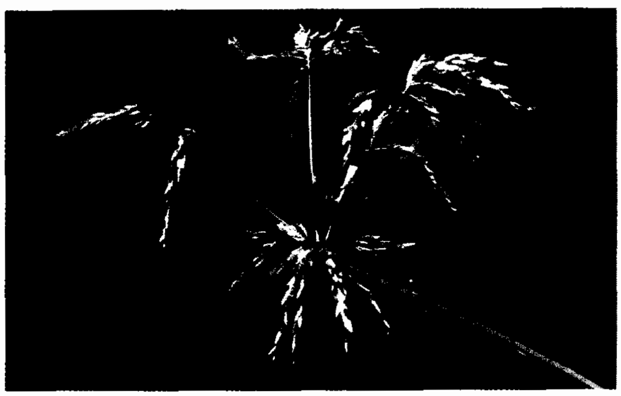
Weedy nature: A prolific seed producer and spreads quickly.

Agricultural concern: Can be very competitive for nutrients and reduce rice yields 40%.

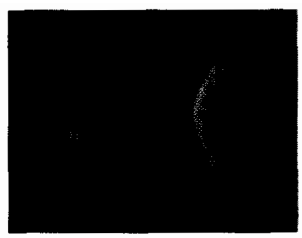


Seedling

Mature plant



Inflorescence



Seed, magnified

Weed name: *Fimbristylis miliacea* (L.) Vahl

Synonym: *Fimbristylis littoralis* Gaud.

Local names:

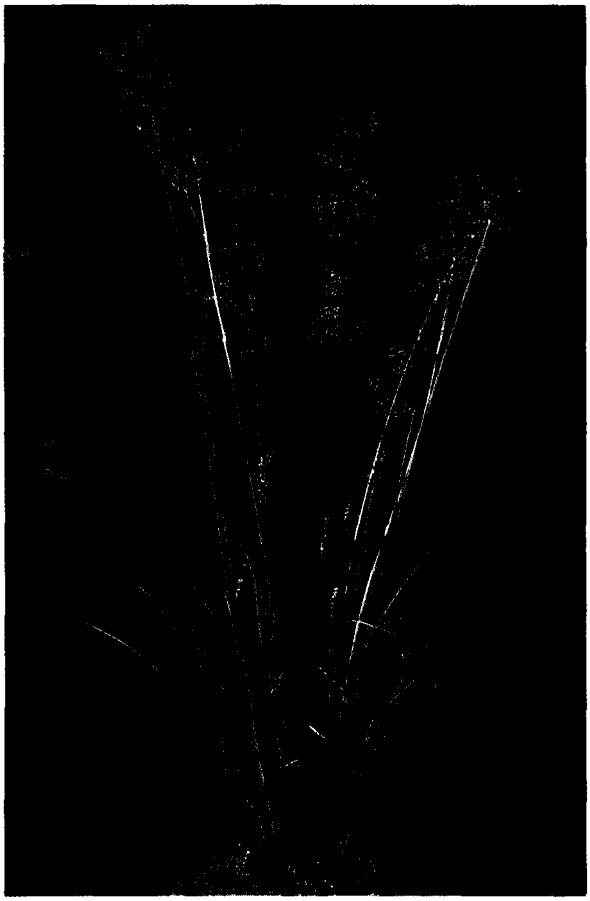
Country	*Commonname*
Bangladesh	bara javani (Bengali)
Brazil	cominho (Portuguese)
Cambodia	kâk phenk kdam (Khmer)
Indonesia	adas-adawan (Javanese)
Japan	hideriko
Korea	barambaneulgiji
Malaysia	rumput tahiker bau
Myanmar	monhnyin
Philippines	ubod-ubod (Tagalog)
Thailand	agor
USA	globe fingerush

Life cycle: An annual sedge that grows as tall as 60 cm. Propagates by seeds. Large proportion of seeds have no dormancy and can germinate immediately after reaching maturity. Seed requires light for germination.

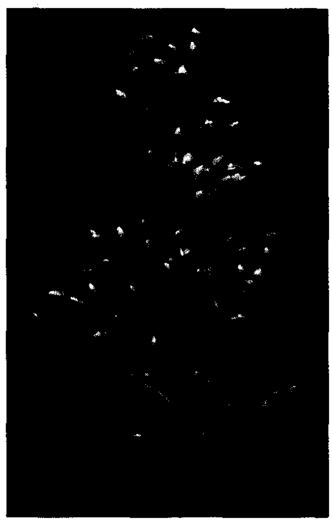
Habitat: Adapted to moist soils and areas of occasional flooding. Does not establish in submerged soils.

Weedy nature: Produces many seeds, which germinate throughout the year. Thus, some weeds escape the weed control measures. Can become a dominant weed within a short time.

Agricultural concern: Competition is mainly for nutrients and water. Can reduce rice grain yields 50%.



Mature plant



Inflorescence

Seedling

Seed, magnified

Weed name: *Scirpus maritimus* L.
Synonyms: None
Local names:

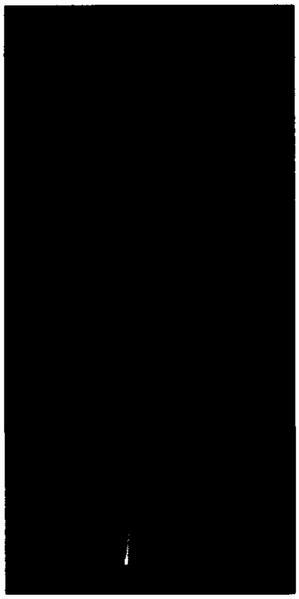
County	*Common name*
France	scirpe maritime
Peru	coco grande (Spanish)
Philippines	apulid (Tagalog)

Life cycle: A perennial sedge that spreads by tubers.

Habitat: Grows in wet and flooded soils.

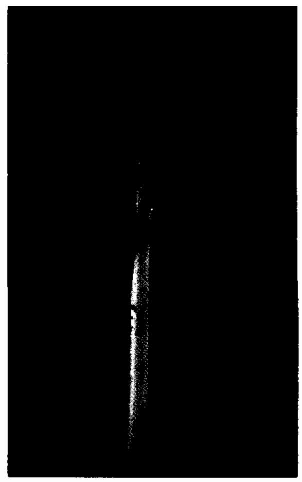
Weedy nature: Tubers have dormancy. Stems grow rapidly during early rice growth and may severely shade semidwarf rice cultivars during the first 40 d. Difficult to control because of apical bud dormancy and capacity to produce numerous tubers. Establishes, spreads, and becomes a dominant weed within a short time.

Agricultural concern: Very competitive in lowland rice. Rice yield losses of 60-80% can occur. Difficult to eradicate because of dormant tubers and buds.


Mature plant


Tubers and rhizomes


Mature plants in the field


Vegetative shoot

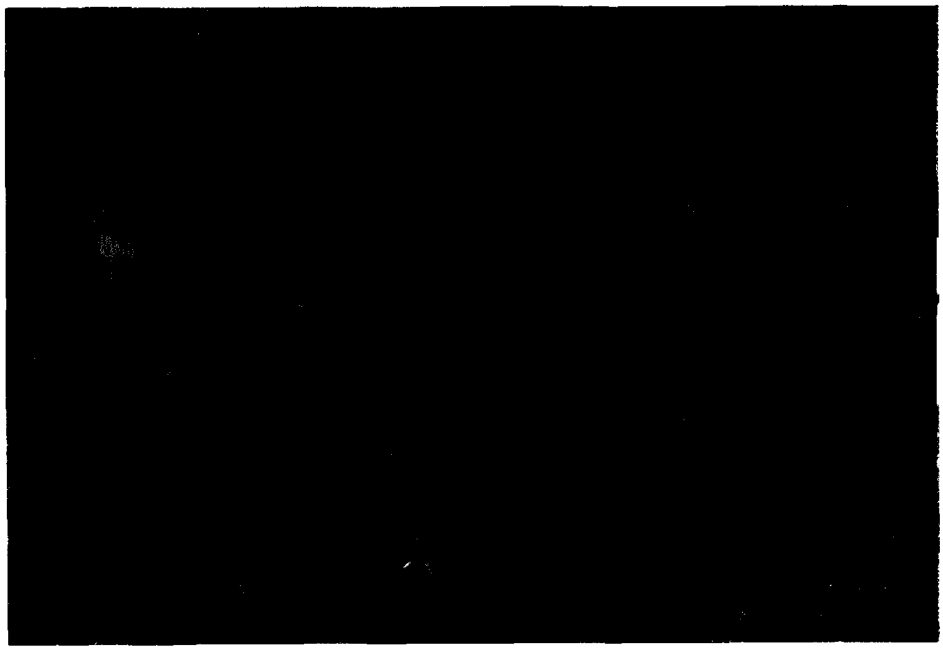
Weed name: *Marsilea minuta* L.
Synonym: *Marsilea crenata* Presl.
Localnames:

Country	*Common name*
France	marsilea a quatre feuilles
Japan	denjiso
Malaysia	tapak itek (Malay)
Philippines	kaya-kayapuan (Tagalog)
Thailand	phakwaen
USA	airypepperwort

Life cycle: An aquatic fern that reproduces by rhizomes and spores.

Habitat: Grows well in lowland fields and along irrigation canals.

Agricultural concern: Persistent and very competitive in rice. Yield reduction of 70% has been recorded.



Mature plant

Seedling

Weed name: *Ludwigia octovalvis* (Jacq.) Raven
Synonym: *Jussiaea suffruticosa* L.
Local names:

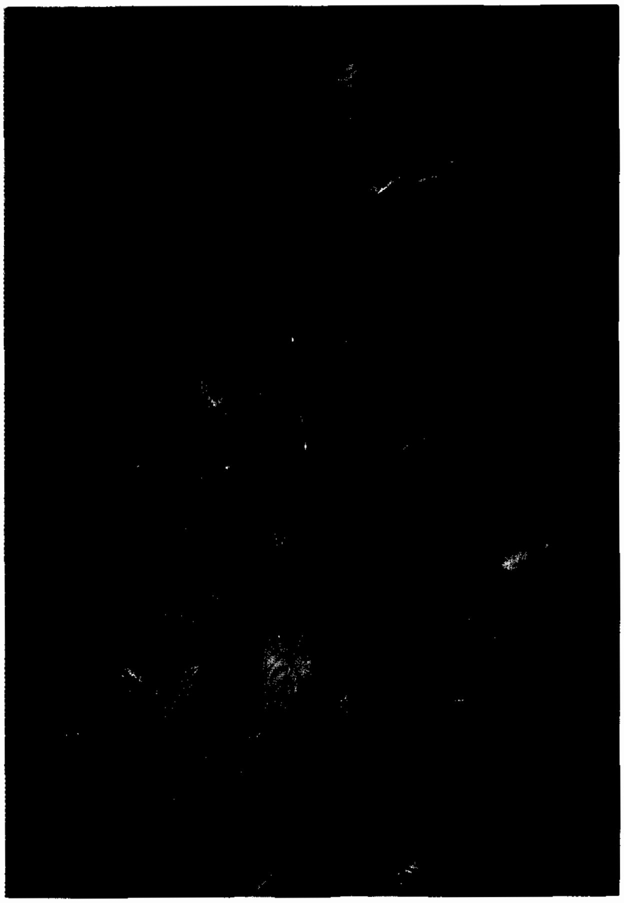
Country	*Common name*
Brazil	cruz-de-malta (Portuguese)
Malaysia	jinaleh
Philippines	balakbak, malapako (Tagalog)
Thailand	phak phaeng phuai
USA	long fruited primrose-willow

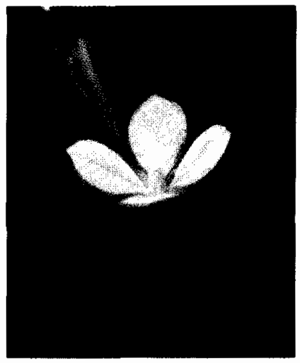
Life cycle: An annual aquatic broad-leaf weed that can grow as tall as 100 cm. Propagates by seeds, some of which will germinate immediately in wet or flooded soils.

Habitat: Adapted to wet and aquatic conditions.

Weedy nature: Very competitive with rice.

Agricultural concern: Can reduce rice yields 50-80%.


Mature plant


Flower


Seedling


Seed, magnified

Weed name: *Echinochloa crus-galli* (L.) Beauv. *E. crus-galli* species is considered to include two subspecies, each with two varieties (Michael 1983):

E. crus-galli ssp. *crus-galli var. crus-galli,*

E. crus-galli ssp. *crus-galli* var. *praticola,*

E. crus-galli ssp. *hispidula* var. *hispidula,* and

E. crus-galli sp. *hispidula* var. *austro-japonensis*

E. crus-galli var. *crus-galli* is abundant in the more temperate rice-growing areas such as the Indian subcontinent, China, Japan, Southern Europe, North and South America, and Australia.

E. crus-galli var. *praticola* is an upland rice weed in eastern Asia.

E. crus-galli var. *hispidula* is an abundant rice weed throughout Southeast Asia, parts of the Indian subcontinent, and Sri Lanka.

E. crus-galli var. *austro-japonensis* is essentially found in eastern Asia, extending south from Taiwan, China, and adjacent parts of mainland Asia to the high, cool areas of Southeast Asia.

Synonyms: None

Local names:

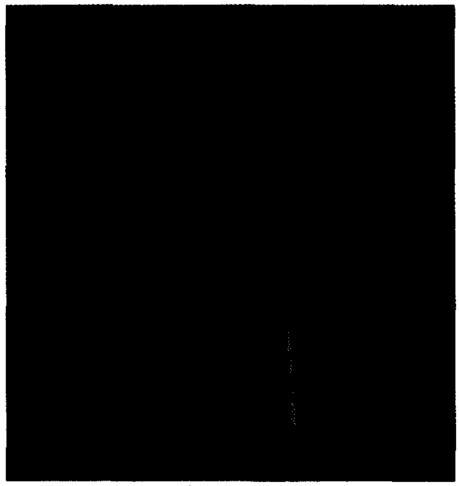
Country	*Common name*
Bangladesh	shama
Brazil	capimp-da-colonia (Portuguese)
France	panic, pied-de-coq
India	kauada, sawant (Malayalam)
Indonesia	djawan (Javanese)
Korea	pi
Malaysia	sambau
Peru	mijo japones
Philippines	daua-daua (Tagalog)
Sri Lanka	martu
Thailand	ya-plong
USA	common barnyard grass

Life cycle: An annual grass that can grow as tall as 150 cm. Propagates by seeds, which may remain dormant 3-4 mo.

Habitat: Adapted to wet soils. Grows best at soil moisture of 80% water-holding capacity. Optimum germination occurs at 70-90% of water-holding capacity. Seeds can also germinate under water. Growth becomes increasingly poor with increased depth of submergence.

Weedy nature: A prolific seed producer; one plant may produce 40,000 seeds. Tillers profusely and germinates throughout the year. Ecologically similar to rice. During early vegetative phase, almost indistinguishable from rice plants.

Agricultural concern: Very competitive with rice. Can reduce rice yields 100%.



Seedling

Mature plant

Inflorescence

Seed, magnified

Weed name: *Echinochloa glabrescens* Munro ex Hook.f.

Synonyms: None

Local names:

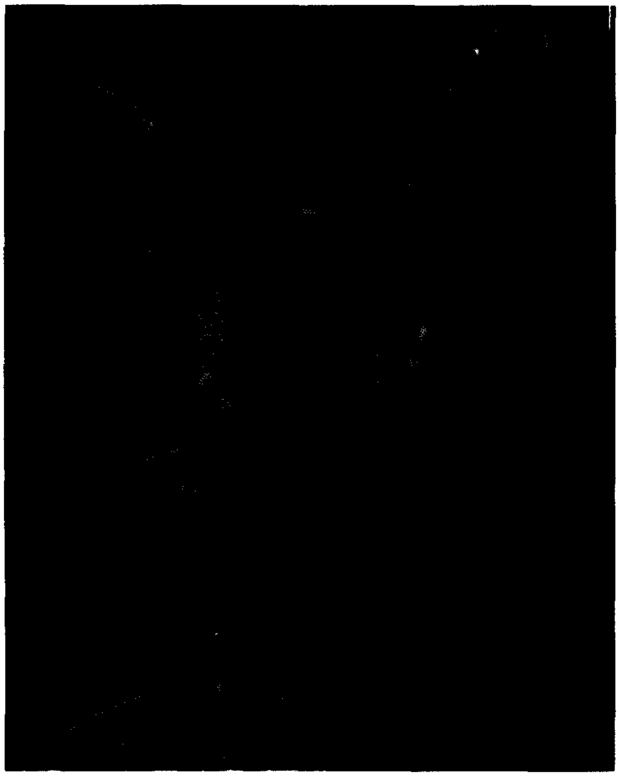
Country	*Common name*
Japan	inubie
Philippines	bayakibok, daua-daua (Tagalog)

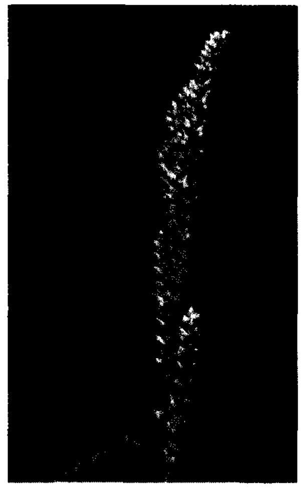
Life cycle: An annual grass that grows 0.5-1.0 m tall. Propagates by seeds.

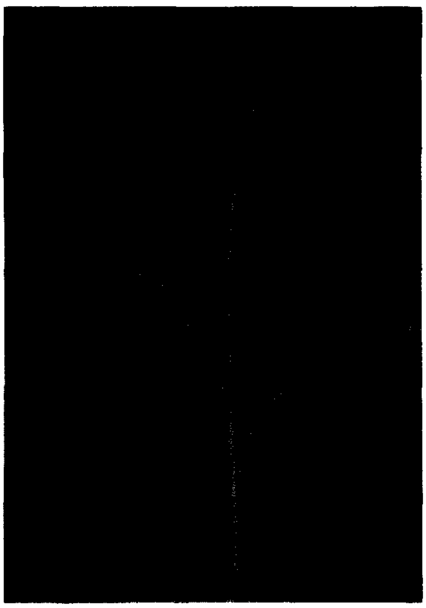
Habitat: Adapted to wet soils. Distribution extends from the Indian subcontinent through mainland Southeast Asia and China to Korea, southern Japan, and the Philippines (Michael 1983).

Weedy nature: Ecologically similar to rice.

Agricultural concern: Very competitive with rice. When *E. glabrescens* seedlings were transplanted with rice, yield losses ranged from 7% when 5% of the rice hills were infested to 87% when 50% of the rice hills were infested (IRRI 1987).


Mature plant


Inflorescence


Seedling


Seed, magnified

Weed name: *Ischaemurn rugosum* Salisb.

Synonyms: None

Local names:

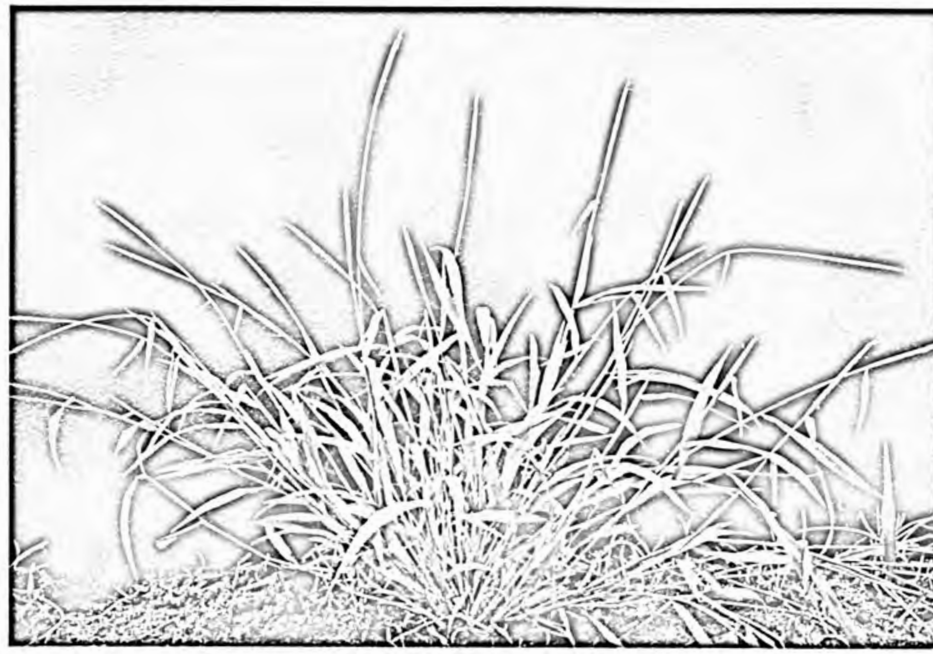
Country	*Common name*
Bangladesh	moran (Bengali)
Brazil	capin macho (Portuguese)
Colombia	trigillo (Spanish)
Dominican Republic	yerba de papo (Spanish)
Fiji	comuraina
India	mararo (Bengali)
Indonesia	blemben (Javanese)
Malaysia	rumput ekor jawi (Malay)
Myanmar	ka-gyi-the-myet
Peru	mozorquilla (Spanish)
Philippines	tinitrigo (Tagalog)
Sri Lanka	kudukedu (Sinhalese)
Thailand	yah daeng
USA	saramollagrass

Life cycle: An annual grass that grows to 120 cm tall. Propagates by seeds, which may remain dormant.

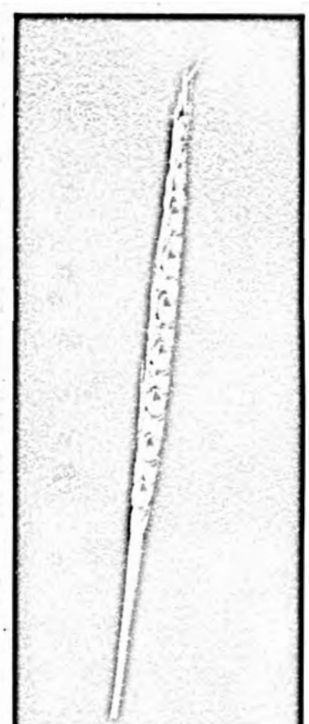
Habitat: Prefers wet soils and swampy areas.

Weedy nature: A vigorous, aggressive weed. Seeds shatter easily, so that there is a constant source of infestation. During vegetative growth, resembles the rice plant, making it difficult to recognize as a weed. *I. rugosum,* however, has deep reddish-brown to purple leaf sheaths, a color only weakly developed in rice.

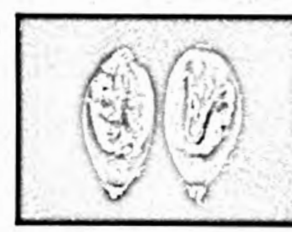
Agricultural concern: Very competitive: 5 plants/m^2 reduced rice yields 15% and 80 plants/m^2 reduced yields 82% in IRRI trials (IRRI 1987).



Mature plant



Inflorescence



Seed, magnified

Weed name: Leersia hexandra Sw.
Synonyms: None
Local names:

Country	*Common name*
Australia	swamp ricegrass
Bangladesh	araila (Bengali)
Brazil	arroz-bravo (Portuguese)
Indonesia	kalamenta
Malaysia	rumput lidah riman (Malay)
Myanmar	thaman-myet
Philippines	barit (Tagalog)
Surinam	alesi grasie
Thailand	yah-sai
USA	southern cutgrass
Venezuela	lamedora
Vietnam	có bac

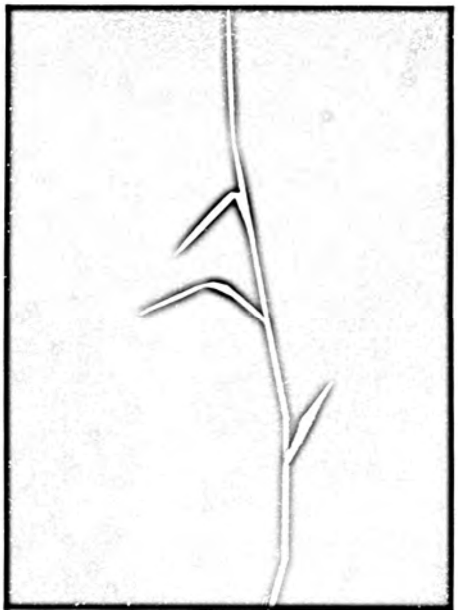
Life cycle: An aquatic perennial grass that can grow as tall as 100 cm. Propagates by seeds, rhizomes, and stolons.

Habitat: Grows in constantly flooded or marshy habitats.

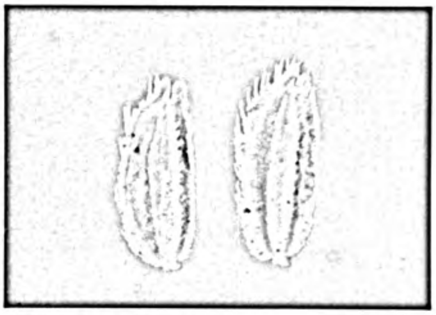
Agricultural concern: In some habitats, resembles rice plants. Because it propagates by both seeds and vegetatively, has a tremendous ability to survive and proliferate. Can cause 60% rice yield losses.

Mature plants in the field

Inflorescence



Mature plant



Seed, magnified

Weed name: *Leptochloa chinensis* (L.) Nees

Synonyms: None

Local names:

Country	*Common name*
Colombia	plumilla (Spanish)
El Salvador	cola de buey (Spanish)
Indonesia	bebontengan (Javanese)
Japan	azegaya
Philippines	palay-maya (Tagalog)
Thailand	yoa yon hun
USA	Chinese sprangle top
Vietnam	có duöi phung

Life cycle: An annual or perennial grass that can grow as tall as 120 cm. Propagates by seeds.

Habitat: Grows well in marshy fields but will not survive continuous flooding. Can also grow in upland fields.

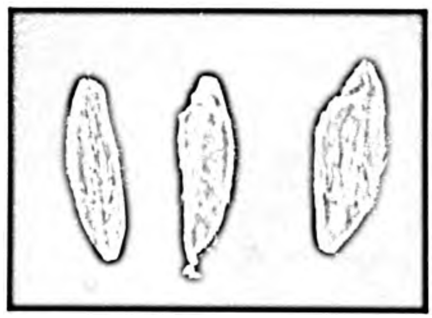
Weedy nature: Propagates from cuttings of the culm or rootstocks, therefore establishes and spreads easily under tillage.

Agricultural concern: A serious weed in rice. Competes with rice for nutrients and light and can reduce yields more than 40%.

Mature plant

Inflorescence

Seedling



Seed, magnified

Weed name: ***Paspalurn distichurn*** **L.**
Synonym: ***Paspalurn paspalodes*** (Michx.) Scribn.
Local names:

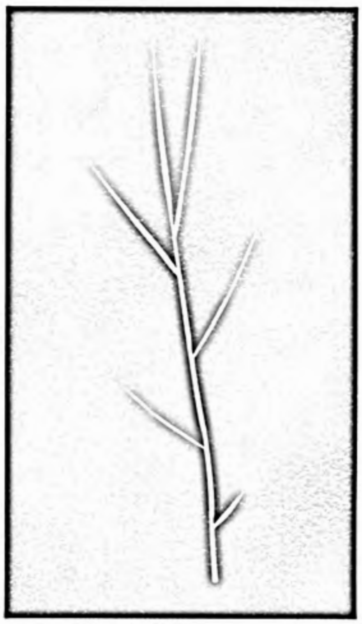
Country	*Commomame*
Australia	**water couch**
Indonesia	**lamhani (Sundanese)**
Japan	**kishusuzuuenchie**
Malaysia	**rumput masin**
Philippines	**luya-luyangdagat, pagetpet(Tagalog)**
USA	**knotgrass**

Life cycle: **A** perennial grass that can grow as tall as 30-60 cm. Propagates mainly by creeping stolons and, to some extent, by seeds (flowers but produces few viable seeds).

Habitat: Grows well in moist to wet soils.

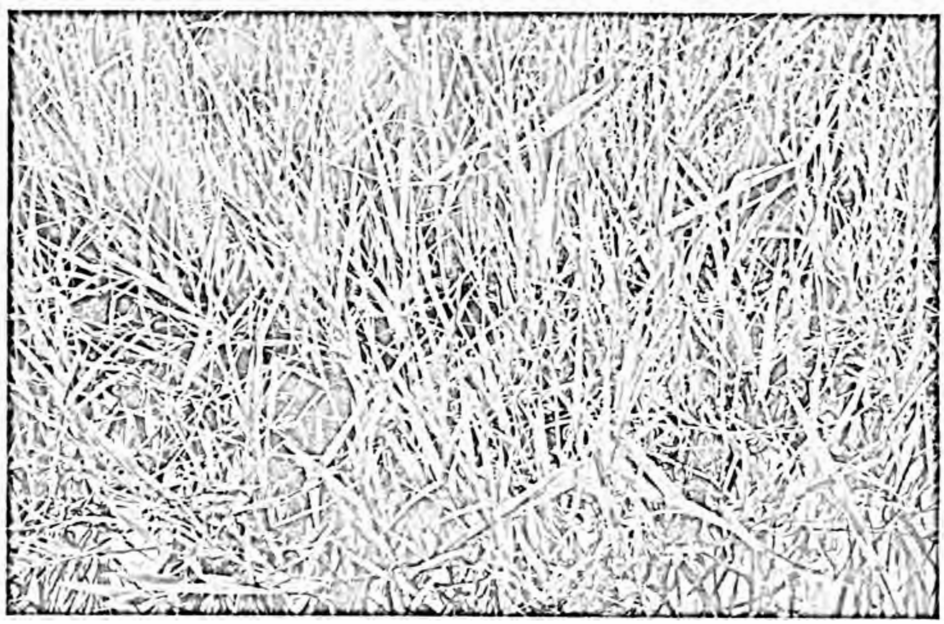
Weedy nature: Spreads aggressively by means of stolons. Difficult to control because detached stolon fragments regenerate easily. Tolerant of many herbicides.

Agricultural concern: Can be very competitive in rice, reducingyields up to 85%.



Mature plant

Inflorescence



Mature plants in the field

Weed name: *Monochoria vaginalis* (Burm. f.) Presl

Synonyms: None

Local names:

Country	*Common name*
Bangladesh	panee kachu
Cambodia	chrach (Khmer)
India	neerthomarai (Tamil)
Indonesia	et jeng padi
Korea	mooldalgebi
Malaysia	keladi agas (Malay)
Philippines	biga-bigaan (Tagalog)
Thailand	ninlabon
USA	monochoria
Vietnam	rau mác lá thon

Life cycle: A perennial aquatic monocotyledonous plant. May behave like an annual in flooded ricefields, where it grows as tall as 50 cm. Propagates by seeds.

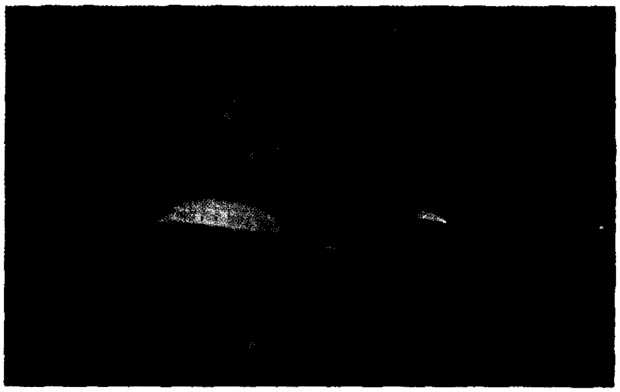
Habitat: A lowland weed that grows well in subaquatic to aquatic conditions.

Weedy nature: In saturated soils, seeds germinate throughout the growing season, enabling seedlings to emerge and establish after early-season weed control. A very aggressive weed in soils with high N levels.

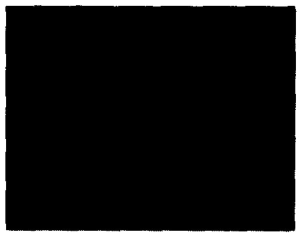
Agricultural concern: Can reduce rice yields 85%.

Mature plant

Inflorescence



Seedling



Seed, magnified

Weed name: *Sphenoclea zeylanica* Gaertn.

Synonyms: None

Local names:

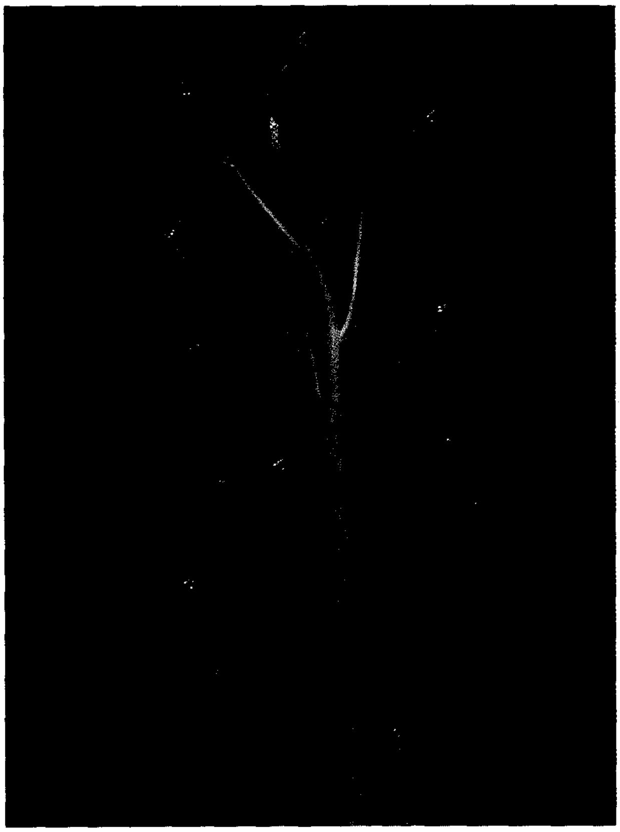
Country	Common name
Indonesia	goenda
Malaysia	cabaikera
Pakistan	mirch booti
Philippines	silisilihan (Tagalog)
Thailand	phak-pot
USA	gooseweed
Vietnam	x̄a bông

Life cycle: An annual broadleaf that grows as tall as 150 cm. Propagates by seeds.

Habitat: Grows in wet soils; prefers stagnant water.

Weedy nature: Grows and flowers throughout the year.

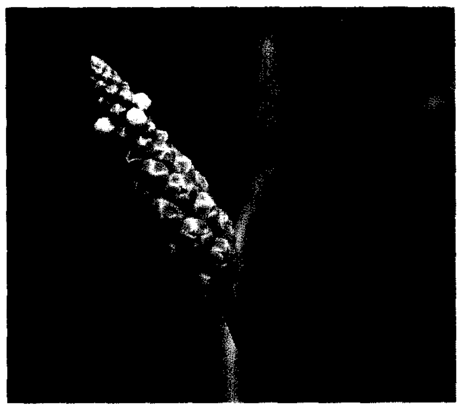
Agricultural concern: In dense populations, competes with rice for light and nutrients and can cause 45% yield loss.



Mature plant

Seed, magnified

Seedling



Inflorescence

Upland rice weeds

AIZOACEAE (carpet-weed family)

Weed name: *Trianthema portulacastrum* L.
Synonym: *Trianthema monogyna* L.
Local names:

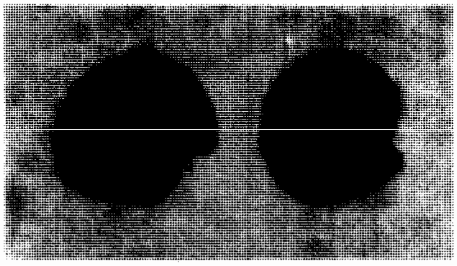
Country	*Common name*
Australia	giant pigweed
Cambodia	pti thmâr (Khmer)
France	pourpier courant
Ghana	adwera-akoa (Twi)
India	pasalikeera (Malayalam) saranai (Tamil) verrugoligeru (Telegu)
Mexico	verdolaga de hoja ancha
Nigeria	dáaburin sa aniyaá (Hausa)
Philippines	toston (Tagalog)
Thailand	phak bia hin
USA	horse purslane

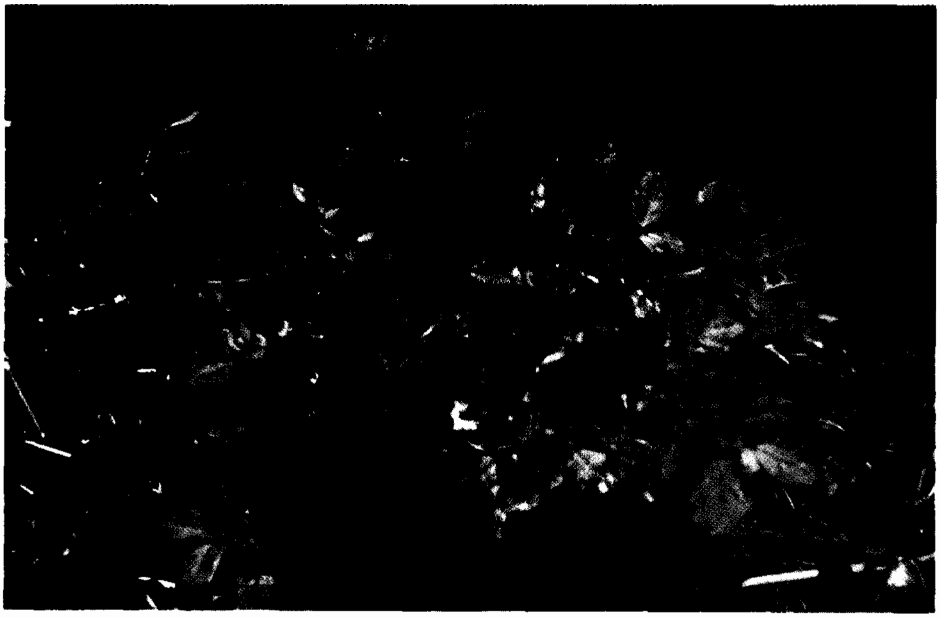
Life cycle: An annual broadleaf weed that can grow 40 cm tall. Propagates by seeds, which may be dormant for as long as 4 mo.

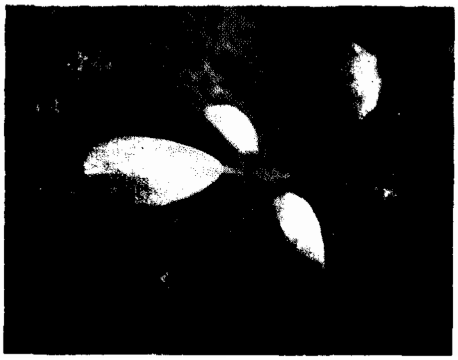
Habitat: Grows well in dry to moist soils.

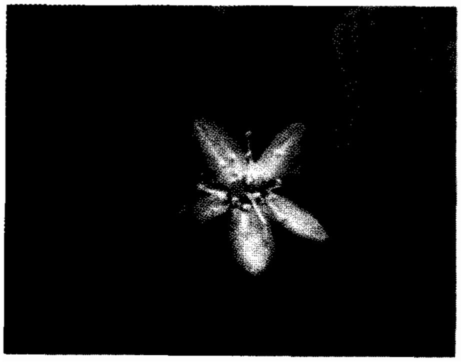
Weedy nature: A prolific seed producer with a short life cycle. Completes several life cycles within a year. Early vegetative growth is very rapid, especially in fertile soils.

Agricultural concern: If control in upland rice is delayed, can smother rice seedlings within 2-3 wk. Normally succumbs to insects after about 5 wk but can reduce rice yields 30%.


