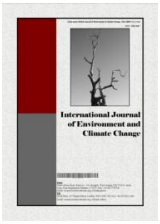

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Weed Management Strategies in Organic Rice Production System- A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors SP, RCD, AKS and CMM managed and collected the literatures. All authors read and approved the final manuscript.

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ABSTRACT

Farmers view weeds as the number one barrier to organic rice production. Also, organic rice-growing farmers feel weed management is their number one priority, so they need more research about weed management under organic conditions from the researchers. Weeds can be considered a significant problem because they have a tendency to decrease crop yields by increasing competition for moisture, sunlight and nutrients also serving as host plants for pests and diseases. Since the development of herbicides, farmers have been used these chemicals to eradicate weeds from their fields. Using herbicides not only increased crop yields as well as reduced the labour required to remove weeds. Today, some farmers have a renewed interest in organic methods of managing weeds since the widespread use of agrochemicals has affected the environment and health. It has also been found that in some cases herbicides use can cause some

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weed species to dominate fields because the weeds develop resistance to herbicides. Moreover, some herbicides are destroying weeds that are harmless to crops, resulting in a potential decrease biodiversity. It is important to understand that under an organic system of seed control, weeds will never be eliminated but only managed. Consistent methods of weed management can reduce the costs and contribute to economical crop production without endangers the environment.

Keywords: Azolla; botanicals; integrated weed management; organic rice production.

1. INTRODUCTION

Rice is one of the major crops that receives higher quantity of fertilizers and pesticides. The rampant use of chemical and fertilizers contributes largely to the deterioration of the environment and soil fertility which has adverse impact on agricultural productivity and soil degradation. Now, there is a growing realization that the adoption of ecological and sustainable farming practices can only reverse the declining trend in the global productivity and environment protection. Organic farming is one among the broad spectrum of production systems that is supportive of the environment [1]. Organic farming is defined as production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators and livestock feed additives to the maximum extent feasible. Organic materials (animal waste, plant waste, bio agent, etc.) are the safer sources of plant nutrient without causing any detrimental effect to crops and soil. However, after the industrial revolution, widespread introduction of inorganic fertilizers led to a decline in the use of organic material in the cropping systems. Today, the awareness on organic agricultural produce is increasing and the demand for organic food is also rising, leading to increase in land area under organic farming [2]. About 71.5 million ha of land is under organic farming worldwide with 2.8 million producers [3].

Irrespective of the method of rice establishment, weeds are a major impediment to rice production through their ability to compete for resources and their impact on grain yield and quality. Weeds are responsible for heavy rice yield losses under extreme conditions. Uncontrolled weeds reduced the rice yield by 62.6% under transplanted conditions [4]. It is estimated that every year, weeds cause yield losses ranging from 15 to 76% in rice [5,6,7,8,9,10]. Experiments showed that yields were comparable across all establishment methods of rice when competition from weeds was removed. Thus, weed control is major pre-requisite for improved rice productivity and production using different methods of rice establishment.

Although weeds can be effectively managed through herbicides, the use of herbicides is affect the soil properties environment quality and human health. Hence organic weed management practices is the alternate option to control the weeds in organic rice production system. Organic weed control encourages weed suppression rather than elimination. This is done by promoting soil health through a combination of crop rotation, cover crops, biologically based bio-fertilizers, manure, compost and mulch. Proper management through organic methods offer varied benefits over chemical herbicides, including increased biodiversity, improved soil nutrition and structure, and protection of ground and surface water [11]. In this context review has been made to study the effects of various weed management practices in the organic rice production system.

2. WEED MANAGEMENT PRACTICE IN ORGANIC RICE PRODUCTION

2.1 Manual Weed Control

Hand weeding in transplant crop was relatively easy, because the seedlings planted in rows between which the weeder can walk [12]. Prasad et al. [13] reported that manual weeding in transplanted rice recorded more number of tillers, panicles, filled grains, 1000 grain weight, grain yield and straw yield in comparison to chemical methods. They further opined that the traditional method of weed control practice in India was manual weeding by hoe and hand pulling.

Usually, hand weeding was practiced two or three times for growing a rice crop depending upon the nature of weeds, their intensity and the method of rice establishment. Hand weeding twice at 20 and 45 days after sowing (DAS) or day after planting (DAT) for broadcast or transplanted crop had been found superior to the chemical weed control for all the growth and yield

attributes [14,13,15,16]. Higher weed control efficiency of 93.1% was recorded in hand weeding treatments [17]. The maximum values of yield attributing characters like tillers, panicle length, grains panicle^{-1}, grain weight plant^{-1}, test weight as well as grain yield under manual weeding twice was also reported [18,19].

