Weed Technology 2015 29:1–17

Weeds and Weed Management of Rice in Karnataka State, India

Adusumilli Narayana Rao, Suhas P. Wani, Mugalodi Ramesha, and Jagdish K. Ladha*

Rice is one of the staple food crops of India, and Karnataka is one of the major rice-producing states. The primary method of rice establishment in Karnataka is transplanting, but farmers are opting to shift to direct-seeding of rice. Weed management is critical for realizing optimal yield of direct-seeded rice (DSR). The objective of this review was to synthesize the published literature on weeds and weed management in rice in Karnataka, identify improved weed-management technologies for delivery to farmers, and suggest research needs. Some 98 weed species are reported to be associated with rice in Karnataka. Weed control to date in Karnataka has mostly been based on herbicides. Hand-weeding was found to be effective in all methods of rice establishment. However, it is time-consuming, tedious, and costly because labor is becoming scarce and unavailable, and labor wages are higher. Several PRE and POST herbicides that were effective in other Asian countries were also found to be effective in managing weeds in rice established by different methods in Karnataka. Bensulfuron plus pretilachlor and pyrazosulfuron in aerobic rice and pendimethalin, thiobencarb, bispyribac-sodium, cyhalofop, fenoxaprop plus chlorimuron plus metsulfuron, and fenoxaprop plus ethoxysulfuron in dry-DSR were found effective in managing weeds. In wet-DSR, butachlor plus safener and pretilachlor plus safener were effective. Thiobencarb, pendimethalin, pretilachlor, azimsulfuron plus metsulfuron, bispyribac-sodium, butachlor, cinosulfuron, oxadiazon, and quinclorac were found promising for weed management in transplanted rice. Integration of herbicides with hand-weeding or intercultivation was found to be effective in rice established by different methods. Options that were found economical in managing weeds varied across the different rice-establishment methods. The need for developing location-specific, sustainable, integrated weed management and extension of available technologies for the farming community in Karnataka is emphasized.

Nomenclature: Azimsulfuron; bensulfuron; bispyribac-sodium; butachlor; chlorimuron; cinosulfuron; cyhalofop; ethoxysulfuron; fenoxaprop; metsulfuron; oxadiazon; pendimethalin; pretilachlor; pyrazosulfuron; quinclorac; thiobencarb; rice, *Oryza sativa* L.
Key words: Aerobic rice, dry direct-seeded rice, integrated weed management, transplanted rice, wet direct-seeded rice.

El arroz es uno de los alimentos básicos de India, y Karnataka es uno de los estados con mayor producción de arroz. El método primario de establecimiento de arroz en Karnataka es el trasplante, pero los productores están optando por cambiar a la siembra directa del arroz. El manejo de malezas es crítico para alcanzar un rendimiento óptimo en arroz de siembra directa (DSR). El objetivo de esta revisión es sintetizar la literatura publicada acerca de las especies de malezas y el manejo de malezas en arroz en Karnataka, identificar tecnologías que mejoren el manejo de malezas, y sugerir cuáles son las necesidades de investigación. Noventa y ocho especies de malezas están reportadas como asociadas al arroz en Karnataka. Hasta la fecha, el control de malezas en Karnataka se ha basado mayoritariamente en el uso de herbicidas. Se encontró que la deshierba manual es efectiva en todos los métodos de establecimiento del arroz, sin embargo, toma mucho tiempo, es tediosa, y de alto costo porque la mano de obra es escaza o no está disponible del todo, y los salarios son cada vez más altos. También se encontró que varios herbicidas PRE y POST que son efectivos en otros países asiáticos son efectivos en el manejo de malezas en diferentes métodos de establecimiento de arroz en Karnataka. Se encontró que bensulfuron más pretilachlor y pyrazosulfuron en arroz aeróbico, y pendimethalin, thiobencarb, bispyribac-sodium, cyhalofop, fenoxaprop más chlorimuron más metsulfuron, y fenoxaprop más ethoxysulfuron en DSR-en seco fueron efectivos para el manejo de malezas. En DSR-en mojado, butolachlor más antídoto y pretilachlor más antídoto fueron efectivos. Thiobencarb, pendimethalin, pretilachlor, azimsulfuron más metsulfuron, bispyribac-sodium, butachlor, cinosulfuron, oxadiazon, y quinclorac fueron promisorios par el manejo de malezas en arroz trasplantado. La integración de herbicidas con la deshierba manual o el cultivo entre hileras fueron efectivos en arroz establecido con diferentes métodos. Las opciones que

DOI: 10.1614/WT-D-14-00057.1
* Visiting Scientist, ICRISAT Development Center (IDC) and International Rice Research Institute (IRRI), International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru- 502 324, India; Director, IDC, ICRISAT, Patancheru- 502 324, India; Scientist, IRRI Rice Breeding Hub, ICRISAT, Patancheru- 502 324, India; Principal Scientist, IRRI, India Office, 1st Floor, CG Block, NASC Complex, DPS Marg, New Delhi 110 012, India; Corresponding author's E-mail: anraojaya1@gmail.com

fueron económicas para manejar las malezas variaron según el método de establecimiento del arroz. Se hace énfasis en la necesidad de desarrollar y hacer disponibles a la comunidad agrícola en Karnataka, tecnologías para el manejo integrado de malezas que sean sostenibles y específicas para cada localidad.

Rice is one of the staple food crops of India, and Karnataka is one of the major rice-producing states in India (Rajanna 2010; Rao 2010). In Karnataka, nearly 70% of the annual food-grain production comes from the kharif season (June to October), which depends on the southwest monsoon. Out of the gross cropped area of 12.89 million ha in Karnataka, 3.94 million ha (30.6 %) are irrigated and the rest are rainfed. Rice is cultivated under irrigated conditions and in areas with normally higher rainfall in Karnataka. The average area in rice production in the state is 1.24 million ha (Table 1; Figure 1), which is about 3.0% of the total area of rice in India. The rice-producing area has undergone a marginal annual increase of 0.83% because the area in cereals in Karnataka is moving from coarse cereals to rice and corn (*Zea mays* L.) (Acharya et al. 2012). The average annual production of rice in the state is around 3.5 million tons (t), accounting for about 4.1% of the rice produced in India. Rice production in the state is growing at around 2.3% yr^{-1} (Acharya et al. 2012). Among 27 rice producing states of India, Karnataka is the ninth largest rice-producing state. Rice productivity in the state is around 2.7 t ha^{-1}. This rice productivity witnessed an annual increment of 1.46% during the period from 1982 to 1983 to 2007 to 2008. Thus, the growth in Karnataka rice production has come mainly from growth in rice productivity rather than growth in area. The results of demonstrations (AN Rao et al, unpublished data) conducted under the government of Karnataka and the Consultative Group on International Agricultural Research (CGIAR) initiative have indicated that potential exists to increase rice productivity to 6 to 8 t ha^{-1} by identifying and alleviating abiotic and biotic constraints, including weeds.

The major method of rice establishment in Karnataka is transplanting of rice seedlings into puddled soil (transplanted rice). Water (Bouman 2001) and labor (Kumar and Ladha 2011) shortages are becoming severe in many rice-growing areas in the world, and Karnataka is no exception. In the Tungabhadra command area of Karnataka, for fields away from the Tungabhadra dam, farmers are opting to shift to direct-seeded rice (DSR) (Manjunatha et al. 2009) because of its advantages, such as water and labor savings, reduced cost, and early crop maturity of 8 to 9 d compared with those of the transplanted crop (Sanjay et al. 2006b). Direct seeding can be categorized as (1) wet-DSR, in which sprouted rice seeds are broadcast or sown in lines on wet/puddled soil, (2) dry-DSR, in which dry rice seeds are drilled or broadcast on unpuddled soil either after dry tillage or zero tillage or on a raised bed (Kumar and Ladha 2011), and (3) aerobic rice, in which especially developed "aerobic rice" varieties are grown in well-drained, nonpuddled, and nonsaturated soils (Bouman 2001). In Karnataka, rice is seeded dry and later converted to irrigated lowland (flooded) rice once canal water is released, which is normally around 25 to 30 d after seeding. However, DSR is subject to more-severe weed infestation than is transplanted lowland rice because weeds germinate simultaneously with rice, and there is no water layer to suppress weed growth (Rao et al. 2007). Fewer weed problems under transplanted conditions occurred because of puddling during land preparation and the presence of standing water in the field immediately after planting, which helps in preventing/reducing weed growth. In DSR, weeds cause yield losses up to 50 to 100% (Kumar and Ladha 2011; Mishra and Singh 2007; Rao et al. 2007). Gandhi et al. (2012) reported that, although farmers accepted aerobic rice cultivation with the new variety MAS 946-1, their main concern was weed control. A survey conducted on cultural practices used by farmers in the hill region of Uttara Kannada district revealed that weed problems were greater in dry-DSR (drilled) than under transplanted conditions because the conditions immediately after sowing under dry-DSR (drilled) are most conducive to weed growth (Nayak and Manjappa 2012). Thus, weed management is critical for realizing optimal yield of DSR in particular and rice established by different methods in general.

A review of insect pests of rice in Karnataka was made recently (Gowda and Gubbaiah 2011). However, no such effort, to our knowledge, has

Table 1. Rainfed and irrigated rice growing area, districts, and agro-ecosystems in Karnataka, India.