Seed, magnified

Mature plants in the field



Seedling


Inflorescence

Weed name: *Amaranthus spinosus* L.
Synonyms: None
Local names:

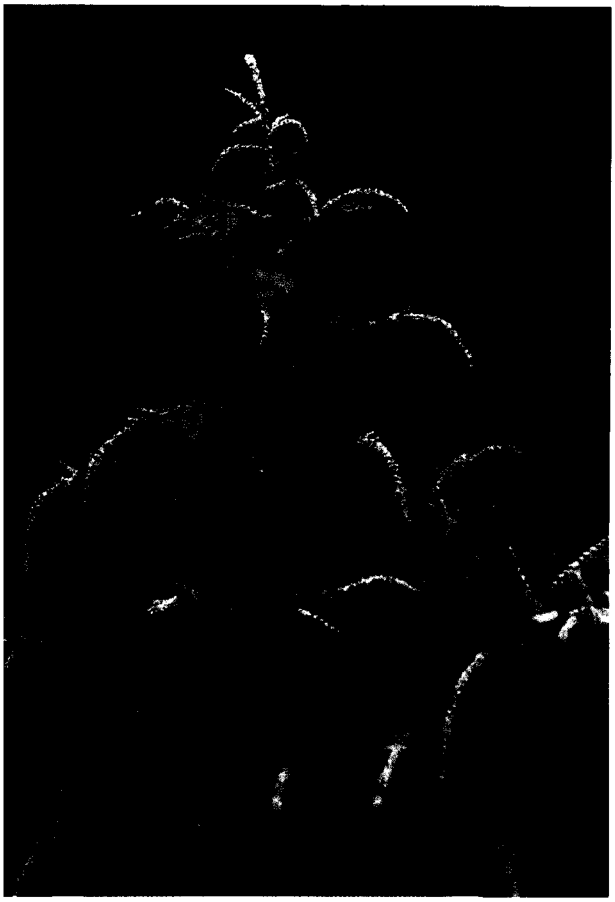
Country	*Common name*
Argentina	atato espinado
Australia	needle burr
Bangladesh	katanata (Bengali)
Brazil	caruru-de-espinho (Portuguese)
Cambodia	pti banla (Khmer)
El Salvador	huisquilite
France	amarante epi neuse, blette epineuse
Ghana	sraha nsoe (Twi)
India	kataili chauli (Gujrati)
	kantaneutia (Orya)
Indonesia	bajem duri (Javanese)
Mexico	quelite espinosa (Spanish)
Myanmar	tsu-gyi
Nigeria	tete elegun (Yoruba)
Philippines	oray, kulitis (Tagalog)
USA	spiny amaranth, spiny pigweed
Zimbabwe	imbowa

Life cycle: An annual broad leaf with red stems and spiny leaves. Can grow as tall as 120 cm. Propagates by glossy, dark-brown seeds, which are dispersed by wind and water. Germination may occur from a few days after harvest to about 5 mo. Germinates throughout the year when moisture is available.

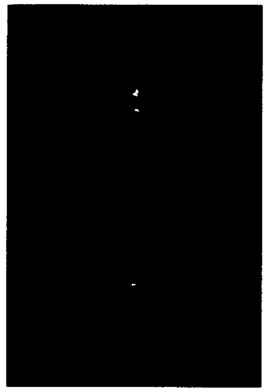
Habitat: Grows best in soils with no standing water.

Weedy nature: A prolific seed producer.

Agricultural concern: Very competitive in rice, can cause 80% yield loss.



Mature plant



Seed, magnified

Seedling

Inflorescence

Weed name: *Ageratum conyzoides* L.
Synonyms: None
Local names:

Country	*Common name*
Australia	billygoat weed
Brazil	erva-de-sao-joao
Colombia	hierba de chivo
France	agerate a feuilles de conyza
Ghana	efoe momoe (Fanti)
India	gundhuabon, mahakaua
Indonesia	ban do tan
Malaysia	ruptahi-ayam
Nigeria	imiesu (Yoruba)
Philippines	bulak-manok (Tagalog)
Sri Lanka	hulantala
Thailand	ya-tabsua
USA	tropic ageratum
Zambia	kabalakila (Chitonga)

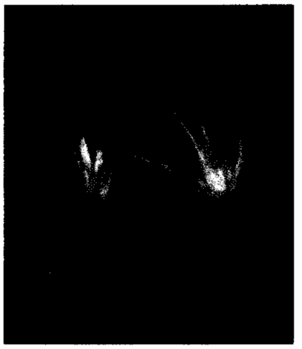
Life cycle: An annual broadleaf that can grow as tall as 120 cm at flowering. Propagates by seeds. Seed germinates throughout the year. In some areas, 50% of the seeds germinate within 2 wk after shedding; in other areas, the seed has a pronounced dormancy with about 1% of the seeds germinating after some months.

Habitat: Grows in dry to moist soils.

Weedy nature: Among the most common weeds found in rice. Rapidly colonizes cultivated areas. Has a short life cycle and completes several cycles in a year. Produces enormous amounts of seeds, which are dispersed by wind and water. Seeds germinate in a wide range of environments. As soon as the first stand is destroyed, another flush of seedlings grows.

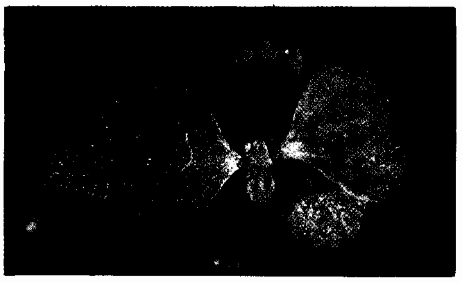
Agricultural concern: Can achieve a dense growth and compete with rice for nutrients and moisture. Can reduce rice yields 40%.

Mature plant



Seed, magnified

Inflorescence



Seedling

Weed name: *Commelina benghalensis* L.

Synonyms: None

Local names:

Country	*Common name*
Angola	ndakala
Bangladesh	kanaibashi (Bengali)
Ghana	nyame-bowu-an amewu (Fanti)
India	kona simolu (Assamese)
	kena (Marathi)
	kanchara kankaua (Orya)
Indonesia	gewor
Mauritius	herbe aux cochons
Myanmar	myet-cho
Philippines	alikbangon (Tagalog)
Samoa	Mauutoga
Thailand	phak plaap
USA	tropical spider wort
Zambia	nkumbaile

Life cycle: A creeping annual or perennial broadleaf that grows as tall as 40 cm. Propagates by seeds and stolons.

Habitat: Grows best in wet soil.

Weedy nature: Able to grow rapidly from stem cuttings. Shows rapid vegetative growth under favorable conditions and forms dense pure stands, smothering low-growing rice crop. Difficult to control because vegetative fragments regenerate easily and because it is resistant to many soil-applied herbicides.

Agricultural concern: Can cause 50% yield loss.

Mature plant

Seedling

Inflorescence

Seed, magnified

Weed name: *Cyperus rotundus* L.
Synonyms: None
Local names:

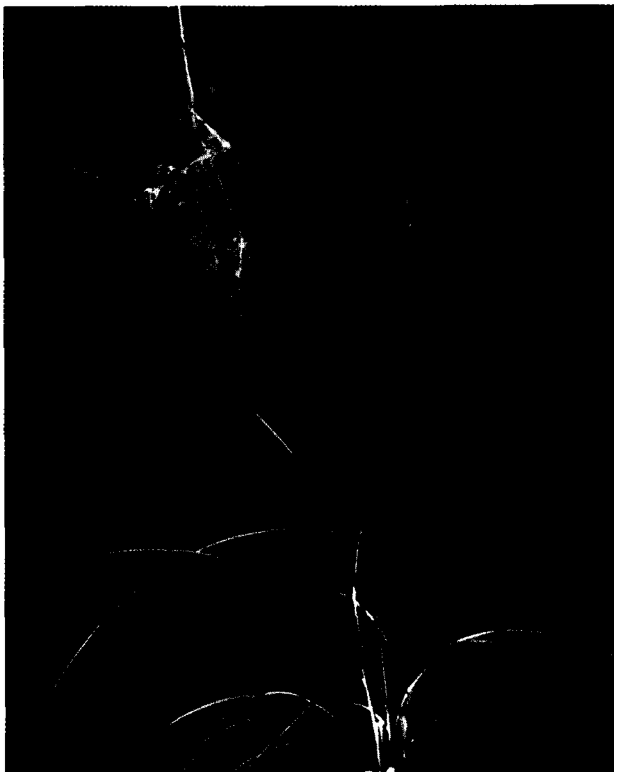
Country	*Common name*
Argentina	cebollita
Bangladesh	motha (Bengali)
Brazil	tiririca-comum (Portuguese)
Cambodia	smav kravanh chrouk (Khmer)
France	souchet rond
Ghana	hyia-me-nonum (Fanti)
India	nagar, motha (Orya) korai (Tamil) dila (Telegu)
Indonesia	teki
Malaysia	rumput haliyahitan (Malay)
Mexico	coquillo (Spanish)
Pakistan	deela (Urdu)
Philippines	mutha (Tagalog)
Senegal	ndidan (Wolof)
Sri Lanka	kalanthi (Sinhalese)
Thailand	haew moo (Thai)
USA	purple nutsedge

Life cycle: A perennial sedge that can grow as tall as 75 cm. Propagates mainly by tubers and produces few seeds.

Habitat: Grows well in moist soils.

Weedy nature: Persistent and difficult to control. Enormous amounts of tubers may be produced. Tubers, which have dormancy, can survive long periods of environmental stress. Difficult to control by cultivation because cultivation breaks the dormancy in the interconnected tuber leading to more vigorous sprouting.

Agricultural concern: Limits rice production by competing for water and nutrients. Can reduce rice yields 50%.


Mature plant


Rhizomes and tubers


Inflorescence


Seedling

Weed name: *Euphorbia hirta* L.
Synonyms: *Chamesyce hirta* (L.) Millsp., *Euphorbia pilulifera* L.
Local names:

Country	*Common name*
Bangladesh	bara dudhia (Bengali)
Brazil	erva-de-Santa-Luzia (Portuguese)
France	euphorbe poilue
Ghana	ahinkogye (Twi)
India	dudhi (Marathi)
	baridhudhi (Orya)
	amman paccharisi (Tamil)
Indonesia	gendong anak (Javanese)
Malaysia	ara tanah (Malay)
Mexico	hierba dela golon drina (Spanish)
Myanmar	majo
Nigeria	buje (Yoruba)
Philippines	gatas-gatas, botobotonis (Tagalog)
Thailand	namnom raatchasee (Thai)
USA	garden spurge
Vietnam	cô sua lông

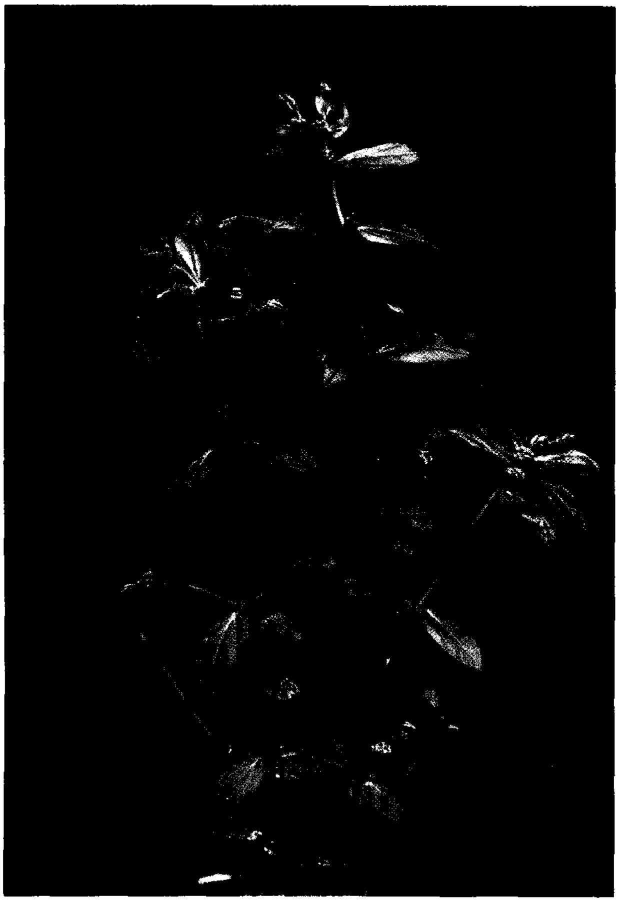
Life cycle: An annual broadleaf that grows as tall as 30 cm. Propagates by seeds.

Habitat: Grows in dry or moist soils.

Weedy nature: A prolific seed producer with a life cycle of about 1 mo. Flowers throughout the year. Dense stands develop easily within a short time.

Agricultural concern: Can reduce rice yields 30%.

Seed, magnified



Mature plant

Seedling

Inflorescence

Weed name: *Cynodon dactylon* (L.) Pers.

Synonyms: None

Local names:

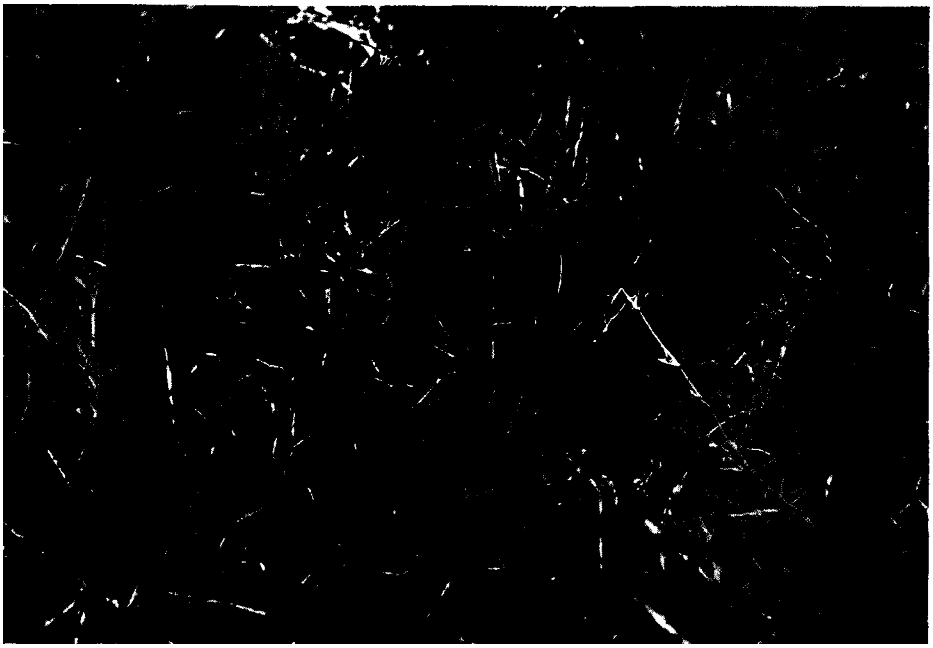
Country	*Common name*
Angola	usila
Argentina	chepica (Spanish)
Brazil	capim deburro (Portuguese)
Cambodia	smav anchien (Khmer)
Chile	pasto gallina (Spanish)
France	herbe des bemu das
India	arugampulu, doob (Tamil) garika (Telugu)
Indonesia	gigirinting
Mauritius	chiendent
Pakistan	dub
Philippines	kotatai, kawad-kawad (Tagalog)
Sudan	nagil
USA	bermudagrass
Vietnam	co chi
Zambia	kapinga

Life cycle: A creeping perennial grass. Can grow as tall as 40 cm. Propagates almost exclusively by stolons and rhizomes and produces few seeds. Seeds are very small but can survive about 50 d submergence. As long as moisture is present, seeds can germinate throughout the year.

Habitat: Adapted to dry or moist well-drained soils.

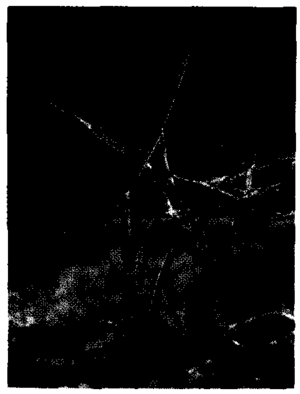
Weedy nature: Rhizomes and stolons root easily at the nodes and reestablish immediately after cutting. Rhizomes grow deeply in the soil, enabling the weed to withstand extreme environments. A common and persistent weed, very competitive, with rapid shoot growth. Difficult to control because detached fragments regenerate easily.

Agricultural concern: Can reduce rice yields by 55%.



Mature plant in the field

Inflorescence



Seedling

Weed name: *Digitaria sanguinalis* (L.) Scop.

Synonyms: None

Local names:

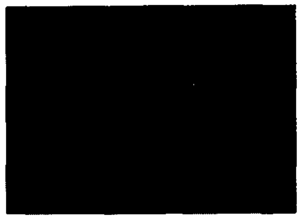
Country	*Common name*
Brazil	milha-de-pendao (Portuguese)
Colombia	conejo
France	digitaire sun guine, panic sanguin
Indonesia	suket djrempak
Myanmar	myet-naya
Nicaragua	manga larga (Spanish)
Peru	digitaria (Spanish)
Philippines	pagpagai (Bontoc)
Thailand	yaa teenka
USA	large crabgrass
Venezuela	pendejuelo (Spanish)

Life cycle: An annual grass that can grow as tall as 70 cm. Propagates by seeds, which have a short dormancy after shedding.

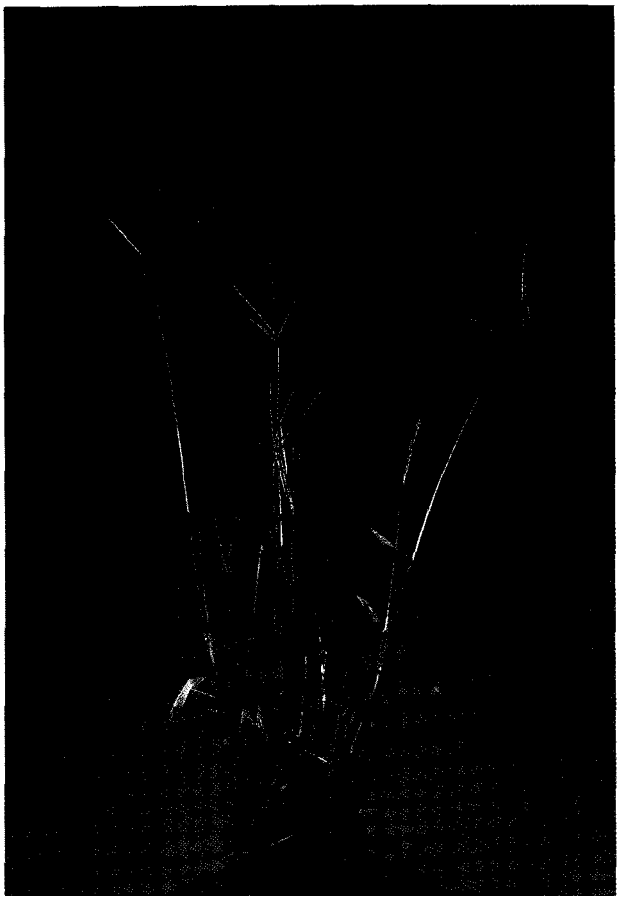
Habitat: Grows in moist to wet soils.

Weedy nature: A prolific seed producer with enormous tillering ability. A few plants can spread to occupy a large area. An elaborate root system gives it an advantage in below-ground competition. Regrowth after weeding is rapid.

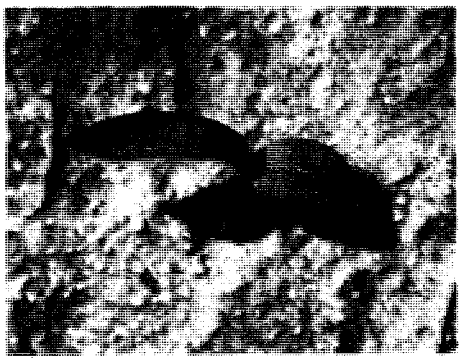
Agricultural concern: Very competitive in rice; can reduce yield 70%.



Seed, magnified



Mature plant



Seedling

Inflorescence

Weed name: *Echinochloa colona* (L.) Link

Synonyms: None

Local names:

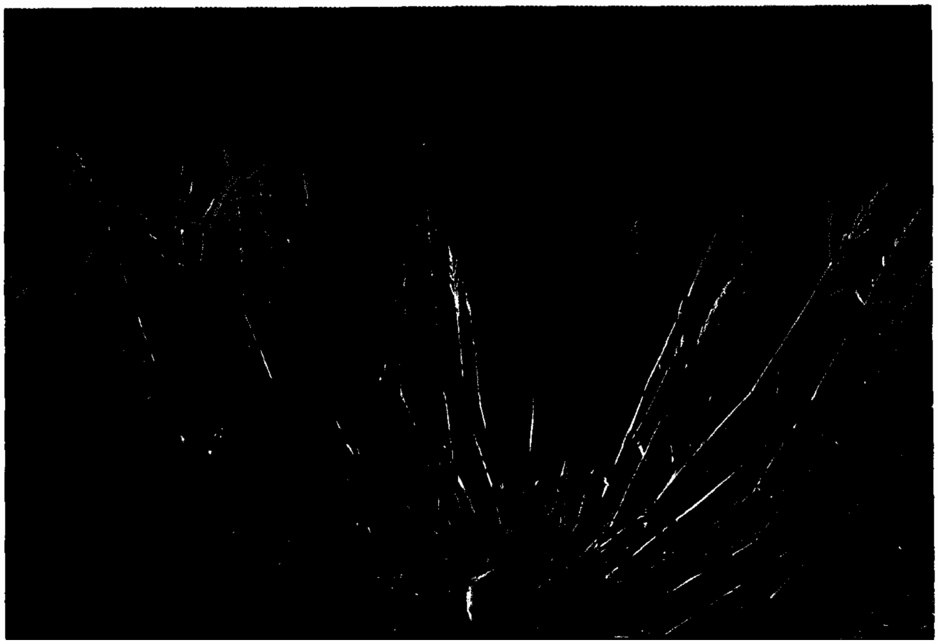
Country	*Common name*
Argentina	grama pintada (Spanish)
Australia	awnless barn yardgrass
Egypt	abu-rokba (Arabic)
France	ble de dekkan
India	kauada, sawank (Malayalarn)
Indonesia	roernpoet bebek
Iraq	dahnan
Malaysia	padi burong, rumput kusa-kusa
Philippines	pulang puit (Tagalog)
Sri Lanka	gira-taro (Sinhalese)
Sudan	difera
Thailand	ya-plong
USA	junglerice
Zambia	zibaila (Chitonga)

Life cycle: An annual grass that can grow as tall as 90 cm. Propagates by oval, tan to brownish seeds. In the tropics, seed has little or no dormancy and germinates throughout the year when moisture is available.

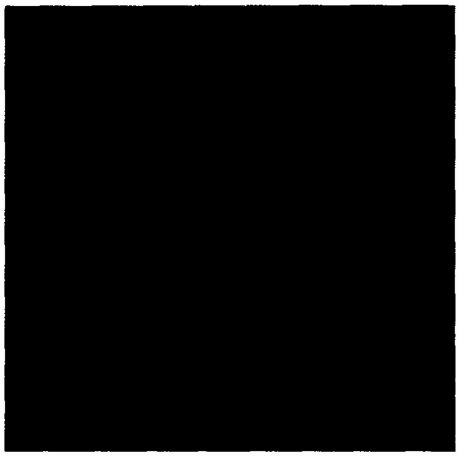
Habitat: Normally grows under dryland conditions: does not thrive in continuously flooded soils.

Weedy nature: A prolific seed producer; has a short life cycle and can complete several life cycles in a year. Easily adapts to the environment—for example, grows erect when in competition with rice and prostrate when not in competition. Young plants resemble rice, which makes hand weeding difficult at early weed stages.

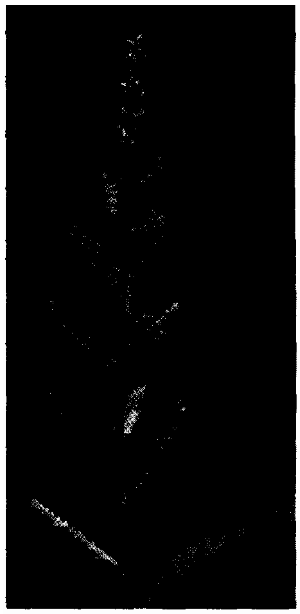
Agricultural concern: Competitive in rice; can reduce yields 85%.

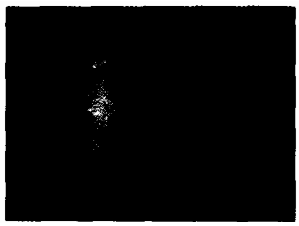


Mature plant



Seedling





Seed, magnified

Weed name: *Eleusine indica* (L.) Gaertn.

Synonyms: None

Local names:

Country	*Common name*
Australia	crowsfootgrass
Brazil	capim-pe-de-galinha
Cambodia	smav choeung kras (Khmer)
France	eleusine des indes
India	kodai, mandla
Indonesia	godong ula (Javanese)
Malaysia	rumput sambou (Malay)
Mexico	pata de gallo (Spanish)
Myanmar	sin-ngo-let-kya
Nigeria	gbegi (Yoruba)
Philippines	sabung-sabungan (Tagalog)
Sri Lanka	bela-tana (Singhala)
Thailand	yah teenka
Uganda	kasibanti
USA	goosegrass
Zambia	lukata (Chitonga)
Zimbabwe	rapoko

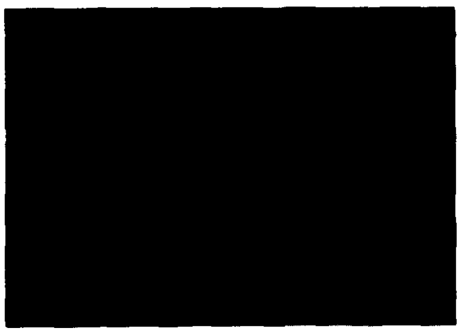
Life cycle: An annual grass that grows as tall as 60 cm. Propagates by brownish-black seeds that germinate throughout the year when moisture is available.

Habitat: Grows best in moist to wet soils.

Weedy nature: Produces enormous amounts of seeds—40,000 seeds per plant have been recorded. Flowers after 30 d and can complete several life cycles in a year, which leads to heavy population buildup. Develops an extensive root system.

Agricultural concern: Competitive in rice; can reduce yields 80%.

Mature plant



Seedling

Seed, magnified

Inflorescence

Weed name: *Imperata cylindrica* (L.) Raeuschel

Synonyms: None

Local names:

Country	*Common name*
Argentina	carrizo marciego (Spanish)
Cambodia	sbauv (Khmer)
Cameroon	baya
Fiji	pi
France	imperate
Ghana	segogro (Twi)
India	dabh
Indonesia	alang-alang
Ivory Coast	nse
Kenya	nyeki
Madagascar	tena
Mauritius	lalang
Nigeria	ekan (Yoruba)
Philippines	kogon (Tagalog)
Tanzania	motomoto
Thailand	yoa khaa
USA	cogongrass
Zimbabwe	ibamba

LIfe cycle: A perennial grass that grows as tall as 120 cm. Propagates by seeds and creeping rhizomes. Seeds have little or no dormancy.

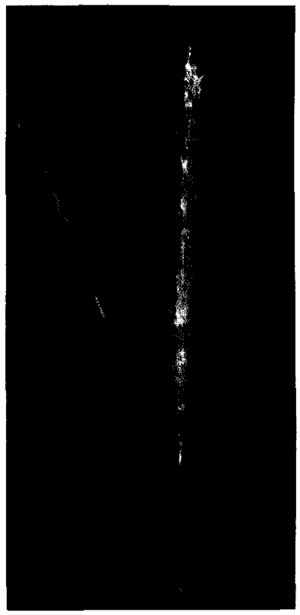
Habitat: Adapted to dry and moist soils.

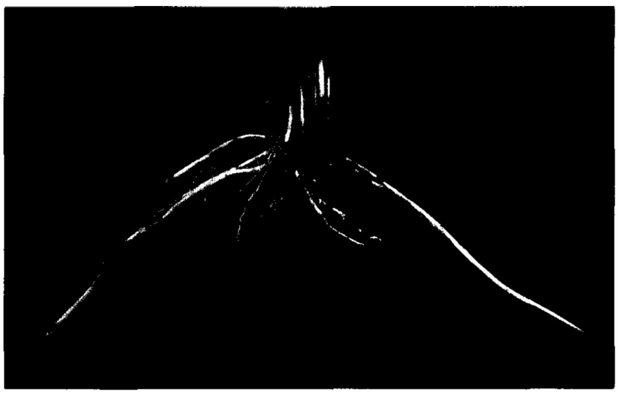
Weedy nature: Produces large amounts of seeds and a tremendous mass of rhizomes, which make weed control by any means difficult.

Agricultural concern: A serious weed in upland areas. Many infested ricefields are abandoned.

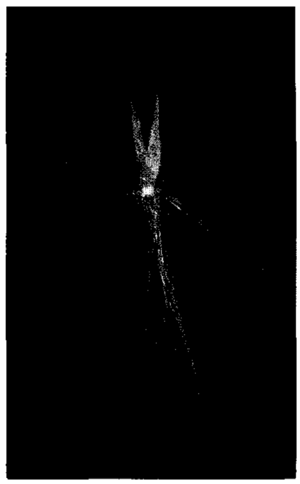
Mature plant

Inflorescence





Rhizomes



Seed, magnified

Weed name: *Rottboellia cochinchinensis* (Lour.) W.D. Clayton

Synonym: *Rottboellia exaltata* L.f.

Local names:

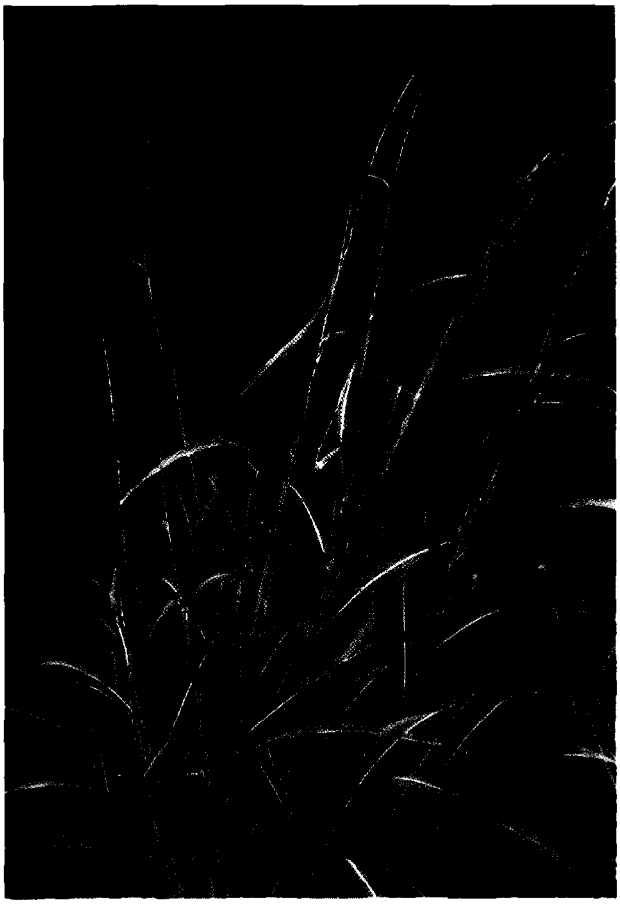
Country	*Common name*
France	herbe bettle-elise
Ghana	nkyenkyemma (Twi)
Indonesia	bandjangan
Philippines	aguingay (Tagalog)
Spain	caminadora
Thailand	yaa prong khaai
USA	itchgrass
Zambia	mulungwe
Zimbabwe	shamvagrass

Life cycle: An annual grass that can grow as tall as 3 m. Propagates by seeds, which have a dormancy of 1-4 mo.

Habitat: Prefers well-drained soils.

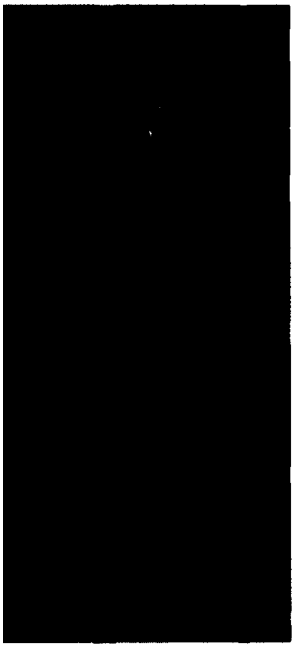
Weedy nature: Produces many seeds, which shatter easily. Grows and flowers throughout the year. These characteristics, combined with rapid growth and sharp irritating hairs, make it very competitive.

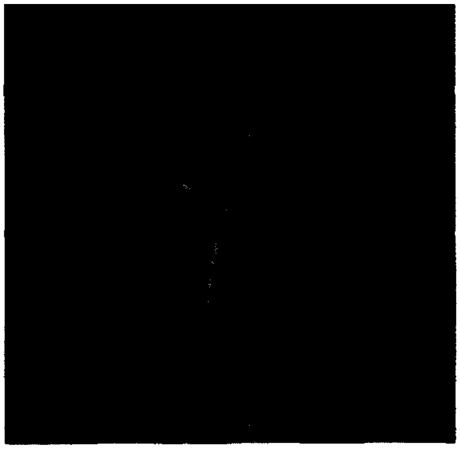
Agricultural concern: Very aggressive in upland areas, where it can completely shade out rice. Total yield loss is normal.



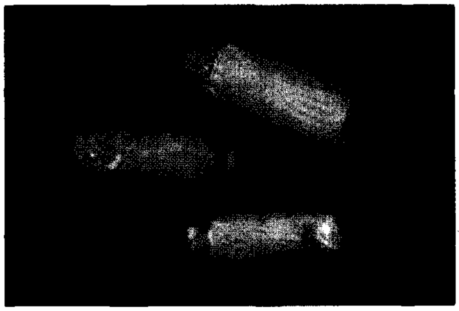
Mature plant

inflorescence





Seedling



Seed, magnified

Weed name: *Portulaca oleracea* L.
Synonyms: None
Local names:

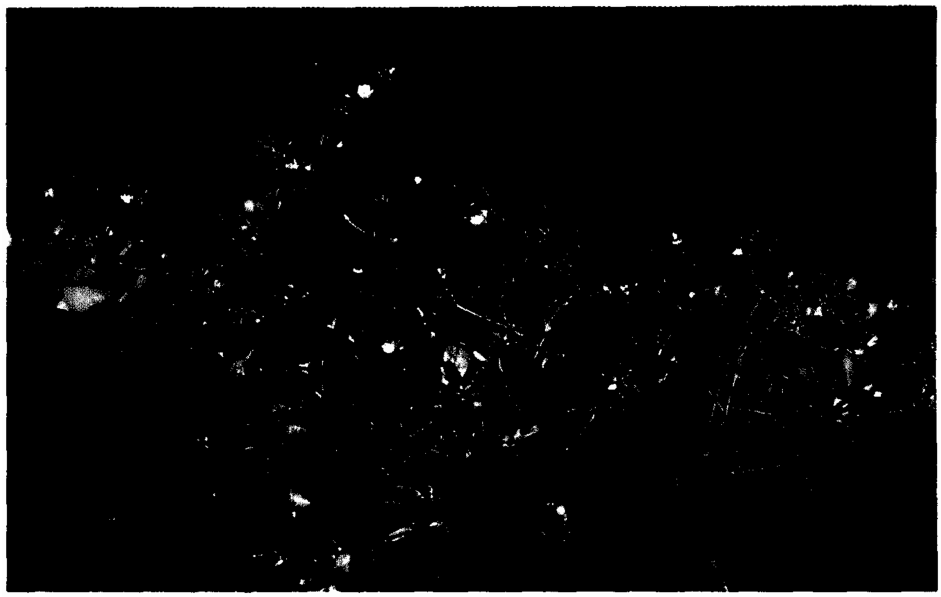
Country	*Common name*
Brazil	beldroega
Cambodia	kbetchoun (Khmer)
France	comun pourpier
Ghana	adwera (Twi)
India	baralunia, kufa (Orya) karie, keerai (Tamil)
Indonesia	gelang
Malaysia	gelang pasir
Mauritius	pourpier
Mexico	verdolaga comun (Spanish)
Myanmar	mya-byit
Nigeria	esan omode (Yoruba)
Pakistan	kulfa, lunak
Philippines	ulasiman (Tagalog)
Thailand	phak bia yai
Vietnam	rausam
Zambia	yelele (Chitonga)

Life cycle: An annual broadleaf with succulent and fleshy stems that are sometimes reddish brown. Grows as tall as 50 cm. Propagates by seeds and stem cuttings. Produces numerous black seeds that normally are not dormant.

Habitat Grows in upland fields.

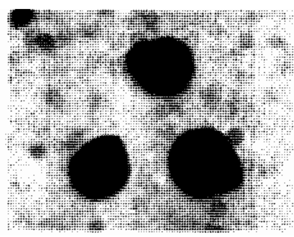
Weedy nature: A prolific seed producer that grows quickly and flowers and produces seeds throughout the year. Difficult to control by cultivation because plants with flower buds have enough water stored in the stems and leaves to complete seed production after they have been cut. Cut fleshy stems root easily upon contact with soil. Under drought stress, sheds its leaves and survives until water becomes available. Can complete its life cycle within 6 wk. Seeds can remain viable for a long time.

Agricultural concern: Can cause 30% yield loss.


Mature plant


Seedling


Inflorescence


Seed, magnified

Deepwater rice weeds

PONTEDERIACEAE (pickerel-weed family)

Weed name: *Eichhornia crassipes* (Mart.) Solms

Synonyms: None

Local names:

Country	*Common name*
Bangladesh	kachuripana
Brazil	aquapede-flor-roxa
Cambodia	kamphlok (Khmer)
France	eichhornie, jacinthe d'eau
India	jalkumbhi, kulauoli (Malayalam) akasa-thamarai, neithama rai (Tamil)
Indonesia	etjeng padi
Malaysia	keladi bunting
Myanmar	beda-bin
Thailand	phak top chawaa
USA	water hyacinth
Vietnam	luc-binh

Life cycle: A perennial, flowering, aquatic, monocotyledonous, broadleaf plant. It spreads by producing vegetative offshoots and seeds.

Habitat: Adapted to fresh water; . found in rivers, canals, and reservoirs. Moves into deepwater rice with water currents or strong winds.

Weedy nature: Grows quickly and crowds out rice through shading. Impedes water flow in irrigation canals and causes large amount of water loss through evapotranspiration.

Agricultural concern: Can completely destroy deepwater rice by crowding the rice plants.

Mature plant

Inflorescence

Weed name: *Ipomoea aquatica* Forssk.

Synonym: *Ipomoea reptans* (L.) Poir.

Local names:

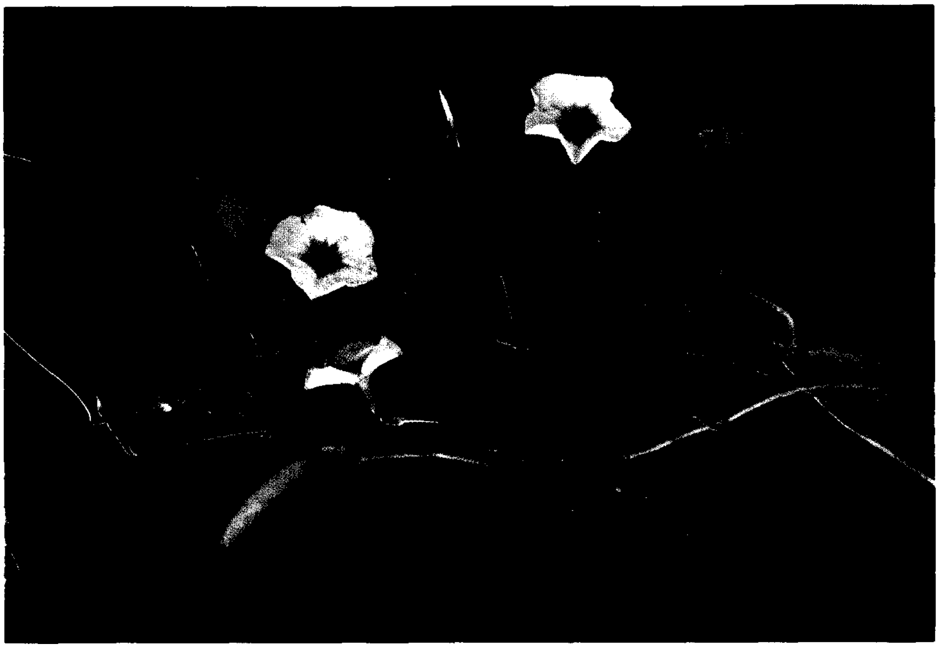
Country	*Common name*
Cambodia	trâkuon (Khmer)
India	vellai keerai, kaladana, nilkalami (Tamil) tooti koora (Telugu)
Peru	camotillo
Philippines	kangkong (Tagalog)
USA	swamp morning glory

Life cycle: A perennial broadleaf vine that propagate by seeds and stem cuttings.

