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Ecology and Management of Sedges in Direct-seeded Rice: A Review

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ABSTRACT

Sedges, resilient weeds from the Cyperaceae family, pose a significant threat to direct-seeded rice cultivation due to their perennial nature and robust propagules, which endure harsh conditions. Their emergence, growth and seed production during fallow periods contribute significantly to seed banks, making their management challenging compared to other weed types. Water levels in paddy fields dictate weed composition, favouring sedges and grasses under saturated conditions but shifting to grass weeds during cropping seasons, influenced by factors like soil conditions and rainfall. Managing sedges requires a multifaceted approach due to their perennial hydrophilic and pro-alkaline nature with extensive propagules. Sedges possessing strong root system with morphological similarities necessitate continuous weed control throughout the cropping season during the critical period ranging from 15 to 60 days after sowing for wet and dry direct-seeded rice. Effective weed management practices proved crucial for minimizing yield losses caused by infestation of *Cyperus difformis, Fimbristylis miliacea* and *Schoenoplectus juncoides* by many researchers. Various methods, including cultural practices like stale seedbeds, physical methods like summer tillage, biological approaches such as integrating poultry and chemical interventions like herbicide application, are utilized for sedge management in rice fields. Higher efficacy of ethoxysulfuron for management of majority of sedge weeds in rice has been reported by many workers. However, relying on a single strategy is insufficient to keep sedge populations below the threshold, necessitating a comprehensive and adaptable approach to weed control in rice cultivation.

Key words: Critical period, Cyperaceae, Herbicide, Rice, Sedge weeds, Yield reduction.

Rice, the staple food grain of the world population has an important role in mitigating poverty and malnutrition. A staple crop abundant in carbohydrates, rice serves as a vital source of sustenance for nearly 70% of the world population, addressing hunger needs. Beyond its dietary and nutritional benefits, its ability to flourish in various ecosystems and adaptability to different farming practices makes it a compelling option for agricultural producers.

Crop productivity primarily depends on the method of cultivation adopted. A cost effective and alternative method having less requirement of labour is direct seeding of rice (DSR). In all these systems of direct seeding, weeds are the major biotic constraints. Weed problems can occur more in dry seeded rice than in wet seeded rice as pregerminated seeds are sown in wet seeded rice. Mostly, grasses can be seen in dry seeded rice (Moody *et al.*, 1996). Shifts in weed flora is considered as one of the challenges in wet seeded rice (Kumar *et al.*, 2023).

Sedge weeds in rice

Weeds display dynamic spatial differences both within and between fields, as well as temporal changes throughout and between seasons (Ameena *et al*., 2024). Weed composition is determined by the season, soil fertility status, fertilizer application rates, water management, herbicides used and the weed management practice adopted. About 51.5% of grasses, 30% of sedges and 17.5% broad leaf weeds are reported as weed flora in wet-seeded rice (Ravisankar *et al.*, 2008). Rajkhowa *et al.* (2006) reported that continuous use of grass killers in rice fields, had changed the weed flora from annual grasses to perennial sedges and broad leaf weeds. Among the weed flora, sedges, belonging to the Cyperaceae family, present a significant risk to rice cultivation due to their perennial nature and the presence of persistent propagules, enabling them to survive adverse weather conditions (Satapathy *et al.*, 2017). The ability of *C. rotundus* to endure different stresses stems from its robust underground tuber system, wherein each tuber generates numerous active buds, leading to continued growth alongside its allelopathic influence (Ameena *et al.*, 2015).

Sedges are considered the ‘worst weeds’ in rice because of their extremely hydrophilic nature and alkaline tolerance (Kumar *et al.*, 2008). Important cyperaceous

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weeds in terms of their adverse effect include *C. esculentus* L., *C. difformis* L., *C. iria* L. and the *Fimbristylis miliacea* (L.) ranking 16th, 32nd, 33rd and 40th among the world's worst weeds, respectively (Bryson and Carter, 2008). The propagation of *Schoenoplectus juncoides* through seeds, vegetative buds and rhizomes has been reported in wet seeded paddy fields in Thiruvananthapuram by Umkhulzum *et al.* (2019).

Sedges are hard and have the potential of vegetative propagation rather than seed propagation which helps in increasing their growth throughout the cropping season. During the entire period of rice, *Schoenoplectus juncoides, Fimbristylis miliacea, Cyperus flavidus* and *Cyperus difformis* were reported as extremely competitive among the sedges (Mukherjee *et al.*, 2008). *Cyperus difformis, Cyperus iria, Schoenoplectus juncoides* and *Fimbristylis miliacea* were the four sedges reported among the twelve most difficult-to-control weeds in the rice fields of Asia by IRRI (2017).