Hand weeding twice at 20 and 40 DAT resulted in significantly lower weed density and dry weight [20] and recorded the highest weed control efficiency (Kathirvelan and Vaiyapuri [21] and Patra et al., 2006). Hand weeding twice was found superior to other treatments with 100% control of weeds in rice [22]. According to Sharma [23], two hand weeding, one as early as possible i.e., 10-15 days after transplanting and the second 25-50 days later were generally sufficient in rice field.

Jayadeva et al. [24] and Subhalakshmi and Venkataramana [25] found that hand weeding at 20 and 40 DAT recorded the highest plant height, dry matter production, tillers m^{-2}, nutrient uptake by crop and highest grain and straw yields of rice. The maximum values of yield attributing characters like tillers, panicle length, grains panicle$^{-1,}$ grain weight plant^{-1}, test weight as well as grain yield recorded under manual weeding twice was reported by Sureshkumar et al. [26]

Jagtap et al. [27] reported that in case of drilled rice the yield attributing characters like number of panicles m^{-2}, length of panicle, filled grains panicle^{-1}, weight of filled grains panicle^{-1} and test weight were significantly higher under weed free check and hand weeding twice than the remaining weed control treatments control (unweeded).

2.2 Mechanical Weed Control

Mechanical weeding is generally economical, non-polluting without residual problems and relatively safe to the operator [28]. Mechanical weed control through the use of rotary weeder or other implements helped in minimizing weed competition, besides improving soil aeration [28] and [29]. Chandra and Manna [30] studied the effect of different weed management practices in transplanted rice grown during summer under shallow condition and found that hoeing with the use of Japanese rotary weeder twice effectively controlled the weeds and increased the grain yield by 29.7% over control.

Sarma and Gogoi [31] reported that increased plant height was recorded, when weeders were operated twice at 20 and 30 days after emergence which was attributed to better control of weeds particularly, broad-leaved weeds and sedges, which emerged during later growth stages. In view of the increasing labour scarcity, negative impact of indiscriminate herbicide use, weed management strategy needs to be reoriented towards mechanical means for satisfactory monetary benefits. Rotary weeder was effective in controlling the weeds present in inter row space, but failed to control the weeds in intra row space or those in the vicinity of the crop [32].

Uphoff [33] emphasized that early and frequent weeding was essential in rice, when fields were not covered with standing water. The rotary weeding three times at 15, 30 and 45 DAT recorded better weed control and higher grain yield in rice [34,35,36]. However, the problem of incorporation of perennial weeds and vegetative propagated weeds might result in faster regeneration of those under mechanical weeding [37]. The cost of weeding for labours could be reduced by 6.6 and 7.6 times by using rotary weeder and cono-weeder, respectively, compared to hand weeding [38].

Akbar et al. [39] reported higher weed suppression and 25% increased rice yield over control under mechanical hoeing and it was statistically on par with hand weeding treatment. Increased demand for labour and escalated cost of agrochemicals together with phytotoxicity posed the farming community to think of mechanical measures, which would help the rice production to free itself from the scourge of weed menace with limited labour [40].

2.3 Cultural Weed Control

Many weeds did not germinate under flooded conditions. The increased submergence up to 15 cm was reported to reduce the germination and growth of *Echinochloa crusgalli* and *Leptochloa* spp. [41,42] and flooding over 10 cm depth at the first-leaf stage almost completely suppressed the growth of *Echinochloa crusgalli* and *E. praticola* [43]. On the other hand, emergence and survival of some weeds, for example *Monochoria vaginalis*, remained unaffected by deep flooding [44,45,46]. The submergence of rice fields was required only for few days after transplanting so as to discourage weeds and subsequently soil saturation was enough [47].

Subbulakshmi and Pandian [48] found that adoption of continuous submergence registered lower weed density and weed dry matter production due to reduced weed population caused by possible inhibition of germination of weeds under anaerobic conditions. Cultural practices greatly altered the competitive relationship between rice and weeds. Proper agronomic management practices like suitable crop establishment method, efficient fertilizer use, proper crop stand, selection of competitive crop cultivars could play important role in providing competitive advantages to low land rice against weeds [13].

It was the timing, duration and depth of flooding that determined the extent of weed suppression by flooding [49]. Singh et al. [4] reported that weeds were killed in transplanted rice due to puddling effect. Subramanyam et al. [50] found that intensive puddling with continuous submergence recorded lower weed dry weight. Transplanting of rice experienced the lowest weed competition thereby recorded the lower weed population and dry weight [22] and [51] as compared to sowing of sprouted seeds in puddled condition and dry drilling of seeds. Flooding was one of the most important weed management options in lowland rice as many weeds would not germinate in anaerobic conditions. Intensive puddling with continuous submergence was very effective in reducing the weed dry weight [50].