Habitat: Requires aquatic or wet conditions.

Weedy nature: Fast-growing and wide-spreading. Roots at the nodes. Also floats on water.

Agricultural concern: Can cause 30% yield loss.



Mature plant

Flower

Chapter 3

Weed control

Weeds have always reduced rice yields. As a result, many different weed control methods have evolved. Farmers consider financial resources and availability of labor in deciding what weed control method to use. Problems of input availability, availability of new technologies, specific weed problems, farm size, and availability of family labor are basic management factors they take into account in making weed control decisions.

Planning effective control

Planning is important in making appropriate decisions on weed control. Unfortunately, weed control often is not planned. The decision to control is not made until the problem has become serious, when control may be uneconomical, ineffective, or even impossible.

Advance knowledge of weed problems can be obtained by surveying and recording the weed species in a ricefield after rice emergence, at midseason, and at harvest. This record is useful in planning weed control and crop rotation programs.

Control methods

Weed control methods can be grouped into cultural, manual, mechanical, chemical, and biological techniques. Each control method has advantages and disadvantages, and a single method is rarely adequate for effective and economical control.

Cultural methods

A basic principle of cultural control is to increase the competitive ability of rice and enable it to suppress weed growth. A vigorous rice crop competes more effectively with weeds than does a less vigorous crop. Cultural control methods include prevention of weed introduction, land preparation, crop rotation, cultivar selection, time of seeding, planting method, plant population, fertilization, and water management.

Prevention of weed introduction. Although weed seeds may be introduced in ways beyond a farmer's control, many aspects of weed dispersal are controllable. Control involves preventing the introduction, establishment, and spread of weeds, seeds, tubers, and rhizomes in a crop or between two crops. In rice, this is best achieved by planting rice seeds free of weed seeds in weed-free seedbeds and by seeding rice or transplanting seedlings in weed-free fields. Field borders not cropped or not kept clean are a constant source of weed seeds. Levees and irrigation canals also must be kept weed free. Weed seeds can be introduced into a clean area by machinery or tillage equipment that are carrying weed seed-contaminated soil.

Land prepration. Land preparation includes plowing, disking, harrowing, soil puddling, and land leveling. A well-prepared field allows the rice crop optimal early growth. Careful land preparation primarily provides weed-free conditions at planting.

In general, tillage practices most affect plant growth during germination, seedling emergence, and stand establishment stages. Plowing buries weed seeds to depths from which they cannot emerge, but it also brings some weed seeds to the soil surface where conditions favor germination. Thus, a new flush of weed seedlings occurs after each cultivation.

To destroy as many weeds as possible, the interval between successive cultivations should be long enough to allow many weed seeds to germinate and be killed by later harrowings. This can reduce a weed seed population about 50%. Tillage during the dry season is a practical method of controlling perennial grasses such as *Paspalum distichum, Cynodon dactylon, Oryza longistaminata,* and *Imperata cylindrica;* it desiccates the perennial structures. In temperate areas, tubers and rhizomes brought to the soil surface are killed during cold, dry periods.

The type of land preparation needed for rice depends on the water management system. Land preparation can be classified broadly as wetland tillage, dryland tillage, and limited tillage.

Wetland tillage is common in most tropical Asian countries. Traditionally, it involves plowing and puddling the soil. The processes involved are

- flooding the field for about 7 d.
- plowing the soil to 10- to 20-cm depth, to bury the weed seeds and weed and rice stubble.
- harrowing to break up big clods in the soil. Two to three harrowings are done at 7- to 10-d intervals.
- leveling the field.

Puddling hastens crop establishment and tillering of transplanted rice seedlings. This results in vigorous rice growth and increases the crop's competitive ability against weeds. During transplanting, weed seedlings also are trampled and incorporated into the soil.

Dryland tillage is the basis of many rice culture systems. Almost all rice-growing areas in the United States and southern Australia, most of Latin America and West Africa, and parts of tropical Asia and Europe use dryland tillage. In dryland preparation, soil clods are broken up so they do not interfere with seeding and seedling emergence. The seedbed is left rough because germination of weed seeds, which are usually much smaller than rice, is encouraged by fine tilth. Rice is seeded immediately following the last tillage operation, to give rice an even start with weeds.

Limited tillage covers a range of land preparation techniques, from zero tillage to elimination of one preseeding cultivation. Herbicides replace the omitted tillage operations. Limited tillage has soil conservation advantages.

Smallholders who use slash-and-burn land preparation are practicing limited tillage. Rice is planted in a dead mulch with only enough soil disturbance to cover the seed. Minimum and zero tillage techniques can result in timely land preparation and savings in labor, water, power, and capital.

Under limited tillage, perennial weed problems increase over time. Where perennial weeds are controlled, limited tillage can be used for both upland and lowland rice culture.

Herbicide use is an integral part of a limited tillage system. However, if inappropriate herbicides are used, perennial broadleaf weeds and grasses common in fallow in the tropics are not controlled and significant yield losses can occur. Plowing and harrowing more often does not eliminate the need for direct weed control. Farmers still must follow land preparation with other weed control methods. It is more cost-effective to reduce preplanting harrowings and combine those with direct weed control methods.

Crop rotation. Weeds adapt to the growing conditions of rice. A ricefield that is tilled regularly has more annual weeds than many undisturbed habitats, which have more perennial weeds. Continuous cropping encourages the buildup of difficult weeds.

Each rice culture is associated with a characteristic weed problem, influenced by the cultural practices used. Lowland rice has predominantly water-tolerant weeds, upland rice has mostly dryland weeds. Rotation of lowland rice with an upland crop reduces infestation by water-tolerant weeds in the rice and by upland weeds in the upland crop. Growing a broadleaf crop in rotation with rice allows the use of herbicides effective against grassy weeds, which are difficult to control in rice.

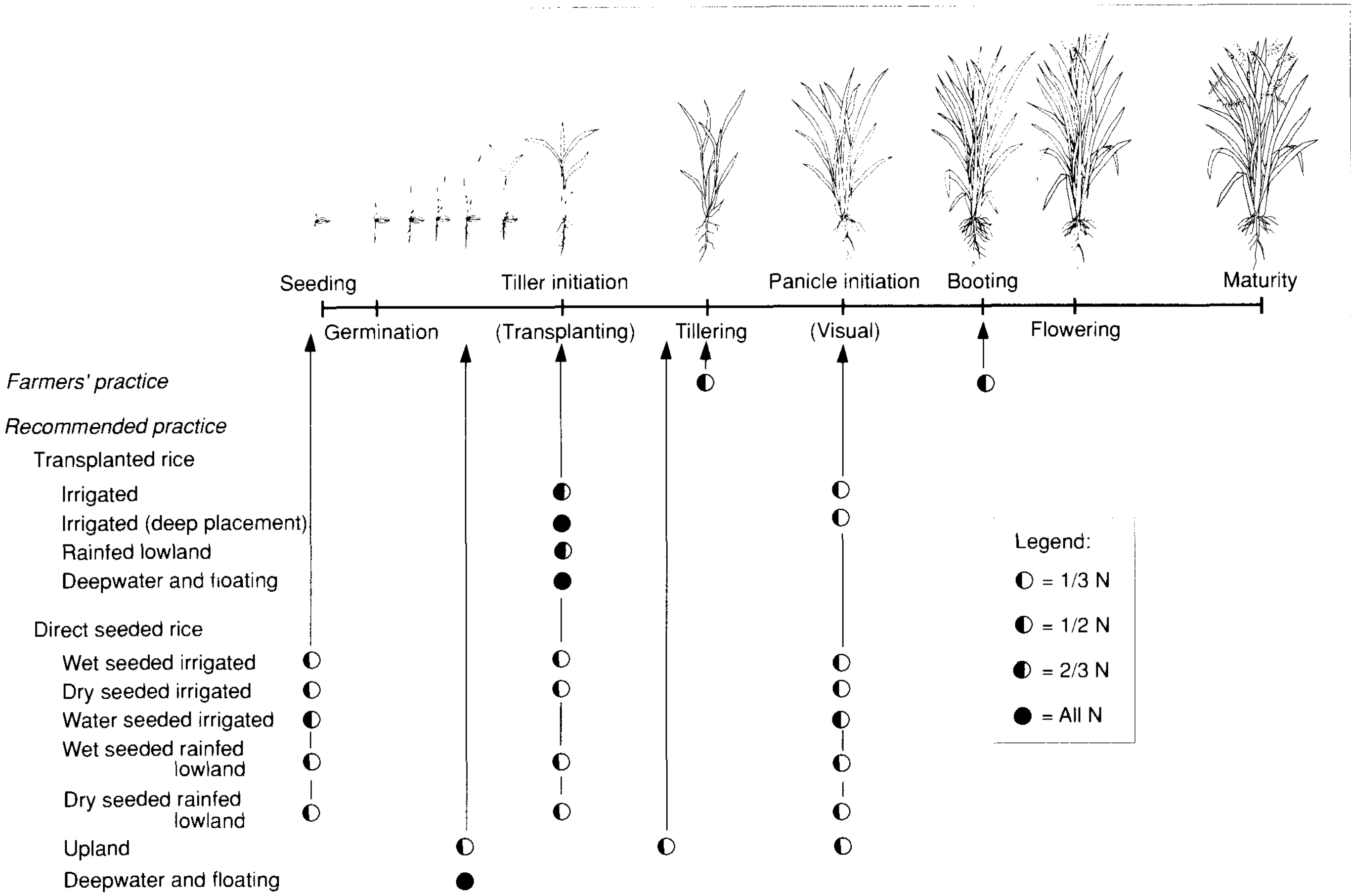
Varietal selection. Improved rice cultivars resistant to diseases and insects are more competitive against weeds than are traditional rices. Traditional, tall varieties with droopy leaves are thought to be more competitive against weeds, but research has failed to measure competitive differences that are due to cultivar. The height advantage of traditional varieties is offset by the high-tillering capacity of modern high-yielding cultivars. Traditional varieties also have other attributes, such as susceptibility to lodging, that make them undesirable.

Modern rice cultivars, although competitive against weeds, can have more weed problems than traditional rice cultivars. The erect leaves and short stature of modern rices allow light to reach the soil and stimulate weed seed germination. Within the crop canopy, small differences in crop height affect the quantity and quality of light received by weeds. The high nitrogen rates used on modern cultivars also aggravate weed problems. This makes competitiveness with weeds a breeding objective for modern rices. When available, such cultivars should be used.

Time of seeding. When soil moisture is not limiting, allowing weeds to germinate before tilling and seeding rice reduces weed populations. Rice seeding, however, should not be delayed beyond the optimum time of planting.

In rainfed rice crops, time of seeding is critical. Rice plants affected by drought become stunted and cannot compete effectively with weeds that are more tolerant of drought. Dry weather after sowing can reduce the number of weeds that germinate near the soil surface, but rice seed germination will also be delayed. Perennial and large weed seeds from deeper soil depths are still able to germinate and compete strongly with the rice crop.

Planting method. Planting method affects the ability of rice to compete with weeds. Rice may be transplanted or drill seeded in straight rows, or broadcast seeded. Straight-row planting is necessary for hand weeding and for using mechanical weeders. In a broadcast crop, mechanical and hand weeding damage the rice plants.



3.1 Recommended times to apply N fertilizer in different rice cultures. Fertilizer is applied basally and incorporated, or placed 10-cm deep in the soil (deep placement) at transplanting or, for direct seeded rice, before seeding. Fertilizer is topdressed 3-9 d before panicle initiation (48-57 d after sowing [DAS] for 110- to 115-d duration varieties, or 11-14 d before panicle initiation [56-64 DAS] for 125 to 130-d duration varieties).

Transplanting rice in a weed-free field gives seedlings a head start against weeds. If water management is adequate, this competitive advantage is maintained throughout most of the transplanted rice's growth. Age of seedlings at transplanting, however, affects the crop's competitive ability. The older the seedlings, the more competitive they are. With inadequate weed control, older seedlings (20- to 30-d-old) are more desirable than younger seedlings. With young seedlings, flooding the crop to control weeds risks drowning the seedlings.

Deep drilling rice seed, which delays seedling emergence, enables weed seeds near the soil surface to germinate earlier than the rice, making the weeds more competitive.

Plant population. Rice plant spacing is an important production factor. Density per unit area determines the amount of shade created to help rice compete with weeds. Light penetration into the rice canopy increases as row spacing increases. That stimulates weed growth and reduces rice grain yields.

The optimum spacing essential for proper rice crop development and high grain yields depends on cultivar, soil fertility, and season. In the Philippines, the maximum return (above variable costs) has been obtained with manual transplanting at 20- x 20-cm spacing.

In broadcast seeded flooded rice, high seeding rates are usually used to help control weeds, but high seeding rates cannot substitute for direct control methods. No weed control benefit is obtained when seeding rate is increased beyond the optimum 100 kg/ha that will give adequate crop stand establishment.

Fertilization. Nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) are the nutrients most commoly applied by rice farmers. Nitrogen encourages rapid vegetative growth (increased height, tiller number, and leaf size), with the resultant shade helping to suppress late-germinating weeds. Phosphorus encourages rice root development and increases tillering. Vigorous rice root growth is advantageous in below-ground competition with weeds for moisture and nutrients.

Weeds take up nutrients in large quantities, however, and sometimes absorb fertilizer faster than rice. When weeds are not controlled effectively, however, fertilization is of little significance. There is little or no response to N by rice in shade, and P and N left on the soil surface will stimulate growth of shallow weed seeds. At high fertilization levels, it is not possible to produce high rice yields without weeding.

Early- to midseason N applications are beneficial to rice, but weeds must be controlled to maximize the effect of N on grain yield. Figure 3.1 shows the best time to apply N in various rice cultures.

Water management. Since ancient times, water has been used to manage weeds in ricefields. Many nonaquatic weeds do not survive in submerged environments and many aquatic weeds do not survive in upland environments.

Water control during the early rice growth stages has a major effect on weed control. As weeds become established, controlling them through water management is more difficult. Grassy weeds can be largely eliminated by continuous flooding to 15-cm depth maintained throughout crop growth. The response of broadleaf weeds and sedges to different water depths varies. After continuous flooding, C_3 weeds (see page 3) will be dominant.

Weed problems intensify in irrigated and rainfed lowland rice when water supply is inadequate. Increased weed control benefits are obtained with improved water supply and control, high levels of fertilizer, and improved cultivars used in concert.

Increasing water depth to control weeds as part of integrated weed management is cost effective. When combined with other direct weed control methods, increased water depth can give considerable savings in production costs.

Timely and thorough drainage of flooded fields reduces aquatic weed problems.

Manual methods

Manual weed control includes burning, hand pulling, and mechanical hand weeding. These labor-intensive methods are the oldest and, in many cases, the farmer's only means of controlling weeds in rice, and are highly effective.

Several hand tools are still the principal means of rice weed control in many developing countries. But manual methods are slow, unattractive, and tedious, and are often carried out after the rice crop has been severely damaged by weeds. Hand weeding is often ineffective on weeds with special survival mechanisms such as the rice mimics (e.g., *I. rugosum*) and deep-rooted perennial weeds. Rice mimics are difficult to distinguish from rice at the early growth stage. Repeated hand weedings are necessary to effectively control all weeds.

Burning. Burning, common under the slash-and-burn system of land preparation, kills weed seeds and weed seedlings, gets rid of unwanted vegetation, and reduces the amount of weed seeds returned to the soil. It also encourages germination of weed seeds near the soil surface. Thorough burning can keep the ricefield free of weeds for the first 2-3 wk.

Burning saves labor, is low cost, and adds neutralizing ash to low-pH soils. On the other hand, widespread uncontrolled burning leaves the soil bare, increasing soil erosion and loss of N and other nutrients. Careful planning and rational use can minimize the adverse effects of burning. Local regulations on burning should be followed.

Hand pulling. Hand pulling controls weed seedlings growing near and between rice plants where implements are difficult to use. Hand pulling is not effective in dry soil, where weed seedlings break and resprout easily. Frequent hand pulling is necessary for effective weed control because very small weed seedlings that are not removed grow quickly to reinfest the ricefield. This method is the most labor intensive of all weed control measures, and is best suited to small farms.

In some places, lowland rice farmers trample weeds instead of hand pulling.

Mechanical weeding. Weeding using hand tools is common in almost all tropical rice-growing areas. But the degree of weeding and the problems associated with it largely depend on the type of rice culture. In many countries, hand tools such as the hoe, narrow spade, Swiss hoe, knife, machete, and pointed sticks are primarily used to remove weeds in upland rice. Weeds within rows must be removed by hand. The amount of labor required to weed 1 ha ranges from 10 to 30 d.

Weeding by machine involves the use of hand-pushed or powered weeders, and is feasible only where rice is planted in straight rows. Conventional single-row rotary weeders require 80-90 labor h to weed 1 ha, and are difficult to use because they must be moved back and forth. The IRRI-developed cono weeder uses a conical-shaped rotor to uproot and bury weeds. It smothers weeds satisfactorily in a single pass. The single-row cono weeder is about 2 times faster (40-50 labor-hours/ha) and the two-row cono weeder 3-4 times faster (25-35 labor-h/ha) than the conventional push-pull rotary weeder.

Weeds within the crop rows are difficult to remove with a cono weeder. If the soil is too dry, the weeder rolls over the soil surface without burying the weeds. The cono weeder is also ineffective in standing water. To achieve the best results in transplanted rice, a weeder should be run in two directions, at right angles to each other. Mechanical weeding should be supplemented by hand pulling the weeds that are close to the rice plants. The time required for weeding by this combination is less than for hand pulling alone.

Biological methods

Several biological agents, such as insects, mites, and fungi, have been used successfully to control rice weeds. Biological agents are selective in their control action and their activity may be restricted to a single weed.

Biological control programs may be applicable to an introduced perennial weed growing in areas that are seldom disturbed, such as pastures, forests, and water bodies. In a rice cropping situation with a mixed weed flora, the selective control of a single weed will not solve the weed problem. The biological agents also work slowly and may take from 30 d to 10 yr to control the weeds. For these reasons, biological weed control usually is not used by rice farmers.

The possibility of using tadpole shrimp (*Triopus longicaudatus, T. granaris,* and *T. cancriformis)* for nonselective weed control in transplanted rice has been demonstrated in Japan. The small crustaceans feed on weed seedlings and disturb their roots by mechanical agitation of the soil. Labor for hand weeding in farmers' fields was reduced 70-80% in initial field trials with tadpole shrimp. Unfortunately, the shrimp is nonselective and becomes a pest in areas where rice is direct seeded (Matsunaka 1975).

The ability of a thick Azolla mat to suppress weed development has long been observed. In rice, a 79% reduction in total weed weight at 50 d after transplanting has been measured. Growth of Azolla reduced the amount of light and oxygen content of water; this has been suggested as an explanation of how Azolla suppresses weeds (IRRI 1987). Some weeds can push through an Azolla mat, however, and weeds growing above the water surface are not affected.

Chemical methods

Herbicide use is one of the most labor-saving innovations that have been introduced in rice farming. For successful and economical use, it is important to understand how these chemicals work and their limitations. These aspects of herbicide use are discussed in detail in later chapters.

Herbicides, like other components of an integrated approach to weed control, have advantages and disadvantages. Herbicides applied before rice germinates provide good weed control during the early rice growth stages when rice is most susceptible to weed competition. Herbicides can also be applied over large areas in a short time, making them suitable for large farms. Applying herbicides avoids much of the drudgery of weeding and makes farming more attractive. Appropriate herbicide application to fallow vegetation also can replace the need to plow and harrow.

In industrialized countries, herbicides are often essential inputs in rice farming. Their adoption increases with increases in labor cost and profits. Profits increase when farmers adopt improved technological packages.

On the other hand, herbicides have several disadvantages. First, most developing countries import herbicides. With mounting debt problems and foreign exchange shortages, sufficient quantities of the more effective herbicides often are not available to meet the growing demand. Herbicide application requires appropriate equipment, such as a knapsack sprayer. The initial capital expenditure maybe beyond a small farmer's financial resources. Another disadvantage is that herbicide use, unlike the use of hoes and sticks, requires skill. Careless herbicide application, sometimes due to ignorance, may result in inadequate weed control and damage or completely kill the crop, or may adversely affect the environment. Improper application of herbicides can create health hazards for humans and animals.

Economics of control

The economic benefit of weed control must exceed the cost. The primary aim of a rational farmer is to optimize profits. One way to achieve that is to reduce weed control costs. It is logical, therefore, that where one or a combination of methods exists, and both are equally effective, the farmer will choose the least costly.

Weed control costs include direct costs (labor, herbicides, sprayers, etc.) and hidden costs. Management time wasted during frequent visits to the field to take weed inventories to use in weed control planning is a hidden cost. A farmer who cleans weed seeds from contaminated rice seeds before planting will incur hidden costs but will avoid future additional weed control costs.

Selecting the weed control methods to combine in an integrated system will depend on the effectiveness and cost of each method. In some situations, hand weeding is more expensive than applying herbicides; in other situations, hand weeding costs less than herbicide application. Sometimes a combination of herbicides, or herbicides supplemented by hand weeding, is more economical than hand weeding or use of herbicide alone (Tables 3.1 and 3.2).

Table 3.1. Economic acceptability[a] of direct weed control methods in irrigated transplanted rice in the Philippines (data for analysis obtained from Moody et al 1983).

Control method	Grain yield (t/ha)	Total variable cost (US$)	Total return (US$)	Return above variable cost (US$)	Marginal benefit-cost ratio
No weeding	1.5	0	263	263	
One hand weeding	3.6	50	630	580	6.3
Two hand weedings	3.7	90	648	558	3.3
Two rotary weedings	2.9	44	508	463	4.5
2,4-D (0.8 kg/ha)	3.1	10.3	543	532	26
Thiobencarb/2,4-D (1.0 + 0.5 kg/ha)	3.3	19.0	578	559	16.0

[a] Assumptions: Labor = US$2.09/d; First hand weeding = 24 d/ha: Second hand weeding = 19 d/ha: First rotary weeding = 11 d/ha; Second rotary weeding = 10 d/ha: Herbicide = 2,4-D (0.8 kg/ha) = US$10.30. Thiobencarb/2,4-D = US$19.

Table 3.2. Economic acceptability[a] of direct weed control methods in broadcast seeded flooded rice (De Datta and Ampong-Nyarko 1988).

Control method	Rate (kg ai/ha)	Weed biomass (g/m^2)	Grain yield (t/ha)	(US$) Total variable cost	(US$) Total return	(US$) Return above variable cost	Marginal benefit-cost ratio
No weeding		287	2.1	0	350	350	–
Butachlor	1.0	238	2.7	18.4	473	455	5.7
Butachlor + 1 hand weeding	0.5	21	4.2	110	735	625	2.5

[a] Assumptions: Labor = US$2.09/d, One hand weeding = 48 d/ha. Herbicide = butachlor (1.0 kg ai/ha) = US$18.40.

Integrated weed management

The resilience of weed populations under intensive herbicide use, buildup of weed species tolerant of the control methods used, and increasing public concern about indiscriminate pesticide use and its effects on the environment and human health have led to widespread appreciation of the integrated weed management concept (Fryer and Matsunaka 1977, Fryer 1983).

Integrated weed management is the rational use of direct and indirect control methods to provide cost-effective weed control. A further refinement, implied in the terms *integrated weed management* and *integrated pest management* (IPM), is that, whenever possible, weed control should be integrated with measures that further protect crops from insects, diseases, nematodes, and other injurious organisms, and should be practiced with an understanding of the interrelationships between weed populations and those organisms. An illustrated guide to integrated pest management (Reissig et al 1985) is available from IRRI.

Several cultural methods have been suggested to complement direct methods in an integrated approach. However, researchers often do not provide an economic assessment of these indirect methods. As a result, farmers and their agents frequently misjudge the economic significance of the new methods whose adoption they are considering. Among the commonly suggested indirect methods for rice are land preparation, water management, plant spacing, seed rate, cultivar use, and fertilizer application. Direct methods include hand weeding and use of herbicides.

The essential factor in any integrated weed management program is the number of indirect and direct methods that can be combined economically in a given situation. Farmers are interested in net benefits and in protecting themselves against risks. A critical assessment of the indirect weed control methods suggested for use in integrated weed management—their cost-benefit ratio and their relative contribution to long- and short-term weed control—should be provided to put the integrated weed management concept in perspective. For example, increased frequency of plowing and harrowings does not eliminate the need for direct weed control. Farmers still have to follow land preparation with direct weed control. It is, therefore, more cost-effective to use fewer pre-planting harrowings and combine them with direct weed control methods than to carry out more harrowings, with or without direct control measures. A high seeding rate cannot substitute for direct control. No benefit is obtained when seeding rate is increased beyond the optimum needed to give adequate stand establishment. It is also not economical to produce high rice yields by substituting high fertilization for weeding. Fertilizer efficiency is maximized when weeds are controlled.

Maximum rice yields at minimum cost should determine the relative mixture of indirect and direct measures in an integrated weed management system. Agronomic practices such as water management, which indirectly suppresses weeds, and fertilizer application, which increases the competitive ability of rice, are highly economical. Combined with any of the direct weed control methods, these practices can constitute an economically viable production system.

Indirect weed control methods, if proven to be biologically feasible, should be subjected to partial budgeting using relevant prices of major inputs. Farm-level resources, constraints, and other limitations should also be recognized. Cost-effective integrated weed management practices should be consistent and compatible with other rice production practices. That can be designated *integrated crop management.*

Chapter 4

Principles of herbicide use

Herbicides are chemical substances or cultured biological organisms that kill or suppress plant growth by affecting one or more of the processes—cell division, tissue development, chlorophyll formation, photosynthesis, respiration, nitrogen metabolism, enzyme activity—that are vital to plant survival. In general, herbicides applied at high rates kill all plants. At low rates, some herbicides kill some plants without damaging other plants. Herbicides with such an ability are said to be selective. Use of selective herbicides for weed control has become popular among rice farmers because of increasing labor costs for hand or mechanical weeding.

Types of herbicides

Herbicides are commonly referred to as contact or translocated.

Contact herbicides

Contact herbicides control weeds by killing the tissues in direct contact with the herbicide. They are normally applied to leaves and stems. Because they affect only the plant parts they come into contact with, they are less effective on perennial weeds than on annual weeds. Thorough coverage of the plant is essential for contact herbicides to be effective. A contact herbicide may be selective, such as oxyfluorfen and propanil, or nonselective, such as paraquat.

Translocated herbicides

Translocated (systemic) herbicides move from the point where the herbicide comes into contact with the plant to other plant parts. Systemic herbicides may be applied to stems and leaves or to the soil (those applied to soil are known as residual herbicides). Butachlor, 2,4-D, and glyphosate are examples of translocated herbicides. Glyphosate is a systemic herbicide when applied to stems and leaves, but it has no activity when applied to the soil. Translocated herbicides may be either selective or nonselective.

Herbicide selectivity

Herbicide selectivity is very important in crop production. Through selectivity, it is possible to use a herbicide to kill a grassy weed, such as *Echinochloa crus-galli*, in a grassy crop such as rice. In practice, to avoid killing the rice plants and for good weed control, selective herbicides should be used at recommended rates. Reduced rates result in poor weed control. Nonselective herbicides, such as paraquat, are harmful to rice even at low rates.

Herbicide selectivity can also be achieved during application, by directing the spray away from the crop or by using protective shields. Chemical antidotes may be used to prevent the herbicide from killing a susceptible plant. For example, pretilachlor can only be used in direct seeded rice in conjunction with an antidote (e.g., fenclorim).

Physical factors of selectivity

To be effective, herbicides must come into contact with the target plant and be retained on its surfaces (root or shoot) long enough and in amounts large enough to kill the plant. The physical factors of selectivity are those that affect contact between the herbicide applied and the plant surfaces and the retention of the herbicides. Plants absorb soil-applied herbicides through roots and shoots of seedlings pushing upward through the soil. Selectivity is affected by herbicide dosage, formulation, and placement and by the plant growth stage.

Herbicide dosage. The amount of a herbicide absorbed by rice is critical for selectivity. Most herbicides are nonselective at high application rates.

Herbicide formulation. Selectivity may be achieved through application of herbicides as granular formulations. The granules that would be harmful to rice if retained on its leaves bounce off and fall to the soil.

Herbicide placement. To be effective, herbicides must first enter the plant. Selectivity based on placement is achieved by preventing herbicides from coming into contact with sites of entry into the rice plant. This is achieved by applying herbicides to the soil surface, by band application, or by using shields. Selectivity of soil-applied herbicides may be lost if the herbicides leach through the soil and come into contact with rice roots and shoots.

Plant growth stage. In general, plants are most susceptible to herbicides at the seedling stage. As plants grow, they become less susceptible. In direct seeded rice, there is no difference in growth stage between rice and weeds, and selectivity cannot be achieved through plant growth stage. In transplanted rice, however, differences in growth stage and position of growing points of rice and weeds can be used to achieve selectivity. Plants growing under drought conditions are less affected by herbicides than plants growing with normal soil moisture.

Biological factors of selectivity

Biological factors of herbicide selectivity include differences in morphology, physiology, and metabolism among plant species. Leaf surfaces that are waxy, smooth, or densely hairy are wetted less readily by aqueous sprays than are surfaces that are less waxy or moderately hairy. Vertical leaves retain less spray than do horizontal leaves. Once absorbed by a plant cell, the herbicide may be immobilized within the cell; that also contributes to herbicide selectivity. Selectivity among plant species may be achieved when some plant species are able to detoxify a particular herbicide, while others are unable to do so and are killed. For example, rice plants are 40 times more tolerant of propanil than *Echinochloa crus-galli.* This is due to differences in plant enzyme levels. Rice plants have a high level of aryl acylamidase, an enzyme that hydrolyzes propanil to nonphytotoxic 3,4-dichloroaniline and propionic acid. *E. crus-galli* has a low level of this enzyme and is unable to hydrolyze propanil; therefore it is easily killed. This detoxification process can be inhibited by organophosphorus and carbamate insecticides.

Herbicide movement in plants

Herbicides must enter the plant before their toxic effect can be induced. Herbicides applied to leaf surfaces and buds penetrate the plant by diffusion. Higher temperatures increase the rate of penetration. Herbicide absorption takes place in the guard cells of the stomata and through the cuticle.

In the soil, herbicides move in the soil solution to the seed and roots, or are intercepted by the root tips. Herbicides may penetrate the walls of root epidermal cells by mass flow.

Once in plants, herbicides move via the phloem and the xylem systems to cells and tissues remote from the site of uptake. The phloem conveys sugar from the green tissues of the plant (where sugar is manufactured) to storage tissues. Very young leaves do not export sugar, so herbicides applied to them remain there. If the transport of sugar is restricted, as when plants are under low light intensity, redistribution of herbicides will not occur. As a result, the general recommendation for many translocated herbicides is that the weeds should be in active growth. Glyphosate and MCPA are examples of herbicides translocated in the phloem.

The xylem is the plant system through which water and dissolved mineral nutrients pass to the leaves. Herbicides taken up by the root move along this stream. Herbicide uptake is therefore affected by factors affecting transpiration rate, such as light, temperature, wind speed, humidity, and soil moisture. The triazine herbicides are good examples of herbicides transported up in the system.

For a more detailed discussion of the principles of herbicide action, refer to *Weed science principles* by W.P. Anderson (1983).

Timing of herbicide application

Weeds should be removed from rice as early as possible. Thus, herbicides should be applied during early crop growth stages. The time to apply a herbicide depends on the properties of the herbicide and the target weeds, weather, and cultural practices. Herbicides can be applied at several periods before and during the crop growing period. In general, herbicides are applied at preplanting, preemergence, or postemergence.

Preplanting herbicide application

A preplanting herbicide application is made before the rice crop is sown. This application helps in land preparation in a minimum tillage cropping system. Translocated foliar herbicides (such as glyphosate) kill perennial broadleaf weeds and grasses found in the fallow vegetation. Where annual weeds predominate, paraquat is adequate. Where volatile preplanting herbicides are used, they must be incorporated into the soil before planting, to avoid damage to the rice crop.

Preemergence herbicide application

Preemergence herbicides are applied to the soil surface after planting but before rice and weeds emerge for direct seeded rice, and before weeds emerge for transplanted rice. These are also known as residual herbicides. Selective systemic herbicides are normally used this way. Nonselective contact herbicides, such as paraquat, can be used to kill germinated weeds, but they must be applied before rice germinates.

Residual herbicides form a thin, protective, continuous layer 2 cm or so deep on the soil surface. Roots of weed seedlings or emerging shoots take up the herbicide when they pass through this layer and are killed in the process. Moisture is necessary to carry the herbicide to weeds germinating below the soil surface. Good weed control cannot be achieved when a residual herbicide is applied to dry soil and the weather remains dry. Residual herbicides for dry seeded rice cultures should, therefore, be applied to moist soil or during light rain, or irrigation should follow a few days after herbicide spraying.

Postemergence herbicide application

Postemergence herbicides are applied after rice and weeds have germinated or after rice has been transplanted. The herbicide must, therefore, be selective or rice seedlings will be killed. If the herbicide is selective, it can be applied over the foliage to kill the weeds without harming the rice. Examples are 2,4-D, propanil, and bentazon. Selectivity also can be achieved by directing application away from the crop to prevent the herbicides from coming into contact with the rice foliage.

Behavior of herbicides in soil

The environment of a flooded ricefield differs from that of an upland ricefield in physical, chemical, and biological properties of soil, as well as in prevailing aquatic conditions and the kinds and ecology of animals and plants found, including weeds. Soils in flooded fields differ from upland soils in aerobic and redox conditions and soil pH. Because of these differences, the degradation rate of herbicides differs between upland and flooded soils.

A large amount of the herbicides applied to floodwater enters the soil layer with the percolating water. Many herbicides are retained in the soil surface layer, where they are mostly degraded by soil microorganisms. The degradation rate depends on the properties of the soil and the herbicide.

Microorganisms in a submerged soil deplete oxygen. The soil is, therefore, reduced (redox) except for the 0.5-1 cm surface layer, which is kept in an oxidized state by oxygen that diffuses from the floodwater to the soil surface. Thus, in flooded soils, except for the uppermost layer, ferric iron is reduced to ferrous iron, soil pH reaches 6-7, aerobic organisms are inactive, and anaerobes are abundant. These result in differences in herbicide degradation between the oxidative and reductive layers of the soil, and between upland and flooded soils.

Adsorption

When herbicides reach the soil surface, some herbicide is taken up and bonded to the surface of soil colloids (adsorbed) due to electrical attraction between the herbicide and the colloids. Adsorption occurs in the clay and organic matter fraction of the soil.

Weakly adsorbed herbicides remain active against germinating weed seedlings and buds passing through the herbicide layer. Weak adsorption prevents the herbicide from leaching into layers where the growing point of rice is located. This is an example of selectivity by physical separation.

In practice, herbicides are applied at a higher rate to soils high in clay and organic matter than to sandy soils, because more herbicide is adsorbed in clayey than in sandy soils.

Leaching

Leaching causes movement of herbicides through soil with the flow of water. The extent of leaching varies with the water solubility of the herbicide and with soil texture. When a residual herbicide is applied to the soil surface, it must move evenly 2-5 cm into the soil, to the area where most weed seeds germinate. Hence, soil moisture after herbicide application is important. As was pointed out earlier, preemergence residual herbicides applied to dry soil will not be effective. However, too much water or leaching will carry the herbicide too deeply into the soil, below the zone where weed seeds are found. This also reduces the effectiveness of the herbicide.

Herbicides in flooded ricefields are continuously leached with percolating water. Fortunately, many rice herbicides are readily adsorbed to the soil components. Such herbicides are retained in the soil long enough for residual activity to control weeds.

Runoff

Runoff is one of the main pathways of herbicide loss from flooded ricefields. Herbicides are usually transported as solutes in soil water; their movement will depend on solubility and adsorptive capacity. In runoff water, however, herbicides are transported both as solutes and on soil sediment particles. An irrigation system needs to be well-regulated to retain herbicides within the system. Irrigation drainage and overflow should be avoided, to reduce herbicide losses and to protect downstream water from pollution.

Volatilization

All herbicides are volatile (have a tendency to change from a solid or liquid to a gaseous state). Volatility, however, varies among herbicides and increases with higher temperature. Volatile herbicides should be mechanically incorporated into the soil to avoid excessive chemical loss.

Volatilization from the floodwater into the atmosphere is an important route of herbicide loss from lowland ricefields. The volatilization rate depends on water evaporation rate, water depth, water solubility, and vapor pressure of the herbicide. Volatilization loss of herbicides from a shallow, warm water flooded field can be highly significant. Volatilization from the soil surface of upland rice may be much greater than that from the floodwater of lowland rice. Thiocarbamate herbicides are volatile in floodwater.

Photodegradation

Photochemical and biochemical degradation of herbicides govern their fate in a flooded environment. For example, the high pH of the water induces hydrolysis of carboxylic esters. Some herbicides adsorb ultraviolet radiation. The presence of humic acids in floodwater may also induce photochemical degradation of herbicides that do not adsorb ultraviolet radiation (Yaron et al 1985).

Persistence

Herbicide persistence is the length of time a herbicide remains active in the soil. Persistence depends on the amount of herbicide applied, the rate at which it is broken down, properties of the particular herbicide, and leaching. Herbicides with long persistence keep a crop weed-free for a longer time than do herbicides with short persistence. Persistence of a herbicide beyond the rice-growing season, however, is undesirable because other crops sensitive to that herbicide cannot be grown on the same land for some time.

Effect of environment on herbicidal activity

Several environmental factors affect the success of weed control by soil or foliar-applied herbicides. Temperature, relative humidity, soil moisture, and wind are important.

Temperature

Absorption and translocation of herbicides increase as temperature increases, and selectivity can be changed by differences in absorption and translocation. For example, if propanil is applied to rice when the temperature is above 38 °C, phytotoxicity may occur. At high temperatures, simetryn will cause injury, even in japonica rice, as a result of higher absorption through the roots. In general, the rate at which herbicide degrades increases with increasing temperature.

Relative humidity

At high relative humidity, leaf stomata are open, which increases absorption of herbicide into the leaf. Evaporation of herbicides from leaf surfaces is slowed at high relative humidity. Slow evaporation lengthens the time the herbicide can enter the plant.

Soil moisture

Soil moisture affects herbicide effectiveness by influencing the amount of herbicide in the soil solution and the depth of herbicide movement in the soil profile. When a residual herbicide is applied to a dry soil, it relies on soil moisture (from rain or from irrigation) to move it to the root zone. Inadequate movement is a common cause of the failure of herbicides in upland fields.

Wind

Wind adversely affects the absorption of foliar-applied herbicides by increasing the evaporation of spray droplets and the volatilization of herbicide residue from the leaf surfaces.

Properties of herbicides

When the probable behavior of a herbicide can be predicted from its properties, that information can be used to design safer and more effective application. Some properties of herbicides that affect their biological activity and behavior in the crop environment include partition coefficient, vapor pressure, and water solubility. Partition coefficient describes the relative distribution of a compound between a fatlike layer and water when shaken together. Compounds that accumulate in the fatlike layer are likely to be stored in the fat of animals.