Deivasigamani *et al.* (2016) observed the predominance of sedges belonging to *Scirpus* sp. and *Cyperus* sp. in the direct seeded lowlands of Tamil Nadu. The lowland paddy fields of Iran had been infested by the sedges belonging to *Scirpus* sp. *viz*. *Scirpus juncoides*, *Scirpus maritimus* and *Scirpus mucronatus* (Aminapanah *et al.*, 2015). *Cyperus difformis, Cyperus iria, Cyperus compressus* and *Fimbristylis miliacea* were found in all the growth stages of semi dry seeded rice (Arya and Ameena, 2016a).

Umkhulzum *et al.* (2018) observed that the growth of *Schoenoplectus juncoides* which was unnoticed in wet seeded paddy caused a reduction of 81% in net income, in comparison with the most economical weed management practice. Kumar *et al.* (2018) observed serious infestation with the sedges *Cyperus esculentus, Fimbristylis dentatum, Cyperus rotundus* and *Cyperus difformis* in dry-seeded, wet-seeded and drum seeded rice. Based on the summed dominance ratios obtained, Juraimi *et al*. (2009) inferred the dominance of sedges (6-27%) over grasses (8-12%) and broad leaf weeds (2-6%) during the off season and shift to grass weeds in the cropping season.

Ecology of sedges

The water level in the paddy fields has a decisive influence on the weed flora that invades the crop. Tanaka *et al.* (1976) observed luxurious growth of grasses and sedges in saturated fields which constituted 90% of the total dry weight of weeds. Bhagat *et al.* (1999) listed *Cyperus iria, Fimbristylis miliacea* and *Cyperus digitatus* among the six most important weeds under saturated conditions. Sekhar *et al.* (2020a) reported the dominance of *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* in the double cropped wetlands of IFSRS, Karamana in Thiruvananthapuram district.

The undisturbed soil in the lowlands during fallow period promoted the emergence, growth, flowering and seed setting of sedges adding considerably to the seed banks posing greater difficulties during cropping period. Further, untimely rainfall in the beginning of cropping season favours the germination of the weed seed bank. Gogoi *et al.* (1996) observed lower rates of seed germination and emergence of sedge seeds with the application of mulch in rice fields due to reduced light and oxygen supply in DSR grown in heavy rainfall regions of Eastern India. Bhatt *et al.* (2009) reported the amphibious nature of *Schoenoplectus juncoides* due to its ability to grow luxuriantly both in uplands and lowlands. Ameena *et al.* (2013) demonstrated the highest percentages of regrowth and viability of *C. rotundus* in the weedy check plots which indicated that the newly formed tubers of purple nutsedge readily sprouted, displaying no seasonal dormancy.

Wieclaw *et al.* (2022) reported that soil conditions affect the morphology of *Carex buekii* especially potassium, which is the only soil parameter indicated as a factor affecting intra-specific variability. The analysis showed that a lower amount of potassium in the soil gave smaller *Carex buekii* than having higher potassium content. Chauhan and Johnson (2009) observed that compared to *Cyperus iria* and *Fimbristylis miliacea*, *Cyperus difformis* germination was more affected by increased salt and water stress. The triggering of germination, emergence and growth of *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea* by light, warm temperatures and shallow seed burial depth in the lowland paddy fields was observed by Chauhan and Johnson (2009). Singh *et al.* (2016) reported that when undecomposed farmyard manure is used in poorly managed fields, *Cyperus rotundus* tend to poses great threat to rice. Umkhulzum *et al.* (2019) reported abundant growth of *Schoenoplectus juncoides* in the water channels, lowlands and field bunds, as an annual and as a perennial in undisturbed fields. A distinctive trait observed in rock bulrush (*Schoenoplectus juncoides*) was the lodging of culms with mature spikes on to rice plants and shading them completely which began on the 36th day and persisted until the 42nd day, with an average lodging time of 40 days. The variations in light intensity reaching the crop canopy can influence the external physiological characteristics (Pooja *et al*., 2021).