Agro-ecosystem	Districts	Rice area
		ha
Northern Maidan area (zones 2 and 3)	Koppal, Ballary, Gulberga (part), Raichur, Yadgiri	403,563 (irrigated: 400,000; rainfed: 3,563)
North and northeastern transitional area and coastal area (zone 8)	Dharwad, Bidar, Belgam, Haveri, Gulberga (part), and Uttara Kannada (part)	212,461 (irrigated: 30,000; rainfed: 182,461)
Southern Maidan area (zones 4, 5, and 6)	Bangalore (urban and rural); Ramanagara; Kolar; Chikballapur; Tumkur; Chitradurga; Davanagire; Hassan (part); Mysore; Mandya; Chnagara	625,000 (irrigated: 502,000; rainfed: 123,000)
Southern transitional area (zone 7)	Shimoga (part), Hassan (part)	
Hilly area (zone 9)	Chikmagaluru, Kodagu	
Coastal area (zone 10)	Udipi, Dakshina Kannada, Uttara Kannada (part)	

[a] Source: Rajanna 2013.

made to review weeds and weed management of rice in Karnataka. Because weed management is critical to obtain optimal rice productivity, this review was made with an objective of analyzing published research findings on weeds and weed management in rice in Karnataka, identifying improved weed-management technologies for delivery to farmers, and suggesting research needs. A literature survey was made. Research articles published on the selected subject during the past 30 yr were studied, analyzed, and a summary is presented in this review.

Weeds of Rice in Karnataka

Some 369 weed species were listed as major weeds in Karnataka (Sastry et al. 1980). Of these, this review encountered 98 weed species from rice fields in Karnataka (Table 2). Species occurrence varied with variation in the type of rice culture, soil type, hydrology, cultural practices, and irrigation patterns at different locations. Wide variation in the macro and micro environmental conditions in which rice is grown in Karnataka is known (Rajanna 2010).

Among the 98 weed species encountered in this literature review, the 10 most commonly reported weed species of rice in Karnataka were junglerice [*Echinochloa colona* (L.) Link], smallflower umbrella sedge (Cyperus difformis L.); rice flatsedge (*Cyperus iria* L.); eclipta [*Eclipta prostrata* (L.) Hassk.]; waterprimrose (*Ludwigia parviflora* Roxb.); toothcup (*Rotala verticillaris* Linn.); globe fringerush (*Fimbristylis miliacea* (L.) Vahl); European pepperwort (*Marsilea quadrifolia* L.); spilanthes [*Spilanthes acmella* (*L.*) *Murr.*]; and tropic ageratum (*Ageratum conyzoides* L.). The dominant species varied with the method of rice establishment. As more work was done on transplanted rice, greater numbers of weeds were reported in transplanted rice.

The All India Coordinated Project on Weed Management (AICRIP) reported (1) smallflower umbrella sedge, monochoria [*Monochoria vaginalis* (Burm. f.) Kunth], panicum (*Panicum tripheron* Schultes), toothcup, and smooth barnyardgrass (*Echinochloa glabrescens* Hk. f. ex Koss.) in kharif rice; and (2) smallflower umbrella sedge, bulrush (*Scirpus* sp.), monochoria, white kyllinga (*Kyllinga nemoralis* [J.R. & G. Forst] Ddandy ex Hutchins. & Danz.), and junglerice in rabi-season rice as major weeds in Karnataka (DWSR 2010). Cyperaceae plants were also found as weeds, particularly in the rice fields of Karnataka (Prasad and Singh 2002).

The AICRIP survey in Mandya, Hassan, Shimoga, Mysore, Chikkamagalur, Dharwad, Tumkur, Dakshina Kannada, and Udupi districts of India (DRR 2011) revealed that weed infestation was medium to low. In Chikkamagalur district, the major weeds observed were pepperwort (*Marsilea* spp.), waterprimrose (*Ludwigia* spp.), Benghal dayflower (*Commelina benghalensis* L.), and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]. Weedy rice (*Oryza sativa* L.) (<1%) was observed in Mudigere taluk. In Dharwad, the major weed flora included junglerice, sedges, and bermudagrass (*Cynodon* sp.), and weedy rice (<1) was also observed in upland dry-DSR. The Directorate of Rice Research (DRR 2011) also found that in

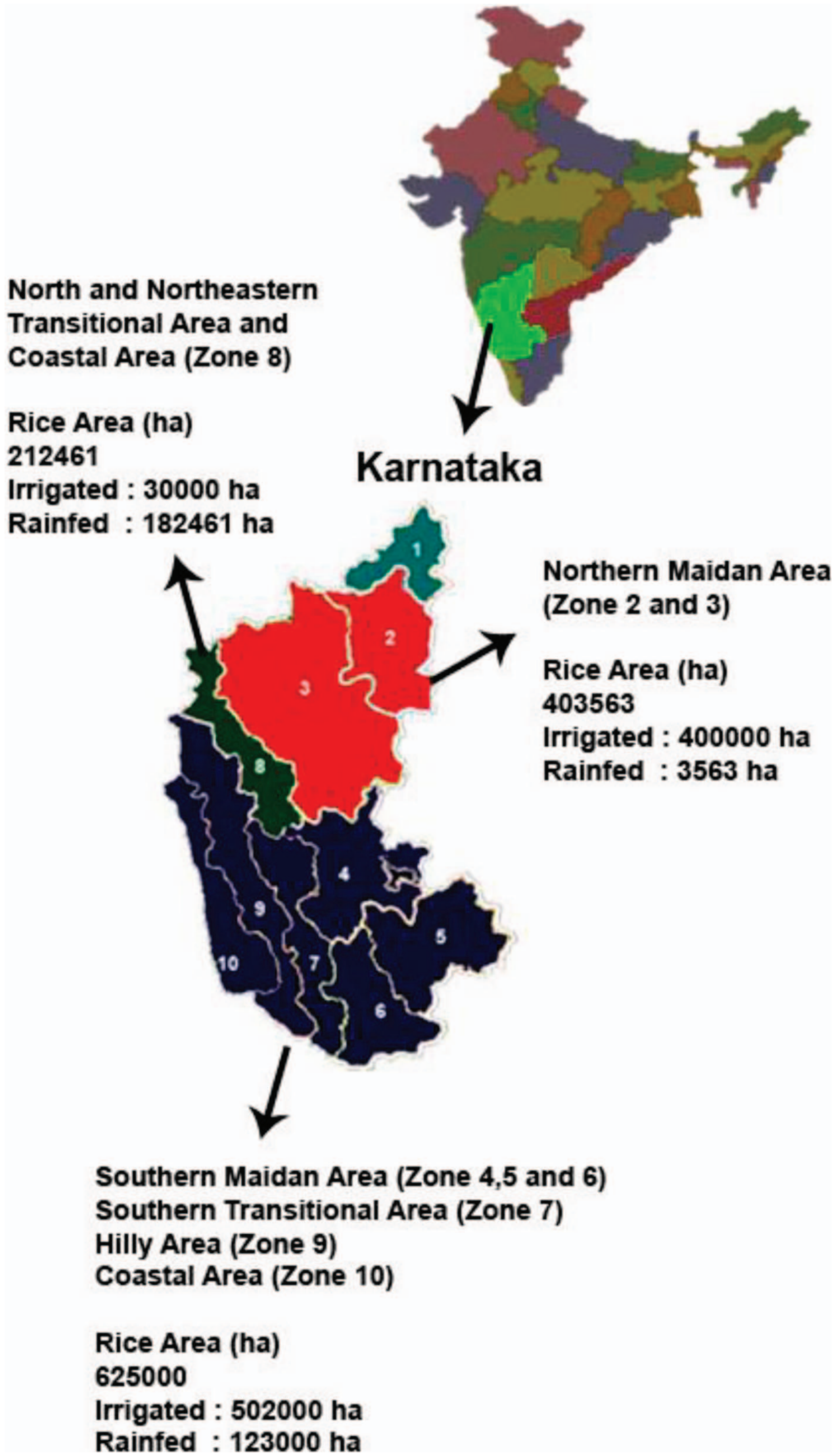

Figure 1. Location of Karnataka in India and the various rice-producing regions of Karnataka.

Table 2. Most commonly reported weeds under different methods of rice establishment in Karnataka, India.[a,b]