Rice bran application under deep flooding significantly increased both spikelet number per panicle and panicle number, leading to substantial increase in total spikelet number per unit area and grain yield as compared to deep flooding with no rice bran reported by Yan et al. [52].

Transplanting and growing rice in submerged conditions were probably the first two traditional steps towards weed control. Water served as an effective cultural means of weed control in rice, as many weeds could not germinate under flooded conditions. In transplanted rice cultivation, weeds were suppressed by standing water and transplanted rice seedlings had a head start over germinating weed seedlings [53].

Gnanasoundari and Somasundaram [11] found that higher grain yield of rice (4816 kg ha-1) was recorded with the application of rice bran at 2 t ha^{-1} on 3 DAT and hand weeding on 35 DAT. The favourable conditions created through the efficient weed control resulted in lesser weed competition between crop and weeds. This favoured the crop to produce more leaf area and plant dry matter production. The increase in number of productive tillers, panicle length and number of filled grains $panicle^{-1}$resulted in the higher grain yield in application of rice bran at 2 t ha^{-1} on 3 DAT.

Bavaji and Somasundaram [54] Mulching with biodegradable polyethylene sheet recorded consistently higher value of yield components viz., panicle length (19.91 cm), fertility percentage (85.70) and least sterility percentage (14.30), the panicle length was not influenced by the adoption of different weed management practices. This might be due to decreasing the germination and nourishment of weeds and keeping the weeds suppressed during the critical growth stages.

2.4 Biological Weed Control

Biological control of weeds is the deliberate use of natural enemies to reduce the density of a particular weed to a tolerable level. The objective of biological weed control is not eradication but simply the reduction of the weed population to an economically low level In fact for biological control to be continuously successful, small numbers of the weed host must always be present to assured the survival of the natural enemy. It has most frequently been applied against these alien weeds and attempts are made to restore the natural control of these weed pests by introducing one or more host-specific, damaging natural enemies from the native region of the weed. The biological control approaches are classified into two broad categories: 1. Classical or inoculative approach 2. Mass exposure or inundative approach. The classical approach is based on introduction of host-specific organisms *viz*., insects, pathogens, nematodes from the weed's native range into regions where the weed has established and become a widespread problems. In a mass exposure or inundative approach is the bio herbicide approach, which involves application of weed pathogens in a manner similar to herbicide applications Reddy, [55].

Boyette et al. [56] reported that the endemic fungus *Colletotrichum gloeosporioides* f. sp. *Jussiaeae* reduced winged water primrose in rice. It controlled>80% of weed plants in rice after four weeks. Dubey [57] conducted research on the beetle's ability to suppress weeds in the

rice field as well as under caged conditions. In the field, Steel blue beetles (*Haltica cyanea* Web.) were released in plots planted with rice, under presence of sedges, *Sphenocleazey lanica* Gaertn. and *Ludwigia parviflora* Roxb, which are common weeds of puddled transplanted rice fields. It was observed that the beetles completely denuded the Ludwigia, without harming the rice crop.

The rust fungus *Puccinia canaliculata* (Schw.) Lagerh. having the potential for controlling yellow nutsedge (*Cyperus esculentus* L.). Release of the pathogen early in the spring on seedling yellow nutsedge reduced plant populations, tuber formation, and flowering reported by Phatak et al. [58]. The water lily aphid *Rhopalosiphum nymphaeae* L. Controlled duck salad (*Heteranther alimosa*) biomass by 58-87% and seed pods by more than 82%, without causing any noticeable damages to rice [59].

Nagargade et al. [60] reported that COLLEGO, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene*, was control of northern joint vetch (*Aeschynomene virginica* L.) in rice. The practices of ducks [61] and water birds [62] were also found effective in managing weeds and therefore it have used as a components of weed management in direct seeded rice systems (DSR). The combination of common carp and grass carp in the irrigated lowland rice-fish farming system recorded good suppression of *Fimbristylis miliacea*, *Cyperus iria* and *Sripus maritimus* [63].

2.4.1 Use of Azolla for weed control

Watanabe [64] estimated that azolla contained 3 to 6, 0.5 to 0.9 and 2.0 to 4.5% N, P and K, respectively on dry weight basis, besides secondary and micro nutrients. According to Liu [65] application of azolla to rice resulted in an average yield increase of 18.6%. Dual crop of azolla produced higher grain yield in addition to supplying N equivalent to 30 Kg ha^{-1} [66]. Azolla when inoculated in rice fields, covered the water surface rapidly and suppressed the weeds to the tune of 60 to 100 % depending on the weed species [67,68] and [69].