Critical period of rice- sedge weed competition

In direct seeded system of rice, crops and weeds co-emerge and compete for the limited growth resources such as nutrients, water, space and solar radiation. However, strong fibrous root system of sedges and similarity in morphology makes its effective management in DSR difficult. The year-round presence of sedges raises the importance of maintaining the rice fields weed free during the entire cropping season unlike transplanting. A weed free period upto 29 to 32 DAS for wet seeded and 4 to 83 DAS for dry seeded rice should be maintained for good yield (Johnson *et al*., 2004). Begum *et al.* (2008) demonstrated that by adopting weed management practices from 14 to 28 DAS in broadcasted rice, the effective reduction of yield loss caused by *Fimbristylis miliacea* infestation has been achieved.

DSR faces severe crop weed competition than transplanted rice. According to Arunbabu and Jena (2018), critical period of crop weed competition ranges from 15 to 60 DAS for wet and dry DSR, 30 DAS for upland DSR and zero to 90 DAS for rainfed DSR. Alternate events of wetting and drying reduced the growth of weeds and reduced the competitive advantage of weeds. Rathika *et al.* (2020) identified crop-weed competition during the initial stages as a major factor for the reduction in the outcome from the crop.

Yield losses in DSR due to sedges

Along with grasses and broad leaf weeds, sedges result in significant yield losses in direct seeded rice. The duration of crop-weed interference decides the severity of yield loss in DSR (Azmi *et al.*, 2007). Uncontrolled weed growth in dry and wet direct seeded rice reduced grain yield by 96% and 61% respectively (Maity and Mukerjee, 2008). Grass weeds dominated the irrigated paddy fields, whereas in rainfed system, sedges offered the strongest competition (Johnson, 1996*).* Begum (2006) reported *Fimbristylis miliacea* as a serious threat in DSR due its ability to reduce yield upto 42%. Singh (2008) identified the potential of *Cyperus rotundus* to be the major weed in paddy fields without regular flooding from the trials conducted at Pantnagar. Crop-weed competition when extended throughout the crop season resulted in a decline of upto 80% in yield (Sunil *et al.*, 2010).

In India, yield loss of 17 to 98% has been reported in DSR as against 12 to 69% loss in transplanted system (Singh *et al.*, 2011) as the cumulative effect of growth attributing characters is reflected in the final yield (Pooja *et al.*, 2023). Garg *et al.* (2019) observed dense growth of *Cyperus difformis* over the young direct seeded rice seedlings causing a grain yield loss ranging from 12 to 50%. *Schoenoplectus juncoides* was reported to be a recent threat in rice fields of Kerala causing grain yield reduction of wet seeded rice by 52.2%, if left uncontrolled (Umkhulzum and Ameena, 2019). Alternatively, besides causing damage, tiger nuts could potentially serve as a global food source (Barrett, 2023).

Methods of managing sedges in DSR

Direct seeded rice faces tough competition from its weed counterpart from its emergence onwards. Compared to the different methods in practice, the use of herbicides is cost-effective and efficient in managing the weed problem. But, continuous use of the herbicides against a particular group of weed results in weed flora shift and development of resistance among weeds. Hence, integration of different methods of weed management based on climate, soil and weed flora is necessary for maintaining weeds below the economic threshold level. Shekhawat *et al.* (2020) stated that as seed rate is higher in DSR, any contamination could increase the weed seed bank. Removing weed plants before they flower has been found to be effective in reducing the addition of seeds to the weed seed bank.

Cultural methods

Nagargade *et al.* (2018) stated the importance of cultural approaches based on integrated weed management and weed biology for management of sedge weeds. Sedges can be controlled by adopting cultural practices like summer tillage, crop rotation, intercropping, higher seed rate and allelopathic varieties. One of the cultural management practices which could be adopted before the sowing of the crop to reduce the weed seed bank in the field is the stale seedbed technique (SSB). SSB is a cultural method of weed management wherein land preparation is carried out without subsequent sowing of paddy seeds which triggers the emergence of weed seeds in the soil, killed by flooding or by using herbicides. SSB has been proved particularly good for the sedges like *Cyperus iria, Cyperus difformis* and *Fimbristylis miliacea* due to shorter seed dormancy and failure to emerge from soil depth more than 1 cm (Chauhan and Johnson, 2010). Ameena (1999) reported that combination of glyphosate at 1.5 kg ha^{-1} with 2,4-D sodium salt at 0.25 kg ha^{-1} applied at 6 to 8 leaf stage was effective in controlling nutsedge with no regrowth observed upto 6 weeks after spraying. Managing *C. rotundus* through cultural or mechanical methods presented difficulties because of the tuber viability and their capacity for repeated sprouting as observed by Ameena *et al.* (2014). Kalyani *et al.* (2024a) reported that the tuber viability of *C. rotundus* was significantly impacted by land preparation methods, with SSB combined with glyphosate at 1.5 kg ha^{-1} or SSB with halosulfuron methyl at 75 g ha^{-1} applied at the 2 to 4 leaf stage of nutsedge recorded significantly lower tuber viability of 13.33 and 6.67% respectively.