Vapor pressure

Most organic chemicals tend to change to vapor. This tendency is measured as vapor pressure and is affected by temperature. As temperature increases, vapor pressure also increases. A liquid with a high vapor pressure is recognized as a volatile compound, one that evaporates rapidly. In contrast, herbicides with high boiling points have lower vapor pressures, and thus are less volatile (Davies et al 1988). Thiocarbamate herbicides have a high vapor pressure.

When herbicides with high vapor pressure are applied to the soil surface, they can evaporate so rapidly they are ineffective. Such herbicides should be incorporated in the soil. It has been frequently observed that more herbicide is lost from a moist soil than from a dry soil.

Water solubility

Practically all herbicides have a measurable solubility in water. Water solubility is important in determining leaching, degree of adsorption, and mobility in the environment. Herbicides that are water soluble leach readily. Where a herbicide is less soluble, sorption onto suspended matter in the water tends to take the chemical out of most of the water.

Herbicide formulations

Herbicides are not sold as 100% active ingredient. Powders, solvents, stickers, or wetting agents usually are added to help disperse the active ingredient throughout a carrier. The final product is a formulated herbicide that may have a number of names and may contain different proportions of active ingredient.

A small amount of herbicide (about 2.0 kg) mixed with about 200 liters of water carrier is sufficient to cover a hectare. It is essential that the herbicide be uniformly distributed in the spray water.

Some of the types of formulations are explained below.

Water-soluble concentrate (S). The active ingredient in a water-soluble concentrate dissolves readily in water.

Wettable powder (WP or W). When an active ingredient does not dissolve readily in standard solvents, a wettable powder is prepared. The formulation consists of the dry herbicide plus another inert solid, such as clay, together with agents that allow dispersal and suspension of fine particles in liquid. Wettable powders mix readily with water, but tend to settle at the bottom of the spray tank. Wettable powders are being replaced by flowables and water-dispersible granules that overcome many of the storage and spraying problems that have occurred in wettable powder.

Emulsifiable concentrate (EC or E). An emulsifiable concentrate is used for herbicides that are not water soluble but are soluble in organic solvents. An emulsifier is added to form a stable oil-in-water emulsion when the herbicide is mixed with water.

Flowables (F). In flowable herbicides, the active ingredient is not readily soluble in water or an organic solvent. The flowable consists of a finely ground wettable powder suspended in a small amount of liquid and mixed with emulsifiers.

Granules (G or g). Granules are a ready-to-use, dry formulated product with a carrier, usually clay. Granules, which may contain 2-20% active ingredient, can be broadcast on floodwater to control weeds growing in the water (submerged weeds). Granules are usually designed to improve handling and application properties (e.g., selectivity). An advantage of granules is that there is less drift than with fine sprays under windy conditions. Granules, however, are bulky and often have higher handling costs.

Adjuvant. Adjuvants are materials that facilitate the action of herbicides or modify characteristics of the herbicide formulation. Examples of adjuvants are surfactants and wetting agents, oils, stickers, thickening agents, emulsifiers, and stabilizing agents.

Surfactants are commonly used to improve the emulsifying, dispersing, spreading, or wetting ability of the herbicide formulation by modifying its surface characteristics. A surfactant increases retention of the herbicide on the leaf surface after spraying. It also helps entry of the herbicide into leaves and stems.

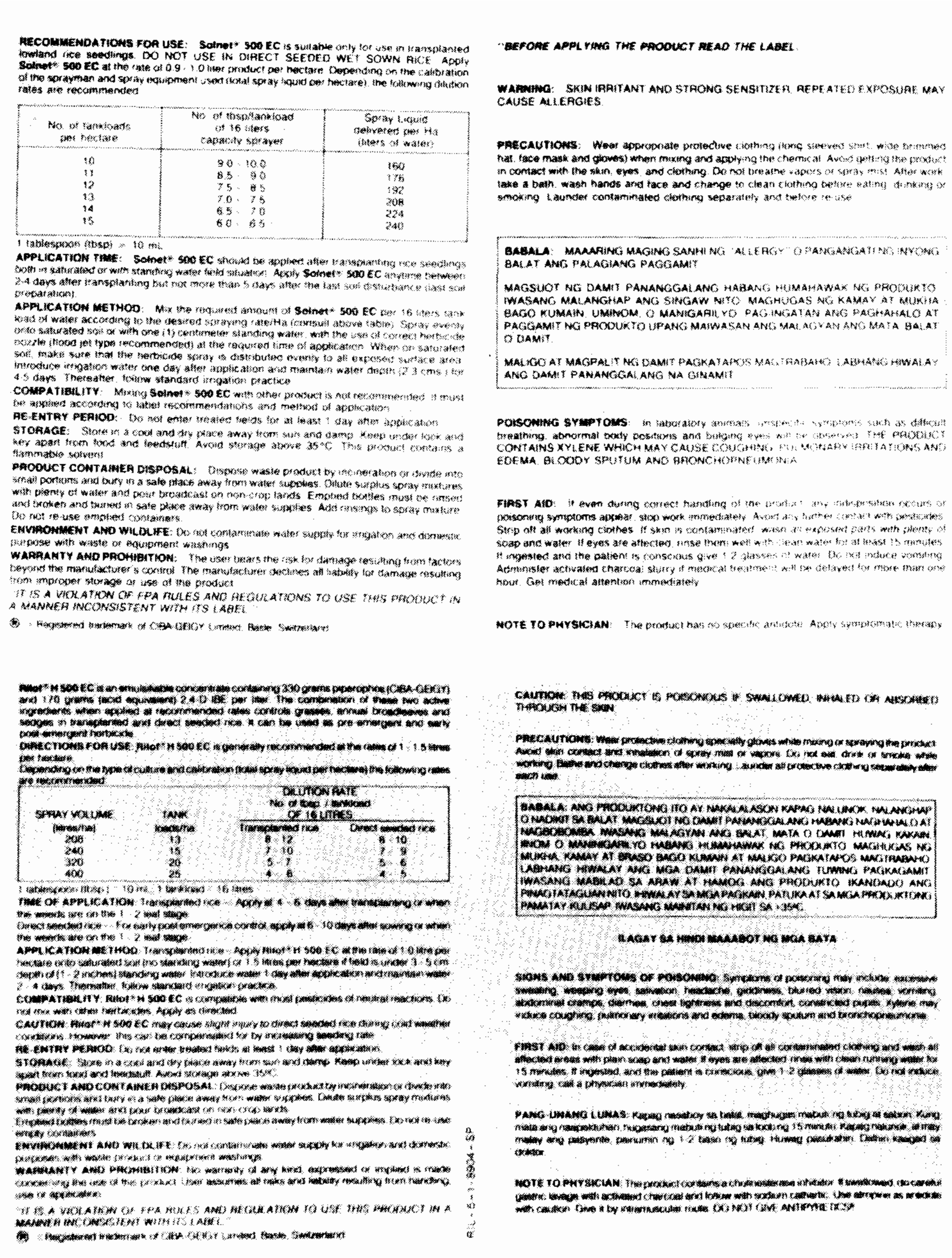
Surfactants are often added to herbicide formulations by the manufacturer, but additional surfactants may be needed for some postemergence herbicides or in some environmental conditions (e.g., bentazon under low temperatures). The herbicide label indicates how much surfactant to use when an additional surfactant is required. When surfactants are not recommended, their use with foliage-applied herbicides can result in loss of selectivity.

Herbicide labels

The best source of information concerning safe and effective herbicide use is the product label (Fig. 4.1) printed on or attached to the herbicide container. It gives directions on effective, safe use of the herbicide. The label should be read carefully and understood before any herbicide is used. The herbicide label is a legal document that in many countries has government approval. Every herbicide product label should contain the following information:

Trade or brand name. The trade or brand name identifies a herbicide of one company and differentiates it from those of other companies. Like common weed names, trade names of herbicides may change from country to country. Thus, the trade name is not always adequate for identifying a herbicide or determining correct rates of application. When an application rate is recommended with a trade name, the rate normally refers to the amount of formulated product, and not the rate of active ingredient or the acid equivalent.

Chemical and common names. Herbicides have complex chemical names. Rules for selecting suitable chemical names are given by appropriate chemical associations (e.g., the International Union of Pure and Applied Chemistry [IUPAC]). The chemical name refers to the active ingredient. In addition to the chemical name, each herbicide is given a common name which also applies to the active ingredient. The common name is not the same as the trade name of the same herbicide. Common names for herbicides are approved by appropriate professional bodies, such as the International Standardization Organization



RECOMMENDATIONS FOR USE: Solnet* 500 EC is suitable only for use in transplanted lowland rice seedlings. DO NOT USE IN DIRECT SEEDED WET SOWN RICE. Apply **Solnet* 500 EC** at the rate of 0.9 - 1.0 liter product per hectare. Depending on the calibration of the sprayman and spray equipment used (total spray liquid per hectare), the following dilution rates are recommended.

No. of tankloads per hectare	No. of tbsp/tankload of 16 liters capacity sprayer	Spray Liquid delivered per Ha (liters of water)
10	9.0 - 10.0	160
11	8.5 - 9.0	176
12	7.5 - 8.5	192
13	7.0 - 7.5	208
14	6.5 - 7.0	224
15	6.0 - 6.5	240

1 tablespoon (tbsp) = 10 ml.

APPLICATION TIME: Solnet* 500 EC should be applied after transplanting rice seedlings both in saturated or with standing water field situation. Apply **Solnet* 500 EC** anytime between 2-4 days after transplanting but not more than 5 days after the last soil disturbance (last soil preparation).

APPLICATION METHOD: Mix the required amount of **Solnet* 500 EC** per 16 liters tank load of water according to the desired spraying rate/Ha (consult above table). Spray evenly onto saturated soil or with one (1) centimeter standing water, with the use of correct herbicide nozzle (flood jet type recommended) at the required time of application. When on saturated soil, make sure that the herbicide spray is distributed evenly to all exposed surface area. Introduce irrigation water one day after application and maintain water depth (2-3 cms.) for 4-5 days. Thereafter, follow standard irrigation practice.

COMPATIBILITY: Mixing **Solnet* 500 EC** with other product is not recommended. It must be applied according to label recommendations and method of application.

RE-ENTRY PERIOD: Do not enter treated fields for at least 1 day after application.

STORAGE: Store in a cool and dry place away from sun and damp. Keep under lock and key apart from food and feedstuff. Avoid storage above 35°C. This product contains a flammable solvent.

PRODUCT CONTAINER DISPOSAL: Dispose waste product by incineration or divide into small portions and bury in a safe place away from water supplies. Dilute surplus spray mixtures with plenty of water and pour broadcast on non-crop lands. Emptied bottles must be rinsed and broken and buried in safe place away from water supplies. Add rinsings to spray mixture. Do not re-use emptied containers.

ENVIRONMENT AND WILDLIFE: Do not contaminate water supply for irrigation and domestic purpose with waste or equipment washings.

WARRANTY AND PROHIBITION: The user bears the risk for damage resulting from factors beyond the manufacturer's control. The manufacturer declines all liability for damage resulting from improper storage or use of the product.

"IT IS A VIOLATION OF FPA RULES AND REGULATIONS TO USE THIS PRODUCT IN A MANNER INCONSISTENT WITH ITS LABEL."

® = Registered trademark of CIBA-GEIGY Limited, Basle, Switzerland

"BEFORE APPLYING THE PRODUCT READ THE LABEL."

WARNING: SKIN IRRITANT AND STRONG SENSITIZER. REPEATED EXPOSURE MAY CAUSE ALLERGIES.

PRECAUTIONS: Wear appropriate protective clothing (long sleeved shirt, wide brimmed hat, face mask and gloves) when mixing and applying the chemical. Avoid getting the product in contact with the skin, eyes, and clothing. Do not breathe vapors or spray mist. After work take a bath, wash hands and face and change to clean clothing before eating, drinking or smoking. Launder contaminated clothing separately and before re-use.

BABALA: MAAARING MAGING SANHI NG "ALLERGY" O PANGANGATI NG INYONG BALAT ANG PALAGIANG PAGGAMIT.

MAGSUOT NG DAMIT PANANGGALANG HABANG HUMAHAWAK NG PRODUKTO. IWASANG MALANGHAP ANG SINGAW NITO. MAGHUGAS NG KAMAY AT MUKHA BAGO KUMAIN, UMINOM, O MANIGARILYO. PAG-INGATAN ANG PAGHAHALO AT PAGGAMIT NG PRODUKTO UPANG MAIWASAN ANG MALAGYAN ANG MATA, BALAT O DAMIT.

MALIGO AT MAGPALIT NG DAMIT PAGKATAPOS MAGTRABAHO. LABHANG HIWALAY ANG DAMIT PANANGGALANG NA GINAMIT.

POISONING SYMPTOMS: In laboratory animals unspecific symptoms such as difficult breathing, abnormal body positions and bulging eyes will be observed. THE PRODUCT CONTAINS XYLENE WHICH MAY CAUSE COUGHING, PULMONARY IRRITATIONS AND EDEMA, BLOODY SPUTUM AND BRONCHOPNEUMONIA.

FIRST AID: If even during correct handling of the product any indisposition occurs or poisoning symptoms appear, stop work immediately. Avoid any further contact with pesticides. Strip off all working clothes. If skin is contaminated, wash all exposed parts with plenty of soap and water. If eyes are affected, rinse them well with clean water for at least 15 minutes. If ingested and the patient is conscious give 1-2 glasses of water. Do not induce vomiting. Administer activated charcoal slurry if medical treatment will be delayed for more than one hour. Get medical attention immediately.

NOTE TO PHYSICIAN: The product has no specific antidote. Apply symptomatic therapy.

Rilof* H 500 EC is an emulsifiable concentrate containing 330 grams piperophos (CIBA-GEIGY) and 170 grams (acid equivalent) 2,4-D IBE per liter. The combination of these two active ingredients when applied at recommended rates controls grasses, annual broadleaves and sedges in transplanted and direct seeded rice. It can be used as pre-emergent and early post-emergent herbicide.

DIRECTIONS FOR USE: Rilof* H 500 EC is generally recommended at the rates of 1 - 1.5 litres per hectare.

Depending on the type of culture and calibration (total spray liquid per hectare) the following rates are recommended:

SPRAY VOLUME (litres/ha)	TANK loads/ha	DILUTION RATE No. of tbsp. / tankload OF 16 LITRES: Transplanted rice	Direct seeded rice
208	13	8 - 12	8 - 10
240	15	7 - 10	7 - 9
320	20	5 - 7	5 - 6
400	25	4 - 6	4 - 5

1 tablespoon (tbsp.) = 10 ml.; 1 tankload = 16 litres

TIME OF APPLICATION: Transplanted rice — Apply at 4 - 6 days after transplanting or when the weeds are on the 1 - 2 leaf stage.

Direct seeded rice — For early post emergence control, apply at 6 - 10 days after sowing or when the weeds are on the 1 - 2 leaf stage.

APPLICATION METHOD: Transplanted rice — Apply Rilof* H 500 EC at the rate of 1.0 litre per hectare onto saturated soil (no standing water) or 1.5 litres per hectare if field is under 3 - 5 cm depth of (1 - 2 inches) standing water. Introduce water 1 day after application and maintain water 2 - 4 days. Thereafter, follow standard irrigation practice.

COMPATIBILITY: Rilof* H 500 EC is compatible with most pesticides of neutral reactions. Do not mix with other herbicides. Apply as directed.

CAUTION: Rilof* H 500 EC *may cause slight injury to direct seeded rice during cold weather conditions. However, this can be compensated for by increasing seeding rate.*

RE-ENTRY PERIOD: Do not enter treated fields at least 1 day after application.

STORAGE: Store in a cool and dry place away from sun and damp. Keep under lock and key apart from food and feedstuff. Avoid storage above 35°C.

PRODUCT AND CONTAINER DISPOSAL: Dispose waste product by incineration or divide into small portions and bury in a safe place away from water supplies. Dilute surplus spray mixtures with plenty of water and pour broadcast on non-crop lands.

Emptied bottles must be broken and buried in safe place away from water supplies. Do not re-use empty containers.

ENVIRONMENT AND WILDLIFE: Do not contaminate water supply for irrigation and domestic purposes with waste product or equipment washings.

WARRANTY AND PROHIBITION: No warranty of any kind, expressed or implied is made concerning the use of this product. User assumes all risks and liability resulting from handling, use or application.

"IT IS A VIOLATION OF FPA RULES AND REGULATION TO USE THIS PRODUCT IN A MANNER INCONSISTENT WITH ITS LABEL."

® = Registered trademark of CIBA-GEIGY Limited, Basle, Switzerland

CAUTION: THIS PRODUCT IS POISONOUS IF SWALLOWED, INHALED OR ABSORBED THROUGH THE SKIN.

PRECAUTIONS: Wear protective clothing specially gloves while mixing or spraying the product. Avoid skin contact and inhalation of spray mist or vapors. Do not eat, drink or smoke while working. Bathe and change clothes after working. Launder all protective clothing separately after each use.

BABALA: ANG PRODUKTONG ITO AY NAKALALASON KAPAG NALUNOK, NALANGHAP O NADIKIT SA BALAT. MAGSUOT NG DAMIT PANANGGALANG HABANG NAGHAHALO AT NAGBOBOMBA. IWASANG MALAGYAN ANG BALAT, MATA O DAMIT. HUWAG KAKAIN, INOM O MANINIGARILYO HABANG HUMAHAWAK NG PRODUKTO. MAGHUGAS NG MUKHA, KAMAY AT BRASO BAGO KUMAIN AT MALIGO PAGKATAPOS MAGTRABAHO. LABHANG HIWALAY ANG MGA DAMIT PANANGGALANG TUWING PAGKAGAMIT. IWASANG MABILAD SA ARAW AT HAMOG ANG PRODUKTO. IKANDADO ANG PINAGTATAGUAN NITO. IHIWALAY SA MGA PAGKAIN, PATUKA AT SA MGA PRODUKTONG PAMATAY KULISAP. IWASANG MAINITAN NG HIGIT SA >35°C.

ILAGAY SA HINDI MAAABOT NG MGA BATA

SIGNS AND SYMPTOMS OF POISONING: Symptoms of poisoning may include: excessive sweating, weeping eyes, salivation, headache, giddiness, blurred vision, nausea, vomiting, abdominal cramps, diarrhea, chest tightness and discomfort, constricted pupils. Xylene may induce coughing, pulmonary irritations and edema, bloody sputum and bronchopneumonia.

FIRST AID: In case of accidental skin contact, strip off all contaminated clothing and wash all affected areas with plain soap and water. If eyes are affected rinse with clean running water for 15 minutes. If ingested, and the patient is conscious, give 1-2 glasses of water. Do not induce vomiting; call a physician immediately.

PANG-UNANG LUNAS: Kapag nasaboy sa balat, maghugas mabuti ng tubig at sabon. Kung mata ang naapektuhan, hugasang mabuti ng tubig sa loob ng 15 minuto. Kapag nalunok, at may malay ang pasyente, painumin ng 1-2 baso ng tubig. Huwag pasukahin. Dalhin kaagad sa doktor.

NOTE TO PHYSICIAN: The product contains a cholinesterase inhibitor. If swallowed, do careful gastric lavage with activated charcoal and follow with sodium cathartic. Use atropine as antidote with caution. Give it by intramuscular route. DO NOT GIVE ANTIPYRETICS!

4.1 All herbicide labels are required to provide important information. Users should read and understand the label before opening any herbicide container.

Table 4.1. Meanings of signal words found on herbicide formulation labels, to state danger to humans.

Signal word	Acute toxicity	Approximate lethal oral dose for an adult human	Lethal oral dose (LD_{50}) for rats (mg/kg body weight) (See p. 62 for discussion on LD_{50})
Danger/Poison	Highly toxic	A taste to one teaspoonful (5 ml)	5-50
Warning	Moderately toxic	One teaspoonful to 2 tablespoonfuls (30 ml)	50-500
Caution	Low to relatively nontoxic	30-450 ml	500-5,000
No signal word	Relatively nontoxic		

(ISO). A herbicide may be produced or formulated by more than one company and thus be sold under several brand names, but the common name or chemical name should always be the same on all products. For example:

Trade or brand names: Machete, Butanex, Lambast

Chemical name: N-(buthoxymethyl)-2-chloro-N-(2,6diethylphenyl) acetamide

Common name: butachlor

Active ingredient. Each label specifically names the active ingredient present in the herbicide. The amount of active ingredient may be given in percentage by weight or in grams per liter, and may be listed by its common name or by its chemical name. The inert ingredients need not be named, but the label should specify their percentage of content.

Formulation. Some labels spell out the formulation, others use abbreviations, such as EC or E for emulsifiable concentrates; WP or W for wettable powder; FW, F, or L for flowables; G for granules; and S for solubles.

Content. Each label gives the total amount of herbicide in the container (eg, in liters [L] or kilograms [kg]).

Signal words and symbols. Herbicide labels state how poisonous the product is, using specific signal words and symbols. Examples are shown in Table 4.1.

Labels of all highly toxic products have, in addition to the word *poison,* the skull and cross-bones symbol. Pictograms — graphically definitive symbols — are also recommended for inclusion on agrochemical labels (Info Letter 1988). Examples of pictograms are drawings of a pair of pants in boots and a pair of hands in gloves, to convey the need to wear footwear and gloves for safe handling of chemicals. These labels also include the statement *Keep out of reach of children.*

Directions for use. Directions for use provide instructions on how to use the herbicide. This includes information on weeds that the herbicide controls, crops on which application of the herbicide is safe, application rates, application time, and application method. All directions for use must be followed.

Name of manufacturer. The name and address of the manufacturer or distributor of the product often is required by law to be on the label.

Hazards to humans and domestic animals. The hazards portion of a label indicates how the herbicide may be harmful to man and domestic animals. It gives information on how to avoid poisoning or contamination, such as the type of protective clothing required.

Environmental hazards. To help reduce undesirable effects on the environment, the label also provides environmental precautions. It may include warnings that it is harmful to birds, fish, and wildlife, and advice on how to avoid contaminating water bodies.

Harvesting statement. A harvesting statement is printed on labels when there is a chance that the treated crop may be fed to animals or handled by humans. Because residues of a herbicide require a minimum number of days to degrade, a harvesting statement specifies the number of days between the last herbicide application and the time when the crop can be safely cut, threshed, or eaten.

Herbicide applicators

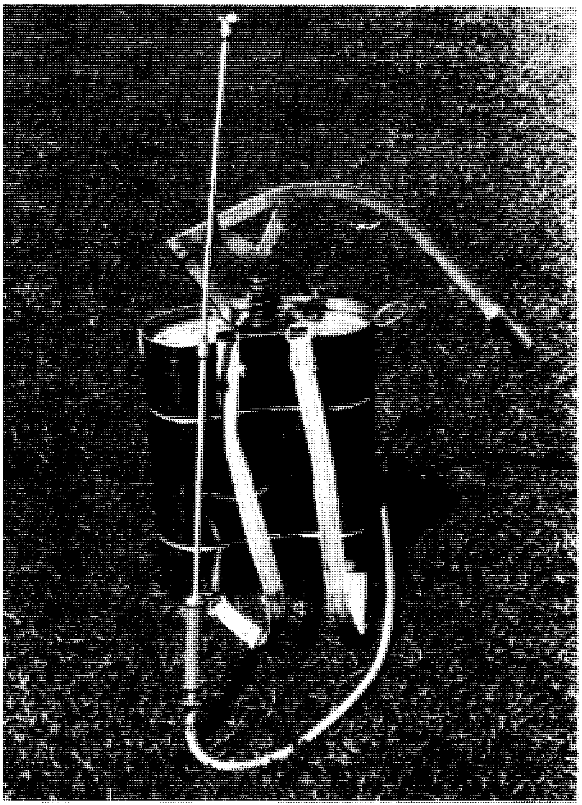
A herbicide applicator is any device used to apply herbicides on plant and soil surfaces. Applicators distribute an exact quantity of a herbicide uniformly over a given area. They can be classified as nonpressurized or pressurized.

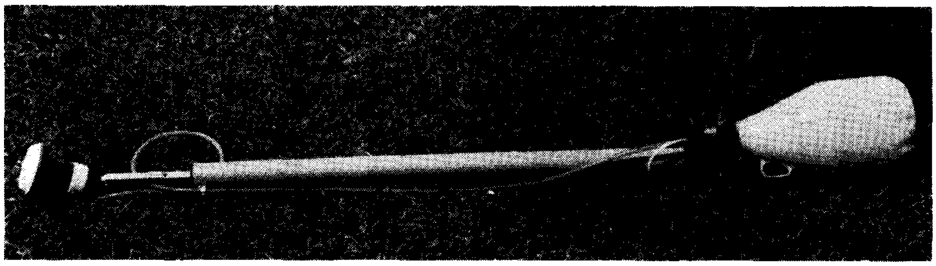
Nonpressurized applicators include the water can, granular applicator, controlled-droplet applicator, and direct-contact applicators such as rope wicks and wipers.

Hydraulic (pressurized) applicators usually need water to work. A pressurized applicator may be manually operated (such as the lever-operated knapsack sprayer), motorized, or ground-driven (Fig 4.2).

Controlled-droplet applicator

A controlled-droplet applicator (CDA) produces uniform-sized droplets of spray. Weeds may be effectively controlled with as little as 18 liters water/ha. Droplet size is controlled within narrow limits by spinning discs inside the applicator. Controlled-droplet applicators are lightweight. They have a plastic spray head, a small motor that drives the rotating disc, a liquid reservoir, a handle, and a power supply (e.g., one to eight 1.5-volt dry-cell batteries). Models that use a manually operated air pump (Fig. 4.3) (e.g., Birky sprayer) have been introduced. This eliminates the cost of batteries for the first-generation CDA.





4.2 Top, a leverage-operated knapsack sprayer; bottom, a controlled-droplet applicator.

Granular applicator

Herbicides sold as granules are applied using granular applicators. Whatever its size, a granular applicator consists of a hopper to contain the granules, a metering device to control flow rate, and a distribution mechanism. Granular herbicides that are soluble in water may not require the same uniformity of distribution as those that are not soluble in water.

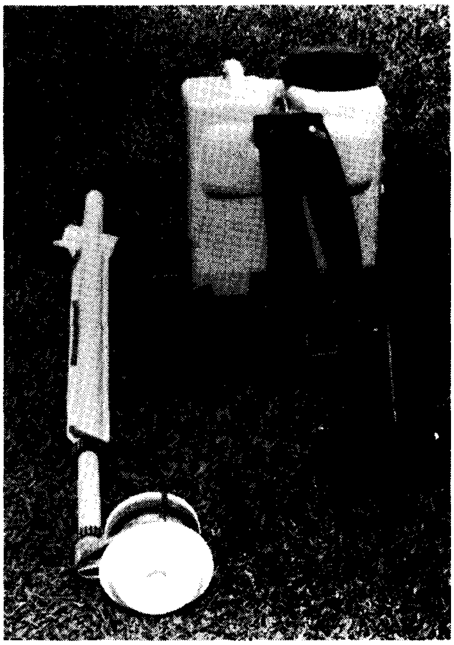
Granules are often applied by hand, especially in the tropics. Because broadcasting granules by hand is not precise, the quantity of herbicide used will be higher than with other application techniques. More uniform application can be achieved on small areas by shaking the granules from a container with a perforated lid.

Hydraulic applicator (pressurized)

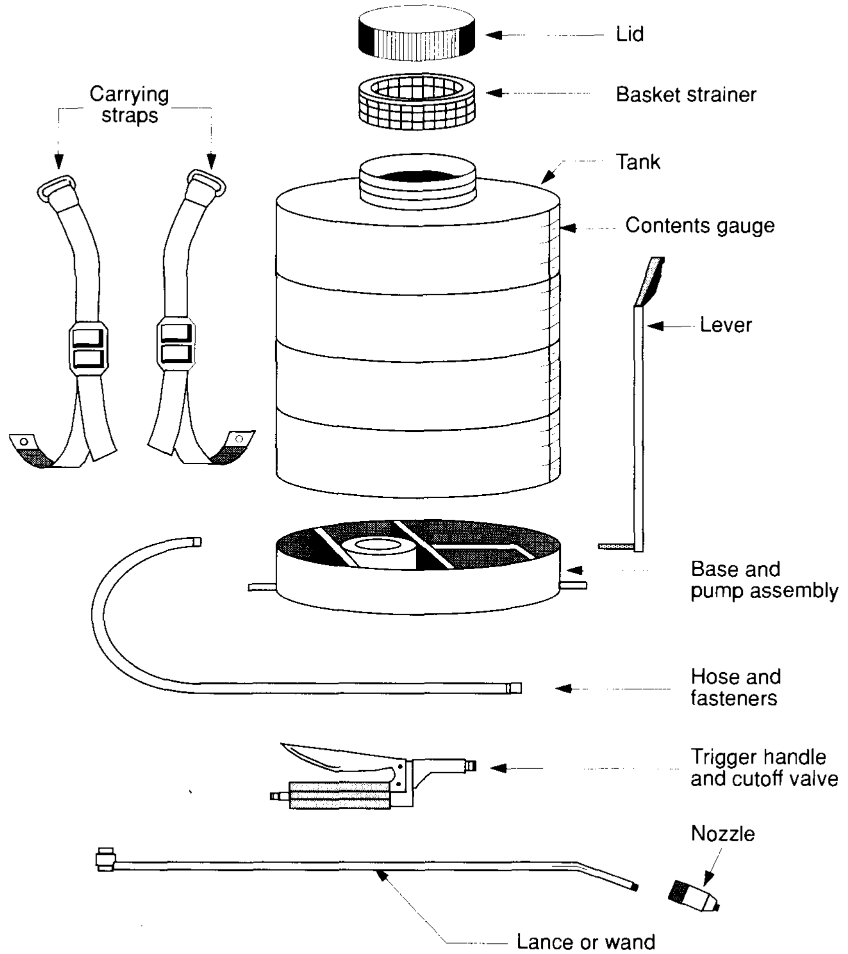
Hydraulic applicators commonly consist of a tank, pump, and nozzle. Other components include an agitator, pressure gauge, pressure regulator, hose, and boom. The tank that holds the spray solution is made of a corrosion-resistant material, such as stainless steel, polyvinyl material, or fiber glass. The tank has a special lid through which it is filled. The lid contains a strainer to remove debris that might clog the nozzle. The pump drives the solution through the pressure chamber to the nozzle. The most widely used small hydraulic applicator is the lever-operated knapsack sprayer (Fig. 4.4). For a detailed discussion, see *Pesticide application methods* (Matthews 1979).

Operation of the knapsack sprayer

Herbicide and water are poured into the sprayer tank. The lever is moved up and down, causing the pump to draw spray liquid from the tank into a special chamber inside the tank called the pressure chamber. Air trapped in



4.3 Controlled-droplet applicators that use a manually operated air pump are available.



4.4 Simplified drawing of a lever-operated knapsack sprayer.

the pressure chamber is compressed as the liquid is forced in. On one side of the pressure chamber is the hose, which is connected to the trigger handle, and the on-and-off switch known as the cutoff valve. Compressed air forces the liquid from the pressure chamber through the hose to the nozzle. The nozzle turns the liquid into droplets, which aid in uniform coverage of the weed or soil.

The faster the lever is moved, the higher the pressure becomes. High pressure makes the herbicide droplets smaller and increases the speed with which the solution comes out of the nozzle (flow rate). For herbicide spraying, where coarse spray droplets are desired, 5-6 lever strokes per minute are adequate.

Selecting the nozzle

The flow rate through a nozzle depends on the size of the nozzle opening and the spray pressure. Increasing the nozzle size (diameter of opening) and increasing the pressure will increase the flow rate. A pressure of 70-275 kPa (see Appendix A) is recommended for herbicide application. The best way to regulate the flow rate is to change nozzle tips and to increase or decrease walking speed.

It is important to select the proper type of nozzle for each activity (Fig. 4.5). For residual herbicides applied to the soil, impact nozzles (e.g., Polijet) should be used because they cause less drift problems. For systemic, translocated herbicides, where thorough wetting of stems and leaves is not required, an impact nozzle or fan nozzle is recommended. For contact herbicides, use a hollow cone nozzle, an impact nozzle, or a fan nozzle operated at 275 kPa.

Sprayer calibration

Sprayer calibration determines the volume of water that will be applied on a given area by a given applicator under given conditions. The volume of water applied by a sprayer depends on walking speed, sprayer pressure, and nozzle size.

Walking speed. An increase in walking speed results in less spray mixture applied to a given area. Conversely, a decrease in walking speed results in application of a greater volume applied per unit area.

Sprayer pressure. Increasing sprayer pressure results in a greater volume of spray mixture applied to a given area. Conversely, a lower spray pressure results in less spray mixture applied. The sprayer should be operated to give as steady a pressure as possible. A pressure gauge may be fitted to the sprayer.

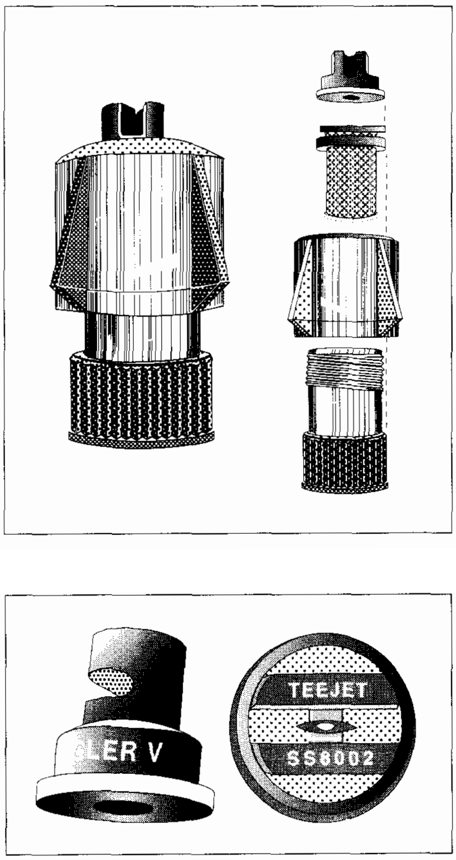
Nozzle size. The use of a large nozzle opening increases the volume of spray mixture applied to a given area. Smaller openings deliver a smaller spray volume.

There are several ways to find out how much spray is applied to a given area for a given time. A well-tested technique for calibrating a sprayer (Fraser and Burrill 1979) is as follows:

Step 1. Make sure the sprayer is in good working condition (no leaks, no blocked nozzles, etc.). Calibration should be done on a surface similar to the field to be sprayed. Measure and mark out an area of 100 m^2 (10 m x 10 m). Trace with a stick the rows on which rice normally would be sown in the field. The row width should be the one you will use in planting rice.

Step 2. Place the sprayer on level ground and put in 10 liters of clean water. Mark the outline of the sprayer on the ground so the same spot can be found later. Put the sprayer on your back. Position the nozzle above the first seed row mark. Pump the sprayer to develop pressure. Begin spraying the plot you have marked, adjusting the height of the nozzle to cover whatever swath width you desire. Maintain a constant nozzle height. Walk at a comfortable pace, which you must maintain throughout the calibration, and later in actually spraying the field. Spray the 100-m^2 plot once. When you have completed spraying the plot, place the sprayer back on the ground in its outlined position and measure the water level.

Step 3. Determine the application rate by subtracting the volume of water remaining in the sprayer from the amount you started with. For example, if the amount of water in the tank before spraying was 10 liters and the



4.5 Selecting the appropriate nozzle for each spraying task is important. Types include top, hydraulic nozzle (shown in the nozzle body, left, and in parts, right) and, bottom, a fan nozzle, left, and impact nozzle, right.

amount after spraying is 8 liters, then the amount of water used was 2 liters. The sprayer output per hectare (10,000 m^2) is then calculated as

$$\frac{\text{Liters of water used} \times 10{,}000}{\text{m}^2 \text{ of area sprayed}} = \text{liters/ha}$$

For the 2 liters used in the example,

$$\frac{2 \text{ liters} \times 10{,}000}{100} = 200 \text{ liters/ha}$$

A simpler calculation is to multiply the number of liters you sprayed on the 10-m x 10-m plot by 100, to get application rate in liters per hectare.

Step 4. Make sure your walking pace is uniform by repeating Step 2 a few times, until you are putting exactly 2 liters of water on the calibration plot every time you spray it. If you use more than 2 liters, you should increase your walking pace while spraying. If you use less than 2 liters, you should walk more slowly. If the rate remains on the 2-liter mark, your walking pace is uniform. Remember: sprayer output for a given area may be adjusted by changing walking pace or nozzle size, or pressure, or any combination of these.

Amount of water to use

Mixing a herbicide with water enables spreading the herbicide evenly over a large area. The amount of water used affects the herbicide's effectiveness and the ease of application. Usually a medium volume of water—200-300 liters/ha—is adequate for bare soil or small weeds. More water is needed for contact herbicide application because the weeds must be wetted thoroughly for effective treatment. Whatever volume of water is used, the amount of active ingredient (ai) per hectare should always be the same (i.e., 2.0 kg of butachlor/ ha can be applied in 200 liters or 300 liters water/ha, depending on the sprayer calibration).

Controlled-droplet applicators and certain very low-volume nozzles fitted to the knapsack sprayers can use as low as 10-40 liters water/ha. When in doubt, check the herbicide label. Most manufacturers indicate the volume rate to be used under certain conditions.

Herbicide dosage calculation

Before calculating herbicide dosage, a herbicide or herbicide combination should be chosen for the best results under the particular set of conditions. To calculate the amount of herbicide to be applied to a given area, the following information is needed:

- Recommended dosage of the herbicide to be used.
- Amount of herbicide (ai) in a given quantity of the commercial product (formulation) to be used.

The product label shows the amount, in ai, present in the formulation. The percentage ai for liquid formulations may be given in weight per volume (e.g., g/liter), or as a weight:weight ratio (percentage). Conversion factors can be used to calculate the correct percent ai in a liquid herbicide formulation from the weight per volume concentration, as follows:

- Divide a concentration given in grams per liter (g/liter) by 10. Example: 600 grams of 100% butachlor per liter

$$\% \text{ ai} = \frac{600}{10} = 60\% \text{ ai/liter}$$

- Multiply a concentration given in imperial pounds (lb) per imperial gallon by 10. Example: 2 Ib/imperial gallon

$$\% \text{ ai} = 10 \times 2 \text{ lb} = 20\% \text{ ai/imperial gallon.}$$

- Multiply a concentration given in pounds (lb) per US gal by 12. Example: 2 lb/US gallon

$$\% \text{ ai} = 12 \times 2 \text{ lb} = 24\% \text{ ai/US gal.}$$

The following general formula may be used to calculate most herbicide dosage determinations:

$$\begin{array}{l}\text{Quantity of}\\ \text{formulated}\\ \text{product}\\ \text{required}\\ \text{per hectare}\end{array} = \frac{\begin{array}{c}\text{Recommended}\\ \text{amount of ai}\end{array}}{\begin{array}{c}\text{Percent ai in}\\ \text{formulated}\\ \text{product}\end{array}} \times 100$$

Example: Apply 2.0 kg ai/ ha of Machete, which has 60% ai as butachlor.

$$\frac{2.0 \text{ kg} \times 100}{60} = 3.333 \text{ kg/ha}$$

Under many conditions, the area to be sprayed will not be exactly 1 ha. Also, the sprayer tank may not be big enough to hold all the herbicide and water required for 1 ha. This makes it necessary to calculate the amount of herbicide and water required for an area less than 1 ha or for a tankful. The amount of water needed to spray a given area can be calculated as

$$\text{Amount of water required (liters)} = \frac{\text{Area to be sprayed (m}^2) \times \text{sprayer output in liters/ha}}{10{,}000}$$

If the area to be sprayed is 1,000 m^2 and the sprayer output is 200 liters/ha (from the calibration described earlier), then the amount of water required to spray this area is :

$$\text{Amount of water required} = \frac{1{,}000 \times 200}{10{,}000} = 20 \text{ liters}$$

When the area to be sprayed is determined on the basis of sprayer capacity, area can be calculated as

$$\text{Area covered by one tank} = \frac{\text{Sprayer capacity (liters)}}{\text{Sprayer output (liters/ha)}} \times 10{,}000$$

If a knapsack sprayer has a capacity of 15 liters and the sprayer output is 200 liters/ha, then the area covered by one full tank (15 liters) is

$$\frac{15 \times 10{,}000}{200} = 750 \text{ m}^2$$

The total amount of formulated product to be used in the examples above can be calculated as

$$\frac{\text{Total water required (in liters)}}{\text{Calibrated liters/ha}} \times \text{Quantity of formulated product required/ha}$$

Thus,

$$\frac{20}{200} \times 3.333 \text{ kg} = 0.333 \text{ kg or } 333 \text{ g}$$

To summarize, the steps required to arrive at the amount of herbicide and water to be sprayed on a given area are

1. Determine sprayer output per hectare (calibrate the sprayer).
2. Determine the quantity of formulated product required per hectare (from label or other recommendations).
3. Use the size of the area to be sprayed or the sprayer capacity (whichever is smaller) to determine the amount of water needed.
4. Calculate the formulated product needed for the quantity of water.