Common name	Scientific name	Family	Rice[c]	TPR	Dry-DSR	Wet-DSR
Junglerice	*Echinochloa colona* (L.) Link	Poaceae	1	2	3	—[d]
Smallflower umbrella sedge	*Cyperus difformis* L.	Cyperaceae	2	—	4	—
Rice flatsedge	*Cyperus iria* L.	Cyperaceae	3	1	3	—
Eclipta	*Eclipta prostrata* (L.) L.	Asteraceae	3	3	3	1
Waterprimrose	*Ludwigia parviflora* Roxb.	Onagraceae	4	4	6	—
Indian toothcup	*Rotala verticillaris* Linn.	Lythraceae	5	5	6	7
Globe fringerush	*Fimbristylis miliacea* (L.) Vahl	Cyperaceae	6	—	6	—
European pepperwort	*Marsilea quadrifolia* L.	Marsileaceae	6	—	6	—
Spilanthus	*Spilanthus acmella* Murr.	Asteraceae	7	5	3	—
Tropic ageratum	*Ageratum conyzoides* L.	Asteraceae	6	3	1	—
Torpedograss	*Panicum repens* L.	Poaceae	6	—	7	—
Benghal dayflower	*Commelina benghalensis* L.	Commelinaceae	9	5	2	—
Bermudagrass	*Cynodon dactylon* (L.) Pers.	Poaceae	9	5	4	—
Purple nutsedge	*Cyperus rotundus* L.	Cyperaceae	9	3	2	—
Sessile joyweed	*Alternanthera sessilis* (L.) R. Br. ex DC.	Amaranthaceae	10	—	7	2
Celosia	*Celosia argentea* L.	Amaranthaceae	10	3	2	—
Pilose sedge	*Cyperus pilosus* L. (Synonym. *Cyperus procerus*)	Cyperaceae	10	4	5	—
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	Poaceae	10	—	7	5
Glinus	*Glinus oppositifolia* (L.) A. DC.	Aizoaceae	10	—	7	—
Smooth barnyardgrass	*Echinochloa glabrescens* Munro ex Hook. f.	Poaceae	11	—	7	—
Scirpus	*Scirpus roylei* (Nees) Parker	Cyperaceae	11	—	7	—
Southern crabgrass	*Digitaria ciliaris* (Retz.) Koel.	Poaceae	12	—	5	4
Panicum	*Panicum dilatatum* Steud.	Poaceae	12	6	6	7
Panicum	*Panicum trypheron* Schult.	Poaceae	12	—	6	—
Common purslane	*Portulaca oleracea* L.	Portulacaceae	12	5	6	—
Bulrush	*Scirpus articulates* L.	Cyperaceae	12	—	7	—
Dopatrium	*Dopatrium junceum* (Roxb.) Buch.-Ham.	Scrophulariaceae	—	6	6	7
Ricegrass paspalum	*Paspalum scrobiculatum* L.	Poaceae	—	4	6	7
Yellow nutsedge	*Cyperus esculentus* L.	Cyperaceae	—	6	—	5
Swollen fingergrass	*Chloris barbata* Sw.	Poaceae	—	6	—	—
Watergrass	*Bulbostylis barbata* (Rottbll) C. B. Clarke	Cyperaceae	—	6	—	6
Bristly starbur	*Acanthospermum hispidum* DC.	Asteraceae	—	7	—	—
Monochoria	*Monochoria vaginalis* (Burm. f.) Kunth	Pontederiaceae	—	7	—	—
Large crabgrass	*Digitaria sanguinalis* (L.) Scop.	Poaceae	—	7	—	5
Cyanotis (Bayer code: CYBAX)	*Cyanotis axillaris* (L.) D. Don	Commelinaceae	—	7	—	3
Croton	*Croton bonplandianum* Baill.	Euphorbiaceae	—	7	—	—
Asiatic pennywort	*Centella asiatica* (Linn.) Urban	Apiaceae	—	7	—	—
Indian jointvetch	*Aeschynomene indica* L.	Fabaceae	—	—	—	3
Cleome	*Cleome chelidoni* L. f.	Capparidaceae	—	—	—	7
Early watergrass	*Echinochloa oryzoides* (Ard.) Fritsch	Poaceae	—	—	—	7
Toothcup	*Rotala densiflora* (Roth) Koehne	Lythraceae	—	—	—	7

[a] Abbreviations: TPR, transplanted rice; Dry-DSR, dry direct-seeded rice and aerobic rice; Wet-DSR, wet direct-seeded rice.

[b] Ranking based on the more-frequently reported (1) to less-frequently reported (12) in the reviewed research papers. The same ranking represents an equal number of reports in the reviewed research papers.

[c] Rice for all establishment methods.

[d] Indicates it was reported.

Turverekere and Tumkur taluks of Tumkur district, along with commonly occurring barnyardgrass, weedy rice (up to 2%) occurred. Weedy rice is emerging as a major weed problem in several Asian countries (Baki et al. 2000; Chauhan 2013), and hence, the spread of weedy rice in Karnataka needs to be checked by undertaking measures to prevent its dissemination by seed (Rao and Moody 1990) and other methods (Chauhan 2013). In Mysore district, barnyardgrass, sedges, pepperwort, and dayflower (*Commelina* sp.) were medium to low in all the surveyed places, whereas in Chamrajnagar,

Table 3. Effective herbicides for managing weeds in rice seedling nurseries in Karnataka, India.[a]

Herbicide	Dosage rate	Time of application	Reference
	g ai ha^{-1}		
(a) Butachlor plus propanil mixture (b) Cyhalofop	(a) 2,062 (b) 75	12 DAS	Jayadeva et al. 2002
Bispyribac-sodium	40	PRE	Masthana Reddy et al. 2012a
Bensulfuron plus pretilachlor	600	PRE	Denesh et al. 2012; Ramachandra et al. 2012a
Butachlor	1,250	POST	Denesh et al. 2012; Ramachandra et al. 2012a
Pretilachlor plus safener	300	PRE	Denesh et al. 2012; Ramachandra et al. 2012a
Pyrazosulfuron	25	POST	Denesh et al. 2012; Ramachandra et al. 2012a
Anilofos	90	3 DAS	Anwarullah 1998
Butachlor	600	1 DAS	Anwarullah 1998
(a) Butachlor (b) Fluchloralin	(a) 1,205 (b) 1,000	10 DAS	Channabasavanna and Setty 1993

[a] Abbreviations: DAS, days after seeding.

overall weed infestation was low and was mainly dominated by grasses and sedges.

Yield Loss from Weeds

In India, weeds were reported to contribute to crop yield losses as high as 37% (22.7% in the rabi-season (October to the end of December) and 36.5% in kharif (June to the end of September) and summer (January to May) seasons (DWSR 2011). Monocotyledonous weed density was inversely correlated with crop yield, whereas the correlations between transplanted rice yield and dicotyledonous and sedge weed densities were not significant (Janardhan and Muniyappa 1994b). However, no systematic work was done in Karnataka on the actual losses caused by weeds in rice established by different methods.

Methods of Weed Control

Most studies conducted in Karnataka were based on herbicides. However, a few weed management studies were conducted involving other methods of weed control.

Weed Control in Rice Seedling Nurseries. Rice nurseries are infested with grasses, broadleaf weeds, and sedges that smother rice seedlings and pose a threat when transplanted into the main rice field, resulting in an increase in the cost of cultivation and lower yields (Anwarullah 1998; Rao and Moody 1987).

The herbicides that were found to be effective in rice seedling nurseries were butachlor plus propanil mixture, cyhalofop, bispyribac-sodium, bensulfuron plus pretilachlor, butachlor, pretilachlor plus safener, anilophos, and fluchloralin (Table 3). Butachlor and fluchloralin applied 0 d after seeding (DAS) reduced rice seedling populations and plant height and dry weight compared with a control. Seedling counts declined 68% with both herbicides applied at 0 DAS. Hence, treatments with herbicides at 10 DAS in the rice seedling nursery were suggested (Channabasavanna and Setty 1993). Anwarullah (1998) reported that butachlor, applied within 24 h of sowing, and anilophos, applied 3 DAS, did not have phytotoxic effects on rice, and the germination percentage was higher.

Weed control in rice seedling nursery with effective herbicides (butachlor 0.60 kg ai ha^{-1} PRE at 1 DAS and anilophos 0.09 kg ai ha^{-1} at 3 DAS) was found to be economical (Anwarullah 1998). Lower broadleaf weed populations were recorded with hand-weeding compared with other treatments (Masthana Reddy et al. 2012a). In a recent study (Denesh et al. 2012), pretilachlor plus safener 300 g ai ha^{-1}, bensulfuron plus pretilachlor at 600 g ai ha^{-1}, pyrazosulfuron at 25 g ai ha^{-1}, and butachlor at 1,250 g ai ha^{-1} applied at 3 DAS lowered weed density and recorded higher weed-control efficiency than the unsprayed control, when observed at 21 DAS. The cost of those herbicides used for weed control in the rice seedling nursery ranged from Rs. 136 (U.S.$2.19) to Rs. 235 (U.S.$3.79) 750 m^{-2} of rice nursery, which was needed to transplant 1 ha of area (Denesh et al. 2012).

Weed Control in Rice. Proper weed management is essential for realizing the potential productivity of rice and to sustain farmers' income because weeds in rice are known to cause enormous losses to rice production in terms of both quantity and quality (Rao and Ladha 2013).

Preventive Measures. Prevention is the best way to manage weeds (Rao and Ladha 2011). However, studies on preventive measures are very limited in Karnataka. In India, the maximum weed seed permitted are 20 kg^{-1} of certified rice seed (CSCB 2013). The maximum number of objectionable weeds (wild rice [*Oryza sativa* L. var. *fatua* Prain]) seed permitted is 5 kg^{-1} of rice seed. A survey conducted to determine the quality of rice seeds used by farmers in the Bhadra command area, Karnataka, showed that 84% of the samples met minimum certification standards for weed seeds and 100% (all the samples) for standard germination percentage (Prasad et al. 1991). This survey indicates a need to quantify the weed species that contaminate rice seed to prevent their dissemination and avoid the spread of tough-to-control weeds, such as weedy rice, which are known to spread by crop seeds (Baki et al. 2000; Chauhan 2013; Delouche et al. 2007; Rao and Moody 1990).

Mechanical Weeding. In transplanted rice, mechanical weeding provided the highest yield (Agasimani et al. 2008). In transplanted rice, four times mechanical cono-weeding (i.e., using manually operated cono-weeder for intercultivation) at 10-d intervals starting from 10 d after transplanting (DAT) was found to be effective in weed control with a higher grain yield and benefit : cost (B : C) ratio (Ramachandra et al. 2012c). During recent farmer field surveys by the authors, farmers were observed using a cycle-weeder for intercultivating rice during the early stages of dry-DSR.

The system of rice intensification (SRI) is one water-saving technology that is being popularized by officials to help farmers overcome the present water crisis (Gujja and Thiyagarajan 2009). Seedling age and weed management practices have an important role under limited water conditions in the SRI production system. In SRI, planting of seedlings that are too young (8 to 10 d) is difficult and planting of 10- or 15-d-old seedlings did not differ significantly in the grain yield of rice (Ramachandra et al. 2012b). Cono-weeder use and incorporation of weeds using a cono-weeder are important components of the SRI method. Mechanical weeding with a cono-weeder four times (at 10, 20, 30, and 40 DAT) was found to be an economical method of weed management (Ramachandra et al. 2012b). However, cono-weeding in SRI entails a lot of drudgery, and a person has to walk a long distance for cono-weeding in rice. Probably, the development and popularization of a power-operated cono-weeder will be a better alternative.