Kim *et al.* (2001) suggested the use of rice bran against *Scirpus juncoides* and *Cyperus serotirus* in lowlands with shallow submergence. Recycled paper mulch recorded higher weed control efficiency (50%) against *S. juncoides* in the rice field (Lee *et al.*, 2005). Kandasamy and Chinnusamy (2005) observed the potential of drum seeding in suppressing sedge weeds in wet-seeded rice in Tamil Nadu. Submergence of field at early crop growth stages, especially within 4 to 6 weeks after sowing (WAS) was effective in managing sedges below the economic threshold limits (NPPC, 2017). Continuous flooding of rice fields to a depth of 2-4 cm reduced the emergence and subsequent growth of *Cyperus iria* and *Fimbristylis miliacea* (Sethulakshmi *et al*., 2024*).*

Physical or mechanical methods

Hand weeding is the traditional and most promising weed management practice especially in India (Yaduraju *et al.*, 2015). However, availability of timely labour decides the success of this method for controlling weeds. Yaduraju and Mishra (2008) observed that while manual weeding is highly efficient it can lead to the escape of sedge weeds due to their morphological resemblance, causing a subsequent threat to the crop because of their perennial nature. Mohan *et al.* (2005) found manual weeding to be effective in managing *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis miliacea*. On the contrary, Devi and Singh (2018) reported that manual and mechanical methods were found to be ineffective against sedges and broad-leaf weeds in DSR.

Biological methods

Integration of poultry in the system inhibited the germination and growth of sedges in rice fields due to the addition of its highly acidic droppings (Kathiresan and Bhowmik, 2006). Kathiresan *et al.* (2001) recommended the use of azolla at the rate of 1 t ha^{-1} to lessen the germination and emergence of sedge seeds which could be due to decreased light reception through the thick vegetative mat formed by the biofertilizer. Inhibition of *Scirpus juncoides* have been observed in rice, dual cultured with *Azolla pinnata* in the lowlands of Japan (Biswas *et al*., 2005). Chung *et al.* (2006) suggested momilactone, the allelochemical secreted by rice as an effective natural control against *S. juncoides* with 90% inhibition when applied at the rate of 4000 g ha^{-1}. Low dry weight (1.20 g) and higher inhibition (84.47%) of *S. juncoides* was observed when mustard crop residue was applied at the rate of 2 t ha^{-1} (Hossain *et al*., 2017). *Bactra verutana*, known as the javelin moth from the Tortricidae family, was introduced to control *Cyperus rotundus* L. However, it has been found to be ineffective in achieving the purpose (Efil *et al*., 2012).

Chemical methods

The most favoured method of weed control in direct seeded rice is the use of herbicides, which is widely adopted by farmers because its application is easy, quick, give visible results, saves time and less laborious in nature as compared to manual weeding. However, climatic factors like rainfall, humidity, temperature, time of day and wind speed influence foliar applications by impacting the permeability of plant tissues (Pooja and Ameena, 2021). Glyphosate, alone or combined with 2,4-D, has shown promise in controlling the growth of *C. rotundus* possibly due to its rapid translocation to the tubers (Ameena and George, 2004). Though effective, repeated application of herbicides have proven inefficient for managing globally noxious weed species such as *Cyperus* sp., *Scirpus* sp. and *Fimbristylis* sp (Kraehmar *et al.*, 2016). Perennial sedge weeds, with their extensive underground growth and C4 pathways, are likely to pose a greater threat in a changing climate, as herbicides cannot effectively control them (Umkulzhum *et al*., 2024).

Ethoxysulfuron (30 g ha^{-1}) applied 10 days after transplanting (DAT) provided better control of *Schoenoplectus supinus, Cyperus difformis* and *Cyperus iria* (Reddy *et al.*, 2000). New-generation herbicides showed improved weed control efficiency, reduced weed dry matter and yield, with minimal or no phytotoxicity symptoms on current and subsequent crops (Kalyani *et al*., 2024b). High herbicide efficacy at small rates of application was observed by Son and Rutto (2002) in controlling grasses, broad leaf weeds and sedges. The efficiency of ethoxysulfuron against the sedges belonging to *Scirpus* sp. has been proved by Sondhia and Dixit (2012). Ali *et al.* (2018) reported ethoxysulfuron as an effective sulfonyl urea herbicide against *Scirpus maritimus*, *Cyperus rotundus*, *Cyperus difformis* and *Fimbristylis dichotoma*. Ethoxysulfuron applied at 15 g ha^{-1} at 15 DAS followed by hand weeding at 35-40 DAS was found to be an effective strategy for the management of *Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice by Umkhulzum *et al.* (2018).