Appendix B gives calculated dosage rates per hectare for different formulations, so that you can cross check your own calculations.

Calculation of dosage in acid equivalents of salts and esters

Herbicide dosage recommendations computed in kilograms of active ingredient per hectare refer to the unaltered chemical molecule. But in herbicide molecules that are acids, the acidic portion is normally transformed to a salt or ester, to improve such characteristics as solubility in water or oil and foliar penetration. In general, the parent acid portion of the herbicide molecule remains as the herbicidally active portion, while the ester or salt attached to the parent acid satisfies the functions for increased solubility or increased penetration. The acid equivalent of a salt or ester form of a herbicide, therefore, is that portion of the molecule representing the original acid form of the molecule. The dosage recommendation for such herbicides is given as kilograms of acid equivalent of the active ingredient per hectare. The recommended dosage of herbicides applied as salts or esters is often based on the herbicidal portion of the salt or ester molecule, and excludes the herbicidally inactive portion (Anderson 1983).

The product labels of most commercial herbicide formulations containing salts and esters specify the amount of acid equivalent present in the formulation. The acid equivalent is equal to the difference in weight, expressed as percent, between the parent acid molecule (minus a value of 1, representing the loss of the H^+) and that of the salt or ester molecule. It is always less than l00%, and is calculated by the following formula:

Molecular weight (mol/wt) of acid

$$\text{Acid equivalent (\%)} = \frac{\text{Molecular weight (mol/wt) of acid form (minus 1)}}{\text{Molecular weight (mol/wt) of salt or ester form}} \times 100$$

Example: The molecular weight of 2,4-D is 221. The molecular weight of its isopropyl ester is 263. The acid equivalent of the isopropyl ester of 2,4-D is determined as

$$\text{Acid equivalent} = \frac{221\text{-}1}{263} \times 100 = 83.6\%$$

Field techniques for using herbicides

Proper field techniques are important to get good weed control from herbicides. Read all labels before using a herbicide, and follow the directions. To kill the weeds and not the rice, using the correct dosage is essential. Contact herbicides work best when they are applied in a high volume of water.

The decision to spray should be made after considering

- the degree of weed species and weed growth,
- the recommendation for weed control,
- the control measures available,
- the correct timing of herbicide application,
- the previous experience in spraying,
- the probable cost-benefit of applying the herbicide, and
- safety.

Always follow the chemical manufacturer's instructions on safety precautions.

A few days before spraying, ensure that

- chemical supplies on the farm are adequate for the job at hand,
- a readily accessible water supply for filling the sprayer is available, and
- the sprayer is clean and in good working condition.

On the day of spraying, check to see that

- appropriate protective clothing is worn,
- the calibration used is correct,
- weeds are in suitable condition for treatment,
- ground conditions are satisfactory,
- weather conditions and forecasts are satisfactory, and
- the person to do the spraying is healthy and fit.

Mixing

The concentrated active ingredient of a herbicide must be mixed thoroughly with water (the carrier). When using a wettable powder, agitate the solution to prevent the herbicide from settling out. That would plug nozzles and give non-uniform application rates. The water used should be clean and free from clay, mud, organic matter, and dissolved salts.

Do not guess the amount of herbicide to use. Always measure or weigh the exact calculated amount. Fill the sprayer tank about half-full with water. Add the measured herbicide to the tank, then fill the tank completely with water. Be sure both herbicide and water pass through the strainer in the tank. Mix the contents of a knapsack sprayer tank by shaking it.

Herbicide selection

Most herbicides are suitable for use only in selected crops; they would kill other crops. To assure the safety of the rice crop, use only herbicides recommended for rice. Some herbicide groups tend to control certain families of weeds better than others. Consider the weeds on your farm and select the herbicide that will control those weeds.

Nozzles

Select the most suitable nozzle size and type. In general, use

- a cone nozzle for applications where it is important to cover the crop foliage (e.g., for foliar herbicides), and
- a low-pressure fan nozzle for residual herbicides.

Spraying

Do not spray when the wind is too strong. If you must spray when it is windy, hold the nozzle close to the ground to prevent the droplets from being blown away during calibration of the sprayer and during actual field spraying. Always walk downwind, so that any spray blown off the crop is carried away from you.

Always carry a spare nozzle. Check the sprayer nozzle often for possible blockage (this would be indicated by a poor spray pattern) and clean it when necessary. A faulty nozzle delivers the wrong dosage. If a faulty nozzle develops, attend to it at the end of the field. Use a soft material to clean blocked nozzles. Never clean a nozzle with a wire or pin.

Maintain a constant nozzle height above the target weeds in the field. A nozzle height of about 50 cm from the target to the ground is ideal.

Avoid missing strips or overlapping spray swaths.

- Use rice rows as a measure (spacing from 25 to 30 cm). Walk over every third or fourth row to give a 1-m spray width.
- Place sticks or sighting poles at swath width intervals before starting to spray.

While spraying, maintain a constant walking speed. When you slow your pace, the amount of herbicide applied increases. When you walk faster, the amount decreases. Underapplication results in unsatisfactory weed control; applying more than the recommended amount may result in injury or death to the rice crop. Overapplication also wastes a costly input.

Cleaning the sprayer

Do not leave herbicide solutions in the sprayer overnight. Whether spraying research plots or large areas, it is important to thoroughly clean the sprayer before using a different herbicide. Herbicides retained in the pump, hose, boom, or sprayer tank, if sprayed later on sensitive plants, will cause crop injury. To clean the sprayer,

1. Rinse the sprayer with clean water to remove most of the chemical. A household detergent can be added to water used for cleaning. Pour this out and add clean water again.
2. Operate the pump for at least 10 strokes and pour out the remaining water.
3. Repeat these procedures two more times.

Granular herbicide application

Most farmers apply granular herbicides by broadcasting. Whatever the method used, safety and uniformity of application are important. Unlike liquid formulations, where the amount of water used is not critical as long as the sprayer has been calibrated to deliver a certain rate, granular formulations are not further diluted with a carrier. Thus the formulated product is constant and the amount applied is determined by the recommended application rate per hectare. It is important to follow this calibration method:

1. Determine the amount of formulated product per hectare using the formula on page 59.

Example: To apply 2.0 kg ai/ha of Machete with 5% ai, multiply 2 kg by 100, then divide by 5 = 40 kg/ha.

2. Measure and mark out a 5-m × 5-m area and determine the amount of granules required for the area. The amount of butachlor required for 25 m^2 is

$$\frac{25}{10{,}000} \times 40 \text{ kg} = 0.1 \text{ kg} = 100 \text{ g}$$

3. Walk at a comfortable pace and practice applying the herbicide several times, until you achieve a 100 g/25 m^2 application rate.

When the granules are to be mixed in a carrier such as sand, use a different calibration method, as follows:

1. Measure and mark out a length of 100 m.
2. Weigh enough herbicide to cover this area. Walk at a comfortable pace and practice applying herbicide uniformly over this area.
3. Reweigh the herbicide remaining. The difference will give the amount of herbicide applied.
4. Measure the swath width.

To calculate the application rate, use the following formula:

$$\text{Application rate in kg/ha} = \frac{\text{Granules applied in g per 100 m}}{\text{Swath width in cm}} \times 10$$

Example: If the weight of granules used over a 100-m length with a swath diameter of 40 cm is 120 g, then the application rate is

$$\frac{120 \times 10}{40} = 30 \text{ kg/ha}$$

Granular herbicides, although about twice as costly as nongranular ones, can be applied once by hand, in association with fertilizer. They can also be applied using any one of a number of mechanical spreaders. In small plots, granules can be applied by shaking them from a bottle with perforated lid (IRRI, unpublished circular).

Safe use of herbicides

Improper herbicide use can harm crops, humans, wildlife, domestic animals, and the environment. There are two types of herbicide toxicity: acute (a single oral dose) and chronic (a sublethal dose repeated over time).

LD_{50} and LC_{50}

LD_{50} is the expression for a single dose that, when taken orally, kills 50% of a group of test animal. It is usually expressed in milligrams of herbicide per kilogram of body weight of test animal. The higher the herbicide toxicity, the lower the LD_{50}. For example, the LD_{50} of paraquat is 150 mg/kg; that of butachlor is 2,000 mg/kg.

We emphasize that the LD_{50} is NOT the safe dose level—50% of test animals die at that dose.

LC_{50} is the concentration required to kill 50% of the test organisms in an environment (usually water). The LC_{50} [96 h] for carp is 0.32 mg/liter.

Indiscriminate herbicide use in irrigated rice can adversely affect wildlife, humans, and the environment. Improper herbicide use will contaminate local water bodies. Inappropriate herbicide use or use of herbicides highly toxic to fish will kill or contaminate the fish in that water, which will affect the fish consumers.

Safe handling of herbicides

Handling an undiluted herbicide is more dangerous than handling the diluted product. Herbicides can enter the human body through the skin, mouth, nose, and eyes. Absorption through skin is common and can occur from chemical spilling and splashing, and from drifting of spray. Absorption through the nose and mouth can occur from inhaling spray droplets, vapors, or chemical dust. Safety tips for herbicide use are as follows:

- Mix herbicides or other pesticides in the open air, never in enclosed places with inadequate ventilation.
- Read the label on the herbicide container and make sure any special instructions are understood.
- Leaks from a badly maintained sprayer may increase contact between the herbicide and the skin, permitting the herbicide to enter the body. Tighten leaking sprayer parts and check seals and washers to avoid leakage.
- Wear protective clothing. Special protective clothing is heavy and expensive, and uncomfortable when used in the tropics. For small-scale farmers who use herbicides occasionally, a complete set of protective clothing may not be necessary. All

farmers, however, should wear clothing and footwear that will minimize any skin contact with herbicide. For operators who spray regularly, protective clothing is required. Basic protective clothing includes rubber boots, long trousers, long-sleeved shirt, and rubber gloves. When opening herbicide containers, or pouring and mixing herbicides, goggles should also be worn. When spraying tall weeds, a waterproof hat and face shield should be worn.

- Wash yourself and your clothes after spraying is done and all spraying equipment has been cleaned.

Herbicide drift

Herbicide drift occurs when the smaller drops in the spray are carried away from the target by wind, or when vapor from a volatile herbicide is carried away during or after spraying. Growth regulator herbicides (such as 2,4-D or MCPA) cause the greatest drift damage. Crops such as tomato, cotton, lettuce, and tree fruits are particularly sensitive to them. Herbicide drift can be avoided by

- Spraying only when a light wind is blowing *away* from susceptible crops.
- Using large nozzle tips, thus applying larger size droplets and larger spray volumes (more than 100 liters/ha).
- Using the minimum pressure required for the nozzles to operate properly.
- Holding sprayer nozzles close to the target.
- Leaving a 10-m-wide strip unsprayed between the rice and any field where sensitive crops are growing. Other weed control methods can be applied to the unsprayed strip.

Storage of herbicides

Herbicides should be stored in a safe place, preferably in a separate building or in a place that can be locked at all times, to prevent unauthorized persons—especially children—from entering. A complete inventory of all herbicides in the storage area is essential.

Herbicides should not be stored near food, animal feed, or other items that could be contaminated by spilled or volatile herbicides. Always store all herbicides, however small the quantity, in the original, labeled container. Herbicides must never be stored in any other containers, especially not in old bottles or other containers where they could be mistaken for food, beverage, or drugs for humans or animals.

Liquid herbicide products, especially those containing organic solvents with low temperature flash points, present special hazards because of their flammability. Highly flammable products will readily ignite and burn, or explode when overheated. Some dry powder formulations may also present fire or explosion hazards. These dangers are important considerations in selecting and using storage areas for herbicides.

Disposal of empty herbicide containers

Empty herbicide containers pose a health hazard to the general public, especially to children. No matter how well empty containers are cleaned, the chemicals can never be removed completely. All empty herbicide containers should be destroyed. Bury them in a pit away from ponds and other water bodies. Bottles and tins should be crushed or broken before burying.

Poisoning by herbicides

Poisoning may result from absorption of herbicides through the skin and eyes, through the gastro-intestinal tract by swallowing, and by the lungs through inhaling vapor, spray, or dusts. In case of poisoning accidents, take the following first aid measures:

1. Remove the affected person from the sprayed area.
2. Keep the patient at rest and warm, but avoid overheating.
3. Remove all protective clothing and other wet or contaminated clothing. Wash any affected body parts thoroughly with soap and water. When the eyes are contaminated, wash them with plenty of clean water, normal saline, or phosphate buffer for about 15 min and cover them with sterilized pads.
4. Make sure the patient is breathing and be prepared to give artificial respiration.
5. If a herbicide has been swallowed, and the patient is awake, induce vomiting by tickling the back of the person's throat with a clean finger or by giving warm salty water (2 tablespoons of salt in a glass of water). Vomiting can be induced only in a conscious person. Retain samples of vomit for analysis in the hospital.
6. Do not attempt to administer anything by mouth to an unconscious patient.
7. If the patient is convulsing, ensure that clothing is loose around the neck and that air passages are free. Place something strong between the teeth to prevent biting the tongue.
8. Obtain medical help as soon as possible. Depending on the severity of exposure, the patient should either be examined by a doctor immediately or taken to hospital. In most cases of poisoning or overexposure to chemicals in the field, it is most practical to take the patient to the nearest casualty or emergency unit. In all cases, the chemical involved should be identified.

For more information on agropesticides and their management, refer to *Agro-pesticides: their management and application* by Oudejans (1982).

Chapter 5

Principal rice herbicides

Herbicides play an important role in integrated weed management in rice. Early-season weed competition significantly reduces rice grain yield, and preemergence herbicide treatments are widely used. But most weed seeds germinate over a long time, and preemergence herbicides, with their relatively short residual life, may not control weeds long enough to optimize rice yields. Then, postemergence herbicides may be needed along with other control measures. Moreover, any one herbicide may not control all the weeds present in a ricefield. Herbicide mixtures are used to obtain a wider range of weed control.

Herbicide mixtures, rotations, and sequences

Mixing herbicides and spraying them simultaneously increases the range of weed control. Using herbicide mixtures can also save time and reduce application costs. A broadleaf herbicide and a grass herbicide are often mixed together (e.g., bensulfuron + butachlor). Residual and foliar contact herbicides may be combined (e.g., thiobencarb + 2,4-D).

Herbicides that may be combined often are sold as formulated products. When these are not available, two or more herbicides may be mixed in the spray tank at the time of application—a tank-mix combination. Combinations must be selected carefully and comply with manufacturers' recommendations to avoid product incompatibility.

Herbicide classification and uses

The herbicides commonly used for weed control in rice are described here. Table 5.1 lists the weeds controlled by the herbicides. Details on their use are discussed in Chapters 6-9. Every effort has been made to ensure that the information presented is correct (Roberts 1982, Swarbrick 1984, Attwood 1985, Chemical and Pharmaceutical Press 1986, Thomson 1986, Worthing 1987). But because herbicide activity varies from locality to locality, only general recommendations are given. Specific recommendations should be obtained from weed specialists in the reader's locality.

Most herbicides are organic compounds. Herbicides are considered ideal if they are toxicologically safe, selective to rice, cost-effective, effective on weeds, and have no lasting adverse effects on the environment. Herbicides may be classified, for convenience, by method and timing of application. Or they may be classified by chemical group, which also gives an indication about how the herbicide may be used.

Anilides

Anilides are used to control germinating annual weeds, especially grasses. They often are most active as surface preemergence treatments. The primary mechanism of action is through interference with nucleic acid and protein synthesis. Butachlor, pretilachlor, and propanil are examples of this group.

Butuchlor. Butachlor is absorbed primarily through germinating shoots and secondarily through roots. Its mode of action is inhibition of protein synthesis. It is used at 2-3 kg ai/ha for preemergence control of most annual grasses at the 1- to 2-leaf stages and of certain broadleaf weeds, and can be applied postemergence. For transplanted rice, it is applied 3-7 d after transplanting. For direct seeded rice, it is applied 10-12 d after emergence.

Table 5.1. Susceptibilitles[a] of important rice weeds to common rice herbicides (treatment at recommended doses and application times).

Weed	Herbicide																						
	Bensulfuron	Bentazon	Bifenox	Butachlor	Butralin	Cinmethylin	Chlomethoxynil	2,4-D	Fenoxaprop	Fluorodifen	Glyphosate	MCPA	Molinate	Oxadiazon	Oxyfluorfen	Paraquat	Pendimethalin	Piperophos	Pretilachlor	Propanil	Quinclorac	Thiobencarb	Dimethametryn
Acanthospennum hispidum		S		R				S	R	R	S	S				S	R	R			MS		
Aeschynomene viginica		S						S	R		S	S		MS	S	S		R			MS	R	
Ageratum conyzoides		S		S				S	R		S	S		S	S			R				R	S
Altemanthera sessilis	S		MR					S	R		S	S		S		S		R		S			
Amaranthus spinosus		S		S	S			S	R	S	S	S		S	S	S	S	R		S		R	S
Ammannia coccinea		S	S	S					R	S	S					S		R		S		MR	
Bidens pilosa		S						S	R		S	S		MR	S	S		R					S
Brachiaria mutica		R		R				R	S	R	S	R		R	R	MR	R	R		R			
Commelina benghalensis		S	S	R				MR	R	MR			S	MR	S	MR	R			R		MR	R
Cynodon dactylon	R	R	R	R	R		R	R	MS	R	S	R	R	R	R	R	R			R		R	R
Cyperus difformis	S	S	S	S	S	S	S	S	R		S	S	MS	MS	S	S	S	S	S	S		S	R
Cyperus esculentus		S	MS	MS		S		MS	R		S		MR		S	S	R	R		R	MR	R	R
Cyperus iria	S	S	S	S	S	s		S	R	S	MS	MS	S	S	R	S	S	S	S	S	MR	S	R
Cyperus rotundus	R	MS	R	R	R	R	MS	R	R	S	MS	R	R	R	R	R	R	R		R	MR	R	R
Dactyloctenium aegyptium		R						R	S	S	S	R		S	S	S	S			S		R	R
Digitaria sanguinalis		R		S				R	S	S	S	R	S	S	S	S	S			MR		S	R
Echinochloa colona		R	MR	S	S	S	S	R	S	MR	S	R	S	S	S	S	S	S	S	S	S	S	R
Echinochloa crus-galli	S	R	MR	S	S	S	S	R	S	MR	S	R	S	S	S	S	S	S	S	S	S	S	R
Echinochloa glabrescens	S	R	MR	S	S	S	S	R	S	MR	S	R	S	S	S	S	S	S	S	S	S	S	R
Eclipta alba		S		MR				S	R	MR	S	S		MR	S	S		R		MR		MR	S
Eichhornia crassipes								S	R			S				MS	R						R
Eleusine indica		R	MS	S	S			R	S	S	S	R	S	S	S	S	S	R		MS		S	R
Eleocharis acicularis		S		S	S		R				S					S		S	S	S		S	R
Euphorbia hirta					S			MS	R		S	MS			S	S	MR					R	
Fimbristylis miliacea	S	S	S	S			S	S	R	S	S	S	MS		S	S	S	R	S	S	MR	S	
Imperata cylindrica		R	R	R	R		R	R	MR	R	S	R	R	R	R	R	R	R		R		R	R
Ipomoea aquatica				R				S	R	R						MR					MS		R
Ischaemum rugosum		R	S	S				R	S		S	R	R		S	S	S			S		MS	R
Leersia hexandra		R		R	R			R	S		S	R			R		R					MR	R
Leptochloa chinensis		R	MR	S				R	S	S	S	R	S		S	S	S		S	MR	R	S	R
Ludwigia octovalvis		S		S			MS	S	R	S	S	S		S	S	S		R	S	S			S
Marsilea minuta	S	S		S					MR	R		S	MR		S		S		R			MS	
Monochoria vaginalis	S	S		S	S	S	S	S	R		S	S		S	S	S	S	S	S	S	MS	MS	
Nymphaea stellata								S	R					S		S							

Table 5.1 continued.

Weed	Herbicide																						
	Bensulfuron	Bentazon	Bifenox	Butachlor	Butralin	Cinmethylin	Chlomethoxynil	2,4-D	Fenoxaprop	Fluorodifen	Glyphosate	MCPA	Molinate	Oxadiazon	Oxyfluorfen	Paraquat	Pendimethalin	Piperophos	Pretilachlor	Propanil	Quinclorac	Thiobencarb	Dimethametryn
Oryza barthii		R	R	R	R		R	R		R	S	R	S	R	R	S	R			R		R	
Oryza longistaminata		R	R	R	R		R	R		R	S	R	R	R	R	MR	R			R		R	
Paspalum distichum		R	R	R	R		R	R	S	R	S	R	R	R	R	MR	R	R		R		R	
Physalis angulata		S						R		MS	S					S						R	S
Portulaca oleracea				R	S			MR		S				MS	S	MR	S	R		S		S	
Rottboellia cochinchinensis		R	R	R			R	R	S	MS	R		MS	R	S	S				MR		R	R
Scirpus maritimus	MS	S	R	R	R	MR	R	S		R	S		R	R	R	R	R		MR	R		R	R
Setaria glauca		R		S					S	MS	S			S		S	S			S			
Sphenoclea zeylanica	S	S	S	S				S			S	S		S	S	S	S	R	S	S	MR		S
Trianthema portulacastrum				R		R										S	S	R		R			S

[a]Blank space = no information available, S = susceptible, MS = moderately susceptible (control partial or inconsistent), MR = moderately resistant (weeds suppressed). R = resistant (no effect).

Butachlor in soil is broken down by microbial activity. In soil or water, it is rapidly converted to water-soluble derivatives. It may persist for 6-10 wk. Formulations available include granules and emulsifiable concentrate. When applied postemergence, it can be tank-mixed with propanil.

Water solubility is 20 mg/liter at 20 °C. LD_{50} for rats is 2,000 mg/kg. Contact causes irritation to skin and eyes. It has high fish toxicity—LC_{50} (96 h) for carp is 0.32 mg/liter.

Pretilachlor. Pretilachlor is a selective chloroacetamide rice herbicide that can be applied before transplanting or any time between transplanting and weed emergence. Pretilachlor at 0.6 kg ai/ha is well-tolerated by transplanted rice, but it cannot be used for direct seeded rice without an antidote. Rice can be protected against injury by applying fenclorim one day before, at the same time as, or up to 3 d after, pretilachlor application (Christ 1985). Fenclorim is also effective in protecting water seeded rice, but is not suitable for use on upland rice.

Water solubility is 50 mg/liter at 20 °C. LD_{50} is 6,099 mg/kg. It has high fish toxicity—LC_{50} (96 h) for rainbow trout is 0.9 mg/liter.

Propanil. Propanil is a contact herbicide that can be applied postemergence. It is effective against several grassy and broadleaf weeds at the 2- to 3-leaf stages, and has no residual effects. Its effectiveness decreases on grasses to negligible at the tillering stage. Rice is extremely tolerant of propanil because rice plants have high levels of the hydrolyzing enzyme aryl acylamidase, which detoxifies propanil.

Propanil can be used at 3-4 kg ai/ha in irrigated and rainfed rice. It should be applied when most weeds have emerged. The water level in a flooded ricefield should be lowered to expose weeds about 24 h before propanil application. Raise the water level again 1-3 d after treatment, before any new weeds emerge. A slight leaf burn may occur on rice after application, but the rice plant normally recovers quickly.

Propanil should not be applied if rain threatens to fall within 5-6 h after application. It should not be applied to rice at the late tillering stage, about 60 d after planting. Propanil-treated rice crops should not be treated with organophosphorus or carbamate insecticides within 14 d before or after treatment because those insecticides inhibit the detoxification of propanil by rice. Commercial mixtures include propanil + molinate, propanil + bentazon, and propanil + bifenox.

Water solubility is 0.2 g/liter at 25 °C. LD_{50} is 1,400 mg/kg. It has high fish toxicity—LC_{50} (96 h) is 13 mg/liter, indicating that streams and lakes should be protected from contamination.

Bipyridyliums

Herbicides from this group are primarily postemergence, foliar-acting compounds with no soil activity. Paraquat and diquat are generally nonselective. On treated plants, toxicity symptoms are a characteristic rapid scorch and desiccation. Light, oxygen, and chlorophyll are required for maximum manifestation of phytotoxicity.

Paraquat. Paraquat is nonselective, with fast contact action when applied postemergence. It kills most annual weeds and grasses, including rice. It can be used in zero tillage or minimum tillage systems and in stale seedbed land preparation, at application rates of 140 to 840 g ai/ha. It is rapidly inactivated on contact with soil by strong adsorption to clay.

Water solubility is 70 g/liter at 20 °C. LD_{50} for rats is 150 mg paraquat/kg. It has medium fish toxicity, depending on the formulation used—LC_{50} (96 h) for rainbow trout is 32 mg/liter.

Dinitroanilines

Butralin and pendimethalin are examples of dinitroanilines. Members of this family are active when applied to the soil and must be applied before weed seed germination. In general, dinitroaniline herbicides do not control established weeds. Their mode of action is inhibition of both root and shoot development (mitotic poison).

Butralin. Butralin is a preemergence herbicide. It is selective to upland rice when applied pre-emergence and to pregerminated rice at the 1- to 4-leaf stages (4-6 d after seeding). It is active against many broadleaf weeds.

Water solubility is 1 mg/liter at 24 °C. LD_{50} for albino rats is 12,600 mg/kg. It has high fish toxicity—LC_{50} (48 h) for rainbow trout is 3.4 mg/liter.

Pendimethalin. Pendimethalin used as a preemergence herbicide inhibits germination and seedling development of susceptible weeds. Where grasses are expected to be a problem, it should be applied after planting and before emergence of rice and weeds. It can also be applied as a postemergence treatment with propanil, which combines the direct contact action of propanil and the residual activity of pendimethalin. Because soil and weeds must be completely exposed to spray coverage, no floodwater should be on the field at the time of application. The residual activity of pendimethalin is activated by moisture. It is most effective when adequate rainfall or irrigation is received within 7 d after application.

Water solubility is 0.3 mg/liter at 20 ºC. LD_{50} for albino rats is 1,050-1,250 mg/kg. It has high fish toxicity—LC_{50} (96 h) for channel catfish is 0.42 mg/liter.

Diphenyl ethers

This group includes bifenox, fluorodifen, oxyfluorfen, and chlomethoxynil. Diphenyl ether herbicides are classified as contact herbicides. When applied preemergence, they inhibit seed germination and early seedling growth. They are relatively insoluble in water, and do not readily leach. They are used principally preemergence or early postemergence to control broadleaf weeds and grassy weed seedlings. In general, these herbicides more effectively control broadleaf seedlings than grassy seedlings.

Bifenox. Bifenox is primarily a broadleaf herbicide. It can be applied at 2 kg ai/ha as preemergence or postemergence up to the 2-leaf stage of rice. Bifenox has been found to be highly toxic to direct seeded flooded rice, resulting in low grain yields (IRRI 1974). Mixtures include bifenox + 2,4-D and bifenox + propanil.

LD_{50} for rats is more than 6,400 mg/kg. It has high fish toxicity—LC_{50} (96 h) for rainbow trout is 27 mg/liter.

Fluorodifen. Fluorodifen is a preemergence and postemergence contact herbicide. It can be used at 3-4 kg ai/ha to control some broadleaf weeds and grasses.

LD_{50} for rats is 9,000 mg/kg. It has high fish toxicity—LC_{50} (96 h) for rainbow trout is 0.18 mg/liter.

Oxyfluorfen. Oxyfluorfen is used either preemergence or postemergence. It is a contact herbicide requiring light for activity. It is absorbed more readily by shoots than by roots. Most annual broadleaf weeds and grasses are controlled at relatively low rates of 0.15-2.25 kg ai/ha. It is more effective on broadleaf weeds than on grasses, and is most active as a postemergence treatment when weeds are small.

Water solubility is 0.1 mg/liter at 20 °C. LD_{50} for dogs is at least 5,000 mg/kg. It is highly toxic to aquatic invertebrates and fish.

Organophosphorus compounds

Organophosphorus herbicides are primarily foliar acting; they have no activity through the soil. A major example is glyphosate.

Glyphosate. Glyphosate is a broad-spectrum, postemergence, nonselective, translocated herbicide. It is effective in deep-rooted perennial weeds and annual grasses, sedges, and broadleaf weeds. Application rates range from 0.5 to 4.0 kg ai/ha, with most perennials requiring 1.5-2.5 kg ai/ha.

Glyphosate is absorbed through the foliage and translocated throughout the plant. The addition of certain salts to glyphosate formulations can substantially increase phytotoxicity in some cases. Ammonium salts are consistently effective in increasing performance. Glyphosate is inactivated on contact with soil (Duke 1988). Translocation to underground organs of perennials prevents regrowth from these sites and results in their subsequent destruction. For best control of perennial weeds, the plant should not be disturbed by tillage until translocation is completed—about 2 wk.

Visible effects of glyphosate normally occur in 2-4 d in annual species and in 7-20 d in perennial species. Rainfall occurring within 6 h after treatment may reduce effectiveness.

Glyphosate can be used in zero-tillage or minimum-tillage system of rice production, especially where perennial weeds are a problem. It should not be applied to growing rice.

Water solubility is 10 g/liter at 25°C. LD_{50} for rats is 5,000 mg/kg. Fish toxicity—LC_{50} (96 h) for trout is 86 mg/liter.

Phenoxy acetic acids

Phenoxys are a type of growth hormone, generally used as foliar-applied, translocated herbicides. Phenoxy acetic acid herbicides tend to accumulate in the growing points of plants. Resulting abnormal cell division and growth interfere with nucleic acid metabolism and disrupt the translocation system. Most phenoxy herbicides are formulated as salts and esters of their parent acids. Members of the group include 2,4-D, fenoprop (silvex), MCPA, and 2,4,5-T. Phenoxys are used selectively to control annual and perennial broadleaf weeds. Grass seedlings also may be controlled, but there is little or no control of established grassy weeds.

2,4-D. 2,4-D is a systemic herbicide. Postemergence application of 2,4-D controls sedges and broadleaf and aquatic weeds. It normally does not control grasses. It can be applied in rice at 0.4-0.8 kg ai/ha 3-4 wk after weeds have emerged. It can also be applied 4 d after transplanting at 0.8 kg ai/ha to control some annual grasses in addition to sedges and broadleaf weeds. 2,4-D mixtures with bifenox, piperophos, butachlor, and thiobencarb are available for use in rice. Butachlor + 2,4-D mixture has been found extremely toxic to irrigated wet seeded rice (IRRI 1985). Rice is susceptible to 2,4-D at emergence, incipient tillering, booting, and heading.

Water solubility is 620 mg/liter at 20 °C. LD_{50} for rats is 375 mg/kg. 2,4-D is not toxic to fish. LC_{50} (24 h) of the sodium salt for rainbow trout is 1,160 mg/liter.

MCPA. MCPA is a postemergence, selective, translocated broadleaf herbicide. In rice, it is similar to 2,4-D but is more selective at the same application rate. It is normally applied at 0.2-1.2 kg ai/ha. Mixtures available include MCPA + bentazon. MCPA should be applied to rice from midtillering to maximum tillering stages. It should not be sprayed at the booting stage.

Water solubility is 825 mg/liter at 20 °C. LD_{50} for rats is 700 mg/kg. LC_{50} (96 h) for rainbow trout is 232 mg/liter.

Thiocarbamates

Thiocarbamates are active when applied to the soil. Some are highly volatile, which makes soil incorporation necessary. Thiocarbamate herbicides control germinating annual grassy and broadleaf weeds. The process of lipid biosynthesis appears to be the most sensitive to thiocarbamates. Examples of this group are thiobencarb and molinate. Most thiocarbamate herbicides have a relatively short soil persistence. Recent evidence (Roeth 1986) has shown increased breakdown of some thiocarbamate herbicides in soils with a history of thiocarbamates application.

Molinate. Molinate is a herbicide for selective weed control in rice at 2-4 kg ai/ha. It is particularly effective for controlling *Echinochloa* weed species. It can be applied as a granular formulation to the water in flooded rice. Emulsifiable concentrates applied to the soil surface are extremely volatile and must be incorporated immediately. Molinate can be applied before sowing rice, at postemergence preflood, at flooding, or postflood. Moisture is required to activate molinate. In pre-flood treatment, the area should be flooded as soon as possible. Once applied, a continuous water cover must be maintained. Rice is extremely tolerant of this herbicide. Cool temperatures will cause less than optimal weed control. Commercial mixtures include molinate + propanil.

Water solubility is 880 mg/liter at 20 ºC. LD_{50} for male rats is 369 mg/kg. LC_{50} (96 h) for goldfish is 30 mg/liter. At recommended rates, molinate had no detectable effects on fish in ditches draining water from treated ricefields in California.

Thiobencarb. Thiobencarb is more effective on grasses and sedges than on broadleaf weeds. Thiobencarb interferes with protein synthesis and inhibits photosynthesis. Protein synthesis and amylase biosynthesis are inhibited more in susceptible grass species than in rice.

In transplanted rice, thiobencarb shows maximum herbicidal selectivity by taking advantage of differences in growth between rice seedlings at the 3- to 6-leaf stages and germinating weeds. Thiobencarb (2-3 kg ai/ha) is distributed in the top soil after application and is readily leached from the soil. Rice plant injury symptoms include dwarf malformation and deep greening. In some cases, leaf scorching appears.

Thiobencarb should be applied between preemergence and the 2-leaf stage of *Echinochloa* spp. because herbicidal activity decreases after this stage. For post-emergence application, thiobencarb should be applied after the 1.5-leaf stage of rice to the 2- to 3-leaf stage of *Echinochloa* spp. to obtain the best weed kill without damaging the rice. Cool temperatures may delay onset of herbicidal activity. Commercial mixtures available include thiobencarb + propanil and thiobencarb + simetryn.

Water solubility is 30 mg/liter at 20 °C. LD_{50} for rats is 1,300 mg/kg. LC_{50} (48 h) is 3.6 mg/liter for carp.

Triazines

The triazines are a large group of herbicides. They are applied preemergence and postemergence to control seedling grasses and broadleaf weeds. They control broadleaf weeds better than grasses and do not control established annual or perennial weeds. Their mode of action is through inhibition of photosynthesis in plants. Simetryn and dimethametryn are triazines.

Simetryn. Simetryn is used as a mixture with thiobencarb to control broadleaf weeds in rice. LD_{50} for rats is 1,830 mg/kg.

Dimethametryn. Dimethametryn is a triazine compound used as a selective, preemergence, and postemergence herbicide. It controls annual broadleaf weeds and grasses.

Sulfonylureas

Sulfonylureas have very high biolgical activity, and rates as low as 0.002 kg ai/ha have been used. Although weed seed germination is not usually affected, subsequent root and shoot growth are severely inhibited in sensitive seedlings. Weed growth inhibition is rapid, with visual symptoms within 1-2 d in rapidly growing plants. The site of action of the sulfonylureas is the enzyme acetolactate synthase. Inhibition of this enzyme, which is needed for the production of the essential amino acid building blocks valine and isoleucine, results in rapid cessation of growth and eventual plant death. All plants contain this target enzyme, but the ability of some plants to rapidly convert the herbicide to an inactive product is the basis for selectivity (Beyer et al 1988).

Bensulfuron. Bensulfuron (0.05 kg ai/ha) is a sulfonylurea herbicide used in direct seeded and transplanted rice. It has good crop safety on indica rice varieties, but less crop safety on japonica types. Indica rices metabolize the herbicide more rapidly than japonica rices. Thiocarbamates herbicides, except molinate, show an antidote effect on bensulfuron through the acceleration of detoxification by rice.

Bensulfuron controls many broadleaf weeds and sedges. It can be applied as preemergence or early postemergence treatment. When used in combination with a grass herbicide such as thiobencarb, molinate, or butachlor, bensulfuron provides excellent weed control. Application can be made up to the 3-leaf stage of the weeds. Bensulfuron provides good control of S. maritimus when applied 6-12 d after emergence of the weed (Bernasor and De Datta 1986).

Water solubility at 25 °C is 120 mg/liter. LD_{50} in rats is 75,000 mg/kg. LC_{50} (96 h) for rainbow trout is >150 mg/liter.

Polycyclic alkanoic acids

Polycyclic alkanoic acids control grass weeds. In general, polycyclic alkanoic acids are lost from the soil through biodegradation, rather than through leaching or volatilization. Rainfall after foliar application can greatly reduce herbicide absorption because of a reduced amount of herbicide in contact with the plant. One example of the group is fenoxaprop. Herbicides such as MCPA, 2,4-D, and bentazon antagonize polycyclic alkanoic acids.

Fenoxaprop. Fenoxaprop (0.03-0.05 kg ai/ha) is a postemergence, selective herbicide for control of annual and perennial grassy weeds. It is a contact herbicide that is partly systemic. Rice is tolerant from the 3-leaf stage to early tillering. Fenoxaprop has no soil activity. It should not be applied with phenoxy compounds.

Water solubility at 25 °C is 0.8 mg/liter. LD_{50} is 2,357 mg/kg.

Miscellaneous herbicides

Several herbicides do not clearly fall into any of the groupings. These herbicides differ in chemistry, selectivity, and mode of action. Bentazon, chlomethoxynil, cinmethylin, oxadiazon, and quinclorac are examples.

Bentazon. Bentazon (1-2 kg ai/ha) selectively controls a number of broadleaf weeds and sedges, primarily by contact action. Broadleaf weeds at the 2- to 10-leaf stage are controlled most readily. Delay in application will result in inadequate control. In irrigated rice, bentazon should be applied only to weeds that have emerged above the water level. Bentazon does not control grasses and has no known preemergence activity. Available commercial mixtures include bentazon + MCPA and bentazon + propanil.

Water solubility is 500 mg/liter. LD_{50} for rats is about 1,100 mg/kg. It has low fish toxicity. LC_{50} (96 h) for rainbow trout is 510 mg/liter.

Chlomethoxynil (chlometoxyfen). Chlomethoxynil is used at 1.5-2.5 kg ai/ha in transplanted and upland rice. It is applied 3-8 d after transplanting rice.

Water solubility is 0.3 mg/liter at 15 °C. LD_{50} for mice is 3,300 mg/kg. LC_{50} (40 h) for carp is 237 mg/liter.

Cinmethylin. Cinmethylin provides excellent control of grasses and moderate suppression of broadleaf weeds and sedges. It has been tested at 100-200 g ai/ha for transplanted rice 4-9 d after transplanting and at 100 g ai/ha for direct seeded rice 7-9 d after seeding.

Water solubility is 61 mg/liter. LD_{50} is 3,900 mg/kg.