A survey conducted on farmers' practices used by dry-DSR (drilled) farmers in the hill region of Uttara Kannada district (Nayak and Manjappa 2012) revealed that only intercultivation was used by 36, 29, and 38% of the farmers; intercultivation in combination with hand-weeding was reported to be used by 14, 18, and 25%, and intercultivation in combination with herbicides and hand-weeding was used by 9, 12, and 0% of the farmers in upland, midland, and lowland regions, respectively.

Hand-Weeding. Hand-weeding was found to be effective in many of the studies, even though it is time-consuming, tedious, and costly. Two hand-weedings at 20 and 40 d after seeding/transplanting was found optimal for transplanted rice (Jayadeva et al. 2009; Manjunatha et al. 2013), wet-DSR (Jayadeva and Nanjappa 1996; Kenchaiah et al. 2009), and dry-DSR (Sanjay et al. 2012), with a B : C ratio of 3.1 (Angadi et al. 1993a). In aerobic rice, two hand-weedings at 20 and 45 DAS (Gowda et al. 2010) or at 20 and 40 DAS (Gowda et al. 2009; Madhukumar et al. 2012) were found optimal in managing weeds.

A survey conducted on practices used by transplanted rice farmers in the hill region of Uttara Kannada district (Nayak and Manjappa 2012) revealed that hand-weeding alone was used by 56%, 61%, and 63% of transplanted rice farmers and 27%, 23%, and 25% of the dry-DSR (drilled) farmers in upland, midland, and lowland regions, respectively.

Crop Competitiveness and Plant Population. Efforts to evaluate crop cultivars as a component of weed management are limited in Karnataka. In a study in the Upghat region of northern Karnataka, grain yield was observed to increase significantly with an increased number of weedings and with increased N–P–K rate but was not affected by plant population (Pujari et al. 1989). Similarly, Angadi et al. (1993a) also found increased grain yield with an increased number of weedings and with increased N–P–K rate (50, 75, or 100% of the recommended N–P–K fertilizer rate of 100–50–50 kg N–P–K ha^{-1}) but not with increased rice plant population (at 100 or 75% of the recommended plant population density of 500,000 plants ha^{-1}).

Smother/Intercrops. Smother crops, such as love-lies-bleeding (*Amaranthus caudatus* L.) and dill (*Anethum graveolens* L.), were found to be effective in reducing weed growth without affecting the productivity of aerobic rice (Umesha Naika et al. 2009). Intercropping rice with sunn hemp (*Crotalaria juncea L.*), cowpea [*Vigna unguiculata* (L.) Walpers], soybean [Glycine max (L.) Merr.], and prostrate sesbania (*Sesbania rostrata* Brem.), and combining with one intercultivation at 15 d after emergence (DAE) and one hand-weeding at 40 DAE, was found to be effective in managing weeds (Angadi and Umapathy 1997). The tested intercrops could replace butachlor application when combined with one intercultivation. Among the intercrops tested, cowpea had better weed-smothering ability.

Use of Weeds as Green Manure for Rice. One of the ways to manage weeds is to use them wherever feasible. The use of voluntary weeds producing large biomass as an alternate organic supply of nutrients to rice was tested by Denesh and Prasad (2012), who found that leaf manures of siamweed [*Chromolaena odorata* (L.) King & H.E. Robins.], ragweed parthenium (*Parthenium hysterophorus* L.), and senna (*Senna* spp.) at 10 t ha^{-1} can supply 25% of crop nutrient requirement. The narrow C : N ratio (15.2 to 17.7) of applied weed biomass helped in the immediate release of nutrients from biomass for the use of rice plants as a result of mineralization (Kolhe and Brambri 2005; Krishnamurthy et al. 2005). The increased supply of nutrients and improved water-holding capacity of soil from leaf manure in weeds have resulted in increased grain yield of aerobic rice. Hence, weed biomass can be conveniently used to improve rice-crop growth and to supplement nutrients supply by quickstick [*Gliricidia sepium* (Jacq.) Kunth ex Walp] and farmyard manure (FYM), whose availability is decreasing and becoming more costly. The cost of weed green manure (from other fields/waste lands) was Rs. 1,500 (U.S.$25) per ton compared with Rs. 1,700 (U.S. $28.30) for quickstick and Rs. 5,300 (U.S. $88.30) per ton for FYM.

In Karnataka, ragweed parthenium is a major weed, and it has also started invading rice fields recently (Mahadevappa 1999; Sushilkumar and Varshney 2010). A study by Biradar et al. (2006) on the nutrient content of ragweed parthenium collected from different habitats (irrigated and rainfed fields and waste lands) in Karnataka indicated that the average N–P–K content of ragweed parthenium was 2.55–0.44–1.23%. The weed also contained substantial amounts of Zn (13.9 ppmw), Mn (161.2 ppmw), Fe (528.3 ppmw), and Cu (9.0 ppmw). The habitat from which the samples were collected showed a significant correlation with the N and K content of ragweed parthenium. The effects of ragweed parthenium, alone (5 t ha^{-1}) or in combination with quickstick (2.5 t ha^{-1}), FYM (6.0 t ha^{-1}), poultry manure (1.0 t ha^{-1}), or vermicompost (1.0 t ha^{-1}), and N–P–K rate (75–37.5–37.5, 112.5–56.25–56.25, or 150.0–75.0–75.0 kg ha^{-1}) on the performance of rice (cv. BPT-5204) and on soil properties were studied. It was observed that ragweed parthenium significantly enhanced grain yield, but the highest mean grain yield was obtained when ragweed parthenium was applied with FYM. Soil organic C content, total bacterial population, and populations of phosphorus-solubilizing bacteria were markedly increased by the organic amendments.

A study conducted to use siamweed as a green manure in paddy fields revealed that the performance of siamweed was found to be on par with that of compost application in terms of organic carbon content, the available N status of the soil, and yield components (Kumar et al. 2009). The highest rice grain yield and the maximum gross and net returns were realized with siamweed used as green leaf manure plus 100% of the recommended dose of fertilizer (RDF) (75–75–87.5 kg N–P–K ha^{-1}) (Manjappa and Kataraki 2004). The application of 100% RDF resulted in significantly higher grain and straw yield, which was on a par with the combined use of 50% RDF plus 5.0 t compost of siamweed (Ramachandra et al. 2008).

Weeds are used to feed cattle by some rice farmers in Karnataka. Smooth barnyardgrass, a major weed of rice, was observed to be fed to cattle (DWSR 2013).

Herbicides for Weed Management. Several herbicides were found effective in rice established by different methods (Table 4). These herbicides were (1) bensulfuron plus pretilachlor and pyrazosulfuron in aerobic rice; (2) pendimethalin, thiobencarb, molinate plus propanil, molinate, bispyribac-sodium, cyhalofop plus chlorimuron plus metsulfuron, fenoxaprop plus chlorimuron plus metsulfuron, and fenoxaprop plus ethoxysulfuron in dry-DSR; (3) anilofos plus 2,4-D, thiobencarb, anilofos, pendimethalin, pretilachlor, acetochlor, azimsulfuron plus metsulfuron, bispyribac-sodium, butachlor, cinosulfuron, oxadiazon, and quinclorac in transplanted rice; and (4) anilofos, butachlor plus halosulfuron, butachlor plus safener, oxyfluorfen, pretilachlor plus safener, and butachlor in wet-DSR. Several of these herbicides were reported to be effective in the respective establishment methods in India (Rao 2010) and other Asian countries (Chauhan 2012; Rao and Ladha 2013; Rao and Nagamani 2013; Rao et al. 2007; Weerakoon et al. 2011). Herbicide use could save up to 75% energy input in weed management and give 20% more energy output than hand-weeding (Prasad et al. 1992).

Mutanal et al. (1998) observed better control of monocot weeds with butachlor application. Pretilachlor applied alone was more effective against grasses but less effective against sedges. Bensulfuron was found to be more effective against sedges than other weeds. Masthana Reddy et al. (2012b) reported that the combination granular product of bensulfuron (0.6%) plus pretilachlor (6.0%) was effective on both grasses and broadleaf weeds in transplanted rice. Pyrazosulfuron at 25 g ai ha^{-1} alone was unable to control heavily infested weeds, and it failed to control goosegrass [*Eleusine indica* (L.) Gaertn.] (Sunil and Shankaralingappa 2014).

A survey conducted on practices used by farmers in the hill region of Uttara Kannada district (Nayak and Manjappa 2012) revealed that herbicides alone were used by 28, 30, and 28% of the farmers for transplanted rice and by 14, 18, and 13% of the farmers for dry-DSR (drilled) in upland, midland, and lowland regions, respectively.

A survey by DRR (2011) in Karnataka revealed that, to manage weeds, farmers used herbicides, such as butachlor (granules) at 1.25 to 1.5 kg ai ha^{-1} in Chikmagaluru district; Butachlor at 1 kg ai ha^{-1} mixed with sand in Dharwad; butachlor, bispyribac-sodium, and pyrazosulfuron in Mysore; and butachlor and a granular formulation of bensulfuron plus pretilachlor in the Chamrajnagar district. In Dharwad, the method used by farmers to remove weedy rice was hand-plucking during the panicle-initiation stage. In Dakshina kannada and Udupi, farmers demanded new molecules of herbicide to control weed infestations and a desire for new varieties suitable for coastal regions was expressed during the survey.