However, weeds with strong nature and abundant food supply could pierce through azolla mat and weeds growing above the water surface before mat formation and largely floating weeds were unaffected by azolla [70]. Janiya and Moody [71] reported that azolla inoculation reduced the weed dry weight by 80 % as compared to un-inoculated control. A thick layer of azolla was found to ward off *Marselia quadrifolia* [72]. Rapid growth and multiplication of azolla limited weed growth and probably altered their gas exchange, light penetration and temperature [73].

It was evident from the experimental findings that Azolla intercropping (dual cropping) with rice significantly reduced the weed population that ranged from 4 to 72% over control. This reduction may be primarily due to the dense mat of Azolla which developed a few days after inoculation and effectively reduced light available for weed growth [74]. Azolla as dual culture recorded significant increase in the tiller number, plant height, and number of panicles, 1000 grain weight and yield [75,76]. Azolla incorporation increased the plant height as well as grain and straw yields during both dry and wet seasons [77].

Sreenivasan and Veerabadran [78] noticed that azolla significantly suppressed the weed growth in rice up to 45 days and further that the suppression was more at 45 days than 30 days probably because of the thick mat development at 45 days. Addition of azolla in rice fields suppressed the weeds like *Echinochloa crusgalli* and *Cyperus difformis* and the degree of suppression increased with increase in percentage of azolla cover and water depth [79]. Azolla intercropping significantly reduced the weed density [80,81]. The ability of azolla to multiply very fast resulted in reduction of weeds in flooded rice fields [82]. Gnanasoundari and Somasundaram [11] reported that growing of azolla as a dual crop with rice resulted in significantly more tillers, longer panicles and more spikelet.

2.4.2 Use of botanicals for weed control

Many farmers in Japan spread rice bran and hulled soybeans in their rice fields as a form of weed control. Japanese farmers use rice bran (200 g m^{-2}) for weed control and as a fertilizer for transplanted rice, resulting in weed reduction and high-quality grain [83]. Rice hulls at half or one inch depth provided 100% weed control. No weeds grew in these pots.

Kuk et al. [84] stated that rice by-products could reduce weed emergence and shoot weight in broadleaf species. The weed population was

decreased by the application of rice bran at 5 days after rice transplanting, and the weed occurrence rate decreased by 68% after the application of 3.5 Mg ha^{-1}. Rice bran application in combination with deep flooding not only effectively suppressed major paddy weeds without herbicide use but also increased grain yield by increasing soil mineral nitrogen concentration.

Rice bran farming had been increasingly adopted in farmers fields. Only a few studies have addressed the potential use of rice bran for paddy weed control and soil amendment [85,86]. Kim et al. [85] reported that rice bran application under shallow flooding conditions suppressed the occurrence of *Scirpus juncoides*, *Monochoria vaginalis* and *Cyperus serotirus* substantially but not the occurrence of *Echinochloa crusgalli*.

Kuk et al. [86] reported that the aqueous extracts of rice bran could suppress the germination and early growth of some paddy weeds; the aqueous extracts of rice bran significantly inhibited the germination and early growth of *Eclipta prostrate* even at the low concentration of the extract but *Echinochloa crusgalli* to a much lesser extent. Maeda et al. [87] also mentioned that scattering rice bran on the surfaces of fields effectively controlled both the germination and growth of weeds. Rice bran application at 7 DAT for weed suppression significantly increased mineral nitrogen concentration in the top soil during tillering stage providing much more available nitrogen for rice growth [88]. Gnanasoundari and Somasundaram [11] reported that the aqueous extracts of rice hull solution 50% spray had much effect on the weed control.

Nongmaithem et al. [89] found that Ocimum sanctum extracts 5% (w/v) gave highest grassy weed population control while *Ageratum conyzoides* extract 5%(w/v) gives highest broad leaf weed population control .Again an another experiment it was shown that higher growth and yield of seasame and green gram under *Ageratum conyzoides* extract but higher harvest index and soil nutrient status under *Ocimum sanctum* extracts [90]

Gayatri and Mahadev [91] concluded that application of either *Cucumis sativus* leaf extract or *Bambusa vulgaris* leaf and shoot extract or *Echinochloa colonam* plant extract or *Xanthium strumanium* leaf extract along with one mechanical weeding at 30 DAT can be used as an effective weed control measures in transplanted paddy field.

3. CONCLUSION

From the above review of literature, it can be concluded that instead of being an obstacle to progress, traditions may become an integral part of it. By adopting organic agriculture, farmers are challenged to take on new knowledge and perspectives and to innovate. This leads to an increased engagement in farming which can trigger greater opportunities for rural employment and economic uplifting. Thus, through greater emphasis on use of local resources and self-reliance, conversion to organic agriculture definitely contributes to better socio-economic status of farmers and local communities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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