Oxadiazon. Oxadiazon is a preemergence herbicide applied at 0.5-0.75 kg ai/ha. Uptake by weed seedling shoots causes plant death because root uptake is low. Its postemergence activity against grasses is limited. Because it has low water solubility and high adsorption, oxadiazon is not leached and has good persistence. It can be used in transplanted and direct seeded rice. Commercial mixed formulations include oxadiazon + 2,4-D and oxadiazon + propanil.

Oxadiazon can be specifically formulated to be applied directly onto the surface of the ricefield floodwater. A shaker bottle with a calibrated stopper is used to spread oxadiazon directly onto the water without any dilution. The field should be flooded 3-5 cm at application and water should not be disturbed for 2-5 d after application.

Water solubility is 0.7 mg/liter at 20 °C. LD_{50} for rats is more than 8,000 mg/kg. LC_{50} (96 h) for rainbow trout is 1-9 mg/liter; for catfish, $\geq$ 15.4 mg/liter.

Piperophos. Piperophos is a piperidine compound used as a preemergence and postemergence herbicide. It controls annual grasses and sedges. The commercial product containing piperophos + dimethametryn in the ratio 4:l is used in rice to control most annual weeds. It is applied at 1-2 kg ai/ha at the 2- to 4-leaf stage of weed. It has good selectivity in transplanted and upland rice.

Quinclorac. Quinclorac is a chinoline-carboxylic acid compound used as a selective preplant, preemergence, and postemergence herbicide. It has been experimentally tested in rice at 125-300 g ai/ha for grass weed control. Organic matter in the soil will decrease herbicidal activity. Early postemergence application when grass weeds are at the 1- to 3-leaf stage will give the best results. Although results are best when quinclorac is applied onto saturated soil, it can also be applied onto dry soil or into standing water not deeper than 5 cm. Quinclorac can be safely used in dry seeded and water seeded rice when application is made postemergence, from the 1- to 2-leaf stage onward. It may be tank-mixed with other rice herbicides.

Oral LD_{50}, is 2,610 mg/kg.

Differences in herbicide tolerance among rice cultivars

Rice cultivars may vary in their tolerance for or susceptibility to herbicides. Broadleaf herbicides are expected to have little effect on rice. The differences in sensitivity to 2,4-D and MCPA (phenoxy acetic acid herbicides) that has been observed is due to differences in the growth stage of the cultivars at the time of herbicide application.

Susceptibility of rice cultivars to grass herbicides has been observed with propanil, butachlor, thiobencarb, pendimethalin, molinate, and piperophos-dimethametryn. For example, IR5, IR28, and IR46 are susceptible to thiobencarb (Shin et a1 1989). Indica varieties are usually more susceptible to simetryn than are japonica varieties. On the other hand, bensulfuron has good crop safety on indica rice varieties but less crop safety on japonica types. Cultivar tolerance may be due to differences in growth rate, growth stage, morphology, physiology, and biochemistry.

Herbicide selectivity is relative and can be overcome by increasing dosage and by changes in environmental conditions. Herbicide label information should be followed at all times to prevent severe damage to the rice crop.

Chapter 6

Weed control in irrigated rice

About 77 million ha of rice (53% of the world's rice area) are partially or fully irrigated throughout the growing season (IRRI 1988b). In South and Southeast Asia, irrigated rice comprises 33% of the rice-growing area; in temperate Asia, most ricelands are irrigated. In Europe, Australia, Egypt, Pakistan, and USA, ricelands are entirely irrigated.

Irrigated rice is classified into four culture groups according to the crop establishment technique used.

- Transplanted in puddled soil.
- Direct seeded on puddled soil (broadcast or drill seeded using pregerminated seed).
- Direct seeded on dry soil (broadcast or drill seeded using nongerminated seed.
- Water seeded.

Transplanted in puddled soil

Among irrigated rice cultures, transplanted rice has the lowest potential loss to weeds, because of the head start rice seedlings have over weeds and because of the weed control effects of floodwater. Despite these advantages, uncontrolled weeds can reduce rice yields by an average 48%, through competition for light and nutrients.

Weed problems

The weeds common in transplanted rice *(Monochoria vaginalis, Echinochloa crus-galli, Cyperus difformis, Cyperus iria,* and *Scirpus maritimus)* are in general highly competitive. They have discontinuous germination and rapid growth and are adapted to aquatic conditions. Weeds grow and infest an irrigated field if optimum water depth is not maintained. In poorly flooded ricefields, most semiaquatic lowland rice weeds can germinate and survive.

Stand establishment method

Twenty- to 30-d-old rice seedlings are normally transplanted into a puddled soil. In the irrigated rice-growing areas of Asia, seedlings are raised in wet bed, dapog, or dry bed nurseries. In the wet bed method, pregerminated seeds are broadcast uniformly on a raised bed of puddled soil. Seedlings are ready for transplanting 20-25 d after sowing. In the dry bed method, seedlings are grown similarly, but the soil is not puddled and drainage is provided.

Weeds in rice seedling nurseries can cause the complete failure of the nursery. Nurseries used to raise rice seedlings should be kept weed free to prevent transplanting grassy look-alike weeds along with the rice seedlings. Transplanted weeds are highly competitive and extremely difficult to control by hand weeding or by selective herbicides.

Because nursery areas are small (about 21 × 21 m will provide enough seedlings for 1 ha rice) and seedling establishment takes only 20-25 d, controlling weeds is easy. Propanil, thiobencarb, butachlor, quinclorac, bensulfuron, pretilachlor + fenclorim, and pendimethalin give good weed control in rice seedling nurseries.

Doubling the seed rate, hand weeding, or removing large weed seedlings from rice seedling bundles resulted in less than 50% control of weeds. Careful examination of each plant to ensure that most weeds are removed from the seedling bundles is laborious, time-consuming, and more expensive than herbicide treatment (Moody et al 1988).

Land preparation

Mechanical land preparation should provide a weed-free field to allow optimal early rice growth. The initial plowing buries weeds and crop stubble from the previous crop. Puddling uproots weeds that grow after plowing and buries them in the layers of mud. The field is leveled after puddling to eliminate inadequately flooded areas that are ideal for the growth and development of difficult-to-kill semiaquatic weeds.

Planting method

Transplanting into well-puddled soil helps rice seedlings to establish quickly. Healthy 20- to 30-d-old rice seedlings transplanted in rows in a well-prepared weed-free field will have a head start over weeds. Small rice seedlings are not competitive against weeds.

Plant population

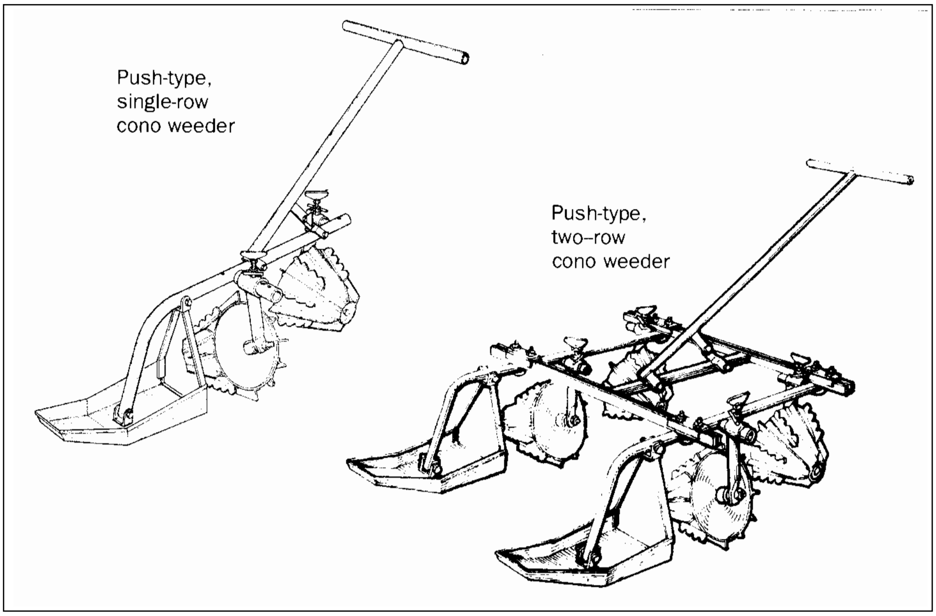
Most modern early-maturing rices, which have a short vegetative period that limits tillering, do best when transplanted at close spacing. No single spacing recommendation, however, is best for all rice cultivars. In the absence of lodging and weeds, yields of most varieties do not change much with planting distances between 25 and 10 cm in rows or hills. Dense planting increases the competitiveness of rice against weeds by reducing later germinating weed seedlings through shading. Rice should be transplanted in straight rows, to allow mechanical weeders to be used for weeding.

Water management

Good water management will eliminate all normal upland weeds in transplanted irrigated rice. The anaerobic conditions prevailing in soil under 5 cm of water inhibit most weed growth. Reductions in water level expose the soil surface, which leads to aerobic conditions that allow weed seed germination. A field should be flooded 2-3 d after transplanting and a 5-cm water depth should be maintained throughout the growing season.

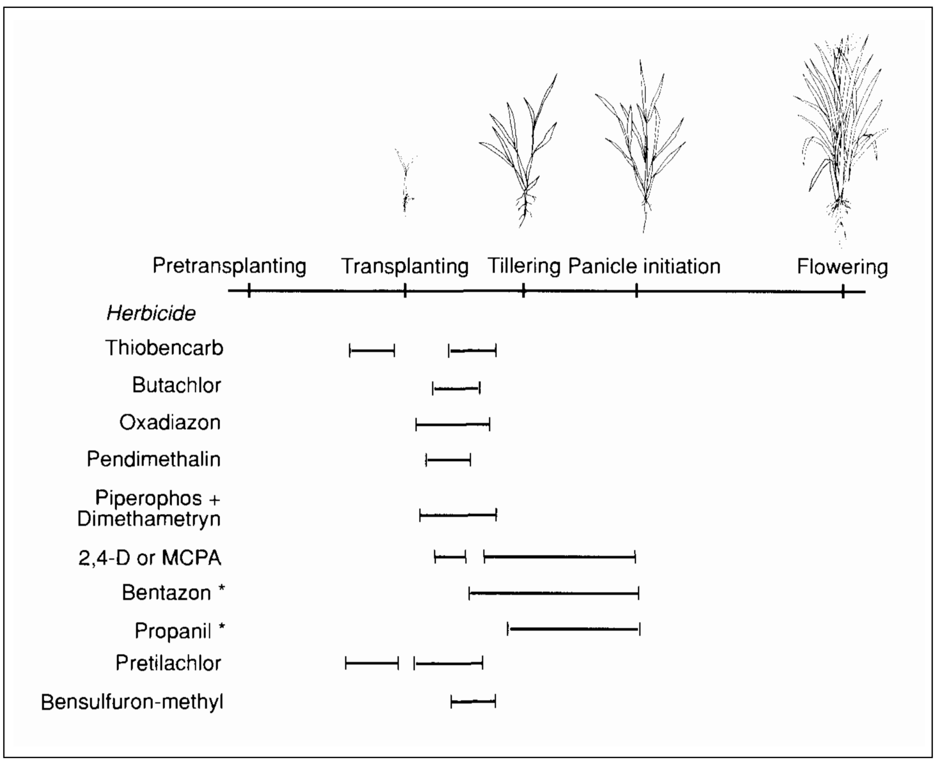
Fertilizer

Rice response to fertilizer nitrogen is markedly increased by good weed control, with maximum yields when weeds are controlled before fertilizer is applied.



6.1 Single and 2-row cono weeders. Drawings, design information, and limited technical supported are provided free to manufacturers who want to produce IRRI designs on a commercial basis. IRRI retains worldwide distribution and patent rights for all designs developed by the Institute, and does not grant exclusive manufacturing rights or licenses in any country or region.

6.2 Rice growth stages when herbicides can be applied in transplanted irrigated rice. Bars (|—|) show periods during which a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.



Hand weeding

Hand weeding is the most common weed control method in irrigated transplanted rice. The first 6 wk after transplanting is the critical time of weed competition. Two or three timely weedings will provide adequate weed control.

Weeding by machine is possible when irrigated rice is transplanted in rows. Hand weeding requires about 120 labor-hours per ha. That is reduced to 30-90 labor-hours when mechanical weeders are used. The conventional single-row rotary weeders require 80-90 labor-hours, but they are difficult to push and must be moved back and forth for proper operation.

The IRRI cono weeder (Fig. 6.1) uproots and buries weeds with conical shaped rotors. Forward movement of the weeder creates a horizontal back-and-forth soil movement in the top 3-cm layer, and the cono weeder weeds satisfactorily in a single pass. Power requirements are low because only a small quantity of soil is moved. IRRI's two-row cono weeder can weed three to four times faster than conventional single-row rotary weeders. Weeds within or close to rice hills must be hand-pulled.

Herbicides

In fields where heavy weed infestations are expected, weed competition can be prevented by a wide range of herbicides. Rice herbicides show maximum selectivity in transplanted rice because of differences in growth between rice seedlings transplanted at the 3- to 6-leaf stage and the germinating weeds. Several herbicides and herbicide combinations can be used in transplanted rice. Applying a preemergence herbicide together with effective water management will provide season-long weed control.

Some important rice herbicides and their times of application in irrigated rice are given in Table 6.1 and Figure 6.2.

Table 6.1. Herbicides suitable for use in transplanted irrigated rice.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bensulfuron	0.05	Apply 3-5 d after transplanting (DT) (IRRI 1986).
Bentazon	1.0-2.0	Apply postemergence to control broadleaf weeds and sedges (IRRI 1979). Drain before application, if necessary to expose weeds.
Bifenox + 2,4-D	2.0 + 0.5	Apply preemergence to weeds 4 DT (IRRI 1981).
Butachlor	1.0-2.0	Apply 3-6 DT. Water depth of 5-10 cm at application and for 3-5 d after (IRRI 1974).
2,4-D or MCPA	0.8-1.0	Apply 3-4 wk after weeds have emerged to control sedges, broadleaf weeds, and aquatic weeds. Drain before application to expose weeds. Reflood within 2-3 d after application. Can also be applied at 4-5 DT, before weeds emerge. Granular herbicides can be broadcast directly into floodwater (IRRI 1973, 1981).
Molinate	2.0-4.0	For preflood appllcation, flood as soon as possible. For postflood application, deepen water at application to cover weed foliage, then lower water after 4-6 d. No need to incorporate granular formulation (COPR 1976).
Oxadiazon	0.5-0.75	Apply 2-8 DT to control annual grasses and broadleaf weeds. Field should be flooded 3-5 cm and maintained at that level for 2-5 d after treatment (COPR 1976).
Oxyfluorfen	0.15-0.25	Apply 4 DT (IRRI 1979, 1983).
Pendimethalin	0.75	Apply 4 DT to control annual grasses (IRRI 1979, 1983).
Piperophos + dimethametryn	0.5	Apply 2-5 DT to control annual grasses, sedges, and broadleaf weeds (IRRI 1977).
Piperophos + 2,4-D	0.3 + 0.2	Apply 2-8 DT to control annual grasses, sedges, and broadleaf weeds (IRRI 1986).
Propanil	3.0-4.0	Apply as postemergence spray to control several annual grasses and broadleaf weeds at the 2- to 3-leaf stages. Draln flooded fields 24 h before application and reflood 3-5 d after treatment. Do not spray organophosphorus and carbamate insecticides within 14 d after appllcation (COPR 1976).
Quinclorac	0.3	Apply 3-5 DT (IRRI 1986).
Thiobencarb	1.5-4.0	Apply 4-8 DT at the 1- to 2-leaf stages of weeds. Water should not be drained or overflowed for 3-5 d after appltcation (IRRI 1971).
Thiobencarb + 2,4-D	1.0 + 0.5	Apply 4-5 DT (IRRI 1971).

Direct seeded on puddled soil

In direct seeded irrigated rice culture, the field is leveled after puddling and pregerminated seeds are broadcast or machine-drilled onto the puddled soil. Direct seeding, also known as wet seeding, is practiced in parts of India, Bangladesh, and Sri Lanka and has become an increasingly important rice crop establishment method in Southeast Asia. Broadcast seeded flooded rice is also practiced in several rainfed areas in South and Southeast Asia (De Datta and Flinn 1986).

Direct seeding has become an acceptable alternative to transplanting as labor costs have increased, less expensive herbicides have become available, and irrigated area has increased. However, root anchorage is poor, and lodging can be more serious in direct seeded than in transplanted rice.

Weed problems

Uncontrolled weeds in direct seeded flooded rice can reduce yields about 53%. The culture requires shallow flooding, which results in more exposed soil areas and aerobic conditions. Because rice and weeds germinate and emerge together, competition is more intense than in transplanted rice. The range of herbicides that can be used safely is also limited, because rice and the weeds are at the same development stages.

Lowland weeds such as *E. crus-gall, Ischaemum rugosum, Leptochloa chinensis, Cyperus difformis, Fimbristylis miliacea,* and *Scirpus maritimus* are adapted to the wet conditions of direct seeded flooded rice.

Land preparation

Thorough land preparation is essential in direct seeded flooded rice. Land preparation is similar to that for transplanted flooded rice. However, the final leveling of the field is even more critical than for transplanted rice because the water level in direct seeded fields is kept shallow. An uneven land surface results in areas where the soil surface is exposed to air. That creates an ideal condition for weed germination and growth. Rice stands in areas that have deeper flooding will be reduced.

Planting method

Rice seeds are pregerminated (soaked in water for 24 h, then incubated for 48 h) before they are sown in the field. This assures a quick and even stand. Pregerminated rice seeds may be broadcast or machine drilled. Mechanical weeding is possible when seeds are drilled in rows.

Cultivar

The cultivar used should have excellent seedling vigor and good tillering capacity. IRRI and national programs have released several such rices.

Plant population

Close spacing is essential to reduce weed infestation and for high grain yields. In wet seeded rice, less weed competition has been observed with seeding rates of 100 kg/ha and higher. Where weeds are not a problem, no rice grain yield advantage has been observed at these seeding rates.

Water management

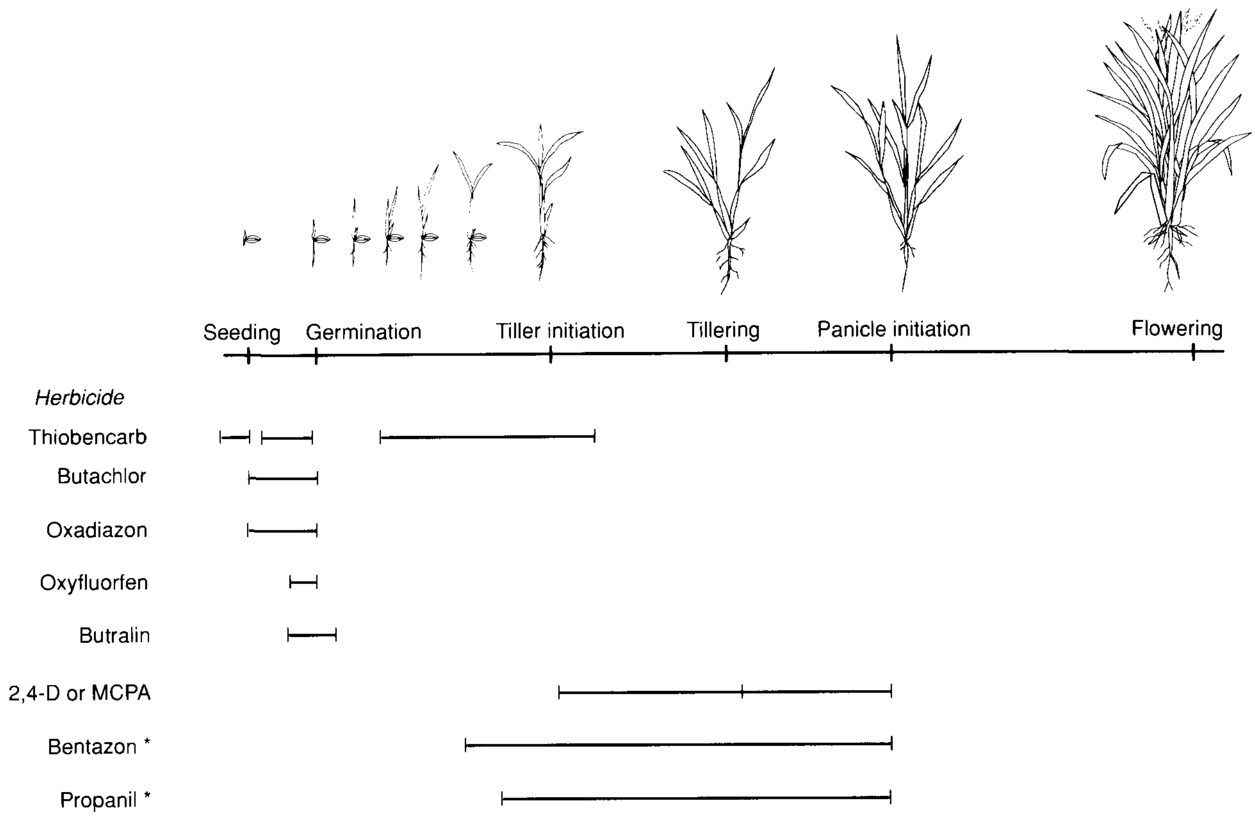
Good water management is an important factor in weed control in direct seeded flooded rice. Seeds are broadcast onto puddled soil with little or no standing water. The water level is increased gradually as the rice grows. Because the field cannot be flooded until seedlings are established, some weeds will grow along with the rice. After rice establishment, the water level should be raised as rapidly as possible without damaging the young rice seedlings, then kept uniform and continuous. Weed emergence and the type of weeds that emerge are closely related to floodwater depth. Shallow (less than 2.5 cm), continuous flooding facilitates weed growth.

For preemergence herbicide application in direct seeded flooded rice, the following water management is suggested.

- Keep the field saturated from sowing to herbicide application. If the soil dries within this period, add enough water to resaturate the plots.
- Flood the field to 2-3 cm deep and apply herbicide directly into the water.
- Raise water depth to 5 cm 1 wk after herbicide application and maintain that depth until 1 wk before harvest.

Fertilizer

High fertilizer application to increase yields of modern improved rice cultivars enhances weed growth. Incorporating N into the seedbed at 5-10 cm reduces N losses and at the same time reduces the availability of N to weed seedlings that germinate near the soil surface.



6.3 Rice growth stages when herbicides can be applied in wet-seeded irrigated rice. Bars (—) show periods during which a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

Hand weeding

The first 6 wk after seeding is the critical period of weed competition in direct seeded flooded rice. Hand weeding in drill seeded and hand pulling in broadcast seeded rice should be done early, although it may be difficult to distinguish grassy weed seedlings from rice seedlings at such an early stage. Two to three hand weedings are sufficient to prevent yield losses due to weeds. The first weeding can be done within 3 wk after seeding. Weeding will take less time if rice seeds are sown in rows rather than broadcast. The use of row weeders in broadcast seeded fields is limited because of the random distribution of seedlings (see figure 6.1, p. 74 for information on row weeders).

Herbicides

Because hand weeding is difficult in direct seeded flooded rice, chemical weed control combined with other cultural practices (such as water control) is an alternative that may be practiced to reduce weed competition, crop losses, and labor costs. Several herbicides offer effective weed control, but because weeds and rice germinate at the same time, the number of herbicides that can be used safely may be limited. In the tropics, butachlor, thiobencarb, butralin, and propanil effectively control weeds and have been widely tested in direct seeded flooded rice.

Table 6.2. Herbicides suitable for use in irrigated rice direct seeded on puddled soil.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bensulfuron	0.05	Apply 6-8 d after seeding (DAS) (IRRI 1985).
Bentazon	2.0	Apply postemergence to control broadleaf weeds and sedges, including S. *maritimus.* Water level must be lowered for good coverage. Annual weeds must be small—2- to 7-leaf stages (IRRI 1984).
Bifenox + 2,4-D	2.0 + 0.6	Apply at early postemergence of weeds, about 4-6 DAS (IRRI 1981).
Butachlor	0.75	Apply 6 DAS to control annual grasses and sedges. Soil should be saturated at application and remain nonflooded for 3 d after application (IRRI 1983). Granular butachlor applied 3 DAS gives better weed control, less stand reduction, and higher yields than when applied 6 DAS (IRRI 1986).
Butralin	2.0	Apply 2-3 DAS to control annual grasses (COPR 1976).
2,4-D or MCPA	0.5-1.0	Apply 3-4 wk after seeding to control annual broadleaf weeds and sedges. Lower water level to expose weeds before spraying and reflood within a few days (COPR 1976).
Molinate	3.0	Apply 6-7 DAS. Raise water level after application (IRRI 1977).
Oxadiazon	0.75-1.0	Apply preemergence 4-6 DAS. Soil must remain moist after application to maintain herbicide activity (IRRI 1985).
Oxyfluorfen	0.15-0.25	Apply 3-6 DAS (IRRI 1978, 1982).
Pendimethalin	0.75-2.0	Apply up to 6 DAS (IRRI 1975, 1982).
Piperophos + dimethametryn	0.4 + 0.1	Apply 4-6 DAS (IRRI 1977).
Piperophos + 2,4-D	0.3 + 0.2	Apply 6-8 DAS (IRRI 1987).
Pretilachlor + antidote	0.3-0.4	Apply 3 DAS (IRRI 1987).
Propanil	3.0-4.0	Apply postemergence to control grass and broadleaf weeds at the 2- to 5-leaf stages (about 10 DAS). Water level should be lowered before application and the field reflooded as soon as possible (IRRI 1980).
Quinclorac	0.3	Apply 6-8 DAS (IRRI 1986).
Thiobencarb	1.5-2.0	Apply about 6 DAS, when grasses have 1-2 leaves but before the 3-leaf stage of grasses and sedges. Keep water low enough to avoid submerging the rice plants (IRRI 1972).
Thiobencarb + 2,4-D	1.0 + 0.5	Apply 6-8 DAS (IRRI 1986).

Herbicides can be soil-incorporated before sowing rice, applied preemergence to water a few days after sowing, or applied postemergence before weeds reach the 3- to 4-leaf stage. Table 6.2 and Figure 6.3 outline various herbicides and their application times for this rice culture.

Direct seeded on dry soil

Dry seeded irrigated rice culture is practiced in Africa, Australia, Europe, and the USA. Nongerminated seeds are broadcast or drill seeded in dry or moist soil. Broadcast seeds are covered by harrowing. More seeds are required for broadcast than for drill seeding, and stand establishment is poorer with broadcast seeding than with drill seeding.

Weed problems

After broadcast or drill seeding rice into dry soil, the field is irrigated just enough to provide the soil moisture that allows the seeds to germinate. Flooding the soil would prevent rice seedling emergence. Thus, aerobic conditions remain ideal for the germination of upland and aquatic weeds, and weed problems are much worse in dry seeded irrigated than in wet seeded rice. Because the water level is increased gradually, it is 2-6 wk before a continuous flood at 5 cm depth can be achieved. Many well-established upland weeds will survive, making weed competition more intense in this rice culture than in the cultures described earlier. The fact that rice and weeds germinate together restricts the number of herbicides that can be used safely.

Land preparation

Land preparation should provide weed-free conditions at planting and favorable conditions for rice growth and development. Land preparation and leveling should be thorough because large soil clods will reduce germination of rice seedlings and cause irregularity in herbicidal efficacy. As clods melt down, the inner, unexposed soil will allow weeds to germinate.

Reducing weeds in dry seeded rice culture is possible by practicing a stale seedbed. After land preparation, weeds are allowed to emerge following rain or irrigation, then destroyed by shallow cultivation or application of a nonresidual contact herbicide. The herbicide should be applied or cultivation done when most of the weeds have reached the 2- to 5-leaf stage. Rice is then seeded into the weed-free field.

Planting method

Rice seeds are broadcast seeded into dry or moist soil and covered by harrowing, or drilled 3-5 cm deep into the soil. High seeding rates can suppress weeds, but the cost of seeds should be considered against other direct control measures available because there is no yield advantage in increasing seed rates above 100 kg/ha.

Cultivar

Both short- and intermediate-statured cultivars are used for rice broadcast or drilled into dry soil. For broadcast seeded rice, the cultivar used should be stiff-strawed to avoid severe lodging.

Water management

Good water management is important in controlling weeds in broadcast or drill seeded flooded rice. After dry seeding, the soil may be intermittently flooded and drained to allow for rice emergence. The water level is then increased gradually for a few weeks until a continuous flood of 5-cm depth is maintained.

Table 6.3 Herbicides suitable for use in broadcast or drill seeded, dry-sown irrigated rice.

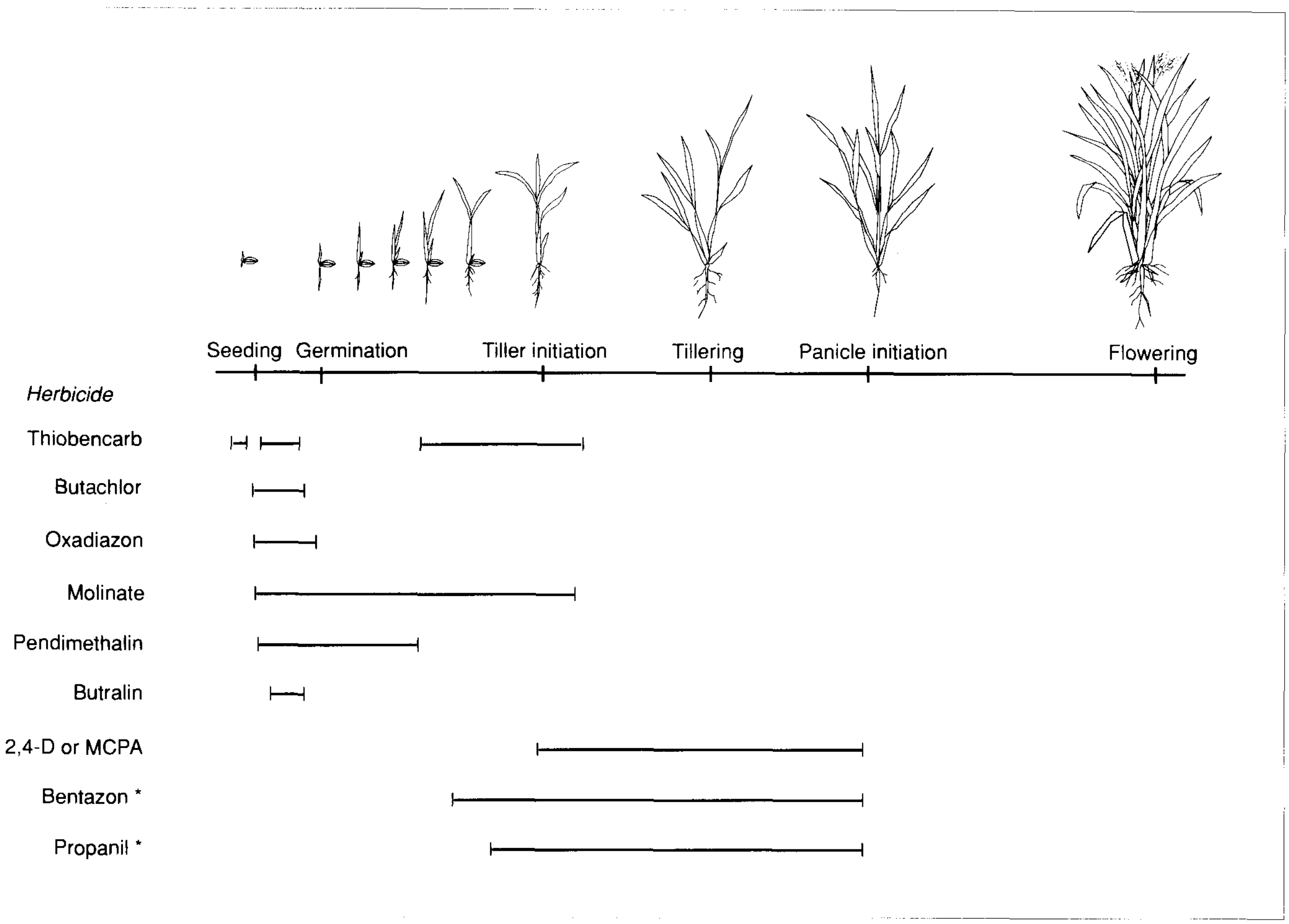
Herbicide	Rate (kg ai/ha)	Comments and source of information
Bentazon	2.0	Apply as a postemergence herbicide to control broadleaf weeds and sedges. Apply when weeds have germinated but are still small. Water level may be lowered to expose weeds 24 h. Raise water level after treatment (COPR 1976).
Butachlor	1.5-2.0	Apply as preemergence spray 0-3 d after sowing (DAS) to control annual grasses and sedges (IRRI 1977).
Butralin	2.0	Apply as preemergence spray 2-3 DAS to control annual grasses (IRRI 1977).
2,4-D or MCPA	0.5-1.0	Apply 3-4 wk after seeding to control annual broadleaf weeds and sedges (COPR 1976).
Molinate	3.0-5.0	Apply from presowing to early post-emergence to control grassy weeds (Smith 1971).
Oxadiazon	0.75-1.0	Preemergence application should be 2-3 DAS (IRRI 1977).
Pendimethalin	2.0	Apply at preemergence of rice (IRRI 1977).
Piperophos + dimethametryn	0.75-1.25	Apply early postemergence to control annual weeds (Green and Ebner 1972).
Propanil	3.0-4.0	Apply postemergence at the 2- to 3-leaf stages to control grasses and broad-leaf weeds (COPR 1976).
Thiobencarb	3.0	Apply preemergence immediately after covering the seeds with soil but before the first irrigation or ram. Irrigate 3-5 d after application (IRRI 1979).

Hand weeding

Interrow mechanical weeding is not possible in broadcast seeded rice. Even when seeds are drilled, the interrow spacing is so narrow that only hand or hoe weeding is possible. In this rice culture, two to three-timely hand weedings are sufficient to ensure optimum yields. The soil disturbance involved, however, can cause as much damage to rice as to weeds. The first weeding may be done between 14 and 21 d, depending on weed growth, followed by subsequent weedings when necessary.

Herbicides

The effects of herbicides are similar for broadcast seeded or drilled dry-sown rice and wet-sown flooded rice. Because of water management problems and difficulties in hand weeding, herbicides are particularly important in this rice culture. Covering the seeds with soil after drill or broadcast seeding increases the tolerance of rice for herbicides but decreases a rice seedling’s flooding tolerance. Butachlor, molinate, oxadiazon, propanil, and thiobencarb are used as



6.4 Rice growth stages when herbicides can be applied in dry-seeded irrigated rice. Bars (–) show periods during which a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

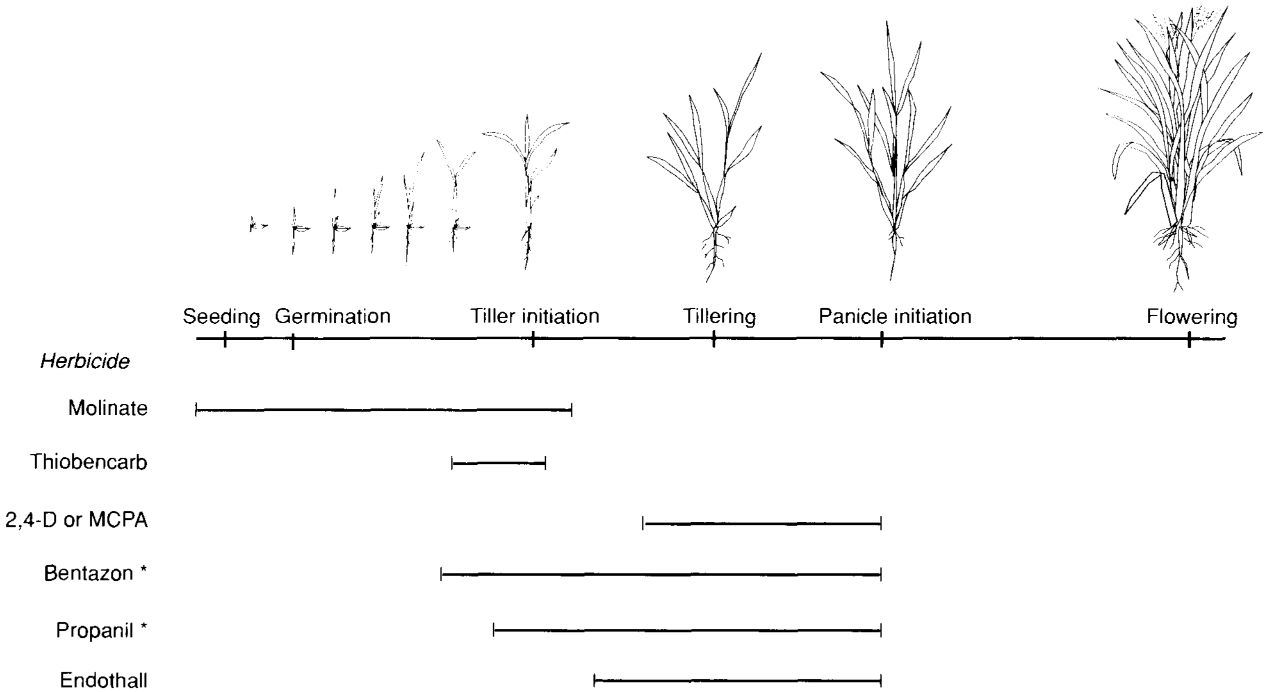
preplant, preemergence, postemergence, or postflood treatment. Propanil is widely used as a postemergence herbicide, either in addition to or in place of a preemergence treatment. Preplanting herbicidal treatments, such as with glyphosate, may also control perennial weeds. Table 6.3 and Figure 6.4 outline the common herbicides and their times of application for this culture.

Water seeded

Water seeding of rice is practiced in several parts of Asia, including India, Sri Lanka, Malaysia, and Thailand. It is widely practiced in the USA, southern Europe, USSR, and Australia. Pregerminated rice is broadcast directly onto the flooded field. The rice, which is seeded into water 7-10 cm deep, sinks to the soil, germinates, and emerges from the water. The field remains flooded at a depth of 7-10 cm until a few weeks before maturity. In the USA, seeding into continuously flooded fields began in the 1930s as a cultural method to control *E. crus-galli* and later as part of a program to control red rice.

Weed problems

Many weeds and rice will germinate through either soil or water, but not through both. Water seeding takes advantage of that by establishing an early water covering to suppress weeds. Continuous flooding in water seeded rice culture, however, encourages aquatic weeds. Where continuous flooding is not maintained, many semiaquatic weeds typical of discontinuously flooded, dry seeded fields can be found in water seeded ricefields. Under such conditions. *E. crus-galli, Lepfochloa* sp., *Aeschynomene virginica,* and *Sesbania exaltata* are weed problems.



6.5 Rice growth stages when herbicides can be applied in water-seeded irrigated rice. Bars (—) show periods during which a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

Land preparation

For better and more uniform stands of water seeded rice, the seedbed should be rough or grooved to help anchor rice seeds and seedlings. Large soil clods that remain exposed above the water level allow the growth and survival of grass weeds. Land leveling eliminates the high spots on the seedbed that favor weed growth, and is especially important if a shallow water depth is to be maintained for growing modern, semidwarf, rice cultivars.

Plant population

To compete with weeds, a rice crop density of 150-200 plants/m^2 at the 3- to 4-leaf stage is desirable.

Water management

Appropriate water management is the most important factor in successful weed control in water seeded rice. The management of floodwater affects the density, vigor, and uniformity of rice stands, the severity of weed competition, and the effectiveness of herbicides. Weeds are a problem when they germinate in moist soil after land preparation and grow before flooding and rice planting.

Flooding to 7-10 cm deep early in the season will provide partial weed control. Timely, rapid drainage and reflooding will encourage rice stands and help control aquatic weeds without supporting the growth of semiaquatic weeds. It is important that some parts of the rice plant be above the water surface by at least the 4-leaf stage, and fields must be kept flooded through the heading stage. The water should be drained only when absolutely necessary, such as when weeds requiring contact herbicides need to be treated.