Integrated Weed Management. Integrated weed management (IWM) is a science-based, decision-making process that coordinates the use of macroenvironmental and microenvironmental information, weed biology and ecology, and all available technologies to control weeds by the most economical and ecologically viable methods (Rao and Nagamani 2010, 2013).

Integration of herbicides with hand-weeding or intercultivation was found to be effective in rice established by different methods (Table 5). Integration of herbicides with hand-weeding (Jayadeva et al. 2011a) or intercultivation (Sunil et al. 2011; Umesha Naika et al. 2009) or both (Kusuma 2007) was found to be more effective in aerobic rice. Integration of 12-d-old seedling transplanted with six intercultivations was suggested (Hanumanthappa et al. 2009). Intercropping of aerobic rice with coriander (*Coriandrum sativum* L.) coupled with intercultivation at 30 and 50 DAS was found to be effective in managing weeds (Umesha Naika et al. 2009). Integration of hand-weeding with herbicides was effective in dry-DSR (Angadi et al. 1993b; Angadi and Umapathy 1997; Mahadevaswamy and Nanjappa 1991; Munegowda et al. 1993;). In rainfed dry-DSR, the highest grain yield was obtained with the farmers' practice of two interrow cultivations plus two hand-weedings and mixed cropping with sesbania [*Sesbania bispinosa* (Jacq.) W. Wight (Syn. *Sesbania aculeata* Poir)] (Angadi et al. 1993b). In wet-DSR, integration of pretilachlor plus safener with hand-weeding (Sanjay et al. 2006a; 2008) or hand weeding and a cono-weeder (Jagadeesha et al. 2009) was effective. Kusuma (2007) reported that the 50% dose of pyrazosulfuron (i.e., 12.5 g ai ha^{-1}) along with hand-weeding and intercultivation four times at 15, 30, 45, and 60

Table 4. Effective herbicides for managing weeds under different methods of rice establishment in Karnataka, India.[a]

Rice establishment method	Herbicide	Dosage rate	Time of application	Reference
		g ai ha^{-1}		
Aerobic rice	Bensulfuron plus pretilachlor	60 plus 600	PRE	Madhukumar et al. 2012
Aerobic rice	Pyrazosulfuron	30	PRE	Gowda et al. 2009
Aerobic rice	Pyrazosulfuron	30	POST	Gowda et al. 2010
Dry-DSR (drilled)	Pendimethalin	2,000	Early POST	Sharanappa et al. 1994a
Dry-DSR (drilled)	Thiobencarb	2,000	Early POST	Sharanappa et al. 1994b
Dry-DSR (drilled); upland	(a) Molinate plus propanil (b) Molinate	(a) 1,800–2,160 (b) 3,840	POST	Prasad et al. 1990
Dry-DSR; upland	Bispyribac-sodium	25	20 DAS	Prasad et al. 2012a
Dry-DSR; upland	Cyhalofop plus chlorimuron plus metsulfuron	90 plus 4	20 DAS	Prasad et al. 2012a
Dry-DSR; upland	Fenoxaprop plus chlorimuron plus metsulfuron	60 plus 4	20 DAS	Prasad et al. 2012a
Dry-DSR; upland	Fenoxaprop plus ethoxysulfuron	60 plus 15	20 DAS	Prasad et al. 2012a
TPR	Thiobencarb	2,000	1 DAT	Purushotham et al. 1990
TPR	(a) Anilofos (b) Pendimethalin	(a) 400–600 (b) 2,000	PRE	Janardhan and Muniyappa 1994a
TPR	(a) Pendimethalin (b) Pendimethalin (c) Anilofos (d) Pretilachlor	(a) 2,000 (b) 1,750 (c) 600 (d) 1,000	PRE	Janardhan and Muniyappa 1994b; Janardhan et al. 1999a,b
TPR	Acetochlor	75	0–3 or 6–8 DAT	Biradar et al. 2002
TPR	Anilofos	600	7 or 10 DAT	Munegowda et al. 1990
TPR	Anilofos plus 2,4-D (ethyl ester)	700, 840, and 900	4 DAT	Nagaraju and Kumar 2009
TPR	Anilofos at 0.60 kg	300–450	6 DAT	Kumar and Basavaraj 1996
TPR	Azimsulfuron plus 0.2% surfactant plus metsulfuron	30 plus 2	19 DAT	Jayadeva et al. 2009; 2010, 2011b
TPR	Bensulfuron plus pretilachlor	60 plus 600	3 DAT	Hanumanthappa et al. 2012; Masthana Reddy et al. 2012b;
TPR	Bensulfuron plus pretilachlor		5 DAT	Masthana Reddy et al. 2012b
TPR	Bispyribac-sodium	25	20 DAT	Manjunatha et al. 2013
TPR	Butachlor	1,500	2 DAP	Munegowda et al. 1990
TPR	Butachlor	1,500	PRE	Agasimani et al. 2008
TPR	Butachlor	1,250	PRE	Jayadeva et al. 2011b
TPR	Butachlor	1,000	3 DAT	Kenchaiah et al. 2006
TPR	Butachlor	1,205	PRE	Prasad et al. 1992
TPR	Cinosulfuron	20	3 DAT	Kenchaiah et al. 2006
TPR	Butachlor	1,500	1 DAT	Jayadeva et al. 2004
TPR	Oxadiazon	500	PRE	Prasad et al. 1992
TPR	Pendimethalin	2,000	PRE	Prasad et al. 1992
TPR	Pretilachlor	625	1 DAT	Jayadeva et al. 2004
TPR	Pretilachlor	1,000	PRE	Janardhan et al. 1999b
TPR	Quinclorac	187	3 DAT	Masthana Reddy et al. 2006
TPR	Thiobencarb	2,000	PRE	Prasad et al. 1992
TPR	Triasulfuron	10	PRE	Sajjam et al. 2013
Wet-DSR	Anilofos	450	1 DBS	Jayadeva et al. 1997
Wet-DSR	Anilofos	450	3 DAS	Madhu et al. 1996
Wet-DSR	Butachlor plus halosulfuron	1,000 plus 15	6 DAS	Pattar et al. 2005
Wet-DSR	Butachlor plus safener	1,500	PRE	Madhu and Nanjappa 1997
Wet-DSR	Butachlor plus safener	1,000	PRE	Prakash et al. 1995

Table 4. Continued.

Rice establishment method	Herbicide	Dosage rate	Time of application	Reference
Wet-DSR	Butachlor plus safener	1,500	3 DAS	Madhu et al. 1996; Jayadeva et al. 1997
Wet-DSR	Butachlor plus safener	1,250	3 DAS	Jayadeva and Bhairappanavar 2002
Wet-DSR	Clomazone plus propanil	750	15 to 20 DAS	Kenchaiah et al. 2009
Wet-DSR	Oxyfluorfen	250	PRE	Prakash et al. 1995
Wet-DSR	Pretilachlor plus safener	400	3 DAS	Kenchaiah et al. 2009
Wet-DSR	Pretilachlor plus safener	300	3 DAS	Jayadeva and Nanjappa 1996
Wet-DSR; rainfed	Butachlor	1,000	1, 3, 5, and 7 DAS	Mutanal et al. 1998
Wet-DSR; rainfed	Anilofos	400	7 DAS	Mutanal et al. 1997

[a] Abbreviations: Dry-DSR, dry direct-seeded rice; DAS, days after seeding; DAT, days after transplanting; TPR, puddled transplanted rice; DAP, days after planting; DBS, days before seeding; wet-DSR, wet direct-seeded rice.

DAS was the best way to combat weeds in aerobic rice.

Sunil and Shankaralingappa (2014) observed that, in aerobic rice, application of a regular dose of fertilizer (100–50–50–20 kg N–P–K–$ZnSO_4$ ha^{-1}) plus FYM (10 t ha^{-1}) plus biofertilizer (*Azospirillum* and *Bacillus megaterium* at 4 kg ha^{-1} each mixed with 80 kg of FYM) plus $FeSO_4$ (12.5 kg ha^{-1}) plus IWM (PRE application of pyrazosulfuron at 25 g ai ha^{-1} plus one hand-weeding at 20 DAS plus first intercultivation at 25 DAS and subsequent intercultivations at 15-d intervals up to panicle initiation) practices provided higher growth, yield parameters, and yield.

A survey conducted on practices used by farmers in the hill region of Uttara Kannada district (Nayak and Manjappa 2012) revealed that IWM (herbicide followed by hand-weeding) was followed by 22, 9, and 9% of farmers of transplanted rice and by 9, 12, and 0% of farmers for dry-DSR (drilled) in upland, midland, and lowland regions, respectively.

Economics of Weed Management. The total cost of cultivation of rice in Karnataka increased from Rs. 9008.95 (U.S.$145) in pre-World Trade Organization (WTO) to Rs. 23,482.68 (U.S.$378) ha^{-1} in the post-WTO period because of the increase in the quantity of inputs used and their prices (Kollurmath et al. 2008). Hence, it is essential that effective weed management be economical to benefit farmers financially.

During the 1990s, PRE application of oxadiazon at 0.5 kg ai ha^{-1}, butachlor at 1.25 ai ha^{-1}, pendimethalin at 2.0 kg ai ha^{-1}, or thiobencarb at 2.0 kg ai ha^{-1} provided yields comparable with those of hand-weeding and were cheaper than hand-weeding (Prasad et al. 1992). Recently, the use of herbicides (butachlor plus hand-weeding or chlorimuron plus metsulfuron) resulted in lowering the cost of production compared with hand-weeding (Sanjay et al. 2012). Farmers of Mandya district in Karnataka reported using pretilachlor plus bensulfuron to manage weeds in transplanted rice because it costs (Rs.1,000 ha^{-1} = U.S.$16.66 ha^{-1}) less than hand-weeding (cost: Rs.3,000 ha^{-1} = U.S.$50 ha^{-1}) (DWSR 2013).