Penoxsulam at 25 g ha^{-1} gave satisfactory control of broad leaf weeds and sedges compared to butachlor and pretilachlor (Nath and Pandey, 2013). Arya and Ameena (2016 b) reported that whether applied before or after plant emergence, herbicides lingered in the active surface soil, leading to fluctuations in soil enzyme activities over varying days of post-treatment in semidry rice. Reddy and Ameena (2021a) found that at 45 and 60 DAS, the combined post-emergent herbicide penoxsulam + cyhalofopbutyl demonstrated significantly greater efficacy with lower dry weights of grasses, sedges and broadleaf weeds in wet seeded rice.

Chauhan and Yadav (2013), observed that combining two or more herbicides could significantly reduce weed growth in DSR. When compared to grasses, post-emergence spraying with metsulfuron methyl (10%) + chlorimuron ethyl (10%) provided better control of broad leaf weeds and sedges (Saha and Rao, 2009). When applied at 4 g a ha^{-1} at 15 to 25 DAS, metsulfuron methyl + chlorimuron ethyl, the ALS inhibitor, was very successful in controlling broad leaf weeds and sedges (Kumar and Ladha, 2011). Carfentrazone-ethyl, an aryl triazolinone herbicide applied as post-emergence in rice was found effective against sedges and broad leaf weeds (Singh, 2012). In wet seeded rice, bensulfuron-methyl + pretilachlor exhibited higher weed control efficiency upto 30 DAS and was comparable to pyrazosulfuron-ethyl, with respect to control of grasses, sedges and broad leaf weeds (Reddy and Ameena, 2021b).

Integrated weed management

Single method of controlling weeds can lead to weed shift, herbicide resistance, or increase in weed seed bank. Sedges, grasses and broad leaf weeds can be effectively controlled by judiciously combining two or more approaches. Shekawat *et al.* (2020) observed that adoption of integrated weed management strategy could decrease the reliance on herbicides in DSR systems, with a greater emphasis on preventive and cultural methods.

Peerzada *et al.* (2017) reported the integration of herbicides and summer tillage in fallows as effective method for destroying the rhizomes and tubers of *Cyperus rotundus* in rice fields. Reduced tuber viability (20-23.3%) and regeneration (6-8 sprouts per m^2) were documented by adopting a stale seedbed along with pre-plant application, followed by directed post-emergence application of glyphosate for the management of *C. rotundus* (Ameena *et al.*, 2006). Effective and economic management of *Schoenoplectus juncoides* was achieved by spraying ethoxysulfuron at the rate of 15 g ha^{-1} at 15 DAS followed by hand weeding at 40 DAS (Umkhulzum *et al.*, 2019). Good weed suppression in direct seeded rice can be achieved by using stale seedbed technique, clean cultivation with balanced fertilizer applications, appropriate weed management and hand weeding in conjunction with herbicides. Sekhar *et al.* (2020b) reported that the combination of stale seedbed followed by the application of glyphosate plus oxyfluorfen followed by cyhalofopbutyl plus carfentrazone ethyl proved effective in suppressing the germination and establishment of *C. iria* and *M. vaginalis* during the early stages of the crop in wet seeded rice.

CONCLUSION

Direct seeding of rice has become increasingly popular among farmers due to its numerous benefits such as water and labour savings compared to puddled transplanted rice. However, the management of weeds, particularly sedges, poses a significant challenge in DSR. Sedges tend to dominate fields more than grasses and broadleaf weeds due to their ecological characteristics, leading to substantial yield losses in DSR. Various techniques for sedge management exist, including preventive, cultural, physical or mechanical, biological and chemical methods. Among these, chemical methods involving herbicides are preferred due to their speed and efficiency. To achieve effective sedge management in DSR, it is vital to prioritize preventive strategies based on seed ecology to check the build-up of the soil seedbank. This involves integration of stale seed bed technique with clean cultivation, balanced fertilizer application and judicious herbicides use.

Conflict of interest

I declare that the authors do not have competing interests.

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