Exposure of the soil to air, if it lasts long enough to allow *E. crus-galli* seedlings to develop secondary roots, reduces the effectiveness of most herbicides. Sedges and broadleaf weeds are favored by shallow water or when the field is drained.

Fertilizer

Incorporating N and P fertilizers to 5- to 10-cm soil depth reduces their availability to weed seedlings that germinate near the soil surface. Fertilizer so applied remains available to rice plants throughout the season if a 7- to 10-cm flood is maintained. If the field is drained and air reaches the N, it will change form and be rapidly lost into the air. If N is applied to flood water early in the season, 50% or more of it will be rapidly lost. Topdressed N and P applications into water also encourage weed growth. Weeds must be controlled before topdressing with any fertilizer.

Hand weeding

Avoiding weed competition is important during the first 30 d or so after water seeding of rice. Early weed removal, when the rice is still at the early vegetative phase, is desirable to maximize yields. One to two hand weedings at 3 wk and at about 6-7 wk after seeding will give adequate control. Again, as in broadcast or dry seeded flooded rice, mechanical methods are difficult to use.

Herbicides

Use of herbicides is essential to increase the efficiency of other crop management practices to control weeds. Because water seeded rice is grown under continuous flooding, the ideal times of herbicide application are preflood, preplanting; postplanting into the water; and postplanting, postemergence above the water.

For foliar-applied herbicides such as MCPA, bentazon, and propanil, the weed foliage must be exposed to the herbicide. The water level may have to be decreased for 24-48 h to avoid washing the herbicide off the leaf, to allow sufficient uptake of the herbicide. The water level should then be reestablished. Common herbicides of importance in water seeded rice are listed in Table 6.4. Time of application is indicated in Figure 6.5.

Table 6.4. Herbicides suitable for use in water seeded irrigated rice.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bentazon	2.0	Apply as a postemergence. Weed foliage must be exposed during application, but avoid draining field completely (UC 1983).
2,4-D or MCPA	0.5-1.0	Apply as postemergence. Lower water level to expose foliage of small weeds, but do not allow soil to dry (UC 1983).
Endothal	1.0-6.0	Apply as postemergence 25-60 d after sowing to control water weeds. Do not apply before rice has emerged above water surface. Do not draw water for 3-5 d after application. Do not apply after rice starts heading (UC 1983, California Weed Conference 1985).
Molinate	3.0-5.0	Incorporate preplanting or preflood. Postflood application can be preemergence or postemergence. For postflood applicattons, raise water depth to cover all weeds. Lower water level 4-6 d later (UC 1983).
Propanil	3.0-4.0	Apply postemergence. Lower water level to expose weed foliage. Raise water level after application (UC 1983).
Thiobencarb	1.5	Apply postemergence at the 2-leaf stage of rice. Do not expose soil surface after application (IRRI 1986).

Chapter 7

Weed control in rainfed lowland rice

Rainfed lowland rice is grown on about 23% of the world's rice area (IRRI 1988b). It accounts for about 45% of the rice area in South and Southeast Asia, 22% in Africa, and 6% in Latin America (De Datta 1981). In South and Southeast Asia, rainfed lowland rice dominates the area, although its importance differs among countries. For example, 76% of the rice area in Bhutan is rainfed lowland, 69% in Thailand, 56% in Bangladesh, 56% in Myanmar, 43% in Philippines, 37% in India, and 17% in Indonesia (IRRI 1988b).

Most of the rainfed lowland rice area of Southeast Asia is in major rice deltas, such as the Mekong in Vietnam, the Chao Phraya in Thailand, the Irrawaddy in Myanmar, and the Ganges-Brahmaputra in India and Bangladesh.

Rainfed lowland rice is not irrigated, but the soil is flooded to a maximum depth of less than 50 cm during a portion of the crop cycle. Water is supplied by frequent rains during the growing season. Soil moisture is usually maintained between field capacity and saturation. When there is no rainfall, however, moisture content may drop below field capacity. With excessive rainfall, deepwater conditions may develop.

Rainfed lowland rice is classified into three culture groups according to the crop establishment technique used.

- Transplanted in puddled soil.
- Direct seeded on puddled soil (broadcast or drill seeded using pregerminated seed).
- Direct seeded on dry soil (broadcast or drill seeded using nongerminated seed).

Transplanted in puddled soil

Transplanting is the major crop establishment method for rainfed lowland rice in most of tropical Asia. Primarily grown as a monsoonal crop, rainfed lowland rice is known as *kharif* in India and as *aman* in northeastern India and Bangladesh. Seedlings raised by a wet bed, dapog, or dry bed technique are transplanted into a puddled soil.

Weed problems

Because the amount and distribution of rainfall for growing rainfed lowland rice are uncertain, fields may not remain flooded from planting to maturity. In Asia, most rainfed lowland ricefields change from upland to submerged conditions during the monsoon season. Lack of water control reduces the effectiveness of using water as a tool in weed management. Upland, semiaquatic, and aquatic weeds all present problems. Conditions favorable for weed germination and growth, such as exposure of the soil surface (aerobic conditions) and high soil moisture, occur for extended periods. Once weeds become established, deeper flooding is needed to reduce weed growth substantially (Moody et al 1986). Transplanting gives rice a head start over weeds, but uncontrolled weeds can still reduce rice yields as much as 50%.

Weed species of importance in this rice culture include *Echinochloa* spp., *lschaemum rugosum, Monochoria vaginalis, Sphenoclea zeylanica, Cyperus difformis, Cyperus iria, Fimbristylis miliacea,* and *Scirpus maritimus.*

Nurseries

Seedling nurseries should be kept weed free to prevent transplanting grassy weeds along with rice. Weeds in the nursery also compete with the rice seedlings and can cause complete nursery crop failure. Herbicide such as thiobencarb, propanil, oxadiazon, and butachlor can be used to control weeds in the nursery.

Land preparation

Mechanical land preparation can provide a weed-free field that is optimal for early rice growth. The land should be leveled after puddling the soil. Unevenness in the field results in areas of inadequate flooding. Dikes, to contain and control an undependable water supply, are essential. In India, *Sesbania aculeata* grown during the dry season as a green manure crop is plowed in before transplanting rice (Mukhopadhyay 1983). This practice results in less weed infestation in the main rice crop.

Cultivar

Water depths largely determine the type of rice grown. In general, modern semidwarf cultivars are grown in shallow rainfed rice-growing areas. In medium-deep rainfed rice-growing areas, tall cultivars that are mostly photoperiod-sensitive are grown.

Plant population

Close spacing, between 10 and 25 cm in rows or hills, increases the ability of rice plants to compete with weeds. Rice should be transplanted in straight rows to allow the use of mechanical weeders.

Table 7.1. Herbicides suitable for use in transplanted rainfed lowland rice.

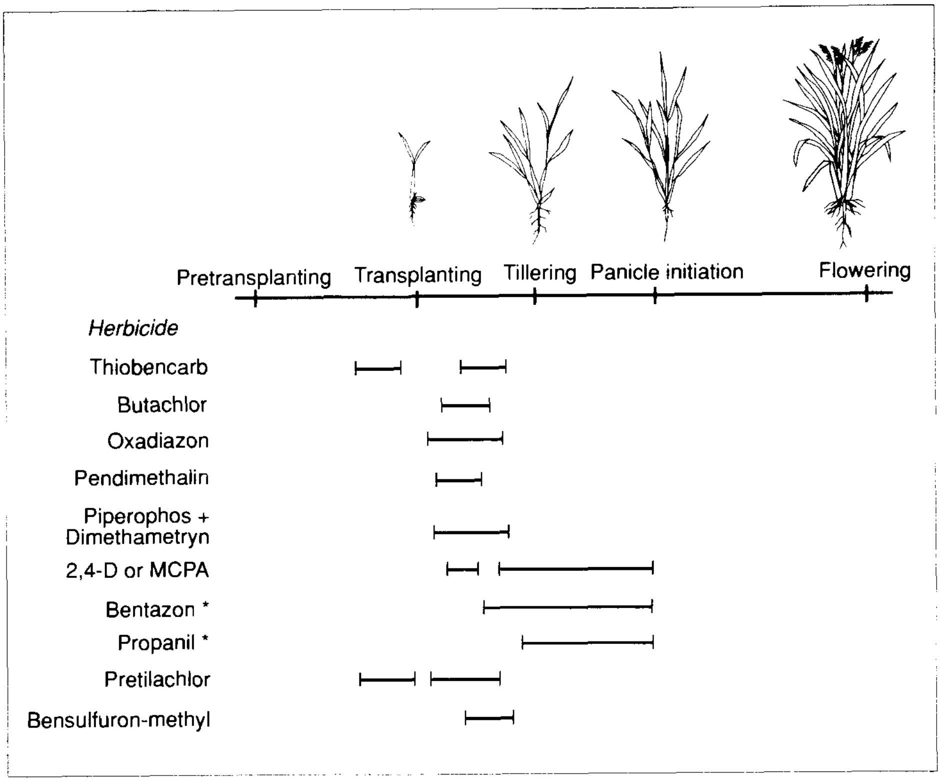
Herbicide	Rate (kg ai/ha)	Comments and source of information
Bensulfuron	0.05	Apply 3-5 d after transplanting (DT) (IRRI 1986).
Bentazon	1.0-2.0	Apply postemergence to control broadleaf weeds and sedges. Weed foliage must be exposed at application (IRRI 1973).
Butachlor	1.0	Apply 3-6 DT (IRRI 1987).
2,4-D or MCPA	0.5-1.0	Apply 3-4 wk after weed emergence to control sedges, broadleaf, and aquatic weeds. Lower water level to expose foliage of small plants before spraying. Also may be applied 4-5 DT (IRRI 1973).
Molinate	2.5-3.0	Apply 4-8 DT.
Oxadiazon	0.5-0.75	Apply 2-6 DT to control annual grasses and broadleaf weeds (IRRI 1980).
Oxyfluorfen	0.25	Apply 4 DT (IRRI 1980, 1983, 1988a).
Pendimethalin	0.75	Apply preemergence about 6 DT to control grasses and broadleaf weeds (IRRI 1980).
Piperophos + dimethametryn	0.5	Apply 2-5 DT to control annual grasses, sedges, and broadleaf weeds (COPR 1976).
Piperophos + 2,4-D	0.3 + 0.2	Apply 2-8 DT to control grasses, sedges, and broadleaf weeds (IRRI 1986).
Propanil	3.0-4.0	Apply postemergence to control several grasses and broadleaf weeds at the 2- to 3-leaf stage. Lower water level of flooded fields about 24 h before application to expose weed foliage (COPR 1976).
Quinclorac	0.3	Apply 3-5 DT (IRRI 1986).
Thiobencarb	3.0	Apply 5-8 DT. Water should be shallow at application. Avoid draining or overflowing for 3-5 d after herbicide application, but do not expose soil surface after treatment.
Thiobencarb + 2,4-D	1.0 + 0.5	Apply about 5 DT (IRRI 1983).

Water management

Keeping the rainfed lowland field flooded after transplanting kills some weeds and reduces the growth of others. In most ricefields, continuous flooding to a 5-cm depth is seldom achieved because of problems in regulating water depth and drainage. With good land preparation and good water control, weed problems will be minimal. Other weed control methods are necessary when rainfall is not enough to provide continuous flooding.

Fertilizer

Nitrogen application should be timed to provide the maximum benefit to rice but the least benefit to the weeds. Applying fertilizer to a rice crop with poor weed control could be worse than applying no fertilizer.



7.1 Rice growth stages when herbicides can be applied on rainfed lowland rice transplanted on puddled soil. Bars (—) show periods when a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stages.

Hand weeding

Hand weeding is the most common weed control method in rainfed lowland transplanted rice. The field should be weed free for 30 d after transplanting (DT) to prevent yield losses caused by weeds. Two to three properly timed hand weedings, the first about 21 DT, combined with good water management will ensure optimum rice yields. Mechanical weeders can be used in rice transplanted in rows, but weeds within the rows still have to be removed by hand.

Herbicides

The efficiency of herbicides on transplanted rainfed lowland rice depends on water management. If the water depth in the field exceeds 10 cm during the first week after herbicide application, herbicidal efficacy will be reduced due to dilution and leaching. Despite water management limitations, however, weeds in rainfed lowland rice can be adequately controlled by herbicides.

Herbicides that can be used as an alternative or supplement to manual or mechanical weeding include 2,4-D, MCPA, butachlor, thiobencarb, propanil, oxadiazon, pendimethalin, piperophos, and oxyfluorfen. Table 7.1 and Figure 7.1 provide information on available herbicides and timing of their application.

Direct seeded on puddled soil

Direct seeding rice on puddled soils is common in some rainfed areas of the Asian tropics (Sri Lanka, Bangladesh, and Philippines). Pregerminated rice seeds are broadcast onto puddled fields without much standing water.

Weed problems

Direct seeded rainfed rice is more susceptible to weed competition than is transplanted rainfed rice. Although soil puddling reduces the weed problem, uncontrolled weeds still reduce rice yields about 60%. In some cases, a puddled lowland field may be saturated but without any standing water, because of lack of water control. The moist, warm, aerobic soil condition created promotes germination and rapid growth of many upland, semiaquatic, and aquatic weeds which are little affected by later flooding. Deeper-than-normal flooding is often required to significantly reduce weed growth. Because in this culture, rice and weeds germinate at the same time, competition by weeds is more intense than it is in transplanted rice.

Weeds of importance in this culture include *E. crus-galli* and other *Echinochloa* spp., *I. rugosum, M. vaginalis, S. zeylanica, C. difformis, C. iria, F. miliacea,* and *Scirpus* spp.

Land preparation

Leveling the puddled soil is critical in direct seeded rice; poor drainage results in poor germination of rice seeds. An uneven land surface also results in exposed areas which are ideal for germination and growth of weeds.

Planting method

Pregerminated rice seeds are broadcast or drilled onto puddled soil. Pregermination ensures quick growth and even, rapid crop establishment. Hand or mechanical weeding is enhanced when pregerminated seeds are drilled in rows.

Cultivar

Traditionally, rainfed lowland rice farmers in tropical Asia depend on tall, vigorously tillering plants to provide weed competition. Early-maturing semidwarf rices, such as IR28, IR30, and IR36, have been grown successfully when direct seeded.

Plant population

As in other rice cultures, close spacing is essential to minimize weed infestation. Higher seeding rates are beneficial when heavy weed infestations are expected. Seeding rates of 100-200 kg/ha have been used. A higher seeding rate helps control weeds but does not necessarily increase rice grain yield.

Table 7.2. Herbicides suitable for use in rice direct seeded on puddled soil.

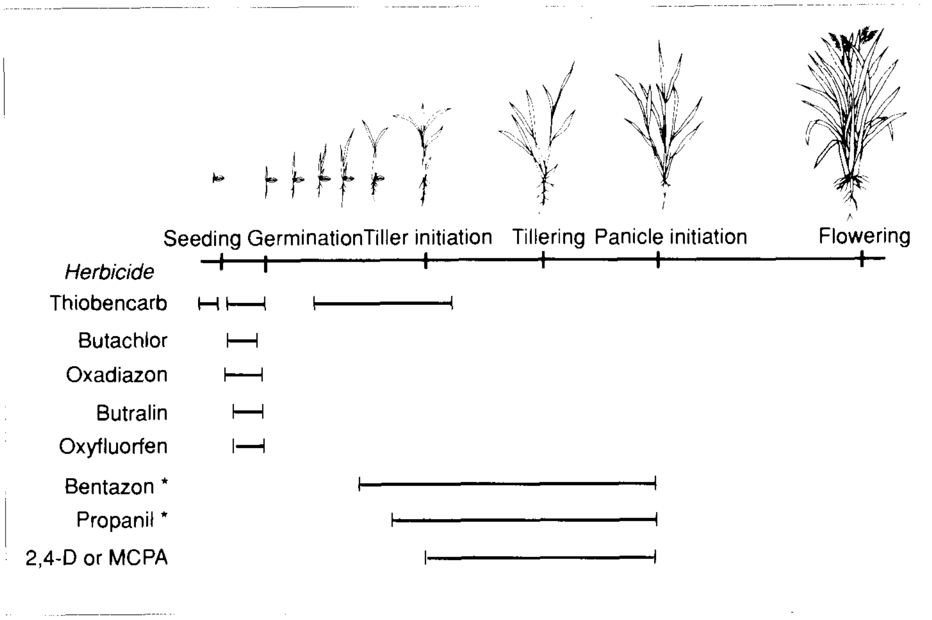
Herbicide	Rate (kg ai/ha)	Comments and source of Information
Bentazon	2.0	Apply postemergence to control broadleaf weeds and sedges at the 2- to 10-leaf stages. Weed foliage must be exposed at application (IRRI 1984).
Bifenox + 2,J-D	2.0 + 0.66	Apply at early postemergence of weeds (about 6 d after seeding [DAS]).
Butachlor	1.0	Apply 6-8 DAS to control annual grasses and sedges. Soil should be saturated at application (IRRI 1981).
Butachlor + 2,4-D	0.75 + 0.6	Apply 6-8 DAS (IRRI 1981).
Butralin	2.0	Apply 4-6 DAS pregerminated rice (1- to 4-leaf stages) (COPR 1976).
2,4-D or MCPA	0.5-1.0	Apply 3-4 wk after seeding to control annual broadleaf weeds and sedges. Expose weeds before spraying.
Oxadiazon	0.75-1.0	Apply preemergence 6-8 DAS. Slight phytotoxicity has been observed in rice seeded on puddled soil (IRRI 1975).
Oxyfluorfen	0.10-0.25	Apply 5-10 DAS. May initially be toxic to rice (IRRI 1981, 1983).
Pendimethalin	0.75-2.0	Apply up to 6 DAS (IRRI 1982).
Piperophos + dimethametryn	0.4 + 0.1	Apply 4-6 DAS (IRRI 1977).
Piperophos + 2,4-D	0.3 + 0.2	Apply 6-8 DAS (IRRI 1977).
Pretilachlor + antidote	0.3-0.4	Apply 3 DAS (IRRI 1987).
Propanil	3.0-4.0	Apply postemergence to grassy and broadleaf weeds at the 2- to 3-leaf stages (IRRI 1980).
Quinclorac	0.3	Apply 6-8 DAS (IRRI 1986).
Thiobencarb	1.5-2.0	Can be used preemergence or early postemergence. Postemergence application should be done after the 1- to 2-leaf stage of rice but before the 3-leaf stage of grasses and sedges, about 10 DAS (IRRI 1980).
Thiobencarb + 2,4-D	1.0 + 0.5	Apply 6 DAS (IRRI 1980).

Water management

Good water management often reduces weed competition and eliminates some weeds in direct seeded rainfed lowland fields. Continuous flooding at 5-cm depth is desirable but seldom achieved. Puddling enhances water-use efficiency. Water control can be improved by the use of dikes.

Fertilizer

Modern improved cultivars respond better to nitrogen than do tall traditional cultivars. Therefore, modern improved cultivars are normally grown with high fertilizer rates in order to realize their full yield potential. This high fertilization, however, enhances weed growth.



7.2 Rice growth stages when herbicides can be applied on wet-seeded rainfed lowland rice. Bars (—) show periods when a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

Hand weeding

Hand pulling of weeds can be done in broadcast or drill seeded rice; mechanical weeding is feasible only when rice is planted in rows. Two to three hand weedings at 2-3 wk after sowing are usually sufficient to ensure optimum yields.

Herbicides

The use of herbicides for weed control has proved effective and economical in direct seeded rainfed lowland rice. Because weeds and rice germinate together, the number of herbicides that can be used safely is limited. The efficacy of herbicides is dependent on soil moisture conditions and is markedly reduced by dry or deep flooding conditions immediately after herbicide application. In the tropics, butachlor, thiobencarb, butralin, and propanil have been used in direct seeded rice. Table 7.2 and Figure 7.2 provide herbicide information for this rice culture.

Direct seeded on dry soil

Direct seeding on dry soil provides an opportunity to increase cropping intensity in rainfed lowland rice. Eliminating puddling shortens land use time. In this culture, dry seed is sown directly into moist, nonpuddled soil at the beginning of the rainy season. The field may be bunded to accumulate water as the rainy season progresses and the crop may end its cycle under flooding.

Direct seeded dry rice culture is practiced in Africa, South America, and in parts of tropical Asia. In Africa, direct seeded rice is grown in valley bottoms and on hydromorphic soils—soils on transitional slopes between upland soils and valley-bottom soils, with the groundwater table in the root zone for most of the growing period. Direct seeded rainfed lowland rice is known as *aus* cropping in northeastern India and Bangladesh. In Indonesia, it is called *gogorantja* (gogorancah).

Weed problems

Among rainfed lowland rice cultures, weed problems in direct seeded rice are more intense and wider in range than those in transplanted or broadcast rice where puddling reduces weed problems. Rice yield losses from uncontrolled weeds can be as high as 74%. Rice-weed competition for moisture is heavy during the early growth stage, when there is no standing water. Dry rice seeds germinate 3-5 d later than pregerminated rice seeds. Weeds germinate and establish faster than rice.

The prevailing moist, aerobic condition for direct seeded rice encourages the growth of upland, semiaquatic, and aquatic weeds. Dominance of any of these weed communities depends on the availability and depth of standing water. Many well-established upland weeds continue to survive under flooding later in the crop cycle. Lowland weeds that are important include *E. crus-galli, I. rugosum, L. chinensis, C. difformis, F. miliacea,* and *S. maritimus.*

Land preparation

Land preparation should be done to provide weed-free conditions at planting. Land leveling is essential to improve water control. Large soil clods must be broken up so that they do not interfere with rice seedling emergence. A stale seedbed may be practiced, but it gives no advantage if planting is delayed until after the start of rains.

Planting method

For most direct seeded rainfed lowland rice, common establishment methods include broadcasting on a leveled field, broadcasting over shallow furrows and passing a spike-toothed harrow at an angle to concentrate seed in rows, drilling, and dibbling seeds for uniformly spaced seedlings in hills. In all planting methods, close spacing will increase the competitive ability of rice against weeds. Seed rates of 100-150 kg/ha are often used, with higher seed rates where weed problems are expected.

Cultivar

Early-maturing, drought-tolerant rice cultivars are desirable.

Water management

There may be no standing water in the early crop growth stages of direct seeded rainfed lowland rice. Later, when water from rains has accumulated, water is an important tool in suppressing weed growth. However, continuous flooding to a 5-cm depth is seldom achieved. If weeds establish because of lack of standing water early in the season, deep flooding at 10-20 cm is necessary to reduce weed growth. Where rainfall is not enough to maintain continuous submergence, other weed control methods are essential.

Table 7.3. Herbicides suitable for use in rice direct seeded on dry soil.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bentazon	1.0-2.0	Apply postemergence to control broadleaf weeds and sedges at the 2- to 10-leaf stages (IRRI 1984).
Butachlor	2.0	Apply as preemergence spray 0-3 d after sowing (DAS) to control annual grasses and sedges (IRRI 1988).
Butralin	2.0	Apply preemergence 2-3 DAS to control annual grasses (IRRI 1978).
2,4-D or MCPA	0.5-1.0	Spray 3-4 wk after seeding to control annual broadleaf weeds and sedges (COPR 1976).
Oxadiazon	0.75-1.0	Apply preemergence 6-8 DAS (IRRI 1978).
Oxyfluorfen	0.14-0.20	Apply preemergence 3-5 DAS (IRRI 1982).
Pendimethalin	0.75-2.0	Apply preemergence (IRRI 1982).
Pretilachlor + antidote	0.3-0.4	Apply 3 DAS (IRRI 1987).
Propanil	2.0-4.0	Apply postemergence at the 2- to 3-leaf stages to control grasses and broad-leaf weeds. Decrease water level of flooded fields 24 h before application to expose weeds (IRRI 1982).
Quinclorac	0.3	Apply 6-8 DAS (IRRI 1986).
Thiobencarb	3.0	Apply preemergence Immediately after covering rice seeds with soil, before rains (IRRI 1982).

Fertilizer

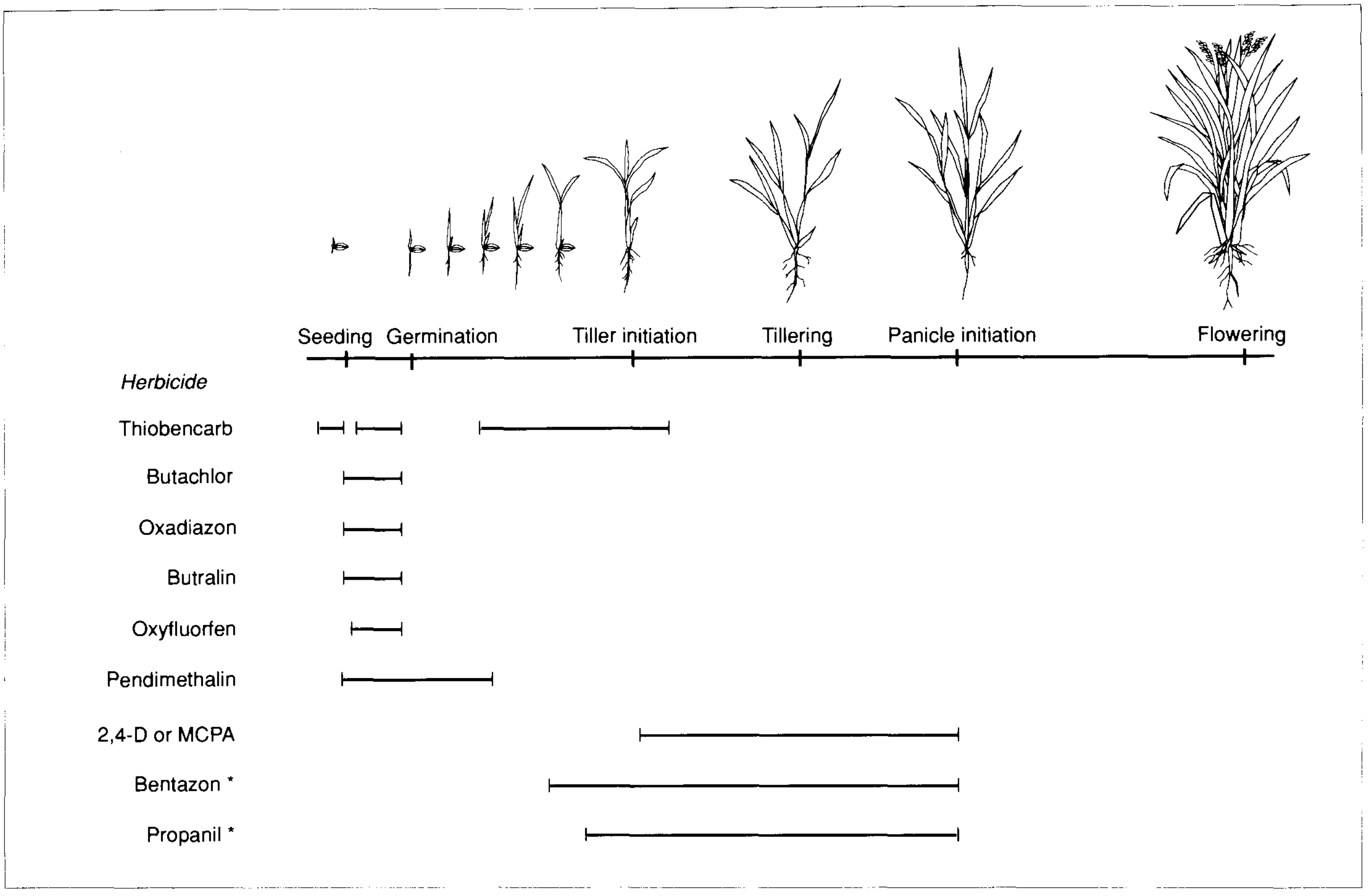
Nitrogen application should be timed to prevent weed proliferation and to obtain maximum benefit from the fertilizer applied. In direct seeded rainfed lowland rice, application of fertilizer after thorough weeding gives maximum benefits.

Hand weeding

Two to three well-timed hand weedings should provide adequate weed control. An advantage of early hand weeding is that it requires less time. Early-season hand weeding, especially where there is no standing water, reduces the competition of weeds for nutrients and moisture. The first weeding should be done 15-21 d after seeding. Hand weeding later than this will reduce rice yields. Mechanical weeders can be used if seed is drilled or dibbled in straight rows.

Herbicides

In fields with no standing water, rainfall after herbicide application is needed for preemergence herbicides to be effective. The persistence of residual preemergence herbicides under warm, moist, or flooded conditions may be too low to provide a weed-free rice crop. Follow-up hand weeding or postemergence herbicide application may be necessary.



7.3 Rice growth stages when herbicides can be applied on dry-seeded rainfed lowland rice. Bars (—) show periods when a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

The use of herbicides has proved beneficial in direct seeded rainfed lowland rice, considering the crop's high labor requirements and unfavorable weather at weeding time. Herbicide combinations, whether as tank mixtures or sequential sprays, will improve weed control where the weed spectrum is too diverse for any one herbicide. Propanil plus butachlor, thiobencarb, or pendimethalin applied early postemergence provide good broad-spectrum control of weeds.

Sequential applications of residual preemergence herbicides followed by 2,4-D perform better than do residual herbicides alone. Table 7.3 and Figure 7.3 provide information on the common herbicides available for direct seeded rainfed lowland rice.

Chapter 8

Weed control in upland rice

Upland rice, also known as dryland or pluvial rice, is grown on rainfed, naturally well-drained soils. Strictly defined, upland ricefields are not bunded and no surface water accumulates.

About 13% (18.8 million ha) of the world's rice area is upland (IRRI 1988b). About 11.9 million ha is in Asia, 4.5 million ha in Latin America, and 2.2 million ha in Africa. It is the dominant rice culture in Latin America and West Africa.

Upland rice is grown under a wide range of management practices that vary from shifting cultivation — as practiced in Malaysia, Philippines, Peru, and West Africa — to the mechanized cultivation practiced in Brazil. Most of the world's upland rice is grown on poor soils in areas with uncertain rainfall by small farmers using traditional, low-input technology.

Weed problems

Weeds rank second to drought stress in reducing upland rice grain yields and quality (Sankaran and De Datta 1985). Yield losses caused by uncontrolled weeds in upland rice are about 96%.

Upland rice, like all upland crops, is planted in moist soil, that, in general, does not retain moisture beyond field capacity. Water is supplied by rains during the growing season. Optimum temperature, sufficient aeration, and ideal moisture for weed germination and growth exist at planting time. This enables weeds to germinate earlier and grow more vigorously than the rice crop.

Weed competition is more intense in upland rice than in irrigated and rainfed lowland rice because upland fields do not have standing water to suppress weed growth. Some weeds in upland rice can withstand drought better than rice because their roots penetrate deeper into the soil to tap moisture. Poor rice germination due to drought results in excessive weed growth, especially if semidwarf varieties are grown.

Because weeds in upland rice germinate throughout the season, dense weed growth may reoccur after hand weeding or after the residual effects of herbicides have worn off.

A mixture of annuals and perennials, and grasses and broadleaf weeds, intensifies the competitive effects of weeds in upland rice. C_4 weeds, which have higher water-use efficiency than rice, prevail (Ampong-Nyarko and De Datta 1989). Common upland weeds include *Cyperus rotundus, Echinochloa colona, Eleusine indica, Rottboellia cochinchinensis, Cynodon dactylon, Digitaria sanguinalis, Imperata cylindrica, Amaranthus spinosus, Commelina benghalensis, Trianthema portulacastrum, Ageratum conyzoides, Portulaca oleracea,* and *Euphorbia hirta.*

Land preparation

Land preparation for upland rice varies greatly among regions. In West Africa, where shifting cultivation is common, slash-and-burn is practiced with hand tools. In South Asia, upland fields are plowed by bullocks and in Southeast Asia, by water buffalo.

Deep plowing (25 cm or deeper) moist soil at the end of the rainy season is recommended for upland rice grown in the West African savannahs (FAO 1976). Deep plowing and subsoiling conserve soil moisture in the rainy season and enhance root growth and extraction of soil moisture from deeper soil layers. It also will bury weed seeds deep enough to prevent them from emerging. Subsequent tillage operations must be shallow.

An upland field should be harrowed to break up soil clods, but field leveling is not critical. Rice should be planted as soon as possible following the last harrowing to provide rice an even start with the weeds.

The stale seedbed technique can reduce weed problems in upland rice. After land preparation, weeds that grow are killed at the 2- to 5-leaf stage by herbicides or using mechanical methods. Germination of most of the viable weed seeds is essential to the success of the stale seedbed technique. Under unfavorable conditions for weed seed germination (e.g., dry soils), no weed control advantage may be achieved.

Use of the stale seedbed technique should not delay rice seeding beyond the optimum time. Planting at the optimum time assures more rainfall from seeding through spikelet filling; late-planted rice is likely to suffer drought and reduced solar radiation during the reproductive stage, which can substantially reduce yields.

Zero tillage can be used to establish an upland rice crop where no difficult-to-control perennial weeds are found in the fallow vegetation or when appropriate herbicides are available. But zero tillage may not be successful under all soil conditions; restricted root development and reduced grain yield have been observed (Stone et a1 1980).

Planting methods

Broadcasting, dibbling, and drilling are the common seeding practices for upland rice. Broadcasting is common in many countries in Asia, Africa, and Latin America. Dibbling, or hilling, is practiced in Africa and Asia by farmers using slash-and-burn systems. A pointed stick is used to make holes in the soils; 4-8 unsprouted seeds are dropped in and covered with soil. In Latin America, mechanized drilling is becoming increasingly popular.

Row drilling or dibbling in rows makes weeding and other management practices easier. Timely sowing and rapid canopy closure minimize weed growth and ensure good stand establishment.

Weed problems in broadcast seeded fields are higher because mechanical hand weeding cannot be done, and weeding must be delayed because it is difficult to tell grassy weeds from rice at early growth stages.

Cultivar

Upland rice cultivars with drought avoidance (through deep root systems) and drought recovery abilities are preferred. Intermediate-statured cultivars with moderate tillering, big panicles, blast resistance, and tolerance for iron deficiency and aluminum toxicity are also desirable.

Plant population

Seeding rate and spacing for upland rice vary with planting method and the rice cultivar used. A high plant population is important for upland rice to quickly develop a canopy that will suppress weed growth. Seeding rates vary from 80 to 150 kg/ha, depending on the seeding method. Row spacing also varies between 20 and 30 cm. Broadcast seeding requires more seeds than drilling or dibbling. Tall leafy cultivars should be planted at wider spacing than semidwarf cultivars. Growing tall cultivars at narrow spacing increases lodging.

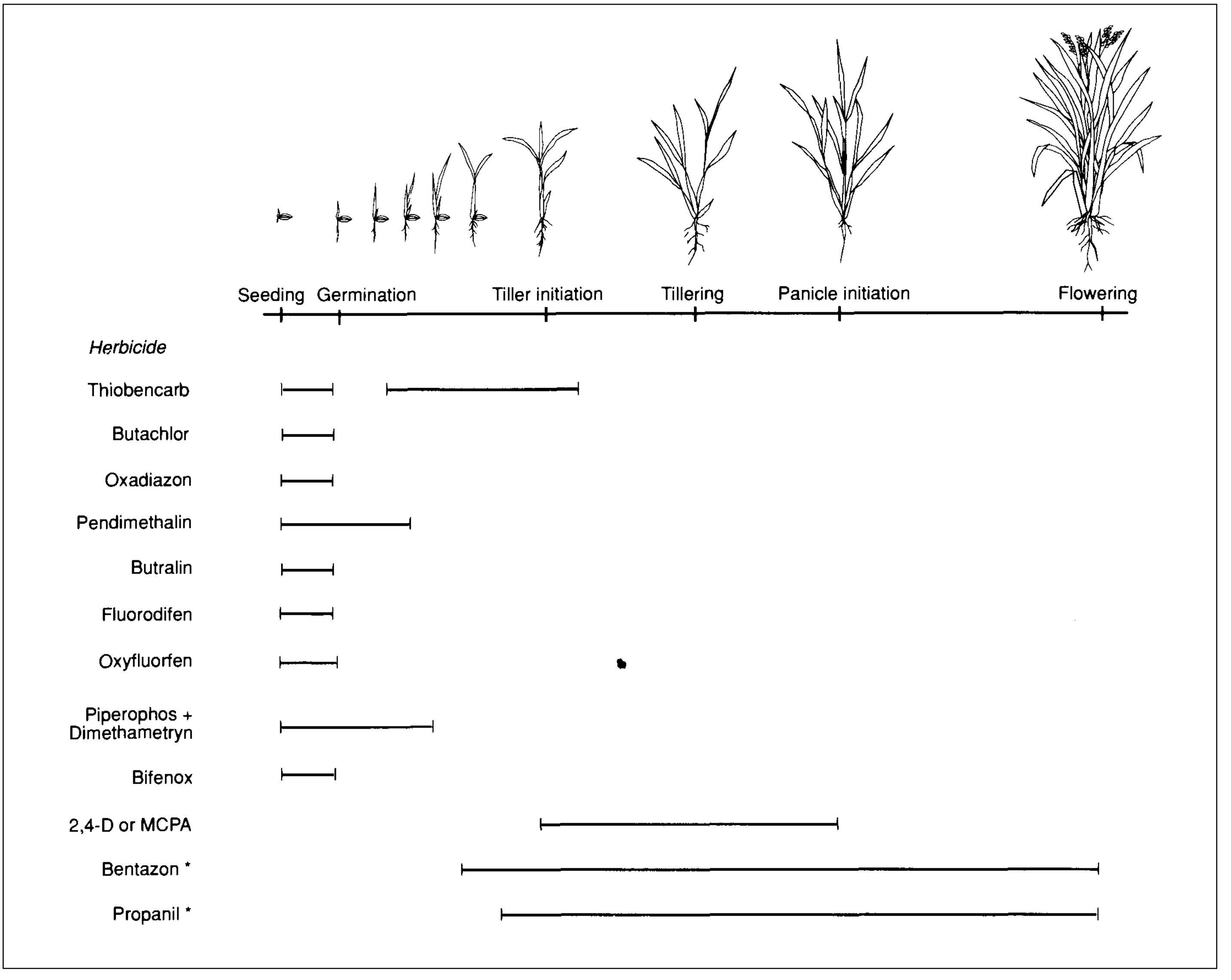
Crop rotation is practiced to prevent the buildup of weeds adapted to upland ricefields, but easy to control in other crops. Herbicides that control problem weeds but are toxic to rice also can be used on a tolerant crop in the rotation. That will reduce the rice weed problem.

Fertilizer

Nitrogen response is high for modern short- to medium-statured upland rice cultivars that are resistant to lodging. In most soils, split application of N gives higher grain yield than does single basal application.

Applying fertilizer to upland rice, however, will reduce grain yield if the field is not weeded. The first application should be delayed until after weeding. Subsequent topdressings of N after weeding will maximize fertilizer-use efficiency. The N application rate should be reduced in drought-prone areas.

Phosphorus deficiency is common in upland rice, especially in Oxisols and Ultisols in Brazil, West Africa, and some parts of South and Southeast Asia (Gupta and O'Toole 1986). In the Philippines, 18 kg P/ha is recommended for upland rice (PCARR 1977). Some coarse-textured soils in high-rainfall areas are affected by potassium deficiency. Applying 33 kg K/ha has been adequate in some African countries (IRCN 1982). Zinc, iron, and sulfur deficiencies also occur in upland rice. Deficiency of any of these nutrients will reduce the vigor of rice and, hence, its competitiveness against weeds.



8.1 Rice growth stages when herbicides can be applied on upland rice. Bars (—) show periods when a particular herbicide is applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

Hand weeding

The weed-free period required by upland rice is from 10 to 60 d after seeding (DAS). By and large, keeping the crop weed free for the first 60 DAS will give optimum yields. Weeds germinate earlier and grow more vigorously than upland rice during the first 5 wk after planting. Weeds should be removed 15-25 d after planting to obtain good rice yields.