The cost of herbicides, including application cost, was cheaper with pyrazosulfuron (Rs.1,240 ha^{-1} = U.S.$20 ha^{-1}) and cyhalofop plus chlorimuron plus metsulfuron (Rs.2,870 ha^{-1} = U.S.$48) than hand-weeding (Rs.6,750 ha^{-1} = U.S.$109 ha^{-1}). Thus, herbicide usage could save weeding cost to an extent of Rs.3,880 (U.S.$63) to Rs.5,510 (U.S.$89) ha^{-1} over hand-weeding (Prasad et al. 2012b) in dry-DSR (upland). In wet-DSR, the use of pyrazosulfuron followed by one hand-weeding (45 DAS/P, Rs.2,400 ha^{-1} = U.S.$39 ha^{-1}) and the use of a cono-weeder (15, 25, 35 DAS/P, Rs.2,000 = U.S.$32 ha^{-1}) were cheaper than hand-weeding (Rs.6,200 ha^{-1}) and thus saved on weeding costs by Rs.3,800 (U.S.$63) to 4,200 (U.S.$68) ha^{-1} (Prasad et al. 2012a).

Thus, several studies have shown that the use of herbicide either alone or in combination with hand-weeding is an economical method of managing

Table 5. Effective integrated weed management options for managing weeds in rice under different methods of establishment.[a]

Rice establishment method	Herbicide	Dosage rate	Time of application	Followed by	Reference
		g ai ha^{-1}			
Aerobic rice	Butachlor	1,000	Early POST	Intercultivation at 30 and 50 DAS	Umesha Naika et al. 2009
Aerobic rice	Pyrazosulfuron	25	5 DAS	Two HWs: 20 and 40 DAS	Jayadeva et al. 2011a
Aerobic rice	Bensulfuron plus pretilachlor	60 plus 600	3 DAS	One intercultivation at 40 DAS	Sunil et al. 2010, 2011; Madhukumar et al. 2012
Aerobic rice	Pyrazosulfuron	12.5	POST	HW and intercultivation four times at 15, 30, 45, and 60 DAS	Kusuma 2007
Dry-DSR (drilled); upland	Pendimethalin	1,500 and 1,000	8–12 DAS	HW at 30 DAS	Munegowda et al. 1993
Dry-DSR (drilled)	(a) Oxyfluorfen (b) Oxadiazon	(a) 500 or 250 (b) 1,000–750	PRE	Intercultivation once at 45 DAS	Mahadevaswamy and Nanjappa 1991
Dry-DSR (drilled); upland	Pendimethalin	1,500 and 1,000	8–12 DAS	1 HW at 30 DAS	Munegowda et al. 1993
Dry-DSR; rainfed; lowland	Butachlor	1,000	PRE	1 HW at 30 DAS	Angadi and Umapathy 1997
Dry-DSR; rainfed	Pyrazosulfuron plus HW	100	PRE	HW 30 d after crop emergence	Angadi et al. 1993b
Dry-DSR; upland	Butachlor	2,500	4 to 6 DAE	HW at 25–30 DAE	Angadi et al. 1993a
Dry-DSR; upland	Pendimethalin	1,500	4 to 6 DAE	HW at 25–30 DAE	Angadi et al. 1993a
TPR	Azimsulfuron plus 0.2% surfactant	30	19 DAT	One HW at 40 DAT	Jayadeva et al. 2009, 2010, 2011b
TPR (SRI)	Butachlor	1500	5 DAT	One HW at 30 DAT	Ramachandra et al. 2012b
Wet-DSR; drum seeding	Pretilachlor plus safener	300	4 DAS	HW at 30 DAS	Sanjay et al. 2006a, 2008
Wet-DSR	Pretilachlor plus safener	300	4 DAS	One HW at 30 DAS	Sanjay et al. 2006b
Wet-DSR; drum seeding	Pretilachlor plus safener	450	PRE	Passing cono-weeder at 30 DAS plus one hand weeding at 30 DAS	Jagadeesha et al. 2009

[a] Abbreviations: DAS, days after seeding; HW, hand-weeding; dry-DSR, dry direct-seeded rice; TPR, puddled transplanted rice; wet-DSR, wet direct-seeded rice; DAE, days after emergence.

weeds in rice established by varying methods in Karnataka.

Future Research Needs

Based on the review of weed management research in rice carried out so far in Karnataka, future research efforts should concentrate on the following aspects:

Integrated Weed Management. More research efforts are needed to identify location-specific options for integration to obtain optimal weed control with minimal cost and more net income for farmers.

Farmer Participatory Demonstrations and Evaluations. Research must focus on farmer need-based weed-management solutions through development and evaluation with farmer participation. Farmers' feedback on demonstrated weed-management approaches must be used in developing improved alternative weed-management strategies.

Monitoring Weed Shifts. The method of rice establishment is changing from transplanting to direct-seeding in Karnataka. Continuous evaluation of changes in weed flora is advisable to prevent the predominance of difficult-to-control weeds in rice systems.

Studies on Weed Flora in Farmers' Fields and Weed Ecology. Many of the reports on weed flora came from research stations, and there is an urgent need to understand weed flora and ecology in farmers' fields. Weed biological aspects need to be studied in detail. The impact of climate change on weeds and weed management in rice of Karnataka needs to be assessed.

Preventing Herbicide Resistance in Weeds. The shift in method of rice establishment to direct-seeding, increased herbicide use, and continuous use of similar herbicides may result in weed resistance in rice of Karnataka. Even though herbicide-resistant weeds were not reported in rice of Karnataka, it is essential to continuously monitor weeds for herbicide resistance. Weed scientists in Karnataka must focus their research efforts and simultaneously educate farmers on the economical ways and means of proper use of herbicides to prevent or delay the onset of herbicide resistance.

Developing Simple Decision-Making Tools. To enable farmers to use effective and economical weed-management options, simple decision-making tools need to be developed.

Collaborative Efforts. Most of the publications on weeds and weed management were published in Indian journals. Weed scientists of Karnataka need to publish in international journals, which will become a starting point of interaction with other scientists globally. Collaboration with national and international institutions in developed, as well as developing, nations must be encouraged to improve the understanding of weeds and to evolve better weed-management options for managing weeds effectively, economically, and in an ecologically sustainable manner.

Acknowledgments

A.N. Rao extends his thanks to the government of Karnataka for financial support. The authors thank Bill Hardy for his editorial help and suggestions for improvement.

Literature Cited

Acharya SP, Basavaraja H, Kunnal IB, Mahajanashetti SB, Bhat ARS (2012) Growth in area, production and productivity of major crops in Karnataka. Karnataka J Agric Sci 25:431–436

Agasimani CA, Goudar BBC, Raikar DS (2008) Effect of herbicides on weeds in transplanted rice. J Crop Weed 4:49–51

Angadi VV, Umapathy PN (1997) Integrated weed management through smother intercrops in rainfed lowland rice. Int Rice Res Notes 22:47–48

Angadi VV, Babalad HB, Umapathy PN, Radder GD, Nadaf SK (1993a) Weed control in upland rice fields of Karnataka. Int Rice Res Notes 18:50–51

Angadi VV, Umapathy PN, Nayak GV, Patil VC, Chittapur BM (1993b) Integrated weed management in direct seeded rainfed rice of Karnataka. Pages 6–9 *in* Proceedings of the International Symposium on Integrated Weed Management for Sustainable Agriculture. Volume III. Hisar, India: Indian Society of Weed Science

Anwarullah MS (1998). Chemical weed control in rice nurseries of the hill zone of Karnataka. Int Rice Res Notes 23:27–28

Baki BB, Chin DV, Mortimer M, eds (2000) Wild and Weedy Rice in Rice Ecosystems in Asia: A Review. Limited proceedings No. 2. Los Baños, Philippines: International Rice Research Institute. 124 p

Biradar DP, Shivakumar KS, Prakash SS, Pujar BT (2006) Bionutrient potentiality of *Parthenium hysterophorus* and its

utility as green manure in rice ecosystem. Karnataka J Agric Sci 19:256–263
Biradar D, Nagappa P, Chinnabasavanna AS (2002) Evaluation of a new acetochlor herbicide on transplanted rice. Karnataka J Agric Sci 15:491–496
Bouman BAM (2001) Water-efficient management strategies in rice production. Int Rice Res Notes 26:17–22
Chauhan BS (2012) Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technol 26:1–13
Chauhan BS (2013) Strategies to manage weedy rice in Asia. Crop Prot 48:51–56
Channabasavanna AS, Setty RA (1993) Weed management in rice nurseries. Curr Res Univ Agric Sci (Bangalore) 22:7–8
[CSCB] Central Seed Certification Board (2013) Indian Minimum Seed Certification Standards. New Delhi, India: CSCB. 605 p
Delouche JC, Burgos NR, Gealy DR, Martín GZS, Labrada R (2007) Weedy Rices—Origin, Biology, Ecology and Control. Rome: Food and Agriculture Organization of the United Nations Plant Production and Protection Paper 188.
Denesh GR, Prasad TVR (2012) Influence of weed as green leaf manures on growth, productivity and economics in aerobic rice-rice cropping system. Mysore J Agric Sci 46:671–675
Denesh GR, Ramachandra C, Prasad TVT (2012) Chemical weed control in wet rice nursery. Abstract. Page 49 *in* Proceedings of the Biennial Conference on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University, Thrissur, Kerala, India: Indian Society of Weed Science
[DRR] Directorate of Rice Research (2011) Production Oriented Survey 2010. Hyderabad, A.P., India: DRR. 166 p
[DWSR] Directorate of Weed Science Research (2013) Report of the Quinquennial Review Team on Directorate of Weed Science Research & AICRIP–Weed Control (2006 – March, 2012). Jabalpur 482 004, Madhya Pradesh, India: DWSR
[DWSR] Directorate of Weed Science Research (2011) Vision 2030. Maharajpur, Adhartal, Jabalpur 482 004, Madhya Pradesh, India: DWSR
[DWSR] Directorate of Weed Science Research (2010) All India Coordinated Project on Weed Control—Weed Control Recommendation. Jabalpur, Madhya Pradesh, India: DWSR
Gandhi RV, Rudresh NS, Shivamurthy M, Hittalmani S (2012) Performance and adoption of new aerobic rice variety MAS 946-1 (Sharada) in southern Karnataka. Karnataka J Agric Sci 25:5–8
Gowda DKS, Gubbaiah S (2011) Insect pests of rice and their management in Karnataka state of India: a review. Agric Rev 32:55–62
Gowda PT, Murthy KNK, Fathima PS, Vidya A (2010) Studies on chemical weed control in aerobic rice (*Oryza sativa* L.). Crop Res (Hisar) 40:20–24
Gowda PT, Shankaraiah C, Janesh AC, Govindappa M, Murthy KNK (2009) Studies on chemical weed control in aerobic rice (*Oryza sativa* L.). J Crop Weed 5:321–324
Gujja B, Thiyagarajan TM (2009) Indian food security? the System of Rice Intensification. Gatekeeper Ser 143:4–5
Hanumanthappa M, Dalavai BL, Malleshappa C, Nataraju MS (2009) Influence of age of seedlings and use of cono-weeder on growth and yield of SRI method paddy. Mysore J Agric Sci 43:173–175
Hanumanthappa M, Manjunatha KB, Kalyanamurthy KN, Naik KPS (2012) Effect of new herbicide molecules on growth and yield of transplanted rice in coastal Karnataka. Abstract. Page 56 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University. Thrissur, Kerala, India: Indian Society of Weed Science
Jagadeesha N, Sheshadri T, Shet RM, Gireesh C, Umesha MR (2009) Growth and yield of drum seeded rice as influenced by different weed management practices. Environ Ecol 27:898–901
Janardhan G, Muniyappa TV (1994a) Economics of some pre-emergence herbicides in transplanted rice. Curr Res Univ Agric Sci (Bangalore) 22:154–156
Janardhan G, Muniyappa TV (1994b) Correlations between weed parameters and yield components in transplanted rice. Curr Res Univ Agric Sci (Bangalore) 23:161–164
Janardhan G, Muniyappa TV, Reddy VC, Ramachandra C, Bhaskar S (1999a) Studies on weed control and crop toxicity ratings of pre-emergence herbicides in transplanted rice. Mysore J Agric Sci 33:333–337
Janardhan G, Muniyappa TV, Reddy VC, Ramachandra C, Murthy NK (1999b) Studies on efficacy of pretilachlor in transplanted rice. Mysore J Agric Sci 33:16–20
Jayadeva HM, Bhairappanavar ST (2002) Chemical weed control in drum seeded rice. Indian J Weed Sci 34:290–292
Jayadeva HM, Nanjappa HV (1996) Time of herbicide application on weeds and yield of direct-seeded puddled rice. J Agric Sci 30:112–116
Jayadeva HM, Basavarajappa DN, Bhairappanavar ST, Denesh GR, Shivanna S (2002) Evaluation of new herbicide molecules for weed control in wet rice nursery. Curr Res - Univ Agric Sci (Bangalore) 31:179–181
Jayadeva HM, Bhairappanavar ST, Hugar AY, Rangaswamy BR, Mallikarjun GB, Malleshappa C, Naik DC (2011a) Integrated weed management in aerobic rice (*Oryza sativa* L.). Agric Sci Digest 31:58–61
Jayadeva HM, Bhairappanavar ST, Somashekarappa PR, Hugar AY, Rangaswamy BR, Mallikarjun GB, Naik DC (2011b) Evaluation of azimsulfuron for weed control in transplanted rice (*Oryza sativa* L.). Indian J Agric Res 45:239–243
Jayadeva HM, Bhairappanavar ST, Somashekarappa PR, Rangaswamy BR (2009) Efficacy of azimsulfuron for weed control in transplanted rice. Indian J Weed Sci 41:172–175
Jayadeva HM, Denesh GR, Basavarajappa DN, Bhairappanavar ST (2004) Mon 46996 (Butachlor 90% EC) A new herbicide formulation for weed control in transplanted rice. Mysore J Agric Sci 38:480–486
Jayadeva HM, Hugar AY, Somashekarappa PR, Malleshappa C (2010) Efficacy of azimsulfuron in combination with metsulfuron methyl on weed control in transplanted rice. Mysore J Agric Sci 44:246–254
Jayadeva HM, Nanjappa HV, Ramachandrappa BK (1997) Chemical weed control and economics in puddle-seeded rice. Ann Agric Res 18:351–356
Kenchaiah K, Shekara BG, Kalyanamurthy KN, Madhu SC, Shivashankaramurthy M (2006) Cinosulfuron A promising

new herbicide for weed control in transplanted rice. Indian Agric 50:103–105

Kenchaiah K, Shekara BG, Kalyanamurthy KN, Madhu SC (2009) Evaluation of clomazone for controlling weeds in wet direct-sown rice. Oryza 46:78–79

Kolhe SS, Brambri MC (2005) Utilisation of *Parthenium hysterophorus* as green manure in transplanted rice (*Oryza sativa* L.). Pages 181–183 *in* Proceedings of the 2nd International Conference on Parthenium Management. Bangalore, India: University of Agriculture Sciences

Kollurmath VB, Karnool NN, Kunnal B, Basavaraj H, Kulkarni V (2008) Cost of production of rice and maize in World Trade Organization era of Karnataka. Karnataka J Agric Sci 21:241–245

Krishnamurthy R, Gowda CR, Murthy CAS, Prasad TVR (2005) *Parthenium* and *Chromolaena* as compost and green manure in transplanted rice. Pages 193–196 *in* Proceedings of the. 2nd International Conference on Parthenium Management. Bangalore, India: University of Agriculture Sciences

Kumar V, Ladha JK (2011) Direct-seeded rice: recent developments and future research needs. Adv Agron 111:297–413

Kumar MD, Basavaraj B (1996) Evaluation of anilophos herbicide for transplanted rice. Karnataka J Agric Sci 9:520–522

Kumar MD, Anwarullah MS, Shadakshari YG (2009) Integrated nutrient management in transplanted rice genotypes. India J Environ Ecol 27:1002–1005

Kusuma V (2007). Studies on weed management in aerobic rice (*Oryza sativa* L.) cultivation. M.Sc thesis. Bangalore, India: University of Agriculture Science

Madhu M, Nanjappa HV (1997) Nutrient uptake by crop and weeds as influenced by weed control treatments in puddled seeded rice. Crop Res (Hisar) 13:1–6

Madhu M, Nanjappa H, Naik HR (1996) Economics of weed control treatments in puddled seeded rice. Crop Res (Hisar) 12:133–137.

Madhukumar V, Kalyana Murthy KN, Sanjay MT, Ashoka P, Kumbar B (2012) Effect of pre and post emergent herbicides on nutrient uptake and yield in aerobic rice [Abstract]. Page 54 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment. Kerala Agricultural University, Thrissur, Kerala, India: Indian Society of Weed Science

Mahadevappa M (1999). Parthenium and its management. Dharwad, Karnataka, India: University of Agricultural Sciences. 132 p

Mahadevaswamy M, Nanjappa HV (1991) Effect of herbicides on weed control in drill-sown rice (*Oryza sativa*). Indian J Agron 36(Suppl):247–249

Manjappa K, Kataraki NG (2004). *Eupatorium* An obnoxious weed as green leaf manure in rice cultivation. Karnataka J Agric Sci 17:799–800

Manjunatha KB, Hanumanthappa M, Nagesha, Kalyanamurthy KN, Kamath KVS, Jayaprakash SM (2013) Effect of new herbicide molecules on growth and yield of transplanted rice (*Oryza sativa* L.) in coastal Karnataka. Mysore J Agric Sci 47:292–295

Manjunatha MV, Masthana Reddy BG, Joshi VR (2009) Performance of rice (*Oryza sativa*) under different methods of establishment in Tungabhadra canal command, Karnataka. Karnataka J Agric Sci 22:1151–1152

Masthana Reddy BG, Anand SR, Pujari BT (2012a) Effect of herbicide bispyribac-sodium on rice weeds in nursery. Abstract. Page 95 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University. Thrissur, Kerala, India: Indian Society of Weed Science.