Two or three well-timed weedings are enough to meet the weed-free requirement. Weeding during early weed growth stages requires less labor than weeding after weeds have matured. Wet soil may reduce the effectiveness of hoe weeding because most weeds will be merely trans-planted. Improved mechanical meth-ods such as push-type and motorized weeders may be as effective as hand weeding in a row-seeded rice crop. When combined with hand removal of weeds within the row, these methods can also save time.

Herbicides

Chemical weed control in upland rice is economical and effective under certain conditions. It may be the only weed control method feasible for large-scale rice farms. Herbicides can complement other weed control methods or can be used in combination with hand weeding to give acceptable weed control.

For optimum effectiveness of preemergence herbicides, which require moist or wet soil, timely rains after application are essential. When residual herbicides are applied to soils that have remained dry for a long time, they give variable results. The persistence of many preemergence herbicides is so short, they cannot control successive flushes of weed seedlings. This makes follow-up hand weeding or application of a postemergence herbicide necessary.

Among the preemergence herbicides, butachlor, oxadiazon, dinitramine, pendimethalin, thiobencarb, fluorodifen, and piperophos-dimethametryn have been widely tested. Postemergence herbicides such as propanil and MCPA are also effective. Herbicide combinations are often more effective than a single herbicide. Applying a preemergence herbicide such as oxadiazon, butachlor, or thiobencarb, followed by propanil 15-25 d later will provide better weed control than will any of these herbicides applied alone. Early postemergence application of a postemergence herbicide (eg, propanil) combined with a residual herbicide, done at the time the postemergence herbicide is most effective, has the advantages of providing season-long control and saving time and labor by combining two spraying operations. Table 8.1 and Figure 8.1 provide information on common herbicides that may be used in upland rice.

Table 8.1. Herbicides suitable for use in upland rice.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bentazon	1.0-2.0	Selective postemergence control of certain broadleaf weeds and sedges (IRRI 1982). Does not control grasses. Apply postemergence when weeds are at the 4- to 10-leaf stages. Delayed application allows the weeds to exceed maximum size, resulting in inadequate control.
Bifenox	2.0	Apply preemergence from seeding to early spikelet stage. Apply to moist soils for best results. Bifenox + propanil can be applied postemergence when rice has 2-3 leaves and weeds are 2.5 cm high (Akobundu 1987).
Butachlor	2.0	Effective against grasses and broadleaf weeds; less effective against perennial sedges (IRRI 1975).
Butralin	2.0	Apply preemergence to control annual grasses (IRRI 1976).
2,4-D or MCPA	0.5	Apply as postemergence spray after tiller initiation, about 21-30 d after seeding (DAS) (Dixit and Singh 1981).
Dinitramine	1.5	Apply preemergence (IRRI 1978).
Fluorodifen	2.5-4.0	Apply 0-3 DAS for residual preemergence control of annual grasses (De Datta 1972).
Oxadiazon	0.75-1.5	Apply preemergence 0-2 DAS. Rice growth depression has been observed 15-20 d after emergence (IRRI 1975).
Oxyfluorfen	0.35	Apply preemergence. May be moderately toxic to rice (IRRI 1983).
Pendimethalin	2.0	Apply preemergence or early postemergence, combined with propanil (IRRI 1975). Excellent for control of *Rottboellia cochinchinensis.*
Piperophos + dimethametryn	1.0-2.0	Apply 4-6 DAS (Dubey et al 1980).
Propanil	3.0-6.0	Apply at 2- to 3-leaf stages of grass. High temperatures increase contact burn and may injure rice (IRRI 1980).
Thiobencarb	3.0	Apply before 2-leaf stage of weeds and after 1-leaf stage of rice (IRRI 1988a).

Chapter 9

Weed control in deepwater and floating rice

Deepwater and floating rice constitute about 11% of the world's rice area (IRRI 1988b). They are grown in the deltas, estuaries, and river valleys of Bangladesh, Cambodia, India, Indonesia, Myanmar, Thailand, and Vietnam. In Africa, deepwater and floating rice-growing areas are found in the inland Niger River delta in Mali, in the Niger River delta, Nigeria, and in inland swamps.

Deepwater and floating rice cultures

Deepwater rice is grown in areas where the maximum depth of standing water exceeds 50 cm for a significant period of rice growth. Where water depth is greater than 100 cm, the culture is referred to as floating rice or very deep water rice. Fields are not bunded and flooding usually occurs only during the later part of the growing season. Rice may grow under drought conditions for 40-60 d before flooding occurs.

Weed problems

Weeds are a major problem in deepwater and floating rice because rice normally is seeded into soils that may remain dry for 6-12 wk. Fields may also be flash flooded. The dry soil and intermittent flash flooding result in a broad spectrum of weeds—from upland to semiaquatic and aquatic—that successively compete with the rice crop. Weeds adapted to dryland compete at early crop stages, die upon flooding, and are succeeded by aquatic weeds.

Before flooding, deepwater and floating rice may be infested by *Echinochloa colona, Eleusine indica, Cyperus rotundus, C. iria,* and *C. difformis.* These weeds also may compete with rice during the early stages of flooding.

Deepwater and floating rice may suffer severe weed infestations during the preflood period. Weed problems are often aggravated by poor stand establishment due to drought. At the preflood stage, weeds reduce growth and tillering of rice plants and can reduce grain yield as much as 33% (De Datta and Hoque 1982). Total crop loss can occur if flooding is below normal.

Minimizing competition from weeds at early rice growth stages largely determines how well deepwater and floating rice will tolerate stresses caused by flooding at later stages. Aquatic weeds that occur upon flooding are less a problem when stand establishment is good and rice tillering is adequate than when early weed competition is severe. In small cropping areas where farmers wet seed or transplant deepwater rice, puddling reduces weed infestation.

Amphibious weeds, such as the wild rices, *Scirpus* sp., *Sesbania* sp., and *Leersia hexandra,* can compete with rice under dryland or flooded conditions. *Eichhornia crassipes, Ipomoea aquatica, Monochoria vaginalis,* and *Pistia stratiotes* are found in deepwater rice after flooding has occurred.

Weeds such as the wild rices possess flood tolerance and elongation ability, and grow with rice in rising floodwater. Therefore, they are able to cause considerable yield losses. Masses of *E. crassipes* are usually introduced to the ricefield by water currents or strong winds. When this occurs, *E. crassipes* can completely smother the rice crop within a few days. In West Africa, the most troublesome weeds include *E. stagnina* and *E. pyramidalis,* and the wild rices *Oryza longistaminata* and *O. barthii.*

Weed control before flooding

The deepwater rice cycle has two distinct phases—before flooding and after flooding. Weed control methods can be described best within these phases. Deepwater rice before flooding is treated either as rainfed lowland rice or as upland rice, using the same weed control methods.

Land preparation

Land preparation for dry seeded deepwater and floating rice is similar to that for upland rice. At planting, the seed bed should be weed free. Deep plowing and harrowing are recommended in the dry season if rhizomatous perennials are a problem. Many deepwater and floating rice soils have a high clay content, and, the only time to plow them is often when they are dry and very hard. Cultivation must start early because the crop, which draws first on residual moisture and moisture from occasional showers, must reach the stage where it can elongate before flooding starts. The stale seedbed technique can be used to reduce weed problems, particularly infestation by wild rices.

Planting method

Broadcast seeding rice into dry soil is common in deepwater and floating rices. Transplanting or broadcasting pregerminated seeds into puddled soil is also practiced in some areas. If early flash floods occur, however, transplanting involves a greater risk of crop failure than does broadcast seeding. The rice seedling grows as an upland crop for 4-20 wk before flooding occurs. As the floodwaters rise, deepwater rice plants elongate to as tall as 6 m and form a dense mat on the water surface.

Cultivar

Rice cultivars with elongation ability, photoperiod sensitivity, drought tolerance at the seedling stage, and tolerance for stagnant water conditions at later growth stages are ideal for deepwater and floating rice.

Table 9.1. Herbicides suitable for use in deepwater and floating rice.

Herbicide	Rate (kg ai/ha)	Comments and source of information
Bentazon	2.0	Selective control of certain broadleaf weeds and sedges. Does not control grasses. Apply postemergence early, when weeds are at the 4- to 10-leaf stages. Delayed application allows weeds to exceed maximum size and results in inadequate control (COPR 1976).
Butachlor	1.0-2.0	Effective against grasses and broadleaf weeds. Less effective against perennial sedges (COPR 1976).
Butralin	2.0	Apply preemergence to control annual grasses (COPR 1976).
2,4-D or MCPA	0.5	Apply as postemergence spray after rice tillering, 21-30 d after seeding (DAS) (COPR 1976).
Fluorodifen	2.5-4.0	Apply preemergence 0-3 DAS to control residual annual grasses (COPR 1976).
Oxadiazon	0.75-1.0	Apply 6-8 d after application (COPR 1976).
Piperophos + dimethametryn	1.0-2.0	Apply 4-6 DAS (COPR 1976).
Propanil	3.0	Apply at 2- to 3-leaf stages of grass (IRRI 1980).
Thiobencarb	2.0-4.0	Apply before 2-leaf stage of weeds and after 1-leaf stage of rice (COPR 1976).

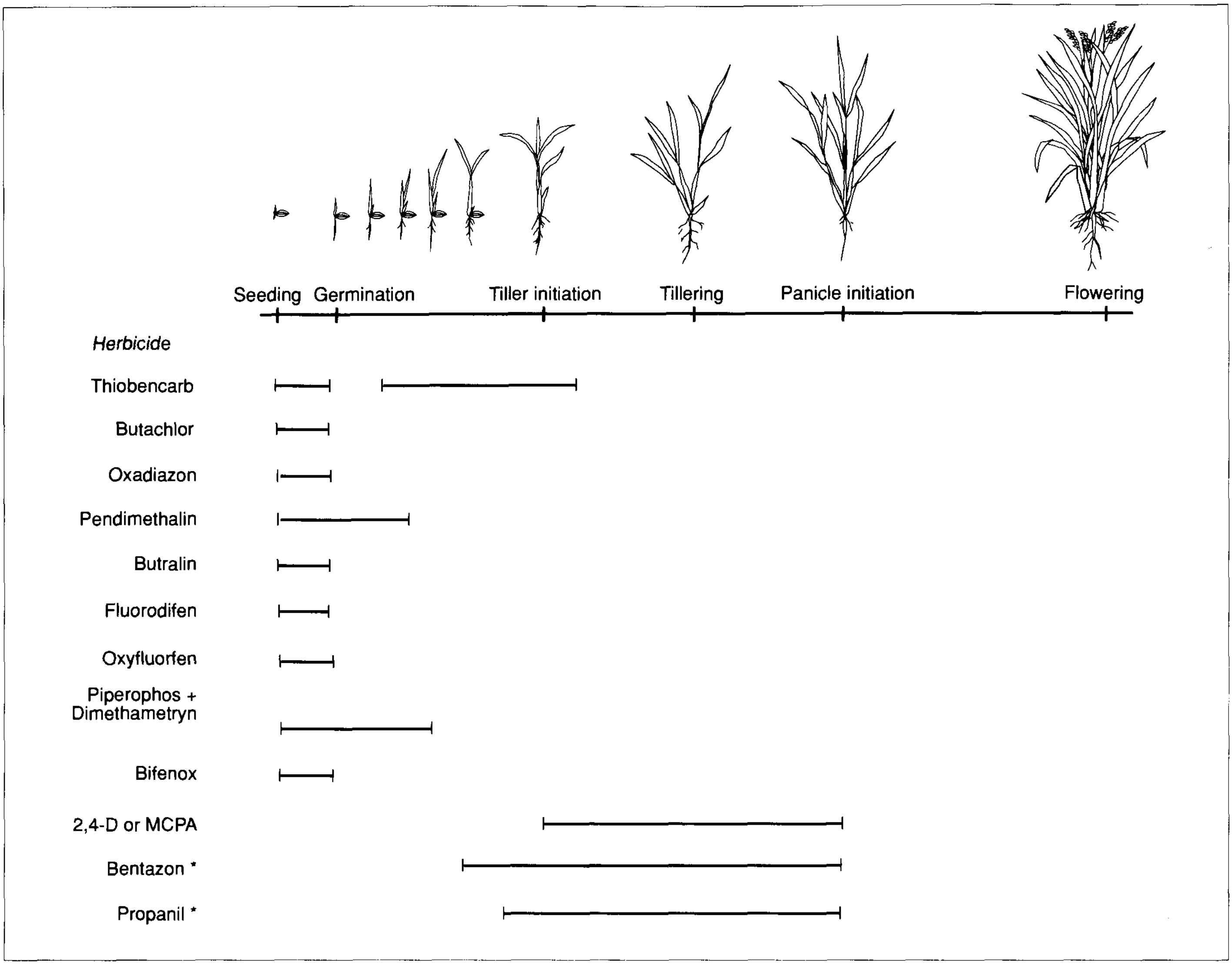
Plant population

Because of poor stand establishment, seeding rates tend to be high—80-200 kg/ha. The crop produces nodal tillers at low plant densities, however, and a high seeding rate does not necessarily increase final grain yield. Nevertheless, the high seeding rate is a good agronomic practice because a high plant population allows rice to develop a canopy that suppresses weed growth.

Crop rotations can help control or prevent the buildup of difficult-to-control weeds. In Bangladesh, farmers on the higher ridges of deepwater rice areas grow a crop of jute after one or more deepwater rice crops. The jute crop suppresses wild rice and other weeds.

Fertilizer

Deposits of the silt carried by rivers during their annual floods provide high fertility for most deepwater and floating rice soils. The high soil fertility improves stand establishment and elongation ability of rice, but weeds also grow quickly and compete aggressively for nutrients, moisture, and light. Weeds must be controlled to maximize the nutrient uptake efficiency of the rice crop.



9.1 Rice growth stages when herbicides can be applied on deepwater and floating rice. Bars (—) show periods when a particular herbicide can be applied. *Timing of herbicide application is based on weed emergence and growth stage within the rice growth stage.

Hand weeding

Hand weeding is the most effective weed control method in deepwater and floating rice. Weeding should be done 15-25 d after planting. Two to three hand weedings may be necessary, depending on the time of flooding. Weeds germinate earlier and grow more vigorously than rice during the preflood period. Mechanical weeding, combined with hand weeding for weed removal within the rows, may be effective when rice is row-seeded.

Herbicides

Most common weeds present before flooding can be controlled by the herbicides recommended for upland rice. Butachlor, oxadiazon, pendimethalin, thiobencarb, piperophos-dimethametryn, and oxyfluorfen are effective when applied preemergence. Postemergence herbicides such as propanil, 2-4D, and MCPA are also effective in controlling weeds such as *I. aquatica.* Residual herbicides give variable results when applied to dry soils or when flash floods occur soon after application. Glyphosate can be used to control *O. longistaminata* during fallow. Table 9.1 and Figure 9.1 provide information on herbicides and their appropriate times of application.

Weed control after flooding

Weed control after flooding in deep water and floating rice is mainly done by hand. Farmers in some areas grow a strip of *Sesbania aculeata* or *Aeschynomene aspera* along the borders of deepwater and floating ricefields to provide a barrier against the entry of *E. crassipes* and other weeds into the fields. Barricades of bamboo poles and bars are sometimes installed.

Hand weeding

Attempts to weed deepwater and floating rice from boats—a difficult task—have been made in cases of severe weed infestation. In Mali, farmers hand weed after flooding to minimize competition from *O. longistaminata* and *O. barthii.* Perennial *E. stagnina* is also removed by hand.

Herbicides

Herbicides are effective in deepwater and floating rice only before flooding.

Chapter 10

Management of some difficult weeds in rice

Many weeds can be controlled effectively only by using a combination of methods. Using only one weed control method leads to a buildup of weed problems. This chapter gives information on how intractable rice weeds can be managed through an integrated approach.

Scirpus maritimus

Scirpus maritimus, a perennial sedge that spreads by tubers, is widespread in lowland rice in several countries in Asia, Europe, and temperate climate USA (see page 000). *S. maritimus* is a very competitive weed: it produces numerous tubers, has fast shoot growth, is able to emerge through fields with standing water, and has rapid nutrient uptake. Season-long competition from *S. maritimus* can reduce rice yields 60-100%. Its tubers and buds can remain dormant in the soil, making this weed difficult to eradicate. *S. maritimus* is most competitive from its early growth stages to 80 d after germination. The S. *maritimus*-free period required in rice is the first 4 wk.

Cultural control

Cultural control of *S. maritimus* involves tillage, crop rotation, and water management.

Depth and type of primary cultivation greatly affect the *S. maritimus* population. Shallow cultivation and zero tillage encourage emergence of tubers retained on the soil surface, resulting in rapid population buildup. Deep plowing buries the tubers and results in growth of fewer seedlings.

The practice of zero tillage leads to the buildup of a *S. maritimus* population, but minimum tillage can be as effective as conventional tillage in limiting its growth. The weed persists under continuously wet conditions but diminishes dramatically with time under continuously dry conditions. A year of rotation of an upland crop with lowland rice will reduce the prevalence of *S. maritimus.*

Hand weeding

Hand weeding is effective in controlling *S. maritimus.* The rice crop should be kept weed-free for at least the first 4 wk. This makes several hand weedings necessary, because *S. maritimus* tubers germinate within 5 d after harrowing and grow rapidly.

Herbicides

Herbicides effective against *S. maritimus* in transplanted and direct seeded flooded rice include bentazon, fenoxaprop, propanil, 2,4-D, and bensulfuron. 2,4-D at 0.5 kg ai/ha is best applied when *S. maritimus* has 6-8 leaves. 2,4-D applied preemergence does not control the weed, although it may reduce the stand of annual grasses. Bentazon at 1-2 kg ai/ha should be applied at the 6- to 8-leaf stage (about 25 d after sowing [DASI). Bensulfuron at 50 g ai/ ha applied at 6-8 DAS or DT (2- to 3-leaf stage of the weed) effectively controls *S. maritimus* and annual weeds.

Integrated control

Integration of all workable weed control practices can provide effective and economical control of S. maritimus. Such integration should begin by creating an environment favorable to rice growth but unfavorable to weed growth. This includes using well-adapted, high-yielding rice cultivars; appropriate fertilizers; good management; and crop rotation. Weed control efficiency is improved by integrating the use of herbicides and hand weeding. The rotational crops used depend on the region; maize, sorghum, and soybean are becoming increasingly important.

Paspalum distichum

Paspalum distichum is a creeping perennial grass found in lowland ricefields (see page 22). Its underground growth system consists of adventitious roots and rhizomes. It tends to resist conventional weed control measures, including the use of herbicides, but is sensitive to shading.

Cultural control

Thorough land preparation is one way of controlling *P. distichum.* Frequent tillage reduces *P. distichum* problems. Cutting up rhizomes by tillage encourages dormant buds to sprout, depleting the weeds food reserves. For long-term control, its rhizome must be killed.

Because *P. distichum* is sensitive to shade, closely spaced, vigorous rice plants offer better competition against this weed than do widely spaced plants.

Herbicides

P. distichum is resistant to many preemergence herbicides used on rice. It is, however, susceptible to glyphosate applied at 2.0 kg ai/ha and moderately susceptible to paraquat. A preplant herbicide, such as glyphosate, used in combination with land preparation, improves control. Translocation of glyphosate into the rhizomes is best achieved when the glyphosate is applied on actively growing *P. distichum* with maximum leaf area.

Integrated control

Integration of cultural control and herbicides will give good control of *P. distichum.*

Echinochloa species

The genus *Echinochloa,* which includes about 50 weed species, includes some of the most important rice weeds. The most common are *E. crus-galli, E.glabrescens,E.oryzoides, E. pyramidalis,* and *E. colona.*

E. crus-galli grows widely in both temperate and tropical regions (see page 16). Its world distribution ranges from 50° N to 40° S latitude. *E. colona* (see page 33) occurs in tropical and subtropical regions. *E. glabrescens* is found in the Indian subcontinent, Southeast Asia, China, and southern Japan. *E. pyramidalis* is abundant in the floating rice areas of West Africa. *E. crus-galli* prefers moist conditions and continues to grow when submerged; *E. colona* ceases to grow when submerged.

Rice yield losses from season-long competition with *Echinochloa* spp. can be as high as 90%. *Echinochloa* spp. are troublesome in rice because their ecological requirements are similar: at early growth stages, they resemble rice, and they accumulate considerable amounts of nutrients, to the disadvantage of rice. Moreover, these weeds compete with rice for light and moisture.

Echinochloa spp. germinate earlier than direct seeded rice. During the first 3 wk of weed growth, profuse emergence of new leaves and vegetative growth of tillers and adventitious roots occur. Echinochloa spp. produce extremely large numbers of seeds, which ensure the weeds dispersal and reestablishment.

Cultural control

Crop rotation can effectively reduce *Echinochloa* spp. populations.

Hand weeding

Hand weeding is effective if done repeatedly, to remove succeeding flushes of weeds and weeds overlooked earlier due to their similarity to rice.

Herbicides

Several herbicides can selectively control *Echinochloa* spp. This include butachlor, oxadiazon, oxyfluorfen, pendimethalin, thiobencarb, simetryn, molinate, propanil, chlomethoxynil, pretilachlor, and quinclorac. Preemergence and early postemergence applications are most effective because the weeds are most susceptible at the seedling stage. Weed resistance to herbicides increases with age.

Butachlor applied preemergence inhibits the enzyme activity of *Echinochloa* spp., delays radicle emergence, and inhibits emergence of the root and primary leaf. Selectivity for propanil depends on the different levels of the hydrolyzing enzyme, which is high in rice but low in *Echinochloa* spp.

Integrated control

Echinochloa spp. can be managed effectively through an integrated approach. Because the weed is sensitive to shade, a vigorous rice stand (achieved with high planting density and high fertilizer application), combined with hand weeding or with preemergence or early postemergence herbicide, will lead to early rice canopy closure. Late-germinating *Echinochloa* spp. can be controlled by herbicides. A 10-20 cm water depth will generally suppress *Echinochloa* spp. weeds.

Wild rices

The important wild rices are *Oryza rufipogon* Griff., *O. nivara* Sharma & Shastry, *O. longistaminata* A. Chev. & Roehr., *O. barthii* A. Chev., *O. punctata* Kotschy ex Steud., and *O. officinalis* Wall. ex Watt. These wild rices resemble cultivated rice *O. sativa.* They are adapted to the environment of cultivated rice, are competitive, and have grains that are highly dormant and shatter easily.

O. rufipogon is a problem in areas in Bangladesh, Brazil, Colombia, Guyana, India, Indonesia, Malaysia, Surinam, Thailand, southern USA, Venezuela, and West Indies. A perennial weed, its mature seed has a long dormancy, shatters easily, and has a pigmented aleurone layer.

O. nivara is an annual weed that occurs in drainage ditches and shallow ponds. Its seeds are highly dormant and shatter easily.

O. longistaminata (synonym: *Oryza perennis* Moench) is a serious weed in most of West Africa. As a rhizomatous perennial grass, it propagates almost exclusively by vegetative multiplication of rhizomes, which are produced prolifically. It thrives in medium to deep parts of flooded ricefields and in deep parts of poorly irrigated fields. It is very competitive and can reduce rice yields as much as 90%.

O. barthii is widely distributed in Africa. It is an annual weed that closely resembles *O. glaberrima.* Characteristics such as early maturity, shattering before rice maturity, and seed dormancy make it difficult to control.

O. punctata and *O. officinalis* are both annual weeds. *O. punctata* is native to Africa, *O. officinalis* originated in Asia. Both have small grains.

Some of the wild rices are photoperiod sensitive. This influences their growth duration, with later emerging plants taking less time. Wild rice stalks are generally weak, resulting in lodging not only of the weeds but also of the rice around them.

Cultural control

Using clean rice seed, free of wild rice seeds, will prevent the introduction or reintroduction of wild rices to noninfested areas. After rice harvest, fields should be managed to kill wild rice seeds (e.g., straw burning). Early-season cultivation and harrowing stimulate red rice germination and may allow the mechanical destruction of several flushes of wild rice growth before rice or rotational crops are planted.

High seeding rates of rice reduce tillering of wild rice. When rice is seeded or transplanted in rows, it is easy to differentiate wild rice growing between the rows.

Crop rotation may reduce infestations of wild rices. Wild rice is easy to control in upland crops. The length of rotation depends on how severely the field is infested with wild rice. Typical rotational crops for red rice in southern USA are maize, grain sorghum, and soybean. Depending on the rotational crop, herbicides commonly used include propazine, alachlor, metolachlor, trifluralin, pendimethalin, metribuzin, bentazon, and atrazine.

Buried seeds of wild rice do not germinate when the soil is flooded or water-saturated. However, the perennial wild rices *O. longistaminata* and *O. rufipogon* propagate through bud germination of stem cuttings or rhizomes under such conditions. Dry seeding with delayed flooding results in a much higher infestation of wild rice than does seeding on a puddled field and keeping the soil saturated. Continuous flooding effectively controls wild rice.

Hand weeding

When crops are planted in rows, the wild rice between the rows can be weeded out easily. In some areas, wild rice is eaten. This not only augments the food supply but also helps reduce the spread of the weed. Wild rice mostly shatters before cultivated rice matures, and grains of wild rice must be harvested before they shatter. Its growth for food should be discouraged, however.

The perennial rhizomatous deep water wild rice *O. longistaminata* is controlled by underwater mowing of rhizomes twice during the growing season.

Herbicides

Herbicides commonly used in rice do not selectively control wild rice because of the similar growth systems. Molinate at 1-2 kg ai/ha applied preplanting and incorporated selectively controls the annual wild rices. For best control, molinate should be combined with continuous flooding. Preplanting application of glyphosate at 2-3 kg ai/ha also effectively controls wild rices. For red rice control, thiobencarb is surface-applied preplanting, just before bringing on the flood (Rice Journal 1988).

Integrated control

Wild rices are best controlled through an integrated approach that includes germination prevention, crop rotation, water management, herbicides, and other cultural methods.

Cyperus rotundus

C. rotundus, a perennial sedge, is a persistent, aggressive weed wherever upland rice is grown. It has been reported to infest fields in tropical areas of Africa, Asia, and Latin America (see page 29). Under intensive cultivation, it becomes a serious weed.

C. rotundus has an extensive underground system of basal bulbs, roots, rhizomes, and tubers, which permit rapid and vigorous vegetative propagation. Buds in a tuber and tubers within a chain exhibit apical dominance. That apical dominance can be broken during cultivation by severing any tuber from the chain. This stimulates dormant tubers to sprout.

C. rotundus germinates before, or simultaneously with, upland rice and competes for nutrients and moisture, causing yield reductions as high as 50%.

Cultural control

Adequate fertilizer, optimum plant density, and optimum time of planting are good cultural practices for managing *C. rotundus.*

Hand weeding

C. rotundus emerges with the rice crop and outgrows it during the early growth stages. Because of the rapid regeneration of *C. rotundus,* hand weeding has to be done at frequent intervals to effectively prevent the smothering of rice by the weed. Hand weeding should continue until the rice canopy closes—whenshade will suppress *C. rotundus* growth.

Herbicides

Glyphosate applied preplanting is best to control *C.* rotundus. Other herbicides that can be used are bentazon at 2.0-3.0 kg ai/ha and 2,4-D at 0.5 kg ai/ha applied postemergence, 3 wk after seeding. These selectively kill *C. rotundus,* but control is temporary.

Integrated control

Management practices, such as applying adequate fertilizer after weed control, optimum plant density, and optimum time of planting to avoid drought, combined with hand weeding or herbicides, will reduce *C. rotundus* and maximize upland rice yields.

Combinations of tillage and chemical methods have proven more effective in controlling *C. rotundus* than tillage or herbicides alone. In an integrated control scheme, *C. rotundus* is allowed to grow as long as possible (at least 3-4 wk) after plowing and harrowing have stimulated dormant buds to sprout. Then, systemic herbicides, such as glyphosate, that have no residual soil activity are applied. Rice is planted within a week without further land preparation. This will provide season-long control of *C. rotundus* and, if continued over several seasons, may eliminate the weed altogether.

Imperata cylindrica

Imperata cylindrica, a perennial rhizomatous grass, is a major weed in tropical Africa, Australia, South Asia, South America, and the Pacific islands (see page 35). It grows under a wide range of ecological conditions ranging from long dry spells to waterlogging.

I. cylindrica produces extensive rhizomes, which readily regenerate. It has a high tillering capacity and establishes quickly to cover a large area. Tillering is encouraged by burning, cutting, or grazing.

Apart from competing directly with upland rice for nutrients, moisture, and light, *I. cylindrica* limits upland rice production by reducing the total land area available for cropping; lands badly infested by the weed are abandoned.

Cultural control

Rhizomes of *I. cylindrica* are susceptible to partial desiccation even in the wet season. Effective control is obtained when the weed is fragmented by plowing to depths of 15-20 cm at the beginning of the dry season, when the fragments have time to dry before the onset of rain. This dry season plowing should be repeated every year until *I. cylindrica* is controlled. Tractor-drawn implements are needed for adequate plowing. The economics of repeated plowing need to be examined.

Hand weeding

Hand weeding has to be done at frequent intervals for good control of *I.cylindrica.*

Herbicides

For effective control of *I. cylindrica,* a herbicide that is translocated to the underground rhizomes to destroy all viable buds is best. Application of glyphosate preplanting gives good control. A mixture of glufosinate at 1.0 kg ai/ha and imazapyr at 0.25 kg ai/ha has been reported to give better and more lasting control than glyphosate in plantation crops. Both should be applied to actively growing plants with mature leaves. Glyphosate has no residual activity.

Integrated control

A combination of cultural and herbicide methods will effectively control *I. cylindrica.*

Rottboellia cochinchinensis

Rottboellia cochinchinensis is an annual grass that reproduces by seeds. It is very competitive in upland rice (see page 36) because it grows taller than the rice and completely shades it. Complete rice yield loss is common. Although *R. cochinchinensis* prefers moist, well-drained soil, it possesses considerable drought tolerance. It cannot tolerate submergence.
R. cochinchinensis has increased in importance because it is tolerant of many herbicides. Most rice herbicides that selectively control this weed do not have long enough persistence to prevent succeeding flushes from germinating.

Cultural control

Rotate upland rice with broadleaf crops in which *R. conchinchinensis* is easy to control. This prevents buildup of the weed.

Hand weeding

Two to three well-timed hand weedings of *R. cochinchinensis* will give maximum rice yield.

Herbicides

Many residual herbicides that control *R. cochinchinensis* are not selective in rice. Pendimethalin at 1.5-2.0 kg ai/ha is the best herbicide for control in upland rice. Pendimethalin will not control weeds that have germinated before herbicide application.

Integrated control

R. cochinchinensis is shade-intolerant and susceptible to competition by the rice crop. Use of N fertilizer; high rice plant density; and tall, fast-growing rice cultivars will give early canopy closure and suppress weed emergence. Crop rotation combined with herbicides and hand roguing reduces weed populations and gives maximum rice yields.

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Appendices

A. Useful conversions

Weights

1 gram	=	0.03527 ounces
1 ounce	=	28.4 grams
1 kilogram	=	2.2 pounds
1 pound	=	454 grams (0.454 kilogram)
1 metric ton	=	2,204.6 pounds (1,000 kilograms)

Area

1 acre	=	4,840 sq yards = 43,560 sq feet = 0.405 hectare = 4,050 sq meters
1 hectare	=	2.41 acres

Volume

1 gallon (Imperial)	=	4.546 liters
1 gallon (Imperial)	=	1.2 U.S. gallons
1 gallon (U.S.)	=	3.785 liters
1 fluid ounce	=	28.4 milliliters
1 liter	=	0.22 gallons = 1.76 pints

Measurements

1 inch	=	2.54 centimeters
1 foot	=	0.305 meter
1 yard	=	0.914 meter
1 mile	=	1.609 kilometers
1 centimeter	=	0.394 inch
1 meter	=	3.281 feet
1 meter	=	1.094 yards
1 kilometer	=	0.621 mile
1 kilopascal (kpa)	=	0.145 pound per square inch (psi)

Quick conversions

1 liter/hectare	=	0.089 gallon/acre
1 kilogram/hectare	=	0.892 pound/acre
1 kilogram/liter	=	8.33 pounds/gallon

B. Conversion table for liquid formulations

Desired active ingredients (in kg/ha)	Percent concentration of active ingredient in formulation (liters of formulation needed to spray 1 ha)										
	100	90	80	75	70	60	50	40	30	25	20
1.0	1.0	1.11	1.25	1.33	1.45	1.66	2.0	2.5	3.33	4.0	5.0
1.5	1.5	1.66	1.87	2.0	2.18	2.49	3.0	3.75	5.0	6.0	7.5
2.0	2.0	2.22	2.5	2.66	2.9	3.32	4.0[a]	5.0	6.60	8.0	10.0
2.5	2.5	2.78	3.13	3.33	3.63	4.15	5.0	6.25	8.33	10.0	12.5
3.0	3.0	3.33	3.75	4.0	4.35	4.98	6.0	7.5	9.99	12.0	15.0
3.5	3.5	3.89	4.38	4.66	5.08	5.81	7.0	8.75	11.66	14.0	17.5
4.0	4.0	4.44	5.0	5.32	5.80	6.64	8.0	10.0	13.32	16.0	20.0
4.5	4.5	5.0	5.63	6.0	6.53	7.5	9.0	11.25	15.0	18.0	22.5
5.0	5.0	5.55	6.25	6.67	7.14	8.33	10.0	12.5	16.67	20.0	25.0
5.5	5.5	6.11	6.88	7.32	8.0	9.13	11.0	13.75	18.32	22.0	27.5
6.0	6.0	6.66	7.5	7.98	8.7	7.96	12.0	15.0	10.0	24.0	30.0

[a]For example, to apply 2.0 kg ai/ha using a formulation containing 50% active ingredient, use 4.0 liters of the formulated product.

B. Conversion table for granular formulations

Desired active ingredients (in kg/ha)	Percent concentration of active ingredient in formulation								
	20	15	10	7.5	5	4	3	2	1
	(kg of formulation required to spray 1 ha)								
0.5	2.5	3.33	5.0	6.67	10.0	12.5	16.67	25.0	50.0
1.0	5.0	6.67	10.0	13.3	20.0	25.0	33.3	50.0	100.0
1.5	7.5	10.0	15.0	20.0	30.0	37.5	50.0	75.0	150.0
2.0	10.0	13.3	20.0	26.6	40.0[a]	50	66.7	100.0	200.0
2.5	12.5	16.6	25.0	33.3	50	62.5	83.3	125.0	250.0
3.0	15.0	20.0	30.0	40.0	60	75.0	100.0	150.0	300.0
3.5	17.5	23.3	35.0	46.6	70	87.5	116.7	175.0	350.0
4.0	20.0	26.6	40.0	53.3	80	100.0	133.3	200.0	400.0
4.5	22.5	30.0	45.0	60.0	90	112.5	150.0	225.0	450.0
5.0	25.0	33.3	50.0	66.6	100	125.0	166.7	250.0	500.0
5.5	27.5	36.3	55.0	73.3	110	137.5	183.3	275.0	550.0
6.0	30.0	40.0	60.0	80	120	150.0	200.0	300.0	600.0

[a] For example, to apply 2.0 kg ai/ha using granules containing 5% active ingredient, use 40 kg offormulated product.

C. Common and chemical names of herbicides

Chemical names of herbicides vary, depending on the standard adopted. The common standards are CHEMICAL ABSTRACTS (CA) and International Union of Pure and Applied Chemistry (IUPAC). When possible. this handbook used CA (which is also followed by the Weed Science Society of America).

Common name	Chemical name
Bentazon	3-(1-methylethyl)-(l *H*)-2,1,3-benzothiadiazin-4(3 *H*)-one 2,2-dioxide
Bensulfuron	(methyl 2-[[(4,6-dimethoxypyrimidin-2-yl) aminocarbonyl] aminosulfonylmethyl] benzoate)
Bifenox	methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate
Butachlor	*N*-(buthoxymethyl)-2-chloro- *N*-(2,6-diethylphenyl) acetamide
Butralin	4-(1,1-dimethylethyl)-N-(1-methyl propyl)-2, 6-dinitrobenzenamine
Chlometoxynil	2,4-dichlorphenyl 3-methoxy-4-nitrophenyl-ether
Cinmethylin	*exo*-1-methyl-4-(1-methylethyl)-2-[(2-methylphenyl) methoxy]-7-oxabicyclo [2.2.1] heptane
2,4-D	(2,4-dichlorophenoxy) acetic acid
Dimethametryn	2-(1,2-dimethylpropylamino)-4-ethylamino-6-methylthio- 1,3,5-triazlne
Fenoxaprop	(±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy] propanoic acid
Fluorodifen	4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether
Glufosinate	DL-homoalanin-4-yl (methyl)phosphinic acid
Glyphosate	N-(phosphonomethyl)glycine
MCPA	(4-chloro-2-methylphenoxy) acetic acid
Molinate	*S*-ethyl hexahydro-1 *H*-azepine-1-carbothioate
Oxadiazon	3-[2,4-dichloro-5-(1-methylethoxy) phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazon-2 (3*H*)-one
Oxyfluorfen	2-chIoro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene
Paraquat	1,1'-dimethyl-4,4'-bipyridinium ion
Pendimethalin	*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine
Piperophos	*S*-2-methyl-1-piperidylcarbonylmethyl *0,0*-di-n-propyl phosphorodithioate
Pretilachlor	a-chloro-2,6-diethyl-N-(2-propoxyethyl) acetanilide
Propanil	*N*-(3,4-dichlorophenyl) propanamide
Quinclorac	3,7-dichlor-8-quinolinecarboxylic acid
Simetryn	4,6-bisethylamino-2-methylthio-1,3,5-triazine
Tiocarbazil	*S*-benzyl N,N-di-sec-butylthiocarbamate
Thiobencarb	*S*[(4-chlorophenyl)methyl]diethylcarbamothioate

D. Common names, trade names, and original manufacturers of herbicides.

Common name	Trade names	Year introduced	Original manufacturer
Bensulfuron	Londax	1984	DuPont
Bentazon	Basagran	1970	BASF
Bifenox	Modown	1970	Rhone-Poulenc
Butachlor	Machete, Butanex, Lambast, Pillarsete	1969	Monsanto
Butralin	Amex, Tamex	1971	Union Carbide
Chlomethoxynil	Ekkusugoni	1972	Nihon Nohyaku Co.
Cinmethylin	Cinch, Argold	1982	DuPont
2,4-D	Aqua Kleen, Demise, Esteron,Weed-B-Gon, Weedone	1942	Amchem Products Inc.
Dimethametryn + piperophos	Avirosan	1969	Ciba-Geigy
Fenoxaprop	Whip	1982	Hoechst-Roussel
Fluorodifen	Preforan	1968	Ciba-Geigy
Glyphosate	Roundup, Rodeo, Shackle, Spason	1971	Monsanto
MCPA	Agroxone, Agritox, Zelan, Chiptox, Frasan, Vacate	1945	ICI
Molinate	Ordram, Arrosolo	1964	Stauffer
Oxadiazon	Ronstar	1969	Rhone-Poulenc
Oxyfluorfen	Goal, Koltar	1974	Rohm & Haas
Paraquat	Gramoxone, Paracol, Cekuquat, Scythe, Sweep	1958	ICI
Pendimethalin	Prowl, Herbadox, Gogosan, Stomp	1972	American Cyanamid
Piperophos	Rilof	1969	Ciba-Geigy
Pretilachlor	Sofit, Rifit. Solnet	1982	Ciba-Geigy
Propanil	Stam F-34, Surcopur, Riselect, Dipram, Stampede	1953	Rohm & Haas
Quinclorac	Facet	1984	BASF
Thiobencarb	Saturn, Tamariz, Bolero. Siacarb, Saturno	1965	Kumiai Chemical Industry, Chevron Chemical

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