Masthana Reddy BG, Pattar PS, Ravishankar G, Joshi VR (2006). Efficacy of quinclorac in transplanted rice. Indian J Weed Sci 38:29–32

Masthana Reddy BG, Ravishankar G, Balganvi S, Joshi VR, Negalur RK (2012b) Efficacy of bensulfuron methyl plus pretilachlor for controlling weeds in transplanted rice. Oryza 49:65–67

Mishra JS, Singh VP (2007). Integrated weed management in zero till direct seeded rice (*Oryza sativa* L.)–wheat (*Triticum aestivum*) cropping system. Indian J Agron 52:198–203

Munegowda MK, Jagadish A, Khan TA, Gowda RC, Kumar NC (1993). Cultural-cum-herbicidal weed management studies in upland drilled rice. Pages 54–56 *in* Proceedings of the International Symposium on Integrated Weed Management for Sustainable Agriculture. Volume III. Hisar, India: Indian Society of Weed Science

Munegowda MK, Nagaraju AP, Varadaraju, Krishnamurthy K (1990) Efficacy of anilophos at different rates and time of application on weed control in transplanted rice. Curr Res Univ Agric Sci (Bangalore) 19:145–146

Mutanal SM, Kumar P, Joshi VR, Honnannavar SY (1998) Effect of butachlor for weed control in sprouted direct seeded paddy field under rainfed conditions. Karnataka J Agric Sci 11:487–489

Mutanal SM, Kumar P, Joshi VR, Mannikeri IM (1997) Time of application of anilophos for effective weed control and crop safety in direct seeded rice. World Weeds 4:169–174.

Nagaraju AP, Kumar HKM (2009) Effect of herbicides alone and in combination with 2,4-D (EE) on weeds and grain yield of rice (*Oryza sativa* L.). Mysore J Agric Sci 43:401–405

Nayak BR, Manjappa K (2012). Documentation of existing cultivation practices followed in rice in hill region of Uttara Kannada district. Karnataka J Agric Sci 25:397–402

Pattar PS, Reddy BGM, Kuchanur PH (2005) Evaluation of halo-sulfuron methyl for weed control in puddled direct-seeded rice (*Oryza sativa*). Indian J Agric Sci 75:230–231

Prakash P, Nanjappa HV, Ramachandrappa BK (1995) Chemical weed control in direct seeded puddled rice (*Oryza sativa* (L.). Crop Res (Hisar) 9:197–202

Prasad SR, Jagadish GV, Aswathaiah B, Reddy TNV (1991) Quality of paddy seeds used by farmers in Bhadra command area. Curr Res Univ Agric Sci (Bangalore) 20:22–23

Prasad TVR, Devendra R, Narasimha Reddy MK, Varadaraju, Krishnamurthy K (1990) Evaluation of molinate for weed control in drilled upland paddy. Curr Res Univ Agric Sci (Bangalore) 19:19–21.

Prasad TVR, Kenchaiah K, Maharudrappa K, Khan TA, Krishnamurthy K (1992) Efficacy, economics and energetics of herbicides in weed management of transplanted rice in agro-climatic zones of Karnataka. Mysore J Agric Sci 26:1–5

Prasad TVR, Sanjay RMT, Pramod G, Shubhashree KS (2012a) Influence of weed management practices under different rice establishment techniques on productivity and economics of rice [Abstract]. Page 58 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University. Thrissur, Kerala, India: Indian Society of Weed Science

Prasad TVR, Sanjay RMT, Shubhashree KS, Pramod G (2012b) Efficacy of herbicides for controlling weeds in direct seeded rice. Abstract 55 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University. Thrissur, Kerala, India: Indian Society of Weed Science

Prasad VP, Singh NP (2002) Sedges of Karnataka (India) (Family Cyperaceae). Jodhpur, India: Scientific. 354 p

Pujari BT, Hosamani MM, Sharma KMS, Goudreddy BS, Patil VC (1989) Response of paddy to nutrient levels and weed management in Upghat region of Karnataka. J Maharashtra Agric Univ 14:189–192

Purushotham S, Munegowda MK, Dwarakanath N, Mohan SL (1990) Evaluation of new herbicides in transplanted rice. Curr Res Univ Agric Sci (Bangalore) 19:73–75

Rajanna MP (2013) Recent Rice Varieties and Hybrids of Karnataka. Zonal Agricultural Research Station, Mandya, Bangalore, India: University of Agriculture Science

Rajanna MP (2010) Status Paper on Rice in Karnataka. Rice Knowledge Management Portal (RKMP). Hyderabad, India: Directorate of Rice Research http://rkmp.co.in/sites/default/files/ris/rice-state-wise/Status%20Paper% 20on% 20Rice%20in%20Karnataka.pdf. Accessed January 14, 2014

Ramachandra C, Denesh GR, Ramachandra Prasad TV (2012a) Chemical weed control in dry rice nursery. Abstract. Pages 91 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on "Weed Threat to Agriculture, Biodiversity and Environment", Kerala Agricultural University, Thrissur, Kerala, India: Indian Society of Weed Science

Ramachandra C, Rajput OP, Anwarulla MSS (2008) Productivity and nutrient balance of rice-based cropping systems as influenced by fertility levels in hill zone of Karnataka. J Farming Syst Res Dev 14:35–41

Ramachandra C, Shivakumar N, Rajanna MP, Kalyanamurthy KN (2012b) Effect of age of seedlings and weed management under SRI on yield of rice. Indian J Weed Sci 44:50–52

Ramachandra C, Shivanna M, Janardhan G, Shivakumar KV (2012c) Growth and productivity of kharif rice (*Oryza sativa* L.) as influenced by cropping sequences and fertility levels in hill zone of Karnataka. Crop Res (Hisar) 36:12–15.

Rao AN (2010) Integrated Weed Management in Rice in India. Rice Knowledge Management Portal (RKMP). Rajendranagar, Hyderabad 500030, India: Directorate of Rice Research. http://www.rkmp.co.in/sites/default/files/ris/research-themes/Integrated%20weed%20management%20in%20rice%20in%20India.pdf. Accessed January 14, 2014

Rao AN, Ladha JK (2011). Possible approaches for ecological weed management indirect-seeded rice in a changing world. Pages 444–453 *in* Proceedings of the 23rd Asian Pacific Weed Science Society Conference. Sebel, Cairns, Australia: Asian Pacific Weed Science Society

Rao AN, Ladha JK (2013) Economic weed management approaches for rice in Asia. Pages 500–509 *in* Bakar BH, Kurniadie D, Tjitrosoedirdjo S, eds. Proceedings of the 24th Asian Pacific Weed Science Society Conference. Bandung, Indonesia: Asian Pacific Weed Science Society

Rao AN, Nagamani A (2010) Integrated weed management in India–revisited. Indian J Weed Sci 42:123–135

Rao AN, Moody K (1987) Rice grain yield loss caused by transplanted *Echinochloa glabrescens* and possible control measures. Pages 203–210 *in* Proceedings of the 11th Asian Pacific Weed Sciences Society Conference, Taipei, Republic of China: Asian Pacific Weed Science Society

Rao AN, Moody K (1990) Weed seed contamination in rice seed. Seed Sci Technol 18:139–146

Rao AN, Nagamani A (2013) Eco-efficient weed management approaches for rice in tropical Asia. Pages 78–87 *in* Proceedings of the 4th Tropical Weed Science Conference. Chiang Mai, Thailand: TWSC.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM (2007) Weed management in direct-seeded rice. Adv Agron 93:153–255

Sajjam G, Jayadeva HM, Krishnamurthy N (2013) Effect of different weed control measures in transplanted rice (*Oryza sativa*). J Agric Res Technol 38:388–392

Sanjay MT, Prasad TVR, Pramod G, Shubhashree KS (2012). Effect of time of sowing and weed management on yield of direct seeded rice [Abstract]. Page 233 *in* Proceedings of the Biennial Conference of Indian Society of Weed Science on Weed Threat to Agriculture, Biodiversity and Environment, Kerala Agricultural University. Thrissur, Kerala, India: Indian Society of Weed Science

Sanjay MT, Setty TKP, Nanjappa HV (2006a). Enhancing productivity of rice under different crop establishment methods through weed management practices. Crop Res (Hisar) 31:192–197

Sanjay MT, Setty TKP, Nanjappa HV (2006b) Productivity, energetics and economics of different systems of crop establishment in rice. Crop Res (Hisar) 31:350–353

Sanjay MT, Setty TKP, Nanjappa HV (2008) Investigation of crop establishment methods and weed management practices on productivity and economics in rice. Mysore J Agric Sci 42:60–66

Sastry KSK, Boraiah G, Govindu HC, Khaleel TF (1980) Weeds of Karnataka. Bangalore, India: University of Agricultural Sciences. 360 p

Sharanappa MK, Gowda M, Maharudrappa K (1994a) Efficacy of herbicides in drill sown rice in hill zone of Karnataka state. Indian J Weed Sci 26:12–15

Sharanappa MK, Gowda M, Maharudrappa K (1994b) Efficacy of herbicides on weed management in drill sown rice (*Oryza sativa* (L.)). Mysore J Agric Sci 28:8–13

Sunil CM, Shankaralingappa BC (2014). Impact of integrated package of agrotechniques on growth and yield of aerobic rice. Agric Sci 5:60–65

Sunil CM, Shekara BG, Ashoka P, Murthy KNK, Madhukumar V (2011) Effect of integrated weed management practices on aerobic rice (*Oryza sativa* L.). Res Crops 12:626–628

Sushilkumar, Varshney JG (2010) Parthenium infestation and its estimated cost management in India. Indian J Weed Sci 42 (Supplementary Issue):73–77

Umesha N, Krishnamurthy, Sridhara N, Venkatesha MMS, Ramulu (2009) Productivity of aerobic rice and weed control efficiency as influenced by smothering crops and intercultivation. Environ Ecol 27:656–658.

Weerakoon WMW, Mutunayake MMP, Bandara C, Rao AN, Bhandari DC, Ladha JK (2011) Direct-seeded rice culture in Sri Lanka: lessons from farmers. Field Crops Res 121:53–63

Received May 19, 2014, and approved August 28, 2014.